Climate Change Management

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Handbook of Climate Change Across the Food Supply Chain

Springer

Climate Change Management

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ISSN 1610-2002 ISSN 1610-2010 (electronic)
Climate Change Management
ISBN 978-3-030-87933-4 ISBN 978-3-030-87934-1 (eBook)
https://doi.org/10.1007/978-3-030-87934-1

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Climate change as a global phenomenon affects the entire food chain. Many studies analyzing environmental impacts of food systems confirm the significant of climate change effects on food production. Most of them associate primary production with emission of greenhouse gasses identified as one of the causes resulting in warming the atmosphere and global climate effects.

A wider perspective shows that the food chains start at farms, with consumers being at the end of the pipeline. This approach emphasizes the role of the entire food chain, highlighting different kinds of environmental impacts associated with climate change. In addition, temperature changes and variations of precipitation patterns, together with extreme weather events and water reduction are acknowleged as being factors which may lead to decreases in crop yields, may affect food quality, and may lead to biodiversity losses which—in turn—may influence food production.

The seriousness of the problem may be better understood if one considers that, as a result of unfavorable climate conditions, almost one billion people do not have sufficient access to food. The UN highlights the need for combating climate change and promoting sustainable food production and consumption, as one of the priorities to the world nations, not only in developing countries. Therefore, understanding food production and consumption processes is important in attempts to address the risks associated with food shortages.

It is based on the perceived need to promote and disseminate information on climate change related to food systems, that the "Handbook of Climate change across the food supply chain" is being produced. This book compiles information, experiences, practical initiatives, and documents projects around the subject matter of climate change and food production and consumption. It contains a set of chapters written by authors from various geographical regions. It is structured around 2 parts:

Part I—Climate Change and Food Production Aspects: this part focuses on papers which look at aspects of food production and how these are influenced by climate change.

Part II—Adaptation Processes and Approaches: this part entails papers which describe a wide range of experiences, projects, and initiatives which illustrate how climate change may influence food production and some of the means deployed to tackle them.

We would like to thank all authors and reviewers for making available their experience in their chapters, and the willingness to share their ideas. By providing their inputs, the authors have made a positive contribution toward a debate which needs to be continued and reach a depth far beyond what conferences, workshops, or seminars may be able to offer.

The Editors

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Summer 2022

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Climate Change and Food Production Aspects

Global Climate Agreements and Policy Translation in the Brazilian Agriculture: More of the Same

Leticia Andrea Chechi and Cátia Grisa

Abstract This chapter discusses how global climate agreements have been translated into public policies in Brazil, particularly in the agricultural sector and manifested in the Sectoral Climate Mitigation and Adaptation Plan for the Consolidation of a Low Carbon Economy in Agriculture and the Low Carbon Agriculture Program (ABC). From a policy translation approach, the chapter emphasizes how the interaction of actors, ideas, discourses and institutionalities produce modifications and adaptations in the policy transfer from global to national. In methodological terms, the study included documentary research and 26 semi-structured interviews. Initially, the paper presents the main actors who participated in the construction of the ABC Plan, and the negotiations in search of the legitimation of the Plan as a public policy. In sequence, the study explores the communicative and coordinative discourses to align actors and in action. Then, the chapter analyses the influence of institutions in the design and focus of the ABC Program. Findings point out that agribusiness actors interpreted climate change as an opportunity to re-signify conventional practices, legitimize its actions in the markets through construction an image of low carbon agriculture. On the other hand, representatives from family farming and alternative production practices had little space in the policy translations process. More of the same, now reframed interpreted as sustainable and agro-environmental, continues to be done in Brazilian agriculture.

1 Introduction

Climate change has become a recurring theme in the international debate. It started in the 1970s, stimulated by the emergence of the discussion of environmental issues in

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_1

relation to the negative consequences of industrialization and the development model adopted, whereas the publication of the book Silent Spring (Rachel Carson) and the constitution of the Club of Rome were important events in that period. The discussion intensified from the 1990s with Eco 1992 (also called Rio-92) gaining strength with the Conferences of the Parties (COPs), supreme organ of United Nations Framework Convention on Climate Change (UNFCCC), particularly with COP 3, which established the Kyoto Protocol, COP 15 and COP 21. COP 15, held in Copenhagen in 2009, brought together representatives from several countries with the expectation of drafting a new global climate agreement, which would replace the Kyoto Protocol, and did not occur. The Copenhagen agreement was based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, known as the IPCC,[1] placing the need to keep the global temperature rise below 2 °C. For that, developed countries, classified as Annex I[2] should assume the commitment to jointly mobilize US $ 100 billion per year, starting in 2020, and other countries should also implement mitigation actions (Brasil, Presidência da República 2009).[3] The new global climate agreement was only established in 2015, at COP 21 in Paris, called the Paris Agreement. Ratified by 92 of the 195 countries, the Paris Agreement entered into force on November 4, 2016.

These international agreements were influenced by and transferred/translated to the countries. In the case of Brazil, while preparing for COP 15, the country started to discuss a specific national policy, which was institutionalized a few days after the event, such as the National Policy on Climate Change (PNMC). Demonstrating a concern with GGE reduction and international relations, the period prior to COP 15 was translated by Brazilian actors as an important platform for the country's projection, given that there was a prospect of signing a new global climate agreement at this event.[4] Aiming at making economic and social development compatible through the

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[1] The IPCC was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) with the objective of providing scientific information and reports to support the creation of public climate policies.

[2] Annex I was composed of developed countries that accounted for at least 55% of total carbon dioxide emissions, with mandatory commitments to reduce GGE emissions, namely: Germany, Australia, Austria, Belgium, Belarus, Bulgaria, Canada, European Community, Croatia, Denmark, Slovakia, Slovenia, Spain, Estonia, Russian Federation, Finland, France, Greece, Hungary, Ireland, Iceland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, United Kingdom of Great Britain and Northern Ireland, Czech Republic, Romania, Sweden, Switzerland, Turkey, Ukraine and the United States.

[3] It is important to highlight that with the advent of the COVID-19 Pandemic in 2020, the financing of actions related to climate change may vary.

[4] It is important to highlight that in the Brazilian context, the first decade of the twenty-first century was accompanied by the commodities boom in the international market and by strong state investments in the agriculture sector as well as in other sectors of the economy. In this context, the Brazilian government aimed at placing agricultural production as the "breadbasket of the world" and, for that, it sought to contemplate a large part of the demands of the international market, including environmental demands. State investments have been decreasing since 2014 and the establishment of new political guidelines has been intensified. The Brazilian government, installed in 2019, in addition to tightening fiscal adjustment and reducing investments, has shown little concern for environmental issues and the debate on climate change, as reported by Santos (2019).

protection of the climate system and the preservation of environmental resources, the PNMC proposed actions in several areas, notably through sectorial plans to reduce greenhouse gas emissions (GGE). One of these was the Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture, called ABC Plan (Low Carbon Agriculture), officially launched in 2012.[5]

The ABC Plan aims at reducing GGE emissions in agriculture and, at the same time, improve the efficiency of natural resources, increase the resilience of productive systems and rural communities, and enable the agricultural sector to adapt to climate change. The ABC Plan was structured in seven Programs, six of which refer to mitigation technologies and the last one refers to actions fostering adaptation to climate change. These actions include: (1) Recovery of Degraded Pastures; (2) Integrated Crop–Livestock–Forest Systems/Agroforestry Systems; (3) No-till system; (4) Biological Nitrogen Fixation; (5) Planted forests; (6) Animal Waste Treatment; and (7) Adaptation to Climate Change (Brasil, MAPA 2012). It is noted, therefore, that the ABC Plan has a primary focus on mitigation actions to the detriment of actions to adapt to climate change (Rodrigues Filho et al. 2016). In order to operationalize the Mitigation Programs, the Ministry of Agriculture, Livestock and Supply (MAPA) developed the ABC Program, a rural credit line launched in the 2010/2011 Agricultural and Livestock Plan and aimed at financing activities within rural establishments. The actions linked to the Climate Change Adaptation program involved strategies at the national level (with actions at the level of rural properties being absent), such as the creation of a Climate Intelligence Program in Agriculture, the development of agricultural vulnerability indexes and maps, and research development.

If, on the one hand, the ABC Plan and Program dialogue with scientific evidence that points to the predominance of the agricultural sector in greenhouse gas emissions in the world and in Brazil (IPCC 2019; Piatto et al. 2017; HLPE 2012), on the other hand, such a Plan instigates reflections on the actors, ideas, interests and institutions that influenced its construction and implementation. Such reflections stem from the characteristics of the Brazilian rural environment, marked by a structural duality and different productive dynamics (Niederle et al. 2019; Sauer et al. 2017; Delgado 2012). According to the 2017 Census of Agriculture, 77% of rural establishments are classified as family farming, which occupy 23% of the area and account for 23% of all Brazilian agricultural production (IBGE 2017). These establishments present different forms of relationship with nature (they are smallholder farmers, extractivists, riverine people, indigenous people, etc.) and means of production (they adopt conventional production systems, agroecological, agroforestry etc.). They contribute mainly in the production of food to supply the domestic market, although they also play an important role in the production of commodities, as coffee, corn, soybean and chicken. As FAO mentions, family farming "has a unique potential" to contribute to more sustainable food systems and, therefore, to cope with climate change, given its rootedness in communities and local ecological conditions (FAO and IFAD 2019). On

[5] "ABC Plan" refers to overarching guidelines for low carbon agriculture, while the "ABC Program" is a financial line of the ABC Plan.

the other hand, 23% of establishments in the country are considered non-familiar—also politically called agribusiness,[6] occupy 77% of the area and account for 77% of agricultural production. They produce to a large extent commodities, aimed at the foreign market (soybeans, meats etc.) and based on intensive production systems in the use of soil, chemical inputs and, often, associated with deforestation and threats to socio-biodiversity (Favareto 2019; Ohashi et al. 2018; Delgado 2012).

Considering these characteristics and the duality of the Brazilian rural (Aquino et al. 2018), several questions stimulate the debate: Which actors participated in the construction of the ABC Plan and Program? Which ideas, interests and values guided their actions? Which models of agriculture and agricultural practices have been contemplated? How has family farming participated in and benefited from the Plan and the Program? Based on these issues, the text aims at analyzing how international agreements on climate change were translated into the ABC Plan and Program, and how they interact with the diversity of rural units and country's productive systems.

For this analysis, the chapter dialogues with the notion of policy translation which can be defined as the activity of recreating (and not only of importing or disseminating) public policy guidelines, contents and instruments from one context or level to another (in our case, from supranational to national) (Hassenteufel et al. 2017; Oliveira and Faria 2017; Hassenteufel 2008; Lascoumes 2006). As exposed by Hassenteufel and de Maillard (2013), the notion of translation allows showing how the models of public action are reformulated; how actors mobilize, confront and negotiate; and, yet, the ways in which ideas are institutionalized in public policies. For the authors, three dimensions must be considered in this process. The first concerns the interactive dimension, which seeks to map the actors involved in the policy translation, their articulations, mobilizations and negotiations. The second addresses the discursive dimension, in which it seeks to identify the argumentative strategies in relation to the political proposal, considering that the discourses have the capacity to put the actors in coordination and guide their actions. Finally, the institutional dimension, which addresses the institutionalization of ideas within the framework of Brazilian policies, interactions with other institutions and adaptations made during the process policy making.

The chapter is organized three main parts, in addition to this Introduction. The second section contemplates the Methodology. The third addresses the main results of the translation of the climate agenda into the ABC Plan and Program, through the analysis of the three dimensions proposed by Hassenteufel and de Maillard (2013). Finally, a series of Final Considerations are proposed.

[6] The Law 11.326/2006 defines family farming as one that does not have an area greater than four fiscal modules, has its income predominantly from agriculture and uses family labor. Meeting these criteria, the family farmer has access to specific public policies, through the Declaration of Aptitude to Pronaf (DAP). Non-family members are all those who do not meet this criterion. Although, in terms of participation in the production chains, this separation makes little sense, and finds support in the debate and in the political organization. Family farming and agribusiness are political categories that, historically in the discourse plan, union organization and institutional spaces dispute different development projects for Rural Brazil (Aquino et al. 2018; Bruno 2016; Delgado 2012).

2 Methodology

Interviewing semi-structured (Gil 2008) was the main data collection technique used in the development of this work. In all, 26 actors[7] involved in the construction of the ABC Plan were interviewed from February to June 2018. This non-probabilistic sample was defined based on the names present in the ABC Plan. The sample was representative of the process of translating the global climate agenda into it. The transcription of the interviews and the analysis of the information collected were performed using the *Nvivo* software, based on the creation of analytical categories that met the proposed objective.

In addition to the interviews, documentary research was also carried out. Laws, Decrees, Ordinances, reports, meetings memoirs and other government documents were mapped and analyzed in order to identify actors, ideas, discourses and institutions mobilized in the translation of international guidelines on climate change to the national context.

3 Results and Discussion

3.1 Actors and Interactions in the Translation of the International Climate Agenda in the ABC Plan and Program

According to Hassenteufel and Maillard (2013), one of the objectives of policy translation analysis is, in addition to analyzing the models of public action adjusted from one context to another, to verify which and how the actors mobilize, confront and negotiate in the construction of public policy. According to Hassenteufel (2006), the notion of translation originally proposed by Callon is focused on the existence of specific interaction networks and the role of actors in the production of common meanings. Applied to public policy analysis, the translation also seeks to emphasize the interactions of the actors, the constructed arrangements, the existing power relations and the repercussions produced in the design and organization of public policy (Campbell 2004). The configuration and relationships among the actors produce different translations from one context to another.

Initially, it is important to highlight that Brazil has a relevant role in the group of developing countries within the scope of COPs. Stimulated from the discussions of the United Nations Framework Convention on Climate Change that took place in Bali in 2007, where developing countries had the opportunity to present proposals for National Appropriation Mitigation Actions—NAMAS, the Brazil decided to anticipate and show the world what it had been doing to mitigate and adapt to climate change. So, before going to COP 15, held in Copenhagen, the President of the

[7] The interviewed actors are presented through numbers, from 1 to 26.

Republic asked the Interministerial Committee on Climate Change (CIM) that each sector discuss how it could contribute to the reduction of GGE emissions. The context signaled the importance and magnitude of COP 15 and Brazil wanted to reinforce its visibility, empowerment and leadership on the international stage. According to one of Empresa Brasileira de Pesquisa Agropecuária—Embrapa's[8] researchers (interviewee 13), representative of the agriculture sector at CIM, the construction of the ABC Plan was derived from a "*decision made by the President of the Republic, to take a strong Brazilian position to Copenhagen in relation to mitigation*". In other words, we could say that Brazil did a strategic and anticipated translation of the Agreement that, effectively, would be carried out only in 2016 (Chechi 2019).

At the same time that the Brazil administration articulated its actions in the international context, early translation and the construction of actions mobilized several national actors in order to meet the demands placed by the Presidency of the Republic. Among these national actors, the Ministry of Foreign Affairs (MRE), the Ministry of Science, Technology and Innovation (MCTIC), the Ministry of the Environment (MMA), and the Ministry of Agriculture, Livestock and Supply (MAPA) stood out, agriculture being one of the main topics on the agenda. In fact, according to the coordinator of the ABC Plan (interviewee 7), the Plan on agriculture was one of the first plans to be prepared after the establishment of the National Policy on Climate Change (PNMC) in 2009.[9] In December 2010, Decree No. 7.390[10] instituted the mandatory creation of a "Plan for the Consolidation of a Low Carbon Economy in Agriculture" (Article 3), and on April 2011 it was already institutionalized.

A large part of the interviewees mentions a diversity of actors, governmental and non-governmental, participating in the meetings for the construction of the ABC Plan. As the representative of the ABC[11] Observatory mentions, "*ABC was built by several hands, perhaps it was one of the sectorial plans or one of the most democratic sectorial policies, due to the participation of different actors*" (Interviewee 3). Similarly, the MAPA representative states that "*several institutions participated, the productive sector, from the governmental environmental area, municipal environmental area, NGOs, the third sector, to producers linked to agribusiness and family farming*" (Interviewee 7). Among the 30 organizations documented in the ABC Plan, we can mention, for example, the Institute for Environmental Research in the Amazon (IERA), the Single Central of Workers (SCW), the National Institute

[8] Created in 1973, Embrapa (Empresa Brasileira de Pesquisa Agropecuária) is linked to MAPA and aims to generate knowledge and technologies for Brazilian agriculture.

[9] It is important to highlight that, before the construction of the PNMC, there was the creation of the Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAm). Created in 2004 and currently in its fourth phase (2016–2020), this plan aims at reducing deforestation and establish a sustainable development model in the Legal Amazon. Similar to this and the ABC Plan, from the PNMC, the Action Plan for Prevention and Control of Deforestation and Burning in the Cerrado (PPCerrado) was also created, being instituted through Decree of September 15, 2010.

[10] Repealed by Decree No. 9,578, of 2018.

[11] Coordinated by the Agribusiness Study Center of the Getulio Vargas Foundation (GVAgro), the ABC Observatory was created in 2013 to debate the topic of low-carbon agriculture, focusing on the implementation of the ABC Plan.

of Colonization and Agrarian Reform (INCAR), WWF-Brazil, and the Institute of Socioeconomic Studies (ISS).[12]

However, not all of these actors had the same political weight or role in drawing up the Plan. Among all the participants, Embrapa, MAPA, the Civil House and the Secretariat for Strategic Affairs of the Presidency of the Republic can be considered "leaders" in the construction of the ABC Plan. Secondly, there are other governmental and non-governmental actors, such as the Ministry of the Environment (MMA), the Ministry of Agrarian Development (MDA)[13]—responsible, respectively, for the management and preservation of natural resources and for actions related to family farming—environmental NGOs and family farming organizations. Such marginal actions are symptomatic of the public and of the production systems that would be privileged in the ABC Plan and Program.

Due to the diversity of actors, with different ideas and interests, there were intense discussions: "*Of course, the discussions have always been very heated, because you join CONTAG with CNA,*[14] *you join environmentalists with producers*" (Interviewee 7). Due to the tensions involved in the process, the Casa Civil coordinated the meetings and mediated the negotiations between different ideas and interests to create the ABC Plan. The performance of the Casa Civil—the main political and articular nucleus of the different Ministries—also demonstrates the centrality that the Plan has gained in Brazilian politics.

Several conflicts and negotiations permeated the elaboration of the Plan. One of the tensions, historically established in this theme, was between the environmental sectors (mainly NGOs) and the productive sector, adopting the strategy of dialogue to minimize conflicts: "*I always say that peace you don't make with friends, you make with the enemy, then you sit down and start negotiating*" (Interviewee 4, Embrapa researcher). However, it is important to consider at least three elements here. Firstly, it is worth reflecting on the marginal role of MMA. According to the field research, MMA, which already played an important role in reducing GGE emissions from the deforestation agenda, interpreted that it would be time for MAPA to formulate

[12] IERA is a scientific organization, created in 1995, that works for the sustainable development of the Amazon. The SCW is a Brazilian union organization, which emerged at the end of the 1970s in a strike movement called new unionism together with the Workers' Party (PT), This movement had as important figure the ex-President of the Republic, Luís Inácio Lula da Silva. INCAR is a federal agency with the mission of implementing agrarian reform in Brazil. WWF-Brasil is a non-governmental organization that works in the environmental area. The ISS was created in 1979, it is a non-governmental, non-profit, non-partisan organization, that works with civil society organizations and social movements to have space in the arenas for discussing public policies.

[13] Created in 1999 (and extinguished in 2016), the Ministry of Agrarian Development (MDA) meant the political and institutional recognition of the duality of Brazilian agriculture. While MAPA was responsible for business agriculture, the MDA directed its actions towards family production units.

[14] Again illustrating the duality of the Brazilian rural environment, the National Confederation of Agricultural Workers (CONTAG) is a union movement that brings together family farmers, campers and settlers from agrarian reform, rural wage earners, sharecroppers, lenders, extractivists, quilombolas, artisan fishermen and riverine people. In turn, the Confederation of Agriculture and Livestock of Brazil (CNA) is an organization that works with employer agriculture (agribusiness).

a proposal. According to the testimony of one of Embrapa's representatives, agriculture was seen as a major GGE emitter and, therefore, it should also be placed on this agenda: "*One of the culprits of the country's rural degradation is agriculture, right? And the agriculture of the great, of the medium, mainly of the great. Then this idea came up—the big emitters—, as a result of pressure from the Ministry of the Environment*" (Interviewee 6). MMA pushed for the agriculture sector to also get involved in the debate and was formally present in the discussion spaces, however it remained marginal in the elaboration of the Plan, considering that the responsibility should be MAPA's. Secondly, it is important to note that the environmental NGOs most critical of the agricultural model supported by MAPA did not participate in the process, and the others also remained in a secondary position. Thirdly, scientific legitimation strategies were used to justify the agricultural practices that would be indicated, thus overshadowing criticisms about the agricultural model that was being promoted. Although, according to the representative of the Special Secretariat for Family Farming and Agrarian Development—Sead, there were questions and conflicts about the crops and agricultural practices that would be contemplated in the Plan—such as soy, commodities produced mainly by agribusiness and associated with unsustainable managements—the actors involved in the construction of the ABC Plan were able to provide evidence on environmental contributions. In this process, Embrapa was crucial in giving legitimacy to the technologies that were being proposed as environmentally appropriate. According to the representative of the Ministry of Finance (Interviewee 10), Embrapa was able to demonstrate that the program was technologically viable and would contribute to the sustainability of agriculture. The use of technology created an intersection, a common field of interest between the actors who had more environmental interests and those who were more productive. The Plan and Program were able to build "*a positive agenda in the sense that it was talking about leveraging productivity through sustainable activities or with better environmental performance*" (Interviewee 10—Representative of the Ministry of Finance). Also according to the same interviewee, through the scientific legitimation of Embrapa, agriculture carried out by agribusiness was considered "agro-environmental".

Another identified point of tension was the definition of the target beneficiaries of the ABC Plan and the dialogue with family farmers. Even though family farming is mentioned in the actions in the Plan, a public manager active in the field of family farming explains that, since the beginning of its elaboration, it was directed to the agribusiness sector for several reasons. One element that contributed to this process was the interpretation that the main drivers of the degradation of natural resources would be medium and large rural producers. As the representative of the Mapa explains: "*with this pressure, a little prejudiced, it ended up that the Plan was restricted to the Ministry of Agriculture, and by extension, our program that serves the medium and the large*" (Interviewee 14). It is also important to consider that MAPA actors were interested in proposing more expressive actions in terms of occupied agricultural area in the country. As an interviewed consultant explains, although family farming also worked with pastures, crop–forest integration systems, agroforestry systems and had degraded areas—crops, technologies and privileged situations at the ABC Plan—the greatest numerical and territorial response in relation to area accounting, would be through medium and large producers. Finally, it is also important to consider that family farming already had specific and more attractive lines of credit in terms of financing conditions than the ABC Program. According to a representative from Sead: "*we did not need, in quotes, this credit, because family farming already had better credit, including to implement these actions, none of which is prohibited in Pronaf*"[15] (Interviewee 16). In fact, the construction of the ABC Plan coincided with a moment of expansion of public policies for family farming, which made political actors and representatives of family farming prioritize their own agendas and actions. As stated by one interviewee, "*the MDA never participated intensively, always tangentially to the plan. Whoever touched all the actions from the beginning was really the Ministry of Agriculture*" (Interviewee 7, MAPA representative). Thus, even though included in the document, family farming did not become the program's public, organizations in the social category barely identified with the Plan, and continued to act and demand specific policies on their field. An alternative project that seeks to finance low carbon technologies associated with technical assistance to small and medium rural producers is the Low Carbon Agriculture Project.[16]

In addition to the marginalized actions, one of the interviewees, representative of the MDA at the time, also mentioned that the various conflicts may have been minimized by the way the discussion was conducted. According to the former consultant, the Plan has already been structured for the meetings, with Embrapa having an important role in its structuring and scientific legitimation. The tension points were restricted to the incorporation or not of some actions, as is the case of the treatment of animal waste, an MDA agenda that was incorporated into the ABC Plan. The construction of the Plan, scientifically legitimized by Embrapa, was able to articulate the interests of agribusiness that saw their production as "attested" as sustainable, the interests of the federal government and public managers in showing measures consistent with climate agreements, and MMA interests to advance your recommendations. Divergent positions (possibly more intense) were not present, were moving away or were marginalized in the process of building the ABC Plan. Representing mainly the interests of agribusiness, the ABC Plan has become a positive agenda for the sector: "*the productive sector, CNA and such said, 'well, this is wonderful, we are going to produce, we are receiving compliments, and we are defending the environment, the forest,* etc.*', it was only positive news*"(Interviewee 13).

Interviewee 14, representative of the Mapa, reinforces this position, mentioning that the ABC Plan and Program were accepted by the main actors involved, being

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[15] Created in 1995, the National Program for Strengthening Family Agriculture (PRONAF) is a public policy aimed at Brazilian family farming. Subdivided into several lines, it is a broad rural credit, making it possible to finance costing activities and investment in family farms.

[16] The first phase of the project, concluded in 2019, covered the Amazon and Mata Atlantica Biomes, while the second phase, actually, develops in the Cerrado Biome. This project is financed by the United Kingdom Government's International Climate Fund, managed by the Inter-American Development Bank (IDB), in partnership with MAPA, IABS, Embrapa and Banco do Brasil (Sustainable Rural 2020).

recognized by President Dilma and becoming a “brand” of Brazilian agriculture. At the launching ceremony of the Agricultural and Livestock Plan (2013/2014), former President Dilma Rousseff cited the ABC Program and its importance in relation to the competitiveness and sustainability of Brazilian agriculture.

> In the last few years, we have built a very important instrument, which is the ABC Program—Low Carbon Agriculture, for which in this harvest there will also be more resources so that we can incorporate more competitive and more sustainable production processes, because low-income agriculture carbon is extremely competitive. I am sure that more and more farmers, by joining this program, by adopting direct planting in straw, crop–livestock–forest integration and the recovery of degraded pastures, will greatly expand the sustainability of our agricultural production, demonstrating that in Brazil rather, agriculture has the capacity to grow, the capacity to be sustainable and to adopt the best practices and techniques (Palácio do Planalto, June 4, 2013).

In this context, an alignment between the interests of the sectorial actors and the Presidency of the Republic was identified. The ABC Plan was “stitching together” an alliance, building understandings between a specific group of actors and, in guaranteeing the centrality of the agribusiness sector, it led divergent actors to seek new spaces for action.

3.2 Ideas and Discourses to Legitimize the ABC Plan and Program

In the previous section, mapped the actors who participated and played a leading role in the translation and construction of the ABC Plan and Program were mapped. In this section, following the proposition of Hassenteufel et al. (2017), the ideas and discourses constructed by the actors will be identified. These ideas and discourses are understood as actors’ resources to produce and legitimize their ideas, to guide the policy formulation and to coordinate the set of actors involved (Hassenteufel et al. 2017; Schmidt 2008; Schmidt and Radaelli 2004).

During the COP 15, Brazil’s negotiators sought to give global visibility to a set of actions that the country had been developing and could develop in the future to contribute to mitigation and adaptation to climate change. At this moment, interpreted as a major GGE emitter, agriculture has become one of the centers of the discussions, and the sector was asked to propose solutions. Scientific evidence pointed to agribusiness as an important contributor to global warming (See: Piatto et al. 2017; Tubiello et al. 2015; Cerri et al. 2009) and, at the same time, agribusiness viewed the topic of climate change as a constraint or obstacle to the development of its economic activities. In other words, the agribusiness sector saw the topic of climate change, until then, as a negative agenda.

However, the political and sector actors decided to use discourse to overturn/reverse this situation, taking advantage of the favorable global moment to promote several actions that were already being carried out by the agricultural sector, now defined by the adjective of sustainability. As Schmidt (2005, 2008,

2010) analyzes, the actors use the mobilization of ideas and discourses to justify their actions and interests. Demanded by the Casa Civil, in order to meet the international agreements that were to be built, agriculture valued technologies already developed and used by farmers and took the opportunity to present a proposal that would not jeopardize the economic development of the sector. Strategically, it would be an opportunity to the agribusiness sector to minimize (or even reverse) the negative interpretation of agriculture, seen as a vector of deforestation and a promoter of degradation.

As a researcher at Embrapa, the dialogue with agribusiness actors began with the following question: "*come on, can we work on a policy where we can show that agriculture has the potential to be a positive vector for forest conservation*?" (Interviewee 13). Based on this, several actors—highlighting Embrapa's performance with its scientific legitimacy—sought to build numbers on the potential contribution of agriculture to reduce GGE emissions from the same technological matrix that had been followed, guaranteeing productivity gains. Indeed, the researcher from the National Institute of Amazonian Research (INPA) mentions that the ABC Plan was built based on technologies and management methods well known in Brazil: "*it has a history of accumulating knowledge and the ABC plan, for the management of soil biology, for integrated systems, for the no-till system, which was also another invention, a Brazilian invention*" (Interviewee 2). Management practices and forms, such as no-tillage system, crop–livestock–forest integration system, agroforestry systems, recovery of degraded pastures, waste treatment and planted forests started to be valued and re-signified in the context of mitigating climate change: "*the basis of a next Brazilian agricultural revolution is there in this process […] ABC technologies, at least, are very strong marketing, for people to show the world that our livestock, for example, is green*" (Interviewee 7).

According to an interviewee, some Embrapa researchers met and estimated the actions and potential areas for the Plan: "*a history of accounting […] had nothing* [data or estimates of possible contributions from] *agriculture, and we started to give figures,* '*we can recover from the fifty million hectares of degraded pastures, we can recover fifteen*'". Through the aforementioned practices, they sought to increase productivity, without advancing on new areas: "*do not move in any area anymore […] the pressure for opening new areas, it decreases, because you better use what is already there open*" (Interviewee 20). Recovering 15 million hectares of degraded pastures, implementing four million hectares of crop–livestock–forest integration, eight million hectares of planting system were some of the measures listed. Actions, programs, goals and expectations in terms of areas were outlined in order to give concreteness and magnitude to the role of agribusiness in mitigating global warming. Normative ideas were outlined (guidelines on what should be done—Schmidt 2005, 2008, 2010), legitimized by data and figures that proved the efficiency of current practices, without compromising what had already been achieved in terms of space and market for Brazilian agriculture.

In the opinion of an Embrapa representative, research and science played an important role in proposing the ABC Plan, including consolidated research and results that the government agency had been presenting for over 20 years. "*It was not just a* *political issue, oh I'm going to decrease so much* '[GGE reduction]', *you proposed and proved it*" (Interviewee 4).

Built with the protagonism of the actors discussed in the previous section, the Plan and Program were accepted by the Minister of Agriculture and submitted to the appreciation of the Civil House. According to an interviewee's testimony, "*we took this as an indication, but the reception was very positive, and it turned out that, as it had been done very quickly, it was taken as a Brazilian position* [at COP 15]" (Interviewee 13). Taking into account the interests of the sector and political actors, the proposed initiatives were translated as the contributions of agriculture in mitigating climate change to be announced at COP 15. More than a communicative discourse on the role of Brazilian agriculture in promoting sustainability, the discourse took on a coordinative role by bringing together actors with distinct institutional actions and ties in validating current practices, the need to strengthen them with a focus on increasing productivity and valuing agriculture and Brazil on the international scenario. As Schmidt (2008, p. 10) mentions, "the discourse serves not only to express a set of strategic interests or normative values of the actors, but also to persuade others about the need and/or suitability of a particular course of action". The coordinative discourse came together in the construction that "*ABC helps in this, ABC reduces the environmental impact, reduces emissions, hijacks emissions in the case of some technologies, and this is very favorable for an image of the Brazilian product abroad*" (Interviewee 3). The coordinative discourse involved the translation by the actors, that Brazil was a developing country, that it had audacious goals to reduce GGE emissions and that, due to current practices, it was already developing a very productive and mitigating global warming agriculture. Corroborating this perspective, the representative of the Ministry of Finance affirms the understanding that COP 15 would be an important space for the projection of the country and of Brazilian agriculture:

> The government and the Presidency at the time realized that there was a positive agenda there, that it was a platform for projecting the image of the country abroad, and also for the image of a clean economy, and somehow this triggered the sectors. And for agriculture and livestock it was also noticed there that there was an opportunity, you know, that Brazil once again exporting commodities was very relevant [...] so there was a bit of this context of also showing that Brazilian agriculture was efficient, clean, capable of offering clean products, including good ones from the climatic point of view. (Interviewee 10).

Although efforts in communicative and coordinative discourses to strengthen a redefined and positive image of agribusiness in relation to climate change, interpretations also show the strategic translation of the agribusiness sector in the search for competitiveness, maintenance and opening of new markets. When asked about the objectives of the ABC Plan and Program, an Embrapa researcher was emphatic in saying that the reduction of GGE emissions was not the main objective of agribusiness: "*It was not the focus. 'Ah, we're going to develop a system to counter these climate changes'. We are doing it because it is good for production, it improves a number of things and increases productivity*" (Interviewee 20). In addition, an INPA representative mentions that the ABC Plan did not effectively propose to promote the sustainability of Brazilian agriculture, with commercial interests prevailing: "*the*

ABC plan also has this intention of forming another image of Brazilian agriculture and eventually having access to differentiated markets" (Interviewee 2). Similarly, a representative of the Ministry of Finance states that, in the face of international criticism about the relationship between export agriculture and deforestation, the agribusiness sector "bought" this agenda strategically to avoid closing markets already conquered by Brazilian products.

3.3 The Translation of the Climate Agenda in the ABC Plan and Program from an Institutional Perspective

In the institutional dimension, translation depends on the institutional context, the distribution of power delimited by the institutions and the capacities for political implementation (Campbell 2004). According to Hassenteufel et al. (2017), the actors are not only constrained by other actors, but also by the existing institutions, inherited and built from past public policies and arrangements. Institutions are understood here as procedures, protocols, norms and official conventions inherent to the organizational structure of a political community (Hall and Taylor 2003, p. 196). These are constitutional norms, the organization of the political system, policies that already exist and that influence the design of new ones, the rules that organize decision-making and the policy implementation. Thus, the formulation of a new public policy is delimited and adjusted to the institutional framework and to the existing organizational capacities and, once defined, the institutions internal to public policy also begin to guide behaviors and actions.

Following a set of understandings that were being built and influencing the actions of the countries, Brazil sought to build a set of data, initiatives and actions to show the world, during COP 15, how the country could contribute to the mitigation of climate change (Chechi 2019). Right after COP 15, on December 29, 2009, Brazil institutionalized such ideas in the National Policy on Climate Change (Law No. 12.187). Based on the systematized data and involving several discussions and rounds of meetings, about a year later, on December 9, 2010, the government published Decree No. 7.390 which established the "Plan for the Consolidation of a Low Carbon Economy in Agriculture" (paragraph IV), one of the five sectoral plans for mitigation and adaptation to climate change demanded by the National Policy on Climate Change.

However in the discursive scope it is possible to observe a significant change in the agribusiness actors, who start to use the climate change agenda to reframe practices and posit the sector's performance—as previously discussed—, in the institutional scope, the creation of the Plan and its instrument (the ABC Program) represents gradual changes that seek to convert (Mahoney and Thelen 2010) old objectives into new purposes. This is not a critical moment, marked by the institutional rupture and the emergence of a new trajectory along the way (Mahoney 2001). In this case, previously established institutions influenced the configuration of the ABC Plan and Program, producing gradual changes.

As noted by Grisa and Chechi (2016), the theme of sustainability (with different meanings) entered the MAPA agricultural policy agenda in the early-2000s. In the Agricultural and Livestock Plan (PAP) 2002/2003, MAPA launched the Commercial Planting of Forests Program (Propflora), which aimed at economic, social and environmental objectives through financing for the implantation and maintenance of forests for industrial use. In PAP 2006/2007, crop–livestock integration activities gained a specific credit line, the Crop–Livestock Integration Program (Prolapec), which subsequently became the Sustainable Agribusiness Production Program (Produsa), with the purpose of recovering areas degraded land, improve land use, generate clean and renewable energy, encourage rural producers to adjust to environmental legislation, and implement organic production systems and Integration of Livestock and Forestry. In August 2010, in the midst of the debate and discourses on climate change and preceding the institutionalization of the ABC Plan itself, the ABC Program was launched through Central Bank Resolution No. 3.896 to finance appropriate practices, adapted technologies and efficient production systems that contribute to mitigating the emission of greenhouse gases. As reported by several interviewees, in 2011 Produsa and Propflora were incorporated into the ABC Program.

As evidenced and reported by a MAPA interviewee, the Ministry was already operating public policies that, although related to sustainability, had mainly economic objectives of expanding markets. Climate change and the reduction of GGE emissions were not part of its objectives. However, faced with the new scenario, gradual changes culminated in the creation of the ABC Program, which converted the objectives previously established for the promotion of low carbon agriculture. According to Mahoney and Thelen's (2010) categorization, the institutions remained, however they started to be interpreted or activated in a new direction. As previously discussed, management practices and systems are the same, but they are interpreted and manifested in communicative discourses and institutions in a new way. Such changes provoked by the agribusiness sector were favored by the absence of contestation or resistance,[17] by the support of the main actors mentioned in Sect. 3.1 and by the Federal Government's willingness to achieve its goals, explained internationally, to reduce GGE emissions. Support and different resources (financial, political articulations, advertising, among others[18]) were used to provide the capacity to implement public policy. As stated in a government document,

> This shows the Federal Government's willingness to place sustainability at the strategic center of national production. The idea is to increase the sector's competitiveness, deepening technological advances in the areas of sustainable production systems, microbiology of the soil-plant system and recovery of degraded areas. Agriculture can and will contribute to the preservation of the environment, whether through carbon sequestration, plant development

[17] Although there were actors who disagreed and questioned the productive matrix stimulated by MAPA, they did not intend the established institutions, given the preference for seeking to intervene in their fields of action. The existence of two Ministries to deal with rural issues contributed to this result.

[18] In addition to the financial resources provided for in the Safra Plans, there was articulation with the Brazilian states for the construction of state ABC Plans, favoring disclosure and seeking greater adherence to public policy.

or the reduction of deforestation. This will happen by expanding agricultural and forestry activities in degraded or recovering areas. (Brazil, MAPA, PAP 2011/2012, p. 09).

Built as an early translation of the International Agreements, the ABC Plan and Program defined their own institutions and they started to interfere with the actions of other actors. With regard to its own institutions, it is important to highlight that the ABC Program requires a technical project signed by a qualified professional, documents of ownership of the property, definition of the area of implementation of the project, and proof of sufficient profitability to settle the obligations inherent in financing. Each farmer can access rural credit for mitigation actions with a value of up to R $ 5 million, payable over 12 years, with interest rates of 5.25–7%, including up to eight years grace period (depending on the type of loan project) (BNDES 2020).

In accordance with the financeable values and the expectations of the contemplated hectares, it is possible to notice that the priority audience of the ABC Program was and are the major producers. When evaluating data on the implementation of the ABC Program in Brazil, from January 2013 to December 2018, we found that the program reached 6,992,478.89 hectares, corresponding to an average area of 270.83 ha/contract (size different from the characteristics of family farming). In relation to the financed programs, the recovery of degraded pastures includes more than 50% of the projects carried out (13,073), followed by the no-till system (23% of the projects in the period). In turn, programs that would be aimed at family farming, such as the treatment of animal waste, registered only 63 projects (0.24%).[19] More detailed questions regarding the issues of public policy implementation can be consulted in Chechi (2019).

Regarding the influence of the institutions of the ABC Plan and Program for other actors, we highlight the transfer of national public policy to the context of the states. According to Dolowitz and Marsh (2000), national governments may be forced to adopt policies as members of international regimes. In the Brazilian case, part of the responsibility was transferred to the state governments through the creation of state ABC Plans, which can be characterized as an indirect coercive transfer (Dolowitz and Marsh 1996), as the states are invited to cooperate with the federal government for the development of low carbon agriculture. However, it is important to highlight that this transfer may have been more or less effective in each state, as can be seen in the study of Chechi (2019), when comparing the implementation of this public policy in the states of Rio Grande do Sul and Minas Gerais.

4 Conclusion

International ideas and debates on climate change were translated in Brazil, involving certain actors, discourses and institutions. As seen, both the PNMC and the ABC Plan resulted from strategic and early translation aimed at strengthening insertion of

[19] It is important to highlight that the values presented are from all over Brazil, and that further details can be found from regional analysis.

Brazil in the international scenario. Particularly in the case of the ABC Plan, the analysis of the translation process of the international climate change agenda, through the interactive, discursive and institutional dimensions, shows that the actions advocated by this public policy are essentially of mitigation and favored the agribusiness sector and the agricultural practices that were already being developed. The protagonists in the construction of the ABC Plan and Program, the communicative and coordinative discourses triggered, and the institutions already underway made it possible to reframe and posit the productive practices of agribusiness, which continued to do "more of the same". It is a new "guise", as said in the proverb "*old wine in new bottles*", legitimized by scientific research and numerical estimates, which reconfigured the image of Brazilian agriculture, previously associated with environmental degradation and deforestation, for low-carbon and agro-environmental agriculture. Although family farming is formally included in the ABC Plan document, the analysis of the translation of the climate agenda in the construction of this public policy shows that the actors representing the social category did not actively participate in this process (privileging their own spaces and public policies), nor Program institutions favored the participation of family farming.

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The Journey of Darjeeling Tea Gardens Over Decades in the Eyes of the Satellite

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Abstract Darjeeling tea is one of the world's famous agro-products of India, which earned its' huge mercantile prospect in the global agricultural world. Darjeeling Tea serves as an ecological indicator, and it is India's first GI tagged product. The geographical features like altitude, rainfall, sunshine, and mist, coupled with the exquisite processing techniques, contribute to the idiosyncratic flavour of this tea. Darjeeling tea accounts for more than 50% of the tea economy of India with its' exquisite aroma and palatable taste. We have analysed the productivity of the Darjeeling tea gardens over the last three decades. We have investigated several remotely sensed datasets spanning over more than 50 tea gardens to assess the changing health conditions of the tea gardens of Darjeeling over the last three decades. Results show a steady decline in tea production since the year 1989. We computed several indices derived from satellite images and used various classification methods to carry out the present study. These indices enabled us to identify the degradation of the health of the tea gardens, particularly in the piedmont region. An in-depth assessment of ecosystem services of the Darjeeling tea, along with tea-trade, tea-related eco-tourism, and livelihood of more than a million tea workers in the time of climate change, is envisaged to be essential for sustainable management for this exclusive GI tagged product of Darjeeling, India.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*,
Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_2

1 Introduction

Tea happens to be one of the most significant economically profitable crops cultivated in several countries throughout the world (Voora et al. 2019). In developing countries, tea cultivation plays a significant role in food security, poverty alleviation, and development, especially in the rural sector (FAO 2018). Almost 58 countries practice tea cultivation. However, the Asian and the African countries produce most of the tea. At present, China holds the first rank in terms of tea production. India, Kenya, and Sri Lanka holds the second, third, and fourth ranks, respectively (Dutta 2014). In India, tea production plays a crucial role in the regional economies, especially in Assam and Darjeeling (Deka and Goswami 2020; IBEF 2020). It is difficult to stipulate a perfect climate for tea as tea plant thrives in a variety of climatic conditions. Tea cultivation depends on a range of suitable temperatures and specific rainfall patterns, which in turn makes tea cultivation vulnerable to climate change (Biggs et al. 2018). Different research works reported that tea production would be affected shortly, both in terms of quantity and as well as quality by climate change (Wijeratne 1996; Dutta 2014; Duncan et al. 2016; Ochieng et al. 2016). Atmospheric temperature enhancement coupled with erratic and extreme weather events such as heavy rainfall, prolonged dry periods, and intense hot wave during summer, heavy snowfall, and frequent cyclonic storms create significant threat and climatic stress to the resilience of tea production systems (Rahman et al. 2017). Due to these unpredictable weather conditions, frequent floods, droughts, landslides, outbreaks of diseases, and pests have become recurrent, which also negatively affects tea production (Wijeratne et al. 2007; Gunathilaka et al. 2017). Such unusual events affect the concentration of secondary metabolites in tealeaves, which mainly imparts the taste and flavour (Larson 2015). Extended summer, increased temperatures dry up the soils, and decrease the water availability that compromises the tea yields. Displacement of tea cultivation in a new land does not seem to be a viable option, as it results in more CO_2 released into the atmosphere through deforestation. Chang and Brattlof (2015) reported that the tea growing areas, as well as tea production in Asia and Africa, are steadily declining. Such decline would very likely lead to undesirable socio-economic consequences on tea farmers, tea industry workers on tea estates, and tea traders. However, our understanding of the effects of climate change on the tea economy is still not clear. Neither do we know much about the necessary measures that can make tea cultivation sustainable. Such a lacuna shows that we badly need some effective adaptation strategies to combat the ill effects of climate change on future tea production.

In India, we consider the tea plantation industry as a branch of agriculture. Tea, as an industry, is one of the most valuable assets of the nation. India exports tea to almost 85 countries of the world, and in the year 2014, India earned revenue of >40,000 million (in Indian currency) by exporting >200 million kg (Tea Board 2015). India cultivates tea in its 16 states (out of the 29), out of which West Bengal, Assam, Kerala, and Tamil Nadu contributes to about 96% of the total production. The northeastern parts of India encompasses about 78% of the country's total tea plantation area (Arya 2013). The teas cultivated in Darjeeling, Assam, and Nilgiris are renowned for their unique quality worldwide. Darjeeling tea grows in the hilly tracts of Darjeeling district situated in West Bengal, India (Fig. 1).

Darjeeling district is famous for three 'T'; Tea, Timber, and Tourism. Among these, Darjeeling Tea (*Camellia sinensis* L.) is the most famous in the world due to its beautiful essence (Plate 1). The economic backbone of these areas directly depends on the number of tea production units. The tea gardens also attract tourists from different parts of the world. The two adjacent districts, Jalpaiguri and Darjeeling, have three tea-producing zones. These are (i) Dooars, the tea growing area in Jalpaiguri district, (ii) Terai, constituting the plains of Darjeeling district, and (iii) the hills of Darjeeling. Tea cultivation is one of the oldest agro-based as well as an organized

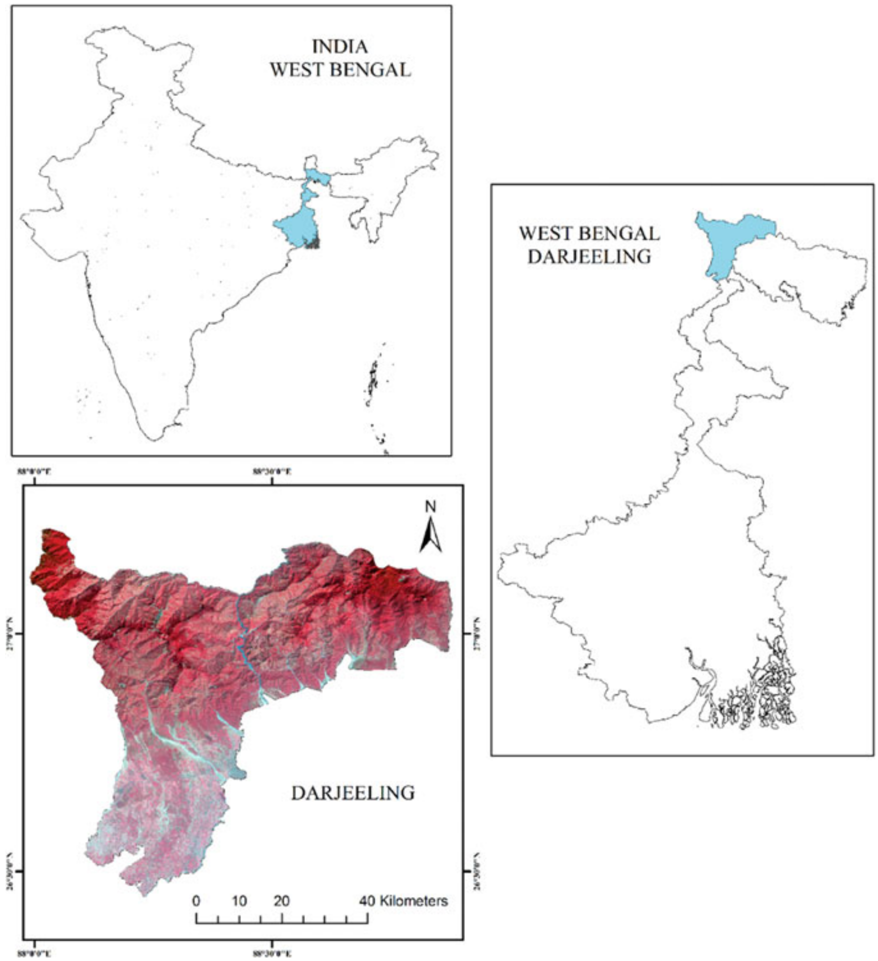

Fig. 1 The map showing the location of the Darjeeling district situated in the state of West Bengal, India (Source: created by the authors)

Plate 1 A collage of photographs showing the glimpse of Darjeeling tea cultivation (Credit: The authors of this chapter)

industry of this country, which provides direct employment to the backward and economically weaker people. Usually the harvest of the green leaves varies between 2750 and 3250 kg ha^{-1}, which ultimately generates almost 600–700 kg ha^{-1} of processed tea (Kumar 2018). The tea sector in India involves almost 1.1 million workers, out of which almost 50% workers are women. Such high rate of women employment also exists in case of the Darjeeling Tea Plantations (Datta 2017). In the recent past, various natural and anthropogenic factors have affected the overall performance of this tea industry and the associated socio-economic well-being of the labourers in the Darjeeling District. At present, additional land is seldom available for the establishment of new plantations or expansion as existing vacant land beyond tea estates is forest cover. Government initiatives to safeguard the forests have restricted the diversification of the tea cultivation area. Topographic limitations and problems in irrigation also hamper the flourishment of this industry in Darjeeling.

Apart from the socio-economic factors, there are some physicochemical and biological factors like temperature, precipitation, relative humidity, duration of sunshine, soil nutrients, pests, and diseases, which influences tea production. Tang et al. (2015) observed that seasonal changes affect tea quality and yield. The annual rainfall in the Darjeeling district ranges from 2500 to 5000 mm. However, during the dry periods, due to scanty and uneven rain, the tea leaves undergo moisture stress. Such irregularity and erratic nature of precipitation significantly hamper the annual operation cycle. Due to the sustained duration of cold winters in this region, the tea bushes occasionally become dormant, followed by a decline in the growth rate (Bhagat and Chakraborty 2010). Dhekale et al. (2014) reported that the West Bengal tea industry is currently facing problems of low levels of productivity added with the high cost of production. In recent times, the vagaries of nature triggered by global warming may lead to sustained monsoons and heavier rainfall than usual. Such climate-change-induced phenomena may lead to considerable losses for the tea estates. The total annual precipitation has not changed much in the Darjeeling district over the past years. However, the rainfall pattern has become irregular. Previously, this region used to experience rain for eleven months, whereas, nowadays, it occurs for only six to seven months. Such shortage has led to excess reliance on the irrigation system, which is not sound enough to support optimum tea production. Frequent landslides in the hilly terrain inflicted by heavy rainfall also cause substantial damage and heavy losses to the tea estates. Workers get cautious of working in landslide-affected zones during heavy rains in fear of further hazards because of which a great deal of valuable picking time is lost. Due to all these factors mentioned above, the study of growth, trends, and production scenario of tea has gained impetus, not only in West Bengal (Rasaily 2013) but also in the other states of India. Also, under these circumstances, the use of remote sensing and GIS technologies have emerged as the most suitable approach for monitoring the growth of tea plantations and the implementation of effective measures as and when necessary (Dutta 2011). Remote sensing technology effectively helps us to differentiate between the tea plantation and other land-use-land-cover (LULC) classes (Dihkan et al. 2013). Remote sensing enables us to use a suite of algorithm and spectral indices to differentiate tea plantation from other LULC classes and monitor the temporal variability (Zhu et al. 2019a). Coupling of historical and social data with that of remotely sensed data can lead to effective reconstruction of the long-term impacts of tea cultivation on the associated social structure, which in turn helps the policy makers to strategize conservation and management initiatives (Prokop 2018).

2 Methodology

2.1 Data and Preprocessing

2.1.1 Satellite Imageries

We have used the Landsat 5 TM and Landsat 8 OLI imageries over seven years from 1989 to 2018 in this study (Table 1). We selected and used the blue (B2), green (B3), red (B4), and near-infrared (B5) bands having a spatial resolution of 30 m. We carried out the radiation monitoring and atmospheric adjustment of the imageries by using image-processing software.

2.1.2 Field Survey Data and Sample Dataset

We prepared the sample bank/training set for the study area by using a combination of data acquired from field surveys and high-resolution remote sensing data from Google Earth. We surveyed 56 locations from typical land-use classes (tea patch) in April and June 2018 (Fig. 2).

2.2 Feature Analysis and Selection

We used the Landsat images to obtain the spectral reflectance of the different (LULC) categories considered in this study. We estimated the mean reflectance of each type and accordingly assessed the difference in spectral variations between tea and that of the other classes. The spectral characteristics of tea plantations have some similarities with other vegetation. There was a distinct difference in the reflectance of water content in the near-infrared (B5) between the tea plantations and other vegetation in some seasons. Whereas, in some seasons, there was no notable difference at all. Therefore, it was difficult to classify tea-plants using the spectral properties

Table 1 The details of the remotely sensed imageries used in this study

Data type	Spatial resolution (meters)	Date of acquisition
Landsat 5 TM	30	4 December 1989
Landsat 5 TM	30	2 December 1994
Landsat 5 TM	30	15 October 2000
Landsat 5 TM	30	29 December 2004
Landsat 5 TM	30	28 January 2010
Landsat 8 OLI	30	22 October 2014
Landsat 8 OLI	30	7 March 2018

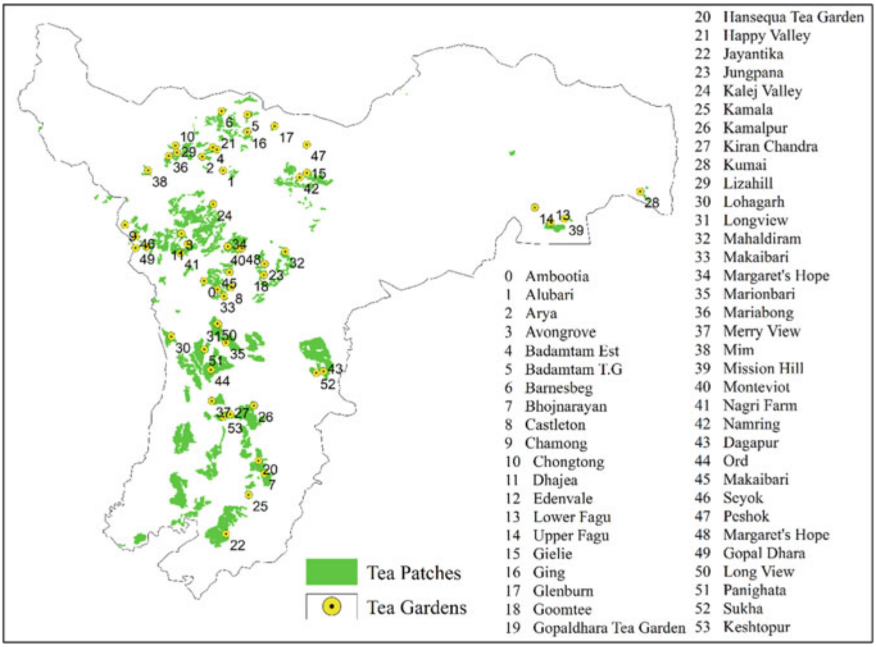

Fig. 2 The map showing the locations of ground-truthing surveys for the present study

of only four bands. To resolve this problem, we analysed normalized difference vegetation index (NDVI), textures (Gray-level co-occurrence matrix (GLCM)), and topographical features to enhance detection (Zhu et al. 2019b). A suite of factors were considered to finally assess the change dynamics of tea patches (Table 2).

We computed NDVI for six standard LULC classes for each of the seven images used in this study (Fig. 3). Firstly, we observed the NDVI of paddies, built-up areas, and water around different tea and forest patches. Secondly, we analysed the spectral reflectance of all the six LULC classes of all the images used in this study. Figure 3 showed that the reflectance for the LULC classes of built area, paddy field, and water bodies had stark difference than that observed for the other LULC classes. In the blue, green, and red bands, the reflectance from the tea patches, deciduous forest, and evergreen forest were almost inseparable. In the near infrared band the reflectance from the tea patches were distinctly different from all the other LULC classes for the image acquired on 7 March 2018. However, in the image acquired on 22 October 2014, there was only a minute difference between the tea patches and the evergreen forests.

Table 2 Factors used for identifying tea patches and their health in this study

Feature type	Feature date	Feature name	Feature variable	Feature Number
Spectral feature	1989, 1994, 2000, 2004, 2010, 2014, 2018	Reflectance	B2, B3, B3, B4, B5	28
Vegetation index	1989, 1994, 2000, 2004, 2010, 2014, 2018	NDVI	Ndvi_1989	7
			Ndvi_1994	
			Ndvi_2000	
			Ndvi_2004	
			Ndvi_2010	
			Ndvi_2014	
			Ndvi_2018	
Texture feature [GLCM]	1989, 1994, 2000, 2004, 2010, 2014, 2018	Contrast	Con_B2, Con_B3, Con_B4, Con_B5	28
		Mean	Mea_B2, Mea_B3, Mea_B4, Mea_B5	28
		Variance	Var_B2, Var_B3, Var_B4, Var_B5	28
		Dissimilarity	Dis_B2, Dis_B3, Dis_B4, Dis_B5	28
		Homogeneity	Hom_B2, Hom_B3, Hom_B4, Hom_B5	28
		Entropy	Ent_B2, Ent_B3, Ent_B4, Ent_B5	28
		Correlation	Cor_B2, Cor_B3, Cor_B4, Cor_B5	28
		Angular second moment	Asm_B2, Asm_B3, Asm_B4, Asm_B5	28

(continued)

Table 2 (continued)

Feature type	Feature date	Feature name	Feature variable	Feature Number
Topographic feature	2015	Elevation	Elo_2015	1
		Slope Aspect	Slo_2015	1
		Aspect	Asp_2015	1
Total feature parameters				262

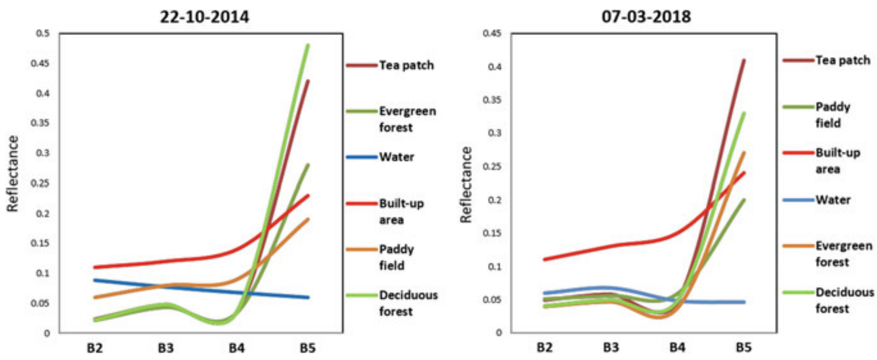

Fig. 3 Spectral reflectance curve for different LULC classes used in the final identification of tea patches

2.2.1 Texture Analysis

The use of texture analysis has been substantial in the classification of remotely sensed images. We usually characterize the texture by analyzing the two-dimensional variations in the intensity of an image. The detection of the perceived consistency of this property is an essential phase in the development of mathematical models for texture. Geophysical changes in the environment lead to the display of varying intensity in an image that ultimately defines the texture of an image (Haralick et al. 1973).

2.2.2 Glcm

The GLCM is a computation that indicates how the pixel combinations are different from each other. The images we analyse usually display the gray-levels (brightness values). The GLCM texture understands the connection between two pixels at a time, called a reference and a neighbouring pixel (Dutta et al. 2012). The GLCM variance uses the GLCM values that arise out of specific combinations of a reference pixel and a neighbor pixel. We refer to the term contrast as the sum of squares variance. Thus, we can calculate the amount of variation in the image, and it is the opposite of homogeneity. A final correlation texture calculates the linear dependence of the greyscale on the adjacent pixels. We can compute the GLCM correlation for wider window sizes. It is quite distinct from the other texture measures, and we can use it in conjunction with other texture measures as well. This measurement provides a meaningful attribute compared to the real measured values: 0 and 1 denotes no association and complete association, respectively. In this study, we used the GLCM tool to evaluate the texture of the tea patches and to differentiate between the healthy and the affected patches.

2.3 Classification Using Machine Language Algorithm

2.3.1 Random Forest

Random Forest (RF) classifier is an algorithm with multiple data sets (Breiman 2001). When we implement the bootstrapping technique, the simple algorithm flow of the RF classifiers takes into account two-third of the total data acquired as training samples (in-bag data). We can use the remaining data as validation samples (Out-of-bag (OOB)) to measure the internal error (Gislason et al. 2006).

2.3.2 Supper Vector Machine (SVM)

The concept of SVM stands on statistical learning and aims to determine the position of the decision boundary that results in an optimal class separation. In the case of a two-class pattern recognition problem in which classes are linearly separable, the SVM selects a linear decision boundary from the infinite number that minimizes the error of generalization (Vapnik and Chapelle 2000). We can resolve the matter of maximizing the margin by using the standard quadratic programming (QP) optimization techniques. We used the data points closest to the hyperplane to measure the margin; therefore, these data points are known as support vectors. If two classes are not linearly separable, the SVM will attempt to find the separating hyperplane while at the same time reducing the quantity proportional to the number of misclassified errors (Pal and Mather 2006). Compiling all these protocols, we were able to identify the tea patches of Darjeeling (Fig. 4).

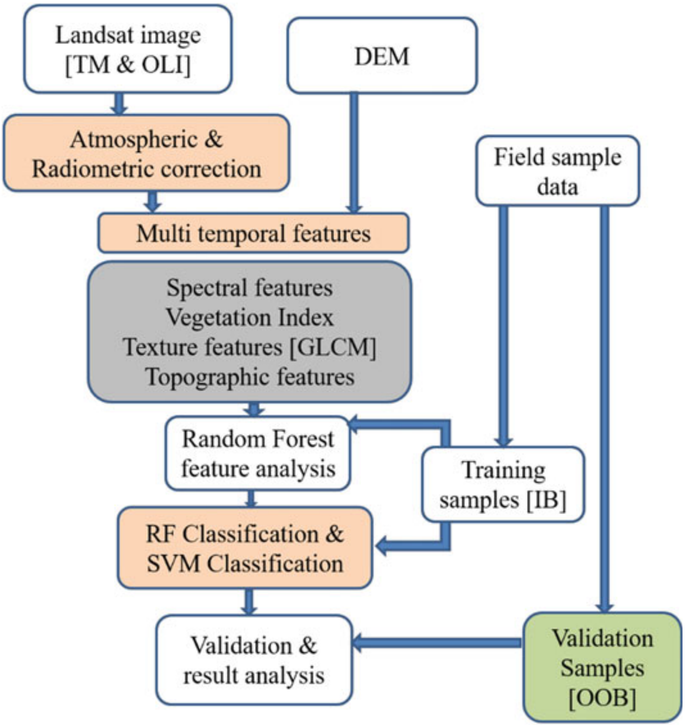

Fig. 4 A flow chart diagram showing the tea patch identification and differentiation methodology adopted in this study

3 Results and Discussion

Using the methods described in Fig. 4, we classified the tea patches from the multi-temporal satellite data, as shown in Fig. 5. We diversified the tea plantation cover into three major categories, namely healthy, moderately affected, and affected (Fig. 6). In the year 1989, the healthy tea bushes covered an area of 11,277 ha, which comprised 56.1% of the-then total tea plantation area. The moderately affected and affected tea patches areas were 5295 ha and 3541 ha, respectively, which accounted for 26.3 and 17.6% of the total plantation area. Subsequently, over the years, the quantum of healthy tea patches decreased, and moderately affected or affected area of tea bushes increased.

As evident from the observations for the year 1994 wherein, the healthy tea patches area covered 10,796 ha, which was around 57% of the total tea plantation area. Simultaneously, the moderately affected and affected areas were 6037 ha and 2108 ha, respectively, which accounted for 31.9 and 11.1% of the total plantation area. In 1994, the healthy tea bushes area was less in comparison to 1989, but the percentage was more than the year 1989. Compared to the year 1989, the affected percentage was

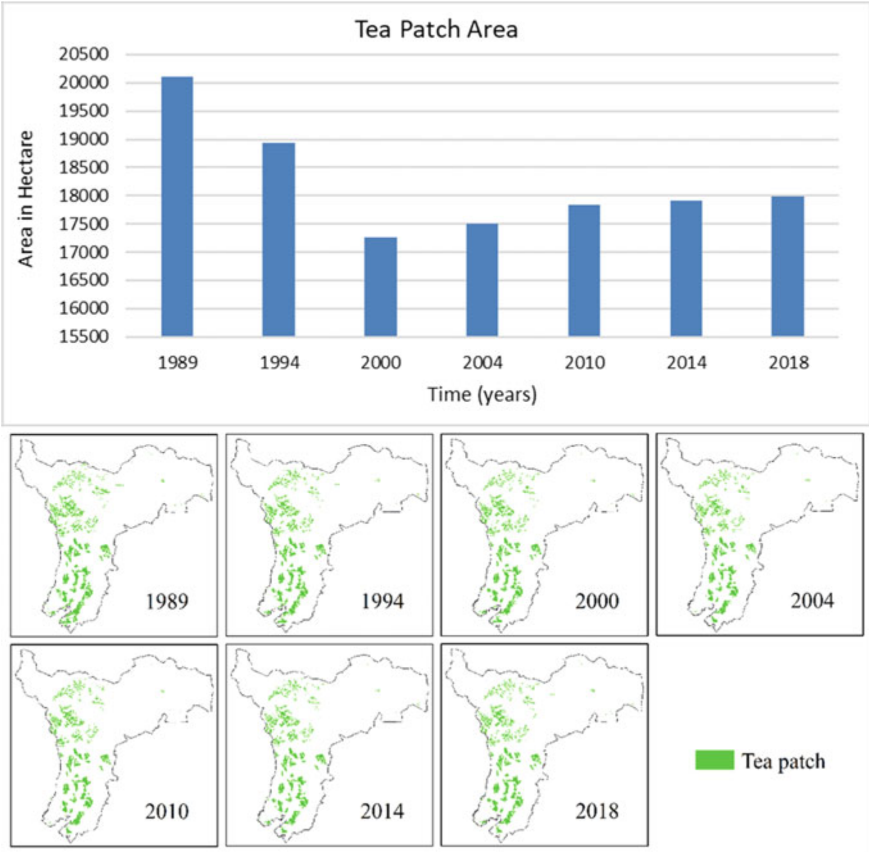

Fig. 5 The changes in tea cultivation areas over last three decades

also less in this year. Only moderately affected areas exhibited a higher percentage than that observed for the year 1989.

From the year 1994, we noticed declining trends in the healthy tea patches area. In the year 2000, the healthy tea patches area covered 7352 ha, which is 42.6% of the total plantation area. The moderately affected tea patches area was 5534 ha, 32.1% of the total area, and the affected tea patches area was 4370 ha, which accounted for 25.3% of the total tea plantation area. Between the years 1994 and 2000, it has been observed that the area and the percentage of affected tea patches drastically increased.

The most remarkable or significant increase took place in the year 2004. In that year, the area of healthy tea bushes increased up to 8990 ha, which was around 51.4% of the total tea plantation area. Simultaneously, the moderately affected and affected tea patches areas were 5419 ha and 3087 ha, respectively, which accounted for 31 and 17.6% of the total plantation area. It shows a lower percentage of moderately

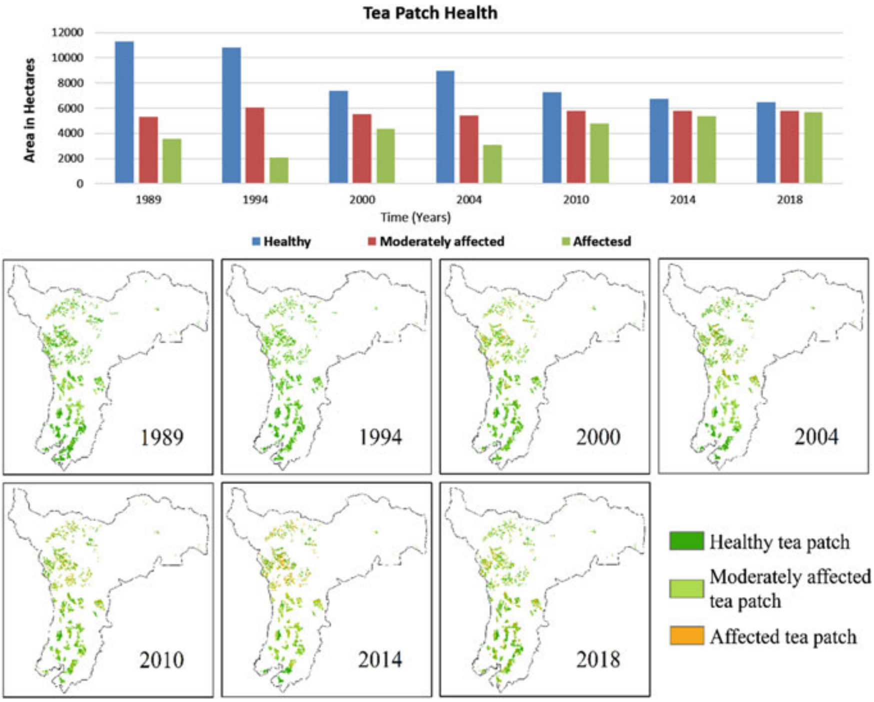

Fig. 6 Dynamics of tea patch health over the last three decades

affected and affected tea patches area in comparison to the healthy patches for the year 2000.

We observed a second declining trend of healthy tea patches after the year 2004. From the periodic data from 2005 to 2010, it again showed a decline in healthy tea patches area and an increase of moderately affected and affected tea patches area. In the year 2010, the healthy tea patches covered 7283 ha, which is 40.8% of the total tea plantation area. The moderately affected area was 5773 ha, 32.4% of the total area, and the affected tea patches area was 4789 ha, which accounted for 26.8% of the total tea plantation area.

In 2014, the decline of healthy tea patches and increment of moderately affected and affected tea patches continued following the previous trend. The healthy tea patches covered an area of 6753 ha, which was around 37.7% of the total plantation area. The moderately affected and affected areas were 5791 ha and 5364 ha, respectively, which accounted for 32.3 and 30% of the total tea plantation area. From the data of 2014, we observed that the percentage of affected tea patches area increased drastically.

In the year 2018, the same declining trend continued for healthy tea patches. The areal cover of healthy tea patches reduced to 6488 ha, which is 36.1% of the total area. The moderately affected and affected areas were 5806 ha and 5695 ha, respectively, which accounted for 32.3 and 31.7% of the total tea plantation area.

Over the period (1989–2018) (Fig. 6), the healthy tea patches decreased from 11,277 to 6488 ha. Moderate healthy tea patches remained almost the same, while the affected tea patches increased to double during the last three decades. The health of the gardens became more vulnerable in the piedmont region.

A steady decrease of tea patch area up to the year 2000 have been noticed. Though after 2000 the reduction of total tea patch area stopped the health of the tea patches continues to degrade after 2000 also. There are several causes of this declining tea health and economy. In Darjeeling, 66% of the tea shrubs are over 50 years of age. Fifty percent of these shrubs are more than 100 years old, and only 8% account for replanted tea shrubs. Such old age of these bushes has seriously affected the productivity of the tea gardens. Thus, the yield of Darjeeling Tea has reduced to less than 550 kg ha^{-1} $year^{-1}$, which is far below the national average of over 1750 kg ha^{-1} $year^{-1}$. Re-plantation of tea takes at least five years for the leaves to reach the desired maturity needed for plucking. The companies fear this gap of five years, as they have to invest a substantial amount in the re-plantation endeavor and pay the workers also without getting any returns (Sharma et al. 2014a, b). Due to the consistent mono-cropping, the soil nutrients have degraded, which severely affected not only the health and yield of these tea gardens but also debilitated the genetic strength of tea bushes as well as affected the bio-diversity of the Darjeeling Hills (Khawas 2011).

4 Conclusion

Because of their synoptic coverage, multi-temporal satellite data and their scientific analyses have the potential to understand the change that has happened in the tea garden for the last 30 years. It can also demonstrate the capability to understand how the health of the tea garden changes with time, which will help the administrator to take suitable remedial measures. The analysis over the last three decades of the Darjeeling tea revealed the fact that the gardens are facing several issues. Apart from losing the operational cultivation areas, the health of the active tea patches is declining steadily. As the health of the active tea patches is most important to maintain the flavor and aroma of the famous Darjeeling tea, the administration and the stakeholders should give priority concerning the sustainable management of the tea economy of Darjeeling. Some of the future strategies may includes

- We should practice planting the tea shrubs in a proper scientific way
- Scientific pruning along with the considerations of post pruning care needs attention
- Plucking methods and plucking period/extent needs serious analysis

- Improvement and application of Biological measures
- The age effect needs a priority
- The soil restoration factor needs research.

The future responsibly lies with the local administrators to use scientific methods for restoration of the affected tea gardens and maintain their past glory.

Acknowledgements The authors are thankful to Tea Board of India, Kolkata office for providing all the necessary support and guidance. We are also grateful to Mr Annamali Rajan, Statistician, Tea Board of India, Kolkata office for his immense cooperation that graciously adorns the chapter. The authors are obliged to NASA, USGS, and ESA for providing satellite datasets. The authors are grateful to the tea workers of various tea gardens of Darjeeling for their unconditional continuous support.

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A New Diet: News on Food Habits and Climate Change

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Abstract This work focuses on the dissemination of messages concerning a healthy diet presented by the Eat-Lancet Commission on Food. Published in January of 2019, this proposal predicted health benefits, keeping in mind the context of climate change as well as our planet's growing population. The proposed diet was shared by several international media corporations and some of them used the BBC´s version as their textual source. Supported by Critical Discourse Analysis, this study aimed to find an answer to the following question: How do these suggestions of how to change food habits provoke individuals to reflect on climate change? Despite some criticism, which is already emerging about that diet model, it is relevant to study the messages which have media impact on topics related to climate change and the role they have regarding the possibility to be followed. Besides the news release on the diet shared by BBC News, two other articles from The Guardian and three Brazilian publications were also analysed—UOL, G1 and Época Negócios. It was concluded that a complexity lens is essential to understand those discourses and the communicational convocations related to that thematic axis.

1 Introduction

1.1 Background

The theme of food cuts across a range of scientific fields and plays a multidisciplinary role in society. Raised as an issue in different areas and enveloped in an interactional dynamic, it follows pathways that take it beyond its relationship with nutrition, by constructing demands and approaches that permeate complexity theory, as defined by Morin (2001).

Under that perspective, it is important to reflect on the different diet patterns recommended in our society, because besides the fact that a diet is defined by the

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_3

variety, quantity and frequency of food and drinks to be usually consumed, food choice also impacts health and environment (Stehfest et al. 2009; FAO 2012; Huyard 2020). As such, diets play a role in climate change. The Territorial Diets bound to geographical particularities, such as the Japanese, the Traditional Nordic, plus the New Nordic, as well as the Mediterranean diet, present themselves as samples, because they are not only associated with health benefits but also contextualized within the cultural, social, economic and environmental aspects of their respective regions (WHO 2019).

In turn, many sciences studies touch on food diets and others come into the frame through their involvement in the production and consumption of food. This Communication Sciences study seeks to verify the role that media messages play in relation to food diets when harnessed on issues of sustainability. For Verain et al. (2017), messages pertaining to the relationship between food consumption and sustainability are likely to guide the consumer, an aspect which endorses the approach taken here. In this framework, sustainable diets involve a complex and challenging approach to withdraw from simplicity and ineffectiveness (Mason and Lang 2017; Springmann et al. 2018). As Mason and Lang (2017, p. 9) stress, “Diets are more complex than the simplicity of the word implies”.

Applying Guy Debord’s (2005) model of society as a spectacle, Luderer (2013) unveiled the media spectacle that has surrounded food in this century and, making use of Bourdieu’s concept of the field (Bourdieu and Wacquant 2005), she explained the agents and discourses that move the field of gastronomy. In this context, the discourses on health are to be highlighted, including those relating to the concept of *Great Health* (Sfez 1996), in which utopian traits are bound to techno-scientific controls that promise a long life and a perfect body. However, sustainability discourses are also emphasised in the spectacle of food, and the voices of specialists become one of the ways of replicating these discourses (Luderer 2013). As Charaudeau (2002, 2009) states, these voices, together with the images, help create an effect of credibility and of truth in the public eye. Besides the journalistic techniques, it is also worth looking at some of the other tools that the media have at their disposal that impose on the communication of food themes, as these messages are also likely to drive the consumption of a sustainable diet.

The challenge, according to Redclift (2005), is to conciliate the values linked to the tripod of sustainability, as there are conflicts and contradictions of interests for the economy when this is faced with ecological or social interests. It is also necessary to take into account economic and cultural issues, which must be added to the social and psychological traits of those who give the information and to the principles established by the media body. Furthermore, as Charaudeau (2009, p. 17) states, these discourses are generally linked to power, as the media are “used by politicians as a means of manipulating public opinion”.

A diet anchored to the principles of sustainability involves the interests of many sectors, including agribusiness, and the increase in meat consumption is one of the environmental concerns. The media certainly address the issue, but how? According to Lahsen (2017), discourses on meat consumption and its relationship with climate change are notably absent from the pages of the major Brazilian periodicals.

Meat consumption is one of the key points of the Planetary Health Diet (PHD), which sets out a model that values people's health and that of the planet, as it is likely to be a great concern feeding 10 billion people in 2050 (Willett et al. 2019). Proposed by the EAT-Lancet Commission, which comprises 37 scientists from 16 countries, this diet suggests the consumption of 2500 kcal/day, of which 810 kcal is from grain, 354 kcal from unsaturated oils, 284 kcal from vegetables, 291 kcal from nuts and, in general, it recommends a daily consumption limit of 30 kcal of beef, lamb or pork, and 40 kcal of fish per day (Willett et al. 2019, p. 451). The PHD was presented at an event in Oslo on 16 January 2019 and caused quite a stir in the media: "EAT-Lancet has generated over 5800 media articles in 118 countries with over 1 million social media shares" (EAT-Lancet n.d.). This impact gave rise to this question: How do these messages redirect people from thinking about how to change their food habits to a reflection on climate change?

To answer this question, it was decided to study the media discourses that addressed the PHD diet, which was analysed along with selected news items that disseminated this proposition across a variety of media types.

2 Object and Methodology

2.1 Object

According to Charaudeau (2009), the credit associated with an item of information is a key element in the subject's creation of a relationship that brings them closer to an effect of message truth. The nature of the source of the data feeds significantly into this process. Thus, an informer associated with a specialist entity will be less suspected of manipulative practices (Charaudeau 2009, p. 53), something that helps to understand the PHD-related media effect.

It is important to understand the agents who were safeguarding the projection of the PHD. Not only was a presentational event set up—a device that engenders the creation of a media event (Charaudeau 2009, p. 188)—but the diet was also published in *Lancet*, a high-impact and prestigious scientific journal in the health field. This latter fact turned it into an attraction in its own right, one that garnered attention from peers and the wider press. The profile of the Commission team also came into play. These scientists, all associated with renowned institutions, serve as specialists in the media narratives about the knowledge discourses pertaining to the health field.

For three years, this team wrestled with the challenge of studying the possibilities for a healthy diet model, which would feed the 10 billion people who will be living on the planet in 2050, and therefore preserve the environment.

According to Charaudeau (2009), an event is born, lives and dies in a dialectic of order and disorder. When there is a state of imbalance, of the rupture of order, one that can be perceived, it is enhanced as a media phenomenon. This fictional effect about a time that is yet unknown, allied with a high order of greatness, drives the creation of a narrative that is to be presented as an event, as it escapes from the possible order of the global imaginary.

2.2 Research Methods

2.2.1 Selection of the Corpus

As previously stated, the PHD has been disseminated thousands of times. This makes it necessary to choose a corpus on which to carry out the analysis. As Brazil figures prominently in international media discourses on environmental issues, it serves as the focus geography for this study. Brazil was also mentioned in the PHD, in the part in which the article addresses the thousands of forest hectares that have been lost around the world this century (Willett et al. 2019, p. 468). The country has also been the target of climate change discourse, particularly when this addresses the consumption of red meat. A recent study concluded that "the consumption of red meat is related to [its] productive capacity" (Farsul 2020). In this regard, Brazil is the second or third largest producer in the world of this commodity and the third largest consumer of the product (24.5 kg/capita) (OECD 2020).

This choice having been made, a search was carried out, using the phrase *Dieta Planetária* (in Portuguese), of Brazilian news from the same date on which the PHD was published and launched. *Google Trends* returned zero records for this phrase, but it was found when searched for along with names of some of Brazil's leading media outlets, such as *G1* and *UOL*, the country's most popular online communication portals. These portals are controlled by the *Globo* and *Folha* groups, respectively, who also publish the country's most circulated newspapers: *O Globo* and *Folha de São Paulo*. The news was also carried by some of the major weekly magazines, such as *Veja*—not analysed in this study—and *Época Negócios,* also belonging to *Globo* company.

The messages conveyed by *UOL, G1* and *Época Negócios* were all linked to the same source, the British news outlet *BBC News*, which thus became a significant part of this work. In Great Britain, the expression Planetary Diet had a high profile on *Google Trends* and there was a specific peak on the PHD launch date.

This data led to looking at other UK media sources and *The Guardian* was selected for closer study. As well as two published stories on the PHD, a significant number of posts on the *EAT Foundation's Facebook* page referenced articles in the newspaper. These pointers indicated that the media was engaged with the PHD causes and, as if it were somehow possible for a communication channel to be politically neutral, the newspaper publicises itself as an independent informant.

2.2.2 Data Analysis

To make itself heard, the enunciator—the media communication structure—builds frameworks for interacting with the addressee. The responses to their activated summonses trigger other formats of summonses in an environment of semiotic overproduction, showing that the addressees are also inserted into the discourse as summoners (Prado 2013). In the operative process of creating and receiving these texts, there are discourses that interfere to summon the individual and form a communication contract between the parties (Charaudeau 2002, 2009).

In the virtual universe, there are devices that can measure this communicative contract between the pairs. *Google Trends* graphs are tools that depict the extent to which internet users have accepted a given theme. There are also resources embedded in virtual communication vehicles that make it possible to check the public's acceptance of certain news items. The number of likes, comments or shares indicates replies that may be associated if a communication contract has been agreed between the parties. These quantitative data contribute to the results of the study through being compared with the qualitative outcomes obtained using discourse analysis.

The selected news items and the EAT-Lancet's process for disseminating the PHD were examined along this methodological axis. Part of the work of assessing the effect of these messages' summoning process involved determining the word of order in the enunciator's discourse. That is, the signifier constructed in language that captures the addressee's attention and motivates them to become a faithful follower of consumption models and values. For Prado (2013), the word of order is the hook for summoning the addressee, thereby sumoning and sustaining a discourse.

To find these devices, the signifiers present in the messages—that gained representativeness in the discourses and could generate a pragmatic response on the part of the addressee—were examined. Thus, word repetition and graphically highlighted expressions were identified, in addition to accents or terms embedded in *modalisation* discourses, bound to verbs that encourage actions.

It was also necessary to understand the enunciator's symbolic spaces, who was the Same and the Other in the discourses, because, as Prado (2013, p. 16) points out, "[…] the media construct Sames and Others from their biopolitical modalisation discourses".

The illustrations were also taken into account, as these are inserted into the narrative structure and help summon the addressee to understand the contract proposed by the enunciator. Thus, semiotic resources were applied to determine the representations of the signs in the images.

Furthermore, it was important here to reflect on the future relationship expressed in the PHD proposition and, to this end, consider the dichotomous logic between ideology and utopia presented by Ricoeur (1986, p. 68), who argues that "the linguistic presence of ideology and utopia is by no means the same […] [and] we have to dig the functions out from under their literary or semantic expression […]". In considering the polarisation of these concepts, this study relied on Ricoeur (1986) when assessing whether the texts expressed utopia, in messages that tried to replace power with something else, through social poetry, mere dream or desirable fantasy or if they leaned more towards ideology and attempted to legitimise power by contrasting reality and science, seeking what is not real and identifying thought as the Other.

These analyses were applied in view of the recognition that high levels of complexity are prevalent in media discourses and in the different voices of the agents. And in this sense, it is worth stressing that "social subjects are not merely passively positioned but are capable of acting as agents and amongst other things of negotiating their relationship with the multifarious types of discourse they are drawn into", as per the words of Fairclough (2008, p. 87).

3 Analysis of the Media Source

3.1 Dissemination of the PHD by the EAT-Lancet

The Eat-Lancet Commission is part of a series of nutrition-oriented initiatives by the *Lancet*. Their main aim is to draw greater attention to issues such as obesity, malnutrition and climate change. The article on the PHD (Willett et al. 2019) that resulted from this work caused a stir amongst their peers and attracted the media spotlight at an event held on 17 January 2019, one day after it was published. Oslo, which hosted the occasion, was the right place for endorsement of a proposition that focused on Sustainable Development Goals (SDGs) and the Paris Agreement on climate change, as the city had won the European Green Capital Award that year. The award, organised by the European Commission, was set up to recognise the role and initiatives of European cities that contribute to sustainability (European Comission n.d.).

Publicising a schedule is important for programmed events, as it marks an advent and the development of social life (Charaudeau 2009, p. 138). This event was determined to be media-like in nature; it was organised in a space in which there is an exchange about social life between participants, the theme was current and some of the participants were representatives of the media or specialists—including celebrities form the world of academia and important figures who served to endorse the messages transmitted.

The moment was captured by live-broadcast images that created the illusion for the audience that they were witnessing history in the making. Social media contributed to this dissemination. The *EAT Foundation's Facebook* page, which was first set up as the *EAT Forum* on 26 May 2015, currently has over 37 thousand followers and was one of the channels to live-stream the event (EAT Foundation n.d.). The live broadcast helped create an illusion of co-temporality, in which the past and the future merge and interactivity creates a simulacrum of contact (Charaudeau 2009, p. 111). The numbers show that there was a good audience for the 97 min broadcast. The piece was entitled 'Watch the World's Most Important Lecture Here'. This phrase, which establishes an action for the addressee by justifying the exuberance of the proposed subject, may have contributed to the 25 thousand views, 191 shares and 90 comments (EAT Foundation 2019).

After *Facebook*, *YouTube is* the world's largest media channel (Ortiz-Ospina 2019). Three days after the event, the video was made available on *YouTube* under the title "The EAT-Lancet Commission Launch Lecture in Oslo" (The EAT 2019a). A text accompanied this publication. Starting with the same title as the *Facebook* broadcast, it was followed by others from which emerged a vocabulary alluding to the positive characteristics of the PHD. They praised the originality of the diet and inflate its temporal locus: "The report has, for the first time in history […]". They attribute celebrity status to members of the commission—"Scientific superstars"—and highlight one member of the team as being a knower of a promising future—"share her vision for a better food future". This text describes a utopia by organising its discourses around fantasies and dreams and these summonses attracted 5,668 views.

The *YouTube* recording was made available on the same *Lancet* journal page as the PHD article (Willett et al. 2019), but the phrase that announces this video conveys technical issues: "Launch event: Watch the launch of the EAT—*Lancet* Commission at the University of Oslo, Oslo, on January 17, 2019". A similar strategy was applied to publication on the virtual platform eatforum.org (EAT n.d.). Here, where just two members of the Commission explain the diet in a stripped-down 27 min version, the event is heralded as "*Eat-Lancet explained*—Co-chairs of the EAT-Lancet Commission, Prof. Johan Rockström and Prof. Walter Willett take you through the ground breaking report."

This shorter version was also released on *YouTube* 12 days after the event, but bundled with another narrative (EAT 2019b). The title asked a question: "What is a healthy and sustainable diet? The EAT-Lancet Lecture—Johan Rockström and Walter Willett". The format of the question helps summon a curious public, including scientists, and causes the addressee to leave the field of dreams or fantasies. They are invited to seek a reality underpinned by science and the names of the academics endorse this intention. The summons is aimed at addressee who are more prudent and less receptive to narratives sprinkled with signifiers that escape from the field of the real, by inserting the subject into the context of ideology. Through this title, this version is focused on the representation of scientists, who deliver more contained, considered and technical discourses and expressions when presenting the PHD, thus endorsing an exercise of reflection. The numbers indicate that this form of summons was effective, as the video attracted over ten thousand views.

Although it is not possible to measure with any accuracy the role that each of these PHD dissemination communication strategies may have played, the outcomes were positive. In the year following the launch, the article was discussed in three further *Lancet* articles (Willett et al. 2019) and cited by over a thousand other articles, according to *Google Scholar*.

3.2 The PHD in the Guardian

Each article in the online version of *The Guardian* comes with a direct appeal at the end to its readers, requesting financial support. This appeal contains the following phrase: "The Guardian believes that the climate crisis we face is systemic. We will inform our readers about threats to the environment based on scientific facts, not driven by commercial or political interests". This would lead the addressee to understand that climate issues are part of the newspaper's values and that readers for whom these principles resonate are, for this enunciator, in the position of the Same.

According to Statista (2020), "The Guardian online was the third most popular online news brand as of February 2019" and "there were more readers from a middle-class background (ABC1)". In this decade, this newspaper has maintained an equilibrium among male and female readers and about half of them have a university degree (Statista 2020; media.info 2014; The Guardian—media kit 2019). They have a passion for arts and culture and, besides that, they "are also passionate about good quality food […], take care to purchase free range, fair-trade, organic and non GM foods where possible and pay attention to where the food they buy is grown" (The Guardian 2012).

This idea is key to understanding this communication vehicle's relationship with the PHD proposition. Firstly, it published two articles on the diet. One was on the day of the event but the other had been published late the night before. Another relevant point is the fact that, over the 14 months subsequent to the launch of the PHD, the *Eat Foundation's Facebook* page listed 24 posts referring to news items published in *The Guardian.* These all had titles alluding to the issues advocated by the PHD and 11 of them contained the word climate.

The articles released the night before the PHD launch event were published in the paper's environment column. Under the title "New plant-focused diet would 'transform' planet's future, say scientists", and the subtitle "'Planetary health diet' would prevent millions of deaths a year and avoid climate change", this article was shared 14,300 times on *Facebook* (Carrington 2019). The single quotation marks in this title accentuate the voice of the scientists, who serve as message-endorsing specialists. The verb 'transform', highlighted and in the conditional form, calls the addressee's attention to the potential of the diet when linked to the planet. The summons is made in the subtitle, where the enunciator lists the beneficiaries: human lives and climate change, a cause embraced by the enunciator.

The accompanying picture, an *EAT forum* photo showing three plates and other small portions of food, illustrates the suggestions for consumption. Coloured vegetables and greens are on the far right, which is where westerner's eyes naturally gravitate. The dish showing the permitted portions of meat is on the left, poorly populated and dull in tone. However, the signifier 'meat' occurs nine times in the text, linked to technical data and mentioned through the voice of the specialists. The messages are aimed at reducing interest in this type of consumption. In addressing the amount of meat that the PHD suggests to be consumed, one specialist argues that the vast majority of the earth's population will not have access to this foodstuff. Thus, this enunciator asks the citizen addressee to adhere to an ideology and to care for the planet and for other people.

The second text, published in the food column, was shared on *Facebook* 2,732 times and attracted 2,002 comments (Sawa 2019). The title "Seeds, kale and red meat once a month—how to eat the diet that will save the world" prompts voracious eaters to tune their physiological instincts to the survival of the planet. The subtitle endorses this message and indicates a prescription for the problem: "A complete overhaul of what we eat may be the only way to meet the needs of a planet in crisis. So what's on—and off—the menu?"

The text is illustrated by an abstract figure created by the newspaper's design team. The symmetrical figure is composed of grains, fruit, vegetables and fish around a white plate that symbolises the planet. The text starts by addressing the question of the 10 billion people who will need feeding by 2050. The image's relationship with the text harks back to Ricoeur (1986, p. 5), who, when speaking of the dialectic between ideology and utopia, states that utopia may be criticised through ideology. The symmetry of the design, with fish jumping out of the representation of a whitening planet and two halves of an avocado that may represent ovaries, that is, procreation, may be representing utopia and, as such, opens itself up to the possible, because, as Ricoeur says (1986, p. 57), "utopia is a dream that wants to be realised". However, utopia evades being in opposition to reality, because reality is mediated by a process and "reality is always caught in the flow of time" (Ricoeur 1986, p. 54). And in the first paragraph the reader is compelled to consider a process of changing reality over the next three decades! As for the subjects involved, the enunciator declares their own involvement with the cause and urges the reader to join them by using the pronoun 'us' twice in the paragraph.

These challenges of liquid life can be assuaged by the *modalisations* scheduled by the enunciator, using formulae that guide the addressee to discover how to be and do, without having to make an effort (Prado 2013). This text made use of this resource, by structuring a diet model that covered all seven days of the week and is based on the PHD guidelines. With this proposition, it reinforces the summonsing effect and underpins the reader's willingness to sign up to a communication contract and an interest in climate issues—the word of order of this enunciator's discourses.

3.3 The PHD on BBC News and the Repercussions in Brazil

The article on the UK's *BBC News* site was published in its Climate Change section under the title "A bit of meat, a lot of veg—the flexitarian diet to feed 10bn" (Gallagher 2019a). The contrast of the adjectives 'bit' and 'lot' emphasises the smallness of the amount of meat and suggests regret on the part of the enunciator. The term 'flexitarian diet' is not used in the PHD proposition but *Google Trends* shows that it was in use in the English-speaking community in late 2018 and in 2019.

This news item was taken up by a number of other media outlets, including Brazil's *UOL, G1* and *Época Negócios*. In these incarnations, the title underwent some changes. "Diet for planetary health—the meal plan that promises to save lives, the planet and feed all of us (and all without banishing meat)" was the version chosen by *UOL* (Gallagher 2019b) and *Época Negócios*' Life column (Época Negócios 2019). *G1*'s version "The diet that promises to save lives, the planet, and feed all of us (and without banishing meat)" (G1 2019) was slightly different. The *UOL* version stresses the name of the diet and states that there is a model meal plan, whilst *G1* generalises these aspects. However, both mention meat at the end of the sentence, without stating quantities, thus creating a semantic repertoire that summons a wider audience, without repelling meat lovers.

The *BBC News* image depicts a trivial motive: a young, white female with straight black hair, wearing a dress of the same colour and selecting colourful fruits from a display. The three Brazilian media opted for different images but stuck to the same theme: coloured foods from the fruit and vegetable groups. On *BBC News*, the use of the indefinite article in the caption for the picture—"A diet has been developed that promises to save lives, feed 10 billion people and all without causing catastrophic damage to the planet"—indicates that the PHD is yet one more diet model amongst many others and has a rather presumptuous ambition, as expressed by its order of magnitude. Through these messages, the enunciator signs a communication contract with the reader who doubts these promises. The three Brazilian media only make use of the second clause in this sentence, replacing the first with the sentence "Scientists have developed a diet that promises to save lives [...]"—thus rescuing the PHD from orphanage and enhancing its value by linking it to scientists.

The format adopted by *BBC News* and the Brazilian media is the same: informative and sparingly intellectualised, it appeals to the reader who is in a hurry but seeks objective questions and answers. For that matter, it is important to think that *BBC* reaches different types of public, among whom the *Worldly Achievers* and the *Culturally Curious* stand out, accordingly to their demographic and behaviour characteristics (BBC News 2018; IOTechnologies 2020). In turn, the Brazilian virtual news portals, *UOL* and *G1*, are even accessed by over a 100,000,000 visitors a month. (G1 Economia 2018; UOL Midia e Marketing 2018), and, as was seen in the analyses by Massuchin and Tavares (2015), the public's interest in those communication media is quite varying every year.

The first question brought by BBC News to the concerning the disconcerting change required by the PHD was "What changes am I going to have to make?" The reply, which follows immediately in the text, invokes lower meat consumption: "If you eat meat every day then this is the first *biggie*". The three Brazilian media state this opening question without mentioning the subject: "What are the changes?" Augmentative expressions are absent from the reply: "If you eat meat every day, then this is the first question".

The BBC News question "Is this for real, or just a fantasy?" was also modified for a Brazilian readership and expressed in a less critical tone: "*An illusion?*" The original question legitimises a critique of the diet, which asks one to do something that lies beyond the boundaries of *the real*. This enunciator legitimises the proposition as the Other throughout the text and places scientific approval in play, by subjugating the PHD to the realm of fantasy. Ricoeur's (1986) dichotomy of utopia and ideology helps to seeing the impasse in which the scientific proposition is critiqued in the enunciator's discourse, for trying to push forward in the field of the fantasy of the desirable, that is, utopia.

Another BBC News question worth discussing is: "Will it taste awful?" When translated literally into Portuguese, this linearly demarcates an aspect that is highly subjective: taste. Bringing the peculiarity of this debate to a head calls for a reply through the voice of the specialist, one of the professors who head the commission, who exempts himself from having to set out his expectations.

It is also worth pointing out another question, one that pertains to agribusiness. In this case, *BBC News* was quite explicit in addressing the harmful effects of this economic model: "How bad is farming for the planet?" Once again, the version in the three Brazilian media takes a softer approach and without being incisive about the harmful aspects of the issue, uses the summons "What is the impact of livestock farming?" This is how they construct a less compromising discourse for a political, economic and social public for whom livestock is of great importance.

One more point worth looking at is raised in the fourth sentence in the *BBC News* version. Here, the enunciator laments the 'enormous' sacrifice that will be required of the Other: "*Their* diet needs an *enormous shift* in what *we* pile onto *our* plates and *for us* to turn to foods that *we barely eat*." The *Época Negócios* uses this sentence in its subtitle, but without the possessive form 'their': "Diet requires an enormous change in what we put on our plate". *UOL* and *G1* add on another sentence that allows for meat and dairy products to remain on our plates—"This is the 'diet for planetary health'—which does not completely *ban* meat and dairy products. But it does require an *enormous* change regarding what we put on our plates", thus lessening the sacrifice inherent in the change of practice proposed by *BBC News.*

This difficulty of changing our food habits is put into perspective by the Eat-Lancet Commission—"humanity has never aimed to change the global food system on the scale envisioned in this Commission (Willett et al. 2019, p. 476). The Commission recognises the importance of other social agents in educating and raising consumer awareness: "Civil society groups, the media, and other leaders have an important role in increasing public knowledge of healthy diets from sustainable food systems […]" (Willett et al. 2019, p. 476). However, as it was seen, there are many complex issues involved if the support of the media is to be assured.

Unfortunately, these Brazilian media texts do not show internet users' commentaries, so as to legitimately infer the audience's reception by the PHD. On the other hand, there was a singular participation from a reader, who endorsed the elucidated questions in a text published by Gonzalez (2019), a journalist who fosters a blog associated with *G1*, where she writes on sustainability and debates themes linked to economics, environment and society. When dealing with the launching of the PHD in Brazil, on 3rd July 2019, Gonzalez (2019) joins the PHD's proposals and emphasizes the relevance of the public policy on the food distribution issue, which "apart from any party or belief, needs to create limits to prevent the big corporations from feeling at ease to favour profit to the detriment of people's health, the preservation of biodiversity and the environment."

That unique and inquiring inference on *G1*, associated with the PHD, aligns with the data compiled by Loose (2019): the debates presented on *G1* and *UOL* to deal with public policies related to security are still rare, in which concerns the climate changes and the food production system. On the other hand, it was possible to state some criticism related to the PHD goals in other communication vehicles, by agents who showed their taste for meat consumption, although those discourses were not mentioned in the news which were analysed.

4 Conclusion

In practical terms and by dealing with the PHD repercussion in different English and Brazilian media, this analysis has revealed a range of discourse constructions around the theme of climate change. Some of these are more committed to the cause espoused by the PHD. This is the case of *The Guardian*, which summons a citizen reader. Others aligned with the cause but set their interlocutions at a tangent, to avoid greater commitment to the theme. This was the case of the Brazilian versions. There are also those that are more daring, as is the case of *BBC News*. Their construction is enhanced by a repertoire of frustrations, questions and doubts regarding the subject and is focused on the prominent disavowal of gluttony.

Thus, these enunciators all apply different devices in their messages to persuade their addressees to reflect on climate change. In specific response to the question underpinning this work, it may be inferred that their discourses on this issue were based on arguments anchored in their premises. Therefore, the words of order and the perception of the Same and of the Other in their messages summoned addressees that were aligned with their arguments. To this end, linking the PHD proposition to the field of Utopia or that of Ideology was part of the dialectical resources employed by the enunciator. These resonate according to their pragmatic interests, which escape from the corporate sphere, spread into the field of power and are better understood when viewed through the gaze of complexity. Given the above, it is clear that much about these issues still remains to be explored. Fortunately, the Communication Sciences are extremely well positioned to carry out research in the area, be it to confer the media communication convocations around a sustainable diet, or to understand the public policies on that issue, or even to unveil the public's voice through their expression in various communication means. This way, this work stands for a device to broaden that investigation beam, which may lead to other shifts of political and geographical discussions, and to ascertain the role of the communicational echoes in which climate changes are concerned.

Consequently, it is pertinent to continue this work checking the media repercussion of the possible advances and proposals dictated by the PHD in the communication vehicles analysed here, as well as in others where those data are to be seen, including those from other countries.

Acknowledgements This work was funded by *FCT—Fundação para Ciência e a Tecnologia, I.P.* (The Portuguese Foundation for Science and Technology) through project no. UIDB/00736/2020

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Perspectives and Limitations of Urban Agriculture in Transition Economies: A Case Study in Bosnia and Herzegovina

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Abstract Challenges of population growth, urban overpopulation, climate change and declining natural resources are pushing food supply systems to their limits. Therefore, urban areas are adopting different/alternative food production and distribution systems, like urban agriculture (UA). UA uses modern/innovative technologies that shorten food supply systems, and this results in mitigating not only the financial burden of modern farming but also climate change effects. With all its implicit and explicit effects, UA offers different food sources for growing urban populations, and it could provide a way of life that is capable of responding to global challenges. Explicit effects of UA often cause misunderstanding of this concept, so UA is often seen as small-scale production, inefficient and limited, which in turn diminish the mitigating effects of UA. Misunderstanding of UA is particularly high in transitional countries, and therefore, this study in Bosnia and Herzegovina aimed to determine the level of understanding of the UA concept and people's expectations of UA, as well as to identify factors that constrain people's awareness of the concept and its mitigating impacts on climate change. The study mapped the existing Bosnia and Herzegovina UA value chain, and lays out perspectives for UA development and the impact of the 2020 COVID-19 crisis on people's perceptions of UA. Finally, we offer our recommendation for all stakeholders to support the UA movement to combat global food supply challenges and help mitigate environmental issues connected with food consumption by urban populations.

1 Introduction

Recently, urban agriculture (UA) has been gaining increased support, recognition and popularity (Redwood 2012; Orsini et al. 2013; Henke and Vanni 2017; Piorr et al. 2018), which illustrates changing attitudes towards city life (Redwood 2012). Today, UA produces 15–20% of the global food supply and it engages 25–30%

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_4

of global urban dwellers (Giseke et al. 2015; Goldstein et al. 2017), while 200–300 million farmers worldwide supply urban areas with fresh agricultural products (Orsini et al. 2013). The ability of UA to combine production with responsible trade and consumption (FAO-FCIT 2011 re-cited in Orsini et al. 2013) makes it appealing to many people (Redwood 2012), and it has become an inextricable part of the debate on improving the quality of life and sustainability of cities (Redwood 2012; Giseke et al. 2015; Sanyé-Mengual et al. 2018; Azunre et al. 2019).

Due to accelerated urbanisation and globalisation of food production and distribution (long supply chains), the existing agrifood system now accounts for 30% of the world's greenhouse gas (GHG) emissions (Vermeulen et al. 2012). Food, mostly consumed in urban areas, greatly contributes to total consumption-based emissions, even more than road transport in some cases (Mohareb et al. 2018). For this reason, cities, as the main location of food consumption (and with a range of necessary accompanying services, e.g. transport, storage) are becoming a focal point in combating climate change where one of the largest sources of environmental pressure is targeted—food consumption (Goldstein et al. 2017). UA responds to urban demand by providing a variety of benefits, such as fresh locally-produced food (Olsson et al. 2016), better and diversified diet, additional employment created by re-activation of under-utilized resources (unemployed people, urban space, waste, etc.), improved quality of urban environments (reduced pollution and temperature, more green areas), provision of recreational, educational and social services (inclusion, justice, equality, access to knowledge, cohesion, solidarity collective actions, etc.). Consequently, UA has evolved from a side-activity that in the past helped people overcome hard times into a modern, innovative practice/initiative/business model, joining stakeholders together in alternative food networks (Paül and mckenzie 2013), developing multifunctional solutions and conferring manifold benefits on social, economic, environmental and cultural levels (Piorr et al. 2018). In this way, UA facilitates creation of an urban–rural continuum to combat problems of poverty, food security/safety, pollution, climate change and GHG emissions (see achievements in Table 1).

A very successful international initiative to develop UA—the Food Policy Pact (that gathers 180 cities from all over the world), and evidence from published research (Redwood 2012; Orsini et al. 2013; Goldstein et al. 2017; Mohareb et al. 2018; Piorr et al. 2018), have outlined a complex set of positive impacts caused by UA. This demonstrates that UA really is a very productive supplier of public goods and services, which is sufficient reason for UA becoming a priority in urban planning (Sanyé-Mengual et al. 2018). UA receives support from international organizations/initiatives such as FAO and UN-HABITAT, as well as from regional (EU), national and local policies (Piorr et al. 2018). This approach has led to rapid development of UA, especially in developing/transitional countries. This suggests that UA opens up windows of opportunity for sustainable development, windows that still remain under-recognised and under-utilised in some transitional countries like Bosnia and Herzegovina (BA). For this reason, we wish to draw attention to UA as a means to combat complex urban problems that have resulted from uncontrolled urbanisation. UA should be implemented on the basis of "greatest and best use/benefit" in

Table 1 Estimated greenhouse gas reduction potential of various measures associated with the United States food system, relative to 2010 emissions (Mohareb et al. 2018)

Target indicator (activities undertaken)	Greenhouse gas emission reduction (%)
Substitute 50% of grocery car trips with delivery	0.4
Improved recycling of food packaging	0.5
Apply 90% of biosolids to agricultural land	0.7
Expanded urban agriculture	1
Meatless Mondays	4
Divert 50% of food waste from landfill to anaerobic digestion	5
Replace 25% of beef consumption with chicken	6
Replace 25% of terrestrial meat with cultured meat	7
Reduce 50% of retail and consumer waste	11
Electricity grid decarbonisation	18

BA, but also in other transitional countries. In this context, this paper aims to: (i) clarify the concept and benefits of UA and the factors that impede its development; (ii) assess the perspectives and sustainability of UA development in BA. Assessment of development opportunities is based on two components: first, identification of stakeholders' attitudes, which are critical for accepting, initiating and developing UA; and second, analysis of the existing UA value chain and identification of a future improved value chain in BA. This approach should shed light on the main drivers and obstacles to stronger development of UA in BA (as a good example of a transitional country), motivate urban policymakers to include UA in urban planning and ensure greater efficiency in combating complex urban problems, including GHG emissions. The text is organised in the following way: first, we give a comprehensive overview of the literature that describes the concept of UA and the benefits and obstacles to its development, and; second, we present the results of our research—mapping the existing UA value chains and identifying the stakeholders' attitudes. Finally, we offer conclusions and recommendations to all stakeholders to support the UA movement in order to contribute to combating environmental issues connected to urban food consumption.

1.1 Urban Agriculture—Concepts, Integrated Multifunctional Benefits and Obstacles

UA is not a new concept. It has evolved from a way to provide for oneself at times of crisis in the beginning of twentieth century to multifunctional land use providing numerous benefits that improve the quality of economic, social, environmental and cultural life (Henke and Vanni 2017; Piorr et al. 2018). UA is a highly diversified activity that uses various technologies ranging from traditional to high-tech landless production, organised in different types of value chains from traditional mainstream to very alternative/innovative food networks, which all provide different levels of multifunctionality. These range from the simple form of combining cropping systems to a very complex form that includes a combination of food production, recreation and social services (Fig. 1).

UA has developed as a practice-based, citizen-led movement (Skar et al. 2020) that responds to very diverse needs of urban, local communities while using locally available resources. For that reason, UA encompasses a wide range of different agri-models that always include an important dimension of context specificity/dependence

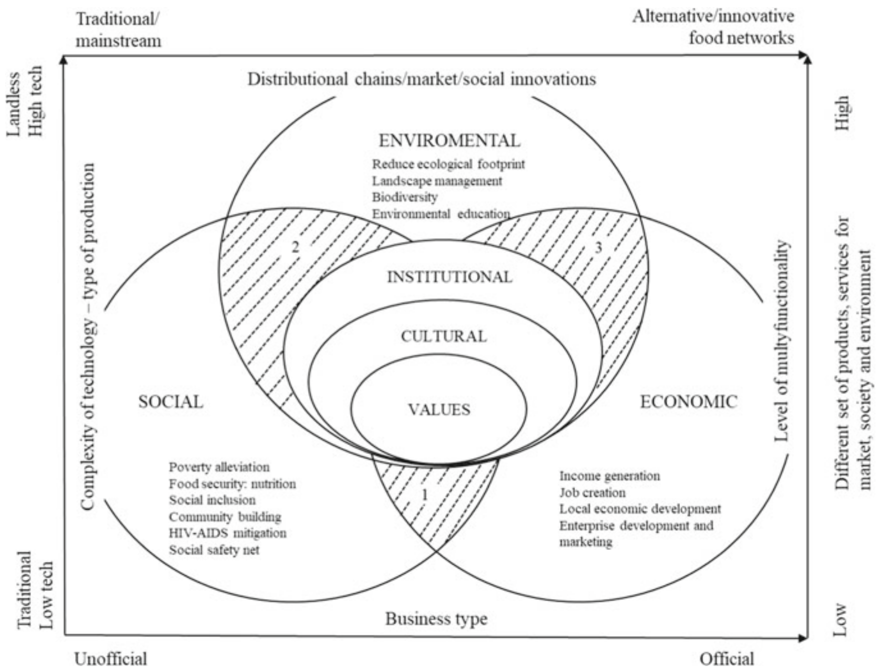

Fig. 1 Complexity of the urban agriculture concept (authors' conceptualization based on Dubbeling and de Zeeuw 2007; Tavanti 2010). *Legend* 1—economic-social: business ethics, fair trade, human rights, labour rights; 2—social-environmental: environmental justice, natural resources, stewardship locally and globally; 3—environmental-economic: energy efficiency, incentives for use of natural resources

(Hamilton et al. 2014; Goldstein et al. 2017; Sanyé-Mengual et al. 2018; Skar et al. 2020), thereby making UA a very complex phenomenon and its conceptualization rather fuzzy and diverse (Zasada 2011; Hamilton et al. 2014). Recognising that numerous definitions of UA are mutually quite similar, i.e. they vary only depending on the point of view from which UA is looked at, we shall not provide their overview here; instead, we shall offer a summary of points where all those definitions overlap. The common descriptors of most concepts and definitions that can be found in the literature include proximity to urban markets, common/grassroots actions, efficient generation of public goods and services, multifunctionality, and innovative/alternative approaches to food production/distribution/consumption based on values and culture. In short, UA is used to describe any activity that is related to production, distribution and consumption of food in cities, as well as the activities connected to building and strengthening the urban green infrastructure. In more recent literature, UA is also called "climate-optimised food production" (Giseke et al. 2015), which, in the opinion of its authors, is a quite precise summary definition.

UA has recently gained in popularity, and a wide range of benefits associated with engagement in UA have been found to directly correspond with quality of life and sustainable development. At the same time, a number of limitations/constraints to the implementation of UA have been identified. The most important benefits and limitations/constraints are summarized in Table 2.

Table 2 sets forth the benefits, but also the factors that restrict development of UA. Since UA is heavily context-dependent, it includes a diverse set of different initiatives and business models, which produce considerably varied benefits and contributions to urban sustainability (Goldstein et al. 2017; Sanyé-Mengual et al. 2018). A complex set of diverse factors restricts development of UA (see Table 2), making it exceedingly difficult to foresee the outputs and impacts of UA development; in other words, it is very hard to formulate an efficient and effective policy intervention. In addition, it is important to note that the success of UA depends on how it is perceived by city officials (Lwasa et al. 2014), the general population, and all the stakeholders participating in the current food value chain. Therefore, attitudes of all stakeholders, combined with relevant and informed decision-making (Giseke et al. 2015), are the key factors that ensure faster and sustainable development of UA. This only adds to the importance of mapping a network of relations in the UA value chain and identifying its weak points in order to develop effective private and public policies to address multiple issues/problems in urban areas (Zasada 2011; Sanyé-Mengual et al. 2018).

1.2 Research Method

Based on a literature overview, the research started with the assumption that UA development has a good perspective, which is, however, undermined by different stakeholders' lack of acceptance (Sanyé-Mengual et al. 2013; Specht et al. 2014; Poulsen et al. 2017) and ignorant attitude of city planners and key decision makers

Table 2 Benefits and limitations of urban agriculture

	Benefits	Limitations/constraints
Economic	• Increased employment (Baker 2004)	• Land availability (Badami and Ramankutty 2015; Yacamán Ochoa et al. 2019)
	• Food security/resilience, locally grown food, fresh products (Barthel and Isendahl 2013; Opitz et al. 2016)	• Human resources—knowledge and cooperation (Sanyé-Mengual et al. 2018)
	• Quality of life, improvements in nutrition and well-being (Kortright and Wakefield 2011; Krikser et al. 2019)	• Limited access to sources of credit and financing (investment and maintenance costs) (Orsini et al. 2013; Piorr et al. 2018)
		• Lack of goods on offer and too small producers (Zezza and Tasciotti 2010; Warren et al. 2015)
		• Strong competition (Yacamán Ochoa et al. 2019)
Environmental and Health	• Decreased environmental degradation and climate change (Freibauer et al. 2011; Specht et al. 2016)	• Uptake of heavy metals in soils, air and water, vector diseases (Hamilton et al. 2014; Mok et al. 2014)
	• Sustainable development of cities (Zasada 2011)	• Occupational health risks, concerns about dust, smell, and noise (de Zeeuw 2004)
	• Environmental resilience, justice (Okvat and Zautra 2011)	• Environmental degradation, carbon footprint (Goldstein et al. 2016; Sanyé-Mengual et al. 2018)
	• Waste and water cycling (Pearson et al. 2010; Proksch 2016)	
	• Reuse of composted urban organic waste, low ecological footprint (Goldstein et al. 2017)	

(continued)

(Giseke et al. 2015), especially in countries in transition. Lack of stakeholders' acceptance of UA is driven by their uninformed attitudes, insufficient knowledge and lack of understanding of UA's concepts, including their poor recognition of the wide range of benefits that stem from UA's multifunctionality (see Fig. 1). Overall, this prevents faster development of UA in BA, and impedes the use of UA as a vehicle to address different urban problems arising from the trend of aggressive and uncontrolled urbanisation. Because of this, the research concept (Fig. 2) focused on:

Table 2 (continued)

	Benefits	Limitations/constraints
	• Greening of the city, reducing local air temperatures, the improvement of the urban microclimate, the conservation of soil, water, biodiversity, and the cultural landscape, and the provision of ecosystem services (Pearson et al. 2010; Beniston and Lal 2012; Goldstein et al. 2016; Clinton et al. 2018)	
Social	• Strengthen social capital, trust and transparency (Hinrichs 2003)	• Public perception as informal sector (Redwood 2012; Goldstein et al. 2016)
	• Social inclusion and participation (Okvat and Zautra 2011; Orsini et al. 2013; Pole and Gray 2013; Poulsen et al. 2015)	• Perception it is purely a social initiative (Piorr et al. 2018)
	• Capacity building, health (Orsini et al. 2013; Dennis and James 2017)	• Romanticised image of agriculture as a low-tech and traditional induces the negative perception of high-tech, landless production (Piorr et al. 2018)
	• Education (Duncan et al. 2016)	• Lack of support services (agricultural extension, veterinary services, small enterprise development support, etc.) (Orsini et al. 2013)
	• Promotion of community-building, civic engagement, empowerment of youth and minorities, physical and psychological relaxation, environmental education, the provision of care for people with psychological disorders (Van Veenhuizen and Danso 2007; Poulsen 2017)	• Policies, legislation, integration into urban planning, high production risks in the urban context (pollution, theft, land insecurity, conflicts with local authorities or neighbours) (Orsini et al. 2013; Piorr et al. 2018; Sanyé-Mengual et al. 2018; Yacamán Ochoa et al. 2019)
	• Resilience during a different crisis (Barthel and Isendahl 2013; Hamilton et al. 2014; Barthel et al. 2015)	
Cultural	• Enhance the symbolic relationship between people and food culture (Sahakian et al. 2016)	• Implementation of UA initiatives without considering the local context (Sanyé-Mengual et al. 2018)

(continued)

Table 2 (continued)

	Benefits	Limitations/constraints
		• Values of stakeholders—elitism, competition, a low wage culture, and cultures of subsidies and inequality (Sanyé-Mengual et al. 2018)

Source Authors' compilation based on literature review

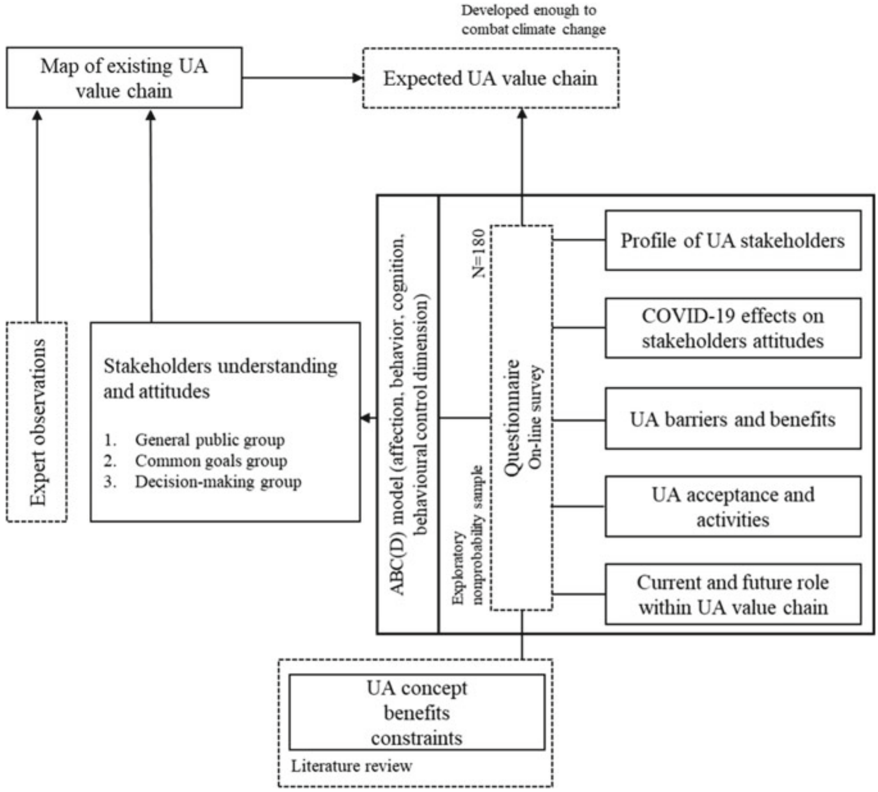

Fig. 2 Research concept and approach

(i) Mapping the existing UA value chain in BA, and identifying the priority areas that must be improved if we want to use the opportunity, attract foreign investments and provide conditions necessary for creating the expected future UA value chain. Based on this approach, the expected future UA value chain will be mapped to visualise the road to UA development in BA. Mapping was completed on the basis of a focus group comprising experts from the EU BUGI project.[1]

(ii) Assessing the stakeholders' attitudes as the main predictor of the general readiness in BA to accept innovation and take action. Stakeholders' attitudes are shaped by simultaneous interaction of dimensions of affection, behaviour and cognition (ABC) (Solomon 2010; Joy 2016; Taha et al. 2020; Yuriev et al. 2020). This ABC approach, frequently quoted in literature (Van den Berg et al. 2006 re-cited in Jain 2014), together with behavioural control (D in this research concept), play a critical role in theory of planned behaviour (TBT), which is widely used (Liu et al. 2020). In our current research, we assessed stakeholders' attitudes on the basis of survey results.

This research place emphasis on the importance of an "integrated cluster" (Wiskerke 2009) of private and public stakeholders, which is divided into three stakeholder groups: (i) general public group (GP); (ii) common goals group (CG)[2] which contains stakeholders who aim for UA as a commonplace means for production, processing and consumption; and (iii) decision-making group (DM)[3]—the people responsible for initiating new measures to support UA development.

An on-line tool was developed for the purposes of this research. The questionnaire included socio-demographic questions, questions regarding the definition of UA, the general perception of any benefits of UA, impediments to UA, and finally, questions regarding the on-going effects of COVID-19 on the respondents' perceptions. Respondents' opinions to all questions (except socio-demographics and effects of COVID-19) were assessed using a five-point Likert scale. The survey was conducted electronically in the course of May and June 2020, with participation of respondents from the whole territory of Bosnia and Herzegovina. An exploratory, non-probability sample of 180 respondents was formed. The internal consistency of the factor construct was estimated by Cronbach's α at the acceptable value of 0.87. The sample was acceptable for exploratory research (Nikolić et al. 2014). SPSS v22 was used to determine simple frequency tables and to explore data using non-parametric tests for mean differences (Table 3).

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[1] BUGI – western Balkans Urban aGriculture Initiative, Erasmus + KA2 Programme of the European Union, 586,304-EPP-1–2017-1-BA-EPPKA2-CBHE-JP.

[2] Common goals group involves representatives from preschool, primary, secondary school, college, student associations.

[3] Decision-making group included representatives from NGOs (youth associations, innovation hubs, development agencies, environment NGOs, etc.) and government organizations (agriculture and food, environment, landscape, architecture).

Table 3 Socio-demographic profile

Socio-demographic profile		All groups		Stakeholders					
				GP		CG		DM	
		F	%	F	%	F	%	F	%
Sex	Female	135	74.86	107	78.68	14	51.85	13	81.25
	Male	45	25.14	29	21.32	13	48.15	3	18.75
Education	Undergraduate	117	65.00	87	63.50	17	62.96	13	81.25
	High school	33	18.33	28	20.44	5	18.52	0	0.00
	Postgraduate	23	12.78	19	13.87	3	11.11	1	6.25
	Other	7	3.89	3	2.19	2	7.41	2	12.50
Age	< 25	57	31.67	47	34.31	10	37.04	0	0.00
	26–35	42	23.33	34	24.82	3	11.11	5	31.25
	36–55	62	34.44	43	31.39	11	40.74	8	50.00
	> 50	19	10.56	13	9.49	3	11.11	3	18.75
Work status	Employed	78	50.98	78	56.93	0	0.00	0	0.00
	Unemployed	44	28.76	44	32.12	0	0.00	0	0.00
	Student	8	5.23	8	5.84	0	0.00	0	0.00
	Freelancer	7	4.58	6	4.38	0	0.00	1	6.25
	Retired	1	0.65	1	0.73	0	0.00	0	0.00
	NGO	9	5.88	0	0.00	0	0.00	9	56.25
	GO	6	3.92	0	0.00	0	0.00	6	37.50
Monthly income	No income	33	24.09	33	24.09	0	0.00	0	0.00
	< 800 BAM	25	18.25	25	18.25	0	0.00	0	0.00

(continued)

Table 3 (continued)

Socio-demographic profile		All groups		Stakeholders					
				GP		CG		DM	
		F	%	F	%	F	%	F	%
	800–1200 BAM	31	22.63	31	22.63	0	0.00	0	0.00
	> 1200 BAM	48	35.04	48	35.04	0	0.00	0	0.00
Food production and UA engagement									
Are you engaged in food production?	No	87	63.50	87	63.50	0	0.00	0	0.00
	Yes, I produce food	39	28.47	39	28.47	0	0.00	0	0.00
	Yes, I work in an institution engaged in food production	11	8.03	11	8.03	0	0.00	0	0.00
Have you heard of the term UA?	Yes, I know what UA is	74	49.01	55	48.25	9	37.50	10	76.92
	Yes, but only a little, not well informed	70	46.36	53	46.49	14	58.33	3	23.08
	No, I haven't heard of UA	6	3.97	5	4.39	1	4.17	0	0.00
	Other	1	0.66	1	0.88	0	0.00	0	0.00
Would you buy products from UA?	Yes	126	83.44	97	85.09	21	87.50	8	61.54
	No	25	16.56	17	14.91	3	12.50	5	38.46
Are you buying products from UA?	Yes	39	21.67	30	21.90	4	14.82	5	31.25
	No	141	78.33	107	78.10	23	85.18	11	68.75
Would you engage in UA?	Yes	124	82.12	92	80.70	21	87.50	11	84.62
	No	27	17.88	22	19.30	3	12.50	2	15.38

Legend GP—General Public, CG—Common Goal, DM—Decision Makers, F—frequency, %—percentage of respondents giving each answer, exchange rate: 1 EURO = 1.9855 BAM

2 Results and Discussion

UA in BA is a recognized activity, and there are public and private stakeholders willing to take on the activities and gain economic and other benefits offered by UA. It is characterised by well-defined value chain actors and roles (Fig. 3) and a lot of potential to act.

The demand for UA products exists, as discernible from the profile where 83.44% of respondents said they would be willing to buy some UA products, and 21.67% of respondents reported they already buy UA products. There is space for further development of this production, as confirmed by 17.33% of respondents who said that due to the COVID-19 lockdown, they would be willing to start their own production "in areas around my living space (garden, balcony, etc.)". Interestingly, the respondents from DM and CG groups (23.08% and 20.83% respectively) were more motivated than those from the GP group (15.93%).

When contemplating the perspective of UA development, it is pertinent to underline that consumer preferences for fresh, local produce have always existed and are particularly strong when buying fruit, vegetables and traditional cheeses. In BA, people still tend to buy these products at green markets, small neighbourhood shops and various fairs promoting bio/traditional/alternative foods and cosmetics.

When determining which models are a part of UA, the respondents emphasised the following: UA as a means of recreation and relaxation (83.5%), urban greenery/urban areas (82.8%), and vertical farms (pots on walls) (80.7%). This suggests the respondents believe UA also includes the development of urban green infrastructure, which adds to the importance of UA development.

Figure 3 clearly shows UA-derived produce is already available in BA.

During the COVID-19 pandemic, we have witnessed a proliferation of web pages offering fresh produce and home delivery, and we have also seen an increase in sales from specialised stores that offer their customers the ability to pre-order the products

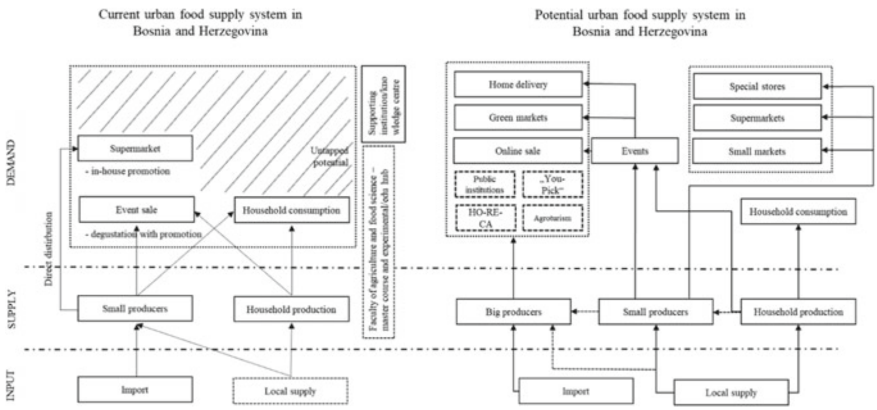

Fig. 3 Current and potential urban food supply system in Bosnia and Herzegovina

online and then collect them from the store. The UA products available are mostly offered by innovative food services, such as interesting, small-scale local producers (e.g. microgreens), e-sale services (e.g. create your own salad—plavatikva.com), specialized shops (e.g. Špajz), or mobile retailers (e.g. local fairs, events).

The main problems that restrict the further growth and development of the UA sector are a lack of legislation that regulates access to resources, and particularly space resources, i.e. use of public areas (e.g. roofs, walls, cellars), and a lack of initiatives to include UA in urban plans and other policies. A comprehensive map of the areas that could be used for such purposes does not exist; however, a step forward has been made with the United Nations Development Programme's Smart City Initiative partially mapping such areas. Continued development and strengthening of the sector requires additional work on establishing an appropriate legislative framework, raising awareness among the population, creating tailor-made public policies to target any identified weakness, and focusing on information and resource sharing and promotion.

It is important to emphasise that in BA there is a knowledge hub at the University of Sarajevo, as well as some internationally supported initiatives/projects that are striving to overcome the main obstacle to continued development of UA—access to resources, and specifically, access to public spaces. The future UA value chain will be based on strengthening production, but also on popularising various aspects of food consumption and individual fulfilment related to UA. In any case, the development will depend on the integration of UA in urban planning.

In order to determine stakeholders' readiness to support UA, it is necessary to determine their attitudes towards UA. Stakeholders' attitudes are defined by the interplay of dimensions of affection, behaviour and cognition, but they also depend on behaviour control components (discouraging factors that require additional effort to support UA). At the affective level, we assessed the level of respondents' recognition of UA's benefits, including its social, cultural and environmental contributions. Among all groups of respondents (right side, Fig. 4), there was a high level of understanding of the whole complex set of UA benefits. The economic contributions of UA were somewhat less understood by all groups, so respondents tended to think that UA does not contribute significantly to production of the necessary quantities of food, and they believed UA cannot become a source of additional income. Respondents received high average scores (above 4) on all questions regarding their understanding of the benefits and expectations of UA. This shows that the respondents do not view UA as a conventional food production system, but more as an unconventional, alternative food production system with more implicit functions and goals. However, UA is recognized for its ecological, social, health, learning, educational, relaxation and recreational functions and benefits to society. This also suggests that the affective dimension of attitudes is quite pronounced.

Good understanding of the UA concept is critical for active participation in production and distribution of food from the urban food systems, i.e. to change people's behaviour, as illustrated in Fig. 5, which shows that respondents from all groups were willing to buy, or already do buy UA produce. The same level of interest was

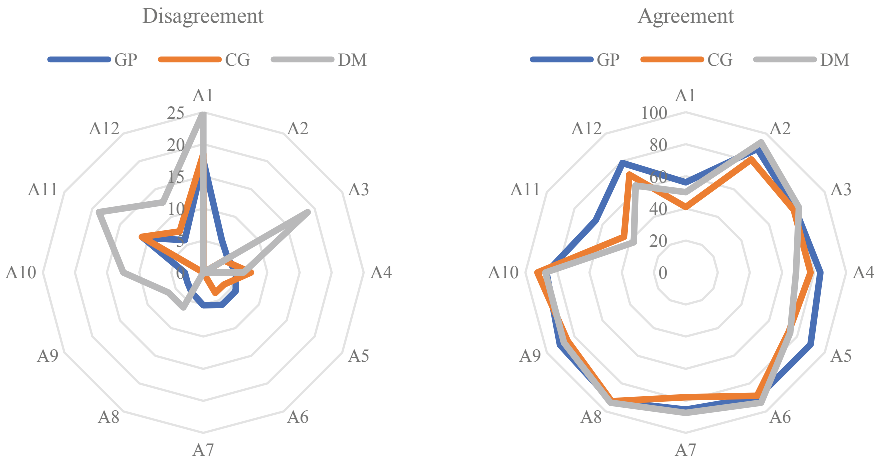

Fig. 4 Definitions, benefits and expectations from urban agriculture (affective domain), frequencies. *Legend* GP—General Public, CG—Common Goal, DM—Decision Makers, if superscripted, these abbreviations show statistically significant differences between marked group and superscripted group, at p = 0.01. A1—UA contributes to providing sufficient food quantities; A2—UA contributes to a more pleasant life due to increase of green areas and greening; A3—UA contributes to strengthening social capital; A4—UA contributes to community strengthening; A5—UA contributes to the improvement of health knowledge; A6—UA provides relaxation and recreation; A7—UA contributes to living better; A8—UA contributes to the return of a sense of nature; A9—Urban farming allows me to try something new; A10—UA allows me to acquire new skills; A11—UA allows me to earn extra; A12—UA contributes to waste reduction. Disagreement—stands for Likert scale group 1 and 2; Agreement—stands for Likert scale group 4 and 5

shown by respondents when it comes to engaging in certain UA activities. The questions related to the COVID-19 pandemic suggest there is a difference among the groups—the DM group was identified as the group that has changed to the least extent its views of food and food systems during the 2020 COVID-19 pandemic and also as the group that is most willing to engage in UA. In any case, all three groups demonstrated a post-pandemic attitude change. All respondents realized that local food production is important and will have a major role in the future, determining people's quality of life. All groups realized there should be a more efficient way to produce and distribute food, and some individuals are even thinking of engaging in food production themselves. All this suggests our respondents are ready to act, which underlines the strength of the behavioural dimension of their attitudes towards UA. According to the change in attitudes (behavioural dimension), and the levels of respondents' understanding of the UA concept (above), we believe this concept has a future in terms of development of a resilient food system.

At the cognitive level of understanding UA, there were significant differences between the GP and DM groups on the question of whether UA is a modern type of agricultural production, and between the GP and CG groups on whether UA is the same as ordinary agricultural production (Fig. 6).

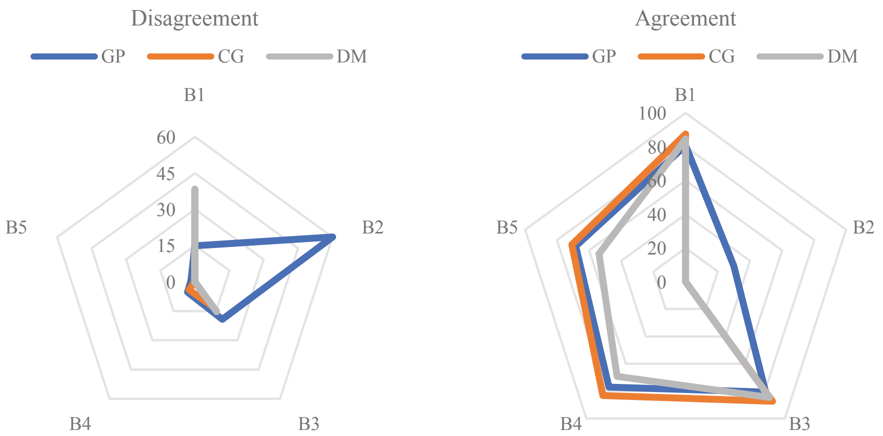

Fig. 5 Behaviour domain, frequencies. *Legend* GP—General Public, CG—Common Goal, DM—Decision Makers, if superscripted, these abbreviations show statistically significant differences between marked group and superscripted group, at $p = 0.01$. B1—Would you buy products from UA; B2—UA products that you are consuming/buying; B3—Would you engage in UA; B4—To what extent has the experience of living in the "age" of COVID-19 influenced you to start appreciating local food production more?; B5—In the "age" of COVID-19, do you pay more attention to the amount of food that you do not use (throw away)? Disagreement—stands for Likert scale group 1 and 2; Agreement—stands for Likert scale group 4 and 5

Most respondents from the CG group saw UA as ordinary agriculture, while on the other hand, most respondents from the DM group considered UA a form of modern agricultural production. This suggests the two groups do not fully understand UA's concepts and, thus, are incapable of grasping all other benefits of UA. This is an issue of concern because the level of understanding of the additional benefits of UA among the DM group directly affects their willingness to integrate it into urban planning for which they are responsible, and without this integration, no continued sustainable development of UA can be expected. Still, all respondents recognised to a large extent that UA involves small, intensive farms and shared gardens, and that it provides emotional and psychological recovery and relaxation, thus contributing to the health and general well-being of the population. This is encouraging. However, it should be noted that the cognitive dimension can also negatively impact the overall attitude of respondents.

According to GP respondents, lack of diversified investment opportunities and government support are the most important barriers (control beliefs) to engaging in UA (Fig. 7). Their opinion on this topic was statistically significantly different from those of the other two groups.

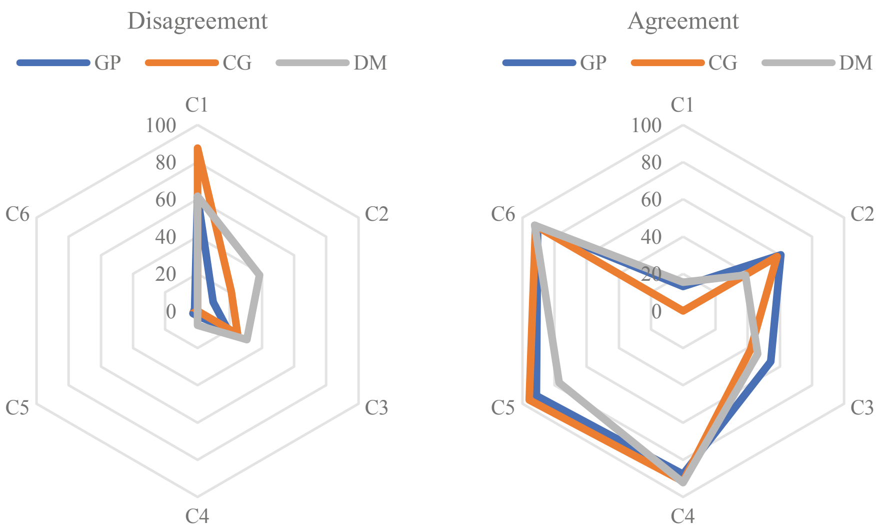

Fig. 6 Definitions, benefits and expectations from urban agriculture (cognitive domain), frequencies. *Legend* GP—General Public, CG—Common Goal, DM—Decision Makers, if superscripted, these abbreviations show statistically significant differences between marked group and superscripted group, at p = 0.01. C1—UA is the same as ordinary agriculture CG–GP; C2—UA is a modern agricultural production DM–GP; C3—UA is a special way of distributing food; C4—UA includes small, intensive farms, shared gardens; C5—UA contributes to the development of communities by promoting the use of green areas of cities for food production; C6—UA provides emotional and psychological recovery, relaxation, contributes to the health and general well-being. Disagreement—stands for Likert scale group 1 and 2; Agreement—stands for Likert scale group 4 and 5

All groups clearly identified access to spatial resources ("there are no public areas designated to UA") as the most important barrier to implementing UA. Furthermore, it is very concerning that the DM group believes not enough people would be interested in UA. The data obtained in this study should be used to combat this incorrect perception. On the positive side, the respondents do not see UA as a potential polluter. The perception that UA provides a low economic contribution is shown in the reasons that were identified as the greatest obstacles to engaging in UA. In fact, this is incorrect on a global level, so in BA, the current and likely economic impact of UA should be studied in-depth. On the other hand, this also speaks eloquently to the steps that need to be taken in order to achieve the desired cumulative contribution of all aspects of the UA concept. Finally, we determined that the positive attitudes of all respondent groups were driven largely by the affective and only partly by

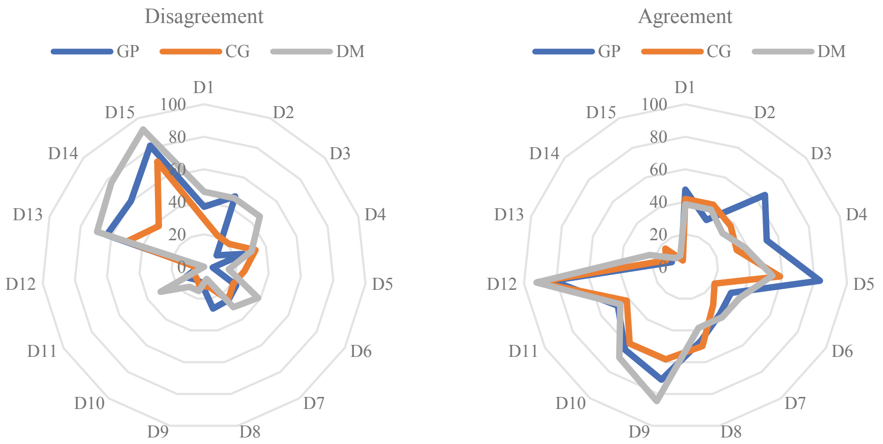

Fig. 7 Perceived barriers to urban agriculture concept (behavioural control), frequencies. *Legend* GP—General Public, CG—Common Goal, DM—Decision Makers, if superscripted, these abbreviations show statistically significant differences between marked group and superscripted group, at $p = 0.01$. D1—I have no space; D2—There is a possibility of pollution; D3—Investment support CG, DM–GP; D4—There is no support from family and community; D5—There is no state support CG, DM–GP; D6—Low earnings; D7—Hard to sell products; D8—I have no knowledge; D9—People's disinterest; D10—Lack of trust; D11—There is no product offer; D12—There are no defined public spaces that can be used for urban agriculture; D13—It destroys the roofs of buildings; D14—Unpleasant odours are created; D15—It's noisy. Disagreement—stands for Likert scale group 1 and 2; Agreement—stands for Likert scale group 4 and 5

behavioural and cognitive dimensions, while the lack of clear support from public policies had a negative impact. However, all findings should be taken with caution because the sample of respondents in our survey was relatively small and was not formed by random selection. However, we emphasize that the internal consistency among the sample groups was quite high, and we believe this allows a high level of generalization. Also all results presented are in line with research findings available in the literature.

3 Conclusion

Although the access to resources (urban space) is very limited and legislation in this area is almost non-existent, UA in BA has developed as a mosaic of different individual business/activities/projects. Its continued development depends on the ability to link such individual activities into organised short food chains or development projects, especially to strengthen the supply of inputs and access to resources. In this context, external support is necessary, and specifically, support that follows on from the existing policies, e.g. the Green Action Plan.

The results suggest that UA has a strong future, that there exists a level of knowledge and understanding that, combined with the effects of the COVID-19 pandemic, have influenced (and could continue to influence) a change in attitudes about food and systems of food production and distribution. Therefore, there is a knowledge base and recognition of the benefits of UA that were sufficiently expressed by all groups of respondents and that reveal positive attitudes towards UA. But at the same time, the results also showed a difference in understanding of the UA concept between the DM and other groups. This gap needs to be narrowed or eliminated in order to see UA promoted as a part of the change in approach towards development of urban centres in BA.

Still, nearly all stakeholders had positive attitudes that were formed mostly by affective, and partly by behavioural and cognitive dimensions. This indicates there is no deep and true understanding of the concept of UA as a means of improving the quality of urban living, or as a way of resolving a whole range of social and environmental problems. This is the very reason why measures stemming from public policies (e.g. the Green Action Plan) are not effective. They are used to "cover up" the actual intentions of the construction industry with its powerful lobby that leads to more concrete, instead of more greenery in the city areas. That is why it will be necessary to ensure participation in the current initiatives, in order to promote all aspects/benefits of UA in appropriate ways and with good arguments, and to initiate a serious public debate and campaign that would ultimately lead to a change of public opinion and the inclusion of UA in urban planning. This level of public debate will shape our common understanding, awareness and commitments towards UA development in BA. Figure 8 depicts one potential road to UA development. It summarizes the necessary outcomes, actors and their respective roles on this road to using UA as a means to solve economic, environmental and social issues in BA, but it also applies to countries in transition in general. This road towards UA as a productive and resilient food system focuses specifically on combating climate change effects and shaping climate-optimised food production and consumption.

If BA and other transitional countries want to utilise UA as a window of opportunity to enhance quality of life in urban areas, they will all need to become a part of international initiatives along the lines of the Food Policy Pact, attract development funds aimed at strengthening the circular economy, and set strategic urban development goals that would strive to win the EU Green City Award. These achievements would mean one of the global United Nations' goals for sustainable development—SDG11—will be fulfilled.

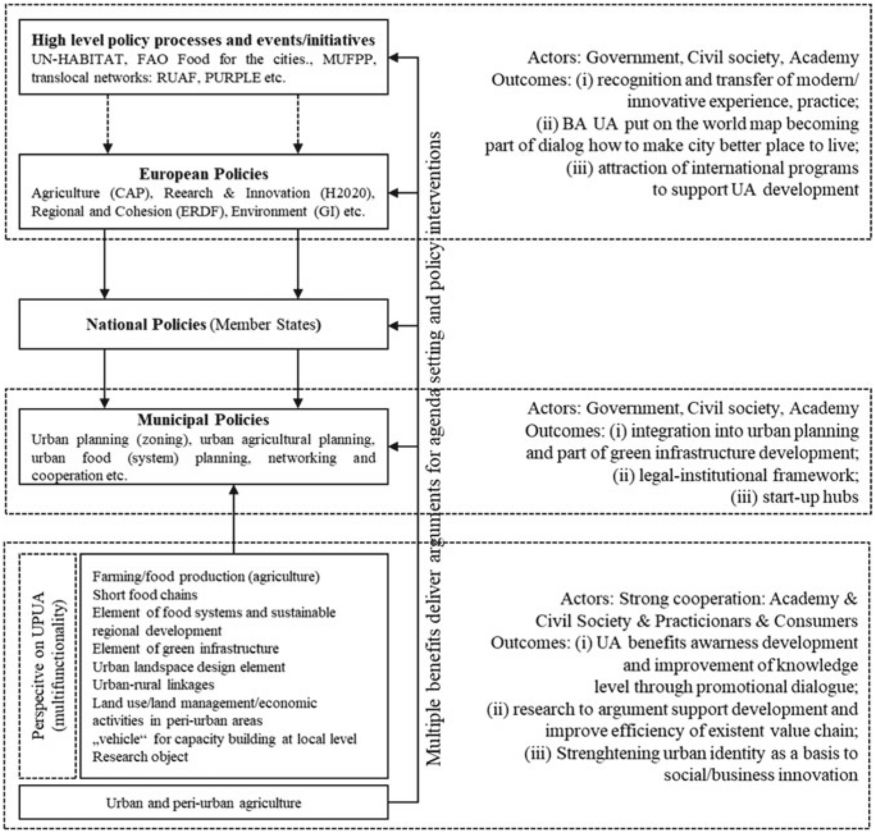

Fig. 8 Road to develop urban agriculture in Bosnia and Herzegovina (adapted from Piorr et al. 2018 to the context of Bosnia and Herzegovina). *Legend* UN-HABITAT—The United Nations Human Settlements Programme; MUFPP—Milan Urban Food Policy Pact; RUAF—Resource Centres on Urban Agriculture and Food Security; PURPLE—Peri-Urban Regions Platform Europe

Annex 1

Definitions, benefits and expectations from urban agriculture	All MS	ALL (%)		GP (%)			CG (%)			DM (%)		
		1–2	4–5	MS	1–2	4–5	MS	1–2	4–5	MS	1–2	4–5
UA contributes to providing sufficient food quantities	3.55	18.3	53.3	3.59	17.5	56.2	3.41	18.5	40.7	3.44	25	50.1
UA contributes to a more pleasant life due to increase of green areas and greening	4.41	4.5	88.3	4.41	5.8	89.1	4.37	0	81.5	4.44	0	93.8
UA contributes to strengthening social capital	4.11	5.5	78.9	4.15	4.4	78.8	4.00	3.7	77.8	3.88	18.8	81.3
UA contributes to community strengthening	4.22	5.6	81.7	4.27	5.1	83.9	4.07	7.4	77.7	4.06	6.3	68.8
UA contributes to the improvement of health knowledge	4.26	5	86.1	4.31	5.8	89.8	4.04	3.7	74	4.19	0	75.1
UA provides relaxation and recreation	4.47	1.7	90	4.46	5.8	89.7	4.41	3.7	88.9	4.69	0	93.8
UA contributes to living better	4.33	1.7	84.4	4.35	5.1	85.4	4.15	0	77.7	4.50	0	87.5
UA contributes to the return of a sense of nature	4.52	3.4	92.7	4.53	3.6	92.7	4.44	0	92.6	4.56	6.3	93.8
Urban farming allows me to try something new	4.47	2.8	89.4	4.48	2.9	90.5	4.37	0	85.2	4.50	6.3	87.6
UA allows me to acquire new skills	4.40	3.3	87.8	4.39	2.9	86.8	4.48	0	92.6	4.38	12.5	87.5
UA allows me to earn extra	3.73	11.6	59.4	3.81	10.9	64.9	3.48	11.1	44.4	3.44	18.8	37.5
UA contributes to waste reduction	4.09	6.7	76.1	4.15	5.8	78.9	3.93	7.4	70.3	3.88	12.6	62.6
UA is the same as ordinary agriculture	2.34	65.6	11.3	[CG]**2.40**	61.4	13.2	2.00	87.5	0	2.38	61.6	15.4
UA is a modern agricultural production	3.53	13.9	58.3	[DM]**3.61**	9.7	60.5	3.46	20.9	58.3	2.92	38.5	38.5
UA is a special way of distributing food	3.33	20.6	51.7	3.39	18.4	54.4	3.08	25	41.7	3.31	30.8	46.2
UA includes small, intensive farms, shared gardens	4.35	2.6	88.7	4.33	2.7	87.7	4.42	0	91.7	4.38	7.7	92.3
UA contributes to the development of communities by promoting the use of green areas of cities for food production	4.36	2.6	90.8	4.39	2.7	91.2	4.29	4.2	95.8	4.23	0	77
UA provides emotional and psychological recovery, relaxation, contributes to the health and general well-being	4.43	1.4	90.7	4.42	1.8	90.4	4.33	0	91.7	4.69	0	92.2

Actions and business models of urban agriculture	MS	ALL		GP			CG			DM		
		1–2	4–5	MS	1–2	4–5	MS	1–2	4–5	MS	1–2	4–5
Community gardens	3.42	21.9	53.7	3.46	21.9	56.2	3.38	16.6	50	3.23	30.8	38.5
Roof-top gardens	3.74	17.2	65.5	3.82	14.9	67.5	3.58	16.6	62.5	3.31	38.5	53.9
Urban greenhouse production	3.50	22.5	58.3	3.56	17.5	57.9	3.42	29.2	66.7	3.08	53.9	46.2
Growing vegetables on the tables	3.67	13.2	60.3	^{CG,DM}**3.82**	7.9	65.8	3.29	25	45.8	3.08	38.5	38.5
Container cultivation	3.46	19.9	53	^{CG,DM}**3.66**	12.2	59.7	2.96	33.3	37.5	2.69	61.5	23.1
Aquaponic production (without land, plant and fish farming)	3.12	30.5	37.7	^{DM}3.28	24.5	43.9	2.75	37.5	20.8	2.38	69.2	15.4
Hydroponic production (cultivation without soil, in aqueous solution)	3.19	29.2	42.3	^{CG}3.34	23.6	47.4	2.71	41.7	25	2.77	53.9	30.8
Vertical farms (pots on the walls)	4.10	10.6	80.7	4.14	10.5	83.3	4.04	8.3	75	3.85	15.4	69.3
Urban greenery / Urban green areas	4.22	5.3	82.8	4.22	5.2	82.5	4.00	8.3	79.2	4.62	0	92.3
Urban agriculture as a means of recreation and relaxation	4.23	5.3	83.5	4.22	5.2	83.3	4.13	4.2	83.3	4.46	7.7	84.6
By creating customer lists for urban products	3.49	17.8	52.3	3.53	14.9	54.4	3.33	25	41.7	3.46	30.8	53.9
By associating for the promotion of urban agriculture	3.72	11.3	60.9	3.72	8.8	59.6	3.54	20.8	58.3	4.08	15.4	77
I would be a regular guest of restaurants selling products from urban production	3.82	9.9	65.6	^{CG}3.89	8.8	68.4	3.38	16.6	54.1	4.00	7.7	61.5

Barriers to UA	ALL			GP			CG			DM		
	MS	1–2	4–5	MS	1–2	4–5	MS	1–2	4–5	MS	1–2	4–5
I have no space	3.21	36.5	45.7	3.24	36.8	47.4	3.33	29.2	41.7	2.69	46.2	38.5
There is a possibility of pollution	2.83	43	33.8	2.75	47.3	31.5	3.17	20.9	41.7	2.85	46.2	38.5
Financial support	3.62	15.2	58.2	^{CG,DM}3.78	10.5	65.8	3.21	20.8	37.5	3.00	46.2	30.8
There is no support from family and community	3.25	27.2	48.4	3.32	25.4	52.6	2.88	33.3	33.3	3.31	30.8	38.5
There is no state support	4.16	9.3	76.9	^{CG,DM}4.35	5.3	83.3	3.50	25	58.4	3.69	15.4	53.9
Low earnings	3.11	23.8	31.1	3.11	22.8	32.4	3.00	20.8	20.8	3.23	38.5	38.5
Hard to sell products	3.17	25.8	35.1	3.16	25.4	36	3.21	25	29.2	3.15	30.8	38.5
I have no knowledge	3.39	22.5	46.4	3.33	26.3	46.5	3.63	12.5	50	3.46	7.7	38.5
People's disinterest	3.87	9.9	70.2	3.91	9.7	71.1	3.71	12.5	58.3	3.85	15.4	84.6
Lack of trust	3.71	9.9	62.9	3.72	9.6	63.2	3.67	8.3	58.4	3.69	15.4	69.2
There is no product offer	3.44	13.9	47.1	3.47	13.1	48.2	3.50	8.3	41.7	3.08	30.8	46.2
There are no defined public spaces that can be used for urban agriculture	4.26	3.3	84.7	4.25	3.6	82.4	4.13	4.2	91.7	4.62	0	92.3
It destroys the roofs of buildings	2.21	61.6	10.5	2.14	63.1	8.8	2.38	50	12.5	2.46	69.3	23.1
Unpleasant odours are created	2.29	58.3	11.2	2.27	60.5	10.5	2.50	37.5	16.7	2.08	77	7.7
It's noisy	1.79	80.8	5.9	1.77	81.6	6.1	1.88	70.8	4.2	1.85	92.3	7.7

Legend GP—General Public, CG—Common Goal, DM—Decision Makers, MS—mean standard, if superscripted, these abbreviations show statistically significant differences between marked group and superscripted group, at $p = 0.01$; min. = 1, max. = 5

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Integrated Assessment Tools in Support of Futuristic Climate Change Towards Rice Production in Nigeria

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Abstract CROPWAT 8.0 model has been an effective multistage climatic induced crop responses to simulate reference evapotranspiration (ET0), effective rainfall, and actual crop evapotranspiration (ETc) which can be of help in determining embedded water (virtual water) in growing a crop and planning irrigation scheduling. This chapter examines the effects of different lengths of recorded morpho-climatic data in predicting rice cultivation for further development at the Lower Benue River Basin, Nigeria using integrated assessment tools (IAT). The explored IAT in the CROPWAT model, the principal component analysis (PCA) technique, and the multivariate inferential regression were utilised in quantifying the basin hydrological response to the varied 10, 25, and 35 years available historical meteorological data. The PCA segregate the physical upper and lower limit of rainfall over the basin to serve as a baseline in quantifying available water and subsequence irrigation schedule planning to facilitate how to manage the watershed in an integrated manner while the multivariate inferential regression relates the past topography conditions to project the future climate scenario. The results show that the net irrigation water requirement per the varied years' length was 711m^3/ha; 1115 m^3/ha and 1343 m^3/ha respectively, while the average value of 36.05% for ET_0 and 49.20% for ETc propose air temperature as a more significant climatic driver irrespective of the varied years' length of data than precipitation. The effective rainfall findings are possibly accurately predicted by the CROPWAT 8.0 model with more lengths of recorded morpho-climatic datasets, thus supporting futuristic climatic impacts assessment for rice cultivation development. These results are of utmost importance to the stakeholders' consideration of

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_5

virtual water strategies for a sustainable transboundary river basin management in extreme hydrological events towards abundant rice production.

1 Introduction

1.1 Background

Given the inseparable link between agriculture and climatic variables, the effect of climate change on food security has been at the forefront of much recent research and policy agendas (Avana-Tientcheu and Tiambo 2019). Many of the river basins are challenged with hydro-climatic processes and complex hydrologic systems, which in turn impacted negatively on agricultural water demand (Gorelick et al. 2019; Ndehedehe et al. 2018). Hence, over a period, variations in crop yield and production are triggered by a mix of agronomics, genetics, and climatic parameters (Dramé et al. 2013; Makihara et al. 2018; Van Oort and Zwart 2018). In order to assist in understanding the rate of yield and the contribution of agricultural products to a country's economy, the role played by these diverse influences need to be unraveled. (Adetutu and Ajayi 2020; De Janvry et al. 2017). However, farmers are assumed to allocate water to a series of crops, according to their water requirements and net value gain (Chauhan et al. 2017). Both the crop planting area, water yield requirement and expected productivity in a planting season may be determined endogenously as a scientific means for planning and scheduling irrigated agriculture towards improving the economic gain of a farmer (Bijl et al. 2018; Kan et al. 2019). Thus, irrigated agriculture is no doubts an essential component of the rural economy in many river basins of the world. Most of the Africa River Basins inhabitants are predominantly fishermen and farmers who depend heavily on the river for water supply (Tran and James 2017; Woodhouse et al. 2017). Besides, many of the existing rural and semi-rural socio-economic engagement in Africa consists of agriculture workers which accounts for 78.3% of the workforce among the populace (Kumalo 2017).

There have increasingly been significant concerns for climate change studies as a result of a mix of its unfavourable effects on socio-economic and meteorological situations of a place (Masson-Delmotte et al. 2018). Among the emerging severe impacts of global climate change on food production has been through hydrological menaces including floods and drought (He et al. 2019). These have caused unbearable loss of infrastructure and created unhealthy environmental conditions which have greatly influenced the volume and quality of available water between the wet and dry seasons. This is besides making the watersheds to witness economic water scarcity. The recently released international panel of climate change (IPCC) special report titled "Global Warming of 1.5 ºC" outlines the fact of an increase up to 2 ºC. This could lead to crises with crops and livestock production (Frieler et al. 2017) as well as adverse effects on water supplies thus posing an additional threat to the coastal area (Conforti et al. 2018). For instance, among the stable foods in Africa which may be extinct or fall significantly by 2080 is wheat and maize as reported in the 5th Assessment Report by IPCC (Center 2011). Also, the arid and semi-arid lands will possibly grow by up to 8%, with adverse consequences for live, livelihoods, poverty extermination, and achieving the sustainable development goal (SDGs)—water for life agenda (Adetutu and Ajayi 2020). Therefore, pursuing appropriate adaptation strategies in breeding rice cultivation development is vital to addressing the current and impending problems and threats caused by a changing climate, which has evolved from a subject of future speculation to an inconvenient reality of the present. This current study, however, examines the effect of different lengths of recorded morpho-climatic data in predicting rice cultivation for further development on a water scare region towards determining its water requirement and extract relevant contents for future soil–water-plant-relationship using (IAT) at a Sub-Saharan Africa country—the Lower Benue River Basin, Nigeria (LBRB).

1.2 Virtual Water, Food and Trade Nexus

Virtual water connotes hidden water or embodied water. In trading perspective, it refers to the water that is used in the production of goods or services or the quantity of water needed to produce a product (Makhlouf et al. 2017) or agricultural commodity (Burritt and Christ 2017). In practice, virtual water trade denotes that a country can possibly ease its water shortages by importing large amounts of virtual water, rather than building new water supply infrastructure. The term denotes global economic processes that could very effectively be used to manage local severe water shortages. The virtual water trading computes the quantity of exported goods through the goods' water use (Fiaz et al. 2018). For instance, when Nigeria imports a ton of rice, it saves the quantity of water required to locally produce this ton of rice. The concept of virtual water trade is to convert the production of agricultural commodities into the corresponding quantity of water that was consumed or utilised to produce these agricultural commodities. The embedded water in traded commodities is essential for adaptation recovery to an extreme hydrological event towards abundant food production (Ridolfi et al. 2018). Though in reality, water is hardly traded over long distances by itself, however, the total volume or weight of the water utilised to produce traded products exceeds the weight of any other commodity traded globally (Oki et al. 2017). This water management concept helps to alleviate the effect of climate on regional water resources shortage through the inter-provincial allocation in water shortage or scarce areas. Quantification of virtual water and mutually agreed price provide agro-economy a powerful method for modifying the environment, which in turn influences how water is redistributed geographically (Oki et al. 2017; Ridolfi et al. 2018). Allan (1997) introduced the virtual water concept in order to proffer solution to water gap and achieve water security. The author opined that water-scarce regions can buy high water consumption crops from regions that have abundant water resources rather than growing such crops by themselves, thus building a virtual water market through trading in agricultural products and food crops.

1.3 Rice Production Background

Different water withdrawal researches across the globe affirmed the agriculture sector as the singular highest user of water (Tilman et al. 2011; White et al. 2018). The bulk of the water abstracted in a river basin is distributed to agriculture irrigation (Koopman et al. 2017), and Nigeria, which is the second-largest economy in the African continent is no exception (Jibrilla 2018). The overall water situation in Nigeria is likely to be further deteriorated because of climate changes, population growth, land-use changes, urbanisation, and migration from rural to urban areas. Most of the States especially within the tropical region of the country show indication of drastic change in rainfall intensity and temperature changes (Chidiebere-Mark et al. 2019; Onyegbula et al. 2017). Irrigation water requirement to different crops varies; however, of these crops, rice (*Oryza sativa)* has the highest irrigation water demand (Djaman et al. 2017).

Rice growing period in the Nigeria field context is in the range of 90 to 110 days, (from the time of planting to the period of harvesting).This could help planting decisions to be made about three months ahead before harvest (Emeribe et al. 2019). Favourable planting settings for rice farming in Southern guinea savannah have been documented by Aondoakaa and Agbakwuru (2012) while the tropical region like the LBRB needs a rainfall range of 1150 to 3000 mm with temperature range of 20 to 27 °C; and best suited acidic soil pH of loamy to clay loam (Abah 2016). Rice consumption represent one of the most staple readily consumed food crop (110 kg/person/year) by the Nigerian citizens (Mani et al. 2018). It can be grown up to thrice in a year depending on the agro-ecological zone of the country (Emeribe et al. 2019; Fregene 2017; Kim et al. 2017). The cultivation rate in country varies and is a function of the local climate, local farming innovation ideas, rice breed species, water resources availability, soil type, and better access to agricultural extension worker services. Also, these variations in agro-climatic variability had favoured the middle belt part of the country for its cultivation. The climate becomes dryer as one progresses northward with steady decrease in both precipitation amount and duration of rainy season (Chauhan et al. 2017; Chidiebere-Mark et al. 2019).

Although, global rice production grew significantly in the last decade as a result of innovative developments such as new varieties (genetics innovation) and improved management practices (Halewood et al. 2018; Makihara et al. 2018). This large improvement has led to increased yields. Nevertheless, the possibility of sustaining the increasing productivity into the future remains uncertain and if the changes to morpho-climatic variables and managerial patterns effect are not assessed for sustainable production (Foley et al. 2011; Tilman et al. 2011). This chapter examines the effects of different lengths of recorded past morpho-climatic data in predicting rice cultivation for further development using integrated assessment tools (IAT) to project further development and extract relevant content for soil–water-plant-relationship at a Sub-Saharan African Country, Nigeria.

2 Related Work

Studies relating to climate impacts and food production are gathering increased attention globally. These studies include investigating the effects of climate change on crop production including maize, cowpea, legume, and wheat (Elum et al. 2018; Nadeem et al. 2019; Stuecker et al. 2018; Xu et al. 2018). Most of these past related studies on the impacts of estimated global warming on crop yields were assessed by indirect methods using the simulation model (Blanc 2017; Frieler et al. 2017; Lv et al. 2018; Porwollik et al. 2017). These studies predicted an increase of about 0.3 °C per decade during the next century because of the accumulation of greenhouse gases in the atmosphere.

Several authors have postulated morpho-climatic effect on rice production (Merem et al. 2017; Shamshiri et al. 2018; Urban et al. 2015; Van Oort and Zwart 2018) but impacts on crop water requirements, under Nigerian weather conditions, have only been studied in scattered and few studies (Abu et al. 2018; Ayoade 2017; Oguntunde et al. 2018; Olanrewaju et al. 2017). Most of these studies addressed the climate effect on rice production based on the precautionary principle and segmented irrigation practice on crop production using integrated water resources management. Their findings indicated that projected future temperature increases will possibly diminish the productivity of the major crops and intensify its water requirements (Abu et al. 2018; Ayoade 2017; Oguntunde et al. 2018). Also, rain-fed upland rice production processes are found to be more sensitive to soil moisture fluctuations than irrigated paddy rice (Djaman et al. 2017; Stuecker et al. 2018). Thus, most of these studies proposed a multiple-problem analysis model using various techniques such as the non-parametric Wilcoxon's signed-ranks test, linear regression, differential evolution methods, differential heuristic optimisation, and extreme machine learning approach as emerging analytical tools to measure the crop water requirement, evapotranspiration and other agricultural meteorological disaster response to drought (Djaman et al. 2017; Nzoiwu et al. 2017; Rice et al. 2017; Shiri et al. 2020; Stuecker et al. 2018; Yu et al. 2018).

2.1 Basic Soil–Water-Plant Relationship

The concepts of morpho-climatic represent a section of geomorphology and investigates the influence of the present and past climate on morphogenetic processes and landforms (Abdulmalik et al. 2019). The land constitute the most valuable natural resource, which symbolizes soil, water, and associated flora and fauna making up the total ecosystem. Their influence extends to erosion abstraction on the land usage changes and process that took place in the basin (Demoulin 2018; Thornbush and Allen 2018). The rates at which climatic processes operate on landform changes and impacts on the soil–water-plant relationship can thus be investigated. Rice cultivation is impaired if adequate water is not available and innovation measures for its growth do not exist. Besides that, rainfall constitutes the main supply to river flow which in turn is typically used for irrigation, drinking, and tourism purposes. Depending on the rainfall pattern and magnitude, this has a profound effect on the availability of water and the socio-economic conditions of a region, especially during extreme hydrological events. Using a parsimony available water for irrigation farming, a correlation matrix model can be deduced as shown in Eq. 1:

$$Q_t = f(R_t, R_{t-1}, Q_{t-1}, Q_{t-2}) \tag{1}$$

where Q_t is the runoff at time (t) and R_t denotes rainfall at time (t). The suffixes t-1, t-2 represents the lagged values of hydrological variables.

To improve irrigation farming, the nexus between soil–water-plant relationships serves as a prerequisite to deliver sufficient water required to boost the farmer's cash and crop production especially rice production in meeting the country's growing population demand (Sofia et al. 2019). However, soil serves as the simple input resources for available water-holding in agricultural production. The selection of a farm irrigation system is determined by the soil factors like texture, structure, soil depth, topography, infiltration or intake rates, real/apparent specific gravity, pore space, soil moisture content and water holding characteristics such as field capacity, and permanent wilting point (Henry 2018). These soil factors are those related to the physical characteristics that affect irrigation water management. Furthermore, among the water delivery methods used in farmland include check structures, siphon tubes, and turnout to the field. Check structures are built to raise canal surfaces so that deliveries can be made to relatively high lands; while when water is to be taken from a field channel into a basin, a turnout into the field proved to be effective. To improve water turnout from the field channel to the irrigating plot, siphon tubes are used to convey water over the channel bank into the field while keeping the other end dipped into the water; the closed end is taken out and released at the ground surface. But some other sources of water which can cause irrigation problems are excess rainfall, over-irrigation, water seepage from the canal to farmland, and the artesian topography condition.

The CROPWAT model has been confirmed for diverse climates across the globe for simulating crop response to climate change under an independent location and soil type (Molua and Lambi 2006). The model calculates the reference evapotranspiration (ET_0), effective rainfall, actual crop evapotranspiration (ETc), and the crop water requirement to determine the net irrigation water requirement as output. The estimation of water requirement (WR) for a crop is one of the basic needs in farm planning and any irrigation project management. The irrigation water requirement in an outlet command area comprise the water requirement of individual farm holdings plus the losses in the conveyance and distribution system. The crop water requirement represents the quantity of water, from whatever source, needed by a crop in each period under normal growth, and field contribution at a place. In addition, the water requirement includes the losses due to evapotranspiration (ET_0) or consumptive use (Cu) including the losses during the application of irrigation water (unavoidable losses) as well as the quantity of water required for special operations such as land preparation, transplanting, leaching, etc. Thus, it is represented as follows:

$$WR = ET_0 + AL + CL \tag{2}$$

where AL = application losses and CL = conveyance losses.

Thus, water requirement is a ‘demand’ and the ‘supply’ from any sources of water. Irrigation (IR), effective rainfall (ER), and soil profile contribution (ΔS) including those from shallow water tables are the main sources. Water requirement could then be represented as:

$$WR = IR_0 + ER + \Delta S \tag{3}$$

For a crop, its field irrigation requirement is referred to as its water requirement excluding the effective rainfall and contribution from the soil profile. This is computed as:

$$IR_0 = WR - (ER + \Delta S) \tag{4}$$

Meanwhile, the farm net irrigation requirement (NIR) is determined by the irrigation needs of each crop, their area, the losses in the farm water distribution system as well as seepage. The NIR can be computed using the Vico, Tamburino, and Rigby (2020) expression in Eq. 5:

$$NIR = WR - (ETc - ER) + AL \tag{5}$$

where ETc represent average crop evapotranspiration value and the crop evapotranspiration for every 10 or 30-days period is calculated as:

$$ETc = Kc \times ET_0 \tag{6}$$

where Kc represent the crop factor and ET_0 the Evapotranspiration parameters respectively.

The accuracy of the determination of crop water requirements will be largely dependent on the type of climatic data available and the precision of the technique chosen to estimate the evapotranspiration or the crop consumptive water use. ET_0 is the combined loss of moisture from plants by transpiration and, soil by evaporation to the atmosphere. Its value is influenced not only by the nature of the soil and crop type but also by variations in latitude and prevailing weather conditions, more specifically, vapour, wind speed, air temperature, pressure, solar radiation and atmospheric humidity. The extent that the quantity of water provided is enough for the growing needs of the crops is described as the adequacy of an irrigation system (Mirjat et al. 2017). This forms the relative water supply (RWS) which can be represented as:

$$RWS = (IR - RN)/IRG \quad (7)$$

where IR represents irrigation water supply, RN is the rainfall and IRG—the gross irrigation requirement. Considering the study area (lower Benue River basin), the major rainfall season lies between June–September, with almost no rainfall in November–March. Therefore, assuming RN is 0, thus no rainfall is considered, Eq. (7) can be simplified to:

$$RWS = IR / IRG \quad (8)$$

This period corresponds to the irrigation augmentation supply season. The gross irrigation requirement (IRG) could be calculated as the product of the net irrigation requirement (NIR) and the irrigation efficiency (IE) to cater for losses during distribution, conveyance, and application. Thus, IRG is calculated as:

$$IRG = NIR \text{ x } IE \quad (9)$$

The analysis thus far, serves as a background in understanding the various input parameters into the CROPWAT model for the various derived output towards an effective irrigation schedule planning and crop growing.

2.2 Futuristic Climate Scenario Models

Future understanding of climate phenomena is the premise of the application of different climate prediction models. Most of these climate models are systems of differential equations premised on the basic laws of fluid motion, chemistry, and physics which are generated classically from mathematical equations that uses many data points to simulate the transfer of energy and water occurring in climate systems (Tamandi et al. 2019; Von Storch and Zwiers 2001). Most of the existing models are dependent on the ability to extract these physically relevant patterns from observations and climate simulations.

The Factor Analysis (FA), MARKOV chain, and regression techniques have been used to study the probabilistic scenario of climatic models (Conforti et al. 2018; Ndione et al. 2017; Yu et al. 2018). Studies of climate change in Nigeria can be broadly classified into those based on the thermal characteristics, studies of the moisture characteristics, and the aerodynamic characteristics studies of climate of the country (Emeribe et al. 2019). Thus, using regional climate models (RCMs) to dynamically downscale will directly simulates the response of regional climate processes to global change. However, an empirical statistical downscaling models (EDMs) have a tendency of more flexibility and computationally efficient. Many assessments inclined to use either type as well as a combination of the downscaling models but the optimal choice depends on the needs of the assessment.

2.3 Integrated Assessment Tools

Organisational decisions and policymaking are commonly supported using integrated assessment (IA) in the form of well-known benchmarks such as the Human Development Index (Singh et al. 2009) or more generic sustainability assessments (Huang et al. 2015). It offers a miniature version of a typical predominant vision for managing catchment on a local scale (Matata and Adan 2018; Richter et al. 2017). It creates inclinations between options by reference to an explicit set of objectives such as quantity, quality, and time of delivery that the decision-making body has to recognise, and for which measurable criteria has been established to assess the degree to which the objectives can be achieved. Integrated assessment is otherwise known as indicator-based benchmarking, sustainability assessment, multi-criteria analysis, composite indicators, etc. All these approaches are aimed at evaluating the possible courses of actions, alternatives and, options by collapsing multiple dimensions into one or more indicators, thus reducing the associated complexity to a handy amount of information (Starkl et al. 2013). Integrated assessment tools are also common for assessing the technical, environmental, and financial feasibility of a project (Malik 2013).

However, the rice-growing index (RGI) is a function of meteorological factors such as relative humidity, temperature, incoming solar radiation quality, and rainfall, as well as non-meteorological factors including the site characteristics, type of seeds, and management practices such as fertilizer, irrigation, and pesticide application. The assumption that the human factor (non-meteorological) can be controlled with adequate measures and prompt technological action brought about its sustainability assessment. Thus, modeling the rice-growing index concerning morpho-climatic variables could be simulated through additional analyses for assessing the technical, environmental, and financial feasibility of its plantation project. The spatial and temporal distribution of rainfall is a major controlling factor that constitutes the available water used for irrigation purposes. The analysis of temporal changes in rainfall patterns can possibly be derived using two locations that have longer daily or monthly records, while the spatial distribution could also be investigated from correlations between distances and the rain catch. As an alternative approach for the temporal and spatial rainfall variation measure, the catchment's long term monthly means, seasonal and annual rainfall can be calculated for the area using both the probability distributions of gamma and normal for the period. The combined probability density function has proved useful through the skewness coefficients for the monthly datasets. The normal probability density function is generally calculated as (Husak et al. 2007):

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{(x-\mu)^2}{2\mu^2}\right) \tag{10}$$

When the skewness coefficients for the monthly data approach zero, the probability distribution of the monthly rainfall is approximately normal, and this can be tested by using the chi-square testing of the goodness of fit. Besides, a high skew coefficient (>1.0) for daily/monthly rainfall indicated that these data like most hydrological variables followed exponential distribution. The probability density function for the exponential distribution can thus be expressed as (Tamandi et al. 2019):

$$\mathbf{f}(\boldsymbol{x}) = \frac{1}{\boldsymbol{\beta}^{\alpha}\boldsymbol{\Gamma}(\boldsymbol{\alpha})}\boldsymbol{x}^{a-1}\boldsymbol{e}^{-x/\boldsymbol{\beta}} \tag{11}$$

The expected value m_r, the variance—$\boldsymbol{\sigma}_{\boldsymbol{R}}{}^2$, and the coefficient of skewness C_s for this distribution are calculated as:

$$\begin{aligned} m_r &= E(R) - \alpha\beta \\ \sigma_R^2 &= Var(R) = \alpha\beta^2 \\ C_s &= 2/\sqrt{\alpha} \end{aligned} \tag{12}$$

where ‘a’ is the shape parameter, expressing the extent of the symmetry around the mode and $\boldsymbol{\beta}$ is the scalar parameter denoting the area covered while E is expected probability of Real values.

Spatial variation in the abnormalities of rainfall at any location may be brought by a simple ratio of precipitation known as the Precipitation Concentration Index (PCI) in determining the rainfall concentration of an area. The ratio may also give the stability of rainfall for the area. The PCI allows quantifying the relative distribution of precipitation patterns into uniform, moderately seasonal, seasonal, and irregular respective categories. The higher the ratio range between 8.3–100, the higher is the abnormality in rainfall and vice versa. PCI can be computed using Eq. 13 as suggested by Tolika (2019).

$$PCI = 100^{\frac{(\sum Pi)^2}{P^2}} \tag{13}$$

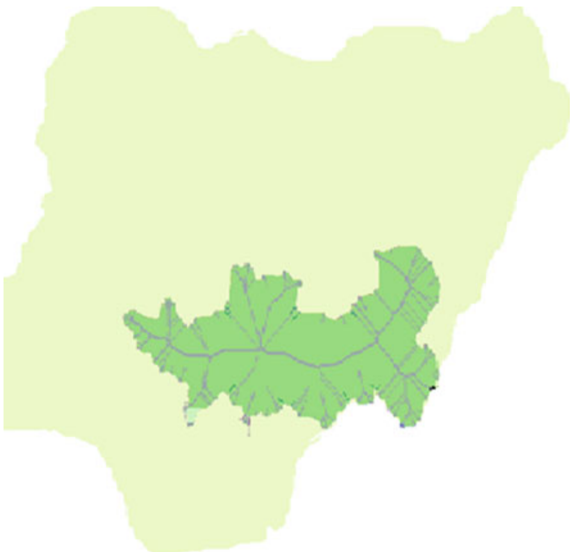
Furthermore, the use of the coefficient of variation can be used to compute the rainfall spatial variation pattern over the years (Brunner et al. 2019). To investigate the meteorological pattern of trends and to measure their impacts on the crop growth rate, while transforming into a normal distribution, the long-term data records fit probability distribution simulation would be applicable (Xinchun et al. 2018).

Also, significant changes in temperature range are imperative indicators in defining the impact of climate variability on crop yield (Asseng et al. 2011; Lobell and Field 2007). The monthly mean temperature (TEM), minimum (T_{min}) and maximum (T_{max}) surface air temperature data were usually utilised to investigate the variability. The ordinary line regression (OLR) computed as $\hat{y} = \alpha t + \beta$ is a way of validating and capturing the correlation; such that the rate of change is expressed as α, the β as intercept coefficient and the monthly or the seasonal temperatures as ŷ at the given time t. The gradient of trends could be computed by using the slope of the linear tendencies expressed in °C per decade. This current chapter uses descriptive and inferential statistics such as Factor Analysis as a choice of principal component analysis (PCA), multivariate regression, and probability distribution function of normal and gamma to serve as a preliminary inference deduction model before applying the comprehensive multistage computation in the CROPWAT analysis model. The preference condensation novel results for determining net irrigation water requirement, ET_0, ET_c and crop planting schedule operation form a significant scientific contribution of the chapter.

3 Research Design and Methodology

Though Nigeria is gifted with significant amount of water resources, the Lower Benue River Basin (LBRB) as shown in Fig. 1 is inherently a complex water resources system with many interdependent components which plays an important role in supplying water to several users—including domestic, irrigation, industrial and hydropower generation (Kim et al. 2017). Recurrent flooding of the River Benue catchment, drought, and pollution are only a few of the environmental problems (Nwilo et al. 2012) in the study area. The network of rivers and streams in the basin is however seasonal, especially as one progresses into the northern areas of the country where the rainy season is only three or four months in duration. The hydrological regime of the basin is classified as a moderately warm, humid climatic region with a convincing discrepancy between the dry and wet seasons as the maximum discharge is observed in the wet season (Henry 2018).

Fig. 1 Map of Nigeria showing the Lower Benue River Basin



The peak flow as a result of local runoff commences during the middle of September. After this peak, the decline is fast and remains until around the middle of April (Abdulmalik et al. 2019). The Benue River watershed belongs to the trans-boundary water bodies, which implies been shared by Cameroon, Chad, and Niger (Abah and Petja 2017). However, the selected Lower Benue River Catchment (LBRC) is 18,500 Sq. Km, in Area and it is situated between latitude 07° 34, longitude 06° 70' and latitude 07°41' and longitude 08° 07' with a minimum and maximum elevation of 31 m and 566 m respectively. Adamawa, Taraba, Gombe, Bauchi, Plateau, Nasarawa, Benue, and the Kogi States are located along and bounded by the river channel. The land use is predominantly savannah (88%) while the prevailing soil type is loamy, and this encourages agricultural practices which are the dominant land use in the watershed. Agricultural products especially cereals, roots, and tuber crops are mostly cultivated in the area. The area is strongly apt for rice cultivation while other crops like yam, cassava, and wheat are moderately grown and rainfed (Dam 2012). The North Central crevice of Nigeria is susceptible to climate change given its geographical location and progressive impact from the Sahara Desert. This has unfavorably distorted the hydrologic cycles hence, portends to aggravate the existing water supply–demand imbalance in the area. The LBRC lies in the Sudano-Sahelian zone which has been challenged by several ecological factors that are already linked to climate change (Matata and Adan 2018). Other major areas of Nigeria that are mostly affected by climate change are the coastal areas, and Niger delta zone of the country.

3.1 Methodology

XLSTAT Microsoft Statistical software was used for the various analysis in this chapter. The varied years' climate data for three weather stations: Lokoja (35 years), Makurdi (20 years), and Ibi (10 years) located along the Lower Benue River Basin were harvested from the Nigerian Meteorological Agency (NIMET). Similarly, 20 years' disjointed streamflow data at Makurdi gauging station was obtained from the National Inland Waterways Authority (NIWA). Hierarchically, the chapter explores the use of PCA to segregate the morpho-climatic variables using FA to identify the physical upper and lower limit of storm rainfall over the basin to serve as a baseline in quantifying available virtual water from the available past data. The different recorded lengths of processed meteorological data were subsequently inputted into CROPWAT 8.0 model to compute the reference evapotranspiration (ET_0), effective rainfall, and the crop actual evapotranspiration (ETc) and net irrigation water requirement for irrigation schedule planning. This facilitates how to manage the watershed area in an integrated manner for greater productivity. The impacts of topographic conditions in projecting future climatic conditions on rice cultivation in the area was demonstrated through the fitted exponential stochastic time series model on the collected discharge data. Along with time, a stochastic model trends in time series can change. It is assumed that the average growth within the historical period is the estimated growth, rather than the future rate of growth.The measured discharge records at a place integrate the impacts of climate, soil, topography, and vegetation to give a distribution of runoff both in time and in magnitude. The established best-fit exponential equation in respect of the basin runoff-rainfall relationship is represented as:

$$(Q_m) = \exp(\alpha) P_m^{\exp(\beta)} \tag{14}$$

where Q_m represents Discharge and; P_m = precipitation; m represents the time step (monthly) with alpha and beta coefficient of 1.2 and 0.5 respectively. Its calculated procedural details are described by Egüen, Aguilar, Solari, and Losada (2016).

The regressive streamflow model utilises a monthly step while its stochastic component is processed by representing the inflow as a Markov process. Thereafter, the varied years available past precipitation records were converted to annual runoff and subsequent available water requirements for rice cultivation. Monthly, annual, and seasonal trend variations in rainfall data were fitted to historical sequences. The subsequent section presents the key findings regarding net irrigation water requirements and irrigation planning scheduling to facilitate how to manage the watershed area in an integrated manner.

4 Key Research Findings

4.1 Rice Growing Index Concerning Morphoclimatic Variation

The rice-growing index was assessed through the temporal and spatial distribution of the meteorological dataset's influence on the watershed. To build up the meteorological statistics in assessing the incremental changes (anomalies) to a baseline climate, both the trends and shifts observed in the meteorological dataset are important. These incremental changes are applied uniformly. Table 1 presents the summarized average daily statistical mean, standard deviation, median, range, maximum, minimum, coefficient of variance, and coefficient of skewness for all three stations (Lokoja, Makurdi, and Ibi) meteorological parameters.

The rainfall range is not too high with varied mean between 2.87 and 199.13 mm, while the coefficient of variation (33.46) varies in its degree between 0.45 and 7%. Before this, a homogeneity test was performed on the dataset to determine if the collected sampled data are from the same population. The standard normal homogeneity test (SNHT) result is shown in Fig. 2 which indicates that the data are uniformly distributed as the calculated p-value of 0.046 obtained is less than the 0.05 significance level alpha, except for rainfall data.

Table 1 Daily statistical summary of meteorological parameters from 1980–2018

	RF (mm)	RH (%)	Solar (MJ/m^2)	Tmax (°C)	Tmin (°C)	Windsp (m/s)
Mean	2.870	59.309	19.866	35.501	21.181	2.688
Median	0.096	62.500	21.181	35.918	21.945	2.601
Std Dev	8.577	136.183	4.846	5.488	3.392	1.568
Variance	73.573	18,545.708	23.488	30.117	11.508	2.458
25th Percentile	0.000	50.200	18.120	31.660	20.721	2.127
75th Percentile	2.123	77.900	22.881	39.147	23.020	3.226
Maximum	199.132	95.700	27.766	49.056	26.847	5.746
Range	199.132	9995.700	126.766	148.056	125.847	104.746
Skewness	8.115	–71.584	–3.862	–2.776	–9.188	–49.862
Kurtosis	102.463	5233.947	67.157	65.003	288.486	3235.926
Coeff. of Var. (%)	33.462	43.551	409.946	646.884	624.440	171.429

where RF-Rainfall; RH-Relative Humidity; Solar-Solar Radiation; T_{max}-Maximum Temperature; T_{min}-Minimum Temperature and Windsp- Wind speed

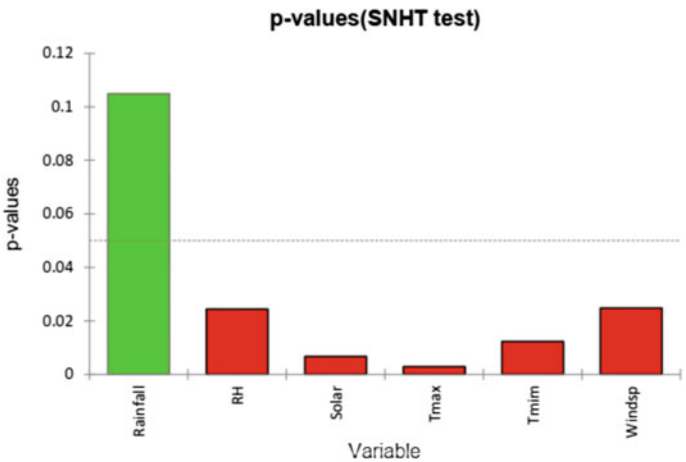


Fig. 2 The standard normal homogenous test (SNHT)

4.1.1 The Tempo-Spatial Distribution of Rainfall Pattern's Findings

The temporal and spatial distribution pattern of rainfall was affirmed as the most indices for assessing potential crop yield (FAO 2014). The precipitation skewness results which are the degree of asymmetry show that the distribution has negative skewness values as depicted in Table 1. This violates the assumption of normality test while the kurtosis values which measure the level of sharpness or flatness of the different data statistics show that the distribution has a relative flatness to demonstrate that the basin is situated in a hydro-meteorologically similar environment. Figures 3 and 4 illustrate the meteorological similarity pattern and trend findings for the watershed.

The principal component one (PC1) coefficient results indicate that the spatial distribution and concentration of rainfall are uniform in patterns over the years. The variation in concentration signifies a positive increasing trend between the mean annual rainfall and time (year). This suggests that the mean annual rainfall within the basin will increase with time, but at a very low rate.

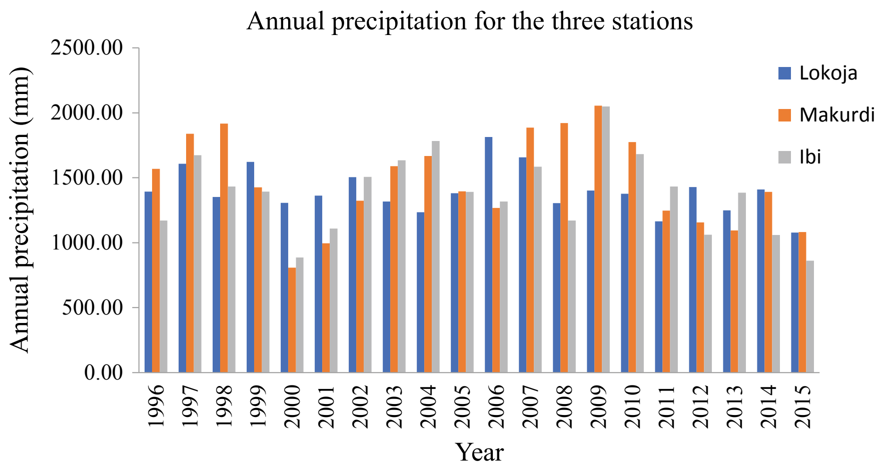


Fig. 3 Yearly average rainfall depth from 1996–2015 for the three stations

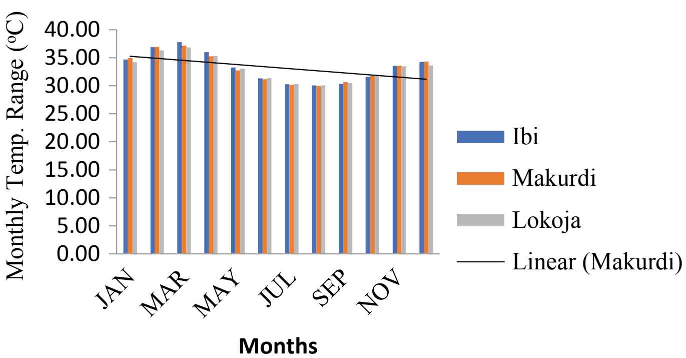
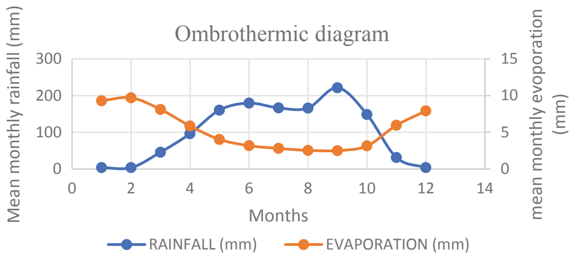


Fig. 4 Monthly temperature range (MTR) for the basin

Fig. 5 Monthly Ombrothermic diagram of various stations in the study area



4.1.2 Impact of Monthly Temperature Anomalies Trend on Irrigation Water

The changes in the Monthly Temperature Range (MTR) measured as $T_{max} - T_{min}$ was as shown in Fig. 4. The monthly air temperature TR anomalies trend for the Basin followed the same distribution pattern with highest in February/March of 36.5° C with an average lowest of 28.2° C in other months. During the rainy period, minimum temperatures are uniformly distributed since cloud and humidity prevent back radiation. The temperature anomalies trend shows a decreasing fair distribution pattern across the basin.

The descending trend of MTR is as a result of the steeper increasing trend of minimum temperatures compared to maximum temperatures. The highest mean daily temperature is recorded at the height of the dry season in March just before the onset of rain while the lowest temperatures are recorded during the height of the rainy season (July–September) and during the intense harmattan period in December and January. The seasonal variation in air temperature shows bigger increase in night-time temperature than during the daytime. Besides the monthly TR, air temperature is closely linked with the rate of growth and development of plants.

4.1.3 Ombrothermic Monthly Trend on Available Waters

The ombrothermic diagrams indicate whether there is a water deficit or water surplus. This is useful in preparing crop scheduling to meet the water budget and in measuring the crop-climate connections at different time scales. Figures 5 depict the ombrothermic monthly deficiency trend. The result follows the traditional November-March months as a water deficit that cannot support rice cultivation due to the dominated decline in rainfall. In general, the model shows abundant surplus wet months but sudden changes in temperature and rainfall may cause abrupt run-off fluctuation.

4.1.4 Factor Analysis in Segregating the Monthly Rainfall Magnitude

The factor analysis as a choice of PCA explores the underlying morpho-climatic variables responsible for historical rainfall. It was used to segregate the long-period monthly rainfall into high and low magnitudes while the spearman's rank correlation coefficient was used to evaluate the degree of relationship between the contributing variables for comparison. The low and high values of the monthly and yearly rainfall are useful for effective irrigation planning. The results of factor loadings as shown in Table 2 account for how fluctuations in several meteorological data impact rainfall segregation into high and low magnitudes which are largely presumably converted into streamflow (Birhanu et al. 2019). The FA correlation evaluates the construct meteorological relation with the rainfall and the spearman's correlation results depicts a strong positive relationship between rainfall and runoff ($p < 0.05$).

While using the PCA for the initial screening of the data, the data was grouped into two main parts, including PC1 and PC2. PC1 is a more significant component than PC2.

While utilising the value of the corresponding factors loading, the PC1 score can be calculated using Eq. 17, while the PC2 scores can also be estimated using Eq. 18.

$$\begin{aligned} PC1 = & \mathbf{0.728} \times Temp_{Min} + \mathbf{0.860} \times Temp_{Max} + \mathbf{0.611} \times RH + \mathbf{0.468} \\ & \times Evap + \mathbf{0.487} \times WS + 0.\mathbf{587} \text{ x Rainfall} \end{aligned} \tag{17}$$

$$\begin{aligned} PC2 = & 0.030 \times Temp_{min} + 0.005 \times Temp_{max} + 0.120 \\ & \times RH + 0.007 \times Evap + 0.281 \times WS + 0.014 \times Rainfall \end{aligned} \tag{18}$$

The estimate of the PC1 of the physical upper limit to a storm rainfall over a basin was used to quantify the basin hydrological responses to construct meteorological relation to serve as a reference in measuring runoff.

Table 2 Factor loadings results with correlation estimates constructs

Constructs	Factor loadings		Spearman's rank correlation coefficient						
	F1	F2	1	2	3	4	5	6	7
1. Tmin	**0.728**	0.030	**1.000**						
2. Tmax	**0.860**	0.005	**0.936**	**1.000**					
3. RH	**0.611**	0.197	0.546	**0.678**	**1.000**				
4. Evap	**0.468**	0.007	−0.409	−0.525	−0.581	**1.000**			
5. Windsp	**0.487**	0.281	0.486	0.579	0.263	−0.565	**1.000**		
6. Rainfall	**0.587**	0.014	−0.614	−0.604	**−0.712**	0.260	−0.392	**1.000**	
7. Discharge	0.067	**0.752**	0.046	0.189	−0.101	−0.139	0.452	−0.232	**1.000**

Bold values match each variable to the factor for which the squared cosine is the largest and are significantly correlated at the 0.05 level or better

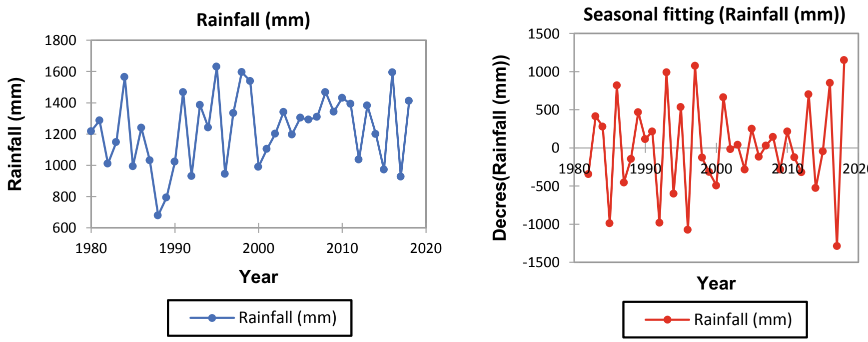


Fig. 6 Mean annual seasonal rainfall variation (1980–2018)

4.1.5 The Variation in Annual and Seasonal Rainfall Conversion

The variation in annual and seasonal rainfall in a basin is vital for sustainable water allocation planning to various crops. Projected seasonal rainfall impacts were model using the Makurdi datasets because of its relatively long data availability (1980–2018). The mean annual seasonal rainfall variation is as depicted in Fig. 6.

The seasonal discharge in a basin helps in understanding the aggregated impacts of climatic variables (rainfall and temperature) on the prevailing water abstraction mechanism occurring at the LBRB. The seasonal fluctuation trend indicates an unequal distribution of the precipitation pattern over the years. The seasonal fitting shows a longer dry period of varying magnitude with a decrease in rainfall amount.

4.1.6 Rainfall and Runoff Relationship

From rainfall anomaly, in order to forecast storm run-off requires investigating the year-to-year variations in sensitivity to the watershed characteristic. Figure 7 indicates the rainfall-runoff annual flow variability over the Basin.

The trend observed presents an unequal distribution of the precipitation pattern over the years. The rates are insignificant (less than 5%) especially in the dry months, while lesser runoff reaches 26.22 mm mean annual runoff (MAR) value at the peak dry months. The seasonal fitting shows a longer dry period of varying magnitude with a decrease in rainfall amount. The result shows that the correlation relationships between the mean annual rainfall and runoff data were significant.

4.2 Climatic Variation Impacts on Annual Streamflow

Figure 8 depicts the annual discharge trend analysis results. The mean annual flow shows a declining trend from the discharge inflow plot. The available outflow for

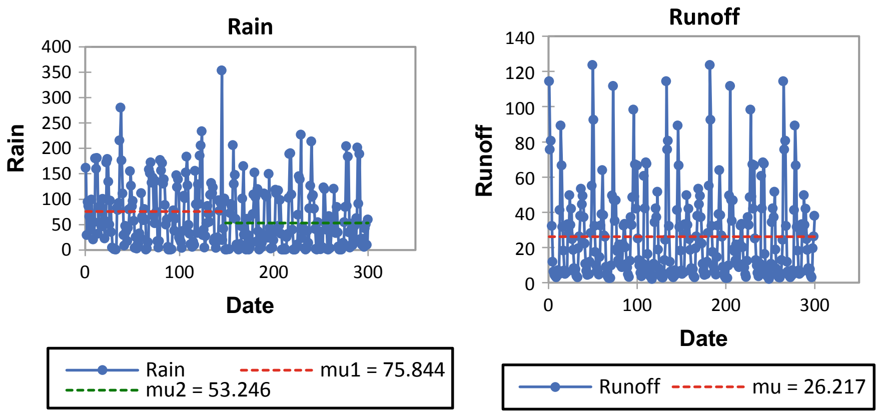


Fig. 7 The annual flow variability of rainfall-runoff

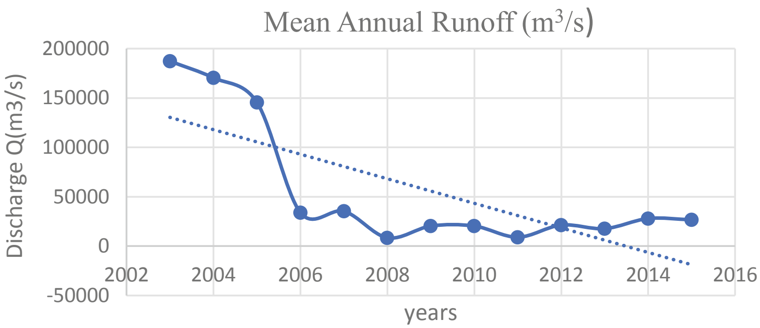


Fig. 8 Makurdi mean annual flow

irrigation abstraction uses shows a minimum annual discharge of 1200 m^3/s with the maximum discharge likelihood range of 13,000 m^3/s based on the available data from the three stations.

4.2.1 Topography Condition's Regression Analysis

Considering the inflow as a Markov process, the MS Excel spreadsheets were used to project the varying different years of rainfall into discharge patterns using Eq. 4. The results of the varying years' length of rainfall into discharge patterns for rice production are depicted in Fig. 9.

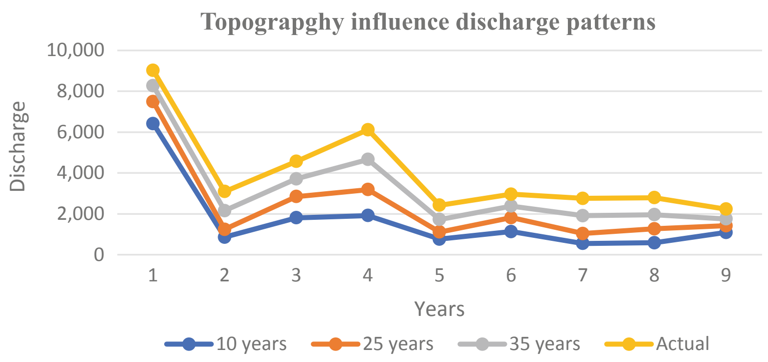


Fig. 9 The varying years' length of rainfall conversion to runoff

4.3 Assessing Rice Cultivation Among the Varying Climatic Datasets Lengths

Since the timing, duration, and magnitude of the season's rainfall of a place is most important in planning and designing irrigation water management, using the past knowledge of morpho-climatic variables to project future climatic trends is of importance in predicting rice development adaptation to adverse weather. The variable such as land cover/land use is assumed constant in the context of micronutrient content or supplement with NPK fertilizer. Therefore, the low rainfall (temporal variable) period is typically a maximum of six months between November and April. This period marks the effective duration to cope with the water deficit required for rice yield production and cultivation processes.

The effects and estimation of the gross irrigation water requirement (WR) include waste as a result of evapotranspiration (ET_0) rate or consumptive use (Cu) plus the losses during the application of irrigation water (unavoidable losses), and effective rainfall has been calculated from the CROPWAT 8.0 software using some key assumptions as follows; the soil's water-holding capacity in the 0–100 cm layer is 21.3% and; the wilting point is 9.5% respectively, crop coefficients (K) = ratio between the consumptive rate and the rate of evaporation from the free water surface (0.3). Other applied parameter includes: the effective Rainfall = 70% of Normal Rainfall; Percolation loss = 2.3 mm/day (for loamy soil); Application loss = 10% of (Net irrigation requirement + percolation); Conveyance loss = 10% of field irrigation. The results summaries are as presented in Sect. 4.3.1–4.3.2.

4.3.1 Evapotranspiration (ETo), Effective Rainfall, and Crop Water Requirement Results

The disproportionate increases in the day and night temperatures is a challenge to rice production. The results of the varying years' length of climatic dataset impact

Table 3 Results of evapotranspiration, effective rainfall, and crop water requirement

Locations/ length		Evapotranspiration (mm/day)			Effective Rainfall (mm)	Irrigation requirement (m^3/ha)	
		(ET_0)	ETc	% difference		Gross	Net
Idi	(10 years)	8.3	2.1		645	1115	771
Lokoja	(25 years)	6.3	2.6	36	1020	1051	1115
Makurdi	(35 years)	4.5	3.0	49	1203	1453	1343

Table 4 Term period of sowing and harvesting rice irrigation schedule and planning

Crop	Stage of development	Time of scheduling		Duration
		Sowing	Development	Days
Rice	Initial	08–09–15	07–10–15	30
	Mid-season	25–11–15	02–12–15	35
	Late season	01–01–16	12–02–16	45

on the average annual evapotranspiration range (ET_0), effective rainfall, and the crop water requirement from the CROPWAT 8.0 software are as summarised in Table 4 (Table 3).

The varying years' length shows the gross irrigation water requirement per 10 years data range variation from 645 to 1115 m^3, while the 25 years data length ranged from 1020 to 1051 m^3. The mean annual rainfall amount for Makurdi (35 years available dataset) range from 1203 to 1453 m^3 at the LBRB. The effective net annual rainfall shows a range difference of 48% for the catchment area. This implies the field capacity and soil water requirement are at variance with different layers of the soil despite the assumption that soil nutrient parameters are relatively uniform to support increases in yields per unit area. As the length of data use increases, the increase in effective rainfall indicates the limits of supply constraints for monthly convolution of available water resources. This is so as there are other sub-constraints within the normal supply constraints such as, limit in uncertainties in forecast residual error, availability of other meteorological variables, amount of rainfall and its intensity, area cover by the crop since each crop type vary in its weather and soil type requirements, etc. This calls for sustainable development measures for the agriculture sector and management to protect and safeguard lives while protecting human wellbeing and health.

4.3.2 Irrigation Planning and Schedule for the Varying Data Length

The crop water requirement using different climatic length data can serve as a baseline in quantifying available water and subsequent irrigation schedule plans to facilitate how to manage the watershed area in a unified manner and to prevent water scarcity.

Table 5 Monthly irrigation water requirement summary as per the ranged data lengths

Periods	Actual Evaporation (mm)			Effective Rainfall (mm)	Irrigation requirement (m^3)	
	Makurdi	Lokoja	Idi		Gross	Net
October	80.1	53.01	100.00	106.01	253	177.1
November	120.7	92.60	130.00	8.26	251	175.7
December	272.3	109.21	150.00	0.66	215	150.5
January	296.7	179.56	98.50	4.67	235	164.5
February	231.8	256.86	107.40	1.73	256	179.2
March	289.6	117.20	216.30	27.30	264	184.7

The pilot-scale study area shows yearly crop irrigation schedule results that can be supported irrespective of the length in varied data. This is as shown in Table 4.

In all, the crop scheduling table depicts an appropriate model considering the constraints from surface water during the dry season which can support both the crop planting area, water yield requirement, and expected productivity in a planting season.

4.3.3 Monthly Evaporation, Effective Rainfall, and Net Irrigation Water Requirement

As a means of comparison between the CROPWAT 8.0 model and manually calculated monthly net irrigation water requirement using built-in Eqs. 1 to 8; Table 5 depicts the monthly gross irrigation water requirement summary as per the ranged data lengths.

The result of the monthly effective rainfall calculation value appears satisfactory compared to discharge collected data to give a fair representation of expected streamflow for the area while the resulting average annual evaporation was 1995.4 mm with the dry season accounting for the greater percentage. Since evaporation pan data cannot be directly applied to free water surfaces like a reservoir but must be adjusted for the differences for the physical and climatological factors. Thus, the pan evaporation data has to be adjusted by multiplying by the pan coefficient of 0.8 to give a reservoir surface evaporation of 1596.3 mm as supported by Abah (2016).

5 Key Results Implication

The regression model's graphical results for different lengths of data reveals that the 35 years model is capable of better simulating runoff as compared to the 25 years and 10 years model data. Consequently, the bigger the length of data, the higher the likelihood of accurate streamflow prediction that can support rice cultivation.

However, the resultant models need to be checked to ensure that the generated streamflow sequences have the desired means, variances, covariance, and other characteristics that were to be reproduced.

Also, an annual minimum of 771 mm amount of water with a maximum volume of 1343 mm quantity of water is required by the smallholder farmer in the basin for rice self-sufficiency production. This amount of water is of utmost importance to ensure food security in the basin and could serve as a stratagem for virtual water re-use and recovery adaptation means in an extreme hydrological event towards abundant food production. Also, the quantification of monthly water requirement for rice cultivation could serve as a means for irrigation water demand among other users in dam storage capacity building. One of the major implications of the key results for sustainable development is the availability or otherwise of sufficient and reliable data useful to examine the seasonal fluctuation while using available meteorological data and rainfall anomaly. This challenge was further aggravated by failing gauging networks as well as inadequate monitoring capacity within the national hydrological agencies. Although, Nigeria has abundant water resources, the twin effect of climate change and the construction of new infrastructure projects along the transboundary River Benue have to make it pertinent for the LNRB to devise ways for minimum irrigation water use (Oduniyi Oluwaseun et al. 2019). Among other key findings, is the observed late pattern of rainfall onset as well as early rainfall cessation with the gradual rising of both the daily maximum temperature and annual average temperature thus resulting to increased heat stress.

The results of crop irrigation schedule show that air and water temperature increase has provided key scientific inquiry to soil–water -plant interaction towards understanding the distribution pattern of rainfall characteristics. Besides, the net irrigation water requirement, the frequency and concentration point of rainfall for different return periods and duration, will need to be prepared for a region based on available long term daily meteorological data or short-duration discharge data of gauging station networks. The most important trade-off between the starting planting date and end of growing planting season remains a top priority for farmers. This period can serve as a virtual water re-use strategy along with the multiple users. Thus, the varying years' data have proved to be helpful to facilitate the sharing of ET_0 data and the development of crop coefficients that can be used in a similar basin in determining net water crop requirements.

6 Conclusions and Recommendations

From the above synopsis, climate change driven dynamics will still represent a major irrigation farming challenge in this part of the country (LBRB). This chapter examines the effects of varying length of recorded morpho-climatic variables in predicting rice cultivation for further development. The study shows that when the concentration of data in a region is low, the precision of crop water requirement estimation is hindered. Also, the varying climatic data length does not significantly affect rice cultivation irrespective of the regional proportional area since the catchment lies in similar watershed characteristics. Besides, the probable maximum storm concentration needed on each farm type to appropriately choose the planting date differs from location to another while considering the acceptable water limit for rice cultivation. Since several meteorological services offer forecasts, advices and consultation to farmers and growers to help their water management, there is a need to reduce duplication of efforts by a different government agency which also renders a similar function. Future direction study by using more data length from different sources and their effects in predicting rice cultivation for further development will still need to be investigated for this area. Likewise, assessing projected future climate change, should include both regional and global fluctuations in precipitation, temperature, and others climate system's physical characteristics. Further trajectories research using the Coupled Model Inter-Comparison Phase Six (CMIP6) based on Representative Concentration Pathway (RCP) as input, into the IAT model in comparison to the fitted regression data should be look into. Furthermore, the use of limited data of less than 10 years in the data-scarce basin will still require subjective interpretation of the well-documented distortions of human judgment. Thus, the emerging twin likely approaches: minimising and stabilising the degrees of heat-trapping greenhouse gases in the atmosphere and/or acclimatising to the climate change symbolises a viable option in feeding an ever growing world population that is expected to reach ~ 9 billion by 2050 (Tripathi et al. 2019).

The current study recommends farming practice habits modification in accordance with obvious variations in climatic elements and that the determination of the total water available in a river or other hydrological basins is important, considering all meteorological variations both in the natures, patterns and shift quantity. The study suggests virtual water trading as a mutual benefit strategy in coping rice cultivation between the northern zone water-scarce and southern-zone water-rich regions of the country. Finally, noting the nature of the Lower Benue River Basin which remains largely ungauged, the need for an effective river gauging stations within the catchment for sufficient and adequate data coordination and management towards reducing the challenge of modeling cannot be over-emphasized. More so, that the country's national development plan (NDP) 2050 wishes her, to be a self-sufficient nation (Jibrilla 2018). The chapter outcome has enhanced projecting and ensuring a sustainable rice cultivation system irrespective of the influence of the extreme future hydrological events while also providing modelers, hydrologists, and irrigation water managers a decision support tools in planning towards an adverse climate adaptation and integrated watershed management.

7 Limitation of the Study

There still lies some grey areas requiring intuitive processing errors that might set out in comparing past and future climate change impacts. This study assumes that soil texture and composition are uniformly distributed. Likewise, the assumption that the majority community is irrigation practice. The simplified uncertainty and minimum bias in-built have been assumed in the discharge exponential rainfall transformation equation. This may limit evaluating the true impacts and effects of future climate change on rice production. Secondly, many of the datasets used in this study were sought through secondary literature documentation as there exist no active websites or online data repositories. Further studies are still needed on rice yield under different morpho-climatic regions considering the handiness of sufficient and good quality input data to test the model's performance.

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Climate Change in the Horn of Africa Drylands: Domestication of Yeheb as a Climate-Smart Agricultural Mitigation Strategy to Protect the Regional Food Chain

Jose M. Prieto-Garcia, Muna Ismail, Valentina Cattero, Moinuddin Amrelia, Scott Darby, and Francis Evans

Abstract Climate change is aggravating the drought in the fragile drylands of the Horn of Africa. While also is further exacerbating food security in an overharvested, overgrazed, and degraded ecosystem. Sustainable regeneration and domestication/cultivation of native flora (environmentally and culturally adapted to the region) may present an opportunity to combat ecosystem degradation and food insecurity in a hotter and drier foreseeable future. One of these indigenous plants is Yeheb, a small tree endemic to the drylands of Ethiopia and Somalia, botanically known as *Cordeauxia edulis* (Leguminosae). This vulnerable species produces a highly sought, tasty edible seed ('nut') of high nutritional and economic value. The energy value of this seed is twice that of the carob and equivalent to soybean, with a rich profile in fatty acids. The leaves exhibit unique chemical features and are an essential source of fodder, especially during the drought season. Its domestication can both diversify income and improve the livelihoods of rural people in the drought zones of the Horn of Africa. In this chapter, we demonstrate how Yeheb not only has the potential for becoming a critical stable source of food in drylands but also an ethical commodity as the next superfood in the climate-change era.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_6

1 Climate Change, Livelihoods and the Horn of Africa

The Horn of Africa is the easternmost extension of African land and denotes the region that is home to Djibouti, Eritrea, Ethiopia, and Somalia. It is one of the most food-insecure regions globally, having a significant vulnerability to climate-related risks. It is also a region that in recent decades has experienced erratic rainfall together with rising temperatures, leading to increased frequency and intensity of droughts and floods. Since the mid-1980s, this region has seen extreme climate variability, mainly in the form of life-threatening cyclical droughts. Climatic shocks continue to pose significant challenges to food security, particularly for the poor, with the knock-on effects of widespread malnutrition, due to causing crop failures, land degradation, livestock deaths and human diseases (Diamond 2011).

African, generally, is one of the most vulnerable continents to climate change due to its high exposure and low adaptive capacity. The latest forecasts point towards African land surface temperatures rising faster than the global land average. The rate of increase in minimum temperature will likely exceed that of maximum temperature. Surprisingly, the projected annual mean rainfall distribution changes do not show a uniform decrease all over the Great Horn of Africa. But a differential increase over the western parts (Ethiopian Highlands) and wetter weather in the Eastern parts (Somalia), although significant uncertainties exist amongst different simulations (Osima et al. 2018), Environmental changes are known to influence conflict and social harmony in the region. The region has developed both a Climate Prediction Center (CPC) and a Livestock Early Warning System (LEWS) based on georeferenced environmental indicators to predict situations. It is believed that precipitation, vegetation, and forage influence pastoral conflict in the Horn of Africa (Meier et al. 2007).

The Horn of Africa land exhibits variation in both its topography and rainfall. The landscape stretches from highlands to lowlands, pastoralist grasslands to coastal lands, characterised by four broad-based land utilisation systems. These systems are pastoralism, agropastoralism, rain-fed and irrigated agriculture. Consequently, the economies and livelihoods of its approximately 140 million population are highly dependent on rain-fed agriculture and pastoralism, both of which are extremely sensitive to weather and climate variability, and without mitigation or adaptation, does not guarantee resilience (The World Bank 2020). The highland areas where there is a higher rainfall, mainly in Ethiopia and Eritrea, host many small-scale farmers who live poorly on the edge of subsistence. Djibouti, eastern Ethiopia and Somalia are home to pastoralists often chronically food-insecure if not vulnerable to extreme weather shocks.

In this region there is a severe case for rangeland restoration. The continuous increase of human population and livestock numbers are pushing the natural ability of the land beyond the recovering point. Climate change adds further stress to the ecosystem. In many parts of the region, land-use changes negatively impact natural resources (e.g., soil, vegetation). It is not uncommon to see a land where resources are being An added threat is charcoal production—a widespread practice in pastoralist commons rangeland. As a result, the endemic acacia forests are disappearing throughout the region and with them the rich topsoil (Mishra and Gebremeskel 2019; Tierney et al. 2015).

Rural deprivation, communal conflicts that led to a breakdown in traditional coping mechanisms, and widespread unemployment indirectly contribute if not fuel an ever-deepening fragility in the region. This socioeconomic fragility disproportionately affects the arid and semi-arid areas—cyclical droughts cause famine and poverty, equally fuelling social, economic, and political tensions. In turn, these external shocks give rise to ethnic, communal conflicts with implications in wider poverty and environmental degradation (Meier et al. 2007). Other environmental factors relating to natural hazards, such as floods, also contribute to social instability in climate change decades. Therefore, there has been a growing rural–urban migration drive during the last three decades, spreading food insecurity to the region's major cities.

A significant demographic trend is the rapidly growing population of young people, where 50–70% of the population is under 30 years. It could offer opportunities and pose challenges to natural resource management already sensitive to climate variables (FAO 2000; ICPAC 2018).

1.1 The Somali Peninsula, the Home of Yeheb

The Yeheb (*Cordeauxia edulis*) plant, which is the focus of this chapter, only grows wild and is indigenous to the Regional State of Ethiopia and Somalia (including Somaliland, where it is called Yicib), collectively known as the Somali peninsula. Specifically, it grows in red sandy semi-arid rangelands areas of the Hawd plateau, where pastoralism is the dominant livelihood strategy. In the last two decades, there have been fundamental changes in how land is used throughout the Somali peninsula, which affected much of the terrestrial ecosystem. In particular, the biodiversity of Hawd plateau rangelands in the pastoralist heartland has been classified as a hotspot of land degradation (USAID 2014).

Two main common threads across this area of the region are:

- Over the past three decades, environmental degradation, over-exploitation of grazing land and unsustainable harvesting due to conflict and periodic prolonged droughts have resulted in the population decline of the plant, albeit with negligible chances for regeneration.
- Increasing vulnerability and trapped cycles of chronic hunger and poverty; the lack of agency and population having a low capacity to cope with more frequent impacts of climate variability.

1.1.1 Culture and Population

Somalia and the Somali Regional State of Ethiopia currently have an estimated combined population of 20.5 million. However, 50% of the total population of this region is still nomadic or semi-nomadic. Who can be: pastoralists moving their livestock according to rainfall and weather, looking for pasture and watering, and agropastoralists, semi-settled smallholder farmers, gathering in villages and having a more seasonal and shorter migration (Metz 1992).

The population profile is relatively homogeneous: 85% of the population is Somali, with the rest divided between other minor ethnic groups, such as Bantu and Arabic. Somali is the state's official language, whilst Arabic is the secondary one; Italian is still somewhat spoken (e.g., academically), a sign of the lasting colonial heritage, whereas English is the transmissive language used in administration. The religious makeup is even more uniform, with nearly 99% of the population being Sunni Muslim and only the few Mogadishu dioceses adhering to Christianism (Metz 1992; Aquastat 2005; CIA 2017). Hence this sets Somalia apart from its neighbours, which practice Christianism (Ethiopia) or indigenous African faiths (Metz 1992).

However, Somalia is one of the countries with the lowest humanitarian indications. Due mainly to the protracting internal conflicts: poverty, social and gender inequality and environmental degradation are only a few of the most severe problems affecting the region. Famine, chronic malnutrition, lack of education (only 40% of children attend school), inadequate health service, and youth recruitment into religious extremism. Factors that all make Somalia one of the top ten origin countries of people displaced across borders (UNHCR 2021).

1.1.2 Regional Economy and Climate Change

The Somali Peninsula generally comprises one of the world's most impoverished areas. In addition, as a country and a major part of the Peninsula, Somalia has a low life expectancy, education rate, and gross national income per capita (UNDP 2012). The country's economy is based mainly on livestock: they raise goats and cattle, but the camel is crucial for their economy. Livestock or livestock products directly or indirectly support the income of over half the population in contrast to agriculture which supports one fifth only. This is further compounded by an economy over reliant on foreign aid and/or money transfers from member of the family migrated abroad (Metz 1992).

The camel, being able to endure the harsh climate and the arid environment with scarce water and grazing areas, is the core of the local people's life. It provides meat and milk and transportation, and it is often used as an exchanging good (as an example, they are always part of a woman's dowry) (Metz 1992). Agriculture, supported mainly by the livestock, makes up for 40% of GDP and 65% of the exports: the industry is only at 10% of the GDP, while the services sector has, over recent years, seen growth (Aquastat 2005; CIA 2017). The livestock is raised mostly with pastoralism, representing the most spread occupation throughout the population (CIA

2017) and the primary source of Somali livelihoods (FAO 2004). On the other hand, agriculture, mostly circumscribed to the humid southern region, is mainly based on bananas, sorghum, corn, coconuts, rice, sugarcane and sesame seeds (CIA 2017).

The region is still struggling with food security issues. It is one of the most undernourished areas globally (70% of the population is malnourished) (Aquastat 2005; Lagi et al. 2011). Apart from the natural conditions to which the region is prone, such as mild and severe drought, flooding and sandstorms, the civil war that has wrecked the country has badly worsened the situation (Aquastat 2005; UNDP 2012). Somalia suffers from chronic food insecurity causing recurrent famines (ONU Italia 2017). In addition to other issues such as contaminated water, deforestation, overgrazing, soil erosion and rapid urbanization, like other countries in the region (CIA 2017).

1.1.3 Pastoralism and Climate Change

Pastoralism is one of the most ancient agricultural branches: animal husbandry generally involves a mobile aspect since the shepherd moves his herd of livestock to find pasture and watering. It is peculiar to those regions where the environment is harsh (e.g. arid areas such as the Haud in central Somalia). Thus, natural resources are scarce and scattered; usually, the herds are moved periodically, following seasons and rainfalls. Nomadic pastoralism requires an in-depth knowledge of the territory and a deep understanding of the environment: the nomads have the first-hand experience of nature and the climate, essential to their survival. Usually, the transhumance and other movements are set by traditions that are transferred from generation to generation orally. Still, the shepherds must be able to adapt to environmental changes, e.g. differences in rainfalls. Therefore, people have deep and strong connections with nature that can hardly ever be experienced in many societies.

It is estimated that approximately 38 million inhabitants of the region were pastoralists (UNECA 2017). Feyissa (2016) explains that “other livelihoods are barely viable”. It is challenging to count pastoralists in the Horn of Africa because of (1) major limitations of datasets from the region and (2) classification issues. Agropastoralism is a dual subsistence strategy to balance the risk of pursuing either livestock or farming alone. In the Horn region, Somalia is the only country where pastoralism predominates livelihood. 63% of the population lives in rural areas. It is the primary source of livelihood for most people in northern Somalia (Somaliland). At the same time, agropastoral livelihood predominates in the south and central parts. Pastoral communities rely on shared livestock management practices, grassland and water resources, trade links, and access to information about weather, prices, and water availability throughout the region. Many agricultural communities take advantage of borders by marketing produce in towns and cities across their border. Others attract seasonal labour from bordering countries. In any one season, there is considerable livestock mobility. So, the decision of where and when to go needs good local knowledge and awareness of traditional participatory systems of governance. With the advent of mobile technology, pastoralists are increasingly using mobile phones to access market prices and trade opportunities. However, satellite imagery provision has not been entirely available regarding the information on vegetation, which would help end-users make decisions on livestock migration to help reduce mortality (FAO 2001).

Several factors have in recent decades undermined the resilience of the pastoralist livelihoods, from the civil war to subsequent severe droughts. Thus, it is more important than ever for them to guarantee themselves an alternative source of income. Of course, one must carefully evaluate such a statement since most of these collateral activities depend on people or resources, relying on natural resources. Examples are services for farmers or other pastoralists, and most of all, trading (Devereux 2006). Therefore, even these incomes can suffer from the so-called "derived destitution" (Sen 1981) since they are indirectly affected by variations in natural resources availability. In the semi-arid environment of the Hawd grazing plateau, the life of the pastoralists revolves around two different periods. That is when the nomads and their herds remain in the small villages with a limited but sufficient supply of water and food, the dry seasons. And, the rainy seasons, when they move around the Hawd grazing lands until their animals have depleted the water and forage (Metz 1992).

Pastoralism has been attributed to be the cause of environmental degradation, depleting natural resources on which it depends, as an activity in sharing common property resources (Fratkin 1997; Hardin 2009). However, aside from the well-disputed theory of "the tragedy of the commons", environmental degradation in the Horn of Africa is caused by a changing climate, growing population. Both humans and their livestock, and the industrialization of agriculture. (Wilson 1992; Pratt et al. 1997; Nori and Davies 2007; Dong et al. 2011).

1.1.4 Livestock and Climate Change

Livestock provides a livelihood bedrock for pastoral and agropastoral populations in most of Somalia and the Somali Regional State in Ethiopia in the Somali peninsula. Livestock production accounts for 40% of the GDP and 80% of the country's exports: the population is about 40 million animals, primarily sheep and goats, followed by camels and cattle (Aquastat 2005). Livestock exports are historically directed to the Arabian Peninsula, with Saudi Arabia absorbing 95% of the Somali exports (FAO 2004). But also, laterally, to Kenya, Djibouti and Ethiopia (FAO 2004). Of course, the Somali meat is raised and slaughtered according to the Islamic customs, which is an advantage when competing with neighbouring non-Islamic countries. It is noteworthy to emphasize that a substantial part of the production is consumed directly by the Somali people as subsistence. Given the importance of the sector for the economy and survival of the country, it is facing many challenges: the competition with other countries is tight, and there are not many markets for significant exports (FAO 2004). Moreover, the producers lack organization and coordination to be able to exert substantial pressure on the market and the banking system.

Climatic conditions or seasons influence livestock grazing patterns and livestock mobility in search of pastures, forages and water. A more significant part of the central and northern Hawd rangeland regions offer all year grazing to pastoralists. In the last three decades, there has been a declining trend in the goats and sheep population. The overall livestock population significantly declined from 2006 onwards and has not recovered since then. As well as that, frequent climatic shocks forced people to sell animals or eat them to survive (Söderberg 2010). Later in the early part of the 21st Century, severe famine and drought also affected the country, causing up to 40% losses of cattle and 10–15% of sheep and goats (Aquastat 2005).

Nevertheless, cattle and camel populations have been relatively steady across the years. The declining sheep and goat populations in 1990/1 and 2006 coincide with two significant droughts that affected Somalia leading to high livestock deaths and erosion of household asset base. Hence an indication that climate-related droughts have had negative impacts on livestock numbers in Somalia (IGAD Atlas 2020).

2 Yeheb, a Candidate for Climate-Smart Agriculture

Climate-Smart Agriculture (CSA) is defined as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals" (FAO 2013). It is supported by three interlinked pillars: productivity, adaptation, and mitigation. (FAO 2013; Lipper et al. 2014) (Fig. 1).

2.1 Adaptation of Yeheb to the Environment

Reducing farmers' exposure to short-term risks, incrementing their resilience and strengthening their capacity to adapt and thrive again despite the extreme weather conditions in a climate change era are vital parameters for any crop aiming to fulfil

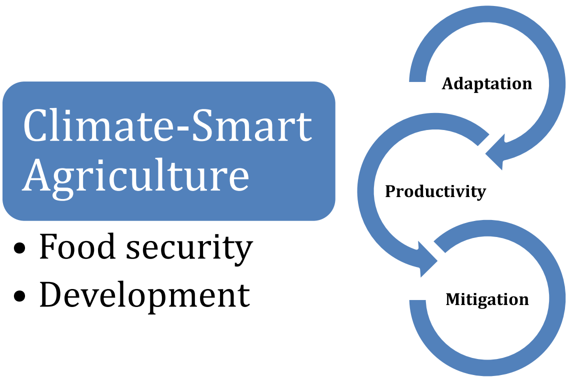

Fig. 1 Principal goals of climate-smart agriculture and its three interlinked pillars. Author's own graphical interpretation of CSA principles

Fig. 2 Distribution area of *Cordeauxia edulis* **a** Contour of Yeheb area established from authentically recorded localities **b** Satellite image of the same region showing typical arid soil. Created with Google Maps © under Creative Commons license

the CSA paradigm. Therefore, it is paramount that the candidate adapts and protects the ecosystem services provided to farmers and others.

Cordeauxia edulis (Leguminosae), commonly called Yeheb or Yicib (in Somali), is a small tree or shrub species endemic to Ethiopia and Somalia. It is a source of food and fodder unaffected to drought. The Yeheb is mainly a wild spontaneous plant; nevertheless, several attempts have been made to acclimate it. In its native land, Somalia, there have been successful attempts on a small scale and in Kenya (Brink and Belay 2006). Yeheb, although currently threatened in its habitat, has been an integral part of the semi-arid ecosystem of Haud rangelands. Surprisingly, the plant was only discovered in science early in the twentieth century, but it has not been thoroughly studied after initial interest.

The plant is native to the Hawd region, which is shared by both Somalia and Ethiopia (Glover 1950; Hemming 1966; Miège and Miège 1978; Drechsel and Zech 1988). The plateau is notably one of the most critical areas for livestock production and pastoralism (Metz 1992). It is characterised by a calcareous red sandy soil of pH ranging from 6.7 to 8.4 (Booth and Wickens 1988): the soil has low nitrogen content and has non-salty origins in contrast with the limestone (marine sediments) surroundings (Merla et al. 1979; Drechsel and Zech 1988; Mekonnen et al. 2011), conditions that seem to be particularly suitable for the growth of Yeheb (Drechsel and Zech 1988).

Yeheb grows well in deep, salt-free sandy to loamy-sandy soils with low lime and gypsum contents and a good, deep infiltration of rainwater. As a result, the plant is resistant to regular drought periods of 4 or 5 months and sometimes even periodic drought up to 10 or 15 months. The average annual temperature of the Haud region is 28 °C, with a yearly rainfall of about 100-300 mm. The long taproot system of Yeheb helps its survival by exploiting water reserves from the deeper soil. It can grow at an altitude of 100 to 1000 m above sea level, at least 100 km away from the Indian ocean but never close to water bodies. The climate in which the plant lives is arid, with temperatures ranging from 25 to 40 °C in the summer and average annual rainfalls from 100 to 300 mm (Seegeler 1983; Drechsel and Zech 1988). Rainfall arrives in two distinct seasons, the long rains ("Gu") from March/April to May/June, and the short rains from October to November ("Deyr") (Brilli and Mulas 1939; Roti-Michelozzi 1957; Booth and Wickens 1988; Drechsel and Zech 1988).

In northern Somalia, Yeheb grew wild mainly in two regions: Togdheer and Sool. The plant used to be much more present in the environment, and in the 1930s, it made up almost half of the woody vegetation in the central part of Somalia. However, due to many factors such as droughts, low seed viability, wars and overharvesting, it is now seriously threatened (NRC 1979). One of the main factors leading to this problem is the total harvest of the seeds for human consumption, a practice that gravely compromises its ability to reproduce (Booth and Wickens 1988). Moreover, the plant is foraged to feed both animals and humans: the wood is well appreciated as building and burning material. The leaves are used as tea for medicinal purposes (Söderberg 2010). Thus, the Yeheb truly represents the backbone of the Somali pastoralist way of life. Unfortunately, excessive use of wild plants causes Yeheb's demise. Neighbouring populations and Somalis across the Somali Peninsula appreciate the shrub properties, also, the pastoralists who come into the Hawd to collect it (Fig. 3). In the 1980s, the Yeheb plant was reported in danger of extinction (Allen and Allen 1981).

Fig. 3 The Hawd region © Yeheb – https://www.yeheb.org/

2.2 Productivity of Yeheb

Yeheb produces a tasty edible seed, often referred to as a 'nut', of high nutritional and economic value (Fig. 4). The energy value of this seed (446 kcal per kg) is twice that of the carob and as much as that of soybean (FAO 2020). The seeds are also rich in fatty acids (Wickens 1984). The leaves are an essential source of food and fodder for animals during the drought season (El-Zeany and Gutale 1981).

The Yeheb seed contains 11.1% water, 10.8% proteins, 12% fat, 69% carbohydrate, 1.2% fibre and about 32 mg calcium, 185 mg phosphorous and 6.4 mg iron, providing approximately 1666 kJ of energy (Leung et al. 1968). In addition, the seed lipid contains palmitic acid (26%-31%), stearic acid (12–13%), oleic acid (31–32%), linoleic acid (25–30%) and trace amounts of linolenic acid (Brink and Belay 2006). El-Zeany and co-workers (1981) confirmed the amino acid content. Furthermore, the nuts contain high levels of essential amino acids like lysine, arginine, but deficient in tryptophan and isoleucine they carried out complete elemental analysis suggesting potassium, sodium, magnesium, calcium and nonmetals such as chlorine and phosphorous in phosphate and chloride forms. Additionally, they compared the chemical compositions of Yeheb's two sub-species: Suuley and Muqley, in regards to their respective constituent nutrients.

Two varieties of Yeheb are recognized: Suuley, a smaller variety from central Somalia and Muqley, a taller and more common variety (Brilli and Mulas 1939) (Fig. 5). Under good natural condition, there are up to 320 plants per hectare with a seed yield of 5–8 kg per plant per season. The plant starts to produce pods after three to four years, and generally production increases with age. They are so desirable that fruits are often collected from the plant before they are totally ripened. This is compounded by the unrestricted access to the rangeland. However, during 2013 members of The Yeheb Project made a preliminary assessment on Yeheb availability in two major cities. Mogadishu in Somalia and Hargeisa in Somaliland. The results showed that the availability of Yeheb seeds in markets was low in harvesting season and non-existent in the rest of the year.

Fig. 4 Fresh Yeheb Nuts (left) and roasted Yeheb nuts with shell (right) © Yeheb – https://www.yeheb.org/

Fig. 5 A 1 year old 'Muqley Yicib' growing © Yeheb – https://www.yeheb.org/

Efforts to domesticate Yeheb outside its natural habitat are challenging. There has been one successful attempt of Yeheb domestication in Somalia: the Yeheb farm in Gras Binto (22 km north of Mogadishu) grows a domesticated variety of Yeheb and supplies local markets there. Unfortunately, other attempts to cultivate the plant elsewhere have failed: Yemen, Israel, Tanzania, Sudan, and even the USA were not suitable for the plant's growth (Booth and Wickens 1988; Brink and Belay 2006). However, other ongoing and recent studies seem promising. For example, in the Somali Regional State in eastern Ethiopia (part of the plant's natural environment), more than 50% have survived the transplant. Still, the growth is quite slow (Mekonnen et al. 2011), while in Sweden, the domestication carried out in greenhouses with fertilizers has shown positive results (Söderberg 2010).

A recent study has investigated the effect of nitrogen and phosphorus supplementation on Yeheb growing outside of its natural habitat and found appreciable improvement in the rate of growing and amount of biomass (Mekonnen et al. 2011). Moreover, in preliminary trials the Yeheb Project conducted in six ecological sites in Somaliland, 2015–17, the following factors made attempts to domesticate the plants through direct sowing:

- excessive dryness due to recent successive droughts,
- lack of fencing from animals, and
- security constraints have made travel more difficult and costly, which has made it harder to support local communities.

The shrubs in the wild start to flower after 2–3 years in the wild, although plants grown in a greenhouse are said to flower after one year. Both varieties are multi-stemmed plants with long, massive roots or taproot that reach deep into soil moisture, making the shrub remain green all year round. In addition, the plant also has smaller secondary lateral roots that develop 10–40 cm under the soil surface but can grow up to 2.5 m long. For this reason, direct seeding is recommended as moving seedlings may cause the taproot to break and the plant to die. Only fresh seeds give good germination, which takes typically two weeks. The viability of the seeds is a few months only but traditionally is extended to one year by covering them in wood ash and stored in a sack. Vegetative propagation is possible. Apart from the nutritional value, the plant has several important uses, its leaves are used as fodder and medicine, and its wood is a precious source of timber (houses and fences) and fuel (Yusuf et al. 2013) (Fig. 6). Hence, making Yeheb a big commodity in the region (Table 1).

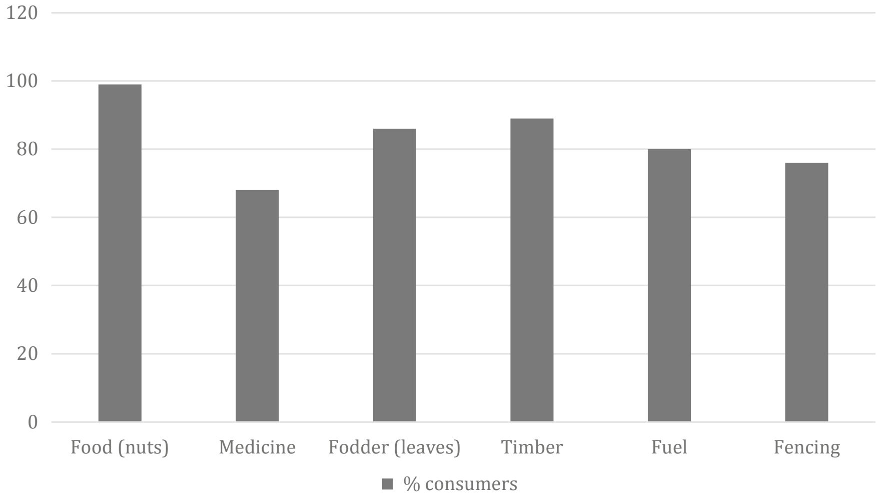

Fig. 6 Prevalence of uses for Yeheb among the local population (each person may give Yeheb more than one use). Author's work using data from Yusuf et al. (2013)

Table 1 Summary of traditional uses of Yeheb plant cited in the text

Part of the plant	Ethno-medicinal uses	Method of usage
Yeheb nut (seed)	Staple food. restore energy, constipation, anaemia and bile problems The oil is used to make soaps	Fresh, roasted, or boiled (decoction)
Leaves	Increase desire in animal Dye industry (contains a red pigment) animal grazing/fodder	Fresh leaves for animal grazing, Maceration and isolation of the red pigment for dyes
Wood	Fuel, construction material	Fresh and dried wood

2.3 Mitigation Potential

Climate-Smart Agriculture (CSA) increases yield and resilience, whilst reducing emissions in an integrative manner that manages trade-offs. Finding candidates for such interventions achieving all three is often near impossible. However, Yeheb may do the trick. It not only touches all the regional value-chains and food systems but also helps to reduce the impact of climate change in the region by fighting deforestation from other types of agriculture. Its introduction has almost a zero-emissions profile and minimal water consumption. The synergies and trade-offs for adaptation, mitigation and food security involved in any CSA intervention (Vermeulen 2012) are fully met by Yeheb:

1. Yeheb maintains ecosystem services and provides farmers with essential food and materials (Yusuf and Teklehaimanot 2012).
2. Yeheb does not contribute to their degradation but rather regenerates the soil (Yusuf et al. 2013).
3. Yeheb qualifies in multiple entry points at different levels and as such goes beyond single intervention at the farm level by facilitating the food system, the landscape, the regional value chain and violence levels (Mihertu and Teshome 2017).
4. Yeheb is context-specific: it is endemic to the area and traditionally integrated into cultural and economic local practices (Ali 1988; Kazmi 1979).
5. Yeheb has the potential to engage the most deprived and exposed groups, particularly women living on bordering lands exposed to both drought and floods. In doing so it ensures food security and resilience. Women typically take ownership of gathering the nuts. This practice is an add-on income that helps build their capacity to manage negative climate events particularly for those populations denied property rights of the land they farm or any other productive and economic resources (Nyasimi et al. 2014; Duffy et al. 2017).

The value of Yeheb is understood and appreciated by local, regional and national stakeholders in decision-making. Hence, it is an appropriate intervention towards partnerships and alliances essential to enable sustainable development to form and engage. Figure 7 illustrates how Yeheb fulfils all the above points.

2.4 Challenges and Threats to Yeheb

Recent evidence points towards Yeheb vanishing from many traditional habitats which prompted its inclusion into the vulnerable category of the IUCN Red List. A recent study on ten villages in the Somali Regional State of Ethiopia, where the only remnants of Yeheb exist (in the Haud areas of Horn of Africa), found that the population is diminishing, and that the plant's natural regeneration is negligible.

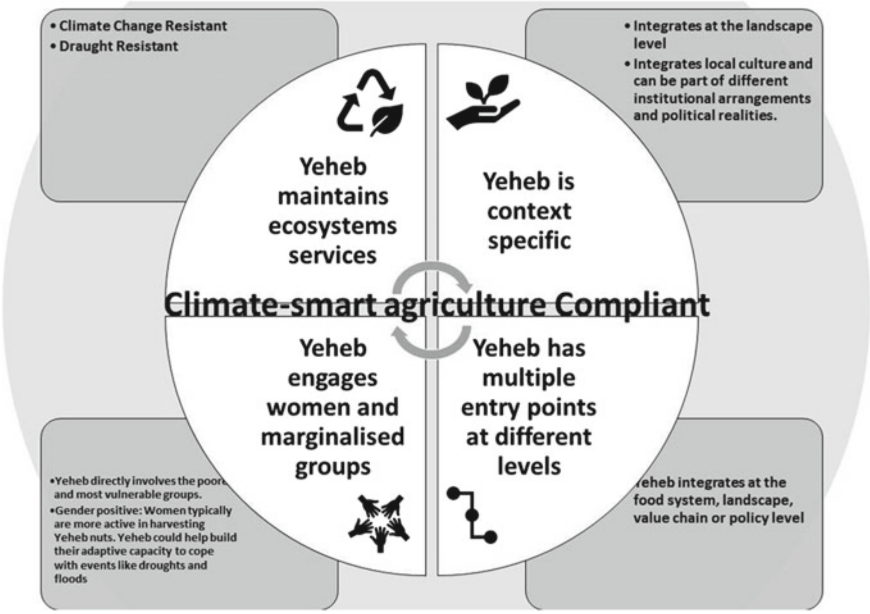

Fig. 7 Yeheb as Climate-Smart Agriculture intervention © Yeheb – https://www.yeheb.org/

Our scoping mission confirmed the disappearance of Yeheb from large parts of its traditional range. Land degradation, over-exploitation of grazing land and unsustainable harvesting due to armed violent conflicts and cyclical droughts during the last three decades have resulted in the decline of the population of Yeheb in its habitat. Significant challenges to its natural and balanced regeneration are:

- Early harvesting of unripen nuts,
- Excessive pressure of the livestock and,
- Excessive use as fuel and timber.

The plant has been considered endangered since the late twentieth century (Lucas and Synge 1980; WCMC 2012; Yablokov and Ostroumov 2013). The situation precipitated during the first two decades of the twenty-first century forcing a re-evaluation. Yeheb is rapidly vanishing from many of its habitat areas and is now considered threatened (Vulnerable A2cd) by the International Union for Conservation of Nature (IUCN 2016). However, little or no plans have been devised to protect the wildlife population (Lucas and Synge 1980; Baumer 1983; WCMC 2012), probably due to the country's unstable security situation.

In response to the above challenges, there is a need to increase the regional production of Yeheb by both regenerations in its natural environment and domestication. The local people have understood the value of the plant and have started to grow them. With the proper awareness and investment, Yeheb may be domesticated and contribute to a sustainable increase of agricultural and livestock productivity, having the potential to improve soil fertility and positively impact the local environment.

Strategies currently being pioneered by the Yeheb Project include the following:

- Determining the optimal conditions and techniques for the propagation/regeneration of the target species and documenting the lessons learned.
- Understanding and documenting the perspective of local people have of Yeheb. And how to regenerate degraded rangeland sustainably, both by and for the benefit of the community.
- Establishing a conservation area for Yeheb and other tree species that grow in the same habitat on land fenced off from grazing. Such a fenced area could act as a pilot for the co-creation of conservation habitats with communities in the region and is likely to identify other species whose regeneration and growth are limited by overgrazing.

3 Concluding Remarks

Both high exposure and a low adaptive capacity makes Africa one of the most vulnerable continents to climate change. The latest forecasts point towards African surface temperatures increasing quicker than any other continent.

Climate-Smart Agriculture can offer a viable approach that can transform agricultural development in this a new climatological scenario thus ensuring food security and development. Finding candidates for such interventions achieving all three is often near impossible. We believe that Yeheb maybe this perfect candidate.

Yeheb is a wild bush growing in the arid region of Somalia, one of the most climate change hit countries situated in the Horn of Africa. The country is also well-known for its unstable political situation, civil war, droughts, and famine problems that have struck the country in the last decades. The country's economy heavily depends on the livestock, both for local livelihoods and as the significant national export income; the majority of the animals are not farmed but bred by pastoralists. The animals follow the nomads and semi-nomadic people through their periodic migrations, chasing the rains. Their primary source of nutrition, especially during the dry season, is precisely this plant, which is one of the few able to adapt and survive the extremely tough conditions of the environment. Moreover, the local people consume leaves and seeds of the plant. In addition, the wood is used as fire-building material and the extract as a dye.

Yeheb may aid the restoration of food security by establishing sustainable production of the Yeheb plant. The benefits generated by the restoration of Yeheb and the increased biodiversity in pastoralist drylands will get an increased sale of Yeheb seeds in local and regional markets and increased fodder for better dairy and meat products.

The plant is currently rated as an endangered species due to overgrazing, low seed viability and lack of institutional protection. It is the only species within its genus. Its extinction would mean an incalculable loss of biodiversity, not to mention its impact on the local people's livelihoods and the broader economy in the country. This study hopes to raise awareness in the scientific community, boost the interest in this plant, and avoid the loss of knowledge, biodiversity, and promising phytochemicals.

Adapting to climate change and addressing drought in the Horn of Africa needs to be a multifaceted strategy. One is supporting farmers and pastoralists with a will to invest in innovative environmental management by introducing drought-resilient livestock breeds and crop varieties (Muller 2014).

Both regenerations of Yeheb in the original habitats and domestication (cultivation) in the wider region would reduce chronic food insecurity in the drought zones of the Horn of Africa. It could be part of more comprehensive climate change adaptive strategies to bring back sustainable livelihoods for many pastoralist communities in the region. Hence, in turn, it will also raise food and nutritional security in a fragile area of the world that's most endangered by future climate changes.

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Food Security and Climate Change Readiness: Navigating the Politics of Dams, Irrigation and Community Resilience in Zimbabwe

Innocent Chirisa, Marcyline Chivenge, George Makunde, Percy Toriro, and Thembani Moyo

Abstract Using document review, the chapter seeks to map and discuss the politics and technicalities around damming as a mitigation measure for climate change and variability that have been put in place since colonial Rhodesia to post-independent Zimbabwe days and the reason behind the lack of desired outcomes in Zimbabwe. Dating back to 1912, the Zambezi-Matabeleland Water Project was mooted and has been a political good for sale. Politicians make campaigns using the water project as a major infrastructure development they will bring to actuation without materialisation. Similarly, as far back as 1955, the Tokwe-Mukosi Dam was suggested, and it took more than 60 years to build it. After building the structure, the master planning around the project remains incomplete. If these plans, among others, are implemented, perhaps food security would be guaranteed in the country with a surplus to export for foreign currency and generate income to purchase other goods and services that the country requires.

1 Introduction

In contemporary times, there is growth in climate change research that unpacks its association with hydrological changes. Such trends have led to a growth in studies on the effects on increases in surface temperature, droughts, floods and changes in precipitation over time (Trenberth 2011). Brown et al. (2012) have articulated that climate change can change water supply–demand balance at a local and global scale, affecting resilience and adaptive capacity strategies. While Muller (2007) has called for authorities to assess the sustainability implications of the changes on the hydrological cycle as this will affect dams' design capacity and operating characteristics. There is a need for risk and vulnerability assessment of water resources systems to assess the implications of floods and droughts on flood control storage, drought resilience, ecological flow, water demand, and energy production (Loucks and van Beek 2017). Given the role dams in ensuring water security, climate change poses a

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_7

threat to this role. To offset the vulnerabilities of water resources systems, local agencies have increased the quantity and size of dams (Muller 2007). This chapter uses the case studies of Zimbabwe's implemented and on-going water projects to argue that the country has not fully embraced the use of dams to help mitigate the negative effects of climate change thereby bringing food security. The Tokwe-Mukosi Dam project, if fully utilised and the Zambezi Water Project, could mitigate several climate change impacts.

2 Conceptual Framework

Previous studies have revealed climate change, if left unchecked, may affect the sustainability of demand and supply of water resources (Hanak and Lund 2012; Mavromatis 2015; Hess et al. 2020). In developing countries, modern day water management practices do not have adequate mechanisms to ensure the reliability of water supply and allow them to cope with the impacts of climate change on natural resources (Watts et al. 2011; Mudzengi et al. 2012). Local water management agencies have developed strategies to adapt to climate variability through structural changes, leading to the creation of dams and transferring water between catchments. However there still a need to develop, alternatives that will ensure numerous beneficial outcomes for communities while also protecting and preserving the natural environment. Several research on exploring the implications of modifying dam operations reveal the potential of 'dam reoperation' to as an adaptive measure to climate change and has potential to restore ecosystems (Hanak and Lund 2012; Kabat and Van Schaik 2003). Common dam reoperation strategies have focused on flood management and water supply. Mudzengi et al. (2012) have outlined the benefits of reoperation of dams such as ecosystem restoration to be realised they may need to integrate multiple dams. These benefits also include increased water and energy supply.

The consequences of large dam constructions are varied and numerous. These include direct and indirect impacts on the socio-economic, chemical, and natural environments. Dam constructions are typically large-scale investments meant to fulfil numerous socio-economic benefits. Although many local agencies are advocating for dam construction given the numerous benefits, such projects often pose grave problems with far-reaching implications. The construction of dams has caused devastating disease and loss of livelihoods among communities (Mudzengi et al. 2012). With growing global environmental awareness, there is increasing realisation of the impacts of dams on society. This implies a need for a better understanding of the societal and economic impacts of dam construction.

3 Literature Review

The growth in global awareness of the impacts of climate change has led to an increase in studies to safeguard water demand and supply. As a result, there is a growing need for contemporary water management practices to cope with the impacts of climate change to ensure reliability of water supply, limit flood risk and preserve aquatic ecosystems (Hess et al. 2020).

3.1 Food Security and Climate Change Readiness

Since 1989, European crop yields such as wheat and barley have reduced by 2.5% and 3.8%, respectively. This reduction was affected by long-term temperature and precipitation trends (Moore and Lobell 2015; Mbow et al. 2019). Cereal production in Greece has also showed climate change had significant implications on wheat and barley production (Mavromatis 2015). While in the Czech Republic, a study revealed an increased temperature has led to increased yields of fruiting vegetables from 4.9 to 12% per 1 °C increase in local temperature. A study in Hungary revealed the stagnation of crop yields was partially due to the warming climate (Pinke and Lövei 2017). Farmers and local climate control agencies have consequently developed strategies to strengthen food security, given prevailing declines in crop productivity due to climate changes.

Several studies have demonstrated the effects of climate change on agriculture and food security in Asia (Bandara and Cai 2014; Jat et al. 2016; Schneider and Asch 2020). While in China, studies utilised remote sensing and statistical data to assess rice production over time. These studies reveal between 1980 to 2000, and the year 2000 had the highest rice cultivation increase (Lv et al. 2018). This trend is similar to other global studies on rice yields over a similar time frame (Saseendran et al. 2000; Ajetomobi et al. 2011). Multiple factors have been put forward as contributing to the observed expansion of rice, such as technological advancements, structural adjustment, and changes in government policies (Mbow et al. 2019). For example, changes in structural adjustment have led to farmers in countries such as Colomi, Bolivia altering planting times, soil management strategies, and spatial distribution of crop varieties (Quiroz et al. 2018). In comparison, farmers in Argentina have seen an increase in yield variability of maize and soya beans due to changes in farming strategies. Saseendran et al. (2000) have outlined these changes in farming have important implications for food security, biodiversity, and human health.

Climate change has led to a reduction in the yield of staple crop production within Africa, which has widened food insecurity gaps (Edame et al. 2011; Ketiem et al. 2017; Tumushabe 2018). In countries such as Nigeria, climate change has affected the livelihoods of arable crop farmers (Enete and Amusa 2010). At the same time, the Sahel region of Cameroon has seen an increase in malnutrition levels due to changes in crop yields and extreme drought (Chabejong 2016). Consequently, climate change affects global food security due to drastic increase changes in precipitation patterns and temperatures. Mbow et al. (2019) have outlined increases in temperatures are affecting agricultural productivity in higher latitudes, consequently increasing yields of some crops such as wheat and maize. However, in the lower-latitude regions, yields of crops such as barley are reducing (Mbow et al. 2019).

Indigenous and local knowledge in Africa has highlighted that climate change is affecting food security in drylands. Sanchez (2016) outlines have led to increased pressure on smallholder farmers across Sub-Saharan Africa. Given that temperatures are rising in all locations and rainfall around the West Africa and Southern Africa, climate change has led to yield decreases. While in countries such as Zimbabwe, weather pattern change resulting in delayed rainy seasons has led to increased water and food supply shortages. Chirisa et al. (2021) have outlined due to Zimbabwe experiencing less precipitation and more hot days, food security concerns have increased. Sanchez (2016) has outlined similar food security concerns, linking these concerns with erratic rainfall patterns and the effects of drought on crops. Consequently, in 2010, Zimbabwe faced a one million metric tonnes of maize shortfall. Since 2010, Zimbabwe has had to import maize to cover a deficit since the country faced a severe food shortage (Brown et al. 2012).

3.2 The Politics of Dams, Irrigation and Community Resilience

The construction of dams has both benefits and detrimental societal, economic and environmental implications. Globally dam projects have been linked to unforeseen changes to agricultural production systems, such as how the influx of workers at these locations during the construction phase has adverse effects on the cultural heritage assets of the local communities (Delinic and Pandey 2012). Typical compensation for communities that are forced to relocate has been monetary payments, however, this alone has not adequate to address communities' needs (Perry and Lindell 1997). A notable example is fishermen losing their traditional livelihoods due to relocation, such as during the Kali Gandaki hydroelectric project (Rai 2007). Cernea (2008) has articulated the timing of cash payments has implications on the ability of displaced communities to initiate new livelihoods. At the same time, inadequate compensation has led to the separation of households and creation of a cycle of poverty (Cernea 2008).

Another case is displacement induced by the construction of the Barra Grande Dam (Roquetti et al. 2017). The construction led to unprecedented effects, namely the second round of farmers' migration and the creation of new agriculture-related stakeholders (Roquetti et al. 2017). Farmers were forced to adjust to new environmental conditions as they were placed in a significantly different habitat (Darrigran et al. 2012). Local authorities' efforts to assist displaced farmers partially worked. However, given how the whole process has selective pressure over displaced farmers, these effects were insufficient (M da Costa 2010). Literature on similar studies on the displacement of farmers reveals the interplay of farmers and the ecological conditions they have to grapple with plays an integral role in the success rates of farmers in new environments (Teweldebrihan et al. 2020).

The growth in organisational structures of farmers has led to a community-based adaptation approach to increase resilience at local levels. These community-based adaptation approaches have successfully built agricultural practices such as drip irrigation, water storage, and crop adaptation. Several scholars such as Menon et al. (2007) and Gentle (2014) have outlined several success stories of community-based resilience projects in Nepal. Common approaches implemented include reforestation, construction of check dams that facilitate the control of sediment build-up, minimum tillage on soil, and the protection of water sources from pollution. The politics on the development of dams has been analysed in literature to reveal comparative politics and international relations (Baboo 2009). Mollinga (2008) has also outlined authorities should assess the impacts of dams as they are a radical transformation of the physical landscape. As such, 'experience' and 'expectations' of proposed strategies to tackle the impacts of climate change through the construction of dams has led to great debates in literature (Mollinga 2008; Tilt et al. 2009). The 'politics of promise' and the 'politics of threat' associated with many dam construction projects present a particular temporal approach that is focused on political and economic orientation towards sustainable development (McCarthy et al. 2011).

Within Africa there has been growing body of knowledge that reveals specific initiatives can strengthen communities' resilience and make economic sense (McCarthy et al. 2011). In the Red Sea Hills of Sudan, attempts have been made to assist beneficiary communities' vulnerability to droughts through investments in activities such as terracing, construction of dams and embankments (El-Sammani and Dabloub 1996). Likewise developing countries such as Zimbabwe which struggle with low socio-economic indicators, are vulnerable to multiple disasters, such as waterborne disease outbreaks, food insecurity, and increased mortality (Manyena 2006; Holleman et al. 2017). The Kariba Dam construction led to the involuntary displacement communities in 1957, as communities were resettled to arid lands (Mashingaidze 2019). This disturbed people's livelihoods that were primarily based around riverbank farming, hunting and fishing.

Although there are many studies on that outline the negative impacts of dam construction on communities' livelihoods, current developmental trends still rely on increasing the number of dams as an adaption strategy to climate variability (Watts et al. 2011). Therefore, there is still a need to identify and invest in alternatives that will have multiple beneficial outcomes for communities and the environment. Watt et al. (2011) have consequently outlined the importance 'dam reoperation', given the many negative implications of climate change. For instance, flood management, hydropower, or water supply have implications on dam reoperation strategies.

Consequently, both developed and developing countries are investing in dam construction for improving food security while also seeking to enhance community livelihoods (Khan et al. 2009). Furthermore, several studies have revealed implications for conserving agriculture-sensitive and livestock production practices (Khan et al. 2009). This, which in Zimbabwe has led to various stakeholders collaborating with local communities to enhance the quality of life and empowering communities to be resilient to shocks (Manyena et al. 2008). As such dams in developing countries as used as tools for developing local farming practices and sustaining the communities' livelihoods.

4 Research Methodology

Research methods engaged for the study that informed the writing of this chapter included literature and document review. Published books, journal articles, and conference papers constituted literature. They were instrumental in engaging past and current debates on food security and climate change readiness, the politics of dams, irrigation, and community resilience. Document review, also known as the archival method, engaged published and unpublished reports by government and civil society organizations. The idea was to get a triangulated picture of the reality on the subject matter at hand within the study area of Zimbabwe (see Fig. 1). Data were analysed through content analysis.

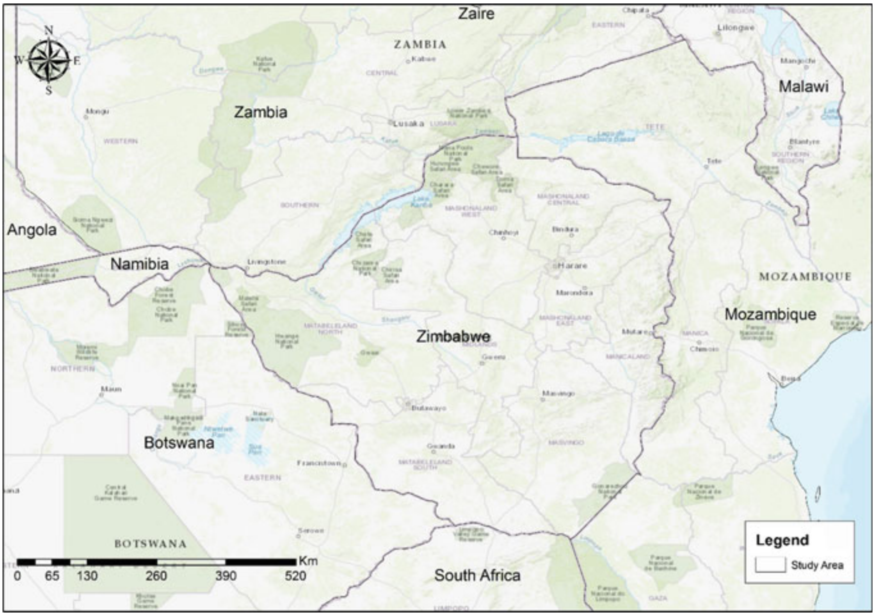

Fig. 1 Study area

5 Results and Discussion

Globally climate change development opportunities remain to be clearly understood despite evidence from the broad socio-economic spectrum (Chanza and Gundu-Jakarasi 2020). In literature there has been a growth of studies on the effects of climate change that has focused on the adverse effects with limited attention on the merits linked with climatic responses. As such, perceptions of dams' aid in addressing climate change are divided despite the developmental contribute to improving livelihoods of local communities in developing countries such as Zimbabwe. Carfagna et al. (2018) have articulated a need for developing countries to unpack climate change effects that are linked to societal and economic development sectors, as these can be used to inform sustainable and improvements on the quality of life of communities.

5.1 Case Studies of Tokwe Mukosi and Zambezi Water Project

5.1.1 Tokwe Mukosi

Completed only a few years ago, the Tokwe-Mukosi Dam has become Zimbabwe's largest inland water reservoir (Nhodo et al. 2021). It is second in size to Lake Kariba on the border with Zambia. Since the dam's completion, there has not been a comprehensive plan to manage and benefit from the large lake. Community leaders have not supported the development of an integrated water use master plan which was proposed by the national government which would make the Tokwe-Mukosi Dam the backbone of the master plan, as the community leaders have outlined that the current available water bodies are being under-utilised, and there is no need to further invest in the construction of new dams (Chanza and Gundu-Jakarasi 2020). The national government developed the integrated water use master plan as a means to address demand and supply for irrigation farming, fisheries, hydropower supply and tourism (Chanza and Gundu-Jakarasi 2020). There are expectations that once the master plan is complete, it could resuscitate idle irrigation infrastructure to boost food production. This which would led to several potential opportunities to use newer, more efficient irrigation technologies (Evans and Sadler 2008), for example, the use of drip and canal irrigation which is a less power intensive alternative (Chanza and Gundu-Jakarasi 2020).

Developmental trends have shown dam construction projects can significantly impact the socio-economic aspects of local communities (Chazireni and Chigonda 2018). However, these implications need to be assessed. Similarly, the construction of Tokwe-Mukosi Dam has led to several socio-economic implications of the local communities (Tilt et al. 2009). Chazireni and Chigonda (2018) have examined several impacts of water provision and tourism development and their implications on the lives of the community. It is evident, without government actively assisting to improve the quality of lives of the community, local communities are negatively affected by such large construction projects.

The local community has also benefitted through increased access to fish. In addition to fishing by individual households, the Zimbabwe Parks and Wildlife Management Authority has also launched aquaculture at Tokwe Mukosi. Fish boosts the diets of the residents, particularly the protein nutrients in the diets. Tokwe-Mukosi Dam is also essential in that the livestock in the area does not suffer from water shortages. Therefore, the creation of a constant supply of water for livestock by the dam is of great importance. Tokwe-Mukosi Dam also provides water for domestic uses that include laundry, bathing, and cooking. Unfortunately, some members of the community use the water from the dam for drinking purposes. This highlights the inadequacy of clean and safe potable water in the rural areas of Zimbabwe (Chazireni and Chigonda 2018). Mazvimavi (2010) further notes that approximately 40% of the Southern African population has limited access to clean potable water.

Tokwe Mukosi also supplies water for irrigation, chiefly to farms in Hippo Valley, Triangle and Chiredzi. The construction of Tokwe Mukosi is fundamental in supplying irrigation water in the south-east Lowveld region of Zimbabwe (Mukwashi 2019). This finding is in line with Auret (1990), who states irrigation development in developing countries such as Zimbabwe has become a critical water supplement for dryland cropping and securing food provision in the country. Several studies have also shown irrigation development as essential element of addressing climate change and the related influx of disaster events, such as El Nino and related droughts (Mabhaudhi et al. 2016; Trnka et al. 2018; Chirisa et al. 2021). In addition, tourism activities in the area had been boosted by the construction of Tokwe-Mukosi Dam (Chazireni and Chigonda 2018). While for the people in the surrounding communities have received increased incomes due to Tokwe-Mukosi Dam, mainly through the selling of fish and also the selling of various crafts to tourists.

The major positive impacts of Tokwe-Mukosi Dam are that the dam provides fish to the surrounding communities, and the constant supply of water is utilised by livestock and household use. The dam has now become the main water source for irrigation, particularly in the south-eastern Lowveld area. During the interview with the Agricultural Research and Extension Officer around Tokwe Mukosi, it was outlined the dam supplies water to the plantations in Chiredzi, Hippo Valley and Triangle.

5.1.2 Zambezi Water Project

The Zambezi Water Project is an ambitious vision to draw water from the mighty Zambezi River for use by the City of Bulawayo and other projects along the route (Gope et al. 2015). If fully implemented, this project will resolve Bulawayo's perennial water shortages whilst bringing new agriculture opportunities along the route from the Zambezi River to Bulawayo, a distance of more than 400 kms. Water is a key driver for sustainable development, leading to developments around the Zambezi basin (Mukuhlani and Nyamupingidza 2014). "The basin is riparian to eight southern

African countries and the transboundary nature of the basin's water resources can be viewed as an agent of cooperation between the basin countries" (Nkhata 2020; 17). However, during the Agricultural Research and Extension Officer interview, it was outlined there have been cases of conflicts between water users for the same water resource. To address conflicts, authorities have developed policies which the southern African Water Vision informs. The vision seeks to ensure "equitable and sustainable utilisation of water for social, environmental justice and economic benefits for the present and future generations" (Mutschinski and Coles 2021:4). However, for communities to benefit there should be integrated and efficient management of water resources within the basin.

High variability in climate and availability of water resources have threated efforts to safeguarding water and food security within the Zambezi basin area. It has also been noted that water resources in developing countries such as Zimbabwe are under continuous threat from pollution, urbanisation, and global climate change (Mabhaudhi et al. 2016). Such risks have consequently increased water demand and given this vulnerability of the basin, local authorises have had seek financial assistance to ensure sustainable water resources. Local agencies have also struggled with balancing the basin's economic and societal well-being which are heavily dependent on rainfall. High demand for water, has also led to conflicts, this which has the potential to hinder growth of value of water resources.

Given the widespread impacts of global climate, there is a need for innovative solutions to create another water source for the Zambezi basin since the availability of rainfall largely determines its economic benefits. This study believes there is a need to create a means to evaluate climate change impacts using planning tools. Suppose the historical patterns of variability are not clear, then planning for future climate and hydrological resources becomes difficult leading to the failure mitigation measure. For successful water resource plans, it is crucial to have reliable quantitative estimates of water availability. However, such initiatives have been hindered by a lack of information, especially developing countries with limited resources to enable them to maintain infrastructure with the latest technologies. Shortages further compound this in human and financial resources to ensure adequate monitoring.

5.2 Discussion

Adaptation strategies have the potential to inform public and private sector investment or disinvestment decisions commonly used to inform long-term investments in the agricultural sector. While investment on storage and transport facilities has increased during the short-term to ensure adicatquate food security. Such short to long term investments have sought to increase societal welfare against the backdrop of climate risk. Adaptation and mitigation have consequently been used as tools by authorities to inform the percentage contribution of investments in relation to monetary and non-monetary cost–benefit analyses.

Carfagna et al. (2018) has outlined dam reoperation strategies are complex as they have the potential to impact water availability and power production. Successful dam reoperations hence require constant involvement by water managers, planners, river operators and stakeholders (Richter and Thomas 2007). There is a local agency to identify and manage the multiple benefits of dam reoperations as a means to provide strong support for change. There has been a growth in consensus that the integrated assessment will lead to opportunities for finding benefits of dam reoperation and whilst also upscaling normal operations.

Local agencies have sought to educate local communities on the importance of inter-connectedness of river basins as this would have implications on provision of public goods (Koning 2018). Solutions to develop dam reoperations in developing countries should be extended beyond a single dam and integrating the energy grid. As climate change could make environmental flows more essential and more problematic to maintain, this has forced governments and communities to assess their ecosystems and develop new strategies safeguard water availability (Watts and Allan 2012). Lessons learnt during extreme events namely floods and droughts show the potential of complementary outcomes and benefits of dam reoperation through water savings. Dam reoperation have as such created opportunities for sustainable water usage whilst also being weary of the future changes. Consequently, dam reoperation is a climate-change adaptation strategy, with merits for both the environment and society, even with minimal change in precipitation, shifting the operation.

6 Conclusion and Policy Options

Zimbabwe has not fully utilised damming opportunities to address food security and other climate change effects. This chapter sought to map and discuss the politics and technicalities around damming as a mitigation measure for climate change and variability that have been placed since the colonial days and the reasons behind the lack of desired outcomes in Zimbabwe. For Zimbabwe to implement possible climate mitigatory measures, the plans that remain unimplemented for decades or centuries need to be continuously revised in the light of climate change. What was planned in the previous century may not be possible or may give unexpected results due to changes in rainfall patterns that have reduced natural water supply, thus fuelling conflicts, especially for international shared rivers.

It is concluded that regarding Tokwe-Mukosi Dam and the Zambezi Water Project, the dams are underutilised, and opportunities remain largely untapped. Although there are many links between water available, food provision, and energy provision, these linkages have not been explored. Numerous authorities see the construction of new large dams as a stable opportunity to achieve resource security for a future marked by climatic variability and unpredictability. Modern-day dams' developments are viewed as critical adaptation strategy that can be utilised to meet the challenges of climate change. Future sustainable planning for dams promises to facilitate preservation of essential environmental flows, while also safeguarding water resources threats. Consequently, developing countries must utilise the opportunities existing at the many dams to address food security and climate variability.

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Edible Flora as a Sustainable Resource for World Food

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Abstract The components with the greatest presence and permanence in ecosystems are vascular plants. It is estimated that there are between 300,000 and 500,000 species of higher plants (bryophytes, gymnosperms, ferns, angiosperms and lycophytes), some of them are edible. Anthropological vestiges show that, since prehistoric times, edible plants have been key to human nutrition. Currently, productive and environmental factors limit food production. This review presents an analysis of the subject of the use of edible flora as a resource for food production. For which the state of the main factors that affect the agri-food production system is discussed, considering the agricultural information of the eight main countries of origin of the domestication of plant species. This allows us to understand how edible flora becomes a resource for research on new crops despite environmental threats caused mainly by climate change.

1 Introduction

In terrestrial ecosystems, one of the components with the greatest permanence and prevalence are vascular plants (Ren 2021). Plants are the basis of terrestrial ecosystems, forming an essential part of the fauna's diet; in addition to the fact that some plant products are essential for human survival and well-being (Pimm and Joppa 2015). It is estimated that there are between 300,000 and 500,000 species of higher plants (bryophytes, gymnosperms, ferns, angiosperms and lycophytes), with a greater amount of diversity concentrated in the humid tropics of the planet (Corlett 2016). Approximately 369,000 species of plants have been described or identified. In addition to the fact that a third of land plants are at risk of extinction as a result of degradation, fragmentation and habitat loss, as well as overexploitation of species, environmental pollution and global climate change (Willis 2017).

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_8

Paleoethnobotany has shown that edible vascular plants have been an important part of human nutrition since prehistoric times (Chantran and Cagnato 2021). Since humans could have collected edible wild plants to diversify their diets (Tereso 2021; Zanina 2021). This situation prompted primitive man to develop the domestication of wild plants, creating cultigens; whose main characteristic results from dependence on human care (Krapovickas 2010). Therefore, the process of plant domestication was a consequence of the close relationship between human practices of crop management and the agricultural environment. It is estimated that around 2,500 species of plants present some degree of domestication, and that only 250 species are completely domesticated, this with respect to the fact that their life cycle came to depend on human cultivation (Gaut et al. 2018; Smýkal et al. 2018). At present, this process of domestication of plants continues, since currently agricultural producers use adaptation strategies to counteract the negative effects perceived by the effects of climate change (Atube et al. 2021).

Currently, between 10 and 50 species of edible plants are those that offer 95% of the world's caloric intake. Most of the dietary intake of humans is concentrated in a small collection of crop plants; among which are rice, potato, corn, wheat and soybeans. His dependence of the world food system on a few species of edible plants, becomes a key element for the vulnerability in the world food supply affected by the outbreak of new diseases for plants and the impact of climate change (Von Wettberg et al. 2020). As global warming is predicted to alter the distribution of climatically suitable space for plant species, including agricultural crops (Gardner et al. 2021). In recent years, international actions to address climate change have intensified. The 2015 Paris Agreement mentions that it is necessary to keep average global warming below 2 °C above pre-industrial levels. So food production plays an important role in keeping carbon dioxide and greenhouse gas emissions low (Roelfsema et al. 2020).

This review presents a compilation of literature on the available knowledge on the use of edible flora, it also includes an analysis of production information and food security indicators in the eight main countries of origin of the domestication of plant species. This information is intended to contextualize edible flora as a resource for food in the context of climate change.

2 Centers of Origin and Domestication of Plants

Agriculture as a model and/or technological development is likely to have arisen independently in more than one geographical location on the planet (Harla 1992). However, the exact number and geographical limits of the different centers of origin of domestication of plant species have not yet been determined. Due to the above and for the purposes of analyzing the information, the contributions of the botanical study carried out in 1926 by the Russian scientist Nicolai Vavilov were considered. Vavilov proposed a differential botanical-geographic method to determine the places where the cultivated species presented greater variability. In his findings, he found that these sites contrasted with the development of ancient developed civilizations and the

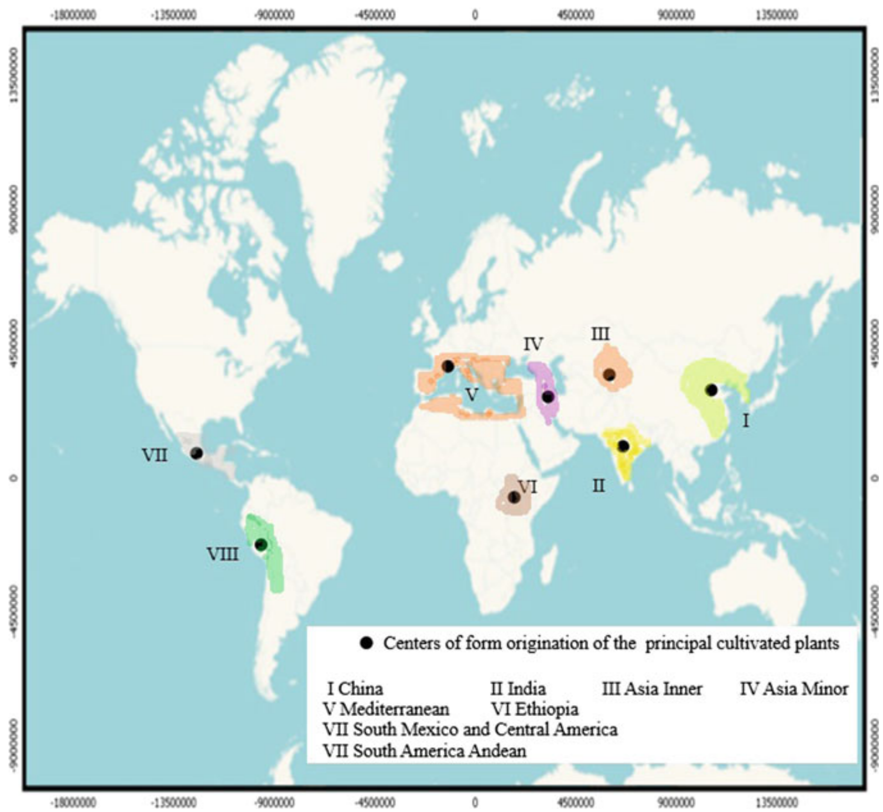

Fig. 1 Centers of crop diversity. Modified with information from Hawkes et al. (2000)

existence of particular ecosystems (Vavilov 1926; Turril 1926). In 1935, he proposed eight primary domestication centers for plant species, identifying the following: (I) China, (II) India, (III) Central Asia, (IV) Near East, (V) Mediterranean, (VI) Ethiopia, (VII) Southern Mexico and Central America, (VIII) Peru and Bolivia (Fig. 1), and three secondary centers: IIa) Indo-Malay, IIa) Chiloé and VIIIb) Brazil-Paraguay (Hawkes et al. 2000; Vavilov et al. 1992).

2.1 Prospects for Food Production

The current world population is approximately 7,700 million and it is estimated that, for the year 2,100, it will be 10,900 million people (ONU 2019). Feeding a growing population has led to intensification of measures to increase the productivity of the planet's agricultural production systems. Mainly, between the period of the years between 1965 and 1985, the "green revolution" took place, which consisted in increasing crop yields by 56% worldwide, this based on systematic plant breeding, together with advances in agricultural management technology and strategies (Thudi et al. 2021). Despite this, since the 1990s, food sovereignty has emerged as a set of legal and causal norms and practices aimed at transforming agricultural and food systems in each country (Edelman 2014).

Self-sufficiency in supplying the population is limited by various environmental and economic factors (Lobell et al. 2009). The productive specialization of the planetary agricultural system is tangible. An example of this, considering the information available from FAO in 2019, food production in eight of the countries that are part of the main primary centers of plant domestication, is concentrated in at least 10 crops (Table 1). Where altogether 45% of the world population lives. In this period, crop production in tons represented only 30% of the international total (FAOSTAT 2021b). In addition, the figure corresponding to the cultivated area on the planet (1.6 billion hectares), shows that 27% was concentrated in the eight countries that we have referred to for this study. The largest amount of food consumed comes from the 12% of the land area that belongs to cultivated land (Erb et al. 2016). In addition, food production is affected by inappropriate agricultural practices, changes in land use, the decline of pastures and forests; and above all the use of solid fuels used the rates of CO_2 and other greenhouse gases (nitrogen oxide-N_2O, methane-CH_4 and carbons of flora-CFC_5, N and O) (Dellal et al. 2011; Kuden 2020). For this reason, the dependence of agriculture on the use of non-renewable resources such as water and fossil fuels are visible (Egerer 2021, Tang 2021).

2.2 *Panorama of Food and Nutrition Security*

Access to food is a universal right. FAO estimates that 800 million people suffer from hunger (FAO 2012). Despite the fact that countries have created campaigns to combat malnutrition, part of their population continues to suffer from food insecurity (Long et al. 2020; Masron et al. 2020). This is demonstrated by the food safety indicators. Also noteworthy is the daily calorie intake which, in 2019, among the group studied was 2,951 kcal per day (Table 2) (FAOSTAT 2021c).

The recommendation for caloric intake in a healthy diet is 2,000 kcal per day for women and 2,500 kcal for men (WHO 2020; Storey and Anderson 2018). The World Health Organization recognizes unhealthy diets as one of the four factors that cause the increase in non-communicable diseases (NCDs) along with the consumption of harmful alcohol, physical inactivity, and harmful use of tobacco. By 2020, NCDs accounted for 71% of all deaths on the planet (WHO 2021), making them a public health problem. The optimal strategy to have quality in the diet is dietary diversity, which as a consequence would generate a good intake of nutrients (Kojima et al. 2020).

In each country there is an incessant search for alternatives to adequately feed its population (Gebremedhin and Bekele 2021). Despite this, there are different causes

Table 1 Top ten main commercial crops by production volume in the countries center of domestication of plant species. Period 2019. Elaborated with data from FAOSTAT (2021)

Country- Code Area	Item crop	Production (tonnes)	Import quantity (tonnes)	Export quantity (tonnes)
China _ I	Maize	260,957,662	96,15,335	26,070
	Rice, paddy	211,405,211	23,125	17,527
	Vegetables, fresh nes	181,836,818	1,80,735	4,96,182
	Rice, paddy (rice milled equivalent)	141,007,276	29,52,451	28,29,549
	Wheat	133,601,131	45,59,169	8,525
	Sugar cane	109,963,447	–	–
	Potatoes	9,18,81,397	78,493	5,03,539
	Cucumbers and gherkins	7,03,38,971	24,456	67,474
	Tomatoes	6,28,69,502	28,235	1,96,541
	Watermelons	6,08,61,241	2,98,199	50,897
India II	Sugar cane	405,416,180	–	–
	Rice, paddy	177,645,000	–	–
	Rice, paddy (rice milled equivalent)	118,489,215	5,753	97,31,549
	Wheat	103,596,230	1,666	1,90,058
	Potatoes	5,01,90,000	10	4,17,402
	Vegetables, fresh nes	4,22,11,000	332	1,28,525
	Bananas	3,04,60,000	–	1,73,804
	Maize	2,77,15,100	3,12,389	3,79,469
	Mangoes, mangosteens, guavas	2,56,31,000	911	1,47,242
	Onions, dry	2,28,19,000	76,178	14,60,547
Kazakhstan III	Wheat	1,12,96,643	3,37,123	53,75,940
	Potatoes	39,12,103	10,404	2,63,963
	Barley	38,30,069	38,485	16,40,083
	Watermelons	13,40,993	1,190	43,312
	Melons, other (inc.cantaloupes)	10,41,153	2,025	99,845
	Linseed	10,07,244	1,573	5,12,659
	Onions, dry	9,16,205	1,24,257	1,03,161
	Maize	8,95,978	7,543	86,779
	Sunflower seed	8,38,710	83,347	5,39,934

(continued)

Table 1 (continued)

Country- Code Area	Item crop	Production (tonnes)	Import quantity (tonnes)	Export quantity (tonnes)
	Tomatoes	7,90,501	43,372	19,780
Saudi Arabia IV	Dates	15,39,756	939	1,82,317
	Fruit, fresh nes	7,70,015	2,31,256	3,874
	Watermelons	6,87,718	6,755	–
	Barley	6,27,982	39,05,759	–
	Wheat	5,34,000	30,99,235	–
	Potatoes	4,72,127	70,303	–
	Tomatoes	3,32,608	2,10,129	–
	Sorghum	1,23,869	163	–
	Grapes	1,17,639	60,157	–
	Cucumbers and gherkins	81,880	1,344	3,546
Algeria V	Potatoes	50,20,249	90,467	1,214
	Wheat	38,76,876	67,75,910	2
	Watermelons	22,06,866	2	97
	Barley	16,47,746	1,22,297	–
	Onions, dry	16,13,729	–	1,034
	Tomatoes	14,77,878	–	61
	Oranges	11,99,535	6,300	30
	Dates	11,36,025	563	54,185
	Vegetables, fresh nes	10,78,035	68	2,485
	Olives	8,68,754	–	28
Ethiopia VI	Maize	96,35,735	25,698	–
	Cereals nes	57,35,710	–	–
	Wheat	53,15,270	13,06,000	–
	Sorghum	52,65,580	2,50,000	–
	Barley	23,78,010	16,009	366
	Sweet potatoes	17,55,855	–	–
	Roots and tubers nes	16,57,097	–	–
	Sugar cane	14,99,134	–	–
	Millet	11,25,958	–	–
	Broad beans, horse beans, dry	10,06,752	21	28,000
Mexico VII	Sugar cane	5,93,34,059	–	–

(continued)

Table 1 (continued)

Country- Code Area	Item crop	Production (tonnes)	Import quantity (tonnes)	Export quantity (tonnes)
	Maize	2,72,28,242	1,54,72,700	6,44,889
	Oranges	47,36,715	30,913	55,937
	Sorghum	43,52,947	7,43,650	300
	Tomatoes	42,71,914	417	18,57,755
	Wheat	32,44,062	48,04,441	7,36,265
	Chillies and peppers, green	32,38,245	1,976	10,67,203
	Lemons and limes	27,01,828	2,407	7,66,031
	Mangoes, mangosteens, guavas	23,96,675	1,942	4,13,443
	Avocados	23,00,889	–	11,52,977
Peru VIII	Sugar cane	1,09,29,341	–	–
	Potatoes	53,31,063	–	86
	Rice, paddy	31,88,306	–	1
	Plantains and others	22,80,103	–	1,346
	Rice, paddy (rice milled equivalent)	21,26,600	2,92,762	37,361
	Maize	15,79,796	40,09,801	11,381
	Cassava	12,86,013	–	–
	Oil palm fruit	9,12,929	–	–
	Grapes	6,38,204	1,118	3,76,049
	Onions, dry	6,31,580	–	2,48,722

of food insecurity, the main ones being instability in the food supply due to high-level political risk and weak institutions (Abdullah et al. 2020). In addition to the fact that food production systems are vulnerable to the effects of the alteration in the planet's climate (Mbuli et al. 2021). Every year agricultural hydrological reserves (groundwater, soil moisture and surface water) are affected by the direct and indirect effects of global warming (Ndehedehe et al. 2021).

3 Edible Flora as a Resource for Consumption

Edible plants play an important role in food in the context of climate change. Therefore, there is a growing consumer market for wild edible plants, domesticated and semi domesticated, because the people prefer them for their aromatic and fresh taste.

Table 2 Suite of Food Security Indicators about the countries centers origin of domestication plants. Elaborated with data from FAOSTAT (2021b)

Country	Item Suite of Food Security Indicators (2017 / 2018/ 2019)	Value
Algeria	Average dietary energy supply adequacy (percent) (3-year average)	145
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	3343
	Prevalence of undernourishment (percent) (3-year average)	2,8
	Number of people undernourished (million) (3-year average)	1,2
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	9,3
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	17,6
	Number of severely food insecure people (million) (3-year average)	3,9
	Number of moderately or severely food insecure people (million) (3-year average)	7,4
China	Average dietary energy supply adequacy (percent) (3-year average)	128
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	3137
	Prevalence of undernourishment (percent) (3-year average)	< 2,5
	Number of people undernourished (million) (3-year average)	ND
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	ND
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	ND
	Number of severely food insecure people (million) (3-year average)	ND
	Number of moderately or severely food insecure people (million) (3-year average)	ND
Ethiopia	Average dietary energy supply adequacy (percent) (3-year average)	105
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	2338
	Prevalence of undernourishment (percent) (3-year average)	19,7
	Number of people undernourished (million) (3-year average)	21,5
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	14,1
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	57,9
	Number of severely food insecure people (million) (3-year average)	15,4

(continued)

Table 2 (continued)

Country	Item Suite of Food Security Indicators (2017 / 2018/ 2019)	Value
	Number of moderately or severely food insecure people (million) (3-year average)	63,3
India	Average dietary energy supply adequacy (percent) (3-year average)	109
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	2526
	Prevalence of undernourishment (percent) (3-year average)	14
	Number of people undernourished (million) (3-year average)	189,2
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	ND
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	ND
	Number of severely food insecure people (million) (3-year average)	ND
	Number of moderately or severely food insecure people (million) (3-year average)	ND
Kazakhstan	Average dietary energy supply adequacy (percent) (3-year average)	136
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	3197
	Prevalence of undernourishment (percent) (3-year average)	< 2,5
	Number of people undernourished (million) (3-year average)	ND
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	36 646,95
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	2,1
	Number of severely food insecure people (million) (3-year average)	< 0,1
	Number of moderately or severely food insecure people (million) (3-year average)	0,4
Mexico	Average dietary energy supply adequacy (percent) (3-year average)	130
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	3117
	Prevalence of undernourishment (percent) (3-year average)	7,1
	Number of people undernourished (million) (3-year average)	9
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	11,5
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	34,9

(continued)

Table 2 (continued)

Country	Item Suite of Food Security Indicators (2017 / 2018/ 2019)	Value
	Number of severely food insecure people (million) (3-year average)	14,6
	Number of moderately or severely food insecure people (million) (3-year average)	44
Peru	Average dietary energy supply adequacy (percent) (3-year average)	118
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	2730
	Prevalence of undernourishment (percent) (3-year average)	6,7
	Number of people undernourished (million) (3-year average)	2,2
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	ND
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	ND
	Number of severely food insecure people (million) (3-year average)	ND
	Number of moderately or severely food insecure people (million) (3-year average)	ND
Saudi Arabia	Average dietary energy supply adequacy (percent) (3-year average)	132
	Dietary energy supply used in the estimation of prevalence of undernourishment (kcal/cap/day) (3-year average)	3223
	Prevalence of undernourishment (percent) (3-year average)	4,8
	Number of people undernourished (million) (3-year average)	1,6
	Prevalence of severe food insecurity in the total population (percent) (3-year average)	ND
	Prevalence of moderate or severe food insecurity in the total population (percent) (3-year average)	ND
	Number of severely food insecure people (million) (3-year average)	ND
	Number of moderately or severely food insecure people (million) (3-year average)	ND

Those who consider them rich in mineral nutrients, with medicinal benefits and linked to a pollution-free origin (Alam 2020). The flora that is traded represents an important resource for the ethnic groups from which they come. Where they are used as basic foods, dyes, medicines, construction materials, and a source of economic income (Liu 2021; Ong and Kim 2017; Uprety 2012).

Edible plants are important in different aspects of the life of farming communities (Bharucha and Pretty 2010). Agricultural communities have developed a close relationship with their ecosystems throughout their history, generating traditional knowledge about the use of natural resources (Cao et al. 2021). This has led to the subsistence of gastronomic cultures based on the consumption of a diversity of foods. This is a consequence of the role of rural farmers for the management and domestication of crop germplasm, where the agroecological management of crops is relevant (Oluwatimilehin and Ayanlade 2021). Currently, variations between rainfall and temperature have become one of the main concerns for the maintenance of these agricultural systems (Tesfahunegn and Gebru 2021) besides reduction of organic matter by burning agricultural biomass and continuous monoculture (Fig. 2).

One mechanism that has sought to preserve the dietary diversity of these agricultural products is local food supply markets (Vlkova et al. 2015). They represent primary sources of information on the diversity of foods consumed locally, where wild, semi-domesticated and domesticated food plants are traded, and a great diversity of edible fungi (Alexiades and Sheldon 1996). Traditional markets in each place on the planet reflect the ways in which the people of a region interact with their territory and biodiversity, as well as traditional ecological knowledge is integrated into the daily life of society (Farfán et al. 2018).

In every place on the planet, food marketing reflects its own unique socio-cultural characteristics. Documenting ethnobotanical knowledge makes it possible to understand with a comprehensive approach the various facets in which research could infer the management and conservation of plant species (Aziz et al. 2020; Sulaini and Sabran 2018). The planet's intensive agricultural supply systems do not incorporate information on the commercial management of this diversity of foods. Obtaining ethnobiological records of each food species could generate public policies to promote their sustainable management, through a balance between the local gastronomic culture and conservation priorities (Luczaj et al. 2021). Edible plants, along with livestock with their varieties and races, as well as other wild organisms, are part of the biocultural resources that ethnic groups possess, whose benefits need to be studied to improve the quality of life of humanity (Argumedo et al. 2020).

Fig. 2 Harvesting and burning of cane fields (photographs taken in Veracruz, Mexico)

3.1 Edible Plants Within Agricultural Sustainability

The holistic approach to sustainability allows us to understand and recognize the relationship between the different links between culture and nature (Folke 2006). Biocultural heritage contextualizes the various interrelationships that biological diversity has with cultural memory, language, ecological knowledge and social values (Gavin 2015; Davidson 2012). In these communities the agricultural practice of politiculture is common. This food production system allows diversifying the number of crops on the same farm, optimizing the use of the soil (Nuryati et al. 2019). This practice becomes a strategy that maintains the balance between available agricultural resources (Beaupré et al. 2020). That is why present and future government actions must converge in an ethical–political dimension that focuses on the articulation of plural values, power relations and local governance systems (Merçon et al. 2019). In agricultural communities where edible flora is distinguished as a biocultural resource, two phenomena are observed. The first is the sustained production of goods with use values for self-sufficiency and the second the production of exchange values that enter monetary resources (Colin et al. 2021).

3.2 Flora Diversity and Climate Change

The use of natural resources has been a means of subsistence for the rural population. Actually, concern for the sustainable management of biodiversity is growing in different parts of the planet (Alexandre et al. 2021; Barros et al. 2021; Wang et al. 2021). For example, in the geographic area of the tropics, the greatest threat to plant diversity today is habitat loss and increasing fragmentation of ecosystems in small agricultural plots with low productivity and highly susceptible to pests, weeds, diseases and the effects of climate change, mainly droughts (Ter Steege et al. 2015). This has led to the conversion of tropical forests, to commercial monocultures, and to grasslands (Fig. 3).

Fig. 3 Small agricultural plots, deforestation and pest affectations (photographs taken in Huasteca, Mexico)

Therefore, the fragmentation of ecosystems causes immediate changes in the vegetation cover of the soil, since few are the plant species that manage to subsist (Kettle and Koh 2014). Another great threat to biodiversity is represented by global climate change, causing prolonged droughts and alterations in the climate (Stuart and Díaz 2020). These factors that directly affect plant diversity, place wild flora in a vital role within the conservation of natural resources (Goettsch et al. 2015). Additionally, the effect on the yields of cultivars has been observed, since alterations to humidity, soil nutrients, and sowing dates have been observed, in different crops it is exacerbated (Ren et al. 2021).

Even the visible impacts of climate change are complex and will be unpredictable. In some species, global warming by one degree centigrade has stimulated their early spring flowering and consequently their delay in the fall of leaves in autumn (Ge et al. 2015). Certain species of plants have extended their spatial distribution towards altitudes and/or the geographic poles; and others have not (Hijioka et al. 2014). There is scientific evidence that local plant extinctions have occurred, although global extinctions have not been attributed to changes in global warming (Buse et al. 2015).

Climate change is expected to be directly related to other environmental impacts: both negatively, such as fires and the fragmentation of ecosystems; and positively with increasing levels of carbon dioxide in the atmosphere (Corlett 2014). Possibly the phenomenon that occurs when changes in climate occur when they exceed the range of natural variation, will be that plant populations adjust physiologically (acclimatization), adapt by evolutionary changes or disappear progressively. Unfortunately, little information is available on the acclimatization capacity or the evolutionary potential of plants (Corlett and Westcott 2013; Corlett 2015). Studies suggest that a sudden change in temperature would seriously affect a large number of wild, semi-domesticated, domesticated plant species (IPCC 2013). The above idea proposes the intensification of measures that identify the diversity of edible plants as a source of food for an increasing world population and with difficulties in accessing a healthy diet.

4 Conclusions

The specialization of agricultural production is a fact that reflects the fragility of world food systems. Edible flora could represent a valuable resource for the global food system. The sustainability of current supply chains are limited by a number of external and internal factors, which limit their growth. For this reason, the study helps to understand this phenomenon, which in the coming years will worsen as a direct effect of climate change. By diversifying crop plant species and improving varieties, it is possible to offset the effects of climate change on crops (Ruan et al. 2021). This could allow the development of research to document this great global wealth. The economic policy in each country could incorporate mechanisms for the diffusion of a wide range of still unexplored food products to the markets.

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The Utility of Agri-Compatible Virtual Resource Flows for Food Security Policy and Strategy Under Climate Change

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Abstract The effects of climate change on agriculture and productive resources would be geographically different. As a result, food trade would provide a vital bridge between countries with surplus and those with deficits. The virtual resource flow concept, such as virtual water or land use, quantifies the indirect transfer of productive resources via food commodity trade. Virtual water or land use refers to the volume of water or area of land used, respectively, to produce a given quantity of food commodity which is traded. The hypothesis of the virtual resource flow concept seems potentially capable of providing a theoretical context for a trade strategy or policy that can serve coupled resource-food security goals to support adaptation and resilience to climate change. However, opponents have argued that some conceptual limitations diminish the utility of the virtual resource flow concept for trade policy or strategy. The main limitation relates to difficulties in quantifying and isolating the usefulness and effects of virtual resource flows on the resource security of the destination country. The conceptual limitation for policy or trade strategy can be redressed by evaluating virtual resource flows in an agri-compatibility framework. The objective of this chapter is to promote the agri-compatibility framework to advance the utility of the virtual resource flow concept for strategic trade decisions or adaptive policy in response to climate change. The chapter reviews the virtual resource concept and its limitation for policy and then sets out the usefulness and the conditions for evaluating virtual resource flows in the agri-compatibility framework as a basis for coupled resource-food security policy or strategy under climate change. It is concluded that the virtual resource flow concept is useful for policy if it meets the conditions of agri-compatibility. Future work on estimates of agri-compatible virtual resource flows in different contexts is recommended to facilitate wider practical applications.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_9

1 Introduction

1.1 Resource Scarcity

Land, water, and food are fundamental requirements for human life. The availability and use of these are locked up in a paradoxical relationship as we require substantial amounts of land and water to produce enough food. Globally, agriculture consumes more land and water than any other economic sector. Agriculture uses about 50% of the world's habitable land (Ritchie and Roser 2013) and 70% of water withdrawals (FAO 2020). Food security remains a topical subject and development priority in the policy and research communities. The UN Sustainable Development Goal 2 aims to achieve a zero hunger by the year 2030 through a combination of national initiatives and international partnerships. Yet, land and water, which underpin food production and availability (the first pillar of food security) are becoming scarce. Currently, the UN Food and Agriculture Organization estimates that 3.2 billion people live in agro-ecosystems that suffer high or very high water shortages or scarcity, out of which 1.2 billion people (a sixth of the global population) face extreme water limitations to production and livelihoods (FAO 2020). In crop plants, water plays a primary role in nutrient uptake, photosynthesis, assimilate transport, chemical and enzymatic reactions, cell division, among others, and constitutes the bulk of the fresh weight of growing plants. For example, water is known to be a primary regulator of yield formation and is fundamental to the realization of yield potential in cereals (Rajala et al. 2011). Similarly, arable land per person keeps declining and suitable land could be the scarcest factor of production (Lambin 2012).

In the future, pressure on land and water for food production is expected to increase significantly. The global population could reach 9.7 billion in 2050 and approximately 11 billion at the end of this century according to the medium variant projection (UN DESA 2019). The projected increase in population, together with expected increases in disposable income, urbanization, and shifts in dietary preferences, will have far reaching consequences for food systems at varying administrative and temporal scales. Estimates of food demand by mid-century, regardless of methodological differences, are colossal. Examples include increase of 25% to 70% over current levels (Hunter et al. 2017), 60–100% (Tilman et al. 2011; Alexandratos and Bruinsma 2012), or more than 100% due to income convergence (Fukase and Martin 2017). At the same time, food production should remain resilient and sustainable, respond effectively to the increased and varied demand in quantity and quality, as well as the intense competition for productive resources from other use sectors while supporting biodiversity, livelihoods, and economic development. In the past few decades, food production seems to have matched population growth and considerably helped reduce the gap between demand and supply. For example, between 1960 and 2010, the production of cereals, roots and tubers, and meat increased by 2.7-fold, 1.6 and fourfold, respectively (Foresight 2011). However, concerns about constraints to mobilizing the required land and water resources, across local to global scales, to meet the projected increases in food production have been expressed in several studies (e.g. FAO 2020; Falkenmark 2013; De Fraiture et al. 2007; Falkenmark and Rockström 2004). To achieve this, substantial increases in irrigated agriculture and cropland area, in combination with non-conventional resource management and productivity improvement practices, will be required.

In addition, climate change poses direct threats to the spatio-temporal distribution or availability of land and water for agriculture, on one hand, and food production on the other. In this way, climate change threatens to complicate the tenuous balance between resource scarcity and food production. Climate change will likely increase the spatio-temporal variability of precipitation, change the long term mean supply and demand for water by all sectors, intensify competition for water between use sectors, the frequency of extreme events (Gosling and Arnell 2016), and increase speed and scale of land degradation and agricultural land abandonment. Climate change will, therefore, intensify land and water scarcity and constrain food security (FAO 2020) in a direct and reinforcing manner.

1.2 Trade, Virtual Resource Flows, and Food Security

The distribution of land and water scarcity is currently uneven and shall be so in the future. Climate change will likely increase the geographic coverage and the severity of land and water scarcity. This will help drive spatial reconfiguration or redistribution of resource limitations and food production capability, with cascading impacts on markets, supply chains, and trade flows. Trade provides an opportunity for nations to maintain food security in the face of limited production. Trade has played crucial roles in diversifying and enriching global food supplies and consumption despite domestic production realities (Aguiar et al. 2020; Fader et al. 2013). Today, thanks to trade, about a quarter of global crop harvest is consumed outside the producing countries (D'Odorico et al. 2014). This ability of trade to help subtly decouple consumption from domestic production realities can be instrumental as part of a suite of adaptive responses to the impacts of climate change on food security (Zimmermann et al. 2018). It is imperative, therefore, to address all forms of bottlenecks to international food trade and associated supply chain capacities in accordance with climate justice principles (Yawson 2020).

Economists have long believed that traded commodities embody and indirectly transfer the scarce productive resources used to produce such commodities. This idea is captured in the Heckscher-Ohlin (H–O) theorem of trade, undergirded by the Ricardian Comparative Advantage theory (Krugman and Obstfeld 2003). Applied to food commodity trade, the concept of virtual resource flow becomes evident where scarce resources used to produce the traded food commodities are indirectly transferred to the destination country. Hence, virtual resource flow has been introduced to capture the magnitude and impacts of the circulation of resources embodied in traded food commodities on sustainable resource management and food security at varying administrative scales. So far, there is disproportionately larger body of literature on virtual water compared to virtual land use transfers, but least on virtual nutrients transfer. This overfocus on virtual water is, perhaps, fuelled by the pervasive concerns about the rate at which both acute and chronic water scarcity is spreading over space and time. Notwithstanding, the virtual resource concept helps make explicit the instrumental role of trade in weaving subtle tele-connections and globalization of the challenges in agri-food systems in the nexus of resource-food security.

1.3 Aim and Objectives

This chapter aims to show the utility of the virtual resource flow concept as a component of adaptive policy in the resource-food security nexus. The objectives are to: (i) present the nature of the debate on the limitations of the virtual resource flow concept for policy, and (ii) explain and draw attention to the idea and usefulness of agri-compatibility as a solution to the policy limitations of the virtual resource flow concept. The rest of the chapter uses virtual water, interchangeably with virtual resource flow, to explore the conceptual promise and limitations for policy and the components or requirements of agri-compatibility.

2 Virtual Water

2.1 The Origin and Nature of the Concept

Virtual water is equivalent to the volume of water used to produce a given quantity of food commodity that is traded (Allan 1997). Similarly, virtual land use is equivalent to the total area of land used to produce a given quantity of food commodity that is traded. In other words, the volume of water (or land area) used to produce the food commodity is virtually embedded in that food commodity. For a given food commodity and trade transaction, the virtual water flow is estimated as the product of the virtual water content and the total quantity of the food commodity that is traded. For primary crop commodities, the virtual water content is the volume of water consumptively used to produce a unit yield. It is estimated as the ratio of total volume of water used in evapotranspiration (to satisfy crop water requirement) and the yield.

The virtual water concept is believed to have been introduced by Tony Allan after examining why scarcity of water resources has not resulted in armed conflict in the Middle East and North African (MENA) region (Allan 1997). The finding was that countries in this region had moderated the impact of water scarcity on their economies and food security by importing huge quantities of water-intensive cereals and other food crops. Initially, Allan borrowed the term ‘embedded water’ (from Israeli economists who had suggested in the 80 s that it was economically senseless for arid Israel to export scarce water embedded in avocado and oranges);

but this was 'under-whelming in its impact' compared to virtual water (Allan 2003). Allan argued that unlike conventional engineered solutions for transporting water to people, virtual water constituted a soft engineering approach that moves water to people through food commodity trade in a manner that is politically silent and economically invisible. The subsequent rapid popularity of virtual water in the water policy community could be due to its metaphorical strength in linking and globalizing water scarcity and providing a soft solution via food trade.

Proceeding from this perspective, it is not difficult to perceive the usefulness of virtual water in addressing the coupled problem of water scarcity and food insecurity. However, while the water is moved through food commodities, excessive attention has been given to the virtual water flows as opposed to food security which is, arguably, the primary reason for the food imports. This focus was, perhaps, facilitated by the development of a method for estimating virtual water flows through global food trade (Hoekstra and Hung 2002, 2005), which unleashed a copious body of literature on virtual water flows through food commodity trade and the implications for water resources management or policy at varying administrative and time scales (e.g. Harris et al. 2020; Antonelli et al. 2017; El-Sadek 2011; Aldaya et al. 2010; Hoekstra and Hung 2005). Since then, virtual water or resource flow studies have multiplied but continuing in this trajectory, together with estimates of water savings and/or losses to the global water system. Here, water savings or losses are estimated based on differences in water productivities between trading nations. Estimates from these studies are colossal and have helped shine the light on major sources and destinations of global virtual water flows.

2.2 Conceptual Promise and Limitations

The argument that virtual water moves water to people (Allan 2003) reveals the conceptual hypothesis or promise of the virtual water concept, i.e. countries can ameliorate the impacts of water scarcity by importing water-intensive food commodities (Allan 1997, 2003). This suggests that water scarcity is a fundamental driver of food imports. This position seems to have been supported with studies using the MENA or Mediterranean countries (e.g. Allan 2003; Youkhana and Laube 2009; Novo et al. 2009; Hakimian 2003). However, opponents have raised counter arguments, mainly regarding (i) nomenclature and (ii) the conceptual strength and usefulness of the virtual water hypothesis for policy. The debate on nomenclature was short-lived. The argument was that the name 'virtual water' is misleading since it is the food that is imported but not the water, and since virtual water essentially is equivalent to crop water requirement, there is nothing virtual about it and another name is unnecessary (Merrett 2003).

Substantively, however, the discourse on the usefulness of the virtual water hypothesis for policy, or the virtual water savings for addressing water scarcity in the destination country, remains active. To this end, opponents (e.g. Wilchens 2010a, b; Frontier

Economics 2008) argued that the virtual water concept has analytical value but deficient for policy, making virtual water-based policy proposals potentially harmful. In summary, the virtual water hypothesis is theoretically limited because (i) it is considerably inconsistent with the observed structure and patterns of virtual water flows, (ii) the estimated virtual water flows are not linked to relevant environmental targets to guide policy or management decisions, (iii) the estimated water savings are irrelevant for reducing physical water deficits, (iv) potential policy failures and opportunities for developing water resources or improving productivity are poorly considered, and (v) it poorly considers political and socio-economic impacts on destination (importing) countries (Wilchens 2010a, b; Ridoutt and Pfister 2010; Ansink 2010; Frontier Economics 2008).

To address this limitation, it was argued that the value of virtual water for policy can be improved by using comparative advantage or opportunity cost of water in food production as analytical lens, or by given due consideration to other environmental, socio-economic, technological, and political factors (Wichelns 2010a, b; 2004; Lant 2003; Earle 2001). This proposition was intuitive since the virtual water or resource concept itself is consistent with the Heckscher-Ohlin (H–O) theorem of trade, which, undergirded by the Ricardian Comparative Advantage theory, embodies the idea of indirect transfer of factors of production and the relative abundance of these factors in the trading nations shape the structure and direction of trade flows. The assumptions in the H–O theorem are that the relative abundance of productive resources dictate factor prices and confer comparative advantages between trading nations, and proportions of the input factors used in the production of goods differ between the trading nations (Krugman and Obstfeld 2003). Applied to food commodity trade, the expectation is that water-scarce countries will import water-intensive primary food commodities despite the fact that both water and food do not bear a true economic cost (Reimer 2012) and green water which dominate virtual water flows (Aldaya et al. 2010) is not accurately incorporated. However, results from studies that applied the comparative advantage theorem (using relative endowment of water resources) to analyse virtual water flows and test the virtual water hypothesis largely showed either the Leontief Paradox (water-intensive primary food commodities rather flow from water-scarce sources to water-rich destinations), or no relationship between water scarcity and food imports (e.g. Ansink 2010; Seekell et al. 2011; Ramirez-vallejo and Rogers 2010; Verma et al. 2009; Kumar and Singh 2005; Lant 2003; Earle 2001). The inconsistency with trade theories led to the conclusion that the structure of virtual water flows could not be explained by relative water endowment alone but is considerably influenced by other factors such as arable land, labour, or trade policies. The virtual water hypothesis or concept, then, has analytical value but insufficient value or limitations for policy. Subsequently, research on virtual water or resource continued in the direction of quantifying flows and savings/losses rather than addressing its limitations for policy (Antonelli and Satori 2014; Yawson et al. 2013).

In addition, because the total virtual water flows constitute a fraction of the total consumptive water use in agriculture, it is easy to question or ignore the relevance of global water savings when there is no guarantee or evidence that it helps relieve water stresses in any particular country or region, at least in agriculture. Hakimian (2003) reported that the virtual water hypothesis is sensitive to the definition or indicator of water scarcity employed in the analysis as the use of annual water withdrawal gave better result compared to the use of internal renewable water resources or annual agricultural withdrawals. This suggests a need for compatibility between the definition, indicator, or concept of resource scarcity and food production needs, which underpin food security and related trade. The problem with the debate, on both sides, has been the exclusively hydro-centric view of the value of the virtual water hypothesis for policy. Food production and imports basically serve food security goals while the primary purpose of water resource management is to optimize or prioritize some components of human welfare. This implies the importance or priority of some welfare components can be diminished depending on the severity of water scarcity. In this context, it is usual for water allocation to agriculture to be diminished to sufficiently meet domestic or industrial needs. However, the virtual water concept couples water resources management with food production (intensive or agronomy side) and consumption (extensive or socio-economic side) via trade. While the environmental impacts in the source country can easily be quantified, the challenge lies with providing evidence for water scarcity constraining food production and thereby driving imports in the source country. This points to the two key elements missing in the debate, which are addressed by the agri-compatibility framework (Yawson 2013; Yawson et al. 2013).

3 Agri-Compatibility

3.1 The Framework and Its Requirements

The debate on the value of the virtual water hypothesis for policy can be reduced to the meaningfulness and practical utility of the so-called water savings in addressing the limits of water scarcity to food security in the destination countries. The two missing elements or questions central to the debate on the value of the virtual water hypothesis for policy are (i) what policy? (ii) what is the strength of the conceptual or practical relevance of water scarcity for food security at the place and time of analysis? The virtual water hypothesis, though predated by trade, is significant in that it essentially couples water (scarcity) and food production (supply) in a single management framework at local/national scales and links this to the international arena through food commodity trade. As pointed out earlier, the primary purpose of water resource management is to optimize some human welfare function and that some welfare components can be diminished, when necessary, to respond to water scarcity. Similarly, food production or import of primary food commodities serves several purposes, including food security and industrial use, and any component of these purposes can be elevated or diminished in priority depending on given circumstances. As a result, the value of the virtual water concept for policy should be sought in the coupled water (resource)-food security nexus where the purpose of

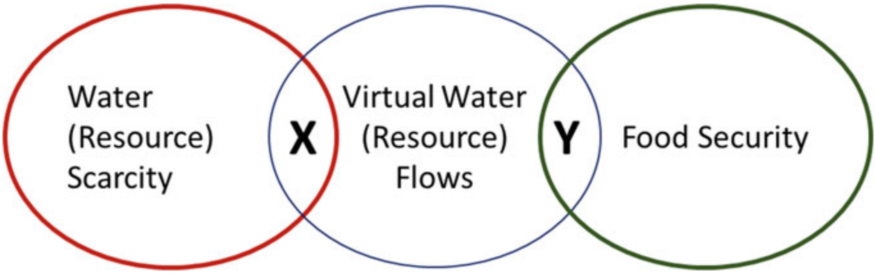

Fig. 1 The main connective requirements of agri-compatibility represented as X and Y, which denote agri-compatible water (resource) scarcity and agri-compatible food import, respectively. *Source* Adapted from Yawson (2013)

water management and food security goals are congruent, consistent, or compatible. Focusing on water endowment alone will lead to missing the forest for the tree. It is in this context that agri-compatibility becomes useful, a situation where the conceptual characterization of water scarcity and food insecurity become compatible for coupled management. In other words, water-limited food production or supply and its influence on food imports to address food insecurity is identifiable or deducible.

The agri-compatibility framework (Yawson 2013) aims to address the two missing elements identified above in the debate on the value of the virtual water or resource hypothesis for policy. Agri-compatibility is a state in which a given quantity of food commodity is imported to fill actual or potential supply gap which is created by deficient available water to produce the desired quantity of that food commodity in the destination country (Yawson 2013; Yawson et al. 2013). The fundamental idea of agri-compatibility is illustrated in Fig. 1, which basically seeks to tighten the relationship between water scarcity and food security to achieve a singular policy for resource-food security.

In Fig. 1, agri-compatibility is achieved when conditions X and Y are met, which are agri-compatible water scarcity and agri-compatible food import to serve the goal of food security. Agri-compatible water scarcity is a condition in which food production is limited by deficient available water from all relevant sources at a given geographic area and time (Yawson 2013). In other words, the concept or definition of water scarcity must be conceptually and practically relevant to food production at the given geographic area and time. The quantity of food commodity imported to fill the water-dependent food supply gap created by agri-compatible water scarcity is referred to as agri-compatible food import. Applied to the virtual water hypothesis, the value of virtual water for policy and its analysis, then, should be placed within the context of identifying water-limited production or supply which then contributes to water-dependent food import to obtain agri-compatible virtual water flows. Not all forms of water scarcity threaten to diminish food production or supply, and not all manner of primary food commodity imports serve the purpose of food security. This distinction is important for advancing the usefulness of the virtual water hypothesis for policy as some definitions or indicators of water scarcity or endowment do not have practical relevance for food production. The agri-compatible water scarcity condition can explain why relative water endowment, in the context of comparative advantage but decoupled from agro-ecosystems, might not work for testing the virtual water hypothesis. What this implies, again, is that the food crop under consideration should be grown in both trading nations, with substitution permitted only in the sense of shifting water away from the target food crop to others to account for water savings (or consumed via the imported food). In this context, a country or region suffering from or faced with the threat of chronic or acute water scarcity, which in turn threatens food production, can find the virtual water concept instrumental to policy in the water-food security nexus. Outside this framework or context, estimated virtual water flows will be merely embedded water that is not agri-compatible and the associated water savings will have only analytical value.

3.2 Utility for Policy Under Climate Change

The conceptual relationships between virtual resource flows and food security under climate change is shown in Fig. 2 using virtual water for illustration. Figure 2 shows that climate change can directly increase the severity of water resource scarcity and variability in yields of food crops. Indirectly, water resource scarcity can limit food production, resulting in the need for import to serve food security needs and reduce the pressure on domestic water supply. Assuming these conditions are met agri-compatibly, it is easy to see that food trade and virtual resource flows will play significant roles in the future. Here, agri-compatibility tightens the language and the conceptual connections between resource scarcity and food security to address policy needs in the nexus of resource-food security. While the geographically and temporally uneven impacts of climate change on resource availability and food production will make trade play important adaptation roles (Zimmermann et al. 2018), so can the virtual resource flow concept be important components of adaptive policies. It is important, however, to clarify this role using agri-compatible resource scarcity and food imports as espoused in the agri-compatibility framework. In this way, the virtual resource concept gains practical significance and its value for resource-food security policy becomes evident. Unfortunately, few studies have attempted to quantify virtual resource flows under projected climate change (Yawson et al. 2020a, b; Zhao et al. 2019; Konar et al. 2013) but few had agri-compatibility considerations (Yawson et al. 2020a, b). Hence, attention needs to be given to agri-compatible virtual resource flows under both current and future climate conditions to understand the implications for supply chains.

Resource scarcity and food insecurity can be caused by a myriad of factors which act singly or interact in complex ways at varying administrative and temporal scales. The changes in the availability and distribution of resources underpinning food production from climate change have transformative implications for the reconfiguration of trade flows to serve food security. The definition and components of agri-compatibility focus the role of trade and virtual resource flows as part of a suite

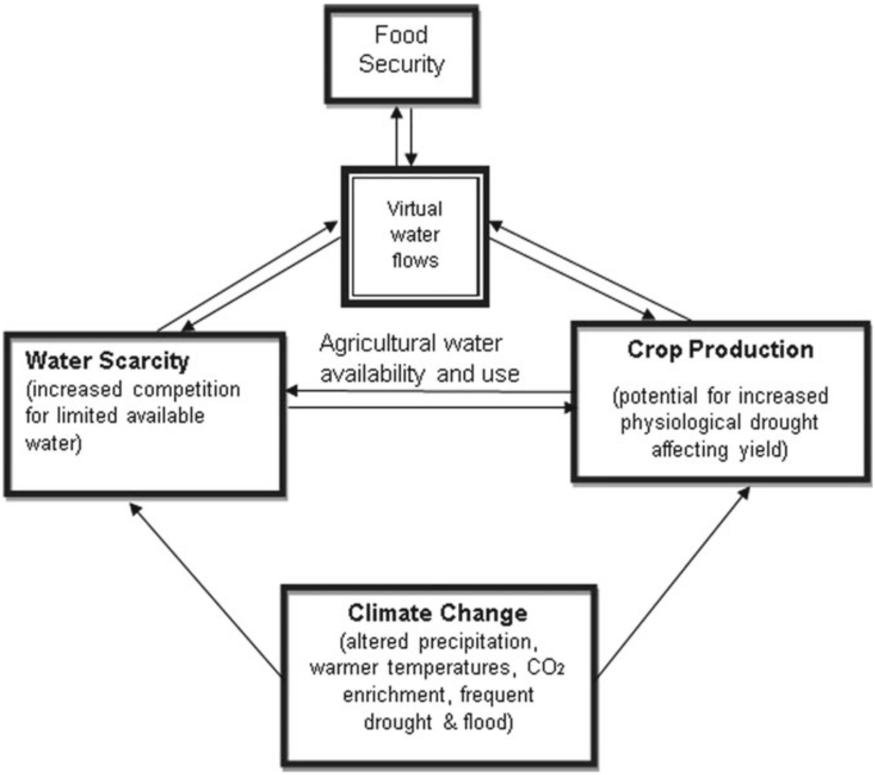

Fig. 2 Conceptual linkages between climate change, resource scarcity, virtual resource flow, and food security

of adaptive strategies or policy responses to climate change. Countries facing agri-compatible resource scarcity, under climate change, can formulate adaptive strategies or policies using the agri-compatibility framework as part of integrated resource-food security management framework. By so doing, these countries can assess and integrate the demands and impacts of such strategies or policies on the functionality, resilience, and sustainability of supply chains.

One of the requirements of the agri-compatibility framework is that the food commodity under consideration should be produced in both trading nations being analysed and have food security value, at least, in the destination country. In this way, the dual meaning of virtual resource (i.e. (i) the amount of the resource used to produce the commodity in the source country and, (ii) the amount of water that would have been used to produce the same quantity of the commodity) is given a practical value. The matrix below (Fig. 3) can be used to support decisions on production-virtual resource flow mix.

Figure 3 is divided into four quadrants and three axes (resource intensity, economic value, and food security). Quadrant I includes food commodities that have low

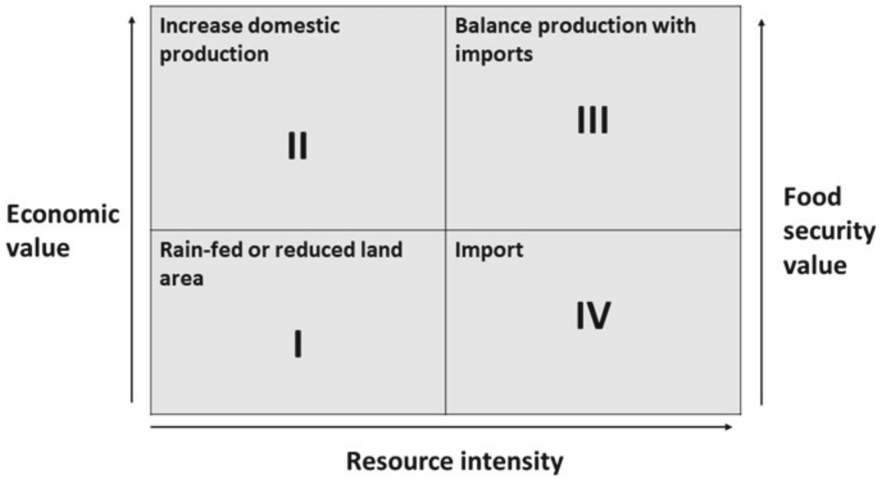

Fig. 3 Decision support matrix for production-virtual resource flow strategy

resource intensity, economic value, and food security value. For example, food crops in this category can be kept entirely under rain-fed production or their land area can be reduced without much concern. Food commodities in Quadrant II have low resource intensity but high economic and food security value. These food commodities should be given level one priority in terms of maximizing production and resource supply (such as increased irrigated and land area) where feasible. Imports can be envisioned here but at a reduced level or only when the need arises due to resource limitations. Quadrant III food commodities are like those in Quadrant II except that the former has high resource intensity. Here, a careful balance between domestic production and imports is necessary to augment Quadrant II production to assure, first and foremost, domestic food security, while supporting economic benefits and livelihoods without compromising the supply capacity of the underlying resource. Finally, Quadrant IV food commodities can be entirely imported on the premise of agri-compatible resource scarcity. Decisions on future production-resource flow mix will have implications for the capacity and sustainability of supply chains. It is important that supply chain actors are engaged early in an inclusive, multi-stakeholder process to formulate and implement these strategies and policies.

4 Conclusions

Food trade occurs between nations regardless of the scale of relative resource endowment or scarcity and predated the virtual resource concept. Trade has helped diversify food consumption and improved food security independent of local production circumstances. However, trade also constitutes an indirect transfer of the scarce resources (such as water and land) used in the production of traded food commodities. This situation is captured in the virtual resource concept such as virtual water or virtual land use. This chapter mainly used the virtual water concept to promote the idea of agri-compatibility to redress the conceptual limitations of the virtual resource hypothesis for policy in the nexus of resource-food security under climate change. It has been shown that the virtual resource hypothesis has value for adaptive policy if applied in the context of agri-compatibility rather than in an omnibus manner to food commodity trade. Agri-compatibility promotes the view that the definition of resource scarcity should be consistent with the use and needs for that resource in food production at a given geographic and time scale of analysis. Armed with the agri-compatibility framework, nations that face agri-compatible resource scarcity can develop mixtures of production-virtual resource flow policies and strategies and incorporate the needs of supply chains to respond to the threats of climate change. Ultimately, this chapter sets out a pathway for the instrumental use of the virtual resource concept as a component of adaptive policies and strategies that address the geopolitical challenges of climate change in the nexus of resource-food security. The main limitation of the agri-compatibility idea, in its current form, is that it is only a theoretical proposition which might present difficulties for application. For the future, it is important to develop practical estimates and quantitative distinction of agri-compatible virtual resource flows from non-agri-compatible flows in different contexts. In addition, research attention can be devoted to establishing agri-compatible resource scarcity thresholds, at varying spatial scales or for specific food commodities, as a pre-condition for easing and increasing the wider application of agri-compatibility.

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Yield Sensitivity of Some Crops to Climatic Factors and Enterprise Models for Adoption of Maize Breeds in Nigeria

Mmaduabuchukwu Mkpado, Chika Ifejirika, and Chinwe Egbunonu

Abstract Crops resilience and resistance to climate change varies from different ecological systems. The paper attempts to explore the sensitivity of yield of different staple crops in Nigerian tropical ecosystem to changes in climatic variables and recommend enterprise models for multiple cropping of the most sensitive crop to improve food security. Secondary data were sourced from Food and Agriculture Organization (FAO) statistics and Nigerian Meteorological stations for 1970–2014. Descriptive statistics and regression analysis were employed to examine the sensitivity of cereals, tubers and perennial crops to climatic factors. The results showed that maize as a cereal was the most sensitive crop to all climatic variables such as temperature, humidity and rainfall; while yam as a tuber was more sensitive than cocoa tree as a perennial crop. The paper discusses potentials and strategies for using early maize and extra early maize varieties by farmers in overcoming climate change effects on maize production. It further examined timeliness of using the varieties for planning lucrative enterprises to meet early and late maize markets in Nigeria. The paper is optimistic that with the proper use of improved climate tolerant breeds, farmers can stomach effects of climate change on maize production.

1 Introduction

Agriculture and food security are undoubtedly adversely affected by climate change. The biological nature of agriculture makes it easily susceptible to environmental hazards. Agribusiness in a developing economy like Nigeria is very much under the

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_10

effects of environmental factors unlike those in developed world where advanced and most efficient production, processing, storage and marketing facilities abound. For instance sub Saharan Africa has only about 3.8 percent of her arable land furnished with some irrigation facilities from 1990 to 2009; while Asia had 44.8 and the World average was 20.5 for the same period (Mkpado 2013a). The same trend goes for fertilizer use in Africa as Nigeria had one of the least rates of fertilizer use in rice production (Ogundele and Okoruwa 2006).

The climate change could cause an estimated loss of about 25–42 percent of species habitats and can negatively affect food and non-food crops (McClean et al. 2005). In developing countries especially African countries, climate change can adversely affect about 11 percent of arable land which will lead to a reduction in cereal production and about 16 percent loss in agricultural GDP for about 65 countries (FAO 2005 in Mkpado 2012; Mkpado 2013b).The ability of ecosystems to stomach shocks may have exceeded the increasing climate change and associated disturbances. Temperature increase from 1–3 °C can result in higher crop productivity at medium to high latitudes for only certain types of crops while production of majority of other crops can reduce (Bates, et al. 2008; IPCC 2007).

The mode at which climate change can affect agriculture and food security include reduction in value of available arable land due to drought and desertification, increasing temperature and pollution which can reduce photosynthetic ability of green crops, reduced rain fall duration and intensity which reduces natural growing season in rain fed agriculture. The impacts of climate change depend on a range of the climate parameters and on a country's social, cultural, geographical and economic background (Nzeh and Eboh 2011). The building of resilience in capacity to cope with climate change is correlated to the level of innovation/technological adaptation and mitigation processes. Agriculture and food security situations of many societies with the same climatic stress can differ because of infrastructure, innovations and management systems in place. Improved breeds and farming system are integral aspect of innovation and technological adaptation for mitigating and adapting to climate change. Maturity period of a crop has a crucial role to play with respect to number of time it can be planted in a growing season. Strategies towards improved agriculture and food security amidst climate change today are dealing with the art of managing available resources such as land, water, fertilizers, labour, breeds and innovative farming systems to achieve a target. Very limited literature exists on how maize farmers can make optimum use of the available resources amidst climate change for improved livelihood.

What do the dynamics of climatic factors' threat on food security hold for Nigerian agriculture among cereals, root and tubers and plantation crops? What are the options for improving agricultural production and food security with the available resources in Nigeria? The paper aimed at examining the trend in yield of few crops from the classes of cereals, plantation crops as well as roots and tubers. It also estimates the responsiveness of the crops yield to climatic factors and recommends strategic model for improved food production (Tables 1, 2 and 3).

Table 1 Descriptive statistics of the yield in kilogrammes of selected crops from 1970–2012

Statistics	Maize Yield	Cocoa Beans Yield	Yams Yield
Mean	13,617.14	3,219.98	98,622.27
Minimum	5,731.00	2,000.00	56,284.00
Maximum	21,961.00	4,980.00	131,034.00
Standard deviation	3,364.53	783.60	21,789.95

Source Authors' computation

Table 2 Statistics of climatic factors and some variables affecting yield from 1970–2012

Statistics	RAIN	TEM	HUM	FT	FDI	AGE	TLEP
Mean	131.73	29.48116	72.18326	41,621.3	7,667.256	4,359.86	12,271.37
Minimum	74.93	28.27	68.77	150.96	6,001	4,165	11,489
Maximum	159.29	32.8	78.99	190,023.4	8,356	4,997	12,583
Standard error	19.47008	1.040948	3.258515	49,318.67	730.9687	208.4069	313.0488

Note: RAIN = rainfall in mm; TEM = atmospheric temperature in ^{o} C; HUM = relative humidity; FT = fertilizer used in kg; AGE = aggregate government Expenditure in agriculture FDI = foreign direct investment inflows; TLEP = total labour employment in Agriculture. *Source* Authors' computation.

Table 3 Time series properties of the variables at first difference order I(0)

Variable	ADF Value	Remarks (%)
Aggregate government expenditure (AGE)	−3.393382	Sig at 1
Maize yield	−7.532655	Sig at 1
Yam yield	−7.215498	Sig at 1
Cocoa yield	−6.231742	Sig at 1
Foreign direct investment (FDI)	−5.829468	Sig at 1
Fertilizer (FT)	−9.388070	Sig at 1
Relative humidity (HUM)	−12.36062	Sig at 1
Rainfall in mm (RAIN)	−7.732818	Sig at 1
Temperature ^{o}C (TEM)	−7.906909	Sig at 1
Total labour force in agriculture (TLEP)	−6.130416	Sig at 1

Critical ADF values at 1% probability = −3.605593; at 5% probability = −2.936942; *Source* Authors' computation.

2 Methodology

The study focused on Nigeria. Secondary data were collected from Nigeria Bureau of Statistics (NBS) and augmented with FAO statistics for agricultural production.

Other sources are, Nigerian Meteorological Stations, and United Nations Conference on Trade and Development (UNCTAD) for 1970 to 2014. Descriptive statistics and regression analysis were employed. Augmented Dickey Fuller (ADF) unit root test and possibility of using Error Correction Mechanism (ECM) in the model which required co-integration test were examined before the regression analysis. Using Ordinary Least Square (OLS) regression with non-stationary variables may give rise to specious regressions (Granger and Newbold 1974). In order to confirm that stationary variables are used, the equation could be rewritten mathematically in terms of differences, but this may result to loss of vital information expressed by the levels, for example, knowledge of long run elasticities. Cointegration analysis can be used to overcome this difficulty (Banerjee et al. 1993). In combination with Error Correction Model (ECM), it overtures a means of obtaining reliable, yet clearly different estimates of the duo (short and long run elasticities). Johansen test statistics are used to determine the number of cointegrating vectors that exist in equation(s) (Johansen (1991). When there is weak or no cointegration the estimation will continue without including Error Correction Mechanism as it is the case with this research (see Table 4). Put differently, as when variables in a regression model are cointegrated, the result will be spurious if ECM is not included. Testing for cointegration helps to adopt appropriate econometric estimation procedure for acceptable results. Cointegration implies linear combination among the variables implying that variables are having major dominant trend.

The model is presented as:

$$Y_{is} = a + b_1 AGE_1 + b_2 FDI_2 + b_3 FT_3 + b_4 HUM_4 + b_5 HUM_5 + b_6 TEM_6 + b_7 TLEP_7 + e$$

where: Y_{is} refers respectively to the yield in kilogram of yam (YAM), cocoa beans (COCOA) and Maize (MAIZE) respectively.

AGE = aggregate government Expenditure in agriculture.
FDI = foreign direct investment inflows.
FT = fertilizer used in kg.
HUM = relative humidity.
RAIN = rainfall in mm.
TEM = atmospheric temperature in ^{o}C.
TLEP = total labour employment in Agriculture.
e = error term.
a is the intercept while bs are the coefficients.

3 Test of Stationarity (Unit Root Test)

The unit root test is used to determine the stationarity of variables and it has become generally accepted over the years. The tests show whether each variable is stationary

Table 4 Johansen cointegration test

Dependent variable	No of cointegrating vectors	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob
Cocoa beans	r = 0	0.812468	188.4925	159.5297	0.0005*	0.812468	66.95233	52.36261	0.0009*
	r = 1	0.566028	121.5402	125.6154	0.0863	0.566028	33.39097	46.23142	0.5654
	r = 2	0.527910	88.14923	95.75366	0.1487	0.527910	30.02345	40.07757	0.4223
	r = 3	0.396832	58.12578	69.81889	0.2974	0.396832	20.22235	33.87687	0.7411
Yam	r = 0	0.853340	219.6641	9.5297	0.0000*	0.853340	76.78552	52.36261	0.0000*
	r = 1	0.636015	142.8786	125.6154	0.0029*	0.636015	40.42570	46.23142	0.1834
	r = 2	0.572543	102.4529	95.75366	0.0160*	0.572543	33.99605	40.07757	0.2063
	r = 3	0.500508	68.45686	69.81889	0.0639	0.500508	27.76657	33.87687	0.2245
Maize	r = 0	0.824102	213.3409	159.5297	0.0000*	0.824102	69.51396	52.36261	0.0004*
	r = 1	0.598990	143.8270	125.6154	0.0024*	0.598990	36.55077	46.23142	0.3657
	r = 2	0.574869	107.2762	95.75366	0.0064*	0.574869	34.21428	40.07757	0.1973
	r = 3	0.507757	73.06194	69.81889	0.0269*	0.507757	28.35132	33.87687	0.1978
	r = 4	0.401365	44.71062	47.85613	0.0958	0.401365	20.52413	27.58434	0.3060

Source Authors' computation

at level 1(0) or first difference 1(1) form and if they are integrated of the same order. The test is done using Augmented Dickey Fuller (ADF) Test (Dickey and Fuller 1979). If the process has a unit root, then it is a non-stationary time-series; if otherwise, it is stationary. If the original unit is found to be stationary, the first differences of the series are tested for stationarity. Hence, the variables will be differenced until they attain stationarity, if the null hypothesis of non-stationarity cannot be rebuffed, meaning rejection of the existence of a unit root. Only then can the test for cointegration be carried out.

4 Cointegration Test

Only variables of the same order of integration would qualify for the pairwise cointegration relationships. Cointegration implies that there exists a linear long-run relationship amid the variables in the model. Cointegration test is solely used to indicate if there is a statistical linear relationship among different series (Bremmes and Wessels 1999; Gujarati 2013). It also tests for further general notion of equilibrium. The maximum likelihood procedure which depends on the relationship among the rank of a matrix and its characteristic roots is the Johansen Vector Auto Regressive (VAR) based procedure (Johansen, 1988) of testing cointegration. The Johansen/Trace test perceives the number of cointegration vector that are present amid two or more time-series. The Johansen methodology involves where the Π matric has less than full rank employing the maximal eigenvalues test and the trace test.

5 Results and Discussion

Descriptive Statistics Results: Considering the yield of maize, cocoa beans and yams, it showed that yam took the lead among the crops. It had a mean yield of 98,622.27 kg from 1970–2012 while cocoa bean had 3,219.98 kg and maize had 13,617.14 kg. (see Table 1). The yield of yam appeared to be impressive, considering its lengthy growing period of about 7–8 months, it is certain that it can only have one phase during a growing season. Cocoa as a plantation crop will require consistent managed long term strategic plan in order to change the ugly trend. Maize with a relatively short maturity period of about three months can be a variable for advancing food security. The graphic presentation of the trend is presented in Fig. 1.

Figure 1 showed that from 1980 to 1988 the yield of yam was lowest but did increase after wards. Mkpado and Arene (2012) showed that price advantage enjoyed by yam helped to increase its cultivation. The price advantage is as a result of the preference enjoyed by yam in a number of ceremonies in Nigeria. Maize yield just like yam has not maintained linear curve. It is evident that a number of agronomic factors such as edaphic features, environmental factors and management strategies have affected the yields leading to such curves.

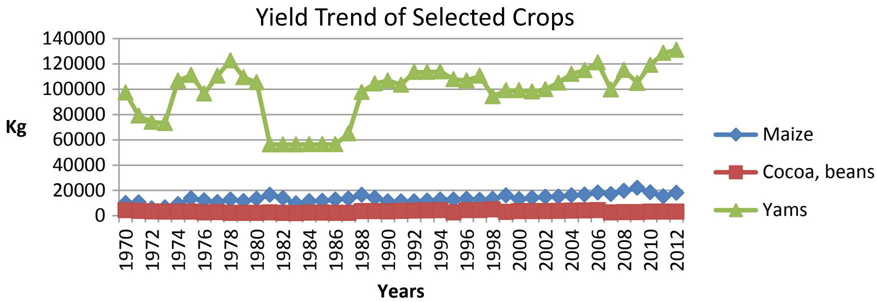

Fig. 1 Yield trend of selected Crops; *Source* Authors' computation

Descriptive statistics of climatic factors and some variables capable of affecting yield are presented in Table 2. It showed that rain fall had a mean of 131.73 mm with a standard deviation of 19.47. Temperature had a mean of 29.48 °C with a standard deviation of 1.04 while the relative humidity had a mean of 72.18 with a standard deviation of 3.26. It is apparent that certain profound changes are associated with the climatic variables as their standard deviations were more than one. Fertilizer usage, foreign direct investment inflows, aggregate government expenditure and total labour employment in agriculture in Nigeria had experienced lots of variations over the years as can be seen on Table 2.

6 Time Series Results

Estimating impact of environmental factors on yield of crops using time series data requires among other things examining time series properties of the variables and testing for cointegration. The variables were tested for stationarity using Augmented Dickey–Fuller (ADF) test. The ADF test results on Table 3 showed that the variables were of the same order of stationarity at first difference. This is an indication of possible cointegration among the dependent and independent variables. In order to make a good decision Johansen Cointegration Test was employed.

The Johansen Cointegration Test was reported on Table 4. There is consistency in the number of Johansen relations, r that are not significant for the trace statistics and Max-Eigen Statistic. The trace statistics and Max-Eigen Statistic were significant only at zero level {I(0)}indicating zero number of integrating vectors or relations. The trace statistics and the maximum eigenvalue statistics are the two types of test statistics normally used. The number of Johansen relations under the null hypothesis are presented in the first column while the ordered eigenvalues of the matrix are in the second column. (Johansen and Katarina 1990). It is because of absence of one co-integrating relations {from the order I(1) and so on} in the Trace statistics and Max-Eigen statistics that it can be concluded that weak cointegration exists (see Table 4). Thus, error correction mechanisms were not included in the analysis as this may lead to poor conclusion. That is to say the Table 4 gives conclusive evidence that the Vector Auto Regressive (VAR) models is appropriate for modeling the estimate at I(0). There is a general and systematic tendency in the series to return to their equilibrium value when variables are co-integrated (1, 1). With this, even though short run discrepancies are constantly occurring, they cannot grow indefinitely. This is an indication that the dynamics of modifications are basically and fundamentally embedded in the theory of cointegration and in a more general way than captured in the partial adjustment hypothesis. According to the Granger representation theorem, if a set of variables are co-integrated (1, 1), it is an indication that the residual of the cointegration expression is of order 1(0), thus showing the existence of an ECM describing that relationship.

7 Regression Results

The estimations of impact of climatic variables on Nigerian agricultural supply chain are acceptable because of high coefficient of determination (R-squared), low standard error of regression and significant F-statistics (Table 5).

Relative humidity had an inverse and significant relationship with yield of yams. It means that higher relative humidity leads to lower yam yield. High humidity

Table 5 Responsiveness of selected crops to climatic factors

	Yam		*Cocoa bean*		*Maize*	
Variables	Coefficient	t-value	coefficient	t-value	coefficient	t-value
AGE	0.003423	0.808828	2.77E-05	1.044928	0.008515	3.885091**
FDI	−0.000795	−0.260273	1.24E-05	0.645949	0.003603	2.278079**
_FT	8.37E-07	0.069522	3.88E-08	0.514424	1.3 E-05	2.103640**
HUM	−0.360941	−2.697588**	−0.000745	−0.888655	−0.142881	−2.062046**
RAIN	0.022267	1.392459	1.54E-05	0.142943	−0.015170	−1.700348**
TEM	−0.016135	−0.020438	0.005526	1.317617	0.245255	0.599884
TLEP	−0.000266	−0.038457	−3.48E-05	−0.804236	−0.008060	−2.251872**
Constant	29.56913	0.509293	0.107296	0.295060	42.23944	1.404856
R-squared		0.354987		0.307780		0.602927
Adjusted R-squared		0.213890		0.156357		0.516068
Standard Error of regression		1.792854		0.011229		0.928454
F-statistic		2.515915		2.032581		6.941398
Prob (F-statistic)		0.035189		0.081307		0.000047
Durbin-Watson statistics		1.68096		1.476118		1.592784

* = significant at 10%; ** = significant at 5%; *Source* Authors' computation

leads to decay of yam leaves on the ground thus, reducing the number of leaves for photosynthesis. This accounts for the reason why yam farmers in rainforest and guinea savannah zones that experience higher humidity stake their yam crops. On the other hand, high rainfall is required for higher yield. This explains why rain fall had positive and significant relationship with yam yield. The yam as a heavy feeder crop requires much rainfall to dissolve soil nutrients and the relatively large leaves requires such heavy rainfall to keep the transpiration pull working. This accounts for why higher rain fall is desirable for yam yield.

Relative humidity had negative and significant impact on maize yield. High humidity can lead to rot and decay of maize fruits in the field or during sun drying as high humidity can encourage growth of molds. Rain fall had negative and significant relationship on maize yield. It means that the higher the rainfall intensity, the lower will be maize yield. This is true in a rain fed system with only one phase cropping in which case mature maize cobs can get spoilt in the field by rain. Maize farmers thus need dryer with which they can dry their crops during the rainy season. However, multiple phases cropping of maize can provide avenue whereby the rain can be used for another phase cropping, thus possibly doubling or tripling output. There are risk and uncertainty with heavy rain fall as high wind can damage growing maize crops. Weather based index insurance programmes are designed to help farmers handle such; incidentally in Nigeria this type of insurance is still at initiation or incubation stage. Total labour employment in agriculture is inversely and significantly related to maize yield. This is apparently because of the mono phase cropping of maize in Nigeria. It is possible that with multiple phases cropping such experiences can be changed. Other variables that had positive and significant relationship with maize yield include aggregate government expenditure, foreign direct investment inflows and fertilizer usage. It is in line with expectations because FDI can help to develop breeds and other innovation for improved yield. Fertilizer is an input which can help maize yield. In fact maize is a sensitive crop more than cassava as it cannot withstand environmental and nutritional stress as cassava (Mkpado and Arene 2003). Aggregate government expenditure on agriculture can be used to provide incentives and subsidies to farmers thus, helping them to obtain necessary inputs or overcoming some production bottle necks with necessary information and technical guidance given by agricultural extension officers.

8 The Maize Varieties for Climate Change Mitigation

Badu-Apraku et al. (2013) noted that two maize varieties early (90–95 days to maturity) and extra-early maturing hybrids (80–85 days to maturity) which are resistant to Striga and tolerate drought and low soil nitrogen have been introduced in Nigeria by the Institute of Agricultural Research and Training (IAR &T). The extra-early hybrids initially known as IITA Hybrid EEWH-21 and IITA Hybrid EEWH-26 and currently referred to as, Ife Maizehyb-5 and Ife Maizehyb-6 were bred by International Institute for Tropical Agriculture (IITA), and tried extensively in Nigeria in partnership with IAR & T, via the financial assistance from the Drought Tolerant Maize for Africa (DTMA) Project. The DTMA Project is implemented by CIMMYT and IITA with funding support from the Bill & Melinda Gates Foundation. When compared with the local varieties which have a yield of 1.5 tonnes per hectare, Ife Maizehyb-5 and Ife Maizehyb-6 have a higher potential yield of 6.0 tonnes and 5.5 tonnes per hectare respectively. (Agronigeria 2013).

The maize varieties can get to market early and attract higher prices to increase farmers' income. They can be grown with lower irrigation cost. They also have the ability to resist Striga weeds and tolerate lower soils with lower nitrogen fertility thus helping farmers to reduce cost of fertilization.

9 Climatic Patterns Capable of Influencing Farming System for Increased Output

The maize production /productivity map of Nigeria (Fig. 2) showes that maize does best within the derived savannah zone of Nigeria. It has lowest production rate at two extreme climatic areas of the country. That is where rainfall is highest (rainforest zone and Guinea savannah) and lowest (Sahel savannah) respectively. This is another indication of maize sensitivity to climatic variables as rain fall can influence humidity and temperature. It may be informative to note that countries especially

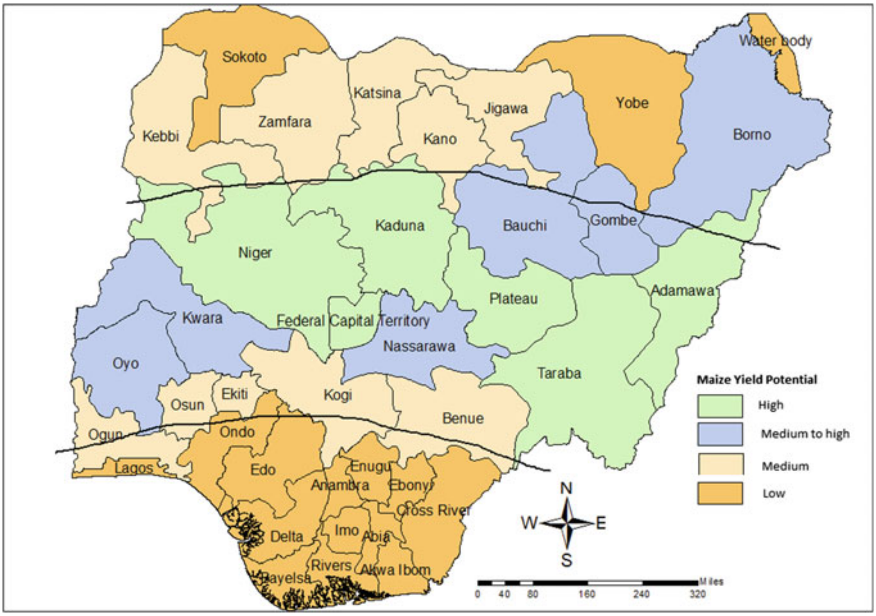

Fig. 2 Maize Production/Productivity Map of Nigeria *Source* Authors' Design

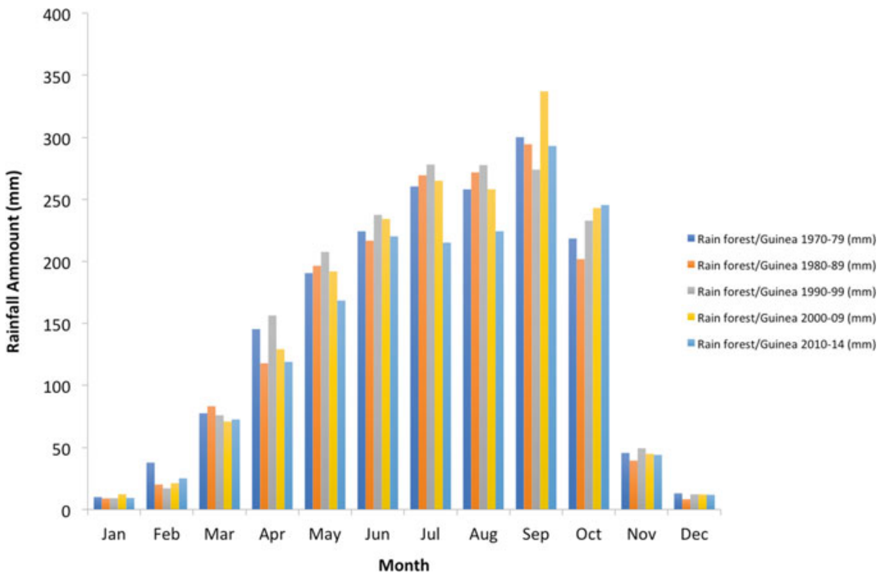

Fig. 3 Comparison of mean monthly rainfalls over Rain forest/Guinea *Source* Harris et al. (2014)

those in the tropics can adopt similar cropping phases recommended. Tropical West African countries occupying the sub-Sahara region often have similar climate outlook depicted in Figs. 3, 4 and 5.

Available data indicates that there are variations in frequency and duration of rain fall across Nigeria major ecosystems (see Figs. 3, 4 and 5). This is in line with the experiences of changing climate. A similar trend was reported by Stephen and Tobi (2014). The task here is how can farmers use the available resources to optimize production.

10 The Proposed Models for Cultivation of the New Improved Maize Varieties in Nigeria

It is assumed that the farmer has more than one portion of land for his/her farming activities at a time and or has a crop rotation system with at least one portion that is left to lay fallow. This will help in the control of pests and diseases associated with increasing intensity of cropping on a piece of land. The proposed model in Table 6 can double or even triple maize production in the country. When maize is grown two to three times in the country, domestic agro based industries using maize will get enough and excess can be exported to generate foreign exchange. Most importantly, the food security situation of Nigerian households can be improved as the crop is

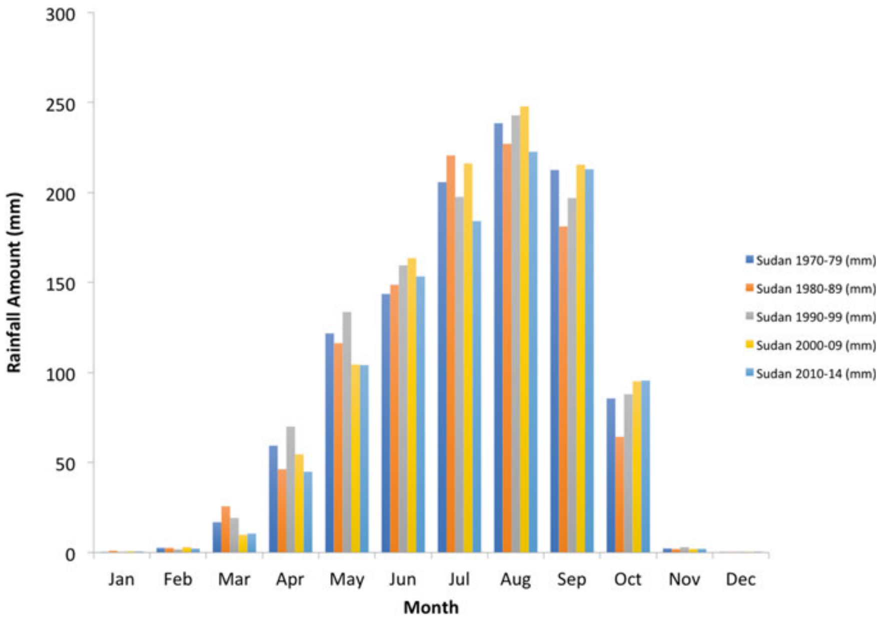

Fig. 4 Comparison of mean monthly rainfalls over Sudan Savanna *Source* Harris et al. (2014)

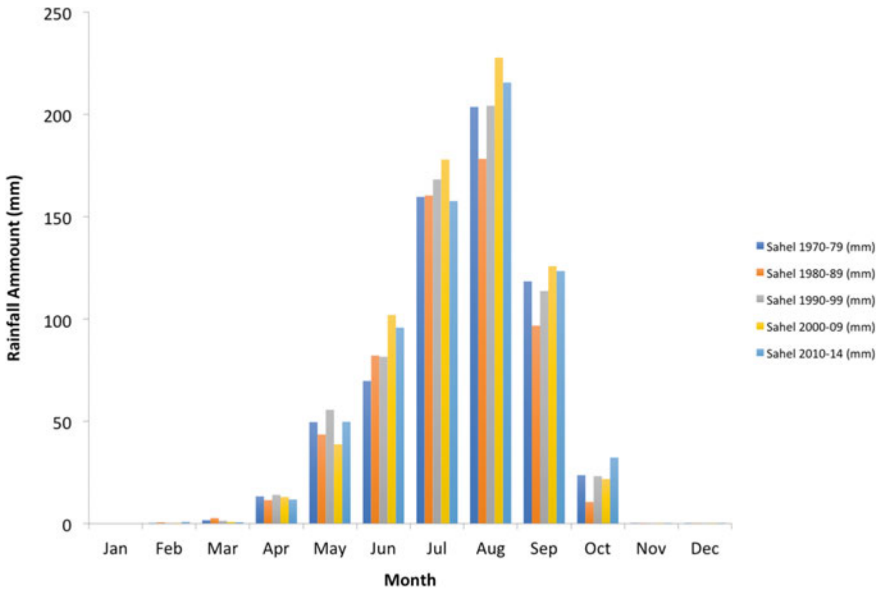

Fig. 5 Comparison of mean monthly rainfalls over Sahel Savanna *Source* Harris et al. (2014)

Table 6 Proposed enterprise models for new improved maize varieties

Ecological zones	Phases of cropping		
	Phase 1	Phase 2	Phase 3
Guinea savannah and rainforest	April–June	August–October	
	March–May*	May–July	August–October
Derived savannah	April–June	August–October *	
	March–May*	May–July	August–October *
Sahel savannah	May–July	August–October *	
	April–June*	May–July	August–October *

* Supplementary irrigation is required; *Source* Authors' computation

fast becoming a major staple as it can be cooked with vegetables, with legumes, as pap with soybeans for baby food and used as snacks in a number of forms.

The major climatic constraints to maize production emerge from rainfall duration, its pattern and variability. The use of supplementary irrigation as indicated on Table 6 is very necessary especially at the onset and cessation of the rain. This can involve the months of March, April and October or even November depending on the agricultural ecosystem the farmer works in. In the rain forest zone trials are ongoing to demonstrate the extension of the planting season of these maize varieties till November and in most enterprises that did not involve wetland; irrigation facilities are required. For simplicity and reduced irrigation cost to small holder maize farmers, the enterprise model on Table 6 is unreservedly proposed. Agricultural extension staff can see the need to sensitize maize famers on multiple cropping using the early and extra early maize varieties.

11 Summary, Conclusion and Recommendations

Aggregate government expenditure (AGE) was significant and positively related to maize yield. It means increasing AGE on agriculture and maize farming can improve maize yield. Foreign Direct Investment (FDI) on agriculture was significant and positively related to maize yield. It means that increasing FDI on agriculture can lead to higher maize yield. Fertilizer (FT) was also significant and positively related to maize yield. It implies that possible increase in fertilizer usage on maize farms can result in higher maize yield. Relative humidity (HUM) was significant and negatively related to yield of yams and maize respectively. It means the higher the HUM, the lower will be yam and maize yields respectively. These possible adverse effects can be corrected by phase cropping systems with good weather variability information. The same explanation goes for maize yield with respect to rainfall in mm (RAIN). Total labour force in agriculture (TLEP) was significant and negatively related to yield of maize. It means that increasing the labour force on maize farms will not result in higher yield per labour. It is not a surprise because small scale farming dominates Nigerian agriculture where marginal productivity of labour is almost zero (Mkpado and Mkpado 2020). But with multiple cropping systems the scenario can be changed.

It has been informative to examine yield sensitivity to different classes of crops in Nigeria. Maize as a cereal has proved to be the most sensitive. Improving food security of the nation has a lot to do with cultivation of cereals especially maize and maintain a good record in cultivation of roots and tubers such as yams. Yam can have one phase during a growing season so it requires optimum allocation of resources to sustain and even gain higher yield. Staking is to be encouraged especially in high humid zones of Nigeria as relative humidity had negative impact on its yield. Maize yield is very sensitive to climatic variables. Maize farmers thus need dryer with which they can dry their crops during the rainy season as humidity and rainfall had negative impact on yield. The performance of plantation crops such as cocoa is not impressive, given the nature of the crop, long term strategy is required.

The paper thus recommends extension of the innovation of early and extra early maize breeds to farmers. Extension agents need to encourage maize farmers to adopt multiple phase cropping systems for maize as this can double or triple maize output and increase Nigerian's food security. Yam farmers need to continue staking especially in the humid areas as well as engage in optimum allocation of inputs to yam as the crop can be grown once in a cropping season. Government expenditure in agriculture and Foreign Direct Investment (FDI) inflows in agriculture need to be encouraged as such funds can be very useful in developing breeds and providing necessary infrastructure including maize dryer and incentives for farmers.

12 Limitation of the Study

Actual weather variability information is lacking for precision timing on the duration and volume of possible irrigation for supplementary water needs for the crops.

13 Future Research

Studies should be doneon the implications of climate change variations on vegetables and other crops so as to find a long-lasting solution to food insecurity through production of better varieties of these crops that can withstand adverse climatic conditions.

Weather variability studies across the ecological zones need to predict rain return and cessation across the months with accurate precision for early and late planting seasons.

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Dietary Shifts to Mitigate Climate Crises: Barriers, Motivations and Willingness

Zahra Saleh Ahmed

Abstract In order the world to realize the target set in Paris agreement and mitigate climate challenge, noticeable change in the global diet should be reached. While present global food system contributes significantly to climate change; environmental friendly, nutritionally balanced and sustainably produced diet present considerable chance to deal with climate change. Despite the difference in the reasons behind, both developed and developing countries are facing many challenges to call for sustainable and climate smart diet. The high prevalence and persistence malnutrition in developing countries, as well as the high foot-print of the diet in developed countries complicate the call for paradigm shift to sustainable and environmental smart diet. This chapter is messaging several strategies including the development of climate friendly food behavior, dietary modification marked with reduction in food waste and loss, as well as aligning dietary awareness with climate challenges. Through different pathways, this work highlights how global diets further exacerbates the already-huge problem of climate change and suggests orientations for sustainable dietary system aligned with diet footprint analysis.

1 Introduction

The global food production activities are considered among the major contributors to climate changes as well as impacting human health. It is repeatedly reported that food production activities are generating up to 30% of global emissions that impact global warming (Bajzelj et al. 2014; Bryngelsson et al. 2016; Hedenus et al. 2014). Livestock productions alone contribute around half of those emissions. Moreover, producing food contributes significantly to the loss of biodiversity, deforestation, water depletion and pollution, and interrupting global nitrogen and phosphorus cycles, as well

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_11

as land use change. Consequently, food system and environment are currently threatening each other where, environmental system is impacted by food production and the prevailing food production activities are negatively affecting the environment.

The current food production systems succeeded in securing adequate calories intake whereas, micronutrients deficiencies is still persisting. Millions of people, according to spatial distribution, are consuming low quality diets causing undesired health outcomes. This is reflected in the substantial rise in the incidence of chronic diseases e.g. diabetes, cardiovascular disease, obesity and stroke. If the current dietary pattern remained unchanged, human diet will continue to negatively impact climate situation. Nurturing the growing global population without harming the environment, calls for a paradigm shift in the food system. As about 60% of total global arable land is uncultivated and possessed by Africa; high potential for crafting carefully tangible change in food system seems valid (McKinsey Global Institute 2010).

Despite many reports are supporting the guidance of reducing animal-based consumption to avert the current trend in global warming, there are no magic solution to solve all climate crises associated with dietary shift (Bajzelj et al. 2014; Bryngelsson et al. 2016; Hedenus et al. 2014). The food system is already complex and the production of GHGs is stretched through the whole food chain. Meanwhile, dietary pattern is also sophisticated and composed of various food chains. In addition, we lose or waste significant share of food products during the journey from farm to fork. Stopping this drain could drive down agricultural emissions.

Strong evidence with consensus indicated the co-benefits of climate change mitigating through changing dietary behavior and economics of health care. Adopting environmentally smart healthy diets have the potential to save food system and diet related diseases. These economic benefits can be expanded even further by restructuring healthcare system and employing preventive approach as well as fostering responsible eating pattern. Assisting people to change their diet to less carbon-intensive food to mitigate climate change require a set of climate-smart principles working in an orchestrated manner. Question like to what extent people's diets need to change within the already sophisticated food system could be answered from different angles and magnitudes either individually and/or globally.

Evidences are supporting with the significant link between animal-based food consumption mainly grain-fed ones and the emission of heat trapping gases The IPCC report (2014b) stated with high confidence that plant based diet balanced with moderate amount of sustainably produced animal food; represent the golden balance between climate mitigation and human health. According to the FAO (2018a) projection to 2050 of food and agriculture, adopting climate friendly diet and cutting down 15% of animal products consumption in high income countries would have dual impact on climate and health. The trend for increasing agro-production to contain the increase in population and its pressure on land, water and emissions would be reversed. Building forth on that, rebalancing the diet in developing countries and increasing the intake of animal-sourced food would enhance the nutrition situation (FAO 2018a). This chapter fuels the efforts to better understanding of the dietary shift towards plant-based diets and discuss behaviors change opportunities including barriers and motivators.

2 Food Consumption Trend Analysis: Health and Climate Impact

Several studies connected high intake of food from animal sources and the implications of climate crises (Stoll-Kleemann and O'Riordan 2015a; Beverland 2014; Cordts et al. 2014; Sabaté and Soret 2014). Literatures point that commercial livestock production and its feed processing emissions account for 14.5% and exceed that of whole transport sector (Steinfeld 2006; Gerber et al. 2013). Heat trapping gases caused by livestock production are mainly generated from enteric as well as manure fermentation (Smith et al. 2014). Additional GHGs are generated from land and energy use as well as transportation (FAO 2014a).

Beef showed the highest direct i.e. husbandry and indirect i.e. feed production environmental impacts followed by pig and poultry due to variations in feed conversion factor. On the other side, livestock productions are susceptible to climate change mainly via increasing temperature that affects water availability, animal production and animal health. Rise in temperature and CO2 affect also pasture quality and quantity. It is projected that global animal based food consumption will continue to rise (Gerber et al. 2013; PBL 2011). Accordingly, GHGs from agriculture will likely exceed the 2050 targets.

In comparison, fruits and vegetables production generates significantly the lowest level of GHGs. Moreover, fruits and vegetables are important for attaining dietary diversity and healthy diet which in turn could improve climate resilience. At the same time, fruits and vegetables are susceptible to climate change specially in tropical and semi-tropical climate i.e. declines in yields, decline in overall product quality, and increasing the amount of wasted or lost food.

2.1 Animal-Sourced Food Consumption

The consumption of animal-sourced food in developed countries is higher than recommended in WHO guidelines (WHO 2003). For instance, the consumption within EU countries is double than the World Cancer Research recommendation. Consequently, measures to combat the emissions associated with high consumption are requested. Meanwhile, animal-sourced food intake in many developing countries is lower than recommended leading to high prevalence of malnutrition. To curb GHG emissions globally, paradigm shift in human diet including inter ilia empowering behavior change is deemed necessary.

Shift to plant-based diets are necessary to attain climate change mitigation target. For instance, halving the consumption of animal foods in EU countries would have 25–40% reductions of heat trapping gas emissions (Westhoek et al. 2014). Also even slight decrease in per-capita animal foods consumption of ca. 1.5 billion Chinese consumer's would have significant difference in cutting down the emissions (Westhoek et al. 2014).

Consumers in those countries will be addressed to cut down the intake of animal-sourced food to compensate the associated GHG emissions. Sustainable livestock productions, consumption of more plant foods, decreasing portion size, are strategies that can be addressed to consumers taking into consideration their own preference. (de Boer et al. 2014).

From communal point of view there are active debate between pro and contra cutting down meat consumption as an effective approach to mitigate climate change. This debate deals with three main pillars i.e. environmental, nutritional as well as ethical aspects. In general livestock production requires more inputs i.e. land, energy and water and generate significant amount of gas trapping emissions. Meat eating supporters argues that livestock production use marginal pasture land, contribute to agriculture productivity through manure production and secure livelihood for millions of people in rural area.

From nutritional perspective, animal sourced food is vital sources of macro and micro-nutrients in the diet. Globally, it provides about one third of protein, one fifth of energy, main source of vitamin B12 and rich in iron and calcium (leMouël et al. 2018). Activists who support plant-based diet argue that there are several health benefits to a vegan/vegetarian diet. People who depend on plant-based diets enjoy longer life expectancies.

Considerations regarding ethical arguments made by meat eating supporters based on the consumption of ethically produced animal-sourced diet. For example, consuming free range animals fed forages free of pesticide and locally sourced are considered ethical and have a lower carbon foot print compared with intensive farmed animals. Vegetarian activists claim that plants provide essential nutrients humans need and consuming animal-sourced foods are unnecessary. They argue further that the right of the animal is an extension of human right referring to the Cambridge Declaration on Consciousness (Low 2012).

2.2 Nutrition Transition: Unfavorable Dietary Impact

Since the fifteenth of the last century, developed countries experienced marked changes in food production and consumption. This is mainly due to growing population, agricultural policies, economic development, technological advancement including bioenergy, and supply chain transformations. By the time most of the developing countries experienced similar rapid changes led to unfavorable dietary shift i.e.

"nutrition transition". Consumption of nutritionally unbalanced diet is directly linked to increased incidence of non-communicable diseases NCDs (WHO 2014; Popkin et al. 2012). Moreover, increased animal sourced-food production and consumption contributes also to land-use change.

Nutrition transition refers to worldwide dietary change converge towards diet rich in calories and animal-sourced foods and low in vegetables termed the 'Western diet'. This diet is low in vegetables and rich in refined carbohydrate, sugar, fat and animal products (Popkin et al. 2012). This dietary change was accompanied by shift to more sedentary life style and low calories expenditure. This phenomenon was first seen in the industrialized countries then diffused to medium and low-income countries due to significant improvements in food availability (leMouël et al. 2018). Marked changes in the epidemiological profiles become evident and were coupled with rapid dietary shift from urban to rural area (Mendez and Popkin 2004).

The worldwide diffusion of this dietary pattern resulted in substantial rise in obesity and diet-related chronic diseases. Developing countries accommodate about two third of diet related type2 diabetes. Hu (2011) reported strong rise in the incidence of diabetes, from less than 1 to 10% in only about three decades, as diets changed in China. This unfavorable dietary shift added more pressure on natural resources as well as more metric tons of carbon dioxide emissions (Bowles et al. 2019; NRDC 2017). Dietary change from traditional diets to western diets and the coexistence of 'double burden' i.e. over and under nutrition was the outcome of this shift. Dietary balance and behavior change are therefore effective contributors to reducing the environmental burden.

3 Diet: Healthy Versus Climate-Smart

Diet has crucial impact on both the environment and human health. Better understanding of its composition is essential to assess which dietary pattern practices will help achieve food-related SDG goals, the Decade of Action on Nutrition and commitments under the Paris Agreement. The recent reviews on the potential of climate mitigation of different diets pointed that the disparities in the dietary composition of the examined diets rely mainly on the type and amount of dietary protein (De Vries and de Boer 2010; Nijdam et al. 2012; Eshel and Martin 2006; Marlow et al. 2009; Stehfest et al. 2009; Popp et al. 2010; Westhoek et al. 2014). These include (a) vegan: no animal-sourced food; (b) vegetarian: low in meat and seafood i.e. one serving per month; (c) flexitarian: low in meat and dairy; (d) pescetarian: consisting of seafood; (e) Mediterranean: moderate meat but high in vegetables; (f) healthy diet: limited sugar, meat and dairy; (g) credible low meat diet: animal source food compensated by pulses.

The environmental impact of each type is highly diet-dependent and different scenarios of the environmental mitigation potential of each were estimated (Smith et al. 2013). For instance, the potential mitigation by 2050 for 'pescetarian', 'Mediterranean', 'vegetarian' diets is estimated to be 1.2–2.3 GtCO2-eq/yr. This range of the potential mitigation of flexitrarian diet is computed to be doubled reaching 3.4–5.2 GtCO2-eq/yr by 2050.

With a world population that will reach 9 billion in 2050, rebalancing diet would help in reducing the footprint of the food system. Where, diet that has similar nutrition quality and similar health impact might have different GHG emission (De Vries and de Boer 2010; Nijdam et al. 2012; Eshel and Martin 2006; Marlow et al. 2009; Stehfest et al. 2009; Popp et al. 2010; Westhoek et al. 2014). About one third of the calculated annual per capita GHGs reduction of the global diet projected for 2050 (GD2050) is achievable if global diets are changed (De Vries and de Boer 2010, Steinfeld et al. 2006). This GHG reduction of the vegetarian, pescetarian and Mediterranean would be below those of GD2050 and reaching 55, 45 and 30% respectively. In other words, if by 2050 diets changed to the three typical omnivore's diets, the projected 80% net rise in global emission from food production and transportation would be averted.

3.1 Transitional and Traditional Diets: Environmental Impact

In general the key features of the termed traditional diets represent moderate eating of animal foods in favor of vegetable, like legumes. These diets are often rich in protective food components and low in salty, fatty and ultra-processed foods, as well as sweetened beverages (Delisle 2010). This consumption pattern will lead to positive environmental impact and linked with better health conditions (Marventano et al. 2017). The EAT-lancet report (2019) pointed with high confidence an optional sustainable plant- based diet rich in vegetables and fruits and whole grains coupled with moderate dairy and eggs consumption (Willett et al. 2019).

In many country-specific contexts, modeling studies revealed that up to 50% reduction of heat trapping gas could be reached by adopting the termed "healthy country specific diet" and proved effective in climate mitigation (Ferrari et al. 2020; Garnett et al. 2008). The promotion of locally produced and distributed food as well as preserving traditional culinary, when adopted will consequently contribute to the mitigation of climate change (Clonan and Holdsworth 2012). In addition, investing in indigenous local knowledge as well as endogenous food technologies and practices can assist in developing climate resilient.

3.2 Locally Produced Food

As agreed dietary pattern is considered sustainable when it fulfill the nutritional as well as environmental requirements. This definition did not explicitly point to the potentially positive impact of locally produced foods. The literature however, is repeatedly stated that adopting locally produced healthy diet could assist in curbing climate change (Michalský and Hooda 2015; Audsley et al. 2010). When workers and peasants migrate to cities, they gradually abandon the consumption of typical rural diets rich in cereals, grains and fibers and converge to diets rich in processed food (Dixon et al. 2007). This is largely due to advertising and mass media as well as access to large supermarket chains.

Little focus is accorded to gases emissions from food processing and transporting activities throughout the whole value chain. Taking into account the globalization of agriculture and increased value added processing as well as long distance transport will aggravate its climate impact. (Mottet et al. 2017a). Locally produced foods can reduce loss by shortening supply chain and minimizing transportation emissions (Michalský and Hooda 2015). This will in turn save considerable emissions as well as improve food security situation. Raising the efficiency of the transportation system can reduce substantial transports' emissions even further. (Newman et al. 2013).

4 Food Choice and Human Behavior

Most literature has focused on climate adaptation and/or mitigation of the food system from the supply side i.e. food production as well as food storage, transport, processing, and trade. (Zimmermann et al. 2017; Bodin et al. 2016; Bond et al. 2017; Swinburn et al. 2019). Whereas, initiatives on demand side adaptation measures of the food system i.e. consumption pattern, dietary practices, and minimizing food loss and waste that can lead to positive outcomes is limited. Eating habits has dual effect on both environment and human health. Current dietary pattern are causing globally deleterious effect in GHG emissions and increasing the incidence of non-communicable disease. Shifting to win–win diets i.e. healthy and environmental smart would reverse current trends.

So our choices of food can lend resilience to the global food system or can drive down the already fragile nutritional situation. Food taste, and convenience, culture, nutritional knowledge, food availability and price, are influencing individual dietary choices and should be considered if dietary changes are targeted. Encouraging sustainable food choices have varying degree of success. For instance, fruits and vegetables consumption campaign i.e. "5-a-day" were publicly known, but have not resulted in significant change in the consumption pattern (Wood and Neal 2009). Thus encouraging people to adopt environmentally sustainable food choice require better understanding of the human behavior. Food cost, taste, convenience and food preference can serve as barrier or motivators for shifting to the consumption of healthy-balanced and pro-environment diets.

According to the dual-process human behavior theories of (Evans 2008), the behavior is divided into two distinguish mechanism in decision taking i.e. slow and fast. This theory further elucidate the difference between slow and fast decision making where the slow is deliberative, conscious and need cognitive effort (Petty and

Cacioppo 1986), and the fast is automatic, unconscious and rely on cues and heuristics (Kahneman 2011). Considering human behavior mechanism to steer people to engage in specific behavior and reach attainable and acceptable change is essential. Comprehensive understanding of the motives as well as barriers of shifting towards sustainable food consumption pattern is considered leapfrog in the right direction.

4.1 Pro-Environmental Behavior Change

The assessment and execution of dietary solutions present an opportunity to address the interlinked diet-environment-health multiple challenges. Nutrition transitions reflected the occurrence of changes in relatively short period and proved the potential of inducing favorable dietary changes (Smith et al. 2013). Also dietary change when acceptable and attainable would be a significant economic intervention with broad effect on climate changes. Favorable dietary changes toward healthy and environmental friendly diets require carefully crafted intervention to steer people to engage in specific behavior. Also pro-environmental dietary changes require changing food choice structure as well.

Although several researches points to the associations between the reduction of animal-sourced food consumption and climate change, many people either do not realize this connection or perceive it less important (Cordts et al. 2014; Whitmarsh et al. 2011; Bailey et al. 2014). This reflects the complex nature of human behaviors and includes diversity of intrinsic and extrinsic factors. This ISM model depicts how Individual behavior is shaped by Social context and restricted by Material available to enable favorable behavior change (Darnton and Horne 2013). In this section motivation/drivers, willingness and barriers will be detailed in order to pave the road for sustainable food consumption pattern.

4.2 Motivations

Interventions to influence the change of consumer behavior toward environmentally sustainable food choices are many include- inter alia- information provision, food labels, visual prompts, nudging, and social norms.

- Information provision: including mass media information campaigns, social media, dietary guidelines e.g. food pyramid guide as well as my plate (Nestle 2013). These interventions rely on making information available to consumers to assist in knowledge-based decision making processes (Carfora 2019). Introducing visual prompt e.g. stickers, posters, signs, flyers help in reminding people to engage in certain behavior (Abrahamse and Matthies 2018). In addition social norms are considered as part of information provision and proved to influence behavior choices (Sparkman and Walton 2017. For example (Stöckli et al. 2018) reported that using message informing "many restaurant's guests are asking to wrap the leftover", resulted in more guests asking for takeaway boxes.

- Food label: considered form of information provision in terms of highlighting the connection between food choices and climate crises (de Boer et al. 2016). Eco-labels as well as carbon labels are examples of making consumer aware of the impact of their food choices on environment (Elofsson et al. 2016). Several researchers reported that food labels proved modest but effective impact on food choices (Brunner et al. 2018; Visschers and Siegrist 2015).
- Nudging: nudges drive people to preferred behavior by altering the choice circumstances. It involve altering something small but significant to promote people to choose with an eye on environmental impact. For instances, making vegetarian item more visible in the menu showed a small but significant sales increase (Campbell-Arvai 2014); highlighting the vegetarian items on the menu influence student's meal choices in a university cafeteria setting, and changing portion size was associated with increase in sale of vegetarian dishes (Garnett et al. 2019). Nudges is one of the promising interventions strategies to steer people to adopt environmentally responsible behavior.

The literature points to the disparities of the effectiveness between nudging and food label interventions. Potentially, nudging encourage sustainable food choices (Zhou et al. 2019), where food labels influence people choice as part of comprehensive information provision campaign connecting food and climate challenge (Vanclay et al. 2011). Irrespective of a nudge, combinations of different types of intervention proved to be more effective in consumer behavior changing toward environmental smart food choice (Visschers and Siegrist 2015; Campbell-Arvai 2014).

Although there are growing evidence of the effectiveness of interventions to encourage environmentally sustainable food choices, more comparative research is needed to explore the effect of food environments e.g. at home, in restaurants, or in supermarket, or in mass catering etc.. Of importance also is to better understand the role of social and cultural dimensions and how they are connected to food choices.

4.3 Drivers

Dietary changes are not happening in vacuum and are triggered by many drivers, i.e. consumer's eating style and/or habits including consumers food choice, snaking pattern and quality, home versus street food consumption; food environment including mass media, food globalization and trade agreements; socio-economic and cultural aspects. Among the proposed economic incentives polices to drive people to eat less animal-sourced foods is to impose taxation conditioned by removing subsidies for mass livestock production (Popp et al. 2010). Another approach is to financially support certain policies e.g. subsidies plant based diet and make it more attractive to consumers (NEIC 2009). The harmonization as well as inter-linkage between governmental and NGOs efforts would assist in integrating expertise and resources to engage people in cutting down animal-sourced foods consumption.

4.4 Willingness

The willingness of all stakeholders in the food industry would contribute and support climate mitigation and adaptation. Some researches reflect obvious sympathy of consumer to serve environmental issues (Dagevos and Voordouw 2013). For instance, although the majority of American are not vegetarians, a nationally representative survey shows the willingness to cut down meat consumption and compensate it with more plant foods to contribute to climate mitigation (Leiserowitz et al. 2020). Newly emerging trend i.e. visiting farmers market and buying directly from local food producers, mirror significant consumer willingness and product use (Kerton and Sinclair 2010). In order to exploit this willingness, dealing with information dispersal, offering sensory appeal, and according more emphasis on human and nutrition benefits deem necessary (Tucker et al. 2018). Carefully crafted communication changing behavior interventions to foster healthier dietary habits that respect environment is also suggested (Pascucci et al. 2011)

The pressures that can be exerted by conscious consumer on food industry sector resemble high priority to attain environmental sustainability throughout the food chain. Consumers of high income countries bear heavily the responsibility for adopting plant-based diets. For middle- and low-income countries, calling for cutting down meat consumption contradict with the need to consume more animal foods to overcome the prevailing malnutrition (Development Initiatives 2018). Targeted governmental as well as NGOs policies and programs interlinking diet, environment and public health should be tailored to climate challenges. As climate mitigation and adaptation is shared responsibility, including local communities in partnership with farmers, businesses, producers, consumers, and policymakers is conducive for behavior change.

4.5 Barriers

Among the barriers to engage in environmental friendly behavior are: inadequate information or limited access to it; lack of trust of the available information; overlap of priorities; inhibition by others; physical and structural obstacles; as well as social norms and values (Lorenzoni et al. 2007; Whitmarsh et al. 2011). In addition, the principles of dietary recommendations directed to public are rarely consider the potential environmental impact. Comparing worldwide average diet with high income countries, the national dietary guidelines have to balance between dietary intake and the pressing need to reduce GHGE. Meanwhile, in middle- and low income nations, and because of the persistence malnutrition, dietary intake of high footprint foods will likely need to be increased. Consequently, it is of importance for public health sector to carefully incorporate climate dimension while crafting dietary recommendations (Willett et al. 2019).

5 Food Waste and Loss

Food waste refers to food rejected by consumer and food discarded during value chain including food wasted during production, postharvest as well as processing (FAO 2011b). Reduction of both food waste and loss to mitigate gas emissions, have been the subject of several reviews (FAO 2015; Gustavsson et al. 2011; FAO 2019b). Globally, about one third of total food production is wasted and/or lost which contributed to about 10% heat trapping gases (FAO 2014b; Birney et al. 2017).

Food waste and loss differ ultimately between developing and developed countries. Substantial volume of food is lost in developing countries because of -inter alia- poor logistics, cold chain, packaging and infrastructures, whereas in developed countries produced food is wasted by consumer (IPPC 2013). With a world population that will reach 9 billion in 2050, robust interventions to reduce food wastes and curb food system emissions could assist climate resilient development. Accordingly, at global scale more focus on technical as well as non-technical interventions to avert environmental burden is required.

5.1 Technical Interventions

The implementation of novel technologies through the whole value chain "farm to fork" can perform crucial role in reducing food loss/waste. For instances, post-harvest reduction technologies, improved food handling, enhanced storages and transportations facilities, and innovative packaging solutions would save significant amount of wasted and lost food throughout the whole food value chain.

5.2 Non-Technical Interventions

A wide range of interventions to changes in behaviors and attitudes of different stakeholders throughout the food supply chain to reduce food loss and waste exist (Lipinski et al. 2013). Information provision pertaining to best practices of post-harvest reduction technologies and raising awareness as well as adopting responsible behavior and attitude to minimize environmental burden can be deployed. However, technical solutions usually include additional cost, non-technical solutions i.e. behavior change is cost effective and economically feasible (Whitmarsh et al 2011).

With respect to inevitable food waste and/or loss various strategies were proposed e.g. using food waste as feed for livestock (Vandermeersch et al. 2014) or directing it to bioenergy production (Pham et al. 2015). In addition, the surplus of edible and wholesome foods can be redistributed among those suffering from food poverty and food insecurity (Vandermeersch et al. 2014).

6 Concluding Remarks

Aside from general principles, such as cutting animal-based food consumption parallel with reduction in food loss and waste, and a dietary change toward plant-based, less carbon-intensive food, could drive down agricultural emissions. In light of climate crises, adopting climate-friendly food behavior is an important action toward mitigate GHG dilemma. Dietary shift is considered a cost effective food venue to curb climate change from the demand side. Diet related adaptation interventions might outweigh the implications of the current food choice i.e. nutritionally poor affordable and empty calories foods. This should be taken with care to avoid any un-destined consequences or progressing in one side at the cost of others.

Several, agro-economic as well as environmental models, were computed to reply to the overarching question on how dietary shift impact climate changes. Hypothetically and scientific targeted "healthy reference diet" is rich in fruits and vegetable, whole grain, legumes, nuts, unsaturated fat; moderate in chicken and fish and low in livestock meat, refined intensively processed foods. The computed average intake globally of this diet is considerably lower than the status quo. By adopting “healthy reference diet” from food produced sustainably, up to 10 billion people can be fed. According to this computed, assumed model ‘healthy reference diet’ reduction of animal-sourced diet, would substantially lessen environmental pressure. Noteworthy, these results should be viewed as signs, not as prognosis. Because one of the limitations of this model is lacking of the policy responses despite feedbacks in consumption and production are considered.

The information presented in this chapter should be viewed in light of some limitations. There are inadequate comparative investigations of certain determinants of pro-environmental behavior between developed and developing countries’ consumers. The literature on behavior changing initiatives is to great extent colored by views from developed countries while the perspective of developing countries is fade. There are also limited coverage of the differences of specific barriers and/or motivators of behavior modulation in developed and developing countries. Worth mentioning also is the fact that this chapter draws on a substantive body of research lacking to some extent detailed data needed for rigorous scientific analyses. Also, many researches were conducted in certain setting and among specific groups, which make extrapolating these results to other settings and situations is limited.

6.1 Future Research Perspectives

The rich and varied body of scientific evidences on the connection between dietary pattern and environmental sustainability was not effective enough to generate proper consumer willingness as well as policy interest in addressing meat consumption. Meaningful policies and initiatives to combat the ecological consequances raised by current meat-eating patterns is almost dearth. From research point of view, more comparative and exploratory evidence-based research for effective interventions is required. Filling the research gab including the identification of important data needs on the effects of luxury, masculinity symbol associated with meat eating, social norms as well as political perspectives and their relationships to each other is essential. Better understanding of such factors while developing behavior changing communication interventions is of utmost importance to pave the road for responsible consumption pattern. In addition, conducting qualitative methods to gather psychosocial and biophysical rich data is required to better understand how to trigger certain behavior throughout the whole supply chain.

It is also suggested to assess the impact and implications of the five key behavior theories and to study how to make it more effective in inducing actions by consumers. It is required to revisit those hypotheses to establish robust knowledge triggering environmentally responsible behaviors. Existing works from developing countries on behavior changes communications is generally limited and more detailed and comprehensive researches in this context are required. Certain barriers and/or motivators differ between developed and developing countries. More rigorous research addressing and dealing with such differences are in need. Comprehensive research work is required to foster incorporating local knowledge and indigenous knowledge in climate mitigation policies including carefully crafted interventions behavior change. As the majority of researches measured immediate as well as near term effects of past behavior, attitude, beliefs and value, more long-term studies could be extended to assess the stability of behavior changes. This would help better understand how to induce and sustain environmental favorable behavior changes.

6.2 Key Messages

- Food productions activities generate considerable amounts of heat trapping gases from farm to fork. This include also storage, packaging and transportation;
- This environmental burden varies greatly between plant and animal sourced foods where meat and dairy production emits more GHGs compared with growing field crops;
- Intensive, industrial livestock production systems, exert substantial environmental pressure because of the enteric fermentation and large amount of methane emission;

- Rebalancing diet and fostering moderate meat consumption via scale, acceptable and attainable consumer behavior change would save livestock production with its climate implications;
- Designing and implementing carefully crafted consumer dietary behavior change interventions can assist climate resilient development. Adopt incremental and simple changes in the choice architecture rather than involving radical behavior change interventions;
- Fostering the consumption of locally and efficiently produced food would provide additional windows of opportunity to mitigate climate change;
- Including food waste/loss consumers' behavior changes interventions of consumers at scale, would save food system emissions;
- Adopting inclusive strategies where all stakeholders are involved could improve the impact of certain interventions. For instance, mobilizing the knowledge on 'healthy' diets, in general, are 'more sustainable' as well would convince environmentally concerned consumers. Another selling point for food retailers is the proposition of offering high standard alternatives to animal-sourced foods;
- In addition, fostering the collaboration between farmers and food suppliers to adopt agriculture best practices and develop climate friendly labels would save considerable amount of emissions;
- In a nutshell, opportunities are there to change the diet of people to be healthier and more sustainable when further steps are taken.

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Integrating Remotely Sensed Soil Moisture in Assessing the Effects of Climate Change on Food Production: A Review of Applications in Crop Production in Africa

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Abstract Remotely sensed soil moisture is crucial in enhancing our understanding of how climate change influences food production. Conventionally, the acquisition of soil moisture data has always been based on in-situ measurements, which are costly, labour-intensive, spatially restricted and time-consuming to acquire. These limitations justify why most resource-constrained developing countries have been paying increasing attention to remote sensing. Although remote sensing has established potentials to address these challenges, progress in the application of this technology to crop production in Africa has not been properly documented. This chapter attempts to bridge this gap by providing a comprehensive review of the progress that has been accomplished to date and the gaps that need to be filled in and, successes and opportunities that have to strengthened and exploited.

1 Introduction

Soil moisture is a crucial link between rainfall and crop growth (Filion et al. 2016) and an essential climate variable that affects terrestrial, atmospheric water and global energy fluxes (Tuttle and Salvucci 2016). Although soil moisture is important for food production (Piao et al. 2010), research continues to sideline the formulation of techniques that can be used to cost-effectively provide information on this variable. This drawback undermines the timely implementation of informed interventions to rainfall failures and drought at critical stages of crop growth (NASA 2015). Rainfall failures and drought are becoming more frequent as climate change shifts weather conditions outside normal thresholds (Walz et al. 2020) with sub-Saharan Africa

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_12

prominently featuring as one the world's regions worst affected by climate change (Nhamo et al. 2019).

Although recent research suggests that climate change will open up the world's cold regions for agriculture on a hotter planet (Zabel et al. 2014), this benefit will be reversed in the long-term by increased atmospheric CO_2 concentrations from the liberation of soil organic carbon in these areas (Win 2020). For southern Africa, increased warming is projected to result in increased aridity and substantial decrease in portable water resources (Fauchereau et al. 2003).

Farmers in areas that are projected to experience rainfall failures will be adversely affected by increasing soil moisture deficits. Although these farmers may try to adapt by shifting from food crops to livestock farming (Etwire 2020), this adjustment will be undermined by global warming from increased release of methane. To avoid this rebound, researchers need to explore innovative water-use efficiency techniques and better ways of providing reliable soil moisture information (SMI).

Although the literature provides wide-ranging empirical and ground-based techniques to measure soil moisture (Walker et al. 2004), these methods are expensive, time-consuming, labour-intensive, spatially restricted and incapable of providing adequate SMI to poor farmers in developing countries (Wang et al. 2016). Fortunately, remote sensing (RS) is able to cost-effectively provide SMI (Mohanty et al. 2017) at appropriate temporal and spatial scales (Zhang and Zhou 2016). Although the scope to exploit RS is increasing as more datasets and processing techniques are becoming available (Peng et al. 2017), the extent to which it has been used to provide SMI has not been adequately investigated. This limitation is demonstrated by emphasis on studies that do not address operational farm-level requirements (Ahmed et al. 2011; Srivastava 2017).

This chapter attempts to shed light on how much RS has contributed to the provisioning of farm-level SMI in Africa. This is done by (a) appraising the utility of RS in estimating farm-level soil moisture (SM), (b) assessing the major RS sensors commonly used to estimate SM and, (c) positioning the assessment in a context that is purposefully designed to identify gaps that need to be filled in and, successes and opportunities that have to strengthened and exploited.

1.1 Importance of Remotely Sensed Soil Moisture and Its Implications for Farmer Preparedness to Climate Variability

RS techniques are crucial for crop production because they can cost-effectively provide the SMI (Lei et al. 2020) required for sustainable food production (Hertel and Baldos 2016). This can be accomplished by increasing the production efficiency of smallholder farmers whose livelihoods are largely dependent on rain-fed crop production. The same applies for commercial farmers whose production efficiency has been pushed to limits by rising production costs and the effects of climate change (Lobell et al. 2020). Agriculture can adapt to these challenges by embracing climate-friendly crop production techniques.

This adaptation requires spatially optimised farm-level SMI to support agriculture by guiding the adoption of appropriate crop production and water use management techniques (Zhang et al. 2016). Although remote sensing can address these challenges (McColl et al. 2017), farmers continue to be undermined by lack of adequate SMI (Brocca et al. 2017). This limitation justifies why available RS data need to be fully exploited in order to complement the limited information provided by conventional in-situ measurements (Mohanty et al. 2017; Petropoulos et al. 2015).

1.2 Seasonal and Long-Term Monitoring of Soil Moisture for Improving Farmers' Preparedness to Climate Variability

Soil moisture is spatially and temporally variable because of localized differences in topography, precipitation, humidity, temperature and vegetation cover (Suepa et al. 2016). Topography determines SM by interacting with energy fluxes from the sun through reflection and scattering (Ahmed et al. 2011). Precipitation and humidity regulate SM by controlling the amount of soil water available for plant growth (Wang et al. 2019). Temperature and vegetation exert influence by mediating evapotranspiration and infiltration (Seneviratne et al. 2010). Because the variable influence of these factors in arid and semi-arid areas tends to be associated with soil water deficiencies (Shang et al. 2016), SM deficits tend to be amplified by wide-ranging externalities that include anthropogenic withdrawals of ground water, diversion and impoundment of surface water flows (Suepa et al. 2016), and removal of vegetation (Karlsen et al. 2008). Since SM is a critical determinant of crop yield, there is need for spatially comprehensible information that can be used to guide on-farm decision making by farmers. This information is particularly crucial for early-warning in drought-prone areas under the aegis of unpredictable weather extremes (Escobar et al. 2016).

Comprehensive compilation of SMI is also necessary for improved understanding of climate patterns (Mearns et al. 1997). This understanding requires information on "*essential climate variables*" (Hollmann et al. 2013) and improvement of the prediction skills of existing models by using robust methods exampled by those provided by European Space Agency's Climate Change Initiative for Soil Moisture ((ESA-CCI-SM), Plummer et al. 2017; Gruber et al. 2019)). These initiatives provide compelling evidence of the importance of long-term observations in enhancing our understanding of how climate change influences spatial and temporal variations in SM (Nicolai-Shaw et al. 2016).

Long-term observations are also important for timely prediction of changes in SM i.e. the likely onset of prolonged droughts (Xu et al. 2018) and timely formulation of informed responses (Morrow et al. 2016). Although seasonal farm-level SMI is crucial for farmers, RS of SM has tended to focus on providing coarse resolution (c-res) inter-annual estimates (McNally et al. 2016; Jung et al. 2019) that are of little value for rain-fed crop production. Although some researchers i.e. Sawada and Koike (2016) have attempted to determine farm-level variations in SM, there is little application of the different methods provided by most researchers.

1.3 Effects of Soil Type and Soil Cover on RS-Based SM Estimation

The accuracy of RS-based SM estimates is influenced by soil type because different soils exhibit different absorption and reflection characteristics. Differences in colour and surface roughness for example, influence the way soils absorb and scatter incoming radiation before the remaining proportion goes back to the sensor (Lakhankar et al. 2009). Dark soils reflect less radiation than bright soils and the same applies for rough areas that exhibit more scattering compared to smooth-surfaced soils. Likewise, vegetation has similar influences, as height variations and uneven plant distributions cause differences in surface roughness (Ahmed et al. 2011). Where the land comprises a mix of bare soil and vegetation, spectral mixing can pose problems by corrupting signatures before they reach the sensor (Zhang et al. 2018). Because variations in land cover types influence variations in SM, not all RS systems are ideally capable of providing datasets that can be used for accurate estimation of SM in heterogeneous environments (Brocca et al. 2011). These limitations require researchers to explore algorithms that can be used to fully exploit the usefulness of multi-resolution datasets.

1.4 The Role of Major RS Systems in SM Estimation

Soil moisture can be retrieved at large spatial scales by using microwave RS and the visible and infrared (IR) bands (Srivastava et al. 2016) in lieu of the problematic ground-based SM measurement techniques (Myeni et al. 2019). Different RS platforms with diverse image acquisition features provide useful SM estimation opportunities/capabilities. In more recent years, simultaneous use of synthetic aperture radar (SAR), combined active–passive (CAP) and passive radiometer (RAD) microwave RS observations has been gaining a lot of interest (Liu et al. 2011). The availability of freely-accessible c-res and medium resolution (m-res) datasets that provide large geographic coverages at high temporal resolutions (Roy et al. 2017; Babaeian et al. 2018) has also facilitated SM monitoring (Periasamy and Shanmugam 2017).

This is demonstrated by broadband multispectral Landsat-type sensors which have played a leading role in providing the RS data used to pioneer the development of SM algorithms (Alexandridis et al. 2013). Although the recent failure of Landsat's Scan Line Corrector (SLC) is a downside, Landsat's free and open data policy shows that m-res sensors will remain the mainstay of SM monitoring in developing countries because other freely accessible datasets are too coarse and expensive for farm-level characterisations (Table 1).

Nevertheless, hyperspectral sensors enable detailed investigation of vegetation properties that are crucial for SM estimation (Im and Jensen 2008). These versatile sensors include the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) and Hyperion sensors. Newer generation sensors i.e. Landsat 8, Sentinel-2 (MSI), Worldview 2, ASTER and RapidEye (Finn et al. 2011; Wang et al. 2011; Sadeghi et al. 2017; Siegfried et al. 2019) now offer better SM estimation capabilities compared to MODIS and other c-res sensors (Dash and Ogutu 2016). The unique capabilities of hyperspectral sensors explains their recognised outperformance of the freely-accessible broadband multispectral sensors (BBMSs) which, have been the primary sources of SM data (Bao et al. 2018). BBMSs are constrained by the fact that they provide c-res data with high overlaps in soil cover, which, are incapable of providing fine-scale products required by most smallholder farmers. These limitations explain why there is urgent need to explore the usefulness of high resolution (h-res) hyperspectral datasets (Finn et al. 2011).

2 Bibliometric Assessment of Publications on RS of SM in Africa

2.1 Literature Search

The literature search included peer-reviewed original research articles published between 1999 and 2019. This period was chosen because it was judged to be long enough for representative assessment of the extent to which RS data have been used to provide SMI in Africa. This periodization was used to identify relevant articles by:

(a) Conducting targeted searches in the Web of Science database that focused on peer- reviewed articles in accredited journals and,
(b) Segregating the datasets into c-res and h-res images.

This screening was designed to identify research articles that focused on RS estimation of SM in Africa based on the following search criteria:

(a) Search title: *soil moisture Africa*
(b) Sub search titles:

- *remote sensing of soil moisture Africa*
- *satellite soil moisture Africa*
- *soil moisture remote sensing Africa.*

This was followed by an abstract search of the above-listed keywords and perusal of the conclusions to determine each paper's focus based on whether it covered the

Table 1 Characteristics of selected sensors that provide data suitable for SM estimation

Sensor/platform	Temporal coverage	Pixel size	Radiometric resolution	Number of bands	Revisit time (days)	Scale	Ref
[f] *Landsat-TM5	1984–present	30 m	8 bits	7	16	i	a
[f] *Landsat-ETM	1999–present	30 m	8 bits	7	16	i	a
[f] *Landsat 8	2013–present	30 m. 15 m (Pan)	8 bits	9	16	i	a
[f] *MODIS	1999–present	250 m, 500 m, 1000 m	12 bits	7	1	j	a
[f] *NOAA AVHRR	1999	1100 m	10 bits	5	1	j	a
[f] *SPOT	2002	2.5 or 5 m 10 m, 20 m	8 bits	5	26/2.4	g	a
[f] *Sentinel 2 MSI	2015	10 m, 20 m, 60 m	12 bits	13	5	g	b
[h] *Quickbird	2001–2015	0.61 m, 2.44 m	11 bits	5	1–3.5	g	a
[h] *Ikonos	1999–present	0.82 at nadir 3.2 at nadir	11 bits	5	3	g	a
[h] *World view	2007–present	0.5 at nadir	11 bits	1	1.7–5.9	g	a
[l] **Scanning Multichannel Microwave Radiometer (SMMR)	1978–1987	25 km	N/A	2	1	h	f
[l] **Special Sensor Microwave Imager (SSM/I)	1987–present	25 km	N/A	3	1	h	c
[l] **Scatterometer ERS	1992–present	50 km	N/A	1	3–4	h	d
[l] **Microwave Imager TRMM	1997–2015	25 km	N/A	5	1	h	e
[l] ***Advanced Microwave Scanning Radiometer-Earth (AMSR-E)	2002–2011	25 km	N/A	2	1	h	c

(continued)

Table 1 (continued)

Sensor/platform	Temporal coverage	Pixel size	Radiometric resolution	Number of bands	Revisit time (days)	Scale	Ref
[l] ****Advanced Scatterometer (ASCAT)	2006	25 km	N/A	1	1–2	h	c
[l] ***Soil Moisture Ocean Salinity (SMOS)	2009–present	35 km	N/A	3	1–2	h	d
[l] **Advanced Microwave Scanning Radiometer 2 (AMSR-2)	2012–present	25 km	N/A	2	1	h	c
[l] * RADARSAT-1 RADARSAT-2	1995–2013 2007–present	1–100 m	N/A	1	24	i	c
[l] ***** Soil Moisture Active Passive (SMAP)	2015–present	3, 9, 36 km	N/A	1	2–3	h	c
[l] **** Sentinel A	2014–present	5–25 m	N/A	1	12	h	c
[l] **** Sentinel B	2016–present	5–25 m	N/A	1	12	h	c

Key
Cost: [f] Free, [l] Low, [h] High
Sensor type: * Passive, ** Microwave, *** Microwave RAD, **** Microwave SAR, ***** Microwave SAR & RAD
References (Ref): (a) Liang and Wang (2020), (b) https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi, (c) Mohanty et al. (2017), (d) https://earth.esa.int/web/sppa/mission-performance/esa-missions, (e) https://gpm.nasa.gov/TRMM/trmm-instruments, (f) Srivastava et al. (2016), (g) Local, (h) Global, (i) Local to Regional, (j) Regional to global

application or development of methodologies. The inclusion/ exclusion criteria for the selection comprised:

(a) Use of RS data for crop production-related SM estimation and,
(b) Publication of the peer-reviewed articles in an accredited scientific journal.

Results from these searches were systematically tabulated as summarized in Table 2 under the content analysis Sect. 2.2 below.

2.2 *Content Analysis*

The articles that met the inclusion/exclusion criteria in the literature search were assessed as explained in the preceding Sect. 2.1 after which the compiled information was summarized as indicated in Table 2.

Table 2 Bibliometric assessment of gaps in RS of soil SM in Africa as identified in web of science: 1999–2019

Publication period	No of papers on soil moisture	Remote sensing	Focus of initiative			Sensor type	
			Algorithm development	Application of algorithms	Review paper	C-res	H-res
1999–2001	76	4	2	2	0	4	0
2002–2004	98	9	4	5	0	9	0
2005–2007	133	6	0	6	0	6	0
2008–2010	199	23	5	18	0	23	0
2011–2013	194	20	2	17	1	19	0
2014–2016	279	52	17	33	2	49	1
2017–2019	358	58	14	42	2	55	1
Total	**1337**	**172**	**44**	**123**	**5**	**165**	**2**
% increase 1999–2019	78.8	93.1	85.7	95.2	100.0	92.7	100.0

Explanation: C-res = coarse resolution (>10 m); H-res = high resolution (1–10 m)

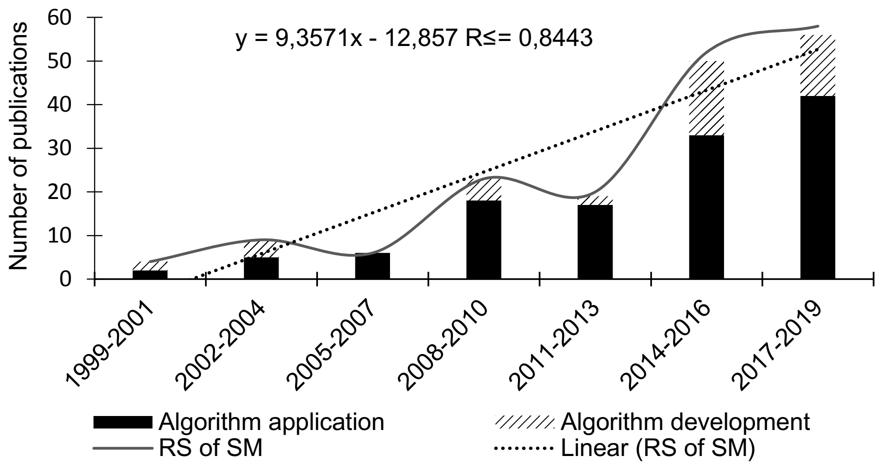

Fig. 1 Number of publications on RS of SM in Africa identified by using the Web of Science search engine: 1999–2019

Although most of the papers on SM since 1999 (1337) may indicate increasing use of SMI in Africa, the actual numbers of RS-based papers (172) and those applying algorithms for SM estimation (123) have been very few (Table 2). This mismatch suggests that the use of RS technologies in Africa is still in its infancy. Figure 1 shows the number of research publications on RS of SM in Africa between 1999 and 2019 as identified in Web of Science.

A possible explanation for the situation shown in Table 1 and Fig. 1 is lack of techniques that are capable of handling c-res datasets for SM estimation. Assuming that most of remote sensing-based papers used freely accessible images, it is logical to conclude that the well-established intensive utilization of Landsat datasets appears to have been biased in favour of non-SM estimation initiatives. Negligible use of unaffordable datasets is confirmed by the near-absence of publications based on h-res datasets. As shown in Table 1 and Fig. 1, the number of publications on SM increased by 78.8% ($R^2 = 0.8443$) between 1999 and 2019 with emphasis being placed on the application of algorithms which had a 95.2% increase in publications. This increase coincided with the launch of Landsat's Free and Open Data Policy in January 2009 (Zhu et al. 2019). Although this analysis provides informative insights on what has been happening, more still needs to be done by assessing the effectiveness of these initiatives.

3 Available RS-Based SM Estimation Approaches, Challenges and Developments

3.1 Available RS-Based SM Estimation Approaches

The visible and infrared (IR) band-based SM estimation techniques have been used widely but they have low cloud penetration capabilities, which make data unavailable for areas obscured by clouds. However, microwave RS overcomes this limitation by penetrating clouds and having high sensitivity to SM (Srivastava et al. 2013). In general, the RS of SM involves the use of empirical approaches, physical-based theoretical models and, machine learning algorithms (Barrett et al. 2009). Of these three methods, empirical approaches are the most widely used (Zhang et al. 2016) because they provide optimized SM estimations by relating RS variables to in-situ measurements (Guo et al. 2019). Parametric algorithms work by assuming linear relationships between SM and RS variables (Jung et al. 2017) but, they are incapable of (a) capturing complex relationships between RS variables and SM (Ali et al. 2015), (b) handling non-linear relationships between dependent and independent variables and, (c) predicting SM in un-sampled locations (Forkuor et al. 2017). Machine learning algorithms have better predictive accuracies compared to parametric methods. Selected examples include, artificial neural networks (ANNs) (Jiang and Cotton 2004), support vector machines (SVMs) (Gill et al. 2006), random forest (RF), (Breiman 2001), and relevance vector machines (RVMs) (Zaman et al. 2012). ANNs and SVMs are the most commonly used machine learning techniques when dealing with geoscience problems (Xing et al. 2017).

Although these algorithms have good SM estimation capabilities, SVMs can give poor results if the number of features is larger than the number of samples (Raghavendra and Deka 2014). Likewise, ANNs are constrained by wide ranging limitations that include slow processing of huge datasets (Ali et al. 2015). Details of these and other constraints are provided elsewhere (Xing et al. 2017; Chatterjee et al. 2020). Apart from using data acquired by space-borne satellites, SM is not difficult to measure because it can be estimated by using manned and Small Unmanned Aircraft Systems which are able to acquire high resolution images under different weather conditions (Huuskonen and Oksanen 2018).

3.2 Challenges Confronting RS of SM

Despite the availability of RS sensors with good potentials to estimate SM, appropriately scaled datasets are not readily accessible in most countries of Africa. Lack of in-situ SM data for validating remotely sensed SM measurements further undermines effective use of the limited datasets, which are not only scarce but also extremely difficult to access. Additional challenges emerge from poor quality data (Ahmadalipour et al. 2017), lack of usable algorithms, and dependence on c-res datasets with low levels of spatial accuracy (Peng et al. 2017; Zhuo 2019). As a result, the RS community continues to find it difficult to strike a balance between image acquisition costs, spectral and spatial resolutions, and optimum geographic coverages that meet the growing requirements of multiple end-users (Finn et al. 2011).

3.3 Developments in RS-Based Crop Production Orientated SM Estimation

Although seasonal variations in SM are difficult to capture by using broadband multispectral RS datasets, the increasing availability of h-res datasets that include Worldview-2, Sentinel-2 Multispectral Instrument (MSI) and Landsat 8 Operational Land Imager (OLI) (Sadeghi et al. 2017; Bao et al. 2018) has provided unique opportunities that need to be exploited. Following the failure of the Landsat's SLC for example, several studies (Palombo et al. 2019) have attempted to use datasets acquired by newer generation sensors. These efforts have yielded increased use of the newer generation datasets provided by Landsat 8 OLI, Sentinel-2 MSI, WorldView-2 and TASI-600 with greatly improved field-scale SM estimations (Bao et al. 2018). These achievements demonstrate that RS has a lot to offer as more datasets are becoming available. Unfortunately, however, most of the data provided by h-res sensors have yielded limited benefits because they are prohibitively costly and temporally restricted due to lack of archiving and acquisition on demand. It is therefore necessary to explore opportunities provided by the limited but reasonably priced medium resolution datasets. An example is Sentinel 2 MSI which has a wide swath width of 290 km, a 5-day revisit period and 13 optical bands (Table 1) that enable its datasets to be used for crop monitoring and SM estimation (Sadeghi et al. 2017) at high levels of accuracy (Babaeian et al. 2018). The important insight from these developments is that research needs to continue exploring better methods of using the readily accessible datasets in order to enhance timely provision of SMI in support of farm-level decision making (Ali et al. 2015; Fathololoumi et al. 2020).

4 Conclusion

The aim of the study was to offer an informative review of the progress that has been accomplished and the gaps that need to be filled, in the remote sensing of soil moisture in Africa. This chapter attempted to do this by providing a contextually placed appraisal of peer-reviewed articles that are readily accessible from the Web of Science. The assessment provided by this study was purposefully intentioned to offer a comprehensive overview of achievements and prospects that have to be strengthened and exploited in the remote sensing of soil moisture in Africa. Unfortunately, however, the study only focused on peer-reviewed information from Web of Science.

Although this limitation is admittedly a shortcoming that needs to be acknowledged, it is also an opportunity for follow-up initiatives by those interested in the remote sensing of soil moisture in Africa. The take home message offered by this initiative is that the apparent inability of hyperspectral datasets to cost-effectively provide SM information is indeed a momentous occasion that needs to be exploited through innovative formulation of robust techniques that can be used to offset the costs associated with the acquisition and utilization of these datasets. The fact that the usefulness of high-resolution datasets has been undermined by high acquisition costs should not be viewed as an insurmountable challenge because the history of remote sensing has been punctuated by successive periods during which data have been becoming cheaper and readily accessible. This trajectory argues for a calculated commitment in which the scientific community should continue exploring techniques that can be used to broaden our capabilities to tap on the rich datasets that are becoming increasingly available by balancing priorities in tandem with what is realistically possible. We conclude by inviting those interested to complement our efforts by identifying further gaps that need to be bridged and innovative ways through which these challenges can be addressed.

Acknowledgements The authors thank South Africa's Water Research Commission project K5/2496/4 for funding, the numerous respondents who provided some of the information and the anonymous referees, whose comments helped us to improve this paper.

Conflicts of Interest The authors declare no conflict of interest.

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Impact of Climate Variability on Maize Production in South Africa

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Abstract Maize (*Zea mays* L.) is a staple food for most people in the Sub-Saharan Africa (SSA) region including South Africa. Climate models are predicting a 1.5–2 °C temperature rise compared to pre-industrial times. This temperature rise has the potential to negatively affect maize production. The purpose of this study was to explore the relationship between climatic elements and maize production from two regions of South Africa- the Highveld represented by the Free state province and the Lowveld represented by Limpopo province over the period 2007–2018. The highest planted hectarage was from the Highveld at 855,000 ha for white maize and 365,000 ha for yellow maize. Correspondingly, the same province produced the highest output per hectare of both white and yellow maize at 4745.25 tonnes and 2208.3 tonnes respectively. Yellow maize yielded a maximum of 8 tonnes per hectare (2016/2017) while for white maize the maximum was 7.5 tonnes per hectare in 2016/2017 as well as 2017/2018 seasons on the Lowveld. A linear regression analysis between maize production and area grown indicated a positive strong association for both regions at ($r^2 = 0.60$) for Highveld and ($r^2 = 0.57$) for Lowveld respectively. For yellow maize, a weak positive relationship was established on the Highveld at ($r^2 = 0.26$) while a very strong association was established in the Lowveld at ($r^2 =$

The original version of this chapter was revised: The author name has been changed from "Terrerence Darling Mushore" to "Terence Darlington Mushore". The correction to this chapter is available at https://doi.org/10.1007/978-3-030-87934-1_29

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_13

0.85). To increase maize output, there is a need to shift from a rain-dependent type of production to a mixed approach where irrigation systems are also infused.

1 Introduction

The maize farming sector is a big contributor to South Africa's gross domestic product (Maize Trust 2014) and the crop is produced in nearly all regions of the country, even in the arid areas (Du Plessis 2003; Grain South Africa (GSA) 2015). This is because it is the main food consumed by the majority of households in the country as well as the whole of Southern Africa; providing 36% of calories consumed (Grant et al. 2012). Estimates indicate that 50% of output within Sub-Saharan Africa comes from South Africa (Durand 2006; Akpalu et al. 2009). In South Africa maize is produced by both commercial farmers and substance farmers. Commercial farmers produce the crop on 2.5 to 2.75 million hectares and substance farmers on 350,000 to 500,000 hectares per annum respectively (Maize Trust 2014; CEC 2015) with the crop predominantly being grown in semi-arid regions of the country (Durand 2006; Benhin 2006) under rain-fed conditions, and only about 17% under irrigation (GSA 2015; Pereira 2017). This makes variability in rainfall a major issue to the production of maize in the country. What is most worrying is that rainfall variability is predicted to get even worse, exacerbated by future climate changes (Walker and Schulze 2008; Gbetibouo and Ringler 2009). Du Plessis (2003) reported that projections are indicating that climate change and variability are likely to reduce areas suitable for maize production within South Africa as well as the whole sub-Saharan Africa region (Du Plessis 2003).

In the past three decades, there has been a decrease of about 1–5% in world agricultural production with cereal production being the major contributor to the decline (Porter et al. 2014). The decline is attributed to the changing climate. The changing climate has been characterised by an increased intensity and frequency of droughts occurrence and this has a detrimental effect on crop production (Ndhleve et al. 2017; Chisanga et al. 2017). According to the IPCC (2007; 2014), there is considerable evidence that indicates that climate change is threatening livelihoods. Besides, there is a notable decrease in average annual rainfall in most regions of South Africa and it has also become very erratic. This has a significant effect on 80% of the maize produced under rain-fed production systems which are highly dependent on climatic conditions. According to UNDP (2010), rain-fed agricultural yields will reduce by about 50% of farmers, especially in sub-Saharan Africa continue with their production practices. South Africa normally produce enough maize for its population except in drought years. However, the frequency of drought years is predicted to increase (Bello et al. 2020) in the forthcoming years because of climate changes. To enhance food security in the country it is key to understand how climate variability and change is impacting maize production to advise policymakers and inform researchers working on improving the crop.

Globally the average surface temperature and intensity of droughts are increasing because of the changing climate (IPCC 2007, 2012). This hurts the yields of maize and other crops. Climate change is also reducing the areas where maize can do well (Mendelsohn 2008; Eitzinger et al. 2011). Surface temperatures across the world have increased by 0.72 °C from 1950 base (Hartmann et al. 2013). It is heartening that the increase in temperature is faster in Africa as compared to the global mean (Collier et al. 2008). It is predicted that by the end of this century, temperatures during the growing season will be above the most extreme seasonal temperatures recorded in the previous 100 years (Battisti and Naylor 2009). According to Ziervogel et al. (2014) average surface temperature in South Africa increased by approximately 0.65 °C in the past 50 years. This is approximately one and half times the world mean. The increase in temperature also negatively affects the hydrological cycle. It results in low erratic rainfall and an increase in evapotranspiration, thereby reducing moisture available to the crops (Chi-Chung et al. 2004; Hartmann et al. 2013). The reduction in mean seasonal rainfall under climate change conditions also result in a decrease in water available for irrigation purposes (Edmeades 2008; Makado et al. 2006).

A temperature rise of only about 2 °C has caused a drastic reduction in world agricultural production in tropical countries (Challinor et al. 2014). Cairns et al. (2013) reported that exposing maize to high temperatures for several days has a lot of effects on many biological processes of the crop. Thomson (1966) recorded a 10% yield decline when the temperature increased by 6 °C during the grain filling stage. According to Dale (1983) during the grain filling period as temperature increases above 32 °C maize yield start to decrease. Lobell et al. (2011) also observed that for every degree day above 30 °C there is 1% and 1.7% maize yield reduction under optimum growing conditions and drought stress respectively. Jones and Thornton (2003) predicted that maize yield will decline by a 10% margin in the future as a result of climate change, however, the situation might be more severe in other areas. Over South Africa, climate change is likely to have a more detrimental effect on some parts of the Highveld, which is the epicentre of maize production (Walker and Schulze 2008). They predicted a reduction in maize yields as temperature increases, and rainfall reduces. Abraha and Savage (2006) predicted that the eastern parts of South Africa will receive adequate or more than adequate rainfall. Maize yield reduction will be influenced more by a rise in temperature than received rainfall in that region. A proper assessment and understanding of the impacts of climate variability and change will allow the crafting of appropriate adaptation strategies that suit different maize producing regions of the country. The following section outlines the material and methods used for the study.

2 Materials and Methods

South Africa is generally a temperate climate country with four distinct seasons namely summer (DJF), autumn (MAM), winter (JJA), spring (SON) (Council for Scientific and Industrial Research (CSIR) 2017). Summer seasons are characterised by high rainfall and high temperatures while winter seasons are characterised by dry and low temperatures, however, there are also coastal regions that are characterised by wet winters and dry summers, for example, South-Western Cape (CSIR 2017). Even though maize farming is predominantly a summer-based activity sometimes there is also winter cropping. Ideally, a maize crop requires 450–600 mm up to the point of maturity and each maize crop requires 250 L of water (Department of Agriculture (DA) 2003). All regions across South Africa are suitable for the growth of maize as the climatic conditions are appropriate. Also, maize is generally regarded as a warm-weather crop and does not do well in conditions with mean daily temperatures below 19 °C as frost can cause damage to maize crops (DA 2003).

For the study, two provinces representative representing two regions were selected namely the Highveld (Free State) and Lowveld (Limpopo). The South African Highveld is a portion of the inland plateau of South Africa located at an altitude above 1,500 m but below 2,100 m (Balashov et al. 2014) while the Lowveld lies between 300 and 600 m above sea level. On average 50% of the Lowveld region receives less than 650 mm per year (Emmanuel et al. 2005). Free State province (Highveld) is one of the biggest maize producing region in South Africa while on the other hand, Limpopo is one of the lowest producing regions partly due to differences in climatic conditions. The Free State receives more rainfall and cooler temperatures while Limpopo receives low erratic rainfalls and the temperatures are higher. Maize output data (commercial farming output only and non for subsistence output) were acquired from the South African Grain Information Service (SAGIS) and Agri South Africa (Agri SA) which are commercial farmer organisations. Historical climate data was acquired from the South African Weather Service (SAWS). Climate data were obtained on a daily scale (Maximum, minimum and daily precipitation). Rainfall and temperature trends were analysed in Microsoft Excel and SPSS Statistical software and represented graphically as shown in the results and discussion section. Furthermore, linear regression was used to show the association between area grown and production output as well as show the relationships between climatic factors and production output. To illustrate the spatial production output distribution across different provinces the study used ArcGIS software version 10.2.2. The next section (Sect. 3) focuses on the results and discussion of the study.

3 Results and Discussion

This section presents the results and discussion of the study with the first part focusing on the annual rainfall analysis. Figure 1 outline the annual temperature and rainfall patterns for the Highveld and Lowveld region.

3.1 Annual Rainfall and Temperature Analysis

According to Fig. 1 average maximum and minimum temperatures were rising resulting in an increase in mean annual temperature between 2007 and 2018 in

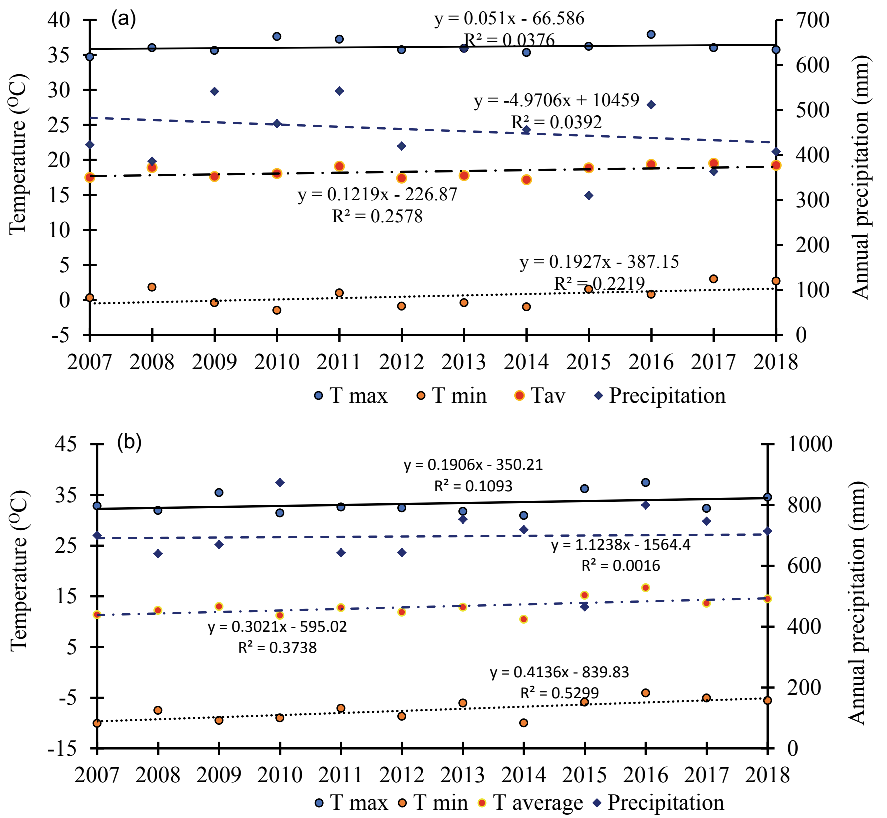

Fig. 1 **a** Annual rainfall and temperature patterns in Limpopo Province (Lowveld). **b** Annual rainfall and temperature patterns in Free State Province (Highveld) (*Source* Authors)

Limpopo Province (Fig. 2). During the same period annual rainfall decreased at a rate of 4.97 mm per year. Figure 1 highlights the mean monthly rainfall received during the period 2007–2018. Both in the Highveld and Lowveld rainfall is predominantly received during the summer months chiefly October through to April. For farmers who depend on rainfed maize production, it, therefore, implies they must plant with the first rains in October. Delayed planting means rains stop before the maturity stage hence poor yields. Since the rainy season lasts for only about three/four months there is a need to grow early maturing varieties or design water conservation techniques that help keep the residue moisture for a longer period. On the other hand, low amounts of rainfall are received between May to September in all regions. Mean monthly rainfall during winter months ranged between 14 and 19 mm while on the Lowveld mean monthly rainfall ranged between 6 and 12 mm.

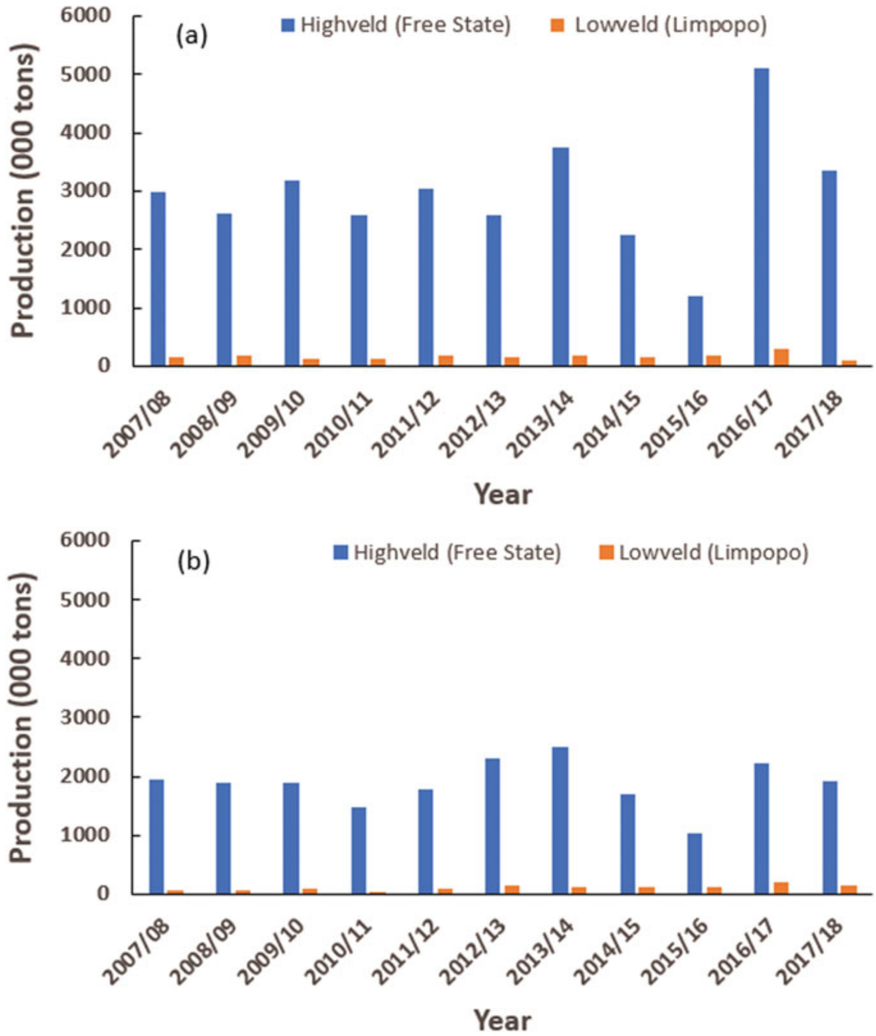

Fig. 2 Production **a** white maize, **b** yellow maize (*Source* Authors)

3.2 Maize Production Analysis

Figure 2 illustrates the production output during the period under review for both white and yellow maize. White maize production dominated across both regions with the Highveld however producing higher quantities as compared to the Lowveld. This can be attributed to the climatic conditions on the high veld being more conducive as compared to the low veld.

Figure 3 highlights the output per hectare for both forms of maize from 2007 to 2018. The Lowveld for the years under review had a higher margin of output

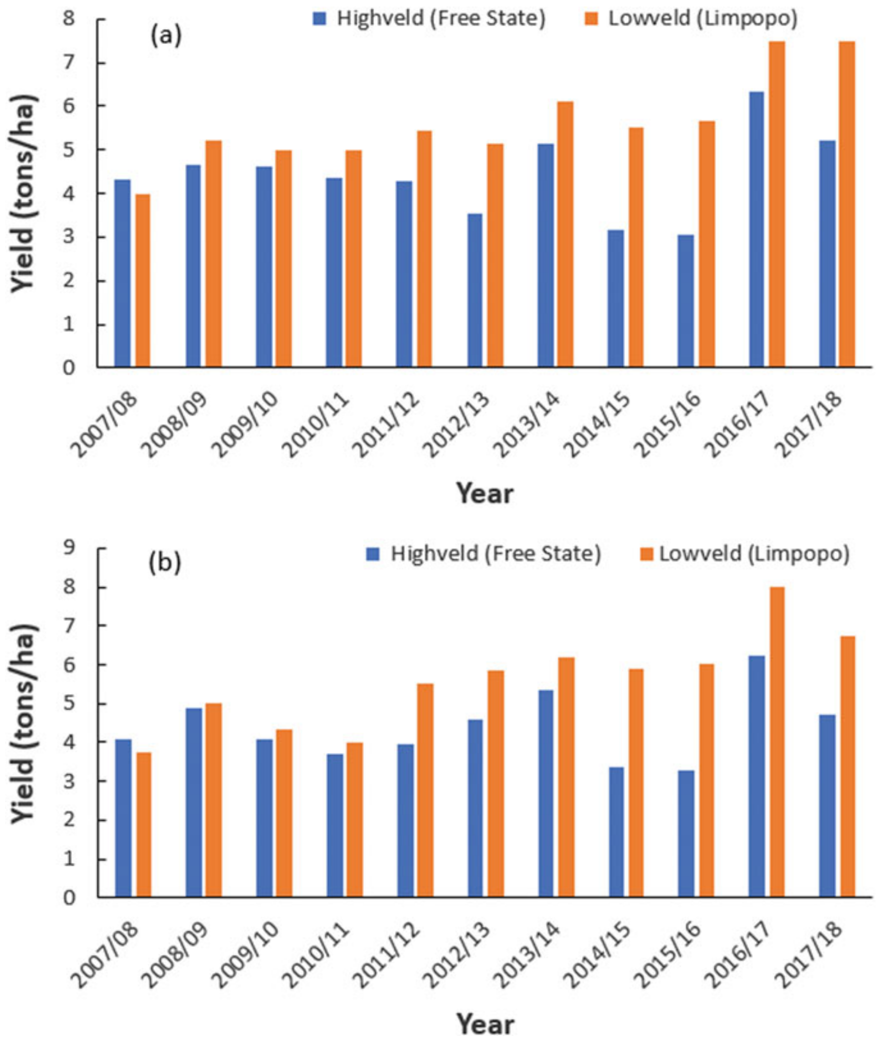

Fig. 3 Output per hectare, **a** white maize, **b** yellow maize (*Source* Authors)

per hectare as compared to the Highveld. The output per hectare has been steadily rising over the years on the Lowveld reaching its peak during the 2016/2017 planting season for both categories of maize. For yellow maize, it reached the maximum of 8 tonnes per hectare (2016/2017) while for white maize the maximum was 7.5 tonnes per hectare (2016/2017 as well as 2017/2018). In the South African context, white maize is the preferred type for human consumption while yellow maize is mainly used for stock feed. Significantly, though the highveld outpaces total output production the Lowveld can produce more per hectare.

Figure 4 highlights the relationship between the area grown and white maize

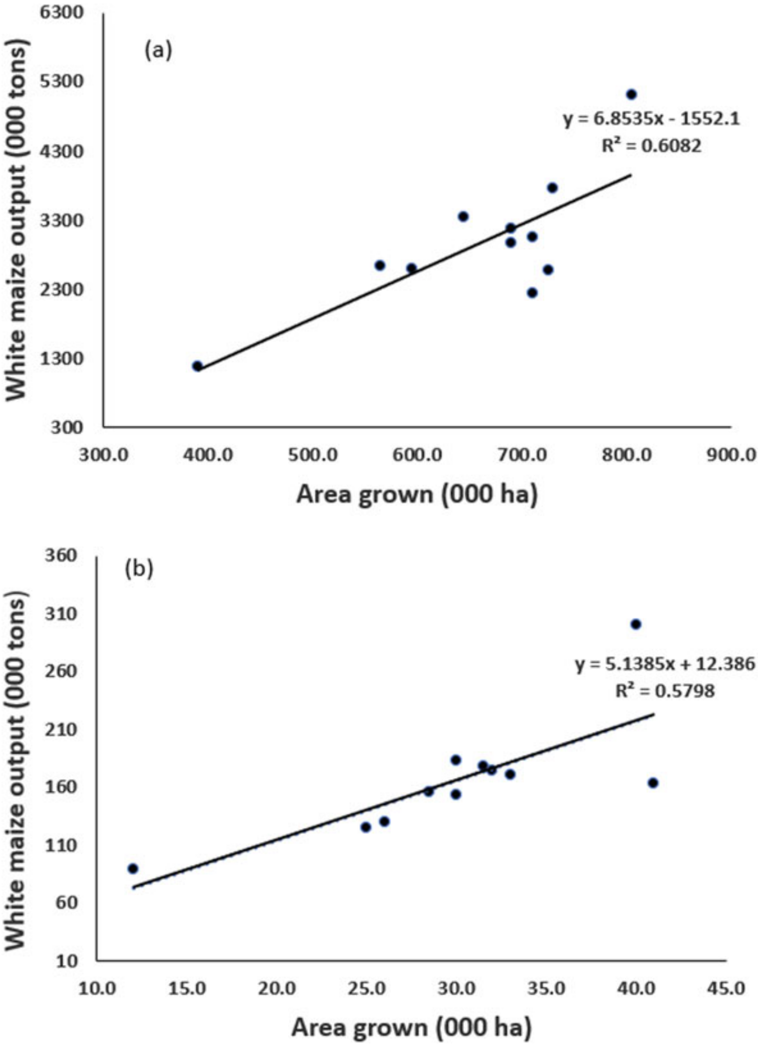

Fig. 4 Association between hectarage and output for white maize. **a** Highveld (Free state). **b** Lowveld (Limpopo) (*Source* Authors)

output with the highveld showing a marginally closer association between hectarage and output at ($r^2 = 0.60$) while on the other hand for the Lowveld the association is still strong at ($r^2 = 0.57$). A positive strong association for both the regions was expected as the output should increase with the increase in land cultivated.

Figure 5 illustrates the relationship between output and the area grown. For the Lowveld, there is a very strong positive association between area grown and the total output produced at ($r^2 = 0.85$) while on the other hand, the high veld has a positive but not very strong relationship at ($r^2 = 0.26$). The strong association for

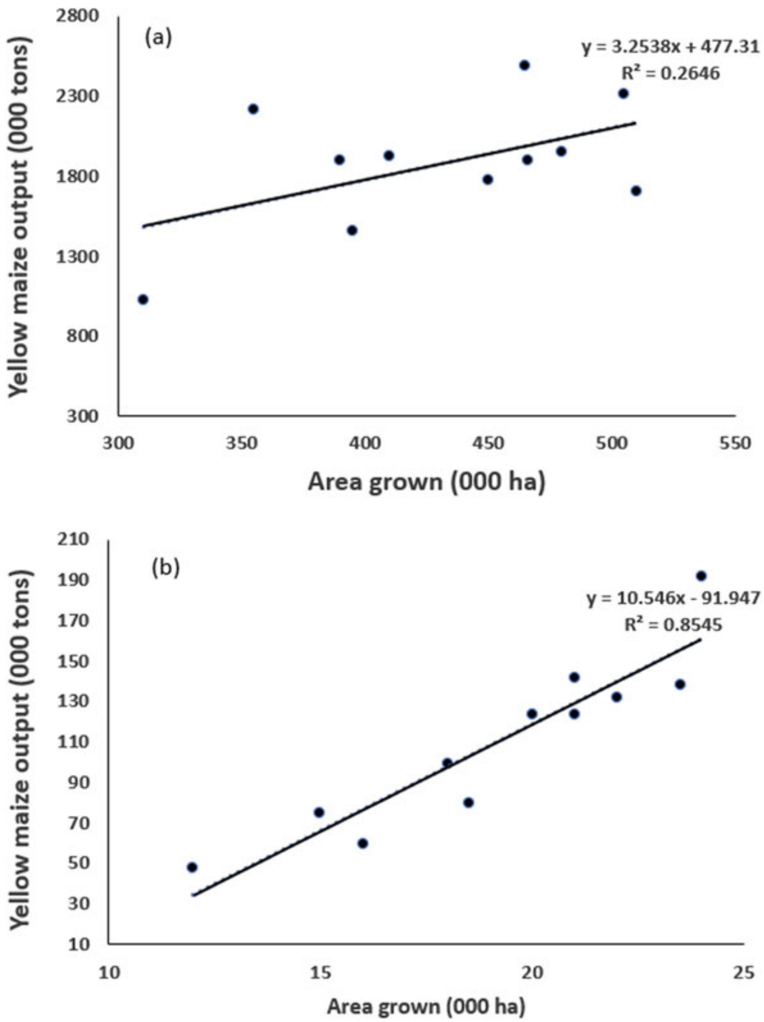

Fig. 5 Association between hectarage and output for Yellow maize. **a** Highveld (Free state). **b** Lowveld (Limpopo) (*Source* Authors)

the Lowveld can also be related to the high levels of output per hectare as compared to the Lowveld.

Figure 6 highlights that there was a linear positive relationship between white maize yield and precipitation while annual yield ranged from 100 thousand tonnes to 300 thousand tonnes. In more than 90% of the studied period, the yield was not exceeding 200 thousand tonnes (Fig. 6). Production is generally higher for white than yellow maize which ranges between 45 and 200 thousand tonnes. The highest yield for both varieties was recorded in the same rainfall year indicating high sensitivity of maize yield to rainfall in Limpopo Province. Yellow maize production was decreasing

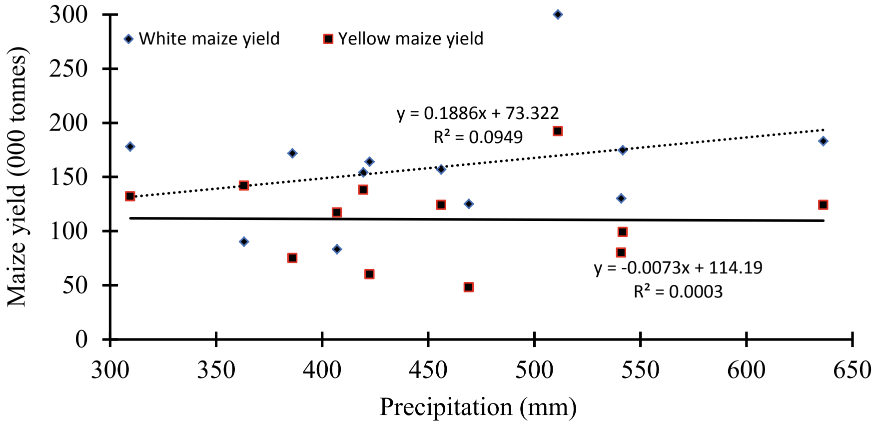

Fig. 6 Responses of white and yellow maize to rainfall variability on the Lowveld (*Source* Authors)

with time during the period under investigation. Overally, the relationship between yield and precipitation was not strong indicating that other factors contributing to maize yield have a significant role. The combined effect of a decrease in precipitation and an increase in temperature seems to affect yellow than white maize in Limpopo Province.

As illustrated in Fig. 7, rainfall and temperature showed an increase between 2007 and 2018. The increase in minimum temperature was stronger (R-squared = 0.5299) than that in maximum and annual average temperature. The relationship between annual precipitation and maize yield (both white and yellow) is positive and non-linear in Free State Province (Fig. 7). The relationships are stronger (R-squared > 0.4) than those observed in Limpopo Province. White maize appears to steadily increase

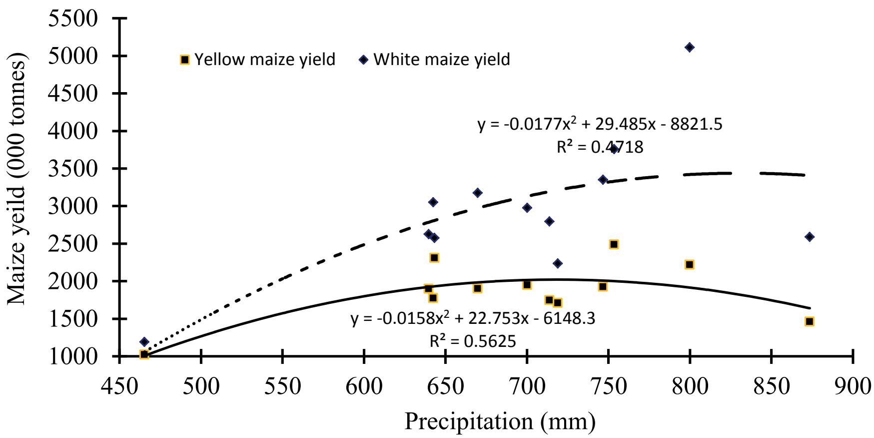

Fig. 7 Responses of white and yellow maize to rainfall variability on the Highveld (*Source* Authors)

with precipitation until about 750 mm where yield becomes saturated. Possibly, after the saturation, white maize yield will begin to decrease with precipitation due to the influence of excessive amounts on soil leaching, pests and diseases. Compared to Limpopo, Free State maize yields are too high for both maize varieties. At all rainfall amounts, the yield for white maize was higher than that for yellow maize variety. Yellow maize yield increased with precipitation up to an optimum of about 700 mm after which it began to decrease with precipitation. These findings are similar to Mushore et al. (2017) which also established a very strong linear association between climatic conditions and maize output within the Zimbabwean Highveld.

As illustrated in Fig. 8, from a national perspective, Free State Province is the biggest producer of white maize followed by North West Province while Eastern and Western Cape produce the least, respectively. Production in Limpopo Province is comparatively moderate. During the study period Limpopo, Mpumalanga and North West registered a declining trend in white maize yield while the rest recorded increases. Free State experienced the highest rate of increase in white maize yield (34.28 tonnes/year).

Figure 9 illustrates that the Western and Eastern Cape were the least producers when considering the average yellow maize yield while Free State showed the highest records between 2007 and 2018. A decreasing trend in yellow maize yield was recorded in Mpumalanga and North West Provinces during the same period. The rest of the Provinces recorded a rising trend which was greater in Free State than elsewhere.

Study Limitations

There are several limitations for the study firstly, the study did not take into account other key inputs that are ideal for the production of maize, for example, soil type, fertiliser, manure, general management by individual farmers, humidity, amount of sunshine as well as the genetics of different maize varieties.

4 Conclusions

The current study was based on two regions of South Africa (Highveld and Lowveld) with contrasting climatic conditions yet all are producers of the maize crop. The Lowveld consistently had higher output per hectare compared to the Highveld for both white and yellow maize reaching a peak of 8 tonnes/ha during the 2017/2018 cropping season. During the 12 years which were reviewed the study established that rainfall trends have been negatively decreasing on the Lowveld while on the Highveld rainfall trends have maintained. The study established that maximum temperature trends have been positively increasing on the Lowveld. An increase in temperatures potentially has an impact on maize output as temperatures beyond 32 °C are detrimental to the maize crop (DA 2003). Even though the Lowveld recorded higher output per hectare total production per region was higher for the Highveld reaching an annual peak of 5111.75 thousand tonnes (white maize) during the 2016/2017 cropping season while

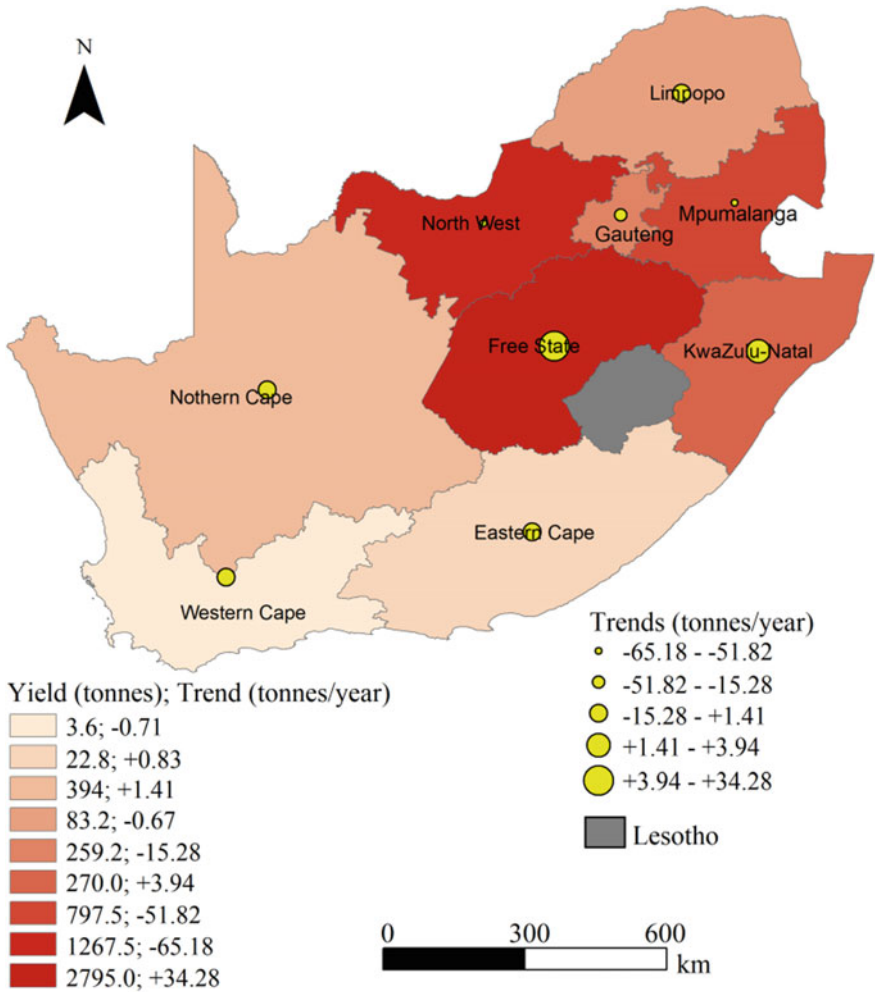

Fig. 8 Average white maize yield per Province and production trends per Province from 2007 to 2018 (*Source* Authors)

in the same year the Lowveld reached 300 thousand tonnes for white maize. For yellow maize, the highest output was realised during 2013/2014 at 3759 thousand tonnes while for the Lowveld the highest output was 192 thousand tonnes during the 2016/2017 season. These variations can be linked to the incremental increase of land cultivated on the Highveld over the years as compared to the Lowveld. On the other hand, another fundamental determinant of output could be the maize price factor. The study only focused on commercial production whose main aim is to profit maximise thus maize prices play a key role in determining the area to be grown. Good prices can transform into an increase in the area grown. The study did not find evidence

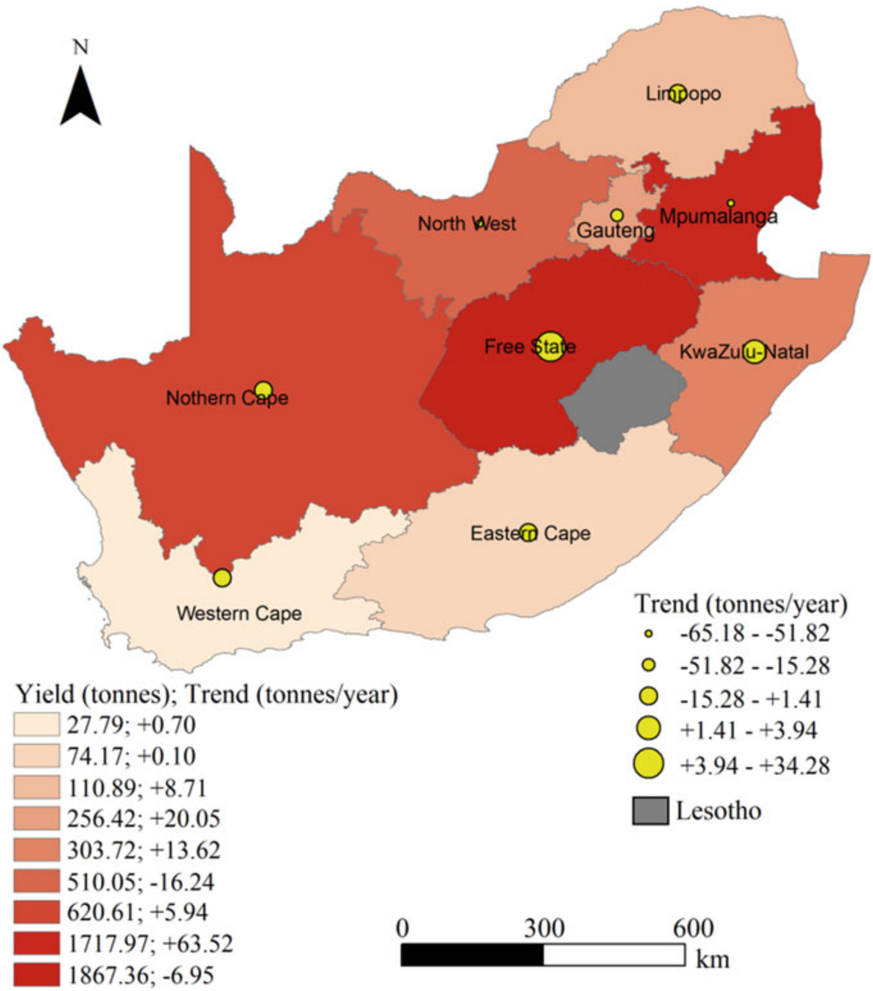

Fig. 9 Average yellow maize yield per Province and production trends per Province from 2007 to 2018 (*Source* Authors)

that directly linked production output to the climatic conditions though an increase in output can also be attributed to the improvement of maize crop genetics over the years thus translating into high yields per hectare more than before. Furthermore, the high temperatures on the Lowveld could also have played a key role in the decrease in the total area grown for both white and yellow maize grown on the Lowveld. This is because of differential risks between the two regions. It's riskier to conduct rainfed maize production on the Lowveld than the Highveld. Even though there is marked maize production output variations between the Highveld and Lowveld regions there was no evidence that output has been negatively impacted from a historical perspective. South Africa remains a leading producer of maize and this position might have been aided by having access to maize varieties of great genetics allowing an increase in output per hectare compared to other neighbouring countries. Climate variability however remains a real threat in the near future.

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Climate Change and Food Production Aspects

Adaptation Processes and Approaches

Hybrid Application of LCA to Analyze the Global Warming Potential of Food Supply Chain

Amin Nikkhah and Sam Van Haute

Abstract Life cycle assessment (LCA) is one of the best, most practical, and most standardized approaches for evaluating the environmental consequences of a food supply chain (FSC). It covers a comprehensive range of impact categories in which the global warming potential (GWP) is the main impact category that is included in almost all LCA's impact assessment methodologies. LCA has been applied to investigate the GWP of various FSCs worldwide. Recent studies show that the hybrid application of LCA is more powerful than single LCA. LCA can be combined with other methodologies to model, and optimize processes and decision-making purposes as well. In this regard, LCA has been coupled with mathematical approaches (regression, Cobb–Douglas, and data envelopment analysis), artificial-based intelligence (artificial neural networks, adaptive neuro-fuzzy based interface, particle swarm optimization, and genetic algorithms), and multi-criteria decision making (analytic hierarchy process, and fuzzy analytic hierarchy process). This chapter provides the relevant literature regarding the joint application of LCA in analyzing the GWP effects of FSCs, along with the pros and cons of hybrid approaches.

1 Introduction

Over the last few years, because of the population growth and increasing demand for food, some keywords, such as "achieving food security" and "sustainable agriculture" have become trends for policymakers, authorities, producers, and consumers (Ala and Ridwan 2020; Ulian et al. 2020). Additionally, the second aim of the United Nations (UN) is to "end hunger, achieve food security, improve nutrition and promote sustainable agriculture." One solution to achieve the second goal of the UN is resource conservation and management. In this regard, decision support tools play a key role

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_14

in resource management. So far, this has been applied by policymakers and producers to achieve a more sustainable production system. They can be used for modeling, prediction, or optimization of different production systems.

2 Decision Support Tools for Analyzing Sustainability

Decision support tools can contribute to the identification, evaluation, and optimization of multiple control variables potentially leading to improvements in the performance of supply chains in general and sustainability of the system particularly (Taticchi et al. 2015). To date, various decision support tools have been proposed and developed in the agri-food sector to improve the overall sustainability of food production systems. The sustainable development of new alternative technologies in agri-food systems needs to focus thorough attention to resource management within production systems and achieve a better understanding of its multiple impacts (Nikkhah et al. 2016). In this respect, life cycle assessment (LCA) is a well-known standardized methodology for examining the sustainability of the food production systems due to its cradle-to-grave perspective.

3 Life Cycle Assessment

The procedures of LCA are standardized by ISO 14040, and ISO 14004 (Huang et al. 2018). LCA is a methodology to comprehensively estimate the environmental consequences of human activities from the mining the raw materials, through processing/manufacturing, transportation, consumption, and to waste (cradle to grave) (Saba et al. 2020). An LCA study comprises four phases, which are described in the subsequent subsections.

3.1 Goal and Scope Definition

Goal and scope definition are considered the first phase of each LCA application. It is also needed to specify the functional units (FUs) considered by the system and system boundaries in the this phase of an LCA study (Elhami et al. 2017). Various FUs are considered to be evaluated by LCA, including mass-based (Bacenetti et al. 2020), land-based (Pishgar-Komleh et al. 2020a), energy-based, nutritional-based (McAuliffe et al. 2020), and economic-based (Van der Werf and Salou 2015) FUs. The choice of FU can significantly affect the process of decision-making toward determining a sustainable food system (Masset et al. 2015). Nevertheless, mass-based FUs are usually one of the common FUs in LCA studies in the food sector. However, nutritional FUs are more appropriate in some food systems and thus, certain studies have applied nutritional properties as FUs, such as protein quality for human diets (Sonesson et al. 2017) and the contribution of foods to the nutrient composition of a weekly diet (Tyszler et al. 2014).

After the selection of appropriate FUs, the system boundary should be specified. A system boundary may be chosen as the cradle of the process, for instance, from mining the materials to the grave (the treatment of the waste). Some LCA studies have specified the system boundary from cradle to gate, gate to gate, or gate to grave.

3.2 Inventory Analysis

The aim of the life cycle inventory analysis is to determine the inputs and outputs of the investigated system. The emissions of the system (to air/soil/water) are divided into the off-site, and the on-site emissions. Off-site production emissions consist of the pollutants released from the production of inputs (usually off-site emissions); while on-site emissions consist of the direct emissions released from the consumption of inputs, such as on-site CO_2 emissions from the burning of diesel fuel in a food industry engine. Several LCA databases have been developed since the release of environmental management standards (ISO14040 and ISO14044) (ISO 2006a, b), including Agri-Footprint, Ecoinvent, ELCD, and the Swiss input–output database (Durlinger et al. 2014; Martínez-Rocamora et al. 2016; Wernet et al. 2016; Famiglietti et al. 2019). SimaPro, Gabi, Umberto, and OpenLCA software can also be applied for LCA analysis (Emami et al. 2019; Silva et al. 2019).

3.3 Impact Assessment

The specification of impact categories and calculation of the characterization factors of the selected impact categories are mandatory in the impact assessment of LCA studies. However, the normalization of the investigated impact categories and weighting of the damage categories are optional in LCA analysis. Several impact assessment methodologies have been proposed for LCA analysis, such as CML-IA baseline, Ecological Scarcity 2013, EDIP 2003, EPD (2018), EF Method, IMPACT 2002+, and ILCD 2011.

3.4 Interpretation of Results

The last LCA phase is the interpretation of the obtained results. In this phase, the results are explained and discussed in comparison with other relevant studies.

4 Global Warming Potential Calculation in LCA

The different impact categories that are considered in various impact assessment methodologies are shown in Table 1. LCA covers a wide variety of impact categories in which global warming potential (GWP) is the main impact category included in almost all LCA's impact assessment methodologies. Therefore, LCA has been applied to investigate the GWP of various FSCs worldwide. Some other impact categories are (directly/indirectly) connected to GWP, such as ozone depletion and formation. GWP characterization factors of food products are expressed as kg CO_2-eq, usually calculated according to IPCC guidelines (IPCC 2013) in most LCA impact assessment methodologies (Huijbregts et al. 2017). The obtained GWP characterization factor can be normalized and weighted. Several methods have been applied for weighting LCA results, including panel-based, monetization, and distance-to-target (Castellani et al. 2016).

5 Food Supply Chain

Food supply chains (FSC) are networks in which edible products move from farm to fork/waste, including the production/agricultural phase, food processing, packaging, consumption, retail, and waste (Nikkhah and Van Haute 2020). Several factors influence FSCs, including sustainability, which refers to the quality of life improvement, for the current as well as subsequent generations (Tümenbatur and Tanyaş 2016). FSCs are one of the main contributors to global warming; for instance, in Europe, FSCs are responsible for 31% of the global warming potential (Jonkman et al. 2019). However, LCA can be applied by policymakers, farmers, companies, and consumers to mitigate FSC greenhouse gas emissions. The following paragraphs explain how LCA can be applied to different phases of FSCs to contribute to sustainability.

6 LCA Contribution Toward Sustainable Food Production

Different phases of an LCA study within the FSC are shown in Fig. 1. LCA is the core methodology in the European Union applied to evaluate the carbon footprint of products (Van der Werf et al. 2020). Lu and Halog (2020) investigated the frequency of LCA application in different stages of FSC. They indicated that the agricultural phase is the most frequently included, while the retail, preparation, consumer level, and waste phases are included fewer times.

Table 1 Impact categories considered by different IA methodology

CML-IA baseline	Ecological scarcity 2013	IMPACT 2002+	EDIP 2003	ILCD 2011	EPD (2018)	EF Method
Abiotic depletion	Water resources	Carcinogens	**Global warming**	Freshwater ecotoxicity	Ozone layer depletion	Cancer human health effects
Abiotic depletion (fossil fuels)	Energy resources	Aquatic eutrophication	Ozone depletion	Ozone depletion	Eutrophication	Ozone depletion
Acidification	Mineral resources	Respiratory organics	Resources (all)	Ionizing radiation	Abiotic depletion, fossil fuels	Ionising radiation
Ozone layer depletion	Radioactive waste to deposit	Non-carcinogens	Ozone formation (Human)	Human toxicity, cancer effects	Photochemical oxidation	Photochemical ozone formation
Photochemical oxidation	Heavy metals into soil	Ionizing radiation	Ecotoxicity water chronic	Particulate matter	Abiotic depletion, elements	Climate change—fossil
Fresh water aquatic ecotox	Ozone layer depletion	Land occupation	Terrestrial eutrophication	**Climate change**	Acidification	Non-cancer human health effects
Global warming	Main air pollutants and PM	Aquatic ecotoxicity	Aquatic eutrophication	Marine eutrophication	Water scarcity	Eutrophication freshwater
Eutrophication	Carcinogenic substances into air	**Global warming**	Ecotoxicity soil chronic	Photochemical ozone formation	**Global warming**	Acidification terrestrial and freshwater
Marine aquatic ecotoxicity	Heavy metals into air	Terrestrial acid/nutri	Human toxicity air	Acidification		**Climate change**
Terrestrial ecotoxicity	Water pollutants	Non-renewable energy	Human toxicity water	Terrestrial eutrophication		Water scarcity
Human toxicity	POP into water	Aquatic acidification	Human toxicity soil	Freshwater eutrophication		Climate change—biogenic

(continued)

Table 1 (continued)

CML-IA baseline	Ecological scarcity 2013	IMPACT 2002+	EDIP 2003	ILCD 2011	EPD (2018)	EF Method
	Heavy metals into water	Mineral extraction	Acidification	Water resource depletion		Ecotoxicity freshwater
	Pesticides into soil	Ozone layer depletion	Ecotoxicity water acute	Human toxicity, non-cancer effects		Land use
	Global warming	Terrestrial ecotoxicity	Slags/ashes	Land use		Eutrophication marine
	Land use	Respiratory inorganics	Hazardous waste	Ionizing radiation		Resource use, energy carriers
	Radioactive substances into water		Bulk waste	Mineral, fossil and ren resource depletion		Climate change—land use and transform
	Radioactive substances into air		Radioactive waste			Respiratory inorganics
	Non radioactive waste to deposit		Ozone formation (vegetation)			Eutrophication terrestrial
	Noise					Resource use, mineral and metals

* *Source* SimaPro 9.0 Software (PRe 2010)

Fig. 1 Four phases of an LCA study within the food supply chain

6.1 Application of LCA by Farmers

Over the last few years, several studies have been done to investigate the environmental consequences of the agricultural phase of food production. These results could be effectively used by farmers for making decisions regarding the mitigation of environmental impacts of agricultural processes. For example, many studies indicate that nitrogen-based chemical fertilizer has the largest environmental adverse effects in some agricultural production systems due to its influence on some impact categories, including global warming and eutrophication (Bacenetti et al. 2020; Mostashari-Rad et al. 2020). Accordingly, this can encourage producers to mitigate the environmental impact of nitrogen-based fertilizers through (i) nutrient content monitoring of soil and (ii) the selection of an environment friendly fertilizer, such as bio-fertilizer or a low environmental impact chemical-based fertilizer (Graham and Vance 2000; Nikkhah et al. 2017). In this regard, using green manures, bio-fertilizers, and farmyards can be considered as alternatives to supply the nitrogen required by crops (Firouzi et al. 2017). Another issue with the agricultural phase of the FSC is the substantial fossil fuel footprint that has been reported as one the major contributors to the environmental burdens of food production systems (Pishgar-Komleh et al. 2020a; Saber et al. 2020). In this case, the replacement of fossil-based fuels with biofuel could remarkably mitigate the overall environmental impacts of the system (Esmaeilpour-Troujeni et al. 2020).

6.2 Using LCA by Food Processing

Although environmental data related to the agricultural phases of FSCs are increasingly becoming available, there is a gap regarding the GWP data of food processing (Sanjuán et al. 2014). In the case of food processing, environmental legislation could significantly contribute to reducing the environmental impacts of FSC (Nikkhah et al. 2017). For example, a law in France and also a recommendation from the Swiss Federal Office for the Environment encourage producers to label their food products with environmental indicators like greenhouse gas emissions (De Menna et al. 2015). There are already some food production companies that compute the environmental footprint of their products, mentioning these data on the food product packages. In this regard, LCA as a powerful tool can be used by the food processing industry to examine their environmental footprints.

6.3 LCA Results for Consumers

Consumers can play a key role in moving to sustainable food production systems. Gruber et al. (2016) studied the LCA of the customer stage of FSCs, i.e., shopping, storage, preparation, and disposal. The authors indicated that the shopping phase has the largest adverse effect on the selected impact categories and highlighted that if consumers act carelessly regarding environmental protection, then the customer stage will appear as an environmental hotspot for FSCs. However, information on the environmental life cycle of the food that customers eat is not always available to them (Jones et al. 2008). For instance, the consumer awareness of the environmental impacts of the meat industry has been studied in Belgium, Germany, Finland, Portugal, the Netherlands, and the United States, with percentages of aware participants ranging from 23 to 35% (Sanchez-Sabate and Sabaté 2019). However, replacing meat with alternatives could mitigate the environmental impacts of human diets. The following section explains the GWP of meat alternatives.

7 GWP of Meat Alternatives

There is a need to discovering alternative sources of protein due to the increasing demand for meat (Nikkhah et al. 2021). In addition, many studies have shown that most common meat production systems, such as beef (Biswas and Naude 2016; Perez-Martinez et al. 2018), chicken (Kalhor et al. 2016; Skunca et al. 2018; López-Andrés et al. 2018), pork (Reckmann et al. 2013; Winkler et al. 2016), and fish (Buchspies et al. 2011; Dekamin et al. 2015), are not sufficiently environment friendly. Hence, the development of new alternative sustainable food sources is essential. LCA has been applied to investigate the environmental consequences of meat alternatives. For instance, Halloran et al. (2017) compared the environmental impact of cricket farms to that of chicken farms in Thailand. The results revealed that protein from insects is more environmentally efficient compared to that of chicken. Likewise, Smetana et al. (2019) claimed that the insect biomass in the investigated system is twice as environmentally efficient compared to chicken meat.

8 Hybrid LCA in FSC

Recent studies show that the hybrid application of LCA is more powerful than single LCA applications. LCA can be combined with other methodologies to model, optimize processes, and enhance decision-making purposes. In this regard, LCA has been coupled with mathematical approaches (multiple regression, and data envelopment analysis), artificial-based intelligence (artificial neural networks, adaptive neuro-fuzzy based interfaces, particle swarm optimization, and genetic algorithms), and multi-criteria decision making (analytic hierarchy process). Table 2 shows a few recently published papers on the use of hybrid LCA in FSC.

In this chapter, the frequency of hybrid LCA applications with various models and with different purposes in FSCs was investigated. Twenty recently published papers (from 2018 to now) on hybrid LCA in FSCs were investigated; the results are shown in Fig. 2. The results highlight that the data envelopment analysis and adaptive neuro-fuzzy inference system are the most frequently applied approaches. The results shown in Fig. 3 indicate that the hybrid applications of LCA with multi-criteria decision-making models have been included fewer times in hybrid LCA studies in FSCs, compared to molding and optimization.

Table 2 Recently published studies on the use of hybrid LCA in FSC (from 2018 to now)

Food/services	Number(s) of farms/sites	Selected impact categories	Decision making/modeling/optimization	Joint LCA with	Authors
Chicken meat	One farm	GWP, OLD, TE, AC, MEx, NRE, AEU, LO, AET, RO, IR, RI, NC, and C	Optimization	Genetic algorithm	López-Andrés et al. (2018)
Arecanut	70 farms	GWP, C, AC, AET, EU, IR, LO, MEx, NC, NRE, OLD, RI, RO, and TE	Optimization	Data envelopment analysis	Paramesh et al. (2018)
Paddy rice	240 farms	GWP, AD, AC, EP, TE, HT, PO, OLD, and ME, and FE	Modeling	Artificial neural networks and adaptive neuro-fuzzy inference system	Nabavi-Pelesaraei et al. (2018)
Grape	58 orchards	GWP, AC, HT, AD, EP, ME, OLD, FE, TE, and PO	Optimization	Data envelopment analysis	Mohseni et al. (2018)
Sugarcane	120 farms	GWP, AC, AD, TE, PO, EP, OLD, HT, ME, and FE	Modeling	Artificial neural networks and adaptive neuro-fuzzy inference system	Kaab et al. (2019)
Tobacco	225 farms	GWP, AC, TE, FDR, PhRD, and PRD	Decision making	Analytic hierarchy process	Nikkhah et al. (2019)

(continued)

Table 2 (continued)

Food/services	Number(s) of farms/sites	Selected impact categories	Decision making/modeling/optimization	Joint LCA with	Authors
Rice milling factories	60 milling factories	GWP, AD, OLD, AC, PO, EP, HT, TE, ME, and FE	Modeling	Adaptive neuro-fuzzy inference system	Nabavi-Pelesaraei et al. 2019
Rice	Multiple years and farm sizes	GWP and EP	Optimization	Data envelopment analysis	Masuda (2019)
Grocery stores	30 groceries	GWP and CEDnr	Optimization	Data envelopment analysis	Álvarez-Rodríguez et al. (2019)
Maize	Field experimental design	GWP, ODP, POCP, AP, EP, and AD	Decision making	Fuzzy analytic hierarchy process	Król-Badziak et al. (2021)

* Abbreviations: global warming potential (GWP), abiotic depletion (AD), human toxicity (HT), acidification (AC), cumulative non-renewable energy demand (CEDnr), aquatic ecotoxicity (AET), aquatic eutrophication (AEU), carcinogens (C), climate change (CC), eutrophication (EP), fossil resources depletion (FD), respiratory inorganics (RI), fossil resources depletion (FRD), fresh water aquatic ecotoxicity (FE), land occupation (LO), terrestrial ecotoxicity (TE), ionizing radiation (IR), land use (LU), marine aquatic ecotoxicity (ME), mineral extraction (MEx), photochemical oxidation (PO), non-carcinogens (NC), non-renewable energy (NRE), ozone layer depletion (OLD), phosphate resources depletion (PhRD), Potash resources depletion (PRD), respiratory organics (RO), and water depletion (WD)

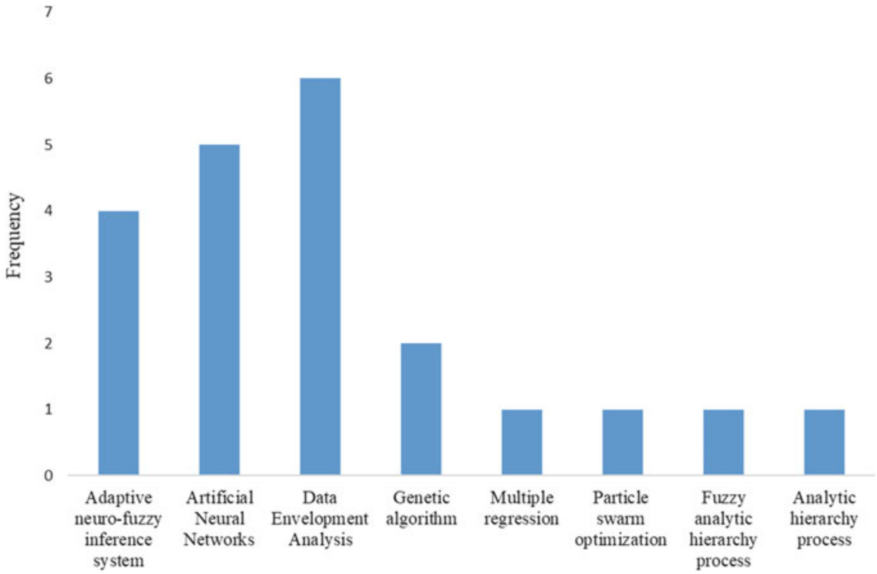

Fig. 2 Frequency of coupling other models with LCA

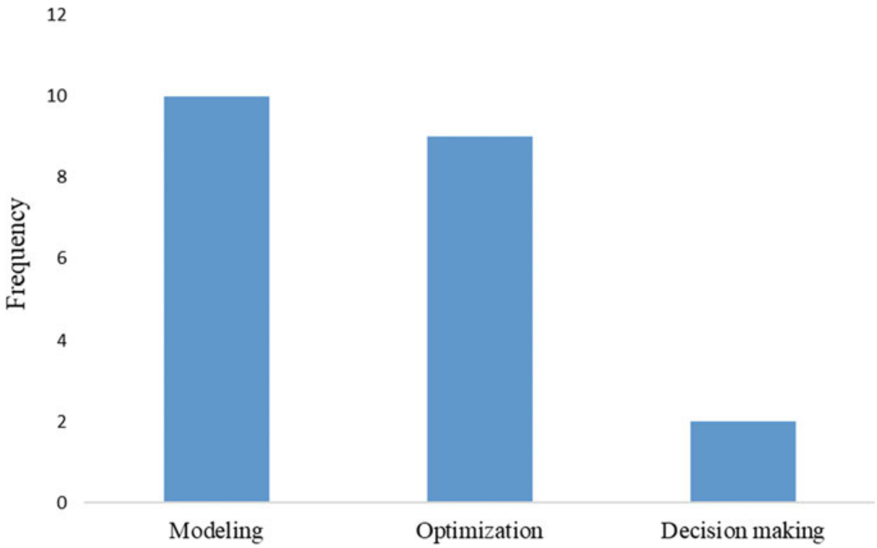

Fig. 3 Frequency of hybrid LCA application with different purposes

9 Hybrid LCA for Climate Change Mitigation of FSC

LCA has been coupled with mathematical and artificial-based intelligence approaches to model, optimize, and make decisions in various food production systems (Fig. 4). In this regard, a hybrid application of LCA with regression, artificial neural networks, and/or adaptive neuro-fuzzy inference systems can be applied to model the GWP of FSCs. The integration of data envelopment analysis, particle swarm optimization, and genetic algorithms with LCA can contribute to the optimization of a system in terms of its mitigation of the GWP. Hybrid LCA and multi criteria decision making (analytic hierarchy and fuzzy analytic hierarchy processes) is a tool for policymakers toward designing/moving toward a more environment friendly system.

An LCA + DEA framework was employed for the environmental optimization of grocery stores. The proposed framework could decrease approximately 9% of the GWP of the investigated grocery stores (Álvarez-Rodríguez et al. 2019). Pishgar-Komleh et al. (2020b) applied a hybrid LCA + DEA model to optimize the wheat production system in Poland. They indicated that there is significant potential for the mitigation of global warming caused by the system. In another study, Pishgar-Komleh et al. (2020a) modeled the obtained LCA data using artificial neural networks and subsequently applied two optimization algorithms: such as, the multi-objective genetic algorithm (MOGA) and multi-objective particle swarm optimization (MOPSO). The potential decreases of GWP according to MOGA and MOPSO were 43% and 39%, respectively.

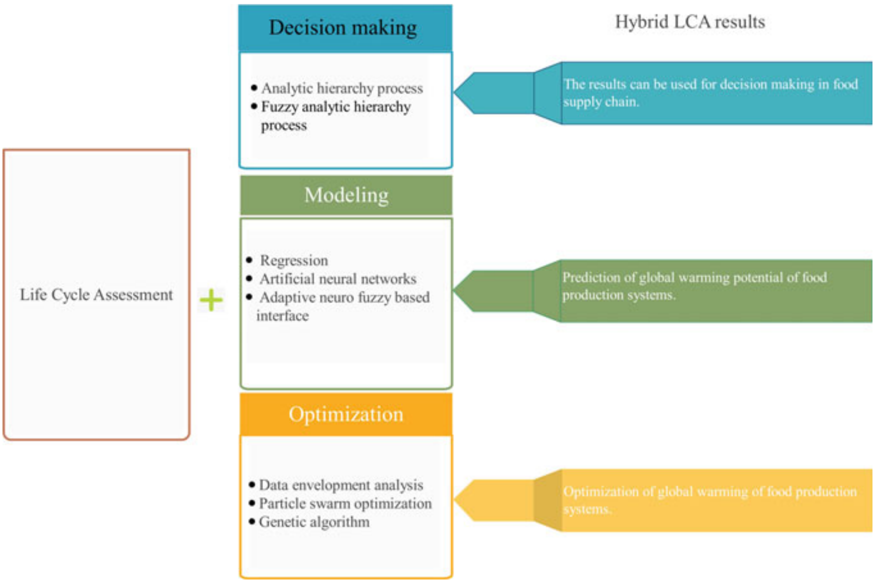

Fig. 4 Hybrid LCA for analyzing GWP of food supply chains

Hybrid LCA shows potential in mitigating the global warming effects of food production systems. However, three major issues need to be considered in hybrid LCA applications in FSCs. Few studies have been conducted on hybrid LCA + multi-criteria decision making. However, the combination of LCA + MCDM models could effectively be applied for decision-making in FSC, such as choosing an appropriate line/technology for food processing considering multiple criteria. Another issue with the hybrid application of LCA in FSCs is the data collection limitation from food processing and packaging industries. Therefore, studies concerning hybrid LCA applications of food processing and packaging are highly valuable toward designing a sustainable FSC. Additionally, to the best knowledge of the authors, there is no published document on the practical application of the recommendations based on the optimization models/algorithm of hybrid LCA studies in the food sector. Thus, further research is needed focusing on implementing the recommendations of the developed models/algorithms and evaluating their accuracies in real-life conditions.

10 Conclusions

Recent studies highlight that most food production systems are not sufficiently sustainable. In this regard, moving toward sustainable food production is essential to address the UN development goals. Several methodologies have been proposed and developed to contribute to moving towards sustainability. Among them, the LCA methodology has been widely applied to evaluate various production systems. It can also be applied by policymakers as a decision support tool to select an environment-friendly production system. GWP is one of the most important impact categories considered by LCA. This chapter presents the hybrid application of LCA for analyzing the effects of FSCs on global warming. LCA has been coupled with several methods, including regression, data envelopment analysis, the analytic hierarchy process, the fuzzy analytic hierarchy process, artificial neural networks, the adaptive neuro-fuzzy inference system, particle swarm optimization, and genetic algorithms. Hybrid LCA is a promising tool that contributes to designing an environment friendly FSC with a focus on the mitigation of global warming. Nevertheless, three issues need to be addressed in future hybrid LCA applications in FSC: (i) investigating the further potentials of the coupled implementation of LCA and multi-criteria decision making; (ii) focusing on the neglected phases of FSC, such as food processing and packaging; and (iii) further research on the practical application of the recommendations based on the optimization models/algorithms of hybrid LCA studies.

Acknowledgements The authors would like to gratefully acknowledge the financial support provided by Ghent University Global Campus.

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The Challenges of Food Sovereignty's Program by Global Climate Change in Tropical Ecosystem in Indonesia

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Abstract Destruction of the earth and global climate change has now become a painful reality. Excessive exploitation of natural resources up to 1.7 times beyond the earth's carrying capacity and contrary to nature-based development makes the dark future earth. Our earth, which is 4.5 billion years old, has been inhabited by around 7.3 billion people. The present and future population explosion require a giant leap to provide sufficient food to sustain life on earth. Lack of food, water, and energy supplies has triggered new widespread conflicts throughout the world. Located in tropical ecosystems, Indonesia is one of the megadiverse nations with the highest biological productivity in the world. However, these advantages are coming with a significant challenge. Having all of those natural potentials, Indonesia holds a crucial responsibility in global life cycle equilibration, not only in terms of environmental issues, such as climate change and biodiversity, but also a socio-economy-cultural issue. Therefore, balance management is needed to utilize the resources while preserving them for generations ahead wisely. Moreover, the challenge is even more significant with the COVID-19 pandemic, which hit the all-economy sector in the real world. In combination with the COVID-19 pandemic, global climate change could somehow obstruct the food sovereignty program that the Indonesian government has formulated. However, with solid food security and sovereignty system

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_15

integrated from upstream to downstream, Indonesia could build a strong foundation for national food sovereignty.

1 Introduction

The global population is predicted under medium growth projections to reach nine billion people by 2050 (FAO 2011). With rapid population growth, especially those in developing countries, by 2050, FAO predicts that the global food demand will increase up to 70% or even more (FAO 2011). All sectors that produce life necessities emit greenhouse gas as residues. Agriculture might not be the primary source of carbon dioxide (CO_2), but it is the leading emitter of gasses that even a hundred times more dangerous than CO_2. The anaerobic condition of agricultural soil, the use of fertilizer, and the soil management practice are the prerequisite drivers for CH_4 production (Smartt et al. 2016) and nitrous oxide (N_2O) production. It accounts for an estimated 50 and 60% of global artificial CH_4 and N_2O emissions, making agricultural activities one of the highest greenhouse gas emitters (Smith et al. 2007).

Developing countries with more citizens employed in the agriculture sector and relying on their financial income mainly from the agriculture sector are far more vulnerable to climate change than industrialized-based nations (FAO 2011). For example, with about 70% of the population relying on agriculture, Indonesia is among the vulnerable nations (Fuglie 2004). Respond to that, FAO (2011) has formulated several recommended actions to overcome those issues, they are:

1. Make a prediction right on target.
   Identify the specific type of production system in each region so that the action taker could make a better and specified prediction.
2. Education for the local community.
   Educate several essential techniques regarding modeling and climate adaptation, assist and ensure its development and application for a better agroclimatic future.
3. Think about different solutions.
   Bring up different solutions, which adapted to existing investments, and consider long-term embodied and operational energy utilization.

Food is a basic human need as life energy, derived from organic matter, which is also an element of living things (Agus 2013). Living organisms will die if they do not eat for a few days and cannot be brought back to life (Agus 2018). Present and future population booms require a giant leap to provide food security and sufficiency that is needed. The increase in food production occurred in arithmetic sequences, while population growth occurred in a geometric sequence. The realization of national food security begins with the fulfillment of food in the smallest region, namely villages, as well as strengthens the food security by objectifying food sovereignty with food resilience and food safety (Indonesia's food Law No. 18/2012 reported in Agus 2013; Bulog 2020). All stakeholders must strive for the quantity, quality, and continuity of healthy food from upstream to downstream (Pertiwiningrum et al. 2018).

Formulating an integrated sustainable farming system that constrains climate change's impact is a considerable challenge, especially for farmers used to the conventional farming system. Several new farming systems are being introduced by adapting to the local farming system and its socio-cultural habit. One of them is known as "The integrated bio-cycle farming system," which concerns community-based, prime land (soil, water, air) and biological (animal, plant, and human) resources sustainability (Agus 2018). The goal of being a whole food security nation could be achieved if agriculture is managed integrated and synergistically from upstream to downstream (Agus 2019).

Global temperature has been increasing since 1985 (Dlugokencky and Tans 2004), and it is predicted will continue to increase in these years. The greenhouse gas emissions are produced from fossil fuel energy utilization and other anthropogenic activities such as agriculture, forestry, livestock, etc. (Tubiello et al. 2014). In 2010 GHGs emission came directly from agriculture, forestry and the other land use (25%), industry (21%), transportation (14%), building (6.4%), and other energy (9.6%) sectors while 25% indirectly from industry, building, transportation, and the others for electricity and heat production. The GHGs emission grows on average by one gigatons CO_2eq per year or 2.2% from 2000 to 2010, which is greater than 1970 to 2000 on average 0.4 gigatons CO_2eq per year (IPCC 2014).

The challenge of climate change effect on extreme weather that can disrupt food supply chain (productivity and food distribution) as well as food security (availability, access, and utilization) Miranda-Ackerman and Colín-Chávez 2019). Rural areas become the most affected area in food security, and urban areas become the affected area in supply, market, and price of food. Governments and policymakers need to develop efforts for a sustainable food supply chain system. In the long term, mitigating climate change can avoid future food and livelihood systems breakdown and increase food security. Therefore, adaptation is the best practice for mitigating climate change's effect on the food supply chain system.

Biological resources in tropical ecosystems are abundant, productive, and renewable resources. Therefore, a nature based-productive and conservative resource management system will have a strategic role in realizing the environment and life on a dignified and sustainable blue earth (Agus et al. 2019a, 2020a). This chapter will discuss the challenges and opportunities for managing tropical land and biological resources in realizing food sovereignty due to global climate change.

2 Material and Methods

This chapter was analyzed using primary and secondary data from several types of research. The primary data were obtained by employing two techniques: (1) conducting direct observation of the object, (2) conducting a discussion with information sources via interviews, questionnaires, and/or focus group discussion (FGD). The secondary data were collected from reports, such as the National Statistics Center (BPS), Regional Planning Agency (Bappeda), and other agencies related to the study theme. In addition, books, journals, and other information from the internet and theories, precedents, and standards used in the field were also included as secondary data. The thematic study was considered the suitable method to identify the data, not only the current but also future issues regarding the challenges of food sovereignty's program by global climate change in tropical ecosystem in Indonesia.

3 Results and Discussion

3.1 Tropical Forest and Biodiversity

Indonesia is the world's third most biodiverse country after Brazil and Colombia (Bappenas 2016). Indonesia has approximately 89,326 vascular plants that reproduce with spores, including ferns, and 27,500 species of flowering plants (Spermatophyta). Indonesia's contributing factors to high biodiversity is that Indonesia has a tropical climate, and its geography situates it as an archipelagic country, with around 17,504 islands, land, and water areas 8,300,000 km^2, and a coastline of 108,000 km. The second, Geologically, Indonesia is part of the Pacific Ring of Fire, where many active volcanoes affect the dynamics of geological processes and their ecosystems. Third, the topography of Indonesia varies significantly from the narrow to the broad as well as from the flat, hilly, and mountainous, demonstrating the rich, highly diverse ecosystems with various types of plants (Bappenas 2016).

Tropical forest ecosystems play a significant role as the 'lungs' of the earth that continually offer benefits through their environmental services, i.e., the provision of oxygen, freshwater, pollination services, soil formation and retention, nutrient cycling, pollution control, and global carbon stocks (Alkama and Cescatti 2016). About 10% of the Earth's surface is covered by tropical forests that store terrestrial carbon and terrestrial gross primary productivity (GPP) of 25% and 34%, respectively (Malhi 2012). Of the total carbon or energy produced by forest plants through the process of photosynthesis in the form of gross primary production (GPP), more than half of it will be used by plants, while 30–40% of net primary productivity (NPP) included the canopy, wood, and fine roots (Corlett 2016).

Tropical forests play an essential role in greenhouse gas mitigation due to their high carbon storage and sequestration productivity. The availability of sunlight all year round and optimal temperature and humidity support the photosynthesis process and store them in the form of above and/or belowground biomass (Agus et al. 2019a). Tropical forests also can reduce the evapotranspiration rate by evaporative cooling directly so that earth's temperature can be lowered. In contrast, the indirect effect of lower evapotranspiration rate is on the formation of clouds and rain, reducing sunlight to the Earth (Bonan 2008).

Conversion of tropical forests for other land causes biodiversity damage significantly (Agus et al. 2020b). The main driver is deforestation and forest fragmentation due to land use application for agricultural (FAO and UNEP 2020). Nevertheless, it is mainly caused by complex social, economic, institutional, political, and technological interests (Schneider and Neupane 2016). Deforestation leads to habitat destruction and ecological imbalance, eventually causing a reduction in forest species' diversity, even for rare and endangered species (Morris 2010).

3.2 Biodiversity of Tropical Agricultural and Food Commodities

Biodiversity is crucial for safeguarding national food security in the future by providing a variety of natural, nutritious, and healthy foods for humans. The availability of foods does not necessarily rely on their quantities or calories but also nutritional value such as vitamins, minerals, and other micronutrients (Eghenter et al. 2018). Besides, there is a paradigm shift in which modern people prefer to use natural products, including medicinal plants, directly.

Indonesia is rich in a variety of local crops that can supplement rice as the leading staple food. About 470 local genetics were identified as having potential food sources, including cassava, arrowroot, breadfruit, corn, sago, potatoes, sweet potatoes, and taro (Cahyanto et al. 2012). Efforts to reduce people's dependency on rice motivate them to re-explore the potential of natural food resources and elevate their values to be noticed and utilized widely. Tubers are potential food sources rich in carbohydrates and have been cultivated widely and processed into various foods. A smallholder agroforestry system with multispecies helps optimize land and environmental services and supports national food sovereignty in providing various food products (Neal 1965; Walujo 2011).

The Indonesian Agency for Agricultural Research and Development has collected 1,330 accessions of cereals that consist of 892 accessions of corn, 225 accessions of sorghum, 147 accessions of wheat, and 66 accessions of barley in 2018. Rice is the primary food of agricultural countries and almost one-third of the world's total amount of food. It is also a staple food where more than 2.7 billion people consume 35–60% of its calories.

Indonesia is an agricultural country that does not necessarily prevent it from catastrophic crises in food demand. The government attempts to overcome this issue by establishing the food sovereignty program by threatening the sustainability of Indonesia's biodiversity and encumbering food sovereignty. First, the depletion of agricultural land due to land conversion into settlement and industrial space has been a serious menace and challenge to sustain the food resilience of the nation (Triyono 2013). Second, exploitation and excessive use of biodiversity, not to mention illegal activities. Third, habitat destruction is caused by using hazardous materials to utilize natural resources, i.e., heavy metals that potentially contaminate the environment

(Indrawan et al. 2007). Fourth, habitat fragmentation and habitat degradation. Fifth, pests and diseases, alien species, sixth, social factors are increasing the population growth rate. Seventh, relatively low educational socio-economic backgrounds in most Indonesian people heighten the pressure on biodiversity. Eight, limited research and innovation on the potential of natural resources and their products. Ninth, regulations that only partially relate to several aspects.

For breeders, the latest climate global becomes a big challenge for creating high-yielding and adaptive varieties. The effects of climate change have been linked to several extreme events, i.e., the outburst of pests and diseases, soil acidity, prolonged dry season, El Nino, relatively short rainy season, and heavy rainfall occurrence of floods and landslides. Such events also affect organisms, populations, and ecosystems. Thus, climate change has changed the ecosystem. Smith and Smith (2000) stated that climate almost influences ecosystems, such as productivity, the competitiveness of species, cycling of nutrition, physiological responses and behavior of living things, population growth, and community structure.

Regarding the biodiversity of foods related to the changing climate conditions, several technological-based research and innovation approaches are necessary and mainly prioritized in the activities. The first is inventory, characterization, and the valuation of biodiversity for food, mainly related to climate factors and environmental stress. Second, product and food production processes from plants, crops, livestock, and microbes using modern technology and innovation. Third, the modification of food raw materials through tissue culture propagation, breeding, genetic engineering, and bioprocess technology creates superior varieties. Fourth, discovery and refinement of local community knowledge about biodiversity-based food diversity (Walujo 2011). Finally, to address future challenges in the agricultural sectors, mainly due to climate change, it is crucial to synergize various stakeholders in initiating effective, efficient, and sustainable exploration and management of biodiversity.

3.3 Food in Tropical Ecosystem

Forest landscapes and other areas with tree cover provide much wild food, which is very important for people who depend on forests, including indigenous people, for an essential part of their diet (HLPE 2017). Wild foods, e.g., vegetables, fruit, and animal source foods, are essential for food security and nutrition (Sunderland et al. 2013). Forests themselves have an essential role in providing ecosystem services. Forests also contribute in the percentage of calories food no directly by preventing micronutrient deficiencies (iron, vitamin A, vitamin C, folate, calcium) deficiencies (Asher and Shattuck 2017).

The most robust and most continuing challenge is producing enough food for the growing living things in the world. Food availability in the future will depend on the availability of inputs, including available agricultural land. Agricultural land sometimes referred to as ‘rural facilities’, is crucial because it provides scenery, wildlife, recreation, and open space to benefit the community. Securing food security, which is focused on increasing and expanding agricultural production, is a critical dimension in protecting agricultural land in the future. Without land, there is no opportunity to improve agricultural practices and produce sufficient food (Sunderland et al. 2013).

Some suggest that we have grown enough food, and food scarcity is also caused by inadequate distribution. Thus, emphasizing forest and agricultural land use alone is not enough to guarantee future food security (Sunderland et al. 2013). In this case, food sovereignty can be a solution if every country maintains and develops its essential food through environmentally friendly and sustainable methods (Patel 2009). This concept is a prerequisite for genuine food security at a national level and a meaningful step to overcoming the climate crisis. The concepts also become part of cultural dan environmental preservation.

Life cycle analysis (LCA) enables quantifying carbon footprint (CO_2-equivalent per kg of product) contribution in different agricultural food production methods that give climate change risks (Litskas et al. 2020). Practicing food sovereignty can reduce the carbon footprint because of the promotion of producing food within and for their territories, which means shorter food transportation distances. Short-distance food transportation in practicing food sovereignty is another way to reduce the carbon footprint because long distances transportation of food emits total carbon in food production, distribution, and storage pathways from a few to more than half percent (Wakeland et al. 2012).

With a rapidly developing population and climate change, pressure on the increase in the food production system in the coming decades. Water scarcity also reduces crop productivity, so that it should be noted that water counts throughout the product life cycle are increasingly prominent (Fitton et al. 2019). Food production in agriculture is an activity that consumes water, contributing 99% of the global consumptive water footprint. In other words, total water is used for food production (Mekonnen and Hoekstra 2014). The promotion of native plant cultivation in the practice of food sovereignty can reduce the water footprint. Ledezma (2020) reported that food crops like corn, potatoes, cassava, tomatoes, peanuts, and chocolate are over-consumption globally, while many other native or local food plants have not been explored well even though these plants are more robust resistant to climate change and food security and also potential as innovative food products and derivatives.

Agus (2018, 2019) practiced the Integrated Bio-cycle Farming System (IBFS) by managing land resources (land, organic, mineral, water, air, temperature, etc.) and biological resources (animals, plants, humans, and other living organisms) in an optimally integrated management. The balance of production and consumption must be developed in one land management unit (Cahyanti et al. 2017, 2019) to produce food, feed, fuel, fertilizer, wood, water, oxygen, medicine, tourism, etc. (Agus et al. 2013, 2019a). IBFS provides environmental values, aesthetic values, social values, cultural values, and economic values in harmony and balance, without anyone dominating. IBFS is also carried out with a crop rotation and diversity system that are maintained knowledge-based development to support the sustainable and dignified life and environment (Agus et al. 2019b).

3.4 *Bioeconomy and Strategies for Food Security*

Anderson (2018) argued that there are three conditions to state that our agricultural system is sustainable. First, it can meet demand with acceptable farm-level economic and environmental costs. Second, it leads to acceptable economic and environmental costs for costs beyond the farm gate. Third, it meets some criteria for equity that societies agree on, especially for intergenerational equity. Bioeconomy is defined as an economy that considering the use of materials from renewable resources in all activities (McCormick and Kautto 2013). The sustainable need of humankind mainly drives the global trend toward bioeconomy in the future on the security, sustainability, and safe availability of food, energy, water, industrial raw materials, and efficient utilization (Braun 2018). Innovation and bioeconomy are also called the key tools expected to lead sustainable economic growth (Kristinsson and Jörundsdóttir 2019). However, the implementation bioeconomy is a challenge. Bioeconomy is the solution to creating new eco-friendly products, but on the other hand, it must compete with food to obtain raw materials. It is a dilemma because the rapid development of the biofuel industry in the world threatens food security (Subramaniam et al. 2019). Then, excessive utilization of biomass for bioenergy also worsens food availability (Braun 2018).

The food insecurity issue due to the development of bioeconomy arises because of some factors. First, the biomass production cost tends to increase (due to water scarcity), impacting higher food prices and food security in the coming years (Rosegrant et al. 2013). Second, both use the same feedstock for production, so that it triggers competition. If sizeable percentages of food crops are used for biofuel production and sacrifice food production, it will create food scarcity for consumption, rising food prices, threatening food security, and pushing the hunger level to be more serious (Subramaniam et al. 2019). However, they believed that losses in food security due to biofuel growth would only occur in the short term. The existence of strategies and innovations in technology, such as biotechnology, nanotechnology, modern irrigation, and many others, eliminates negative impacts and, on the contrary, brings benefits to food availability, utilization, and stability in the long run. Bioeconomy and food are inseparable in the production process; if bioeconomy grows sustainably, food production must also be sustainable and vice versa (Kristinsson and Jörundsdóttir 2019). Therefore, to overcome the trade-off between them, the first is to increase agricultural productivity (Braun 2018). Second, it is better to look for new types of biomass for bioeconomic to avoid competition for obtaining raw materials that is sensitive to food security. Finally, government intervention is needed to create policies to maintain price stability to achieve food security.

Almost every country in the world faces a lack of food. It varies depends on the population growth to climate change (Srivastava 2019). The International Food Policy Research Institute (IFPRI) states that global demand for food will increase around 90% between 2015 and 2030, especially in less-developed countries (LDCs), i.e., Asia, Africa, and Latin America (Anderson 2018). Instead of being profitable, without innovation, an increase in food demand will lead to new problems related to land availability and food price stability, which threatens food security. Wollenberg et al. (2016) argue that one of the biggest challenges to food security in the twenty-first century is climate change. Unpredictable weather due to climate change impacts many sectors both in developed and developing countries, such as agriculture, industrialization, and economic status (Srivastava 2019).

There are four dimensions of food security interrelated to climate change directly or indirectly, i.e., availability, accessibility, utilization, and stability (Srivastava 2019), namely:

(1) Availability, climate change reduces local food availability through damage to various nutrients in the soil. It results in a decrease in soil quality and soil fertility, which will hinder food production. The reduced production is also driven by an increase in pests and diseases due to uncertain environmental changes.
(2) Accessibility is related to people's ability to access food caused by factors such as purchasing power and food prices. So, how does climate change affect accessibility? Through disturbance in food distribution. Damage to the transportation system due to climate change causes chaos in the food supply, increasing food prices.
(3) Utilization, food utilization is related to food quality. Climate change impacts food safety through the supply chain and health status. Food intake with low rates of protein and micronutrients due to changes in income and consumption patterns is one factor influencing health status.
(4) Stability is how to protect food availability, accessibility, and utilization to remain stable in uncertain environmental changes. For example, various disasters caused by climate change, such as floods and drought, disturb food production variability and lead to instability.

Besides being a player, climate change also plays a role as a victim in this food security issue. Bellotti et al. (2018) argued that our food and agricultural activities contribute 30% to greenhouse gas emissions. It implies a need for smart innovation in our food systems to reduce emissions and tackle the global demand for food. Unfulfilled demand in food, for example, due to lack of supply or hard to access, cause humankind to be in big chaos, namely hunger (Subramaniam et al. 2019). Therefore, a giant leap should be made to achieve food security and sustainability.

3.5 Food Supply Chain

Food systems are related to demanding and supplying food, which ensures food production, processing, marketing, and consumption activities (Abu Hatab et al. 2019). The supply chain is responsible for ensuring that food reaches consumers through an efficient process. Our food supply chain has faced considerable challenges so far. Supply chain management means discussing how activities from the procurement of raw materials to the distribution of end products to consumers are integrated efficiently. Optimizing performance in each chain of activities is an integral part of creating stability in the food supply. Saptana and Darmawati (2019) mention that some classic problems often occur in the food supply chain, especially rice, in Indonesia. First, yield loss rates are still high, and the quality of grain and rice produced is also still low. Second, planting time is still carried out simultaneously in certain seasons. It causes a surplus of supply during the harvest season and a supply shortage during the famine season. Third, the distribution system from producers to consumers is still in a mess, which causes uneven food availability between regions. Fourth, logistics costs are still high. Finally, there are obstacles to handling crop yields, staging, storage, cooling processes during post-harvest, packaging, tracking, and inventory control issues.

Putri et al. (2019) argued that today's Indonesian rice supply chain problems are related to downstream activities, i.e., processing and marketing. They believe Indonesia is no longer in problem with the on-farm process because various government policies have been intensively carried out to achieve self-sufficiency in grain. These policies range from irrigation assistance to seed and fertilizer subsidies. However, they state that efforts to reform the downstream activities had not been carried out optimally. Both are interrelated activities in which the grain produced from the on-farm process must be processed first through the processing or grinding to become rice and ready to be distributed to consumers. They believe that the rice milling industry and distribution chain play a crucial role in determining the price, quality, and quantity of rice produced.

Rice milling has a central role in the supply chain system because the quantity or yield of rice and the quality of rice and by-products (for example, husks, bran, *menir*) are determined in this stage (Putri et al. 2019). However, the problem of idle capacity causes the process to be inefficient. In addition, technological issues and the renewal of tools also impact the low yield of rice, such as the rice yield level in Central Java, which is only 62.74% (Saptana and Darmawati 2019). The next problem is the extended supply chain or food distribution chain in Indonesia. In Central Java, there are 6–7 actors in the rice supply chain, namely farmers, grain collectors, rice mills, inter-regional wholesalers, wholesalers in market centers, and retailers (Saptana and Darmawati 2019). In Bolaang Mongondow–North Sulawesi, supply chain actors start from farmers, mills, collectors, retailers, and end consumers (Tiwu et al. 2019). However, in general, the main distribution patterns of rice trade in Indonesia are producers, wholesalers, retailers, and end consumers (BPS 2019).

The extended supply chain from farmers to end consumers, such as in Central Java, impacts low grain prices at the farm level and high rice prices at the consumer level (Saptana and Darmawati 2019). The distribution chain also creates a rice Trading and Transport Margin (TTM). Based on BPS (2019), the total TTM received by rice traders in Indonesia reached 20.83%. It shows an increase in rice price by 20.83% from the producers to the end consumers in Indonesia by involving the main business actors are wholesalers and retailers. As a result, Indonesian rice's prices are pretty high compared to neighboring countries in Asia. Databoks (2020) reported that local Indonesian rice has a price of US$ 0.79 (Rp. 10,665) per kg in 2017 that faces obstacles related to logistical competitiveness. The Indonesian Logistics

Performance Index (LPI) in 2018 is ranked 5th in ASEAN with a score of 3.15 (World Bank 2020).

The biggest challenge is uncertainty and risks, from product to market (Lezoche et al. 2020). Esteso et al. (2018) stated that there are four uncertain parameters in the supply chain. First, uncertainties in a product: in this case, uncertainties related to food quality, food safety, product shelf life, product heterogeneity, and deterioration rate. Second, uncertainties in the process: uncertainties occur from the harvesting process to production, i.e., supply characteristics, lead time, resource needs, costs, and production. Third, uncertainties in the market: uncertainty of the supply chain in the market ensures the demand and prevailing market prices. Fourth, uncertainties in the environment: the extreme uncertainties are related to the weather, pests, diseases, and regulations. If not handled properly, these uncertainties will cause a variety of food chaos. The new technology development in the food supply chain is needed to deal with these uncertainty problems. Various digital-based technologies have been developed in recent years, such as the Internet of Things (IoT), Big Data, Blockchain, Cloud Computing, Robotics, and Artificial Intelligence (Lezoche et al. 2020; Astill et al. 2019).

Agri-Food 4.0 become an innovation as an intelligent technology developed for future agriculture (Lezoche et al. 2020). Based on digital innovation, this technology enables the food supply chain to run automatically from the farm to the fork, information is obtained in real-time, production costs become lower, food prices become reasonable, purchasing power increases, and farmers prosper. This technology uses sensors and drones to make it possible to obtain accurate data, such as pests and diseases, weather, harvest time, and others. Agri-Food 4.0 is a solution to reduce uncertainty and risk problems so that the food supply chain can run efficiently and sustainably. Uncertainty arises because there is no transparency. Transparency makes processes in the four parameters (product, process, market, environment) more traceable, thereby improving sustainability (Astill et al. 2019). Therefore, using digital-based technologies in the supply chain can solve a transparent supply chain (Astill et al. 2019).

Astill et al. (2019) stated that using IoT-connected sensors becomes a strategy to improve transparency in food systems because partners, stakeholders, and consumers can oversee the whole process through real-time data availability. They also suggest combining blockchain and big data technology to achieve a more efficient supply chain. Blockchain can be used as a security for financial transactions, while big data can be used as a source of data to analyze the market (Astill et al. 2019).

PT. BUMR "*Pangan Terhubung*" is a farmer corporation that implements technology in the food supply chain. This corporate runs the business from upstream to downstream, from planting to marketing, including establishing cooperation contracts from farmers to consumers. BUMR contributes to changing the conventional supply chain to digital technology "Smart Farming *iPangan*" to survive in Industry 4.0.

The digital-based technology concept offered by BUMR is, that combines IoT and Big Data, making it possible to monitor input and output processes in an integrated and real-time. This technology enables us to collect data precisely related to vital agricultural aspects, such as weather, soil moisture, solar intensity, pests and diseases, land mapping, yield prediction. Using this application will also benefit consumers. Consumers can easily track where the food they consume comes from to guarantee the quality of food. This application also closes the possibility of brokers in the distribution chain becoming more competitive than traditional. With this food system, excess stock or supply problems, which often cause food prices to become unstable, can be reduced. It is because the process of data collection in real-time can be done with this system. Therefore, the goal of achieving food security and sustainability can emerge.

3.6 Indonesian Food Sovereignty

Food Security is defined as a condition at an individual level that has been fulfilled quantity and quality food. Thus, every individual gets safe, diverse, nutritious, equitable, and affordable food for healthy, active, and productive life (UN-WFP 2015; Pertiwiningrum et al. 2018).

Food sovereignty is the right of the state and nation so that the nation can determine food policy to guarantee the right to food for all people by the potential of local resources (Bulog 2020). Whereas Agarwal (2014) stated that food sovereignty is the right of peoples to produce healthy through ecologically and sustainable methods.

Food independence is defined as the ability of the state and nation to produce various kinds of food to ensure the fulfillment of sufficient food needs at the individual level by utilizing the potential natural and social resources.

So far, some foodstuffs are still imported even though they have started to decline, such as corn, meat, onions. Indonesia has a natural ability to produce itself. Programs must focus on sources of food vulnerability through extensification, intensification, breakthrough innovations, and empowering farmers to help themselves independently. Increasing food production must also be able to improve the welfare of farmers. Indonesia relies more on the advantages and advantages of "equatorial emerald" as a giant earth factory known to have the highest biological productivity in the world, about ten times the biological productivity in temperate regions, including the United States. The strategic effort towards Indonesian food sovereignty based on *Nawacita* is reasonable enough but still conventional. There are by creating agricultural attractiveness for young workers, rehabilitating 3 million ha of damaged irrigation networks and 25 dams, reducing the rate of conversion, exploiting ex-mining land, distributing 9 million ha of land to farmers, restoring the quality of fertility of polluted land, expanding rice fields only 1 million ha and 1 million ha of dry agricultural land outside Java-Bali. The program is also supported by forming Food Authority Agency, Technopark and science park, the National Innovation System, 1,000 sovereign seed villages and 1,000 organic farming villages, as well as a unique bank for agriculture-SME-Cooperatives (Indonesia 2020).

At the technology level, bio-nanotechnology is used to improve land resources (soil, water, minerals, micro-climate, etc.), biology (animals, plants, humans, and other living things). Besides, the neglected environment to support food self-sufficiency in the future will, of course, be a "Blue revolution" that will shake the world even more (Agus et al. 2019c). Therefore, the development of Innovation Center in the field of Agro-Techno-Park in leading universities and agricultural R&D need to be developed in order to become a national reference in achieving a structured and accurate national food sovereignty program (Agus 2013).

Indonesia can reach a resilient food country if integrated village development locomotive, agriculture, is managed in a synergic and reasonable manner upstream and downstream. It has been seen as a fundamental program orientation, not merely as a project orientation. Not only can it meet domestic needs, but it can also be exported to provide added value to the national economy. To become a new, dignified, and sustainable superhero sector in managing land (land, water, air) and biological (animal, plant, and human) superior local, community-based resources. Production, consumption, and distribution management must be managed and synergized with all stakeholders comprehensively. Everyone must play a role and contribute significantly to the common interest, not just spectators, let alone losers. Indonesia must win the competition from the Asean Economic Community (AEC) next year by exporting food, not by invading imported products.

4 Conclusions

Tropical ecosystems play an essential role in all aspects of life, such as global climate change, biodiversity, life cycle, food supply chain, bioeconomic, environment, social culture, and environment. Global climate change that caused a lack of food, water, and energy supplies has triggered new widespread conflicts throughout the world. The integrated bio-cycle farming system can become a new key for the national economy to manage resources, prime land (soil, water, air), and biological (animal, plant, and human) resources. Global climate change and the COVID-19 pandemic maybe have delayed the food sovereignty program, but the agricultural sector continues to have positive growth. Indonesia can have strong food security and sovereignty system if agricultural management from upstream to downstream is synergistic and profitable as a locomotive for integrated village development. Research and genuine efforts from all parties are needed to mitigate climate change and Covid-19 disasters to achieve food security and sovereignty.

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Climate Change Risk Assessment and Adaptation Measures in the Food Supply Chain—Perceptions and Responses of Buying Firms

Esther Hoffmann and Patrick Schöpflin

Abstract Food supply chains (SC) are vulnerable to the effects of global warming, including changing temperature and precipitation patterns and increases in extreme weather events. To deal with these risks companies must increase SC resilience. Buyer perceptions are analyzed with respect to the effects of climate change and their implementation of resilience practices. Focusing on the coffee, fish and seafood, and fruits and vegetables sectors, 17 semi-structured interviews were completed with buyers and other stakeholders and two workshops organized. The findings indicate that importing companies are generally aware of the risks of climate change. Most consider flexibility practices such as a flexible supply base or ad-hoc adaptation of the product portfolio to be sufficient to tackle current climate change risks. Additionally, many are engaged in collaboration with suppliers and some with actors outside the food SC (e.g., research bodies). Current measures are suitable for addressing disruptions and shortages similar to those already experienced, but to address the transformative consequences of extended climate change, strategic approaches are needed that include the establishment of a risk aware culture in companies and practices that enhance adaptability across the entire SC. To date a few of the analyzed companies, along with an industry-wide initiative in the coffee sector, are realizing these approaches, but many only see a need for strategic and transformative action in the mid- to long-term.

1 Introduction

Adverse weather events and conditions are responsible for about 40% of all supply chain (SC) disruptions (BCI 2018). In the last 35 years, the average trend curve of weather-related global natural catastrophes has risen by a factor of three (Hoeppe 2016) and the inevitable impact of climate change will include an increase in the number and intensity of extreme weather events in the next decades (Field et al. 2012). Turbulence, such as disruptions due to natural disasters, are generally identified as

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_16

an important vulnerability factor for SCs (Pettit et al. 2010). Food SCs are especially at risk due to the high sensitivity of food products to weather conditions and climatic changes. The 2016/17 winter, for instance, led to a 60% decline in European vegetable production due to heavy frosts, flooding, and snowfall; as a result, overall prices for vegetables increased as the supply declined (Gore-Langton 2017). An ability to adapt to a changing climate is thus crucial for ensuring the resilience of the food SC today and will gain in importance as the effects of climate change increase in the future. This ability to dynamically adapt to a changing environment is an important aspect of Supply Chain Resilience (SCRES).

Strategies to increase SCRES can be further differentiated according to the cyclical phases of disruption (e.g. Stone and Rahimifard 2018). In the phases well before (readiness or preparedness) and after disruption (adaption or growth), proactive strategies predominate. During the immediate response and recovery phases, the focus is on reactive strategies to cope with the disruptive event (Scholten et al. 2014). The majority of definitions of SCRES focus on the ability to respond to and recover from an acute disruptive event (e.g. Paloviita 2015; Stone and Rahimifard 2018); however, in the context of climate change, the ability to prepare for and adapt to long-term changes such as rising temperatures and sea levels is at least as important for SCRES. For the purposes of the presented research, the definition of strategic resilience is applied as proposed by Manning and Soon (2016) in their work on resilience in the food SC: "*Strategic resilience is not about responding to a single crisis or rebounding from a setback, it encompasses anticipating and reacting to secular trends that can permanently impair the earning power of the core business*" (Manning and Soon 2016, p. 1480).

Food SCs, moreover, are characterized by international trade; thus the scope of climate change must be considered beyond regional borders. In analyzing the resilience of food SCs, other researchers have already noted that buyers, processors, and manufacturers are better positioned to address the risks of climate change than those further upstream (de Sá et al. 2019; Paloviita 2015). To gain insights into how a food SC can become more climate resilient, it must be understood, first, how climate change drives food SC vulnerability, and second, which abilities food SCs need to adapt to the changing environment (Pettit et al. 2010). The research is thus seeking to answer the following research questions:

1. How do buying firms and other stakeholders perceive climate change impacts in the food supply chain?
2. What kind of adaption measures are buying firms implementing to address these impacts and to increase supply chain resilience?

In seeking answers to these two questions, the focus was set on food manufacturing companies in Bremen, located close to the North Sea coast in Germany. The State of Bremen, with its eight ports, is an important transshipment center and home to a substantial food and beverage industry. In terms of import value, foodstuffs are among the German state's most important imports. Coffee, fish, and seafood, in particular, but also fruits and vegetables are imported in large quantities (Destatis, Statistisches Bundesamt 2018). For import goods SCs, the vulnerability to the effects of climate change in the country of origin influences overall SC vulnerability to a large degree. Among the chosen product groups' countries of origin are many that are vulnerable to climate change according to the Notre Dame Global Adaptation Index (Notre Dame Global Initiative 2018).

The conducted research contributes to the understanding of SCRES in the context of climate change by offering empirical insights into climate change impacts and adaption measures in food SCs. In the case study, elements of SCRES that are important in preparing for the impacts of climate change are identified. The results can serve as a starting point for a stronger integration of climate change adaptation measures into the concept of SCRES and for strengthening the role of proactive strategies. Moreover, companies involved in food SC activities can find indications for developing and implementing suitable adaptation measures to reduce the effects of climate change and minimize disruptions.

2 Conceptual Background

Climate stimuli and impacts are powerful drivers of food SC vulnerability. Rising temperatures and changing rainfall patterns pose a challenge for the cultivation of agricultural products such as coffee, fruits, and vegetables (Bresser et al. 2005; Pommerening and WWF 2015; Watts 2016). Extreme weather events, including temperature shifts in both directions, but also droughts, heavy rain, flooding, and storms jeopardize crop yields and negatively impact the food manufacturing sector (Harvey et al. 2018; Panhuysen and Pierrot 2018; Webb et al. 2014). By 2050, for example, areas suitable for the cultivation of Arabica and Robusta coffee are projected to decrease by 49% and 54% respectively (Bunn et al. 2015; Panhuysen and Pierrot 2018). The cultivation of fruits and vegetables is negatively influenced by hail, fire, and soil salinization (Bresser et al. 2005; Webb et al. 2014). The fishing industry is affected by rising sea temperatures, ocean acidification, sea level rise, and decreasing seawater oxygen content (Altieri and Gedan 2015). In combination with changes in ocean currents and non-cyclical current systems (e.g. El Niño), primary fish production is expected to decline. In terms of extreme weather events, the fishing industry is mostly affected by storms, drought, flooding, and storm surge (Barange et al. 2018; Roberts et al. 2019). Overall, a 2 °C increase in average air temperature is projected to result in a total loss in global fish catches of more than 17 billion USD by 2050 (Roberts et al. 2019; Holmyard 2014).

The general ability of a SC to cope with vulnerabilities and adapt to a changing environment can be characterized as SCRES. This also includes adaptations to climate-driven changes as described above. The literature presents manifold categorizations of elements and associated practices for enhancing SCRES. For the purposes of the study, the framework established by Stone and Rahimifard (2018) was applied that identified elements and associated practices to enhance SCRES by conducting a literature review of resilience in agri-food SCs. Their framework includes the following elements:

Flexibility: The ability to adapt to changing operating environments and customer requests (Stone and Rahimifard 2018), it encompasses practices that enhance adjustability in sourcing and order fulfillment (Pettit et al. 2010; Stone and Rahimifard 2018; Tukamuhabwa et al. 2015). *Redundancy* is also subsumed under this category as it involves the duplication of capacity in order to continue operations during a system failure and can thus be considered a route to greater flexibility (Tukamuhabwa et al. 2015).

Collaboration: The ability to work with other actors to generate a mutual benefit that could not be achieved individually (Pettit et al. 2013; Stone and Rahimifard 2018). Collaboration practices can involve information-sharing, sharing and creation of knowledge, and joint relationship efforts (Paloviita 2015; Scholten and Schilder 2015; Tukamuhabwa et al. 2015). SC collaboration can help to build strong networks and enables SC partners to support each other during a disruptive event (Tukamuhabwa et al. 2015).

Agility: The ability to respond quickly to changes in demand or supply, which mainly involves *visibility* and *velocity* (Tukamuhabwa et al. 2015). *Visibility* includes practices that aid in the availability of information and refers to the ability to see structures, processes, and products throughout the entire SC (Stone and Rahimifard 2018; Tukamuhabwa et al. 2015). *Velocity* focuses on the pace of adaptations and determines the speed of SC recovery from a disruptive event (Tukamuhabwa et al. 2015). Since the focus here is on proactive strategies, only visibility is considered, as velocity is mainly relevant in the phases of response and recovery.

Risk aware culture: Managing risk by means of suitable infrastructures, such as an early warning system, and developing a culture that encourages and enables organization-wide learning and adaptation from past disruptions. Leadership support is an important enabler for this element (Stone and Rahimifard 2018).

Security: The defense of assets (including knowledge, staff, and physical assets). In the literature this is most often addressed with respect to defending against deliberate attack or intrusion (Pettit et al. 2010; Stone and Rahimifard 2018). In the context of climate change, technical and organizational measures to defend against impacts of climate change need to be included.

Adaptability: The ability of a SC to transform itself in a changing environment. The ease or difficulty with which this can be done depends on the internal organizational structure of the SC, including its network design, and the creation of a SC identity, e.g., through policies, inter-organizational culture, and human resource structures. An adaptable SC improves resistance against external forces and enhances co-learning throughout the network (Pettit et al. 2010; Stone and Rahimifard 2018; Tukamuhabwa et al. 2015).

A certain amount of interplay exists among the various elements. Certain collaboration practices may strengthen or adversely affect other aspects, such as flexibility. Most can be clearly associated with either the organizational or supply chain level. Only flexibility applies to both, but with different practices. Table 1 summarizes the elements of SCRES to climate change, including definitions, exemplary practices, and applicable level, used for the empirical analysis.

Table 1 Elements of supply chain resilience to climate change

Elements of supply chain resilience	Definition	Exemplary practices	Level
Flexibility	Ability to adapt to changing operating environments and customer requests and to build in redundancy in the SC	Flexible supply base, alternate distribution channels, portfolio diversification, substitute ingredients	Supply Chain (SC)
		Alternate production capacity, order fulfilment flexibility, duplication of capacity, strategic use of spare capacity and inventory	Organizational
Collaboration	Ability to work with other SC actors to generate mutual benefit not individually achievable	Risk-sharing protocol, sharing and creation of knowledge, resource-sharing, incentive alignment	SC
Visibility	Ability to see structures, processes, and products through the entire supply chain	Monitoring tools to map the SC, channels for the sharing of risk information	SC
Risk aware culture	Infrastructure to manage risk and developing a business culture that encourages and enables organization-wide learning and adaptation from past disruptions	Early warning system, leadership support, strategic integration of climate risks	Organizational
Security	Defense of assets including knowledge, staff, physical assets	Greening of buildings, adaptation of cooling technology, adaptation of workflows and working hours	Organizational
Adaptability	Ability of a supply chain to transform itself in response to a changing operating environment	Network design, supply chain identity (e.g., culture, policies, skills, human resource structures)	SC

Based on: Paloviita (2015), Pettit et al. (2010, 2013), Scholten and Schilder (2015), Stone and Rahimifard (2018), Tukamuhabwa et al. (2015)

3 Research Method

In order to gain insights into the potential impacts of climate change on various SCs and applied adaptation measures, 17 semi-structured interviews with importing companies and further stakeholders were conducted (see Table 2). One to three

Table 2 Overview of information on interview participants

Company/Organization	Supply chain involvement (steps)	Size of business[a]	Role of interviewees
Coffee (C1)	Import, Processing, Trade	Large	Sustainability Management (2x)
Coffee (C2)	Import, Processing, Trade	Small	Managing Director
Coffee (C3)	Import, Trade	Small	Sustainability Management
Coffee (C4)	Industry initiative	N.a.	Managing Director
Fruits and Vegetables (F&V1)	Trade	Medium[b]	Managing Director
Fruits and Vegetables (F&V2)	Trade	Medium	Quality Management, Marketing and Communication
Fruits and Vegetables (F&V3)	Import, Trade	Small	Purchasing Manager, Managing Director, Sustainability Management
Fruits and Vegetables (F&V4)[c]	Cultivation, Import, Processing, Trade	Large	Research and Development, Quality Management
Fish and Seafood (F&S1)	Trade	Large	Sustainability Management (2x)
Fish and Seafood (F&S2)	Import, Processing	Large	Quality Management
Fish and Seafood (F&S3)	Import, Processing, Trade	Large	Marketing and Communication
Fish and Seafood (F&S4)	Industry initiative	N.a.	Managing Director
Fish and Seafood (F&S5)	Processing	Medium	Managing Director
Fish and Seafood (F&S6)	Research	N.a.	Managing Director, Economic Analyses
Fish and Seafood (F&S7)	Fishing, Processing	Large	Managing Director
Fish and Seafood (F&S8)	Harbor management	N.a.	Marketing and Communication
Fish and Seafood (F&S9)	Import, Trade	Medium	Managing Director, Sustainability Management
Fish and Seafood (F&S10)[c]	Import, Processing, Trade	Large	Research and Development, Quality Management

[a] Based on number of employees in Germany: <9 (small), 50–49 (medium), >250 (large)
[b] Based on number of employees in the Bremen region
[c] The companies F&V4 and F&S10 are the same

persons in each organization were interviewed; the interviews were carried out between March and July 2019 and lasted on average about 45 min. The response data was evaluated by means of a qualitative content analysis using the software MAXQDA.

Additionally, two workshops of 20–30 participants each (September and November 2019) were conducted. The participants were representatives of food companies (mainly from the structured interviews), logistics companies, local government representatives, and further stakeholders. The first workshop focused on climate vulnerability and the participants discussed vulnerability of companies in Bremen as well as their dependency on procurement regions. The discussion was stimulated by a poster summarizing insights that were gained in the interviews regarding vulnerabilities, including an aggregated impact chain, which aided in the validation of the interview results. The second workshop dealt with adaptation measures. The authors designed a business game to simulate various possible climate change impacts and asked participants to develop adaptation measures to handle and prepare for these impacts on their company. To analyze the outcomes of the workshops, minutes of the discussions were taken, as well as photographs of the developed materiel, such as flip charts and posters.

4 Results

In the following, the climate change impacts perceived by the actors in the three product groups are described and summarized in impact chains Sect. 4.1. Then, the ability of the SC members to adapt to these impacts is addressed Sect. 4.2.

4.1 Climate Change Vulnerabilities of Food Supply Chains

Impacts of Climate Change on the Coffee Supply Chain

Coffee plants are sensitive to changes in climatic conditions, including, for example, shifts in temperature differences between day and night [C3]. Rising temperatures thus lead to a shift in cultivation towards cooler regions and higher altitudes. Arabica coffee is particularly vulnerable, as it is already grown at high altitudes, leaving limited scope for relocation [C1].

Due to the sensitivity of coffee plants to climatic conditions, importers are reporting increasing crop failures and reduced harvests. Highlighted climatic impacts include heavy rainfalls and moisture, drought and heat [C1, C2] as well as unexpected frosts, and water shortages [C3]. Changes in climatic conditions also favor the spread of pests and diseases. The fungal disease coffee rust, in particular, is viewed with alarm, as it causes massive damage to coffee crops [C1, C2]. Moreover, high temperatures lead to increased soil degradation [C1]. Besides affecting harvest volume, climatic change also influences the quality of the harvest. Heat waves in Brazil, for example, have reduced the size of coffee beans [C4]. In addition, importers are observing extensions of the ripening period, which increases the risk of premature harvesting and, thus, lower bean quality. Managing longer harvest cycles also increases labor and machinery costs [C2, C3].

Because of crop failures and low harvest quality, delivery shortages occur more frequently. Furthermore, weather extremes may hinder the transportation of goods throughout the SC. In one example, low water levels have prevented ships from being fully loaded [C3]; in another, soil erosion subsequent to flooding events and storms have damaged transport infrastructure (railway, roads) [C2]. The result of poor harvests and alternative transportation routes is increased coffee prices [C3].

In the future, new markets in China and India might emerge; however, the respondents still expect a net loss of cultivable land due to land-use conflicts, a lack of alternative suitable cultivation areas, and the limited capacity of small farmers to adapt to climate change [C1, C3, C4]. Potential climate change impacts on the coffee supply chain are summarized in Fig. 1.

Impacts of Climate Change on the Fruits and Vegetables Supply Chain

Long-term climatic changes in temperature and precipitation increase pressure from insect pests. One company, for example, pointed out that milder winters and the absence of heavy frosts allow the tomato moth to spread [F&V2]. In addition, the potential for diseases increases with higher air humidity [F&V3]. Here, too, cultivation areas are shifting between regions due to increases in temperature, changing precipitation patterns, and more frequent extreme weather events such as drought and frost [F&V1, F&V2, F&V4].

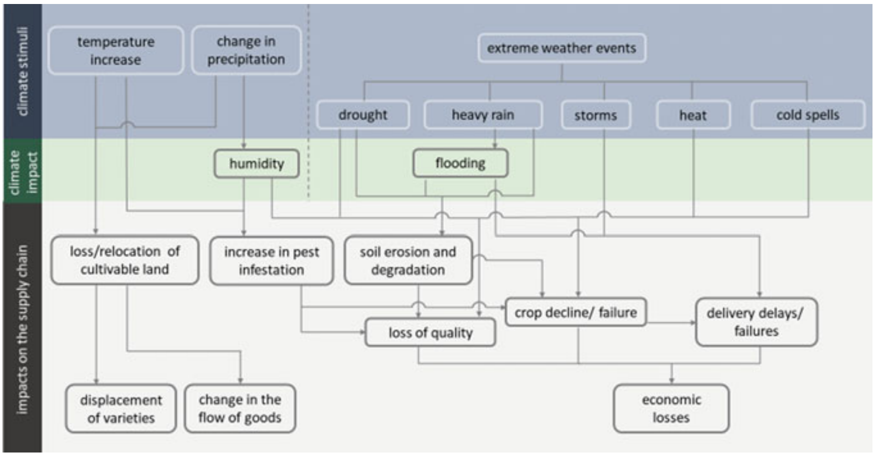

Fig. 1 Impact chain (coffee)—Potential climate change impacts on the coffee supply chain (based on interviews and workshop results). *Source* Translated from Hoffmann et al. (2019a)

Extreme weather events also directly lead to declines in the harvest. Excessive heat, for example, has caused damage to tomatoes [F&V3]. Cold spells, heavy rain, drought, and storms hold a risk potential as well, particularly when occurring in combination [F&V2, F&V3]. One company pointed out that harvest failure and delays from local extreme weather events occur frequently, but rarely affect the operational business [F&V4]. Nevertheless, supra-regional events such as the dry season in 2018 increase the risk of supply bottlenecks and shortfalls. One company stated that it was unable to source peppers in this period as the original supply region suffered from massive crop failures and alternative supply regions were unable to supply adequate quality [F&V3]. Overall, crop failures and delivery delays have led to rising product prices [F&V1, F&V2, F&V3]. Additionally, product quality may suffer as farmers may counter harvest failures with an increased use of fertilizers or the picking of unripe produce [F&V3].

In the future, the interviewed importers and traders assume that the current trends in climate change will continue. In part they expect new opportunities due to this development—for example increased trade with regions in Eastern Europe and Central Asia and potential new growing areas for tropical fruits in Southern Europe [F&V2, F&V3], but overall they anticipate a progressive decline of suitable cultivation areas. In particular, the aggravation of water shortages in important sourcing regions like Spain is highlighted as a reason for this decline [F&V4]. Potential climate change impacts on the fruits and vegetables supply chain are summarized in Fig. 2.

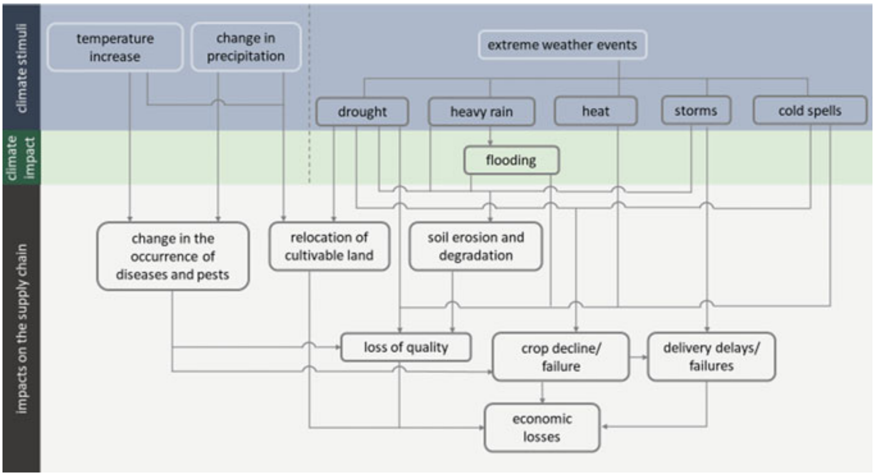

Fig. 2 Impact chain (fruits and vegetables)—Potential climate change impacts on the fruits and vegetables supply chain (based on interviews and workshop results). *Source* Translated from Hoffmann et al. (2019b)

Impacts of Climate Change on the Fish and Seafood Supply Chain

Increases in average sea temperature and higher ocean acidity cause fish stocks to shift northwards (e.g., migration of cod from the North and Baltic Sea to the Norwegian Sea) [F&S1, F&S2]. New fishing grounds in northern latitudes therefore hold opportunity for the fishing industry; however, a moratorium currently prohibits fishing in Arctic regions as long as a sustainable management of the area cannot be guaranteed [F&S4]. Pursuit of these new opportunities will only be possible if the international distribution of fishing areas and quotas per country is adjusted. Moreover, the shift and scattering of fish stocks into more northerly, ice-rich regions leads to extended fishing trips, which will result in increased expenses for energy and technical improvements [F&S7]. In addition, catch losses also occur due to storms that prevent vessels from leaving port [F&S9].

Changes in climatic conditions also affect aquaculture. Heat waves lower the productivity of temperature-sensitive farm fish such as trout [F&S4]; simultaneously, storms and cold spells in winter may negatively influence farming activities. One of the companies interviewed has experienced destroyed net enclosures after a storm event as well as the formation of ice on ponds, which impedes farming activities [F&S9].

The majority of the respondents assume that previous negative effects will continue to occur to the same extent in the future while new effects might emerge as well. Among other things, they expect a long-term decline in the productivity of marine fish and an associated price increase for fish products [F&S6, F&S9]. In addition, they assume an increased need for cooling and higher efforts for sustaining the cooling chain (e.g. improved cooling directly after catching) [F&S6]. Food security risks that might stem from this aspect were not mentioned. Furthermore, they expect a rising risk of flooding due to sea-level rise in combination with heavy rainfalls is expressed [F&S6]. Some also expect positive effects in the future, such as the establishment of new fish species and the positive development of local stocks at higher latitudes [F&S7]. Potential climate change impacts on the Fish and seafood supply chain are summarized in Fig. 3.

4.2 Adaption to Climate Change Impacts in Food Supply Chains

Coffee

The companies describe a *flexible* supply base as critical for coping with the impacts of climate change. They are mainly focused on the expansion of their supplier networks and a broad coffee portfolio to minimize the dependence on individual growing regions and suppliers [C1, C2, C3, C4]. In one case, for example, quality losses due to changes in rainfall and humidity in Colombia led to the resourcing of coffee from other countries [C3, C4].

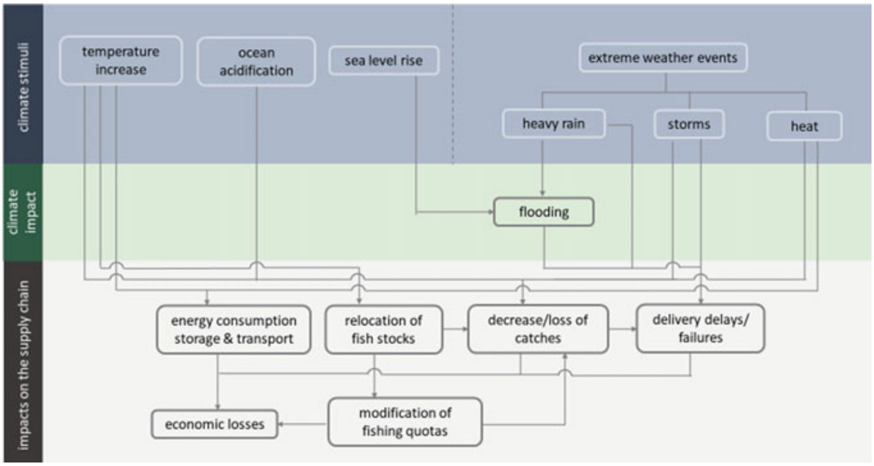

Fig. 3 Impact chain (Fish and seafood)—Potential climate change impacts on the fish and seafood supply chain (based on interviews and workshop results). *Source* Adapted and translated from Hoffmann and Schöpflin (2019)

Besides these strategies of supplier diversification, the respondents are committed to supporting and intensifying *collaboration* with the directly affected coffee farmers [C1, C2, C3, C4]. One company plans to enhance cooperation through knowledge transfer with training programs for sustainable agricultural practices [C1]. Furthermore, it strives for an inclusion of its suppliers in certification programs as these programs support, among other things, compatible and resilient cultivation methods [C1]. Moreover, an industry initiative has led to workshops with producers, in which possible adaptation measures were identified and partly tested. The measures include, among others, soil protection, diversification to prevent the spread of pests, the extension of product portfolios beyond coffee, and the modernization of water management. Moreover, the initiative has supported farmers by identifying weather trends through the combination of climate data and observations. Further studies are planned to determine the future suitability of land under various climate scenarios [C4]. The industry initiative itself can be seen as a practice of *adaptability*—a holistic approach that enhances co-learning throughout the network. The companies interviewed were not members of this initiative, but they were aware of it and utilize the provided information; one company is also considering becoming a member [C1].

In addition to *collaboration* with farmers, the companies point to the importance of *collaboration* with research bodies. Generally, various research programs exist to breed more robust coffee varieties less sensitive to temperature fluctuations and droughts and more resistant to disease [C1, C3]; however, the breeding of climate-resistant plants takes several years [C3]. The companies emphasize the importance of cooperation throughout the entire industry and a need to reduce competitive thinking in the long-term to support the sustainable cultivation of coffee. Some partnerships are already being implemented, and some companies participate in industry initiatives [C1, C3, C4]. Consumer education is also becoming increasingly important to enhance the perceived value of coffee and create acceptance for higher coffee prices [C3].

Fruits and Vegetables

All of the companies interviewed confirm the importance of *flexibility* in their businesses and follow approaches similar to those of the coffee industry. Some are extending procurement regions (including the acquisition of plantations) to compensate for short-term delivery problems and to take advantage of new growing regions, for example in Eastern Europe [F&V1, F&V2, F&V3]. One of the respondents, however, stressed that switching between regions may involve rising costs and decreases in quality and is therefore only possible to a limited extent [F&V3]. Nevertheless, most seem to be developing a *risk aware culture* and are at least thinking about a strategic adaptation of their product portfolio by changes in product varieties, strengthening of regional markets, or increased integration of organic products [F&V1, F&V2, F&V4].

Much as in the coffee sector, fruits and vegetable importers and processors are striving for an intensified and long-term *collaboration* with suppliers [F&V1, F&V2, F&V3, F&V4]. One company emphasizes the importance of knowledge transfer—for example, to ensure sustainable water management in arid regions [F&V1]. Another company renegotiates its contracts with suppliers in cases of crop failures, but instead of reduced payments for low yields and smaller deliveries, price reductions are negotiated for subsequent years [F&V3]. Long-term cooperation also contributes to *visibility* through an efficient communication flow. Thanks to its close relationships with suppliers, one company benefits, for example, from early information sharing in case of delivery difficulties [F&V3]. This company additionally plans a precise analysis of the SC with regard to climate change for the future [F&V3]. Another company uses ingredients trackers to improve the traceability of ingredients [F&V4]. Furthermore, some companies are committed to open communication with their customers in the case of quality losses or delivery failures due to climatic events [F&V1, F&V2]. The role of trading companies in making customers aware of the impact of climate change on fruits and vegetables is also emphasized [F&V1, F&V4].

Adaptation measures to enhance the *security* of regional cultivation are already being implemented, for example, irrigation systems to protect vegetable crops from drought [F&V4]. One company, however, stressed the uncertainty of future climate impacts, which complicates the choice of suitable adaptation measures [F&V3].

Fish and Seafood

Again, much as with the coffee industry, the actors emphasize the importance of having a *flexible* supply base to cushion delays in delivery because of extreme weather events [F&S1, F&S5, F&S7, F&S9, F&S10]. One company has reacted, for example, by increasing its stock of frozen goods to offer as an alternative to fresh fish in the event of shortfalls [F&S1]. Others switch suppliers or fishing areas in the short-term as needed [F&S1, F&S5]. One external expert also stated that large companies tend to integrate backwards or forwards by making up- or downstream acquisitions to gain greater control over the SC [F&S6]. Long-term measures include strategic decisions concerning the product range—an important aspect of a *risk-aware culture*. Some companies are planning or considering an adaptation or expansion of their product portfolios, for example, by offering traditional side dishes such as potatoes, noodles, and vegetables [F&S1, F&S5]; however, they anticipate such strategic measures only becoming relevant in the distant future.

Along with flexibility practices, the companies in the fish and seafood industry are also taking a *collaborative* approach to adapt to climate change. In opposition to the agri-food companies, the focus is on communication with their customers rather than their suppliers. One company gave the example of a several-week shortage of fresh Icelandic salmon. To handle the situation, it openly explained the reasons for the shortfall to its customers and adapted its portfolio by temporarily offering smoked Icelandic salmon from frozen catch instead [F&S9]. In the long term, raising customer awareness of the value of fish and seafood is becoming increasingly important [F&S9]. Nevertheless, obtaining more information about suppliers may help to increase *visibility* and therefore plays an important role. One company, for instance, uses ingredients trackers to improve the traceability of their products [F&S10]. Collaboration with research bodies and programs is of importance [F&S7]. According to the companies, scientific evidence is crucial when deciding on the adoption of measures, particularly for cost-intensive investments.

Several companies have already made technical investments to increase the *security* of their operations. One company upgraded its compressor system for cooling their production facilities. Another renewed its fishing fleet to increase the fleet's resistance to extreme weather events and drift ice [F&S7]. In aquaculture, the focus lies on providing ponds with artificial oxygen to prevent fish dying due to oxygen deficiencies caused by high temperatures [F&S9]. In addition to reactive measures, preventive investments have also been made, for example, in increasing insurance coverage against flooding [F&S1, F&S7].

Workshop in the Food Sector: Long-Term Ideas for Adaptation

The stakeholder workshop addressed various adaptation measures for future scenarios. A business game approach encouraged the participants to develop creative ideas; the goal was not to produce concrete planning measures.

The participants, especially the representatives of the food industry, suggested *collaborative* approaches, for example, shared storage capacity, which would also increase *flexibility*. They perceive an increased need for cooperation with research bodies or governmental institutions with regard to climate-resilient species, or the potential for local aquaculture. Additionally, they stated a need for industry-wide information services addressing climate scenarios and future impacts. Participants suggested that the local chamber of industry and commerce could provide training on implementing contingency plans and risk management, which could support a *risk-aware culture* within the companies. Further approaches for building a risk aware culture were also suggested, e.g. a strategic and long-term adaptation of their product portfolios. Fish and seafood companies suggested, for example, the production or sourcing of alga or fish from aquaculture. Coffee producers considered the integration of tea into their portfolios and fruits and vegetables companies the replacement of fresh fruit commodities with processed fruits or fruit aromas. To reduce risk, they also considered converting their own cultivation to organic farming and sourcing from organic farmers, or more regionally.

5 Discussion

In general, the interviews and workshops showed that company representatives and related stakeholders are aware of the impacts of climate change and the potential vulnerability of their respective SCs. However, perceptions of the degree of severity and relevant time horizon vary widely. The majority of respondents agree that they are already being affected by climate change. Actors in the coffee industry expressed the greatest sense of vulnerability and strongest desire for action, primarily because the suitable coffee cultivation areas, the so-called coffee belt, is found near the equator, in regions already being adversely affected by climate change. Some respondents, however, still consider climate vulnerability to be an issue for the distant future, particularly in the fish and seafood industry. The differences between the product groups are particularly evident with regard to adaptation measures being implemented or planned.

Within the surveyed companies several elements and practices of SCRES were identified. This confirms the insights of other researchers that buyers, but also processors and manufacturers within the food supply chain are in a good position to address the risks of climate change (de Sá et al. 2019; Paloviita 2015). Table 3 summarizes the identified elements and practices of SCRES. It does not indicate frequency: While *flexibility* practices (flexible supply base, ad-hoc adaptation of product portfolio) were found in almost all and *collaboration* practices in several companies, implementations of the other elements were only evident in a few companies. While flexibility practices such as ad-hoc adaptation of the product portfolio through sourcing from other regions and suppliers are partly reactive and help to deal with acute shortages, most of the identified adaptation measures are proactive and aim at preventing future shortages or disruptions similar to those already experienced. The authors observed fewer practices that support more transformative changes like those needed to develop and integrate a *risk aware culture* and to strive for SC-wide *adaptability*. This corresponds with the perception of many companies that there is currently no need for radical change.

Flexibility measures are largely similar among the product groups, except for backwards integration, which was only identified in the fruits and vegetable companies, which in some cases have started their own cultivation in Germany. This approach is less feasible in the other two sectors, as substantially higher financial investments would be necessary.

While agri-food companies (coffee, and fruits and vegetables) do *collaborate* both upstream and downstream, with a focus on suppliers, fish and seafood concerns

Table 3 Identified elements and practices of supply chain resilience (SCRES) to climate change in the food supply chain (based on interview results)

Elements and practices of supply chain resilience (applicable level: SC or organizational)	Product group		
	Coffee	Fruits and vegetables	Fish and seafood
Flexibility (SC/org.)			
Flexible supply base (SC)	✓	✓	✓
Ad-hoc adaptation of product portfolio (org.)	✓	✓	✓
Backwards integration (org.)	–	✓	–
Collaboration (SC)			
Knowledge transfer to suppliers	✓	✓	–
Inclusion of suppliers in certification programs	✓	–	–
Intensified and long-term cooperation with suppliers	✓	✓	–
Open communication with industrial customers	–	✓	✓
Consumer/end user education	✓	–	✓
Cooperation with research bodies (e.g., breeding climate robust species/varieties)	✓	–	✓
Cooperation within industry (e.g., climate data, suitability studies)	✓	–	–
Visibility (SC)			
Ingredient trackers	–	✓	✓
Early information sharing by suppliers	–	✓	-
Precise analysis of the SC with regard to climate change impacts	–	Planned	–
Risk aware culture (org.)			
Strategic adaptation of the product portfolio (change in species/varieties, or regions; more organic products)	–	✓	Planned
Expansion of product portfolio (new/supplementary products)	–	–	Under consideration
Security (org.)			
Technical investments	–	✓	✓
Increased insurance	–	–	✓
Adaptability (SC)			
Sector initiative to adapt to climate change (information platform, training, research etc.)	✓	–	–

focus on downstream SC communication. The supply chain structure is assumed to be a reason for this: While the agri-food companies source from small and medium-sized farmers, fish and seafood companies are often dealing with suppliers that are larger than themselves. Consequently, the agri-food companies are more powerful and better positioned to influence or cooperate with upstream actors. Collaboration with actors from outside the SC is observable in both the coffee and fish and seafood concerns. While industry collaboration is only evident in the coffee sector (see next paragraph *adaptability*), collaborations with research bodies were observed in both industries. The fruits and vegetables companies have a broader product portfolio and use more ingredients in processed food products; thus, resource requirements might be too high for scientific studies. Instead, they are comparatively active in *visibility* practices to meet the need for information about the large variety in suppliers and regions. While *security* practices are found in place for fruits and vegetables as well as for fish and seafood companies, these are largely lacking in the coffee sector. There is less need for security practices because the analyzed coffee importers do no cultivation and thus have no critical requirements for storage and processing, e.g. cooling.

Practices supporting a *risk aware culture* are only evident in the fruits and vegetables sector and as plans or considerations for the future in the fish and seafood industry. The fruit and vegetable companies aim at strategic adaptations of the product portfolio, e.g., increased sourcing of regional and organic products. The fish and seafood firms focus on the future adaptation of species and varieties. While the long-term approaches in these sectors are mainly at the organizational level, the only approach that strives for SC-wide *adaptability* was found in the industry initiative of the coffee sector. Similar sector-wide approaches are lacking for the two other product groups. This is most likely because strongly negative climate impacts are perceived for the entire coffee sector, whereas in the other industries the anticipated impact varies according to species and product. Similar industry initiatives would however be an important approach to offering support to the vulnerable farmers and fishermen and to enhance resilience at the beginning of the SC. Information and training for the whole sector, especially for upstream actors, could be provided by trade associations, cooperatives or government organizations (de Sá et al. 2019).

As a supplement to the interviews, the workshop allowed identifying possible long-term adaptation measures. By focusing on risks and potential adaptation measures, the workshops themselves offered a viable means to develop a risk aware culture among the participating companies. The workshop discussions showed that companies do, for instance, have some ideas, on how to adapt their portfolio strategically (*risk-aware culture*) or for further *collaboration.* As suggested by the Centre for Environmental Risks and Futures (2015), bringing together business sector experts can support building resilience within an organization and potentially also across the entire SC.

Most companies apply practices at the *organizational level* (especially organizational flexibility practices), but there are also many examples of practices at the *supply chain level*. The agri-food companies are balanced between organizational and SC practices, whereas the fish and seafood companies are focused more on organizational practices. One possible explanation for this might be the already noted differences in SC structures and resulting limited possibilities that the fish and seafood concerns have for influencing their often much larger upstream partners. In case studies in agri-food companies in Brazil, Sá et al. (2019) found that these tend to prefer individual strategies, rather than SC solutions because of a lack of cohesion and asymmetries in the SCs. Such SC asymmetries are also present in the analyzed companies, but the agri-food companies still manage to engage in resilience practices at the SC level.

While most of the companies' adaptation measures can be attributed to a specific SCRES element, this was not always possible. In particular, practices of *collaboration* (e.g., with research bodies, industry initiatives or trade organizations) enhance *visibility* (e.g., a precise analysis of the SC with regard to climate change impacts) but also the strategic integration of climate risks and development of a *risk aware culture* (e.g., as a basis for the strategic adaptation of the product portfolio). The importance of collaboration has also been stressed by Scholten and Schilder (2015), who assume that it can enhance other elements such as visibility, velocity and flexibility. Collaboration can also hinder *flexibility*, for example, when closer, long-term supplier relationships are pursued at the expense of ensuring a broad and flexible supply base. A balance between *collaboration* and *flexibility* is therefore necessary (Pereira et al. 2014).

The research presented focused on importing companies in Germany and did thus not include the perspectives of actors from other stages of the SC. To gain more insights into how a collaborative approach can support adaptation in the SC, detailed analyses including actors from other SC stages (e.g., farming/fishing) would be helpful. Such studies should also look more closely at the power asymmetries within the SC and their effect on the implementation of climate adaptation and resilience measures. Some adaptation measures, such as cooling system expansions or more diverse sourcing (and thus transport), may lead to increased greenhouse gas emissions (Lim-Camacho et al. 2017). The conflicts and synergies with other sustainability goals should be studied in more detail. This also includes the question of whether adaptation at one stage can cause unintended effects at other stages of the SC. The interviews, included one or at the most three representatives of the participating companies. For a deeper understanding of intra-organizational and cultural changes, case studies in greater detail would be needed. Moreover, a comparison with other food product groups (e.g., dairy or meat products) could help to identify specific practices and to understand whether insights can be transferred to other sectors. From a practice-oriented perspective, more research on transformative changes in SCs is needed. Adaptability practices should be jointly developed by companies within the SC and researchers. The workshops presented in this paper can be a first step in this direction.

6 Conclusion

Climate change poses significant risks for food companies and the stability of their supply chains. These are not only vulnerable to acute disruptions through extreme weather events but also to continuous climate change, such as temperature increases and changes in precipitation patterns. Integrated models on global warming and land or resource use are projecting serious changes in suitability of farmland and decreased fish catches. Buyers are aware of potential climate change impacts on their companies and the food SC; however, many still perceive climate change to be a problem still on the horizon. Most are not yet taking a strategic approach to climate change and have not engaged in systematic risk or vulnerability analyses. They are engaging in reactive and proactive measures to increase SCRES mainly by applying practices that support *flexibility* and *collaboration*—measures which are suitable to address disruptions and shortages similar to those already experienced. To address the transformative consequences of climate change, however, practices that enhance a *risk aware culture* and *adaptability* across the entire SC are needed. However, only a few companies in the case study are currently implementing or planning to implement a strategic adaptation of their product portfolio, which is an element of a risk aware culture. Adaptability practices to date are restricted to the coffee sector, where an industry initiative is taking a holistic approach to climate change. Given that long term the challenges of climate change adaption are too fundamental and extensive to be tackled by individual companies, such industry collaborations represent a promising approach.

Companies aiming to increase their SCRES to climate change must strategically address long-term changes in climate impacts. Conducting SC vulnerability analyses and integrating climate change impact into corporate risk management are suitable approaches for developing a more *risk aware culture*. Purchasing departments should also consider climate change risk with respect to their procurement strategies. Instead focusing too strongly on short-term *flexibility*, importing companies should engage in long-term, intensive *collaboration* with suppliers, especially smaller business partners and those located in the global south. Farmers and fishermen are directly affected by climate change and need support for successful adaptation. Importing companies should align their supplier relations with sustainable development goals and must not jeopardize them with short-term flexibility practices such as the frequent or indiscriminate switching of suppliers. Instead, they could support their suppliers in establishing a more climate-resilient product portfolio. Long term, buyers will benefit from such an approach by building strong, future-oriented, resilient relationships. Among the companies in the study, some initial efforts in this direction could be observed.

Acknowledgements The research presented was financed by the German Federal Ministry for Education and Research (Funding No. 01LR1723B). The authors are grateful to Undine Gnauck, who supported the project through literature research, data analysis, and the drafting of text passages and visualizations. Moreover, they would like to thank their research partner, the Institute of Shipping Economics and Logistics, especially Rainer Müller, for co-organizing the workshops and co-developing the interview guidelines. Finally, the authors thank their interview partners and workshop participants for sharing their knowledge and expertise.

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Consumers' Motivations Towards Environment-Friendly Dietary Changes: An Assessment of Trends Related to the Consumption of Animal Products

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Abstract In the context of global warming and environmental pressure, food chains must adapt to new production conditions while satisfying the evolving consumer demand. Livestock production is known for its negative ecological footprint, bringing forward the question of a possible transition towards more plant-based diets. Citizens' demand evolves at different speeds and integrates these new environmental concerns sometimes mixed with health or ethical issues. We carried out a survey with 1,715 respondents in France, about their food choice priorities and preferences, as well as the drivers of change. Our results indicate that 40% of respondents claim that their current diet is not what they would ideally have and 98% of them would like to reduce their animal product consumption. Classification algorithms reveals several salient variables separating classes of individuals wishing to shift their food diet towards less animal products: the willingness to change is stronger for the youngest, hindrances to change are food pleasure, health and to a lesser extent social resistance and animal ethics. The less radical the animal products reduction is the more environmental concerns are the main motivation.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_17

1 Introduction

1.1 Background

Animal production is known to have significant environmental impacts (Godfray et al. 2018), and these effects increase as global animal consumption increases (Sans and Combris 2015). Consistent evidence from various studies suggests that diets low in animal-based foods, high in plant-based foods have a low environmental impact (Nelson et al. 2016; Seconda et al. 2018). Overall, the reduction in the environmental footprint is proportional to the extent to which food from animal origin is restricted (Aleksandrowicz et al. 2016). More specifically, the FAO estimated in 2013 that livestock accounted for 14.5% of global greenhouse gas (GHG) emissions (Gerber et al. 2013). According to a global survey of 38,700 farms and 1600 food processing companies, CO_2 emissions from low-impact animal products generally exceed emissions from plant-based alternatives (Poore and Nemecek 2018). GHG emissions from omnivores in the UK are twice as high as from vegetarians (Scarborough et al. 2014). Worldwide, the GHG footprint of vegan and low-meat food diets (i.e. plant-based, including forage fish, mollusks and insects) is minimal (Kim et al. 2019). Reducing GHG emissions by reducing animal products consumption is only one side of the environmental benefits because livestock production is a major user of land worldwide, with an estimated use of 2.5 billion hectares (Mottet et al. 2017). Reducing animals production is not only reducing the carbon footprint of food but saving on land use is an opportunity that could additionally allow carbon sequestration at a massive scale. 1 billion hectares turned to forest and woodland would stock around two thirds of all GHG emissions since the beginning of the industrial revolution (Bastin et al. 2019). It is consequently no surprise that promoting plant-base diets is one among key measures to respect planetary environmental boundaries (Springmann et al. 2018). This recommendation for worldwide dietary change for the environment is reinforced by secondary effects, as diets with low GHG emissions have better overall dietary quality and are more nutritious from several viewpoints (Rose et al. 2019; Clark et al. 2019). These diets could bring substantial health benefits, reduce land clearing and species extinctions (Tilman and Clark 2014; Nelson et al. 2016), increase well-being, satisfaction, reduce food cost (Perignon et al. 2016) while bringing ethical benefits (Fehér et al. 2020).

However, despite compelling advantages, diet change towards plant-based diets remains limited. Modifications of dietary patterns evolve during a person's life and are determined by a wide variety of factors (Povey et al. 1999; Vabo and Hansen 2014). On the psychological aspect, while health and ethics have been key motivations towards plant-based diets in the past (Jabs et al. 1998), the environmental motivation seems on the rise (Ruby 2012). As far as this environmental motivation goes, many factors influence consumers in their transition towards a climate-friendly plant-based diet, including personal and external factors such as socio-cultural ones (Stoll-Kleemann and Schmidt 2017). Identified hindrances for individuals to go towards plant-based diets relate to low levels of awareness, difficulty gaining new know-how regarding cooking, diet balance concerns, pleasure of eating animal products, while enhancing the pleasure of plant-based food and enabling plant-based options in collective meals facilitates the transition (Graça et al. 2019; Fehér et al. 2020; Macdiarmid et al. 2016; Herzog 2011).

1.2 Chapter Objectives

The focus of this chapter is to identify drivers—facilitating factors and hindrances—that may lead individuals to question their current dietary behaviors and consider changes towards reduced animal product consumption.

General Objectives

The general objective of the chapter is to discover these drivers through an empirical approach based on machine learning techniques applied to an extensive survey of more than 1,700 respondents in France.

Specific Objectives

The specific objectives of the chapter are:

1. To present the more salient answers to the survey.
2. To identify through machine learning, and more specifically classification techniques, the factors that best separate consumers who show motivation to move their current diets to less animal-based ones, from those who do not.
3. To analyze the status of environmental concerns within these factors. Are climate-related concerns prominent or secondary within the motivations expressed? Are other types of concerns involved, positively or negatively?

1.3 Chapter Outline

Section 2 presents the collection of data, the pre-processing of the raw data, and the classification models used. Section 3 highlights salient trends in the survey results, provides the classification results, and discusses the role of environmental concerns. Section 4 concludes with some perspectives.

2 Materials and Methods

The methodology used followed the following steps, detailed below: data acquisition, data pre-processing, problem reformulation in the form of a classification question, and classification method used.

2.1 Data Acquisition

In order to get insights on the drivers of individual behavioral changes towards reduced animal product consumption, we conducted an extensive survey, built an argument database from the scientific and grey literature and performed in-depth biographical interviews. All the collected data are published in Salliou et al. (2019). This chapter focuses exclusively on the survey, which is presented hereafter. Interested readers may refer to Salliou and Thomopoulos (2018); Thomopoulos et al. (2019, 2020) for further information on the argument database and to Salliou and Thomopoulos (2020) for further information on the biographical interviews.

The survey was conducted among a panel of 1,715 French citizens. The questions belonged to the following categories:

– Key criteria in food choices
– Current food diet (Single question denoted by Q2)
– Past, ongoing or desired changes in food diet
– Attraction to various types of food
– Knowledge of alternatives to animal products
– Ideal food diet (Single question denoted by Q20)
– Reasons, hindrances and facilitating factors for reducing animal product consumption
– Ways of information practiced
– Socio-demographic information
– Agreement with 16 key arguments about animal product consumption.

These 16 arguments were taken from Kialo's debate platform, allowing internauts to collectively build argument layers for various topics. These arguments revealed central, as they are the main and first degree arguments over a hierarchy of more than 2,000 arguments expressed by over 1,400 participants about the topic of "humans should stop eating meat".[1]

2.2 Data Pre-processing

Splitting Multiple-Choice Questions

Each multiple-choice question Q was splitted into n distinct boolean questions, where n is the number of possible answers to question Q.

For example, the multiple-choice question Q25 "I personally know a vegetarian and/or a vegan: (a) within my siblings, (b) in the rest of my family, (c) among my friends, (d) at work" was splitted into four distinct boolean questions Q25a "I personally know a vegetarian and/or a vegan within my siblings: yes/no", Q25b "I

[1] https://www.kialo.com/the-ethics-of-eating-animals-is-eating-meat-wrong-1229?path=1229.01229.1.

personally know a vegetarian and/or a vegan in the rest of my family: yes/no", and so on.

Hence, from 33 questions initially, the final number of columns is 112.

Encoding the Categorical Data

To facilitate the treatment by machine learning models, categorical data were converted into numerical values on an ordinal scale.

For example, in question Q2 "What is your current food diet?", the answer "Omnivorous" was encoded by 0, "Flexitarian" by 1, "Vegetarian" by 2 and "Vegan" by 3. The same encoding was used in question Q20 "Ideally, what would you like your food diet to be in the future?".

Feature Scaling

The choice not to apply feature scaling was preferred, in order to avoid under-representing questions increasingly with the number of their possible answers.

2.3 *Problem Formulation*

From the description above, the questions addressed by this chapter can technically be summarized as:

- Do the global answers to Q2 and Q20 strongly differ?
- Considering the answer to each question Q as a variable (denoted by the same symbol Q for simplicity), what variables best separate the class of individuals for whom $Q2 = Q20$, from the class of individuals for whom $Q2 \neq Q20$?

The latter is a classification problem. The classes to be separated are:

CLASS 0: $Q2 = Q20$ (1045 samples).
CLASS 1: $Q2 \neq Q20$ (669 samples).

The explanatory variables are the 112 columns of the dataset, from which Q2 and Q20 were removed as irrelevant questions to compute the classification results, since they are used to define the output classes. The 110 remaining columns were thus used as explanatory variables.

2.4 *Classification Method*

After preliminary trials with all classification algorithms included in the scikit-learn Python package (Pedregosa et al. 2011), we ultimately selected Random Forest (RF) as the reference classifier for the following experiments, taking into account both average accuracy in a stratified 10-fold cross-validation and interpretability of its results. RF (Breiman 2001) creates a set of decision trees, training each one on a

Fig. 1 Answers to questions about current and future diets

subset of the available data, thus reducing bias and delivering more robust predictions. RF determines relative variable (feature) importance, by evaluating the frequency of appearance of a variable in the splits of all the decision trees: The more a variable appears, the more important that variable is for the final classification of the ensemble. For all experiments reported in this work, RF has default parameters,[2] using a total of 100 decision trees.

Most classifiers, alongside their predictions, are also able to return a ranking of the relative importance of the variables in the problem, with the ones that best explain the variance in the results among the top. In order to obtain a more reliable ranking, RF is run in a 10-fold stratified cross-validation, and the rankings for each fold are aggregated in the final result.

3 Results and Discussion

3.1 Salient Trends in the Survey Results

As a first stage, the analysis of the global survey results allows setting out major observations concerning the central questions Q2 and Q20. Figure 1 displays the results obtained from the survey for questions Q2 and Q20.

According to these results, for 40% of people, the actual diet they currently have does not conform to the one they would wish to have, in terms of animal product consumption, which they would overwhelmingly like to reduce. In other terms, for 40% of the respondents, there is a gap between actual behavior—current food diet, asked in Q2—and personal convictions—ideal food diet, asked in Q20. This situation, denoted by "cognitive dissonance" from Festinger's seminal theory (Festinger 1957),

[2] Random Forest Classifier:
https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.RandomForestClassifier.html.

is known to be a first step towards an eventual change. This is explained by the fact that humans feel uncomfortable with internal contradiction. Citing Festinger (1957), "The existence of dissonance, being psychologically uncomfortable, will motivate the person to try to reduce the dissonance and achieve consonance". In our case, dissonant individuals, i.e. belonging to CLASS 1, may try to solve the contradiction:

– By changing their dietary behavior to best fit their convictions. This case is primarily captured by the present survey and study. Indeed, dissonant individuals may tend to question and reconsider their food habits, and envision the reduction of animal products as a possibility.
– By modulating their convictions to best fit their actual dietary behavior, especially if the latter is perceived as difficult to change. This is observed in Festinger (1957): "Post-decision dissonance may be reduced by increasing the attractiveness of the chosen alternative, decreasing the attractiveness of the unchosen alternatives, or both". This means dissonant individuals may tend to focus on arguments that foster animal-based diets, or depreciate plant-based diets (Salliou and Thomopoulos 2020), to justify their food habits.

Section 3.2 explores the variables that best separate the class of dissonant individuals (CLASS 1) from the class of consonant ones (CLASS 0).

3.2 Classification Results

The histogram of Fig. 2 shows on the X-axis the list of variables selected in the 10 folds of RF stratified cross-validation, and on the Y-axis the number of folds each variable was selected in. This number may vary from 1—if the variable was selected in one fold only—to10—if the variable was selected in all of the ten folds. The mean accuracy obtained for the classifier was 0.65.

The survey questions corresponding to the top-ranked variables are detailed in Table 1.

We can notice that, within the best explanatory variables (top 4, selected in at least half of the 10 folds), 3 out of 4 play a role of "control" variables. Indeed, questions Q21a, Q22a and Q6 provide confirmation of the coherence of respondents' answers, in the sense that:

– Agreeing with the assertion of Question Q21a "I do not feel concerned by reducing the consumption of animal products" can be interpreted as a statement of cognitive consonance. The respondent does not perceive any issue in consuming animal products. This is clearly in line with membership in CLASS 0, the group of consonant individuals. Obtaining Q21a within the top-ranked variables is thus not surprising.
– The same observation can be made for Question Q22a. The assertion "I am not trying to reduce my consumption of animal products" is coherent with stating

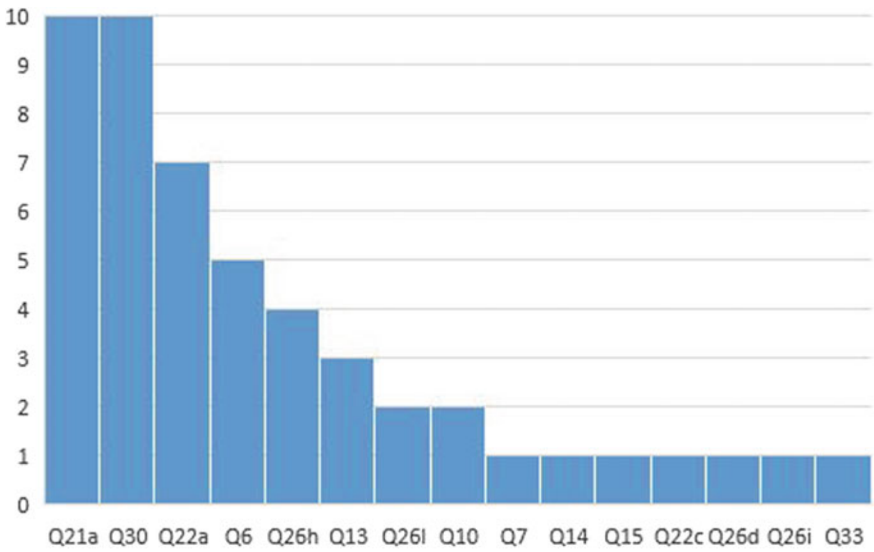


Fig. 2 Top-ranked variables

actual and ideal diets are identical, i.e. providing the same answer for Q2 and Q20, which is the definition of CLASS 0.

- Finally, Question Q6 "On a scale of 0 to 10, to what level would you like to reduce your consumption of animal products?" is a quantitative variant of Question Q22a. Respondents of CLASS 0 are logically expected to provide high-valued answers to Q6, since they perceive little dissonance in consuming animal products. On the contrary, low-valued answers to Q6 are coherent with CLASS 1, whose ideal diet is less animal-based.

More informative is the identification of Q30 "How old are you?" as a top-ranked explanatory variable. In order to gain a deeper insight into the relation between age and dissonance concerning the consumption of animal products, a visual representation of the classification helps analyze the results. Since the classification method used (RF) is based on a set of decision trees, in Fig. 3, we present one decision tree obtained. It was displayed using the Orange software (Demšar et al. 2013). Only the five first levels of the tree are depicted. The blue color is associated with CLASS 0, the red color with CLASS 1. The classification accuracy of this decision tree is 0.643, which is very similar to the mean accuracy obtained for the RF classifier.

Once computed the first two splits accordingly to Q21a and Q22a, the use of Q30 as of the third split highlights cognitive dissonance is higher for young respondents, below 25 years old. In other words, within the individuals stating that (i) they feel concerned by reducing their consumption of animal products and (ii) they are trying to reducing their consumption of animal products, the wish of a different food diet than the actual one is stronger for the young. Q30 also appears in other parts of the decision tree, with the same trend observed i.e. a higher dissonance for the young.

Table 1 Questions corresponding to the top-ranked variables

Best explanatory variables (selected in at least half of the 10 folds)	
Q21a	Do you agree with the statement "I do not feel concerned by reducing the consumption of animal products"?
Q30	How old are you?
Q22a	Do you agree with the statement "I am not trying to reduce my consumption of animal products"?
Q6	On a scale of 0 to 10, to what level would you like to reduce your consumption of animal products?
Complementary explanatory variables (selected in 20 to 40% of the 10 folds)	
Q26h	Do you agree with the statement "Eating animal products makes me happy"?
Q13	On a scale of 0 to 10, how much do you enjoy seafood?
Q26l	Do you agree with the statement "Vegetarian diets are better for health"?
Q10	On a scale of 0 to 10, how much do you enjoy eggs?
Explanatory variables involved to a lesser extent (selected only once in the 10 folds)	
Q7	On a scale of 0 to 10, how much do you enjoy red meat?
Q14	On a scale of 0 to 10, how much do you enjoy honey?
Q15	On a scale of 0 to 10, how much do you enjoy cereals?
Q22c	If you are trying to reduce your consumption of animal products, do you agree with the statement "My family's habits make this goal difficult for me"?
Q26d	Do you agree with the statement "Eating animals involves harming killed animals to obtain them"?
Q26i	Do you agree with the statement "Animals suffer"?
Q33	What is your occupational status?

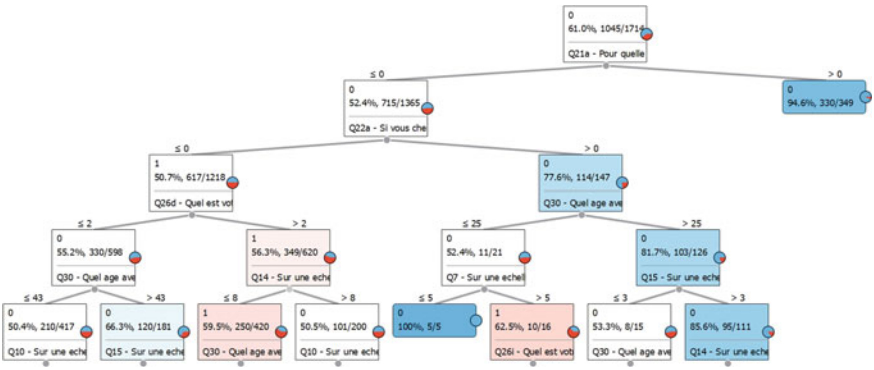


Fig. 3 Decision tree visualization

Conversely, this result also implies the wish of diet change, although present, is less radical for the older respondents, who would thus rather make smaller changes in their food habits within the same category of food diet.

The rest of the explanatory variables selected are discussed in the next section.

3.3 The Role of Environmental Concerns

The classification results above provide some clues about the main concerns that distinguish the respondents who consider, or not, a deep change in their food diets:

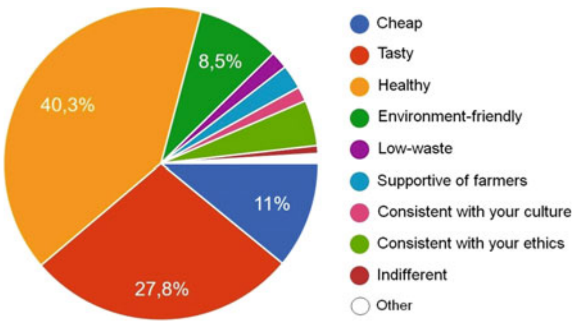
1. The overwhelming majority of the rest of selected variables (see Table 1) concerns the pleasure of food. This is true for variables Q26h, Q13, Q10, Q7, Q14 and Q15.
2. Quite well-ranked is the question of health, with Q26l.
3. A social hindrance explicitly appears in the results, namely the family's habits (Q22c).
4. Ethical concerns related to animal suffering are also present in the result list, through Q26d and Q26i.

In the shift towards less animal-based diets, environmental-related issues do not seem to play a prominent role in the motivations expressed, which first consider food pleasure, and to some extent health, social resistance, and animal ethics.

That being said, however, one must keep in mind that these variables are those which best separate dissonant from consonant individuals, i.e. the variables involved in the wish (or not) for deep diet changes led by a sense of inconsistency. Beside this case, motivations in daily food choices and reasons for more discrete changes in food habits warrant further examination. Therefore, direct respondents' answers also have to be consider, about their priorities in food choices (Question Q1), and their reasons to consider reducing animal product consumption (Question Q21). The results are shown in Figs. 4 and 5, respectively.

Answers to Question Q1 (Fig. 4) confirm the importance of health concerns for food choices in general, cited as the priority by 40.3% of respondents, and of food

Fig. 4 Question Q1 "Above all, you expect the food you choose to be…"



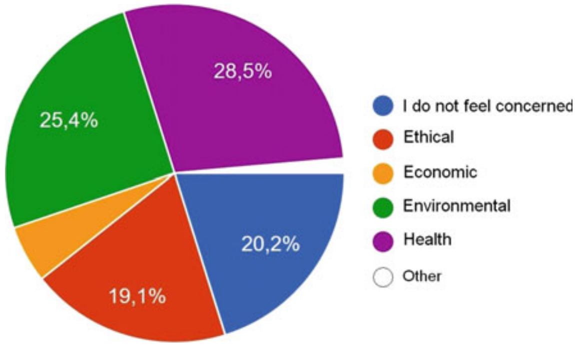


Fig. 5 Question Q21 "What is the main reason that makes you feel concerned by reducing the consumption of animal products?"

pleasure, cited as the priority by 27.8% of respondents. It is worth noting that, compared with the classification results, the ranking of these concerns is reversed. Respondents seem to somehow overestimate rational motivations (health), compared with the results computed by machine learning (food pleasure first). The next criterion cited is food price, with 11% of answers. Then comes the environment, cited as the priority by 8.5% of respondents, followed by ethics. The latter was more significant in the classification results, thus ethics seems to have a stronger involvement in the feeling of inconsistency likely to induce deep diet changes.

Answers to Question Q21 (Fig. 5) specifically concern the reasons for reducing animal product consumption. They still place health at the top of the list of reasons, with 28.5% of the answers. However, this time, health is closely followed by environmental concerns, with 25.4% of the answers. Then comes the "indifferent" answer ("I do not feel concerned") as well as ethical concerns, both around 20%, ahead of economic issues such as product price.

From these results, first, we can note that consumer awareness of the environmental impact of animal products is high. Indeed, compared with food choices in general (Question Q1), the results express a clear prominence of the status of environmental issues concerning animal products (Question Q21). The same observation can be made on ethical issues, which are more represented in the case of animal products. Overall, only 20% of respondents claim not to feel concerned by reducing animal product consumption, which is well below the 60% who do not envision a change in their food diet (CLASS 0). This observation supports the hypothesis of a possible less radical change than a shift in food diet, for the greatest number.

3.4 Achievements and Limitations of the Study

The previous Sects. 3.1 to 3.3 respectively addressed the three specific objectives stated in the introduction and pursued along the chapter, namely (1) salient trends deduced from the answers to the survey related to motivation for diet change, (2) best explanatory variables identified involved in motivation for reduced animal product consumption and (3) role of environmental concerns in motivation for reduced animal product consumption.

However, several questions remain. In particular, a deeper analysis of motivations per diet type (omnivorous, flexitarian, vegetarian, vegan) would allow policies to design targeted messages with regard to global warming. In this perspective, focusing on the category of omnivores who turn out to be dissonant regarding their actual food diet, seems the most promising. Indeed, omnivores constitute the large majority of individuals who could possibly make environment-friendly changes in their food diets and therefore reduce the food carbon footprint of the population.

Another insight would consist in better identifying the contours of the flexitarian category. “Flexitarian” is a fuzzy category of those who do not systematically consume meat, but deliberately somehow limit their consumption of meat, for highly variable reasons. Comparing their motivation profiles with those of omnivores or vegetarians would thus be instructive.

4 Conclusion

The drivers that lead individuals to consider diet changes towards reduced animal product consumption were explored through machine learning, applied to an extensive survey of 1,715 respondents in France. The main findings are:

1. Salient answers to the survey: The analysis revealed that there is a gap between current food diet and ideal food diet, for 40% of the respondents. This situation, known as “cognitive dissonance”, is stronger for the young.
2. Main explanatory factors: Discriminant factors are food pleasure issues, health concerns and to a lesser extent social resistance and animal ethics.
3. Status of environmental concerns: Although environmental concerns do not appear significant in explaining such dissonance, they become prominent when it comes to motivating more discrete food changes towards a reduction of animal product consumption.

The latter finding consolidates the idea that the dynamics of emergence of daily changes in dietary habits, however slight, should be explored. A particularly suitable tool to carry such an exploration is agent-based simulation, which, by representing individual behaviors, allows one to understand and explore the impacts of these behaviors on the overall dynamics of a population. Several works such as (Thomopoulos et al. 2019; Taillandier et al. 2019) propose models of opinion change in terms of consumption of meat products. In particular, Taillandier et al. (2019) proposes to explicitly model the exchange of arguments between individuals and studies how these exchanges impact opinions regarding the consumption of meat products. However, both models only focus on the construction of opinions and do not simulate the gaps between food habits and attitudes towards food. It would therefore be particularly relevant to enrich them with new mechanisms to represent transitions between attitudes and practices.

Ongoing work is dealing with daily food choice in the short term, as opposed to the "ideal" choice in the long term towards a reduction in meat consumption. This is where social norms seem to be an important source of inertia. The analysis of the biographical interviews carried out in Salliou et al. (2019); Salliou and Thomopoulos (2020) showed that social pressure was a major factor for abandoning the adoption of meatless diets. In ongoing simulations, we hypothesize that social acceptance of less meaty diets is underestimated, which is in line with the results of the present chapter. The objective is to observe the effect of a few individuals following their desired food diet, on the whole population over time.

Acknowledgements This work is part of the VITAMIN project ("VegetarIan Transition Argument ModellINg") funded by INRAE.

We would like to thank Thomas Pereira for his help in writing the python script automating the data pre-processing step.

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Environmental Impact of Climate Change on Crop Production

Branka Žarković and Vesna Radovanović

Abstract Obvious changes in our climate system are having a strong negative impact on crop yields. Besides the fact that the temperature of the air is changing, our agricultural fields are often exposed to severe weather conditions and higher levels of CO_2 in the atmosphere. Extreme temperature and precipitation can considerably reduce crop yield. Also, in areas with high temperatures during the summer dealing with drought has become a challenge, and only in some places increased irrigation can be a solution. Various pests, weeds, and fungi thrive under warm and humid climates and enhanced CO_2 levels. This requires more investment in pesticides and creates a potential threat to public health. Also, an increase of CO_2 in the atmosphere is a threat to public health, because it also decreases the nutritional quality of most food crops. A higher concentration of carbon dioxide in the atmosphere can cause a lower content of essential minerals and proteins in wheat, rice and soybeans, and other plant species. Within this chapter, our aim is to present every aspect of the adverse effect of climate change on crop development with special emphasis on potential influence on human health. Evaluation of the influence of the climate change observed through recent studies presented that the most often result are yields decrease and yields variability increase, abundance, and distribution of pests, and nutritional value of crop grains. Furthermore, these effects have a massive influence on safe food production in both quantitative and quality approaches.

1 Introduction

The impact of climate change on safe food production can be defined in two separate routes. In the first route, the direct impact can be observed through quantity and

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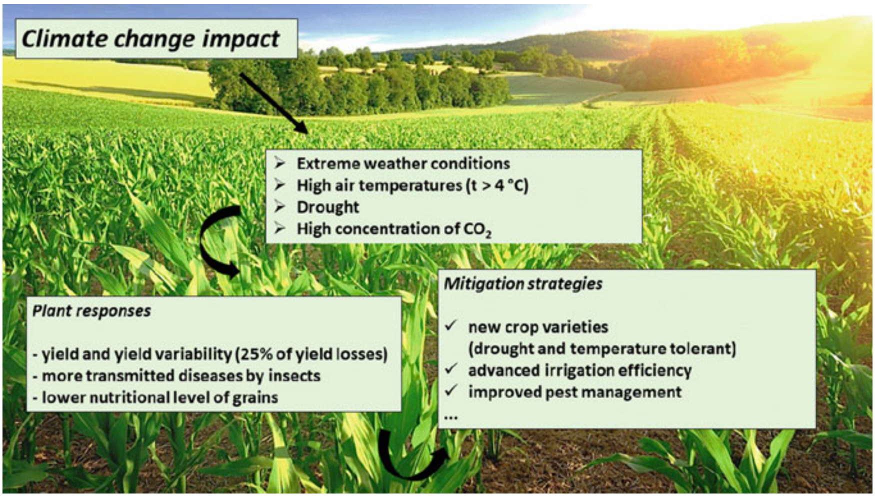
W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_18

variability of yields and the indirect impact can be estimated via more occurring pests and diseases on plants. In the second route, the impact of climate change can be defined through changes in atmospheric CO_2 concentrations, which is altering the nutritional quality (Picture 1).

All of these impacts have the potential to change the quantity, quality, and safety of food for every individual worldwide (Mbow et al. 2019).

Recent studies are confirming that there is a strong connection between climate change, in terms of higher air temperature, and crop yields (Hatfield and Prueger 2015; Liu et al. 2019; Parkes et al. 2018; Jiang et al. 2018; Smith et al. 2013; Wang et al. 2016; Ray et al. 2015; Chen et al. 2004; Iizumi and Ramankutty 2016; Olesen et al. 2011; Olesen and Bindi 2002; Alcamo et al. 2007; Olesen et al. 2011; Arata et al. 2020; Luo 2011; Chen et al. 2020). The results of these studies are implying that higher temperatures can reduce crop yields and increase yields variability. In some cases, for example in northern Europe, higher air temperatures can have a positive effect (Holmer 2008).

Climate change is influencing crop production by modifying the dynamics of diseases and pests, this is reflected in alterations in the distribution and population size of pests. A major influence on the abundance and distribution of pests and their threat to global crop production has been analysed (Pareek et al. 2017; Pareek et al. 2017; Prasad and Mukhopadhyay 2013; Saren et al. 2015; Roy et al. 2019; Sharma 2010). One of the side effects is an alteration in the effectiveness of pest management control, hence frequent treatment with pesticides will be needed and some of the commonly used pesticides have a negative effect on human health (Agostini et al. 2020; Sabarwal et al. 2018; Kumar et al. 2014; Roy et al. 2009; Kabir et al. 2018; Niehoff et al. 2016; Paul et al. 2016; Parrón et al. 2014; Fareed et al. 2013).



Picture 1 The impact of climate change on crop production

High concentrations of atmospheric CO_2 are prone to have a direct impact on physiology, development, and nutritional composition in plants because plants are photosynthetic organisms. The positive effect of increased photosynthesis is enhanced growth, however, the negative effect is the decrease of the crop nutritional value in the term of mineral content in the grains (Mcgrath and Lobell 2013; Leisner 2020; Loladze 2014; Medek et al. 2017; Bisbis et al. 2018; Hogy and Fangmeier 2009; La Puente et al. 2000; Myers et al. 2014; Dietterich et al. 2015; Högy et al. 2010), also decreased of protein content has been observed (Medek et al. 2017; Leisner 2020; Taub et al. 2008; Abebe et al. 2016; Hogy and Fangmeier 2009; Fernando et al. 2012).

The agricultural practice contributes to climate change, every stage of food production releases significant quantities of greenhouse gases into the environment. It is estimated that agriculture releases 10% of the European Union's total greenhouse-gas emissions in 2012. One of the main objects of the new policy Agenda 2020 for the EU is to lower the negative environmental impact of EU farming (Vlontzos and Pardalos 2017).

The purpose of this chapter is to present these aspects of the negative effect of climate change on crop production and the potential influence on public health.

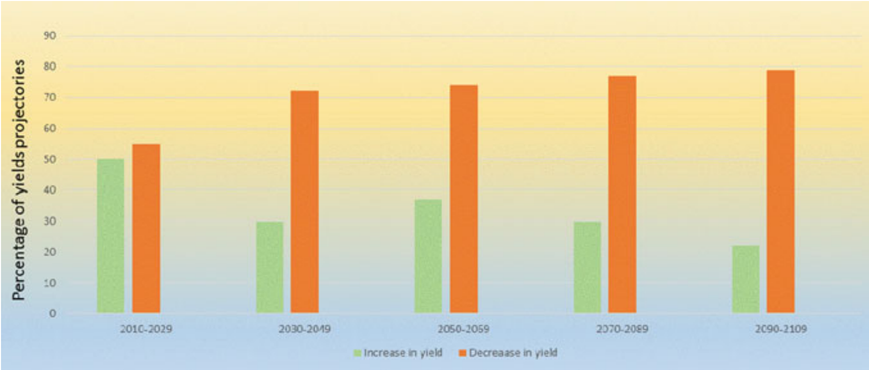
2 High Temperatures Altering Crop Yields

For each crop and every part of the growth development, a different range of temperatures can be determined. The outcome of enhanced temperature will depend on the optimal crop temperature for germination and reproduction.

The impact of global warming is certainly evident in crop production, yield responses to higher temperatures differ among different species depending on their optimum temperature for growth and development (Hatfield and Prueger 2015).

Scientific researches are indicated, with high confidence that global temperature will increase for more than 4 °C during the twenty-first century (IPCC 2014). The changes in the global temperature concurrently with water scarcity and severe weather conditions have a negative impact on every aspect of food safety. Also, the projected impacts are showing 25% of yield losses (Picture 2) compared to the end of the twentieth century (IPCC 2014).

Evaluation of the impact of global warming by 2 °C on wheat production presented that average yield on a global scale will be changed from − 2.4% to 10.5%, related to wheat production from the period of 1980–2010 (Liu et al. 2019). Following this information, we can observe a positive impact of climate change on annual yield, but this projection also suggested that extremely low yields will be frequent in regions with a warm climate and low precipitation, including India, which produces more than 14% of the wheat in the world (FAO 2014). A similar study was conducted in West Africa for maize, sorghum, and millet with the same predictions and conclusions (Parkes et al. 2018).



Picture 2 Review of forecasted changes in crop yields (wheat, maize, rice, and soy) due to climate change over the twenty-first century (IPCC 2014)

Assessment of climate change impact on the production of corn and soybean in Canada implied that higher temperatures would significantly reduce the yield of corn by 27% with just 4% reduce in soybean yield (Jiang et al. 2018). Additional studies with projected climate situations in Canada (Smith et al. 2013) and USA (Wang et al. 2016) observed that corn yields enhanced when cultivars with higher GGD (growing degree day) were planted.

The study of the influence of climate variation on wheat, maize, rice, and soybean crops yield on a global scale defined that nearly 32–39% of the changes in yield can be defined by climate variations (Ray et al. 2015).

A similar study was developed for major crops in the U.S. and the results showed that effects are differed by crop, for example, higher temperatures are reducing sorghum yields and yields variability and corn yields, but also increasing corn yield variability (Chen et al. 2004).

Global analysis of yield variability results showed that more than 21% of yield variation can be defined by climate change, these results also implied that yield worldwide has become unstable (Iizumi and Ramankutty 2016).

Higher air temperatures can also have a positive effect, in northern Europe yields are limited by low temperatures (Holmer 2008). A small increase in yield is apparent in the last 20 years in Finland, however, in Greece, the yields are decreasing (Olesen et al. 2011). Increases in the crop yield in Europe are expected in the northern region, but the significant decreases are expected in the Mediterranean and the south-western Balkans, especially for maize, soybean, and sunflower (Olesen and Bindi 2002; Alcamo et al. 2007).

It is obvious that crop production in Europe is affected by climate change, extreme temperatures in the central and southern Europe followed by drought has an adverse impact on crop yield and yield variability (Olesen et al. 2011).

Agriculture, food security, and policies are considerably affected by changes in crop yields and yield variability. Changes in climate and agricultural practices are mainly accountable for the increase in yield variability (Arata et al. 2020).

Acknowledging these studies it appears that there is an essential need to identify temperature optimum to estimate the effect of higher temperatures on crop production. Experimental studies, in the open field as well as under controlled conditions, can provide necessary information for more precise identification of higher temperature effects on crop production in every region (Luo 2011). For example, the productions of rice in China can be reduced by 13,5% due to climate change impact and higher air temperatures, but with changes in agricultural practices and policies these negative impacts could be partially avoided (Chen et al. 2020).

3 Impacts on Pest Management

The higher existence of pests and diseases is more pronounced while the temperature is increasing in the cooler zones, this effect is enabling insects to achieve more reproductive cycles (Bale et al. 2002). Climate change will enhance the development of diseases, weed and other pests accommodated to a warmer climate (Baker et al. 2000).

Climate change has a major influence on the abundance and pests distribution, therefore it poses a large threat to global agricultural production. Higher temperatures can likely raise levels of growth and potentially add one generation per year. This could influence the crop yield and change the effectiveness of pest management control, hence frequent application of insecticides will be needed (Pareek et al. 2017).

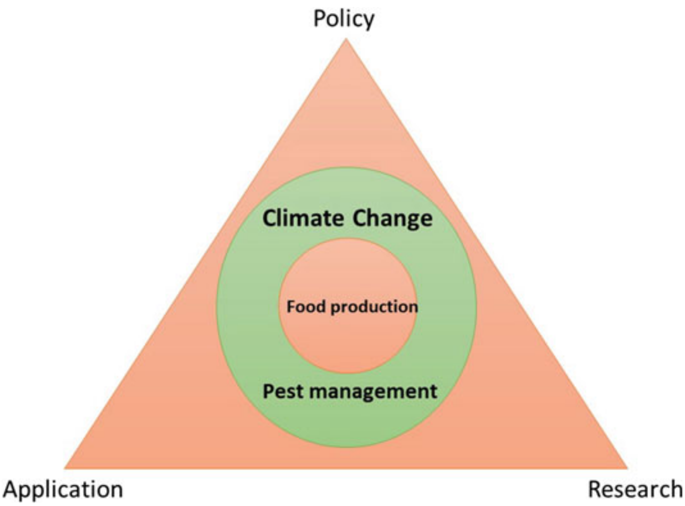
Some of the major impact of climate change on pests are also: different geographical distribution; more population of insects during winter; adjustment to other host plants; less resistance by host plants; different abundance of natural enemies; higher risk of invasive species of pests; the occurrence of more transmitted diseases by insects (Pareek et al. 2017).

Studies of the influence of climate change on tea insects indicate that their life cycle is shorter than expected (Prasad and Mukhopadhyay 2013; Saren et al. 2015), this has a positive effect on the population and causes more damage to crops.

With temperature rise, insects can reproduce more rapidly with the longer breeding season, this phenomenon leads to alteration in nutritional quality in plants, for example, more insects feed on plants so C:N ratio gets modified (Roy et al. 2019).

These impacts will have a significant effect on crop protection and safe food production. As a biological response to higher temperatures, all aforementioned effects will spread through all regions and influence all crops. It is necessary, through multidisciplinary cooperation (Picture 3), to achieve the monitoring of insect population and their adaptation, and to include effects of climate change in the development of improved pest management (Sharma 2010).

Despite the existence of numerous effects of climate change on growth, distribution, and development of pests there is a lack of cross-collaboration between climate and pest management scientists and this leads to limited knowledge exchange between scientists (Young et al. 2019).



Picture 3 Need for multidisciplinary cooperation (Young et al. 2019)

The use of pesticides for control of pests and disease and crop protection is inevitable in agriculture, however, pesticides are posing a threat to the environment and public health. For instance, it has been observed that the use of pesticides is causing in protected areas a severe decrease in the number of insects (Hallmann et al. 2017). Additionally, some of the frequently used pesticides have an accumulative negative effect on human health (Agostini et al. 2020).

It is estimated that pesticide poisoning accounts for 300,000 deaths in a year on a global scale (Sabarwal et al. 2018). Various health disorders are linked with exposure to pesticides, such as childhood leukemia (Kumar et al. 2014), prostate cancer (Roy et al. 2009; Kabir et al. 2018), breast cancer (Niehoff et al. 2016), Parkinson's disease (Paul et al. 2016), Alzheimer's disease and multiple sclerosis (Parrón et al. 2014), Respiratory disorders (Fareed et al. 2013).

4 Impact of High CO_2 Concentration on Grain Quality

Plants are photosynthetic organisms, therefore elevated concentrations of atmospheric CO_2 are prone to have a direct impact on physiology, development, and nutritional composition in plants (Ziska 2008).

Higher concentrations of CO_2 have a stimulating consequence on plant growth because of increased photosynthesis (Müller et al. 2014). However, another effect is the reduction of the crops nutritional value in the term of mineral content in the seeds (Mcgrath and Lobell 2013; Leisner 2020).

Research on this effect, elevated atmospheric CO_2, on wheat and rice indicated a decrease in total mineral content by 8% (Loladze 2014), and protein, Fe and Zn decreased by 3–17% (Medek et al. 2017; Leisner 2020).

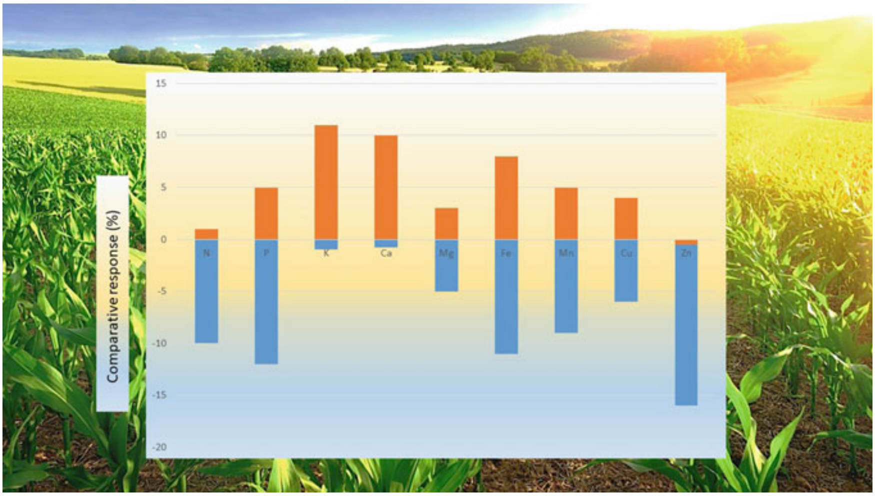
A similar study observed a decrease in protein content in wheat, rice, and barley by 10–15%, in potato by 14%, and soybean by 1.4% (Taub et al. 2008). Another study with a similar experimental design showed a decrease in protein content in maize (11%) (Abebe et al. 2016).

Several studies including leafy vegetables on increased CO_2 influence indicate higher content of sugars and vitamin C in edible parts of plants, while nutrients content decreased (Bisbis et al. 2018).

The study of the effects of elevated CO_2 concentrations on the chemical content of potato tube showed increased content of glucose and fructose by 22% and 21% respectively, and decreased levels of proteins, potassium, and calcium (Hogy and Fangmeier 2009). Furthermore, a similar study observed lower protein content in wheat (13.4–15.3%) (Fernando et al. 2012).

Elements that are essential for our nutrition, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), copper (Cu), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), and selenium (Se) (Smith et al. 2018) are found in grains. The impact of raised CO_2 concentration on grain nutrient content differs within crops. For example, under the influence of higher concentrations of CO_2 canola and wheat (Picture 4) have a lower content of N, however, this is not the case for field pea (Jin et al. 2019).

Previous studies of this impact on wheat reported a reduction in the content of Fe and Zn in the grains (La Puente et al. 2000). More recent studies observed a reduction



Picture 4 Effect of elevated concentration of atmospheric CO_2 on nutrient content in crop grain (Jin et al. 2019)

in nutrients content such as Ca, N, Fe, and Zn in the grains of soybean, sorghum, potatoes, wheat, and barley (Myers et al. 2014; Dietterich et al. 2015).

Spring wheat tested under a high concentration of CO_2 revealed a reduction in Ca, Mg, and Mn by 9.7%, 4.2%, and 4.9% respectively (Högy et al. 2010). The same experiment showed an increase in K by 3.9%, P by 1.1%, and Fe by 1.2%.

According to Högy et al. decrease in macroelements is uniform for all wheat cultivar. Also, under experiment conditions with elevated CO_2 concentration microelements content is decreasing from 3.7 to 18.3% (Senghor et al. 2017).

The higher concentration of atmospheric CO_2 can cause more dietary deficiencies and create a global problem for public health. For example, the content of zinc in significant food crops can be lower, which is prompting dietary deficiency of zinc, on a global scale 2 billion people suffer this deficiency (Myers et al. 2014).

Nutrient deficiencies are more often in less-developed countries particularly concerning micronutrients (Schmidhuber et al. 2018), and the occurrence of anemia will increase since more people will suffer from protein and zinc deficiency (Smith and Myers 2018).

One of the many Sustainable Development Goals by the United Nations General Assembly (2015) is to enhance nutrition and limit all models of malnutrition by 2030 (Wu et al. 2020).

A study on a dietary nutrient deficiency of the population in China prognosticated decreases for both male and female intake of protein, zinc, and iron, as an outcome, the nutrient insufficiency would progress by 1.35–4.42% (Wu et al. 2020).

Other similar studies determined that the average change for the Chinese population in protein intake would be −4.91% (Medek et al. 2017), the iron intake will decrease by 3.8% (Smith et al. 2017), and zinc deficit will enhance by 0.6% (Myers et al. 2015).

The global prognosis is that the average profits of economic growth are higher than the adverse climate change impacts on macronutrient quantities, proteins included, though this prediction doesn't apply to micronutrients (Nelson et al. 2018).

The reduction of CO_2 emissions is a major challenge, hence it is needed to prevent degradation in crop nutrient quality (Wu et al. 2019).

5 Mitigation Strategies in Combating Climate Change Effects

Extreme temperatures followed by drought are showing a negative impact on crop yield and yield variability. Further, this negative impact is leading to increased irrigation, cultivation costs, and negative variations in soil and water quality (Dai et al. 2020; Gomez-Zavaglia et al. 2020). To achieve sustainable agriculture, and to reduce this adverse impact on crop yield, the best option is to breed crop varieties that are drought and temperature tolerant. With this approach, we can improve irrigation efficiency and achieve sustainable use of water for irrigation (Sofi et al. 2019).

Climate change has a significant impact on the effectiveness of pest management control, and on food safety, due to the frequent application of insecticides is needed. FAO advises the use of two simultaneous strategies with actions taken on both, global and local scale, this includes improvement of the system for control and detection, breeding of diseases and pest-resistant crop varieties, and implementing the integrated pest management systems (Sharma 2010). Additionally, a sustainable option is to adjust agricultural systems to enhance the activity of specific cultivation natural enemies and to explore the possibility to use biopesticides or natural essential oils as pesticides (Gomez-Zavaglia et al. 2020).

The essential part of mitigation strategies is the development of integrated monitoring in both sectors, environment, and food, to achieve the early identification of possible problems. Such systems can produce valuable data that can be easily shared on a national and international level and used to improve risk assessment. Adequate control tests are necessary at each step within food chain production to ensure food safety (Zwietering et al. 2010).

The government should provide policies and investment strategies to support education, demonstration training, and to raise awareness about climate change adjustment strategies, especially for smallholder farmers (Thinda et al. 2020).

Mitigation strategies have great success in developed countries, and adaptation options to fight against climate change are very similar on a global level. However, in developing countries, strategies that provide irrigation efficiency or improve crop management are limited.

6 Conclusion

Climate variability has a major influence on crop production, as temperature and CO_2 are increasing quality and the quantity of crop production is decreasing. Evaluation of the impact of the global warming observed through recent studies presented that the most often result are yields decrease and yields variability increase.

Crop production is also very vulnerable to variation in the distribution and abundance of pests. One generation of insects per year as a result of higher temperatures are influencing crop yield and requiring a frequent application of insecticides. The more frequent use of insecticides has a strong negative effect on the environment and public health, hence different health complications are linked with exposure to pesticides. Understanding that the use of pesticides is inevitable in crop production it is essential to achieve multidisciplinary cooperation to implement the effects of climate change in the development of improved pest management.

The aforementioned studies observed that higher levels of CO_2 in the atmosphere are affecting the nutritional value of crop grains. This impact has an important influence on safe food production, more dietary deficiencies are a potentially public health issue on a global scale.

Analysed three influences are among the most significant. Furthermore, there are impacts that we have not addressed, for example, soil microbe interaction under climate change and extreme weather conditions that can reduce access to food and price increases of a particular product. Additionally, it is crucial to analyse the sociological aspect and national security in the event of food deficiencies.

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Climate Change Effects on Agricultural Production Systems in México

Christian Michel-Cuello and Noé Aguilar-Rivera

Abstract In México, agricultural production greatly supports the country's economy, the productive systems of maguey (*Agave salmiana*), sugar cane (*Saccharum officinarum*), beans *(Phaseolus vulgaris*), corn (*Zea mays*) and different citrus species (Citrus sp.) stand out remarkably. These crops are the basis of food and as raw material for the production of alcoholic beverages bioproducts and exportation. The crops are adapted to the different environmental conditions of the country and for this same reason they have very varied yields; It is important to note that the maguey can be used from farming systems, but it is also obtained as a forest product. These two forms of production also present different yields. These variations, together with the fact that a significant percentage of the country's agricultural systems depend on rainwater for irrigation cause a high level of uncertainty in production systems and low yields. This chapter presents a comprehensive review of the alteration of the environmental conditions that sustain Mexican crops and the decrease in agricultural yields due to climate change. As well as the socioeconomic and environmental impact caused by the growth of the agricultural frontier and of the irrigation systems to maintain conventional production. In addition, the chapter focuses on mitigation and transition strategies from waste crops as feedstock to biorefineries in a circular bioeconomy and various factors related to sustainability.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_19

1 Introduction

1.1 Agriculture and Climate Change in México

Agriculture is a human practice that transforms natural ecosystems into production systems or called agroecosystems to obtain goods or services. In an agroecosystem, the proper functioning of the interactions between the organisms that compose it and the environmental conditions is of primary importance. The main matrix of traditional agricultural systems is the soil, defined as a complex ecosystem where microorganisms and elements interact such as organic matter, minerals, and macro and micronutrients whose quality and availability depend on physical, chemical and biological phenomena, which are modified by agricultural practices and geomorphological conditions, but mainly due to environmental conditions and climatic regimes. The soil is considered as an indispensable resource for the development of plants, for this it must have the capacity to supply the necessary nutrients to the crops to carry out the metabolic processes inherent in the growth and development of the crops (Purcena et al. 2014). Agricultural production, understood as a biological process, alters the properties and interactions in the soil, it can withstand these changes, as long as the homeostatic capacity of the ecosystem is not exceeded. Some environmental disturbances and anthropogenic activities disturb the soil-environment balance and can transform it into degraded soil (Cuervo-Robayo et al. 2020; Gomiero 2016).

Climate change is a phenomenon characterized by abrupt changes in environmental conditions and is currently considered one of the most important environmental problems worldwide. These changes can be considered natural and have occurred throughout the evolution of the planet; however, the increase in human activities and their impact on the atmosphere have contributed to accelerating the magnitude of these changes. Its main effects are observed in considerable increases in temperature and solar radiation, which directly influence hydrological cycles and these in turn cause events such as frosts, prolonged droughts, floods, etc. In México, these phenomena combined with the inadequate planning of agricultural systems evidenced by the indiscriminate use of agrochemicals and inefficient irrigation systems, have caused problems such as soil erosion, decrease in organic matter and nutrients, lower energy efficiency, negative impacts. on biodiversity, loss of cultural knowledge and great dependence on the excessive use of the same agrochemicals to maintain or increase agricultural productivity (LaFevor and Magliocca 2020). These phenomena have a great impact on national agricultural production and compromise elements such as the availability of water, production chains, nutrition and food security. The impact of climate change may be greater in those systems that depend on the contribution of rainwater for their crops, known in México as "Rainfed Systems or Temporary Crops" (Ubisi et al. 2019; Knutson et al. 2017; Huang et al. 2016; Elbehri 2015; Abbona and Sarandón 2014; Smith and Smith 2002).

México presents the second most important economy in Latin America. In contrast, a significant proportion of its population (46.2% in 2014) is classified below the national poverty line. Despite its economic development, great inequality of opportunities is observed mainly in the population located in rural areas, but above all in indigenous populations. A very important economic sector is agriculture since 13.3% of workers in the country were engaged in activities related to this sector. Among its most important annual crops are white, yellow and forage corn, sorghum, beans, wheat, soybeans and chili. Table 1 shows the main annual and perennial crops in México, classified by type of agriculture as open or protected, the area planted in hectares and its production in tons per year. Perennial crops are mainly oriented to the production of coffee, sugar cane, orange, alfalfa, maguey, mango, lemon and avocado. Most of the agriculture is carried out in the open air. Protected agriculture, although less developed, has increased considerably year by year. In 2017 there were 32,406,237.10 hectares (ha) of agricultural area, of which 25,595,474.62 ha (78.98%) are temporary crops called "secano" systems or and 6,810,762.49 ha (21.02%) are irrigated crops (INEGI 2017a, 2017b). Most of the irrigation surface and especially those that depend on the rains as a contribution of water for their crops, belong to small farmers; These conditions represent a very important risk situation, since the success of their harvests presents great uncertainty and is subject to changing environmental conditions. Small-scale agriculture is directly related to low productivity. In this scenario, environmental conditions determine the socioeconomic development of many agrarian communities in México (Baez-Gonzalez et al. 2018).

1.2 Environmental Requirements

In México, agricultural production greatly supports the country's economy, notably the productive systems of maguey (*Agave salmiana*), sugar cane (*Saccharum officinarum*), beans (*Phaseolus vulgaris*), corn (*Zea mays*) and different citrus species (*Citrus* sp.). These crops constitute a very important part of the Mexican diet and are also used as raw material for the production of alcoholic beverages and the surpluses are exported.

Each of these crops has very specific environmental requirements for its correct development and production. Genetic selection and adaptation processes have allowed certain agricultural species to be cultivated in different parts of the country with similar environmental conditions.

Maguey

Maguey plants belong to the Agavacea family and represent approximately 200 species, of which 150 are found in México. Among the most important species are *Agave tequilana Weber var. Azul, A. salmiana Otto, A. angustifolia Haw, A. potatorum, A. atrovirens and A. mapisaga.* Its main form of use is as raw material for the production of alcoholic beverages and sweeteners in much of the country. The use of maguey is considered an agroforestry system, because wild maguey is collected that did not have any form of management and care, but it is also possible to manage maguey crops that allow its intensive use. The cultivation of maguey has

Table 1 Main annual and perennial crops in México (INEGI 2017a; Pérez-Hernández et al. 2016)

Main annual and perennial crops in México	Type of agriculture				Total production
	Open pit		Protected		
	Planted area	Production	Occupied area	Production	
	Ha	Ton	Ha	Ton	Ton
Annual crops					
White corn (*Zea mays*)	6 946 999.22	23 142 193.13	1.04	10.06	23 142 203.19
Fodder maize and fodder sorghum	2 093 628.85	NA	0.03	0.50	NA
Yellow corn (*Zea mays*)	1 502 325.42	8 071 836.77	1.00	3.00	8 071 839.77
Grain sorghum (*Sorghum* spp)	2 175 098.73	NA	0.00	0.00	NA
Bean (Phaseolus vulgaris)	1 912 605.11	1 308 277.91	3.72	4.30	1 308 282.21
Grain wheat (*Triticum* spp)	640 580.25	3 214 047.08	0.00	0.00	3 214 047.08
Soy (*Glycine max*)	147 675.44	261 247.35	0.03	0.30	261 247.65
Chile (*Capsicum annuum*)	118 745.12	1 646 285.46	6 377.52	338 936.29	1 985 221.75
Perennial crops					
Coffee (*Coffea arabica*)	834 323.44	858 031.56	65.36	7.24	858 038.80
Sugar cane (*Saccharum officinarum*)	824 747.46	56 354 945.11	0.00	0.00	56 354 945.11
Orange (*Citrus sinensis*)	395 842.89	2 869 737.33	6.44	61.00	2 869 798.33
Alfalfa (*Medicago sativa*)	382 194.57	NA	0.98	19.11	NA
Maguey (*Agave* sp.)	330 000.00	NA	NA	NA	NA
Mango (*Mangifera indica*)	233 352.27	1 689 808.73	9.61	30.00	1 689 838.73
Lemon (*Citrus limon*)	160 796.05	1 110 744.69	40.31	95.24	1 110 839.93

(continued)

Table 1 (continued)

Main annual and perennial crops in México	Type of agriculture				Total production
	Open pit		Protected		
	Planted area	Production	Occupied area	Production	
	Ha	Ton	Ha	Ton	Ton
Avocado (*Persea americana*)	128 839.98	NA	4.19	6.28	NA

Note that some crops such as alfalfa, maguey, avocado, sorghum and forage sorghum do not show production. In the case of perennial crops, production varies due to market, physiological or maturity conditions

the advantage of being interspersed at the same time with the planting of corn and/or beans (Thiede 2020; Zúñiga-Estrada et al. 2018; Mariles-Flores et al. 2016).

Studies indicate that in México the use of the maguey has been carried out since pre-Hispanic times and presents a close cultural relationship, it is used as a raw material to produce more than 10 types of alcoholic beverages and numerous varieties of them depending on the region in which they are produced, for this, about 10 different species of this plant are used, grown or collected in 22 states of the country with a national yield of 73.65 t ha^{-1}(Michel-Cuello et al. 2019) (Fig. 1).

Fig. 1 Agave crop in Mexico (data from SIAP 2020)

The optimal conditions for maguey plantations in México are those areas with an average annual precipitation between 200 and 400 mm, located at an altitude of 1000 to 2400 m above mean sea level, with an average annual temperature of 18 °C (42 °C maximum and −9 °C minimum). The other species of the genus develop optimally with similar environmental conditions (INIFAP 2020).

Sugar cane

In México, the agro-industry for the cultivation and use of sugarcane (*Saccharum officinarum* L.) is very important, representing 0.5% of the National Gross Domestic Product (GDP), 8.9% of the GDP of the agricultural sector, approximately three million people intervene in activities related to cultivation and transformation and it is considered the seventh largest sugar producer in the world. According to data from the 2018–2019 harvest, 804,060 hectares (ha) are cultivated nationwide, with a production of 54,757,557 tons (t) of cane, harvested by 50 mills located in 15 states of the country (Fig. 2).

Nationally, the average annual yield is around 65 t ha $^{-1}$. The current situation of sugar agribusiness in México presents a notable delay in its technological processes in the field and in the factory, unfortunately the infrastructure of the mills is obsolete and has low productive efficiency and high generation of waste and environmental impact, they also do not have an integral project that seek the sustainable development

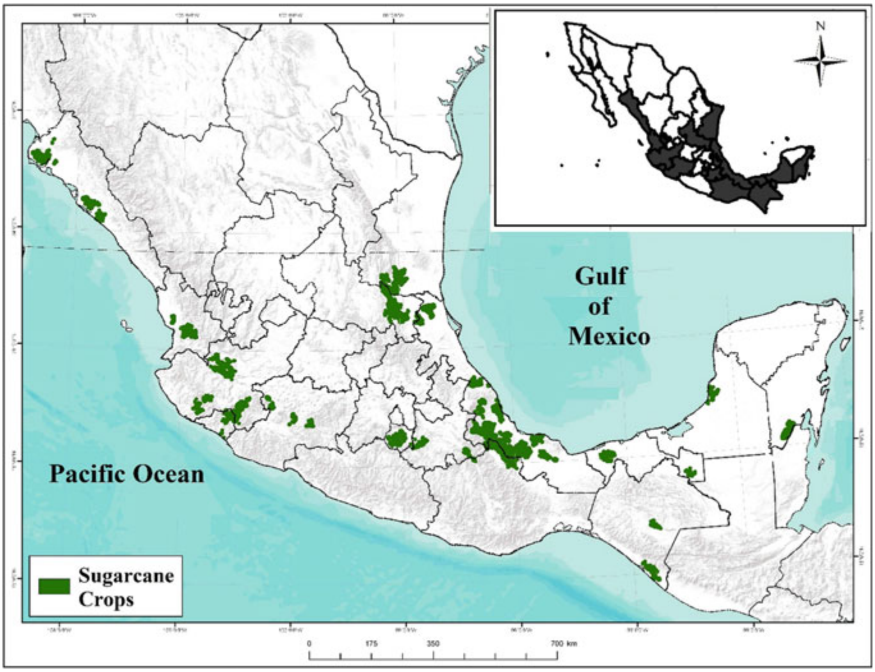

Fig. 2 Sugarcane crops in Mexico (data from CONADESUCA 2020a, b)

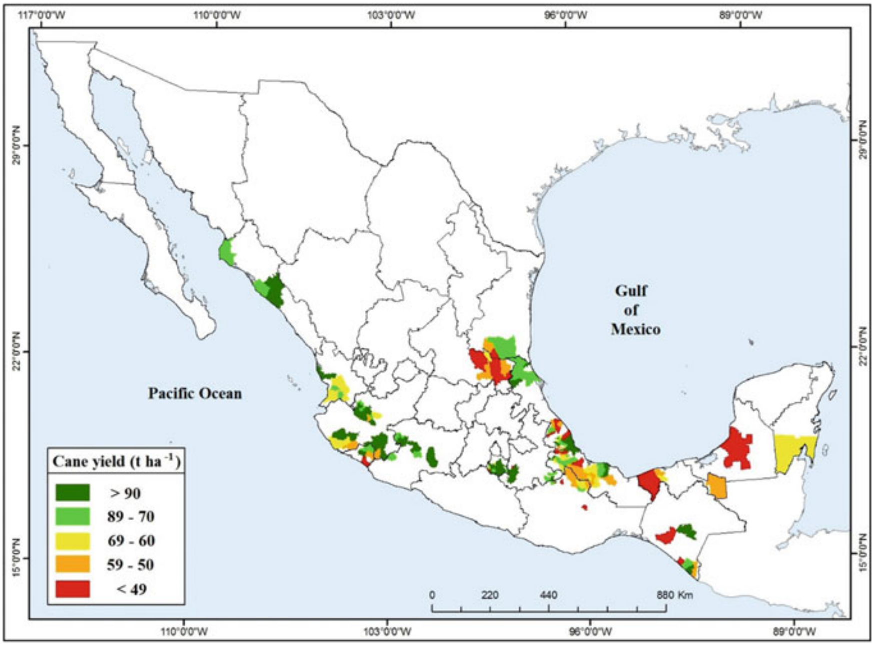

Fig. 3 Cane productivity in Mexico (t ha^{-1}) in 2019 by producing municipalities (data from CONADESUCA 2020a, b)

of this agro-industry (Aguilar-Rivera et al. 2018). As a consequence of these factors, contrasting results are observed in average agroindustrial yields: the highest yield was obtained in the Ingenio de Casasamo La Abeja, Morelos with 117,230 t ha $^{-1}$; and the lowest in the Azsuremex Sugar Mill in Tenosique Tabasco with 41,008 t ha $^{-1}$. The variability in the production of mills in México depends on multiple factors, among which the differences between environmental conditions stand out (Salgado-Velázquez et al. 2020) (Fig. 3).

The productive potential of sugarcane cultivation depends on three climatic aspects in production systems: 1. Climate, the most important determinant in the growth of cane and therefore in the amount of biomass and sugars produced; 2. The adverse climatic conditions mainly droughts that determine the development of pests or diseases; 3. Water, mainly the rain that must be close to 1500 mm precipitation and the environmental temperature in the range of 25–38 °C (CONADESUCA 2020a, b).

Bean

Bean cultivation is very important in México, it occurs in almost all the states of the republic where regions classified as temperate-semi-arid and warm with dry winter are located, and represents a key food in the Mexican diet since its annual consumption per capita is around 10 kg. In 2017, 1,912,605.11 ha were planted, an

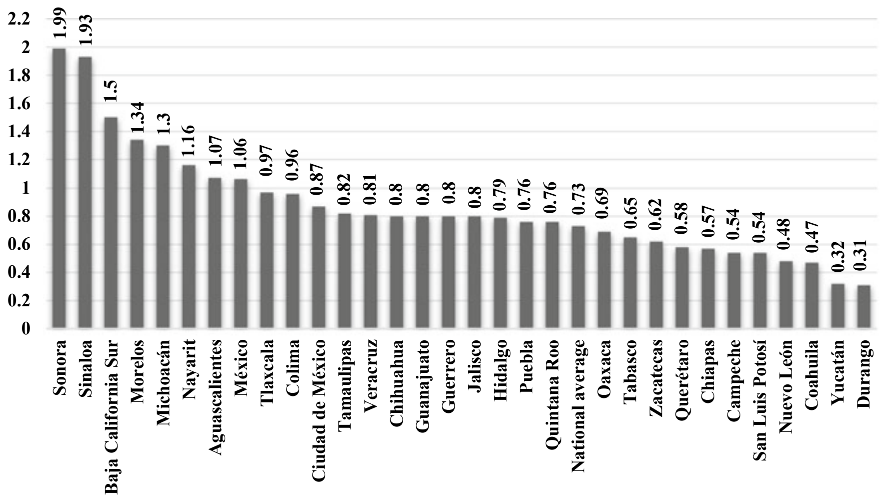

Fig. 4 Bean productivity in Mexico (tha^{-1}) in 2019 by producing states (data from SIAP 2020)

area only surpassed by corn and sorghum crops (INEGI 2017a). The crops are located mainly on flat land at elevations close to 1800 and 2200 m above sea level. Almost 100% of its cultivation is carried out in dry conditions with less than 450 mm of precipitation per year. The optimum temperature for its cultivation ranges between 10 and 27 °C and is very susceptible to damage by extreme conditions. As in most developing countries, bean cultivation occurs on small-scale farms with low inputs and energy inputs. This crop is highly vulnerable to abiotic stress, such as drought and low soil fertility (Rosales-Serna and Flores-Gallardo 2017; SAGARPA 2017b; Castañeda-Saucedo et al. 2014) affecting the productivity (Fig. 4).

Corn

Corn is the main food in the Mexican diet, with per capita consumption by nearly 50 pounds. And represents the crop with the largest area sown in the country, as well as being of great importance in livestock diets (SADER 2019). The use of the plant is integral when all its parts are used such as stems, panicles, olotes and even a parasitic fungus called Huitlacoche (*Ustilago maydis*), which is food of pre-Hispanic origin with an important nutritional content. The different varieties of corn have allowed its use in different environments with remarkable yields (Fig. 5).

The cultivation of corn is carried out in two agricultural cycles: spring–summer and autumn–winter, supported by various weather and humidity conditions called storm and irrigation, the production of corn under storm conditions is one of the main activities of the rural sector. It is cultivated for self-consumption by approximately 2.6 million producers, it is considered a subsistence crop because it is the basis of its food security. Statistics indicate that more than 50% of national corn production is generated under this scheme (Jaramillo-Albuja et al. 2018).

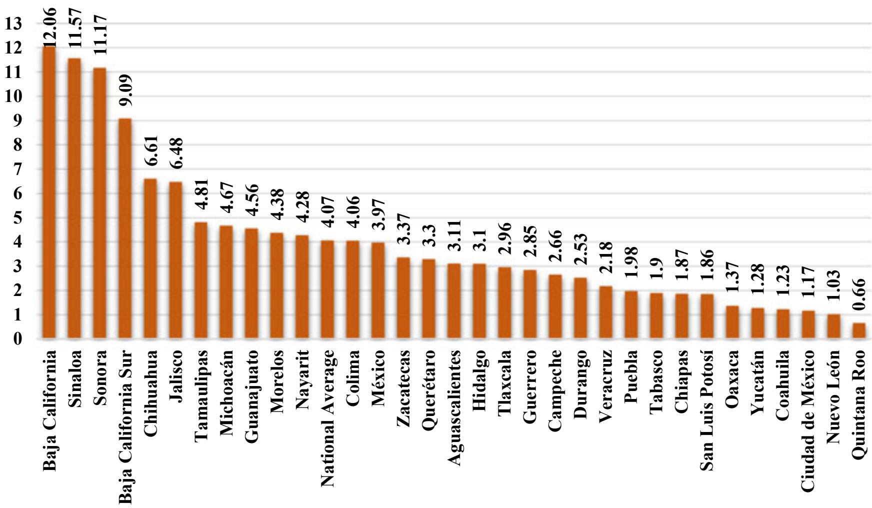

Fig. 5 Corn productivity in Mexico (t ha^{-1}) in 2019 by producing states (data from SIAP 2020)

Citrus

The fruits commonly called citrus fruits are characterized by their high content of vitamin C or citric acid and antioxidant properties. They are native to tropical and subtropical Asia, they belong to six genera, of which only three have commercial importance, being Poncirus, Fortunella (kumquat) and Citrus. The genus Citrus groups nine important species and numerous hybrids. Among its species, lemon, orange, grapefruit or grapefruit, lime and tangerine stand out, these in turn have adapted to various environmental conditions depending on the region in which they are grown. Citrus fruits are an important part of the Mexican diet, national production is sufficient to supply the domestic market, surpluses are successfully exported for their quality. México is the 2nd lemon exporter and the 3rd orange producer, both worldwide (Mayorga et al. 2020; Sandoval and Avila 2019; SAGARPA 2016). (Fig. 6).

Citrus cultivation requires an important contribution of rain or irrigation and warm temperatures for its development as observed in Table 2.

1.3 Climate Change

Climate change is a global environmental phenomenon characterized by consistent and permanent changes in environmental conditions such as thermal and hydrological regimes. Its main effects are observed in the climate, soil and water resources, its considerable impact on the structure and function of ecosystems. Climate change can have positive or negative effects, since in some regions the rains can decrease

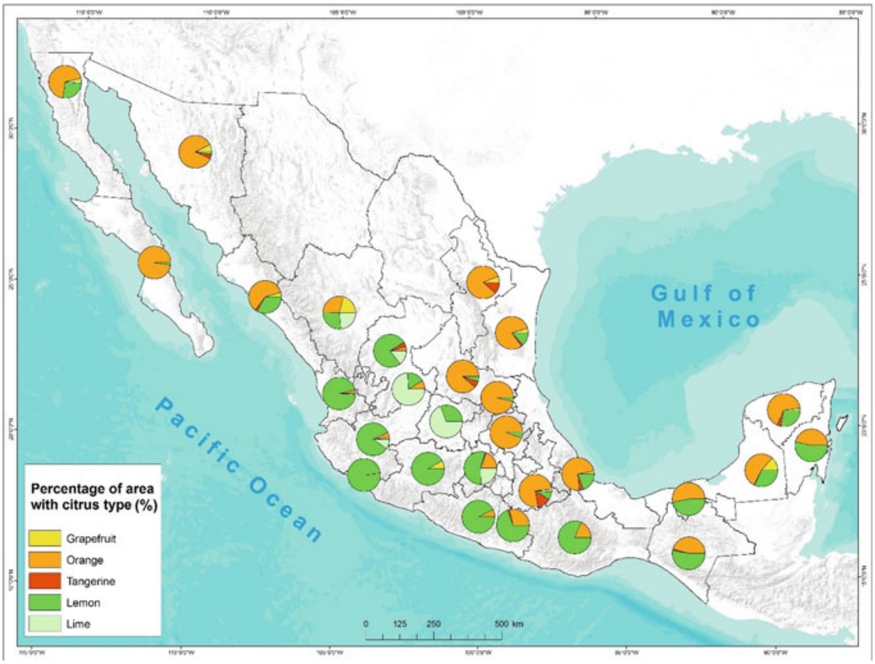

Fig. 6 Citrus crop in Mexico (data from SIAP 2020)

Table 2 Environmental conditions for the cultivation of lemon, orange and grapefruit (SAGARPA 2016)

Common name	Scientific name	Cultivation environmental conditions	
		Temperature	Water supply (rain or irrigation in mm yearly)
Lemon	*Citrus aurantifolia* Swingle	22–28 °C with a minimum of 17 °C and a maximum of 38.6 °C	1,200–1,800 mm
Orange	*Citrus sinensis*	20–25 °C	1,200–2,000 mm
Grapefruit (pomelo)	*Citrus paradisi*	20–25 °C, does not tolerate frost	1,200–1,400 mm

and in others they can increase their precipitation; in the same way, the temperature change can have a detrimental or beneficial effect (Van Meijl et al. 2017).

There are multiple elements that contribute to climate change, activities such as industrial production, forest harvesting and changes in land use, as well as agriculture, are important sources of greenhouse gas emissions such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Studies indicate that 5% of global CO_2 emissions come from such agricultural and forestry activities. Statistics indicate that conventional monoculture-based agriculture releases up to 1900 kg ha^{-1} $year^{-1}$ of CO_2 into the atmosphere, this value may vary depending on the crop, fertilization and climate (Mohammad-Naser et al. 2020). A vicious circle is observed: agriculture drives global climate change, but at the same time, the environmental conditions on which agricultural systems depend are modified and generate uncertainty (Romero et al. 2020).

Statistical studies estimate that by the year 2050, global climate change will have positive and negative effects on agricultural production systems depending on the metabolism of each crop and the new environmental conditions. As of this year, the negative effects will have greater significance when observing effects on arable soils, water sources and biodiversity, this will cause the productive potential worldwide to decrease (Romero et al. 2020); Cuervo-Robayo et al. 2020; Clark and Tilman 2017; Van Meijl et al. 2017; Blanchard et al. 2015). Based on the homeostatic capacity of ecosystems that allows the environment to withstand changes in conditions, it has been predicted that by this year 2050 the dynamic balance between organisms and their environment will be lost. For this reason, the year 2050 is established as the turning point towards negative effects.

The most important atmospheric conditions for the development of agricultural crops are precipitation and temperature, their variability can determine the yield and in turn the success or failure of the harvest (Ureta et al. 2020; Moore et al. 2008). In México, the behavior of these environmental conditions is observed in Fig. 1, according to data obtained from the National Meteorological Service (SMN 2020), according to data from the period 1985 to 2019, there is a trend to increase in maximum temperature, minimum and average annual throughout the national territory; however, this increase is not significant. The average annual precipitation also presents an increasing trend, but the most important thing is that a constant rainfall pattern is not observed that allows predicting future conditions and planning crops and harvests (Arceo-Gómez et al. 2020).

2 Climate Change Effects in México

Agricultural systems are highly susceptible to changes in environmental conditions. In México, 80% of the agricultural area is cultivated in rainfed or also called storm conditions. In recent years, the environmental phenomenon known as drought during the crop cycle has been presented, this being one of the most important environmental problems, since drought significantly reduces the yield and quality of crops. Rainfed or temporary agriculture is characterized in that the main source of humidity that can be used for production is the precipitation that occurs during the agricultural cycle. In this type of agriculture, the aim is to ensure that the maximum amount of water penetrates the soil, is retained and is available to the plant, without interfering with the operation of the crop or causing erosion problems. Under these conditions, water use efficiency and grain yield could be increased, identifying and manipulating

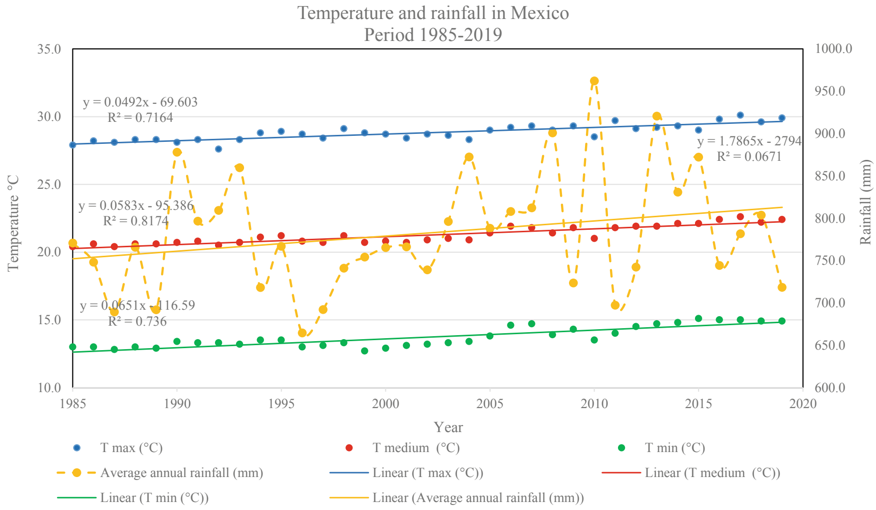

Fig. 7 Temperature and rainfall in México, period 1985–2019 (SMN 2020)

genetically and agronomically the main factors that determine adaptation to drought and other physical factors, and unfavorable biotics (Nabhan et al. 2020).

Given the uncertainty of environmental conditions, which allow guaranteeing large-scale crops with constant growth, it is necessary to define the scenarios generated by climate change towards the year 2050; in this way, having the ability to anticipate changes and establish technological strategies for adjusting agricultural systems to new environmental conditions (Bonilla-Moheno and Aide 2020; Clark and Tilman 2017; Van Meijl et al. 2017; Blanchard et al. 2015).

Figure 7 was prepared from statistical data on maximum and minimum temperatures and annual precipitation on average for the entire national territory of México, in the period from 1985 to 2019, so that in this period no significant changes in temperature and precipitation. However, Saénz-Romero et al. (2010, 2012) exposes environments with more noticeable changes, studies that used climate data from 1960 as a reference, analyzed by General Circulation Models in different emission scenarios. Their estimates for the year 2090 in México could be: (a) 3.7 °C increase in annual mean temperature and an 18.2% decrease in annual precipitation (based on models from the Canadian Center, Hadley Center and Fluid Dynamics Laboratory Geophysicists, emission scenarios (A2, A1B, B1 and B2) adjusted by the climatic polynomial interpolation model "spline"), and (b) 5.0 °C increase in annual mean temperature and a 28.5% decrease in annual precipitation (Hadley Center, Canadian Center, scenario A2). The combination of environmental elements such as the increase in temperatures and the decrease in rainfall precipitation will cause greater aridity conditions in the arid and semi-arid regions of México.

Maguey

Plants of the Agave genus have developed metabolic adaptations to withstand unfavorable environmental conditions in terms of water availability and high temperatures. However, various investigations carried out in México indicate that climate change substantially affects the development of these plants, an example of which is observed in the damage caused by frost to cultivated maguey seedlings and its development (growth, sugar content) because his water stress exceeded the tolerance that his phenotypic plasticity gives him. An alternative to continue with the production of species of economic interest of the Agave genus is the reestablishment of plantations to environments that conserve or have developed optimal environmental conditions (assisted migration) (Saénz-Romero et al. 2012). Climate change also has an effect on the climate-host–pathogen relationship that allows the phytosanitary problem of Fusarium wilt (Flores-López et al. 2016). In plants of the *Agave* genus, heat stress affects their flowering process due to abnormalities in the embryonic sac that prevents seed production (Torres-García et al. 2019; Rodríguez-Garay et al. 2014).

Sugarcane

Sugarcane is a long-lasting tropical crop, making it feasible for it to develop with some tolerance under various environmental conditions throughout the year. Even so, variations in environmental components such as soil moisture, luminosity and temperature significantly affect the growth and development stages of the crop. The relative humidity of the environment has a great influence on the cultivation of sugar cane; if it is greater than 80% during its vegetative growth, the formation and elongation of the sections called internodes will be favored, resulting in the growth of the stems and the multiple underground branching known as tapering. However, during the ripening phase it is necessary for the humidity to drop below 65%, to limit vegetative development and the vegetal moisture content, since this is directly proportional to the concentration of sugar in the juices obtained. The works of irrigation or rain are very important for the cultivation of sugar cane. The contribution must be constant, since variations in the supply of water in deficit or excess, significantly alter yields. Variation in rainfall cycles also significantly affects plant development and harvest or harvest planning. In the case of the temperature, it is necessary that it be in a range between 25 and 38 °C, below the lower limit the regrowth of the stems and the germination of the seedlings is restricted; temperatures above the range increase plant respiration and decrease photosynthetic efficiency, resulting in less dry matter production. If high temperatures occur during the ripening stage, the concentration of sucrose will decrease due to its dissociation or hydrolysis, releasing fructose and glucose. The optimal range of growth presents less variation and is between 26 and 30 °C and it is also required that the average of day and night temperatures do not oscillate more than 8 °C (CONADESUCA 2020a, b).

Bean

In México, bean cultivation is widespread due to its adaptation to different environmental conditions. However, if during its development the contribution of irrigation water is limited, the yield of its seeds is significant and its production can be reduced by up to 60%. The temperature determines in a very important way the growth and development of bean plants, for this reason the minimum growth temperature is observed at 10 °C, below this condition there are very important metabolic changes that affect physiological and biochemical processes in growth and development. The variation of temperature and humidity does not affect the structures with sequential development such as the number of pods, as well as the quantity and weight of the seeds, the important affectations are observed in the quality of the seed with indicators such as germination, emergence and seeds quantity and pods of the new plant (Castañeda-Saucedo et al. 2014; Barrios-Gómez and López-Castañeda 2009).

Because bean cultivation is carried out almost entirely under rainfed conditions, its development presents high vulnerability to environmental conditions in each crop cycle. Research results based on the design of future scenarios of climate change where the decrease in rainfall is analyzed as a determining factor, together with the increase in temperature, will result in higher levels of evapotranspiration, overcoming the water balance of beans. These same estimates conclude that by the year 2070 the area with high potential for bean production will decrease about 40% with reference to the area of year 2016; On the other hand, the surface with medium potential will gradually increase until the year 2030 and later it will tend to decrease (Medina-García et al. 2016).

Corn

In México there are 59 races and thousands of varieties of corn, product of the adaptations to the various environmental conditions to which they have been subjected. Despite this, the increase in temperature due to climate change is causing problems in corn crops such as decreased pollination, increased respiration rate and consequently decreased photosynthetic efficiency and shortening of the phenological cycle, there is a reduction in the leaf area, the production of photosynthates decreases notably, as does the production of biomass and grain. These losses are estimated between 10 and 40%; also low temperatures cause reduced growth and development. The decrease in water supply due to changes in hydrological cycles affects metabolic processes such as cell growth and protein synthesis mainly. Applying mathematical models that allow predicting scenarios based on climate change, it has been possible to estimate that by year 2030, 43 of 47 commercially exploited corn races will decrease their potential distribution areas due to changes in environmental conditions caused by climate change (Ahumada-Cervantes et al. 2014; Ruiz-Corral et al. 2011).

Citrus

In general, citrus crops have considerable agromorphological variability, which allows them to be tolerant to abiotic stress. In citrus fruits, the temperature influences in such a way that it affects the period between flowering to maturation, shortening with increasing temperature and lengthening at colder temperatures (SAGARPA 2016). The increase in atmospheric CO_2 concentrations, causing the greenhouse effect and in turn promoting climate change, does not seem to significantly affect citrus cultivation; on the contrary, in investigations carried out on orange crops, an important increase in its growth was observed due to its greater efficiency in the use of water and its photosynthetic rate caused by the enrichment of CO_2. In some orange varieties, the combination of high CO_2 emissions (greater than 720 ppm) and a 6 °C increase in temperature improved their photosynthetic efficiency, due to the ability of citrus to acclimatize to climate change conditions (De Ollas et al. 2019). The development and growth of citrus fruits under high CO_2 conditions also show lower transpiration rates, conductance and greater efficiency in the use of water compared to those that grew under normal CO_2 conditions, also the concentration of carbohydrates such as soluble sugars and starch was highest (Vu et al. 2002).

3 Conclusion

The effects of climate change in México are evident and have been more noticeable since 1990, as there is a higher incidence of very cold and icy temperatures in the winter period, average temperatures have increased, and rain cycles have been delayed and postponed in different regions from the country. Few quantitative and qualitative studies characterize the effects of environmental modifications applied to specific crops or agricultural regions. However, and as explained above, some studies show both positive and negative effects of increasing the concentration of temperature and CO_2 in the atmosphere on the productive potential of crops.

Although most of the agricultural systems worldwide will be affected by changes in environmental conditions, in México crops such as maguey and citrus fruits such as lemon, orange and grapefruit will resist these changes because they have developed metabolic adaptations that allow them a greater tolerance without affecting their yields; even citrus fruits themselves benefit, since the increase in the concentration of CO_2 increases their production of sugars. It is recommended that the implementation of crops such as these or others that have similar metabolic characteristics be encouraged.

It is important to know the current state and trends in the behavior of temperature and humidity conditions caused by climate change, for the development and improvement of new varieties of seeds or crops adapted to new conditions. Another type of strategies that should be considered are adaptation measures such as improving crop management, applying new varieties, diversifying crops, increasing the efficiency of irrigation systems, etc.

Therefore, it is necessary to focus efforts on identifying areas or surfaces suitable for cultivation according to the environmental conditions of future scenarios in space and time that allow the design and application of adaptation strategies such as the opening of new cultivation areas in regions that offer optimal environmental conditions in order to develop the maximum potential of agricultural production systems and minimize the effects of global climate change as much as possible.

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A Holistic Approach to Address Food Security Risks and Climate Change Adaptation—Insights from Burundi

David Betge

Abstract This chapter presents an approach to combine improved land governance and tenure security with agricultural practices suitable to adapt farming to changing climatic conditions (climate smart agriculture) in order to tackle food security risks in fragile contexts. The core argument presented is that functioning land governance needs to be at the heart of sustainable approaches for addressing food security risks in climatically challenged settings. The chapter describes two tested approaches, one for creating inclusive and functional land tenure systems and one for peer-learning systems that enable sustainable agricultural practices and explains how these can be integrated. The contribution draws on experience and evidence from Burundi.

1 Introduction: Climate Change Adaptation in Fragile Contexts

Environmental degradation and climate change effects have serious impacts on poor populations and weak economies (Betge 2019a, b). Resource poor people struggle to adapt to changing climatic conditions and poverty can exacerbate the decline of natural resources. Governments with weak revenues will struggle to support adequate climate change adaptation or mitigation measures. The effects of this are particularly profound for the agricultural sector. Climatic changes like increased rainfall or extensive periods of draught destroy crops and erode soils. Healthy soils, however, are the basis for agriculture all over the world and the starting point for agricultural value chains. People living in fragile contexts for a large part rely on agriculture as the basis of their food security and livelihoods. At the same time, the quality of soils

The author declares to have been involved in the work described which creates a bias. The intention of this chapter is not an objective evaluation but a problem solution based on experience and third-party evidence. The outlined integrated approach was partly developed in cooperation between ZOA and Wageningen University, specifically Aad Kessler.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_20

is eroding dramatically, induced by human activity (Borrelli et al. 2017) especially in poverty affected contexts. While declining soil fertility and topsoil erosion are not caused by poverty “soil degradation is accentuated by poverty” (Lal 2001).

In countries where the state has limited capacities, comprehensive approaches to tackle the challenge of degrading soils and for adapting to changing climatic conditions are often missing (Betge 2019a, b). Decreasing quality of land and decreasing access to natural resources can lead to exclusion from markets and value chains. The poor people in rural areas are commonly among those most affected by diminished resources and there are indications that resource degradation is the consequence of weak, inadequate or eroding land tenure rights, making this link a point of concern for international development actors (USAID 2007) but one which has not been sufficiently addressed until now.

Smallholders with fragile or contested land rights can easily lose access to land if the pressure on natural resources intensifies (Bruce and Migot-Adholla 1994). In small countries where the population grows rapidly, such pressure builds quickly. Countries like Rwanda and Burundi are threatened by a growing scarcity of arable land. The rural poor there are dependent on agriculture and struggle to survive while support by the government is very limited and donor support decreases.

Burundi is globally among the twenty countries with the highest vulnerability to climate change and natural hazards and has recently experienced massive rains and flooding, including devastating mudslides (UNOCHA 2019). Soil erosion is one of the most serious challenges for Burundian agriculture and almost all farmers lack capacities to adapt to the changing climate (Betge 2019a, b). Generally, “agriculture in Burundi is characterized by low food production due to the shortage of arable land, minimal use of improved seeds, a financial market with very limited access for farmers, the depletion of soil fertility by erosion, and suboptimal fertilizer use” (Ndagijimana et al. 2018). Burundi has a very high population density (see: World Bank 2019) and this puts additional pressure on natural resources. In addition, the land administration and governance system are only partly functional and refugee return from countries like Tanzania and DRC has significantly increased the number of conflicts related to land over the past years (Betge 2019a, b). These issues have resulted in limited protection of natural resources and led to widespread disintegration of Burundian farmers from value chains. Agricultural production is dwindling, and many people produce only for household consumption and local markets Betge et al. (2017a, b).

These challenges are not unique to Burundi and similar situations can be found in other countries on the region. This contribution argues that such contexts of limited and partly dysfunctional land governance seriously impede global efforts to adapt to climate change and create sustainable, effective food systems. The global goals and standards which are set down inter alia in the Sustainable Development Goals and the Voluntary Guidelines on Sustainable Soil Management (FAO 2017) will not be reached in many of the poorest and most vulnerable parts of the world without significant changes in current approaches to food security and value chain development. While the impact of land tenure and land governance on land management might seem to be more indirect, land tenure and land governance need to be key factors in strategies to tackle soil erosion, address food security risks and facilitate climate change adaptation.

It is undisputed that a range of key factors determine people´s investments in the conservation and restoration of natural resources including and maybe specifically land (FAO 1990.). Farmers and rural populations in general will invest in land which they perceive to be secure and which they are likely to be able to access for the long term (Betge 2019a, b). Local institutions are central actors in facilitating conservation and improving farming approaches for soil protection (e.g. zero tillage farming, crop rotation, intercropping) and other environmental practices. Land rights (individual and collective) and local institutions must be bolstered so that people can apply sustainable and effective conservation practices which are suitable to facilitate climate change adaptation and to support value chain integration (Betge 2019a, b). Such measures are key part of food system change. This chapter draws on two approaches applied in the Burundian context, which, if combined can lead to better governance of resources to combat environmental degradation and improve productivity and economic prospects.

The integrated approach sketched out below has so far not been applied. Moreover, integrated approaches that combine land governance and climate adaptive agriculture have generally not yet been applied on a large scale in development contexts. The organisations implementing the approaches described in this chapter took years to realise the potential of truly integrating their work and still this integration has not yet been truly realised. It is important to note that there is a crucial difference between an integrated approach and applying two approaches alongside each other. In many so-called development projects two or more organisations will implement different methodologies and approaches separately to reach common outcomes. In many cases implementation happens in parallel, without sufficient, effective and efficient collaboration. A recent evaluation of major grants programs and strategic partnerships between the Netherlands Ministry of Foreign Affairs and civil society organisations[1] showed a high level of fragmentation and disintegration of development programs that negatively affected outcomes (IOB 2019).

This contribution defines an integrated approach that facilitates the building of effective local land administration systems and establishes peer-learning systems for increased, sustainable production, the application of conservation agriculture and other climate change adaptation measures and can facilitate market oriented smallholder farming (Betge 2019a, b). It is outlined how and why such an approach provides an entry-point to food system change and a comprehensive way to combat soil erosion, better land governance, sustainable land use and why it has a direct link to better value chain integration of smallholders. This integrated approach can be used by development actors globally and is not limited to the organisations mentioned in this contribution in any way.

[1] These partnerships were generally consortia of NGOs financed by the Ministry.

2 Materials and Methods

This chapter uses results from six years of work related to land rights and sustainable, climate smart agriculture in Burundi. Impact evaluations, monitoring data and extensive discussions with peer organizations, donors and academic experts about the results and necessary changes to land rights work are drawn on for this chapter as well as academic research relating to the Integrated Farm Planning Approach (PIP) (van Duivenbooden et al. 2015). This data has been used to sketch out improvements of the tested approaches through integration and the creation of synergies. The comparative assessment of the land rights work and the Integrated Farm Planning Approach (PIP) results in an integrated approach which appears highly promising to rectify shortcomings which have so far impeded long-term and broad-scale successes in fighting soil erosion and creating sustainable, viable agriculture in Burundi. The proposed approach can be adapted in other contexts as the basis for sustainable smallholder value chains. The chapter integrates findings from the broader literature on sustainable land governance and management in developing countries, with a specific view on post-conflict contexts. The approach introduced here can be seen as a key element in facilitating climate change adaptation in the so-called African climatic hotspots and a contribution to food system change (Verburg et al. 2018).

3 Sustainable Soil Protection in Fragile Contexts

Human activity and changes how land is used are key drivers of the global increase in soil erosion (Borrelli et al. 2017) while increasing soil erosion in turn is a key obstacle to climate change adaptation. Climate change adaptation requires protecting soils on a large scale. However, the global phenomenon of soil erosion receives comparatively little attention and its socio-political implications appear to be under appreciated.

Lal (2001) lists land tenure as one of six important anthropogenic factors for soil degradation. The centrality of land tenure for combating soil erosion relates to the fact that conflicts around (access to) land and perceived security of tenure affect people's willingness and ability to invest in land (Ravnborg et al. 2013). However, tenure security alone will not suffice to enable people to invest in their land. If human needs are pressing, sustainable land management is likely to be viewed as secondary to short-term income and livelihoods. The necessity of addressing soil erosion to ensure long-term ability to profit from the land is not equally clear to every land user. Nevertheless, even in circumstances where people are aware of the existence and risks of soil degradation this awareness does not necessarily lead to sustainable land management (Ndagijimana et al. 2018). It has been argued that extrinsic motivation tends to be insufficient to ensure that farmers invest in sustainable land management. Intrinsic motivation is seen to be the key variable (Ndagijimana et al. 2018). In this chapter it is argued that (perceived) tenure security presents an important component of sustainable intrinsic motivation for sustainable land management. To perceive tenure as secure is a key driver of investing in agriculture and land more generally (Ghebru et al. 2016). For this reason, tenure security is one of the key indicators under Sustainable Development Goal number one (SDG 1), No Poverty.[2]

For many farmers the basis for investing in sustainable land management requires intrinsic motivation to undertake action as well as having the financial and physical means to make investments of time, labour and resources (Ndagijimana et al. 2018). The Integrated Farm Planning approach (PIP) strives to enable farmers to invest in and profit from their land by applying simple methods for developing a household farm-plan with activities focusing on family competences and building a vision on household level. At its core is peer-to-peer learning among farmers.

A group of farmers is trained to create a development vision on the household level as well as to apply simple, resource-adequate techniques to improve farming results. These farmers in turn train a second group, which in turn trains a third. The trainings received in the context of the PIP approach (building a household vision, soil and water conservation, integrated soil fertility management, building a community vision) enable farmers to create their own integrated farm plan that addresses different dimensions of household development and can be adapted to the community level (Ndagijimana et al. 2018). The motivation of the farmers to change their life and practices are key to this approach. The PIP approach has been applied in Burundi by the Dutch NGOs ZOA and Oxfam Novib and achieved highly positive results (Kessler and Van Reemst 2018).

The application of PIP in Burundi has led farmers to significantly change their practices not only related to farming itself but also in terms of household and community relations. People have started to do joint planning and to make decisions together within the household (PAPAB 2018). PIP has also led to increased collaboration on community level. A qualitative analysis of the work has indicated that the PIP approach can contribute to reinforcing the role of women in the household, strengthening their say in household matters (PAPAB 2018).

Overall, better communication and collaboration within the household was among the most significant outcomes. At the same time, people mentioned that a lack of cultivable land was contributing to a feeling of helplessness and lack of perspective that was changed by the peer training and positive developments observed among other participants. One farmer reported: "(…) I was trained on modern agricultural techniques, I learned that the use of selected seeds, the respect of spacings and the use of organic manure mixed with mineral manure increases agricultural production if they are done on farms protected against erosion" (PAPAB 2018).

The approach combines mentality changes with integrated soil fertility management, anti-erosion control and natural resource management in the context of the integrated farm plans. The integrated farm plan that gives the approach its name (PIP) essentially consists of two pictures developed by each household, one that depicts the farm's current situation and one that visualises the vision of the household. A similar approach for visualising the planning is applied on community level. These visualisations have proven to be extremely powerful as they make the planning

[2] See here: https://landportal.org/book/sdgs/142/sdgs-indicator-142 (accessed 23-09-2020).

accessible to almost all stakeholders and serve as a constant reminder of the vision and steps (Kessler and Van Reemst 2018). The PIP also entails a specific plan of action. This is a key driver for the family to plan their future and make the necessary investments (Kessler and Van Reemst 2018). Analyses of the PIP approach specifically refer to land tenure security as a key component of intrinsic motivation needed to invest in sustainable land management (Ndagijimana et al. 2018). Where tenure is insecure, sustainable investments in land cannot be expected and motivation to follow through on plans can be affected.

In Burundi, unregistered land is considered as state property and having unregistered land can be discouraging the users from introducing sustainable land management investments (Ndagijimana et al. 2018). Furthermore, many people experience land conflicts with neighbours, family members or returnees who come back after years of internal displacement or living as refugees in neighbouring countries (Betge et al. 2017a, b). This increases insecurity of tenure and discourages people from long-term investments in land or even prevents them from accessing parts of it.

At the end of 2013 ZOA, a Netherlands-based NGO started a project financed by the Royal Netherlands Embassy in Bujumbura (Betge et al. 2017a, b) The project was designed to establish a functioning local land administration linked to a broader land registration program initiated on the national level (ZOA 2013). The approach is based on a concept for fit-for-purpose land rights work (see: Betge et al. 2017b) which implies to building towards an incremental improvement of the status-quo of land governance and management, building on existing capacities and resources and acknowledging existing practices and the diversity of rights instead of a top-down implementation of a formalised (legalistic) land registration program.

In Burundi, ZOA works in areas where the return of former refugees and displaced people makes land rights an issue of concern. The particular, patriarchal context requires a strong focus on safeguarding the interests of women when land is registered (Betge et al. 2017b). One of the central objectives of the project is to enable men and women to invest in their land and increase household food security and income. ZOA cooperates with local partner Mi-Parec an organization that supports the work with resolving conflicts related to land and training local land registration committees in mediation (Betge et al. 2017a, b). The combination of land tenure registration (LTR) and conflict resolution is key. Mediation or other forms of conflict resolution between contestants, particularly between returnees and resident communities, and a recording of the results of the processes are the basis for resolving conflict in a durable way and to ensure the tenure security of all concerned. It is also key for future land investments (Betge et al. 2017a, b). The efforts around land tenure registration are viewed as key to increase peace and stability and for ensuring the food security of the Burundian people (Netherlands Embassy Office Bujumbura-Burundi 2011).

At the core the land registration work is the documentation of the location of a particular plot of land and its dimensions (Betge et al. 2017a, b). The collected data serves as the basis for a certificate, which reduces uncertainties and future conflicts about parcel boundaries. A public land registry facilitates that each concerned party wanting to acquire land can verify the respective land owner as well as the dimensions and other relevant features of the parcel (IDLO/ZOA 2016). Recognition Committees on Colline level are created (CRCs) to facilitate the process. The CRCs publicly establish the existence of land disputes relating to a specific a plot, determine the occupants of the land and the rights holders. The CRCs then survey the plot with handheld GPS devices, mobile phones and in some cases aerial photos. All the neighbours as key stakeholders participate in this exercise. The results are published through public notices and no objection is made after a 15 day period, a land certificate is issued. After the owner retrieves the certificate another 30 day period follows during which objections can be made public (Betge et al. 2017a, b).

ZOA followed a systematic approach to registration that enables all landholders to access the registration service. The systematic approach strives to address the social realities of land tenure documentation and registration by including a broad range of stakeholders and making the process as accessible as possible. This also requires incremental capacity building of statutory and customary authorities who are responsible for maintaining the tenure system in the long term. The approach also offers opportunities to create synergies by integrating it with components aimed at increasing agricultural productivity and sustainability. It aligns well with the PIP approach's focus on integrating all stakeholders and building sustainable structures and systems from the ground up. An integration of the PIP approach also creates direct, tangible benefits to the people whose land is registered, increasing production and enabling the development of a vision based on increased tenure security and the concrete knowledge and capacity increases resulting from the PIP approach. To generate such positive effects however, a true integration of these two approaches is necessary. Activities need to be combined so that synergies are created, and network effects can be realised. Crucial challenges relating to gender relations and conflict are also likely to be better addressed when both approaches are integrated.

One of the central challenges of the registration process the protection of women´s land rights. While women's land rights can be legally registered, the factual access to land cannot always be ensured especially in disruptive situations like the death of a husband or external crises (Betge et al. 2017a, b). Specific efforts have been undertaken to ensure women are not excluded from the tenure registration. This aspect remains a point of attention as it means addressing prevailing norms and beliefs. State and customary authorities play a crucial role in this. The PIP approach offers a way to address the role of women on the household level and increase their voice. This can build towards a greater role of women in overall land management and protecting their land use and access rights, especially through ensuring their voice in developing the community vision for development.

Recent outcome evaluations of the LTR program in Burundi have shown that the local land administrations became functional and enabled the registration of more than 43,000 parcels of land. The role of state and customary authorities is crucial in this. Local communities need to voice demand for services while sate actors need to have the capacity to deliver. Without their cooperation the functionality and legitimacy of the outputs would be extremely limited. LTR interventions can have significant effects on the legitimacy of various actors involved in land governance (Betge et al. 2019) and in a context like the Burundian, low legitimacy can lead not only to a rejection of offered solutions but even to active resistance. The program has run into these kinds of challenges in the past and the political and social complexities of the context need to be navigated in the daily management of the project. An international NGO can play a somewhat neutral, facilitating role in such a context and bring different stakeholders together. Nevertheless, politicisation of the work and legitimacy challenges remain a reality. Different complementary aspects of sustainable land governance such as access to justice for all stakeholders also remain a challenge. Moreover, farmers are expecting to see clear, tangible benefits from improved tenure security. In many contexts, people have become used to receiving free inputs and support (Reincke et al. 2018). However, approaches relying on material incentives often fail to deliver sustainable outcomes as they do not activate the crucial intrinsic motivation of men and women to improve their lives and livelihoods. Sustainable approaches need to provide tangible benefits, but not as free inputs (See also: Ndagijimana et al. 2018).

Combining the PIP approach and the systematic approach to land tenure registration offers a coherent way to integrate participatory land governance and productive, climate adaptive agriculture. There are clear indications that improved tenure security contributes to food security (Ghebru and Holden 2013) and a logical link exists between tenure security and investments in agriculture and climate change adaptation. Applying approaches that create synergies between these aspects should therefore be self-evident. Interestingly, in many contexts where tenure registration programs or agricultural development programs are ongoing such integrated approaches are not standard practice. At best, LTR and climate adaptive agriculture are applied in parallel but even this does not appear to be common. Combining the LTR approach and the PIP approach is highly promising to improve land governance and provide a basis for sustainable smallholder farming.

4 The Integrated Approach

Integrating improved land tenure security with sustainable, climate smart agriculture[3] can contribute to viable, future-proof rural development and a long-term reduction in land conflicts, particularly if based on strong local ownership. The integrated approach to fit-for purpose LTR and the PIP combines land management, household farm planning and sustainable land-based activities with land tenure registration, conflict resolution and overall improved governance. As pointed out in the introduction, the emphasis needs to be on a true integration of such approaches instead of simple parallel implementation. While the distinction might appear marginal, it

[3] *Climate smart* means agriculture that is flexible and adaptive in its methods to respond to changing climatic conditions. In basic forms this means for example low or zero tillage, soil coverage, intercropping or other strategies that are suitable for local conditions and require limited capital investment.

can make or break the success of climate adaptation programs and the development of sustainable value chains. Siloed implementation crucially impedes reaching sustainable outcomes (IOB 2019).

The overall objective of the integrated approach sketched here is to improve local governance, increase the resilience of rural communities and to increase their sense of stewardship and intrinsic motivation to make investments in their land and future. The main objectives are:

- Reducing land conflicts and improving land security through conflict resolution, land rights documentation and registration (LTR).
- Increasing soil protection, combating degradation of soils and increasing the productivity of agriculture.

The integrated approach enables equal access to land and land rights based on fit-for-purpose land tenure registration, while structurally integrating the protection of women's land rights, addressing a population that is mobilised and intrinsically motivated to improve their lives and livelihoods through the PIP approach. Farmers are trained in the PIP approach, learn agricultural techniques to improve soil fertility (Integrated Soil Fertility Management) and become actively engaged with land tenure security issues, based on increased knowledge of tenure rights and external support with solving land related conflicts.

Through the PIP approach, farmers become involved in peer-to-peer learning where they pass on their own knowledge and experience to others while learning new approaches to soil protection and restoration (Kessler and Van Reemst 2018). Additionally, technology that supports farming and access to finance can serve to improve the integrated land management, to address climate change effects, simplify payments for agricultural inputs and enable further inputs.[4] Poverty and insecurity need to be addressed in parallel if sustainable solutions to soil degradation and low productivity are to be found (Lal 2001; Ghebru et al. 2016). Concretely, the fit-for-purpose LTR can be integrated with the PIP approach on three levels (Table 1):

- *Household level*: In the communities to which the PIP approach is introduced, the element of land tenure security can be integrated in trainings and awareness raising of the households. Men and women can be triggered to discuss why and how to secure their land and how to divide land between the family members, as well as the role of women and youth in land management and agricultural production. Tenure security aspects can be included in each individual PIP.
- *Village level*: Integration of LTR with the community vision, awareness raising on (women's) land rights, conflict mediation.
- *District level*: Covering all villages in a district with LTR (systematic approach to LTR). This process can work parallel with the horizontal and vertical upscaling of the PIP approach in a district. The table below summarises key steps of the approach and helps to get a clearer understanding of the process and the synergies that are being created.

[4] An integration of such additional features of the approach is currently being developed for the Burundian context and a pilot is planned to start in 2021 funded by the Kingdom of the Netherlands.

Table 1 Integrated approach summary

Phase	Outputs	Synergetic effects
1: Preparation of target area and 1st generation PIP farmers	*Selection*: target area, PIP farmers (group 1, 30 persons) *Introduction* of program to stakeholders *Awareness raising*: land rights, improved agricultural practices *Training* of land officials, customary leaders, mediation teams, justice sector officials	All stakeholders receive basic information on land rights incl. conflict resolution, PIP approach and climate change adaptation techniques
2: Implementation	Stage 1: Land offices established, land *demarcation/registration* for overall population *Demarcation/ registration* of PIP farmer land Development *household development plan* Ongoing *awareness raising.* Start of *land conflict mediation* for population Stage 2: Implementation of *household development plans*, application of *climate smart agricultural practices*	LTR and conflict resolution available to population PIP household development plan embedded in secured land rights and improved land governance PIP farmers are role models to overall population
3: Preparation 2nd generation PIP farmers	*Peer-to-peer awareness raising:* land rights and PIP approach (PIP farmers, 10 trainees each) *Selection:* 2nd Generation PIP farmers (30 people) *Peer-to-peer training* new PIP farmers *LTR/conflict resolution* ongoing	Snowball effect of peer-to-peer awareness raising and training New PIP farmers to train further 10 PIP farmers each PIP farmers as role models for wider community Increased tenure security
4: 2nd generation implementation	Repeat phase 2	See phase 2
5: 3rd generation PIP farmers	See phase 3 Preparation *community development plan* *Collaboration* with state actors (budget support, integration in development plans), customary leaders and possibly business sector	See phase 3 Common development vision Improved tenure security. PIP farmers as role models/process leaders Increased trust and legitimacy of governance

This integrated approach requires teams of implementers with experts on LTR and PIP and is based on the following assumptions:

1. Participatory and integrated approaches are key for effective land governance and climate change adaptation.
2. Sustainable soil protection/climate smart practices require protected land rights (perceived and legal protection), economic- and food security.
3. Despite complex challenges, solutions are possible as the experience from Burundi with fit-for-purpose LTR and the PIP approach indicates.

Coherent and systematic cooperation with state and customary actors can often be crucial and the experience from Burundi underlines that true local ownership is key to success. Nevertheless, evaluations of the land rights component of the work demonstrate the relevance of capacity development and phased-approaches that facilitate gradual increases of ownership given the capacity restraints of state actors and the limited trust of local populations in state actors and institutions (Betge 2019a, b). Cooperation and co-creation with a range of stakeholders is necessary to ensure sustainability and legitimacy. Furthermore, it is necessary to establish functioning spatial data infrastructure. This needs to happen up to the national level in order to ensure the sustainability of the results. Newly-developed technology will help to ramp up service delivery on all levels and can provide context-adequate and cost-efficient ways in contexts where state authorities fail to deliver accessible and effective services. However, all actors involved need to be conscious that that interventions relating to land rights, agriculture and value chains are in essence social interventions which change social structures. This means that (conflict) sensitive approaches are required which allow for adaptive programming (Betge 2019a, b). The Burundian case underlines that addressing land rights systematically and in a way that is inclusive and accessible is possible, even in conflict-affected, fragile settings. What has until now been missing is a true integration of land rights with integrated farm planning for climate smart practices, soil protection, sustainable production increases and value chain integration of smallholders.

5 Discussion

Accelerated, human induced soil erosion is a major threat to soils globally (Borrelli et al. 2017) especially in combination with the effects of climate change. This contribution shows a way to integrate two highly innovative approaches; the PIP approach for climate smart, effective agriculture and fit-for-purpose land tenure registration. These two approaches focus on reducing tenure insecurity, improving agricultural productivity and introducing climate smart practices in a sustainable, smallholder-oriented way.

The main argument made her is that successes in the above mentioned areas, in particular in fragile, developing countries, require integrated, interdisciplinary approaches. Agricultural improvements and climate change mitigation are not simply technical issues. In many countries state actors do not have the resources to provide the necessary services and support (Betge 2019a, b). Combinations of tenure insecurity and degrading soils as found in Burundi are prevalent across Africa and sustainable solutions have long been sought after (Nkonya et al. 2002). While the FAO underlines that land tenure is a key factor in resource degradation and sustainable land management (FAO 2002) integrated approaches like the one sketched above are scarce.

Land systems generally involve a broad range of actors put a strain on natural resources and this requires coherent land use planning (Briassoulis 2019: (2) Farmers need to have intrinsic motivation to invest in their land and protect soils (Kessler and Van Reemst 2018). In the long-term, this motivation will only be sustained if land rights are secure. "If a farmer cannot look to the future with security, little can be hazarded by him beyond the expenses which the returns of the year will defray; and not only will all great improvements, but even the most common works of the season, be imperfectly performed." (D. Low 1844; Cited after Bruce and Migot-Adholla 1994).

It appears logical that significant results for improved land management, climate change adaptation and agricultural value chain integration of smallholders can be achieved through systematically integrated approaches as the one presented. This requires implementers to change their approaches and donors to revise their requirements and objectives, in order to make true integration instead of parallel implementation possible.

Short financing and reporting cycles or lacklustre consortia of NGOs that work in parallel instead of in cooperation will be insufficient to enable sustainable and broad-scale results. Additionally, clear and enabling regulatory frameworks need to provide the basis for efficient and effective management of such projects (Betge 2019a, b). This is true for international development efforts as well as for nationally financed programs.

Investments in land rights enable the resilience of smallholders and local communities and resilience in turn is closely related to the food security of smallholders (Van Hecke 2018). If land rights work is integrated with targeted support for climate change adaptation, soil protection and productivity increases providing tangible economic opportunities, this can lay the foundation for sustainable value chains even in contexts with high poverty rates and limited infrastructure.

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Climate Change and Poverty: Coping Strategies Adopted by Female-Headed Households in Zimbabwe

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Abstract There has been a rise of households that are female-headed in Zimbabwe caused by socio-economic and environmental challenges bedevilling the country. The study utilisedsecondary data sources inclusive of desktop research and a historical approach which uses the analysis of documents. The researchers measured the strategies used by these female-headed households in Zimbabwe against the following indicators (1) factors affecting female-headed households during the climate change, (2) female-headed household survival strategies and (3) coping strategies adopted by female-headed households. During this period of climate change, various factors are affecting female-headed households in Zimbabwe and these include HIV/AIDS, lower levels of education, poor unemployment rate, little income and poor access towards resources. These female-headed households in Zimbabwe are adopting coping strategies that do not help them to stop the intergenerational transfer of this climate-induced poverty. The coping strategies adopted include resorting to small grain production, vending items such as fruits and vegetables within the house, neighbourhoods and streets. Some female-headed households survive on offering domestic services and prostitution. Therefore the study concludes these coping strategies have made some women remain in the cycle of poverty. Recommendations to improve the status of women include training and educating women about climate change disasters so that they can effectively adopt intercropping. This will assist the women's dependents and children with educational funds to stop the intergenerational transfer of poverty and to provide these women with cheaper access to resources in a bid to reduce their poverty incidences.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_21

1 Introduction

This is a study on climate change and poverty, particularly focusing on coping strategies that are used by female-headed households in Zimbabwe. Female-headed households areprone to climate variability and change. This is because they are poor and are largely dependable over the subsistence economy and some natural resources in their country for their survival (Mugambiwa and Tirivangasi 2017). This becomes more intense to economically marginalised and vulnerable sections of the society such as female-headed households. According to the Zimbabwe Human Development Report (2006), rural and urban poverty has continued to rise in the decade with a majority of female-headed households feeling the brunt. In Zimbabwe, women have constituted a majority of the poor, with ZimStat (2012) and Dzvimbo and Mashizha (2018) highlighting that 31% of households that are headed by females have a greater incidence of poverty as compared to those headed by males. Female-headed householdsadopt certain survival strategies as a way to make a living. Barros et al. (1997:2) define a household as that household that is headed by a person with authority who also have income-earning responsibility. Zarhani (2011) posits Female-headed Households (FHHs) have been increasing particularly in developing regions.However, it would appear there has been an intergenerational transfer of poverty in developing countries such as Zimbabwe, which have been exacerbated by climate change. Female-headed households, for instance, appear to be remaining in the cycle of poverty. One may question the definition of poverty to have a clear understanding of how female-headed households in Zimbabwe are being affected.

UN (2004) notes that poverty implies lower levels of capability. Sen (1992) describes it as a failure to reach basic capabilities in order to reach minimally acceptable levels. A report by UN (2004) further notes that poverty shows high extreme levels of deprivation as capability failures. The report further denotes that it is possible identify basic capabilities that are common in life, for example situations of being adequately nourished, clothed, sheltered and avoiding preventable morbidity. There are also challenges in life like participating in the community life and appearing with dignity in public.

As highlighted earlier, female-headed households appear to be remaining in the poverty cycle due to challenges of climate change. As such, strategies to ensure reduction on the impact of climate change on poverty need to be put in place if developing countries such as Zimbabwe are to stop the intergenerational transfer of poverty among these female-headed households.

Zimbabwe's unemployment rate is very high. For women who head households, the situation becomes even worse because these women appear to be poorer as compared to other households as they have fewer secondary earnings and more dependents. Dubihlela in (Buvinic and Gupta 1997:6) notes that female-headed households have greater responsibility the care and organization of the households. However, these Female Headed Households are failing to take care of their families and they have remained in poverty. The African Forum and Network on Debt and Development (AFRODAD) (2006) has pointed out that one indicator for extreme poverty is median spending done by the poor. AFRODAD (2006) also identifies groups that in extreme poverty to be vulnerable groups such as children, women, youth, handicapped people and the elderly. In respect of routes into female-household headship, Zarhani (2011) argues it is fair to say that these are more usually "involuntary" than by "choice."

Although the United Nations Framework Convention on Climate Change (UNFCCC) accepted that low-income countries have less adaptive financial, technological and social capacities, women-headed households are engaging in several measures to cope with the escalating impacts of poverty. This research examined survival mechanisms that are adopted by these female-headed households in Zimbabwe in fight against the scourge of poverty. Strategies identified included, *inter alia*, vending, firewood selling, doing part-time jobs, forming women clubs, cross border trading and prostitution among others. Although some of these stopgap measures have worked in alleviating the full impact of climate-induced poverty, they are not sustainable and have failed to take them out of poverty but only help them toreduce extreme poverty.

2 Literature Review

In the face of the current economic changes, economic downturns and social pressures faced by humans the world over; survival has become more and more threatened. An increase proportion of female-headed households the world over can be noted due to abandonment, divorce and choosing not to get married during the past decade. Moser (1989) estimates that about one-third of the world's households are headed by women. Female-headed households are increasing at a time when Africa's resources such land are being greatly depleted (Horrell and Krishman 2006; Mashizha et al. 2017). Women and their challenges have generally been blanketed but this research shall delve especially on women heading households who are then forced to make bigger sacrifices indiscriminately to shoulder the burden of household survival to reduce extreme poverty. The marginalization that women endure due to cultural impediments, socio-economic problems and the heading of households as women is in actuality triple jeopardy for female-headed households.

While it can be stated that voluminous academic attention has been given to women's challenges in this world, it is imperative to point out that a lot still needs to be done for women in general and most importantly for the female-headed households. It can therefore be argued that there is still an imperfect understanding on survival strategies that are adopted by female-headed households which are sustainable in their effort to reduce extreme poverty at the household level (Horrel and Krishman 2006; Dzvimbo et al. 2017).

2.1 Theoretical Framework

2.1.1 The Sustainable Livelihood Approach

Chambers (1995) in Scoones (2009) believes livelihoods are experienced in different contexts. What it means is that these livelihoods vary and can be experienced in complex ways. Chambers (1995) describes this as a means of gaining a living. As such, the livelihood approach has influenced many studies towards development thinking or practice within the livelihoods of communities. Scoones (2009) argues that in Zimbabwe agriculturists, economists and ecologists have used this livelihood approach to come up with practical ways of addressing development challenges. The livelihood approach has evolved overtime, particularly after the Brundtland Commission on Environment and Development, alongside the 1992 United nations Conference on Environment and Development in Rio. This approached has placed much emphasis on issues that concern poverty reduction and development (Chambers 1995). This has resulted in long-term sustainability, environmental stress and shock management. The livelihood approach then evolved towards the Sustainable Livelihood Approach (SLA) (Chambers 1995). Chambers and Conway (2009) and Scoones (2009) argue that during the 1990s, the SLA was articulated by Robert Chambers and Gordon Conway by investigating livelihoods of people within poverty situations. The SLA also investigated how people in these situations survive or manage poverty situations. The most significant definition of livelihood was then developed in 1992 to be a livelihood which comprise capabilities, assets and activities that are required for a means of living. According to Scoones (1998) a livelihood is considered to be sustainable if it can cope with and recover from different stresses and shocks. What it means is that the community must be in a position to maintain or to enhance its assets and capabilities without undermining its natural resource base. Carney (2003) observes that this SLA has been utilised by many organisations such as the United Nations Development Programme (UNDP), the Departmental for International Development (DFID) among some others. SLA has been used by these organisations in understanding challenges that are associated with poverty in different contexts. Eventually, the SLA has been used in poverty reduction and creation of better livelihoods for people in marginalised communities. Scoones (1998) agrees that the SLA can as well be utilised as a tool of analysing households, individuals and different categories of people in different settings as it places much emphasis on the reality based on perspectives of particular individuals. To this end, researchers were able to examine the nature of capital assets and structures which limit or enhance access of communities towards resources in achieving desired livelihoods. And as reported by DFID (1999), community livelihoods are normally affected by disasters such as floods, conflicts and earthquakes just to mention but a few. The SLA becomes significant in this study as the researchers are trying to analyse how FHHs are managing their shocks and stresses of life. The SLA also helps in understanding how these FHHs are coming up with strategies that address their stresses to achieve their desired livelihoods.

2.1.2 The Empowerment Theory

Kabeer (2005, p. 13) describes the empowerment theory as a "process in which those who have suffered the ability to make their choices acquire this ability." Kabeer (2005) emphasises that alternatives must exist within the society for people to make different choices. Kabeer (2005) places her emphasis on "choice" as a yardstick for empowerment and some scholars such as Khader (2011) strongly disagree with this "choice" yardstick. Khader (ibid) argues that not every choice can empower individuals. People can make bad choices that go against their basic self-interest. Khader argues choices may result in inappropriately adaptive preferences (IAP). She believes that this state of disempowerment normally happens if IAPs are removed. She also argues empowerment does not need to be imposed, and it can only be achieved through self-realization and self-entitlements. According to Mosedale (2005) empowerment is used widely by development agencies such as the World Bank. However, Mosadele (ibid) observes that not many of these development agencies have been able to show the extent to which they have succeeded during their processes of empowerment. To this end, Mosadele (2005) then argues that empowerment has to be linked in four steps. Firstly, for one to be empowered, he or she has to be disempowered in line with Kabeer's understanding of empowerment. Secondly, it is upon individuals to achieve empowerment. Thirdly, empowerment includes a sense of decision-making that is made by people on desired issues in life and an ability to act upon these. Fourthly, empowerment is not an end or a final product. It is an ongoing process. Overall, Mosedale (2005) argues that empowerment must take the lived experiences of women in bringing change in their lives. As such, women must spearhead these empowerment programmes and they must not be forced upon them. Mosadele (ibid) also emphasises that empowerment must not be seen as an end process, but a continuous process which bring about change in the livelihoods of individuals. Kabeer (2005) has explained the notion of empowerment through concepts such as agency, resources and achievements. To this end, this theory becomes significant as it is a process of gaining empowerment for FHHs.

3 Methodology

The study is qualitative and utilises the historical approach to collect and interpret information. The approach describes, analyses and interprets events that have already taken place among FHHs in light of the climate change impact. It explores the past to understand events and motivations that precede current state of affairs among female-headed households (Babbie and Mouton 2009). Events explored helped in identifying patterns of behaviours in which the present merely represents a point on a continuum of development using largely secondary sources (document analysis).

4 Findings and Discussions

4.1 Factors Affecting Women

Zimbabwean women occupy the largest disadvantaged position within the society because of patriarchy. Some of these women are facing challenges arising from the HIV and AIDS pandemic. According to UN (2006) and Mashizha et al. (2017), each year more than half a million of these women are dying from treatable and preventable complications arising from pregnancy and child-birth. The number of people that are dying from the HIV pandemic worldwide has increased to 2, 9 million in 2006 because preventive measures are failing to keep pace the growth of this epidemic (UN 2006; Mashizha et al. 2017). This has increased the number of orphans, home-based caregivers and vulnerability of women towards HIV and AIDS (UNDP 2006). Eventually, this has added to the challenges faced by women. Mutanana and Bukaliya (2015) have also highlighted that women in Zimbabwe generally have more limited access to inputs, services, productive infrastructure as compared to men.

These problems have severe effects on women who head families in Zimbabwe more than on women who do not head households. Sidloyi (2010), for instance highlights that women in Zimbabwe are facing are number of socio-economic challenges that includes lower levels of education, poor employment rate, little or no income, and poor resources yet they have many dependents and children to look after. This has created situations were women are operating within little opportunities circle (Sidloyi, ibid). The immense pressure on women in Zimbabwe for household maintenance activities and work means that female-headed households' poverty levels extend to non-income dimensions of poverty for example "time poverty" aspect and disadvantages extended to children or members of the household through poor nutrition and children's education. Dzvimbo and Mashizha (2018) and Buvinic and Gupta (1997) have also argued that the double burden faced by these female heads to support their family and household chores imply that FHHs are likely to have poor time and less leisure time as compared to females or male heads that are jointly households.

4.2 Female-Headed Households Survival Strategies

Household survival strategies show that poor women in Zimbabwe are failing to cope and survive in context of restructuring (Lingham 2005:17). There are several household survival strategies that FHHs in Zimbabwe have been known to adopt in their bid to reduce extreme poverty. The socio-economic status and residential location have influenced participation of women in development projects and the type of employment. Schroder (2000) observes that household composition can be used as a key indicator which determine how women are engaged towards income-generating projects and how these women rely on other women in facilitating these income-generating work away from home. Similarly, Mosedale (2005) has argued that empowerment must take the lived experiences of women in bringing change in their lives. As such, women must spearhead these empowerment programmes and they must not be forced upon them.

Vending is a survival strategy aimed at generating income from selling goods that are essential for individual and household economic welfare among FHH in Zimbabwe. A majority of the women in Zimbabwe normally sell, fruits and vegetables and edible items and this does not require high capital injection. In a similar study, MacPherson (1998) revealed that women rely on vending fruits, vegetables and many other small items. Olukwe (2005: 30) notes that in Nigeria, Sudan and Tanzania, women constitute more than 70% of vendors and they account for a significant proportion of household income and welfare. The low capital injection required for these businesses in Zimbabwe is a sign that the gains are also low and not largely sustainable. FHHs in Zimbabwe also involve themselves in urban agriculture to protect themselves from challenges such as hunger. Potts (1995) notes that some poor women in urban grow food on arable parches of land within urban areas as coping strategies.

Another survival mechanism adopted by FHH in a bid to reduce poverty or to survive is prostitution. Lingam (2005:4) observes that deepening poverty among these women is contributing towards the rise in prostitution and this has been considered as one reasons behind the spread pf sexually transmitted diseases worldwide. The physical body is becoming the site of work for these women because of lower employment opportunities. Examining this in the context of FHHs, it shows that that equally affected and in some cases have ended up surviving on prostitution.

4.3 Coping Strategies in Zimbabwe

Climate change has brought about new ways of survival and innovative solutions societal problems that most FHH would never think of before. Female-headed households employ multifarious coping mechanisms in their bid to reduce extreme poverty. Most of the women survive from informal work as noted by Lingham (2005:5; Dzvimbo et al. 2017) that women are concentrating on a narrow range of activities with the lower returns. They survive from cross boarder activities were they buy new and second-hand clothes and shoes from South Africa, Zambia and Mozambique for sale locally. Vending is also another survival strategy that FHH adopt and these women sell various products to make ends meet such as vegetables and fruits, airtime and sweets, cooked food and edibles and firewood. Chant (1997) has identified activities such as income generating projects and domestic labour to more negative strategies such as prostitution.

Of the most significant and prominent strategies adopted by FHH in Zimbabwe are social networks within communities. Writing on the social capital model Sidloyi (2010:31) has illustrated that social capital normally begin household level through responsibilities or obligations which household members may have towards one another and these responsibilities may be extended towards the communities and even towards the broader society if they successfully maintained and established. Women tend to survive from benefits accrued from social capital through the exchange process (reciprocity). These relations that the female headed households build allows them to absorb stresses and shocks and threats to their survival. Amongst the most prominent of the social networks, savings club have come up top for most FHH.

Operationalization of the savings club differs but generally, two types are common. The first is that known as the "grocery club" and the second known as "rounds". In the former, a secretary is chosen amongst the group to take care of the collective savings. At an agreed period during the year or at the end of the year, household groceries are purchased in bulk and distributed to members. In the latter type of savings, a group of four or five chooses one person as secretary of the club. All the women in the group at the end of every week or month according to their arrangement contribute an agreed figure and the money is given to one of them. The following month or week the same is done to the other person until all have gone through the "round". These saving clubshave been realised as useful strategies that assist FHH to a great extent.

In response to climate-induced poverty, female-led households especially those who rely on farming in rural areas of Zimbabwe have adopted disruptive innovative farming models. These include water-harvesting methods, mixed-cropping, crop diversification, non-seasonal farming, and the recently introduced conservation farming methods to climate-proof agriculture as one of the anchors of household food security. However, these have proved ineffective in the absences of financial and technological capacities.

5 Limitations of the Study

This was a qualitative study in nature that utilised the historical approach to collect and interpret information. The major limitation associated with this approach is that the sources of information that were used may not be authentic and valid. The written histories may not be real and some pieces of evidence may be buried and forgotten.

6 Conclusions

There are various factors affecting women in Zimbabwe and these include HIV/AIDS, lower levels of education, poor employment rate, little or no income and poor access to resources just to mention but a few. In light of these challenges, some of the female-headed households survival tactics include vending items such as fruits and vegetables within the house, neighbourhoods and streets. Some female-headed households survive on offering domestic services and prostitution. Despite the array of strategies adopted, sustainability concerns have been raised as what the women do to survive are just steps to absorb shocks and stresses but not to actually to eradicate poverty. This has been revealed by the various meagre incomes these female heads make every month compared to the huge bills of expenditure. FHH have also been known to adopt unethical survival strategies such as prostitution which poses those involved to high risks of health both physically and psychologically. The perseverance in the face of various challenges suggests that FHH are resilient enough to work out solutions though ephemeral and pitiful in a bid to reduce extreme poverty.

7 Recommendations

Given the many challenges that women who head households face and also the fact that most of their survival strategies are not sustainable there is a need for sustainable solutions to be provided to better their situation. The following recommendations have been suggested in a bid to improve the situation of the female-headed households;

(i) ***Granting loans***

Lending arrangements for FHH will enable them to access savings within the local area which may cushion them against economic fluctuations. According to Dubihlela, (2010) interest rates and the terms and conditions should be affordable and reasonable so that women can be able to access the loans. Despite the possible advantages of adopting micro-credit schemes, there are associated challenges. Jackson, (1996:491) has argued that money has proved to be an inadequate currency for changing gender relations. Therefore, the Government needs to consider having a loan facility specifically targeted at FHH so that men will not take advantage of them.

(ii) ***Education and Training (capacity building)***

Education in basic business and communication skills to help the women upgrade their business knowledge is a necessary tool that will assist FHH to consider options of dealing with extreme poverty more sustainably.

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Exploring Climate Change Impacts on Smallholder Farmers in Mhondoro-Ngezi District, Zimbabwe

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Abstract Africa is among the global continents that are more vulnerable to the detrimental effects of climate change. Numerous stakeholders in Africa are negatively impacted by climate change, and among them are small scale farmers whose livelihoods depend on subsistence farming. Primary and secondary data sources were used to examine farmers' perceptions on local climate change adaptation measures. The study examined how farmers perceive climate change adaptation measures in their region.. The researchers worked with communities to identify and prioritize strategic and appropriate measures to enhance agricultural production and improve livelihoods. The perceptions and adaptations were then scrutinized using the Heckman probit model and multivariate biprobit model (MVBP). The findings show that using chemicals fertilizers', manure and pesticides and mixing farming and non-farming activities had positive values and are the most perceived and preferred adaptation measures. Improving the farmers adaptation measures will be necessary to improve their adaptive capacity at the household level. The study recommends that government and Non-governmental organizations must enhance farmers' access to improved drought-tolerant seeds such as sorghum (mhunga) and millet (zviyo). Seed houses should develop seed varieties that are drought tolerant and also varieties that are weed competitive and tolerant of Africa's significant pests and soil toxicity.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_22

1 Introduction

The observed variation of the worldwide climatic system is not a new singularity and can be drawn to about two or more centuries ago (Dube et al. 2016). The fragile African economies have been severely affected by climate change variations. These include crop cultivation, tourism (Dube and Nhamo 2019) and livestock to mention a few. Mitigation and adaptation have been identified as pathways to deal with climate change impacts, and adaptation has received much attention (Zelda et al. 2016). However, even if one takes an optimistic view of the effectiveness and suitability of mitigation, some degree of climate change is inevitable; hence adaptation is unavoidable (Mashizha et al. 2017; Smith and Olga 2001). Hence the need to consider adaptation as a critical component to balanced and viable responses to climate change. In natural sciences, the concept of adaptation refers to societies and ecosystems concoct for or regulate to future climate change (NRC 2010). Adaptations can be independent or procedure-driven, that is, adjustments in practices, processes, or structures (Chanza and De Wit 2013; Dube et al. 2017; NRC 2010; Phiri et al. 2014).

The terms adaptation and coping are used interchangeably in climate change discourse to explain mitigatory measures to a changing climate (O'Brien et al. 2012). Eriksen and Kelly (2004) view that the two terms are related to different timelines in climate change studies. Coping is regarded as a short term responsive mechanism to climate change, whilst adaptation is linked to more extended timelines. Climate change coping approaches and mechanisms can be manipulated to act as adaptive mechanisms when farmers are obliged to embrace them over climate change catastrophic years and seasons rather than temporally during a certain catastrophic time of the year (Anderson et al. 2010; Dube and Phiri 2013). Therefore, coping measures in the context of this paper will include both adaptation and other personal practices employed by the farmers. These may also include temporal short term coping mechanisms to react to unexpected extreme weather events such as floods and droughts.

Climate change adaptation entails farmers to agree in the beginning to the perception and reality that climate has changed (Phiri et al. 2019). Local-level adaptation strategies have been developed in Mhondoro to help farmers adapt to the adversative climate change impacts in the area. Anecdotal information and evidence of this adaptation is available and has already been investigated (Dzvimbo et al. 2017; Limantol et al. 2016; Zelda et al. 2016). However, Gbetibouo (2009) is the view that several climate change abberations research and studies select a particular adaptation mechanism. These assumptions pay little attention to how adaptation occurs in the ecosystem and environment. The assumptions neglects the finer details of the occurrence, duration and timing of climate change adaptation strategies. Knowledge of perceptions on coping measures is a vital entry point for decision-makers and policymakers because this enables them to learn better ways to improve smallholder farming activities exposed to extreme weather events.

These measures' success to minimise the impacts of climate change, as alluded to earlier on, require perception, mitigation, adaptation, and perception again. Perception can be defined as a range of opinions, decisions and values (Ng'ombe et al. 2020; Slegers 2008). To promote climate change mitigation measures while solving its threats to the farmers, it is necessary to consider farmers' perceptions of climate change mitigation measures and a variety of mitigatory solutions. A consideration of the associated barriers and challenges they encounter to adapt to climate change mechanisms is important.

The research's objectives were threefold. Firstly, the study looked into how the farmers perceive climate change abberations and variability from smallholder farmers view, which assists to promote climate change understanding at a localised level. Secondly, the study drew from the attitudes values, and experiences of the smallholder farmers to exude appropriate climate change adaptations measures embraced at a community level. Factors that determine the choice of adaptation measures are examined from the farmers' point of view. Gbetibouo (2009) noted that not all farmers who will perceive climate change would respond by taking adaptation measures. The research in this context sought to establish common characteristics of the respondents into two categories namely the respondents who viewed climate change variations in their activities as a reality and those who feel that they are not affected by it. There is a need to understand farmer's climate change perceptions and their rationale on whether they adapted to climate change or not. In identifying the factors that determine adaptation options, this paper provides important data which assist promoting various sustainable climate change adaptations mechanisms and strategies at a local scale (Mhodoro-Ngezi) and enhancing smallhoders' livelihoods. Thirdly, it interrogates the importance of adopting and integrating climate-smart agriculture by smallholder farmers.

2 Research Methodology

The research design underpinning study this is a descriptive survey design. This design provides answers to questions of who, what, when, where, and how variables are associated with the research problem. The descriptive survey design used the mixed methods research approaches. This permitted the researcher to attain pertinent data required to detail farmer's perceptions. Qualitative data were derived from interviews and FGDs. Quantitative data were derived from questionnaires. Sampling constituted a combination of random sampling and purposive sampling. The sample size was 150 participants from wards 1–5, including 30 participants from each ward, constituting 30% of the population. This is a larger sample, which guaranteed a more representative sample of the population. Thus, the research was informed by the "Law of Large Numbers". A large enough sample size allowed the study to detect a statistical effect when it occurred.

Primary and secondary data collection methods were used in this research. The tools for primary data collection were the key informant interviews, semi-structured questionnaires with the Likert Scale, whilst the secondary data was gathered from a variety of publications, journals and textbooks. The first section of the questionnaire collected general demographic and personal information. The second section of the questionnaire established the participants' perception of the climate change impacts. Questions were asked to assess their knowledge about climate change issues by answering questions on various climate change-related issues. Section C was about climate change adaption measures, effectiveness and challenges faced in implanting adaptation. Multiple possible choices for each question were provided.

A multi-variate methodology analysis was conducted to examine the various available methodology options to enhance the most suitable data collections instruments. However, arguments for and against the instruments ensured the researcher to opt for triangulation to develop the advantages of each data collection method and validity and reliability and credibility.

Graphical presentations such as histograms, tables, bargraphs, grouped frequency distributions and pie charts were used to present the study findings for simplicity in understanding the data. Data analysis of numerical data included analysing data to summarize data's essential features and relationships to generalize and determine particular outcomes patterns. Descriptive statistics and inferential statistics, including multivariate analysis, were employed. Gbetibouo (2009) noted that the MVBP model operates with an approximation of the effect of the independent variables on a dependent variable which involves several choices with a couple of unstructured categories. The rationale and advantage of using the MVBP model in this study was that the model allows the use of a set of explanatory variables on each adaptation choice. It also allow the unobserved and unmeasured factors to be easily correlated (Lin et al. 2017). Interviews were analysed using thematic analysis.

3 Study Area

Mashonaland West Province is a vast province with fertile land in Zimbabwe. The province consists of several district; among them is Mhondoro-Ngezi. The district is famous for its primary economic activities, among them platinum mining and agriculture. The area is shown in the map in Fig. 1. Maize is the dominating crop, followed by wheat, groundnuts and other cash crops (Intergovernmental Panel on Climate Change 2007; Musarurwa and Lungu 2012). This area receives an average of above 750 mm rainfall per year with varying rainfall per month during each season. The area is warm like most of Zimbabwe, and the winter months, June and July, are often very cold. The rains usually came between November and March. The district has many subsistence farmers whose livelihoods are based on small scale farming and proceeds from informal trading of farm produce to Ngezi Platinum mine workers. According to the Zimbabwe National Statistics Agency (2012), Mhondoro-NgeziDistrictis a home to 104, 342 inhabitants.

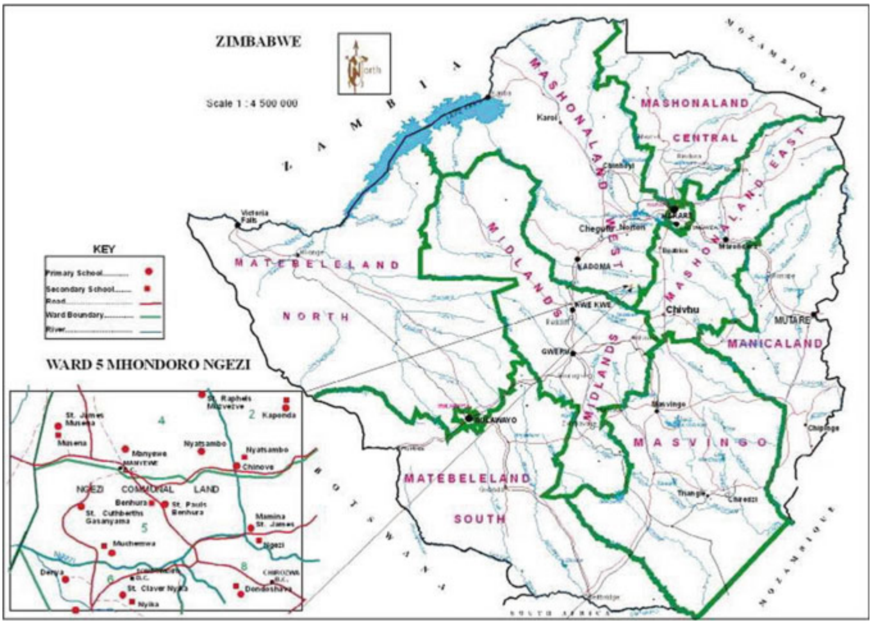


Fig. 1 Showing map of Mhondoro–Ngezi within Zimbabwe. *Source* Mashizha et al. (2017)

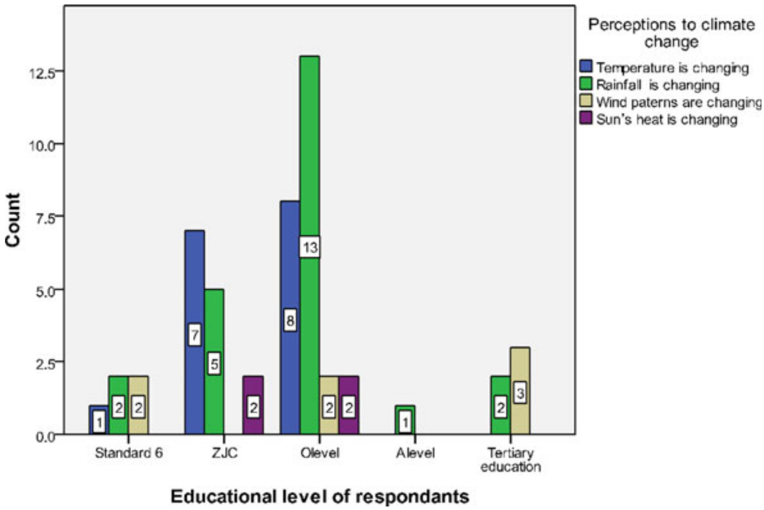


Fig. 2 Perceptions to climate change. *Source* Fieldwork

4 Results, Analysis and Discussion

4.1 Household Characteristics

A significant variance in gender between the surveyed respondents was 62 per cent males and 38 per cent females. Thus, the majority (62 per cent) of the participants in the survey were male-headed families. Seventy per cent of the farmers participants were married, with 10 per cent, 19 per cent and 1 per cent being widowed, single and divorced, respectively. The respondents' averaged 50 years of age, ranging between 35 and 80 years. (88 per cent) of the household heads have attended the most number of years in school. The results revealed that a low proportion of the farmers (10 per cent) had primary education only while 80 per cent had attained secondary education and about 10 per cent of the farmers attained tertiary education.

The household average size was seven family members, consisting of four males and three females per family. The study also reveals that a significant proportion, 80 per cent, of the family heads were into farming fulltime whereas 17 per cent and 3 per cent, were involved in formal employment and self-employment, respectively. Eight per cent of the farmers had an income of more than $400 per month supplemented by formal employment, whilst 80 per cent of the farmers had an income of less than $160 per month, and 12 per cent had no reliable source of income. The FGD discussions and findings established that the primary revenue sources for the majority were crop farming (averaging $53 per month through selling vegetables and maize to Ngezi high school and GMB, respectively), livestock (mainly goats and chicken, averaging $47 per month). Other non-agricultural part-time work contributing as a source of income to these households was manual labour (averaging $60 per month, at Ngezi high school at $3 per day). Artner et al. (2010) argued that income earned from non-agricultural proceeds is a global phenomenon and it is motivated by climate change risks among a variety of challenges. Furthermore, they identify a marked increase of 20 per cent to 40 per cent in sources of non-agricultural income for sub-Saharan Africa in the last 15 years of the twentieth century.

Most of the respondents have stayed in Mhondoro-Ngezi for more than two decades. However, the prolonged stay of these participants in the setting ensued that the respondents have rich data on climate change they have experienced over a considerable period of time. Therefore, the majority of the sample possessed a reasonable or above average knowledge and understanding of climate change risks on farming and the environment and how the community adapted to this challenge.

The results from the field study have shown that the basis of farmers perceiving the effectiveness of coping mechanisms to a changing climate is increasing crop production per hectare over the years. This does not corroborate with district recorded crop output for the ward over the past ten years. The mean maize output per hectare is 1 tonne fluctuating between 1½ tonnes in the period between 2007 and 2017. The results of the study indicated a continuous diminishing harvest of the maize crop. This could be a result of declining rainfall over the years. The reduction in maize harvest is reinforced by supplementary data obtained from Jiri et al. (2015). The authors argued that there has been a reduction in maize output due to climate change in Zimbabwe.The time-line series of the total crop harvest data shows an average downwards trend of about 50 per cent in crop production for the past ten years. This means that crop production each season is decreasing. Decreasing maize yield is thus associated with ineffective coping measures in the study area. The above assertion can be attributed to farmers perceiving the ineffectiveness of most agronomic adaptation measures.

4.2 Climate Change Impacts and Farmers Perceptions

Climate change abberations in terms of whether the climate is changing or not influences an analysis of climate change coping mechanisms adopted by a community. This in turn influences farmers decisions on whether to act or not to act in response to perceived climate change and its impacts. The respondents (100 per cent) agreed that indeed climate is changing and there is a vast difference of it compared to what it was a decade ago. Focus group engagements at a local level in Mhondoro-Ngezi concluded that climate change impacted on the rainfall pattern, amount and duration. The farmers concluded that they were experiencing extreme temperature variations. In addition, the farmers noted that the beginning of the rainfall season has shifted from the end of October to the end of November or early December. The Agricultural Extension Officer was specific and pointed out that the season was delayed on average by 33 days. During the FGDs, farmers pointed out that they tend to receive enough rainfall to start planting in mid-December in most years. Other changes noted by farmers were (i) that the length of the season had become more unpredictable. Farmers pointed out that the rainy season sometimes ends abruptly and too early. It was unanimous in the FGDs that seasons ended as early as mid-March in the past decade. (ii) Rainfall variability, that is, the rainfall was not evenly distributed throughout the season. One farmer highlighted that they received enough rainfall within the month of January.

The Agriculture Extension Officer reported that the unpredictable rainfall pattern is erratic in their area and around the country in general, as shown in Table 1. Farmers

Table 1 The direction of change weather elements

	Increasing count	Decreasing count	No change count	Do not know count
Rainfall	11	39	0	0
Wind	0	0	50	0
Sun heat	42	0	8	0
Frequency of drought	29	12	9	0

Question Indicate whether the change is increasing, decreasing, no change or do not know
Source Fieldwork

commented that two decades ago the rainfall pattern and distribution during the summer season was easy to predict such that farmers usually planted their crops from the 15th of October with the knowledge that it will definitely rain. More so, in the past rainfall season, distribution over the season was not even and unpredictable. The unpredictability and unevenness of rainfall make it difficult for farmers to cope with their agricultural activities effectively and adequately. This is exacerbated by the fact that they are currently unaware of the dates when to expect rainfall. In other words, the prolonged dry spell is hindering their quest to produce on their farms. A huge number of farmers (86 per cent) noted with concern an upward increase of temperature in the last ten years. Another 14 per cent of the participants noted a decrease in temperature. Catastrophic climatic events in the form of prolonged arid spells of exaggerated rainfall increased in the past decade. Therefore, the study established that respondents were more informed of climatic changes associated with the rainy season than other seasons (Thomas et al. 2007; Cohn et al. 2017). The lack of adequate rainfall has negatively affected human activities in this ward as opposed to some areas around the world which are affected by flooding, El-Nino and heat waves.

4.3 Attitude Towards Climate Change

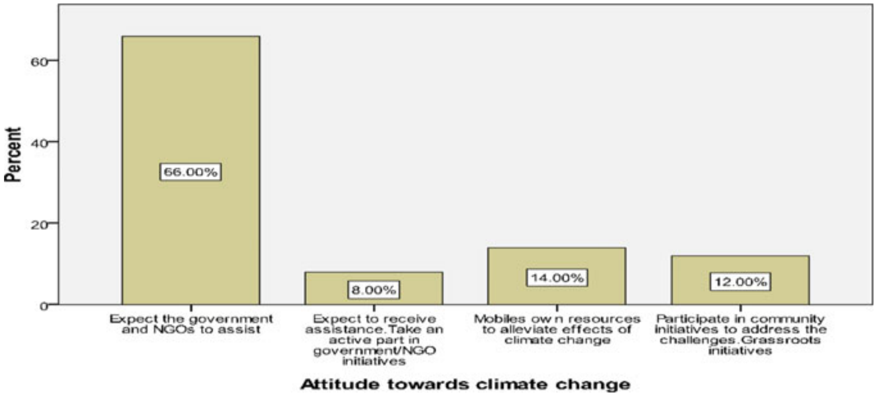
Respondents were asked to indicate the attitude that they adapt in response to climate change.

The majority (66 per cent) of respondents, as shown in Table 2 above, expect the government and the various NGOs to assist a concept referred to as the donor dependency syndrome. Social aid programs by NGOs are significant to communities in helping them cope with climate change. In that regard, Amadu et al. (2020) assert that humanitarian aid directed by local authorities rather than by external donors are efficient in helping marginalized rural smallholder farmers to adapt to the undesirable effects of climate change. Fourteen per cent of the farmers mobilized their resources to cope with climate change. One villager during FGD lamented that donors are no longer assisting them as they used to do ten years ago; one villager pointed out that:

> The government has been giving us seed maize and fertilizers, which were not enough considering my large family.

Most villagers, however, agreed that government programs such as the presidential input scheme have been effective in alleviating the effects of climate change. Results depicted in Table 2 indicate most of the farmers were reluctant to partake in command agriculture, which is a new government initiative to avert impacts of climate change. The above results indicate that farmers in the ward do not have the necessary attitudes for climate change coping measures. A climate change positive adaptation attitude is vital in determining what one will do in a situation. Kalonga (2011) asserts that people's attitude is a relatively permanent way of feeling, thinking and behaviour towards something.

Table 2 Attitude towards climate change *Source* Fieldwork



4.4 Farmers' Adaptation Strategies to Climate Change.

Seventy per cent of the farmers adapted to climate change through altering their agronomy practices under dry conditions in their ward. Three typical responses have been established about cropping adaptation: crop diversification, practising conservation agriculture, and gardening. Twenty five per cent of the farmers simultenously practiced agronomy and animal husbandry as a mechanism to use crop residue as feedstock. A Livestock adaptations only without crops were done by 4 per cent of the farmers. Three responses have also emerged concerning livestock adaptation: the use of veterinary services recommended drugs, stock diversity, increasing stock and agricultural extension officers support. Adaptation using indigenous knowledge systems was practiced by the farmers but not so common in the ward (1%). However, it is essential to note the significance of indigenous knowledge systems in climate change adaptation, as they are the underlying local and well-understood principles and basis of local strategies to climate change and unpredictability (Musarurwa and Lungu 2012).

4.5 Traditional Adaptation and Coping Strategies

Local indigenous knowledge systems which farmers used to rely on to avert impacts of climate change are rapidly eroded by climate change extremes and intensity (Musarurwa and Lungu 2012; Holland et al. 2017). Climate change is affecting the farmers at a rate they have never witnessed before making it extremely difficult for them to keep pace with the abberations. This development has signalled clearly to the farmers that there is a dire need for them to revisit land use practices at their farms. In addition, the farmers realised that they must change their farm management methods aligning them to the new challenges posed by climate change.

They also need new infrastructure in the form of trickle irrigation, water reservoirs, wind pumps and electricity for water pumping and processing of farm produce. The research results indicates that even farmers who were not aware of climate change coping mechanisms adopted at least one climate change coping mechanism voluntarily (Kalonga 2011; Jiri et al. 2015). From various known climate change coping mechanisms, the Mhondoro-Ngezi farmers adopted planting short-season plant varieties and crop diversification planted on different dates to avert the impacts of climate change. As a coping mechanism, most crops were planted in times when they get adequate water critical for their growth and development such that in the event of prolonged dryness, the plants can still ripe and produce a decent harvest (Chanza and De Wit 2013; Donatti et al. 2018).

Households food security was ensured by planting a variety of crops with different abilities to withstand climate change. Small holder farmers grew short season crops to avert the impacts of mid-season dry periods usually ranging between March to October per year. The plants they grow include the drought resistant rapoko, sorghum, and finger millet (IPCC 2007; Zimbabwe National Statistics Council 2012; Kalimba and Culas 2020). Hybrid maize with good characteristics to without climate change impacts was grown by the smallholder farmers to enable the availability of their staple food. The hybrid maize cultivar is common for early maturity and ripening periods as well as pest and diseases resistance. The adoption of these hybrid maize variety is proving to be an effective coping mechanism to avert climate change such that the manufacturers of the seeds must continue improving the cultivars to promote drought-resistant crops from food security among both small holder farmers and even commercial farmers.

4.6 Factors Influencing Farmers' Adaptation Options

Discussions from the focus groups revealed that male household heads choose adaptation methods that require physical strength while female-headed households chose the opposite. Gender differences of various household heads has a positive and substantial effect on the type of cropping and livestock adaptation options and indigenous practices. Chiotti (1997) cited in Jiri et al. (2015) in a study in Southern Alberta, United States, argued that female farmers adapt easily to new natural resources management systems as opposed to their male counterparts. In several rural African farming households, women are often neglected by their husbands in terms of farming planning, discussion and decisions (Jiri et al. 2015; Evelyn, Charles and Patricia 2017). In most of these rural settlements, the number of cattle owned by these households play a pivotal role on adopting climate change mitigation strategies aligned to agronomic and indigenous knowledge practices. However, income, age and level of education had a momentous influence on adopting agronomic practices. The authors noted that only livestock practices were thus independent of the mentioned characteristics.

4.7 Perceptions of Coping Mechanisms

In coping with climate change during this study, several questions were used to assess perceptions regarding the efficiency of suggested interventions in coping with climate change. Table 4 (agronomic adaptations) and Table 5 (livestock and other adaptations) depict the enquiry results. Interpretation Table 3 will be used to analyse the results.

The mean values for the partcipants' responses range from as low as 1.68 to as high as 4.57; this,however,shows much heterogeneity in responses. A mean of 1.68 and a standard deviation of 0.935 show that the respondents disagreed with the perception of the use of different crop varieties among them which include early maturity crop varieties, for example,SC402 maize seeds, as an effective coping measure. The result concurs to the perception by farmers that rainfall pattern is hard to tell and understand and it varies from season to season due to a myriad of climatic factors. A mean value of 2.22 and a low standard deviation value of 0.864 signifies uniformity in responses. The mean value implies that the research participants disagreed with the view that new planting dates also known as (early planting or late planting/ planting whenever a spell of rains is determined) or planting during the wet rainy season in summer is an effective coping mechanism. The unpredictability of the rainfall pattern and climate change abberations resulted in farmers rendering the afore-mentioned coping mechanism unworthy and ineffective. The farmers attested to the fact that they cannot time exact dates when it will rain. Moreover, the amount of rainfall is extremely difficult for them to predict. However, the rationale of planting early maturity crops is to ensure that crops will not be affected by a long spell of a dry season in their critical growth and development stage. The practice of planting different of crops is premised on the scientific discovery that a variety of crops are affected differently by the same environmental conditions due to their different genome.

The overall mean of 3.72 and a standard deviation value of 0.701 indicate that respondents agreed that one of the effective climate change coping measure is to use drought-tolerant seed varieties. One of the elite respondent, an Agritex Officer was of a different view that drought tolerant varieties are no longer giving high yields due to their weakness in resisting pests attacks and an increase in soil toxicity levels. The respondent further explained that drought resistant crops lose water to competing

Table 3 Interpretation table

Scale	Response	Mean interval	Verbal interpretation
5	Strongly agree	4.50–5.00	Strongly agree
4	Agree	3.50–4.49	Agree
3	No opinion	2.50–3.49	Undecided
2	Disagree	1.50–2.49	Disagree
1	Strongly disagree	1.00–1.49	Strongly disagree

Source Fieldwork

Table 4 Agronomic adaptations

		Different crop varieties Use early maturing crop varieties e.g.SC402 seed maize	New planting dates(early planting or late planting/ planting whenever a spell of rains is determined) continuous planting	Use of drought-tolerant seed varieties	Mixing dry land and rainwater farming	Use of irrigation (home gardens)	Use of chemicals fertilizers, manure and pesticides	Increasing soil conservation on farms making shallow basins around every crop	Shading and sheltering young plants Mulching to reduce loss
N	Valid	150	150	150	150	150	150	150	150
	Missing	0	0	0	0	0	0	0	0
Mean		1.68	2.22	3.72	1.68	2.10	4.57	2.08	3.46
Std. Deviation		0.935	0.864	0.701	0.653	1.055	0.858	1.175	1.041
Variance		0.875	0.747	0.491	0.426	1.112	0.736	1.381	1.084
Skewness		1.319	0.736	0.452	0.434	0.772	0.787	1.411	−1.072
Std. Error of Skewness		0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337

Source Authors
Question Which of the following adaptation measures do you think are effective in combating the challenges of climate variability and change

weeds and lose army-worm battle. The result also seem to disagree with the practice of mixing dryland farming and home gardens depicted by mean values of 1.68 and 2.10. A high standard deviation value of 1.055 designates heterogeneousness responses to the usefulness of irrigating home gardens. The result concurs with the farmers thoughts and view that there is a water deficit for irrigating crops. The damming of Mamina dam along Ngezi river upstream has disturbed the natural flow of water down that downstream users are deprived water for irrigation. Using chemicals fertilizers, manure, and pesticides have a high mean of 4.57 and a standard value of 0.858.This result shows homogeneity in responses and implies that respondents are in agreement that the coping measure is effective. The respondents supported the result by claiming good harvest each time they use fertilizer donated by NGOs or the government.

The participants also elicited that they are coping with the impacts of climate change through making shallow basins around crops and practising soil conservation practices on the farm. These practices attained a standard deviation of 1.175 which is very high showing the effectiveness of these measures to curb negative impacts of climate change. The following results indicates a mean value of 2.08 which implies that some respondents disagreed with the usefulness of the this coping mechanism. The other respondents had no opinion about the usefulness of shading and sheltering young plants and mulching to reduce water losses as a climate change coping mechanism. Their result was depicted by a mean of 3.46 and standard deviation value of 1.041. When asked to comment, most of those interviewed say they lack information about how the measure operates whilst some cited lack of vegetation to use as mulch in fields as big as one hectare. The uptake of new farming technologies or smart agriculture by the new farmers was deficient in this study. The lack of money to invest in these new technologies and the lack of technical know-how and education hampered the Mhondoro-Ngezi farmers to adopt smart agriculture.

4.8 Parameter Estimates from MVP Models

Nhemachena et al. (2014) as an acclaimed scholar postulated that climate change has negatively reduced the amount of rainfall received in Sub-Saharan Africa. As a result poor farmers who rely on rain-fed crop farming in arid regions of Zimbabwe in this case Mhondoro-Ngezi will suffer the consequences and worst impact of extreme weather events in the form of El-Nino and prolonged agricultural and meteorological drought. These farmers as a result turned to livestock farming which require less water compared to crop farming as a strategy to become food secure. Gukurume (2013) noted that there is an increase of livestock farming in Bikita region a region which conctitutes Mhondoro Ngezi. These farmers in these dry areas are reverting to livestock for sustainable livelihoods as an alternative to crop farming due to negative impacts of climate change. The government agricultural extension services is promoting farmers in dry prone areas to switch from crop farming to animal husbandry which can withstand extreme weather events in the form of drought and land barreness. The rearing of goats, sheep, and indigenous keeping of chicken are on the rise as farmers and ordinary people are trying their level best to cope with drought whilst enhancing their rural livelihoods (Gukurume 2013). However, Munhande et al. (2013) noticed that climate change enormously effects or causes extreme high temperatures, severe water shortage, reduced fodder for livestock, and extensive stock, leading to insufficient animal production. The rearing and expansion of livestock under the government department drive called Livestock Production Department (LPD) is increasingly visible in Zimbabwe although the government has not yet made it an official policy. This program is seen as a way to promote rural livelihoods through specific location and localised based climate change responses. Such responses are seen as easy responses to embrace due to their synergy with indigenous knowledge systems.

According to Bunce et al. (2017), farmers were indirectly taught by harsh climate change lessons to re-visit landuse and management practices resulting in them adopting additional and sustainable coping strategies. The section below presents perceptions of farmers to these other coping mechanisms. The interpretations of the participants responses were illustrated in Table 5. Increasing water conservation on farms in the form of rain harvesting into weirsas an effective coping mechanism resulted in a mean of 3.56. This mean value show that some farmers agreed that the coping mechanism is effective. In the same vein, a mean of 4.02 also indicates an agreement that shifting from crop production to livestock rearing as a coping measure is effective in the ward. However, a high standard deviation value of **1.220** denotes heterogeneity in response to the question. The results aligns to Thomas et al. (2007) who noted that farmers often lessen the amount of land for cropping or even stop the planting of crops during dry spells while switching to animal husbandry which requires less water. Most farmers interviewed, however, assert that this is a temporary measure. One farmer was emphatic:

> We have always shifted to livestock during years of droughts, and we always return to crops during the next season. This season (2017–2018) was promising to be a drought year. I have already reduced my hectarage and intend to buy goats.

Although a higher frequency of farmers attested that they temporarily switch from crop farming to animal husbandry during dry spells. This coping mechanism turns into a long-term coping strategy. The frequency of climate change-induced droughts in the district has resulted in hectarage under crops declining and livestock rearing increasing.

A mean value of 4.56 was achieved from a group of farmer who firmly believe that te practice of migrating with livestock to nearby resettlement schemes or selling livestock during years of drought intending to replace them in good rainfall seasons is a good coping mechanism. Another farmer pointed out that:

> Most of my livestock is with my young brother, a new farmer, resettled in the former commercial farms nearby where there are many pastures.

This coping mechanism appears good and reasonable but most farmers during FGDs complained that stock market buyers take advantage of their desperation and offer lower market value for their livestock. This situation is viewed as a threat by the

Table 5 Livestock and other adaptations

		Increasing water conservation on farms(rain harvesting intoweirs	Mixing crops and livestock (diversification	Shifting from crop production to livestock keeping	Livestock diversification (different animals)	Adjusting livestock management practices (crop residues used as	Migrating with livestock to forests/Sale of livestock Buy	Use of prayer and socio-cultural adaptations	Insurance	Use local indigenous knowledge systems such as
N	Valid	150	150	150	150	150	150	150	150	150
	Missing	0	0	0	0	0	0	0	0	0
Mean		3.56	1.60	4.02	2.86	1.64	4.56	3.04	4.14	1.92
Std. Deviation		1.146	0.756	1.220	0.405	0.776	0.664	1.195	0.606	1.104
Variance		1.313	0.571	1.489	0.164	0.602	0.441	1.427	0.368	1.218
Skewness		0.271	0.827	−0.882	−1.122	0.737	−0.344	0.220	−0.067	1.682
Std. Error of Skewness		0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337

Source Authors
Question Which of the following adaptation measures do you think are effective in combating the challenges of climate change and variability

farmers since their intention is to sell their livestock with the anticipation of buying it back when pastures are replenished after good or normal rainfall. Sometimes they fail to replace the exact number of the livestock sold. Despite this, most farmers contend that it is better than to lose the livestock due to climate change-induced droughts.

The use of prayer and socio-cultural adaptations is depicted in Table 5. Most respondents are undecided as to the usefulness of these coping mechanisms against adverse impacts of climate change. A mean of 3.04 and a standard deviation of 1.195 suggest no opinion and heterogeneity in responses to the effectiveness of this coping measure. The concept of livestock diversification (keeping different animals) has a mean of 2.86. This results confirms that the participants were also undecided on the usefulness of the measure. Therefore, the participants did not indicate their views on whether the coping strategy is effective or not.

The concept of insurance is substantiated by a high mean of 4.14and a standard deviation value of 0.606. This shows homogeneity in responses and indicates that respondents agree and trust that insurance companies will cushion their losses in the event of drought induced farm losses. This coping measure was approved by several farmers as viable. However, when researchers probed the number of insured farmers, the results show that not a single farmer was insured. During FGDs, several farmers allude to the fact that insurance is known to cover assets in the event of environmental wicked problems among other challenges. However, they also said that there is no insurer who covers climate change risk in their district and vicinity, resulting in them not insured. One young farmer suggested that the government assist them by bringing insurance companies in the area to get insured. Most farmers perceive insurance to be effective, which could be due to their educational backgrounds or hear say from other farmers who once benefitted from insurance payouts. As pointed out earlier, the majority have gone through secondary school where agriculture and elementary agricultural economics is taught. They have been taught the purpose and benefits of being insured.

The use of indigenous knowledge systems received a mean value of 1.92 which suggests a disagreement in responses to the coping measure. The participants response implies that climate change is too complicated and cannot be sorely mitigated using indigenous knowledge systems which were crafted centuries ago when climate change impacts were minimal. Dzvimbo et al. (2017) noted how the impacts of climate change erodes indigenous knowledge systems as coping strategies. The authors noted that the intensity at which extreme weather events are occurring in Mhondoro-Ngezi district and other districts have not been witnessed before. This renders indigenous knowledge ineffective as this new phenomenon does not exist in oral environmental knowledge. In support of the afore-mentioned argument, Dube et al. (2016) and Mashizha et al. (2017) noted that the relevance of indigenous knowledge to climate change coping strategies can be relevant or irrelevant depending on the magnitude of the extreme weather events and also whether those events are a new phenomenon or business as usual as captured by previous generations.

5 Parameter Estimates from MVP Models

Table 6 below presents biprobit model results of livestock determinants of adaptation measures.

The MVBP model included eight choice set to different livestock adaptation options. These include: Shifting from crop production to livestock keeping, Livestock diversification (different animals), Adjusting livestock management practices

Table 6 Parameter estimates

	Parameter	Estimate	Std. Error	Z	Sig	95% Confidence Interval	
						Lower Bound	Upper Bound
PROBIT[a]	Shifting from crop production to livestock keeping	0.206	1.855	0.111	0.911	−3.430	3.843
	Livestock diversification (different animals)	−1.000	2.457	−0.407	0.684	−5.815	3.815
	Adjusting livestock management practices (crop residues used as feed	1.067	1.363	0.783	0.434	−1.604	3.739
	Migrating with livestock to forests/Sale of livestock	1.586	4.732	0.335	0.738	−7.690	10.861
	Mixing crops and livestock (diversification	1.886	1.473	−1.280	0.201	−4.774	1.002
	Insurance	1.898	3.371	0.563	0.573	−4.710	8.506
	Use of prayer and socio-cultural adaptations	−0.001	1.180	0.000	0.999	−2.314	2.312
	Seek agricultural extension services,	−0.550	0.785	−0.702	0.483	−2.088	0.987
	Intercept	−0.850	4.204	−0.202	0.840	−5.055	3.354

a. PROBIT model: PROBIT(p) = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm.)
Source Authors

(crop residues used as feed), Migrating with livestock to forests/Sale of livestock, Mixing crops and livestock (diversification), Insurance, Use of prayer and socio-cultural adaptations, Seek agricultural extension services. The results suggest that Adjusting livestock management practices (crop residues used as feed), Migrating with livestock to forests/Sale of livestock, Mixing crops and livestock (diversification), and insurance have positive values. The model shows that farmers are more likely to perceive and adapt these measures more than those with negative values such as livestock diversification.

The results of the study revealed that farmers perceive mixed farming as a less useful coping measure. This is corroborated by a mean value of 1.60. A low standard deviation value of 0.756 implies that there was much homogeneity in their responses. Respondents also disagree (1.64) and suggest that adjusting livestock practices is an ineffective coping measure. However, a high standard deviation value of 1.104 depicts heterogeneity in responses, as shown in Table 6.

6 Challenges Limiting the Effectiveness of Coping Mechanisms

Table 7 show the challenges limiting the usefulness of coping mechanisms in Mhondoro-Ngezi area..

The respondents (44 per cent) viewed poverty as a challenge to the effectiveness of the coping mechanism. Poverty is defined in several literature as a deficiency or lack of resources required to have a decent standard of living (Neuman 2003). For the purpose of this study, poverty refers to a failure to meet one's basic needs due to a deficiency of resources, capital, choices, skills, and assets. The participants (22

Table 7 Challenges limiting the effectiveness of the coping measure

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	Lack of knowledge about climate change. I do not have information on ways to reduce the effects of climate change	30	20.0	20.0	20.0
	No access to water for irrigation	21	14.0	14.0	34.0
	Lack of finance there are no credit facilities		22.0	22.0	56.0
	Poverty	66	44.0	44.0	100.0
	Total	150	100.0	100.0	

Source Survey data 2017
Question Which of the following challenges do you think are limiting the effectiveness of the interventions that you adapt as a farmer to mitigate the effects of climate change?

per cent) in number cited a lack of finance as a huge challenge to mitigate climate change impacts. Participants from FGD pointed out that there are no credit facilities for the farmers in Mhondoro-Ngezi due to a lack of land tenure or 99 years leases from the government required by banks as collateral. One farmer noted that soon after independence, soft loans were made available to farmers through banks such as Agri-bank, and farmers were able to purchase livestock and scotch carts that they are using up to this day. No access to water for irrigation was indicated by 14 per cent and lack of knowledge about climate change that is not having information on ways to reduce the effects of climate change was indicated by 20 per cent as some of the identified factors limiting the effectiveness of coping measures. Table 7 also shows that farmers in the ward identified irrigation as an urgent need for them to cope with climate change abberations affecting rainfall patterns. They lamented access to credit facilities too as another way to bloster their effort to avert climate change. If these needs are met, farmers insisted that poverty will be a thing of the past.

7 Conclusion and Recommendations

The aim of this study was to interrogate and analyse farmer opinions and views on climate change response strategies in a selected ward in the Mhondoro Ngezi district. On the contrary, the first section highlighted farmers' opinion on climate change through asking questions about their experiences on the type of extreme weather events they had encountered during the past ten years. This was also followed by an investigation into their attitudes and adaptation strategies towards climate change. The study showed that there had been a substantial variation in minimum and maximum rainfall and temperature over time. The study has provided evidence that farmers are adapting to climate change in the surveyed ward. Heterogeneity in responses to most questions has shown no one size fits all coping measures; thus, climate change and coping strategies are context-specific and place-based. Füssel (2007) substantiated this when he argued that adaptation is more individually explained, unlike mitigation, which is commonly inapplicable. Results showed that farmers' attitudes strongly favoured planting drought-tolerant varieties, increasing water conservation on farms (rain harvesting into weirs), changing from planting crops to the rearing of livestock, migrating with livestock to greener pastures and the use of insurance cover. However, the perceptions to coping measures in this study are not an indicator of the relative importance of these practices. This is because of the applicability or importance of adaptation practices is likely to vary by context, place, various challenges from various people, environmental characteristics, and differential effects of climate change, among other factors.

The study recommends that:

Farmers must make use of drought resistant crops or seed varieties to avert the impact of climate change on agricultural and meteorological drought. It is, therefore, imperative for the government and NGOs to encourage and augment farmers' access to improved drought-tolerant seeds such as sorghum (mhunga) and millet (zviyo).

Seed houses should develop seed varieties that are drought tolerant, disease and pest resistant and tolerant of Africa's soil toxicity.

The study pointed out that the unavailability of insurance cover was the principal reason why most farmers did not have insurance. This calls for the need to bring insurance products to rural smallholder farmers. Insurance companies are encouraged to avail farming insurance cover and bolster insurance adoption among small-scale farmers by supporting programmes such as premium subsidies to make it affordable to rural communities. This should, however be a win–win situation without compromising the quality of cover given to small-scale farmers.

Funding The authors received no funding for this research, authorship and publication. There are no conflicting issues.

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An Analysis of the Impacts of Climate on the Agricultural Sector in Malta: A Climatological and Agronomic Study

Charles Galdies and Anthony Meli

Abstract Research shows that southern European countries are expected to experience a 10% reduction in their agricultural productivity as a result of climate change. This study shows how, on the basis of an analysis of the latest climatological observations to date, 54% of Malta's total utilisable agricultural area, could in effect be rendered economically unsustainable due to a fall in productivity of principal crop types. In fact, the period 1946–2020 shows an increased mean annual air temperature anomaly of + 0.17 °C per decade. This is accompanied by a corresponding reduction of –6 mm per decade in the total yearly precipitation for the same time period. This study reveals how this climate period was accompanied by a significant decrease in revenues from grape, olives and wine production, also reflected by a 69% decline in grape production and 22% fall in wheat production, amongst other crops. The observed reduced sustainability of local agricultural productivity is adversely affecting the livelihoods of farmers that are dependent on this already threatened economic sector in Malta.

1 Introduction

The Maltese islands are located in the central Mediterranean region between 36° 00′ 00" and 35° 48′ 00" north–south latitude and 14° ′35′ 00" and 14° 10′ 30" east–west latitude. Its population of 502,653 people resides in an area of just 316 km^2 (World Bank 2020). Malta's agricultural sector is a vital resource to the country's economy and social well-being since it is seen as crucial for the preservation of Malta's cultural and physical landscape.

Maltese agriculture land is typified by small land parcels owned or farmed by individual farmers. In 2013, the number of farm holdings amounted to 12,466, equivalent

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_23

to 11,689 ha. of Utilised Agricultural Area (UAA) (National Statistical Office 2016), of which 75.6% have a UAA of less than 1.0 hectare.

The climate of the Maltese islands is a typically Mediterranean one with an annual mean air temperature of 18.6 °C, a mean maximum of 22.3 °C, and mean minimum of 14.9 °C (Galdies 2011). Combined with an annual total precipitation of 553 mm, this climatological profile makes the islands relatively hot and dry. The islands experience a maximum and minimum monthly sunshine hours of 365 h (July) and 156 h (December) respectively. The hot summer days and mild winters are in turn modulated by marine influences, which tend to give cooler summers and warmer winters.

However, the Mediterranean is considered to be a climate change hotspot (Tuel and Eltahir 2020) and shifting rainfall patterns, rising temperatures and drought are already evident in Malta, leading local farmers to face increasing challenges in agriculture. While, at times, alternative production shifts can sustain their livelihood, a decline can threaten their survival. Therefore, a study aimed at determining specific climatic and production trends in conjunction with the provision of the financial margins within which decreases can be tolerated, is highly needed in order to provide more insight into the prevailing situation and suggest ways how Malta's agricultural sector can become more resilient.

The primary aim of this study is therefore to analyse the current state of knowledge on the historical trends in Malta's climate and their observable impacts on the long-term productivity of its agriculture. This study endevours to (1) provide an understanding of the latest climate trends based on official long-term data; (2) review past trends regarding (i) *typologies* and (ii) *crop yields* with climatic trends; (3) determine the break-even factor for which a decrease in yield would render a loss in production of important crops, and to (4) recommend possible adaptation options. The ensuing information is not only limited to local authorities but also to international communities that are interested in learning more about climate change and Malta's agriculture.

2 Methodology

The following section represents a methodology designed to answer the above-mentioned objectives. The first part addresses the collection and analysis of long-term climate data while the second part describes the data sourcing using national agricultural census and reports published during the same time period, i.e. 1956–2014 and their subsequent analysis.

(i) *Observed climate change in Malta*

The analysis presented by this study documents the most updated, published climatological trends in Malta in terms of air temperature and its extremes, of precipitation and of cloud cover. We continue this study by correlating these observations with agriculture trends related to yields and weight of major agricultural produce over the longest available time period. This was made possible following the availability of the latest datasets made available by the National Weather Service (maltairport.com/weather), reaching up till December 2020. The climatological parameters analysed have direct and indirect impacts on Malta's agricultural sector. For example, both average and extreme temperatures (minimum and maximum) and precipitation patterns influence crop yields, pests, and the length of the growing season. On the other hand, extended droughts periods may lead to larger production losses, earlier spring arrival, and warmer winters that may cause increased pressure as a result of higher incidences of diseases and pests. Decreased cloudiness can also bring about higher land surface temperatures and increased rates of evapotranspiration, both of which can be detrimental to an agricultural sector situated in a semi-arid environment, characterised by scarce surface- and groundwater, and therefore strongly reliant on seasonal rainfall.

In this study, long-term anomalies of a select number of meteorological parameters recorded during the period 1946–2020 were calculated against Malta's 30-year climate reference period of 1961–1990. Parametric and non-parametric statistical tests of correlation were used depending on the normality or otherwise of the long-term observations being investigated (Galdies 2011, 2012). Both the sign and magnitude of the trend-line slope were noted and tested at 95 and 99% confidence level (Cannarozzo and Viola 2006; Crichton 2001).

(ii) *Observed trends regarding crop yields and typologies in Malta*

A detailed analysis was carried out based on official national sources, including the Reports published by the National Statistics Office of Malta (NSO; NSO.gov.mt) as well as scholarly articles focusing on the impact of climate change on agriculture. Agriculture census data spanning the period 1946/47 till 1982/3 were obtained from the Malta's censusus of Agriculture. Detailed information regarding covered agricultural area, tonnage and yields per individual crop measured in tons/acre were extracted and analysed from these documents. Other separate censuses carried out in 2000 and 2010 were also analysed in detail, supported by the agriculture statistical data provided by the NSO publications on a yearly basis for the period 2000–2014. All data collected were digitised and numerically and statistically analysed. Additional data regarding production and costs for wheat, vines and olives as from 2015 were obtained directly from local growers.

The calculation of the resultant revenue and the profitability margin associated with three major crop types (see objective 3 above), the values used to calculate the production costs varied from one crop to another. This was calculated on the basis of the following costs (when applicable): *Variable costs* included rotovation, pruning, thinning, seed purchase (kg), seed spreading, irrigaton, pesticides, fungicides, fertilisers, harvesting, baling, pressing and fuel (litres); *Fixed costs* included land rental and national insurance; *Depreciation* included sprayer, rotovator, irrigation system, initial purchase costs, a van, netting and start-up costs; *Taxes and Subsidy* included 3% tax on income, VAT refund, and subsidy on less favoured area.

3 Results and Discussion

The following sections are organised in accordinace with the objectives stated under Sect. 1.

(i) Observed shifts in Malta's climate

Air temperature.

Figure 1 shows the annual mean air temperature anomaly based on Malta's climate norm for the period 1961–1990 (WMO 2011). The normally-distributed dataset shows a statistically significantly positive trend for the entire 1946–2020 period, significant at the 99% confidence level. For this long-term period, the mean air temperature trend showed an increase of +0.17 °C per decade.

Based on this information and taking the period 1990–2012 as an example, Malta's mean anomaly for the mean air temperature with respect to the 1961–1990 average is found to be +0.8 °C. This observed anomaly is much higher when compared to the average global air temperature anomaly of +0.38°C for the same time period (UK Department of Energy & Climate of Change 2013; p. 2). From an agriculture point of view, the observed increase in the mean, as well as the highest maximum and minimum air temperatures can be seen as supportive of a lengthened growing crop season. However, this seemingly positive impact for agricultural production of this trend is very likely to be overshadowed by an increase in the number of hot days that are accompanied by a decrease in soil moisture content, leading to reduced agricultural yields. Despite the overall positive trend, it can be observed that, till the end of the 1970s, there was higher incidence of lower temperature, which would also have contributed to influence yields.

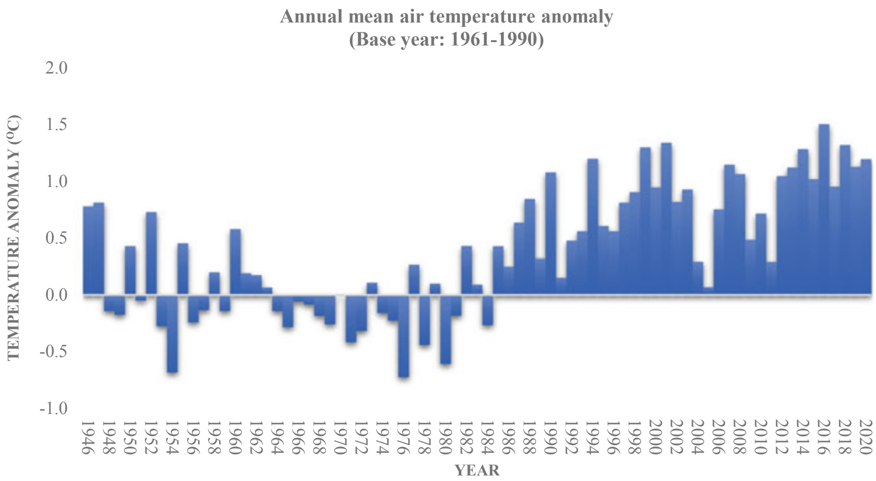

Fig. 1 Malta's annual mean air temperature anomaly for the period 1946–2020. The positive trend is significant at 99% confidence level

Of particular importance to agricultural crops is the local warming trend of both the annual highest maximum and lowest minimum temperatures for the period 1946–2020 (Fig. 2a–b). Both trends are positive and statistically significant at the 99% confidence level. The annual anomaly trend is + 0.18 °C and + 0.15 °C per decade for the annual highest maximum and lowest minimum air temperature respectively. This is also indicative of a higher incidence of warmer nights.

Cloud cover.

A negative anomaly trend is detected for the mean cloud cover for the period 1964–2020, significant at the 99% confidence level, decreasing by 0.05 Oktas every decade (Fig. 3). Cloud cover is, of course, related to the duration of sunshine received at the surface, which is expected to have an inverse trend to that of the cloud cover for the same observational period. The presence of a decreasing trend in cloud cover in a semi-arid environment will certainly alter surface temperatures and the receipt of solar radiation, affecting both crop productivity and crop water requirements. This

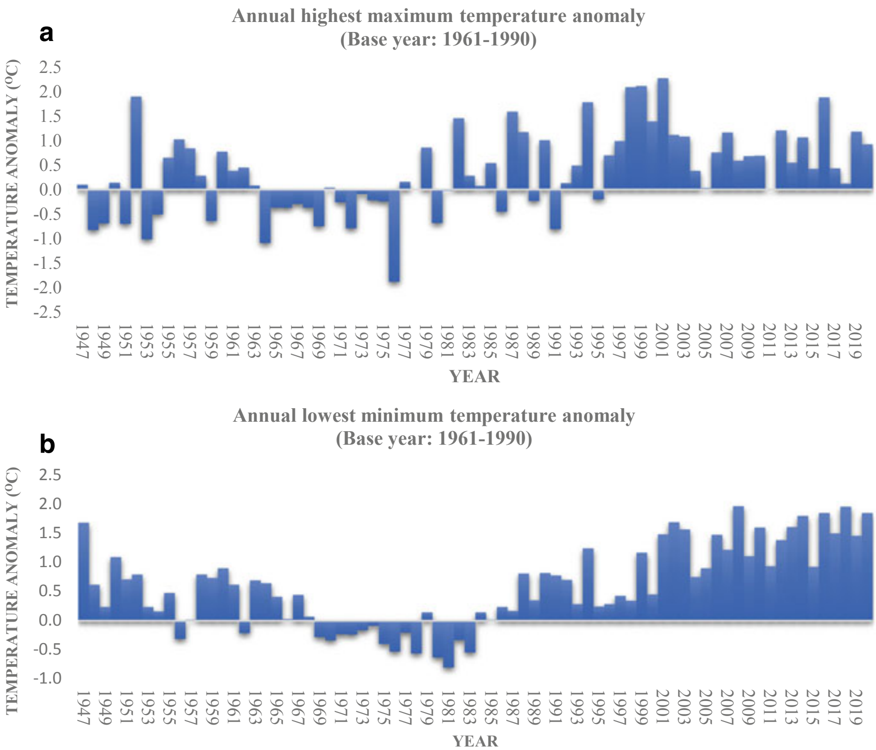

Fig. 2 **a** Trend of the annual extreme maximum air temperature over the Maltese islands. The temperature trend is statistically significant at 99% confidence level. **b** Trend of the annual lowest minimum air temperature anomaly over the Maltese islands. The temperature trend is statistically significant at 99% confidence level

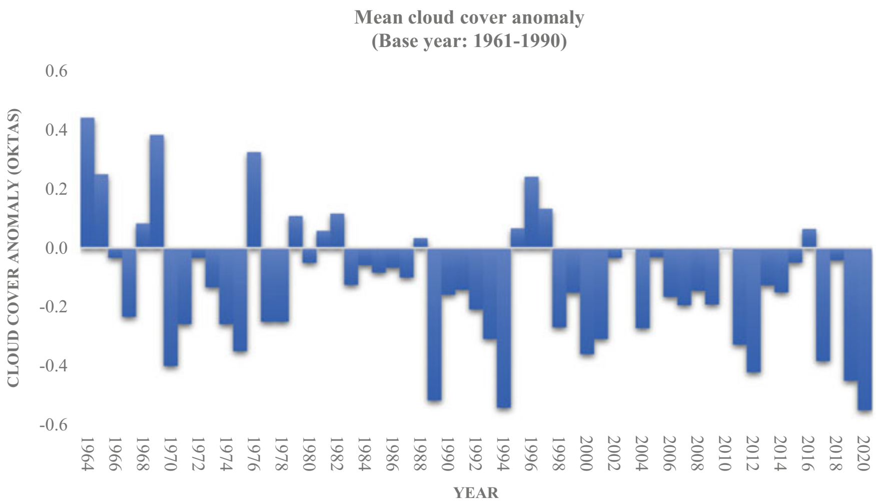

Fig. 3 Trend of the annual mean cloud cover anomaly over the Maltese islands. The negative trend is statistically significant at 99% confidence level

impact must, therefore, be considered in any long-term water management practices (Garcia-Carreras et al. 2017).

Precipitation.

Precipitation in the form of rain plays a crucial role in the freshwater supply to Malta's agriculture. Records dating back to 1946 show that the annual total precipitation is strongly affected by interannual variability, thus making local water resources planning and management quite challenging.

The present study shows that the local trend in annual total rainfall during the time series 1946–2020 shows a negative, statistically significant climatic trend at the 99% confidence level, pointing to increasing drought conditions (Fig. 4). The negative anomaly trend shows a decrease of -6 mm per decade. Local drought conditions seem to have increased in *frequency* during the last two decades, the physical processes of which are, however, difficult to identify.

It is interesting to note that while a negative trend in total precipitation is being witnessed for the long-term records, this study shows that the number of days with rain anomaly has increased over the same time period by 0.12 days. This could mean that the increased number of rainy days (characterized by a non-normal data distribution) are giving increasingly less precipitation amounts, in other words, convective and/or frontal precipitation over the Maltese Islands is becoming slowly weaker with time. However, it is important to note that this trend has been found not to be statistically significant at the 95% confidence level. An evaluation of a longer time-series is therefore needed to further clarify this meteorological occurrence.

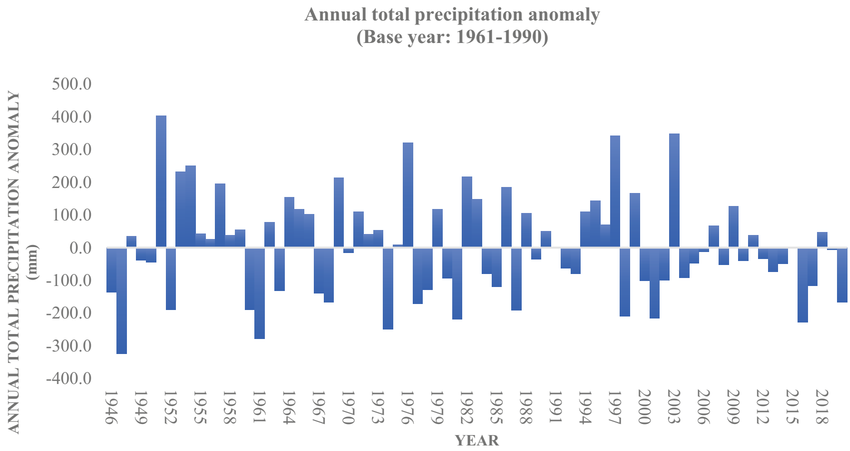

Fig. 4 Trend of the annual total rainfall anomaly over the Maltese islands. The annual total rainfall trend anomaly is statistically significant at 99% confidence level

Table 1 shows a summary of the results obtained by this study for the relevant climate change variables considered. The climate change impact variables considered in the following section are considered to be among the primary responses to changes in the state variables such as changes in crop yield resulting from changes in temperature, rainfall and mean cloud cover patterns.

The length of the time series of a data set was an important consideration for two main reasons. Firstly, the variability from year to year in the climate variables can be substantial and hence a long time series is required in order to determine directional trends in any one variable. Secondly, the chosen climate time series corresponds to the earliest rigorous data available based on national agriculture censuses. This multidecadal time series is considered to be sufficient to detect climate change impacts. It is important to note that this information is being regularly updated and available, therefore giving the possibility of applying the present methodology for a continued investigation in the coming years and decades.

Table 1 Results of the climate change trend analysis. § significant at 95% CL; §§ significant at 99% CL

Climatologic anomaly	Change per decade
Annual average air temperature	+0.17 °C §§
Annual mean Highest maximum air temperature	+0.18 °C §§
Annual mean Lowest minimum air temperature	+0.15 °C §§
Annual mean cloud cover	−0.05 Oktas §§
Annual total rainfall	−6 mm §§
Annual rainy days	+0.12 days §

(ii) *Crop-climate relationship and past trends in land use typology, land parcels and related management*

National Agricultural Statistics (National Statistics Office 2012, 2013; NSO, personal communication 2021) show how the cropped areas and related cropping trends have changed over the years (Table 2). Data from the 2016 National Agricultural Statistics identifies nine major crop typologies under different Land Use categories for a total UAA of 11,929 ha registered in 2016.

This information indicates that the total UAA has increased by 23.54% in 17 years, as did the number of holdings by 2.97%, resulting in a net decrease in land fragmentation with a size of 0.81 ha per holding in 2000 increasing to 0.97 ha per holding in 2016, practically a 20% increase (Table 2).

Looking at the three primary crop typologies shown in Fig. 5, the cultivation of Forage has dominated the sector, totalling to an increase of 1,1836 ha or 26.5% on the 2000 area. Forage consists primarily of dryland cereal crops. Except for Fodder production, all other crops are assisted with some form of irrigation that ultimately mitigates adverse drought episodes.

In the case of permanent crops, peaches constitute the most common of orchard trees in the Maltese Islands, with oranges being the most grown citrus. In the case of vines, the UAA increased by 28.63% from 2000 figures, with a noticeable decrease in local (−45.71%) and table (−48.25%) varieties. In 2013 the vegetables and fruits with the highest tonnage were tomatoes, potatoes, onions, cauliflowers and grapes, strawberries and sweet oranges (National Statistics Office 2014).

Further analysis of land use trends (Table 2) shows that the UAA area used for kitchen gardens increased by 463%, while that for market gardens decreased by 22.87%. Similarly, the UAA area dedicated to the sowing of potatoes decreased by 40.21%. The terminology of kitchen gardens refers to those areas reserved to the cultivation of agricultural products mainly intended for self-subsistence. Consequently, there has been practically a shift from the sale of produce to cultivation for self-sustenance given that the total UAA area, originally amounting to 3,639 ha, compared to 3,657 ha for market gardens, kitchen gardens and potatoes, has in practical terms remained unchanged. As a further insight into the associated management practices, data from the Census of Agriculture for 2000–2010 (National Statistics Office 2012, 2013; NSO personal communication, 2021) shows a 99% increase in the use of land machinery and a 132% increase in irrigated areas for this period, indicating a strong drive towards mechanisation and water irrigation (Table 3). The area occupied by greenhouses also increased by 22.59% for the same period.

(iii) *Crop-climate relationship and Impacts in Yield*

In Malta, records show that early higher temperatures have been observed to lead to early budburst and shoot growth, even in December; however, these are often prone to severe damage by inclement weather later in January and February. Limited or lack of adequate rain after this period further strains the vine. Local farmers have expressed the need to replace climate-induced stressed vines every 15 years, with changes in the varieties planted to have a grape maturity potential more conducive with local

Table 2 Major crop typologies under different Land Use categories between 2000 and 2016 (National Statistics Office 2012, 2013; NSO personal communication 2021)

Land use	No. of holdings	UAA	Forage	Market gardens	Kitchen gardens	Vines	Local	Int	Table	Perm. cops	Of which olives	Potatoes	other	Fallow
2000	11,959	9656	4464	2269	216	482	210	129	143	446	–	1154	195	1268
2003	10,897	10,794	5197	2083	423	615	332	131	152	465	–	1207	107	696
2005	11,071	10,254	4574	1594	968	661	309	276	76	429	–	820	93	1115
2007	11,018	10,326	4690	1851	987	751	354	264	134	570	–	712	89	676
2010	12,529	11,453	5553	1661	1123	614	103	435	77	637	140	701	157	1007
2013	12,466	11,689	5290	1909	1458	683	89	548	46	581	104	689	121	959
2016	12,314	11,929	5647	1750	1217	620	114	432	74	691	163	690	138	1177

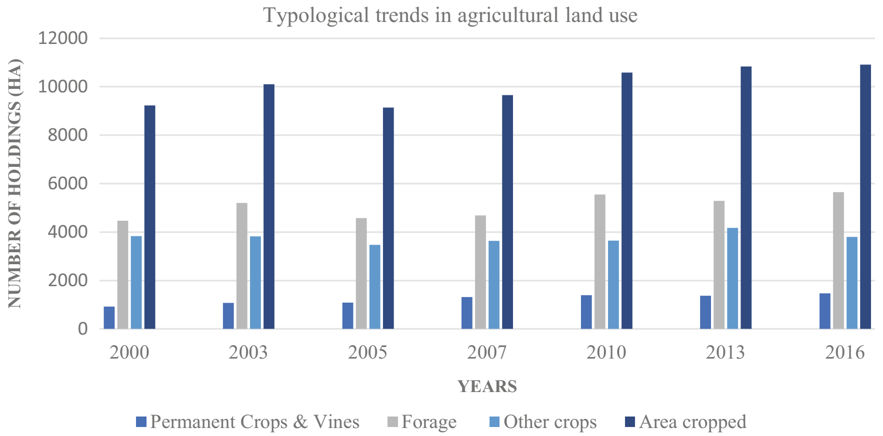

Fig. 5 Typological trends in agricultural land use between 2000 and 2016. (National Statistics Office 2012, 2013; NSO personal communication 2021)

Table 3 Associated management practices for the period 2000–2010 (National Statistics Office 2013, 2003)

	Land cultivation machinery	Tractors	Irrigated area (ha)	Greenhouse area (ha)
2000	7,825	1,996	1,508.8	41.74
2010	15,570	2,020	3,498.4	51.17

conditions–effectively having physiological characteristics less susceptible to heat stress.

As far as freshwater supplies derived from local precipitation, the 2010 UAA area of 4,893 ha has been allocated to irrigated crops (UAA less forage less fallow), to which a total of 28,176,059 m^3 of water were utilised for irrigation (NSO, 2012), translating to 5,758 m^3 per hectare. When the potential annual evapotranspiration is considered, Chetcuti et al. (1992) indicated that for the Maltese Islands, a water supply of 1,060 mm would be required to maintain herbaceous vegetation. Logically, that volume not provided by rainfall would need to be augmented in order to sustain local agricultural production. In 2010, the total annual rainfall registered was 513.08 mm, and the additional 580 mm of water that was irrigated permitted the observed yield for that particular year.

What is also interesting is the correlation shown between the annual weight of Fodder and Fruit crops with annual total precipitation for the period between 1946–1983 (Fig. 6a–b). Both show a strong inter-dependence, implying that freshwater supplies originating from precipitation are being assimilated in the yields of both Fodder and Fruit crops. However, when the trend of the Fodder yield is examined over time, this crop shows that it is being impacted by increased drought conditions (Fig. 7a) as confirmed in the above section. This is indicative that this crop type is also subject to seasonal precipitation, and therefore its yield is expected to significantly

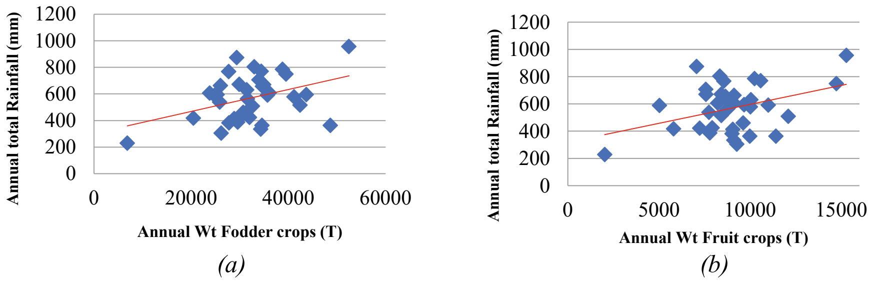

Fig. 6 **a**–**b** Correlation trend between the annual total rainfall (mm) and the weight (in tonnes) of **a** Fodder crops and **b** Fruit crops during the period 1946–1983

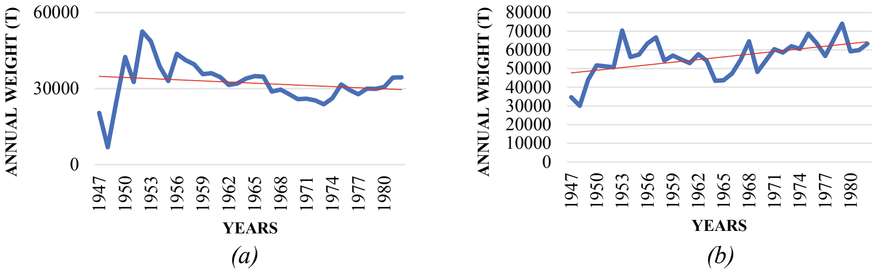

Fig. 7 **a**–**b** Periodic trend in annual weight (T) of **a** Fodder crops (the negative trend is statistically significant at the 95% confidence level), and **b** Other crops (the positive trend is statistically significant at the 95% confidence level) during the period 1946–1983

fall over the coming decades in view of the observed climatic trends. This seems not to be the case for Fruit crops (Fig. 7b) however, which show an increased yield over time. This yield is not simply being sustained by a more or less constant tonnage but is consistently on the increase, meaning that it is being sustained by increasing volumes of freshwater, amongst other factors.

It is very likely that the sources of the above-mentioned freshwater supplies include perched aquifers, treated secondary water and, not uncommonly, unsustainable extraction of groundwater, the quality of which is increasingly becoming deteriorated because of this malpractice. Of the fifteen designated groundwater bodies that Malta has under the Water Framework Directive, chloride levels, which can indicate seawater intrusion, five have high levels. (Environment Resources Authority, 2018). The increasing levels in soil salinity are not being tolerated leading to reduced yields (Hartfiel et al. 2020) and so increased soil salinity could be another factor contributing to decreased yields. In total, The overall yield shows a decrease of 5,028.2 tons per decade or 7,040.3 tons over the period of 2000–2014.

It is interesting to note that Census Reports covering the period 1956 to 1983 show that the trend in yields in the form of the total weight for the three primary crop types tends to show certain similarities up until 1965 with a shared peak around

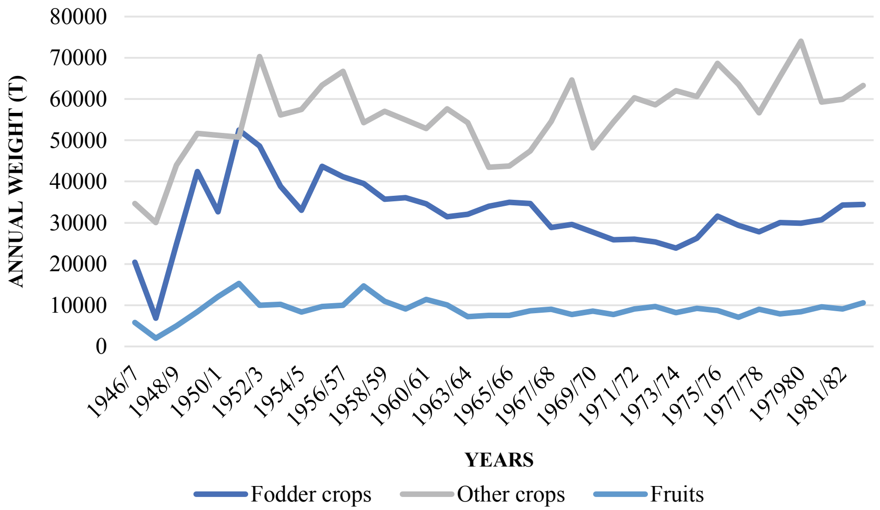

Fig. 8 Yield in Annual Weight (T) of the three main crop types between 1946–1983 (COS, 56–83)

1952/3 followed by a decrease during the period 1957 till 1965. After this period, the yields for these three primary crop types diverge from each other. For example, fruit production showed only minimal shifts during the ensuing period 1966–1982 (Fig. 8). From a horticultural perspective, this could be attributed to limited production because of the ageing of fruit trees. Bowen-Jones et al. 1961 indicated that low water availability in the soil and the wind-humidity relationship were the main restrictive factors for tree crops, whilst yields could be considerably increased by the improvement of stock quality.

With respect to non-irrigated Fodder crops, the yield also shows some particular incongruence with the rainfall measurements observed during the period 1965–1982. On the contrary, vegetable crops show an overall positive increase in their yield that could be indicative of increased use of alternative freshwater supplies for irrigation. In other words, the observed long-term climatic trend in precipitation is not being reflected in the long-term yield of this crop during this period.

Figure 9 provides some new insights when crop-specific yields are based on weight per unit area, as opposed to the total weight. Wheat, for example, as opposed to the Fodder group containing wheat, barley and meslin, vetches and forages, shows very little variation in output, unrelated to the observed rainfall variability during the same period. This could, however, be also attributed to the complete lack of technical improvements in Malta's agricultural sector, such as improvements in seed variety, seeding (which is still carried out by hand or using a seed spreader), fertiliser inputs, weed control and timing of harvesting. The trend of the yield per unit area is not conformant to the specific crop yield by weight; in addition, the former shows a slight upward increase starting as of 1976, as opposed to a general downward shift in the total weight of this crop (Fig. 8).

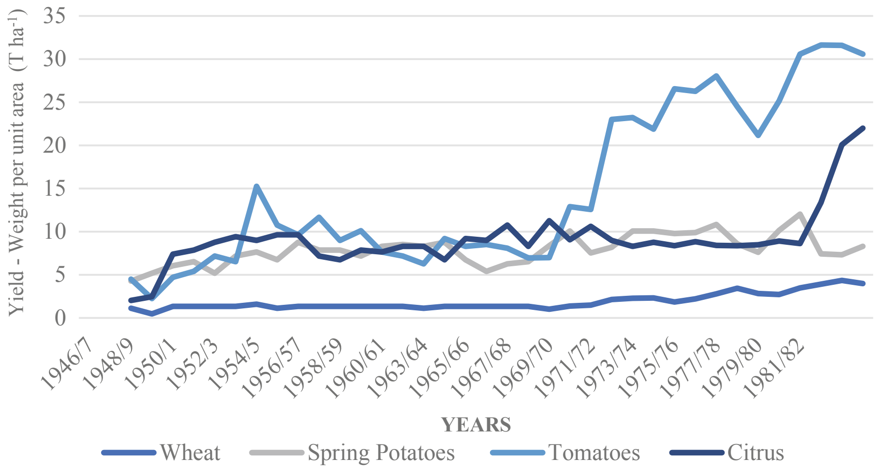

Fig. 9 Yield of specific crop types (in T ha^{-1}) for the period 1946–1983 (COS, 56–83)

Citrus yield per unit area did not reflect small spikes when rainfall was in abundance; however, a sharp increase is seen starting from 1981/2 onwards. This could be accredited to the introduction of new, more productive citrus varieties. The 1980s also saw the introduction of new tillage machinery and associated practices of water drainage and fertilisation that promoted technical efficiency. Given that there were no relevant changes in the irrigated and semi-irrigated land in this period, the final increase in citrus fruit production does not appear to be linked to water availability, nor to rainfall variability noticed throughout the years.

Spring potatoes also showed a gradual increase in production during the period 1946–1983. Potatoes require moisture during most of the growing season in order to reach high yields and quality, and the observed gradual increase can principally be supported by stored soil moisture, freshwater, and irrigation. The observed trend in yields also does not seem to follow the observed rainfall variability and its general climatic shift.

In the case of tomatoes, the post-1970 period is strongly reflecting the initiation of the local 'green revolution' associated with increased agricultural productivity of this crop, brought about by improved seed varieties, use of fertilisers and application of effective agrochemicals. It is even more evident for this crop that the increased production cannot be associated with precipitation levels throughout the years.

An evaluation of the recent local production trends of particular crops should lead to a better appraisal of the degree of susceptibility posed to Malta's agricultural sector arising from the observed climatic changes. Figure 10 shows the presence of a gradual decline (−69%) in Vines production (from 70,000 to 22,000 kg for 89.9 ha in 2015 and 2020 respectively), a lower but less steep fall in Wheat production of 22%(from 9,900 to 7,810 kg for 14.6 ha) and an undulating output (−66%, −93%, + 72%, −100%, + 109%, −25%) for Olive production. This pattern is very similar to that observed in Italy and Greece during the same period (Granitto 2019a,

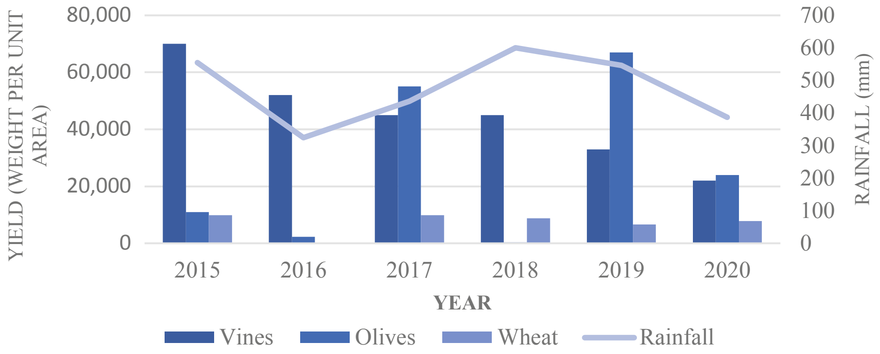

Fig. 10 Specific crop yields in weight per unit area for the period 2015–2020 as per communications with growers. Vines (kg/89.9 ha; Olives: kg/21.9 ha; Wheat: kg/14.6 ha; Wheat: kg/4.5 ha; Rainfall (mm)

b). Their decrease in production was mainly attributed to frequent and recurrent extreme weather events. Poor harvests and several large fluctuations in production over the last decade have been linked to the weather in both Italy and Greece. This may also be the case for the local crop-specific yields, and further detailed studies are here being recommended to try and correlate a larger number of specific, long-term extreme weather events with crop-specific yields registered in the Maltese Islands.

(iv) *Determining the break-even factor for important crops*

Previous economic estimates conducted by Meli (2016) showed that in Malta, Wheat production leaves a profit of €233.5/ha to local farmers (Table 4). The present study shows that there will be a zero profit if the productivity falls by 24%. Similarly, olive production leaves a corrected profit of €6877.3/ha, but which can drop to

Table 4 Local 2015 operational costs associated with Wheat, Olive and Wine production per hectare based on communications with growers

Production per hectare			
	Wheat	Olive	Wine (IGT)
Variable costs	925.6	20,492.4	9976.9
Fixed costs	41.8	1793.6	244.1
Depreciation	80.0	2855.0	3599.4
Total Costs	1047.4	25,141.0	13,820.4
Income	1008	32,400	14,400.0
3% Tax on Income	−30.2	−972.0	−432.0
VAT Refund	103.2	390.3	471.9
Subsidy	200.0	200.0	200.0
Production cost	−1047.4	−25,141.0	−13,820.4
Revenue	233.5	6877.3	819.5
Break-even margin	−24%	−22%	−6.3%

zero profit should the productivity decrease by 22%. In the case of the profitable *Indikazzjoni Ġeografika Tipika* (IGT) wine, productivity would break-even with just a 6.3% reduction, where depreciation factors cover crop replacement. However, with the observed 69% decline in grape production, the 22% fall in wheat production and the -25% to 100% decrease in olive production, local farmers are *already* in a situation that does not offer any adequate financial return from these three important croptypes. The observed (this study) and projected (Galdies and Vella 2019) adverse shifts in local temperature, precipitation and related bioclimatic indices do not augur well for localagriculture.

4 Important Findings and Recommendations

Based on the results of this study, a number of recommendations are being proposed aimed at reinforcing the adaptation capacity of Malta's agriculture in order to become more resilient to climate change. Table 5 lists down such recommendations on the basis of the knowledge gained by this study, assuming that in the near future, national priorities will reflect ongoing observations and improved climate change projections.

With regards to the limitations of this study, the precise quality of weather data collected by the National Weather Service cannot be always known, especially for the distant past. However, the monthly climatological datasets were quality controlled by undergoing basic quality checks against the original weather observations registers. This can be considered as a limitation, albeit a minimal one since the values used are the official ones that are being used by natinal authorities. Another challenge related to the analysis of agronomic data was data availability. It should be noted that for the 1956–1983 period, the same methodology was applied for the compilation of the

Table 5 Summary of the key findings and recommendations for Malta's agriculture with respect to the trends in local climate as observed by this study

Climate Change Trends (Key findings of this study)	Potential Impacts	Recommendations
Temperature		
• Average annual air temperature anomaly has increased by +0.17° C per decade • Annual highest maximum air temperature anomaly has increased by +0.18 °C per decade • Annual lowest minimum air temperature anomaly has increased by +0.15 °C per decade	• Reduced water availability for agriculture due to increased rates of evapotranspiration • Expected alteration in phenology, impacting on reproductivity, development and yields • Reduced fruit quality and yields, negatively impacting the productivity of crops	• Changes to planting and harvesting schedules • Introduction of measures to increase cooling of certain crop types, thus minimizing loss of water from crops and soil • Control present and potential pests that are expected to increase under current and projected local climate conditions • Introduction of pest-resistant crop varieties in view of an increasingly warmer climate

(continued)

Table 5 (continued)

Climate Change Trends (Key findings of this study)	Potential Impacts	Recommendations
Rainfall		
• Decreased decadal amounts by -6 mm in the annual total preciptation • Extended consecutive drought years, especially noticeable since 2000 • Variability of drier and wetter conditions	• Continued fluctuations in precipitation amounts will continue to decrease both water availability and crop production in the future • Continued water deficit of seasonal rainfall will increase water stress on local crops	• Introduction of farm practices more suitable for arid land • Update current strategic knowledge on farmers' perceptions and adaptations to reduced seasonal precipitation and related variability (Galdies et al. 2016) • Seek ways on how to persuade farmers who are reluctant to adapt using efficient practices that promote yields under a warmer and drier climate (Galdies et al. 2016) • Assist farmers in improving water use efficiency using better crop, soil and irrigation management practices • Introduce heat- and drought-resistant crops • Continue assisting farmers to improve rainwater capture and storage • Prevention of land degradation and promotion of soil conservation techniques • Improve artificial groundwater recharge in the Maltese islands to counter over-extraction of the groundwater
Cloudiness		
• The annual mean cloud cover has decreased by -0.05 Oktas per decade	• Increased surface soil temperatures, • Increased receipt of solar radiation • Decreased yield due to increased soil temperature and reduced soil moisture • Decreased chance of rainfall	• Introduction of new technologies to minimise the loss of soil moisture from farmland

yearly censuses, which proved to be very convenient for this study. However, the next two census were not carried until 2000 and 2010, giving the present analysis very important but somewhat distant information from the previous group of censuses. The authors partly overcame this limitation by filling this data gap with information derived from the yearly agriculture reports made available until 2014, using a different data collection methodologies.

5 Conclusions

This study clearly reveals that the local air temperature is increasing at significant rates, while precipitation is becoming less frequent. These changes in the local climate are placing increasing pressure on agricultural production systems in Malta. In the absence of timely and effective actions, these negative impacts can further intensify the challenges facing Malta's agricultural sector. It is therefore important that these climatic trends continue to be monitored, in conjunction with updates of the current climatic projections for Malta (CMIP5; Galdies and Vella 2019) using climate model results.

A number of possible adaptation measures are being recommended by this study, most of which are focused on changes in existing climate-risk management practices. This will allow the alignment of Malta's agriculture with an increasingly arid future. For example, authorities need to urgently introduce long-term and adaptive water management by (1) applying precision-farming that promotes efficient irrigation methods, (2) preventing further land degradation and promotion of soil conservation techniques, (3) supporting the cultivation of crops that are heat- and drought-resistant, and (4) utilising more treated wastewater for irrigation at different levels along the agricultural water supply chain.

Moreover, this study provides evidence of changes in climatic conditions that put Malta's local agricultural sector at a disadvantage. This study is a first in showing how certain crop yields have declined over the years. The lesson learnt is that climate change is straining even more the resilience of agriculture in Malta, thus limiting the margin of viable returns by local farmers. There is a strong need for future studies to determine potential rainfall occurrence, compatibility of crops to changed climatic regimes, and initiation of adaptation practices to mitigate climate change and ensure economic and environmental sustainability of agriculture in Malta.

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Climate Change and Food Insecurity: Risks and Responses in Bulilima District of Zimbabwe

Douglas Nyathi, Joram Ndlovu, Keith Phiri, and Natalie E. Muzvaba

Abstract The effects of climate change have been felt across food supply chain due to floods, hurricanes and droughts. As a result, it has led to food security risks resulting from food production and price volatility. Climate is now the primary determinant of agricultural productivity and, in this respect, climate and food availability are deeply intertwined. The purpose of the study is to interrogate the implications of climate variability on food security on rural households in Bulilima District of Zimbabwe. Specifically, the study seeks to discuss the drivers of food insecurity in Bulilima District and examine the implications of climate change on household food production and food security. The study adopted a mixed method approach where document analysis, in-depth interviews and focus group discussions were conducted with key informants. The results show that climate change has reduced crop yields and local food supplies as well as livestock production. Such repercussions have an implication on household income and purchasing power parity. Households have resorted to the diversification of their livelihood portfolios in an attempt to deal with the reparations of food security and climate change. The study concludes that in order for households to improve their livelihoods, they need to focus on portfolios that can increase their access to food and increase their household income in order to adapt and withstand the risks of climate change. In responding to climate risks, the study recommends the use of high temperature resistant crops. To help them adapt to climate change, rural poor communities need to be provided with resources that support farm and non-farm activities.

1 Introduction

Inadequate food supply and hunger is a major challenge in developing countries. Most households in the rural areas have no access to money to enable them to produce sufficient foods on their own. For instance, most households are unemployed and in some cases they cannot generate their own income. As a result, households are constrained

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_24

by many dependents resulting from extended families and few people who receive a stable monthly income which makes them vulnerable economically. Climate change has become one of the leading risks to food security, with droughts, floods and hurricanes expected to result in production and price volatility (Ziervogel and Frayne 2011). Consequently, agricultural productivity and food availability have become primarily determined by the climate. Thus, all the different food security dimensions have become affected by stability and access to food, utilization and food availability. The quality of life for those who are vulnerable and dependent on the environment and weather conditions will considerably be impacted by climate. Poor communities have no means of controlling rainfall, droughts, or cold from disturbing their livelihoods. For instance, "the sub-region is sensitive to climatic hazards, being dependent upon local natural resources for livelihood activities such as agriculture, pastoralism, and fishing" (FAO 2019). Inadequate or less access to healthy foods, lack of nutritious food, inappropriate living conditions have exacerbated the poor people's life styles. So, there are three components which are of great importance that can be used to define food security namely; access, utilization and availability. The purpose of the study is to interrogate the implications of climate change on rural households food security in Bulilima District of Zimbabwe. Specifically, the study seeks to: discuss the drivers of food insecurity in Bulilima District; examine how households deal with and adapt to climate induced food insecurity; analyse the factors determining the households' capacity adapt and manage climate induced food security; and draw conclusions on the effects of climate change on households' ability to produce food and become food secure. The chapter begins with the examination of the intricate linkages between climate change, food security and livelihoods. We explore the impact of climate change on food production and food security as well as its impact on livelihoods. Secondly, we discuss the contextual and methodological aspects of the study, followed by presentation and discussion of findings. Thirdly, we focus on courses of action that can enhance livelihoods resilience, improve agricultural production and food security considering climate risks and variability. The study concludes that the poor people in the rural areas have been negatively affected by climate change which has resulted in high levels of food insecurity. Therefore, in order for households to improve their livelihoods, they need to focus on portfolios that can increase their household income and increase access to food and its utility in a way that will enable them in withstanding, recovering and adapting to climate shocks. In order to help them adapt to climate change, households need to use high temperature resistant crops and explore ways in which they could be provided with resources that support farm and non-farm activities.

2 Climate Change, Livelihoods and Food Security Realities

The most common definition of food security is that used by the FAO which states that food security exists when all people, at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (Ziervogel and Frayne 2011). Agricultural production has been affected by climate change which has resulted in the change of prices inputs which has subsequently limited the quality and amount of food production. Sub-Saharan Africa (SSA) is one of the world's most food insecure region with people who are undernourished amounting to approximately over 230 million (FAO 2019). The social, political and economic factors have affected the sub-region's capacity to cope with climate change external stressors (Scoones 1998; Tshuma and Mathuthu 2014; United Nations Development Programme 2018) including food insecurity and the prevalence of climate related hazards (Willliams 2004; Ombogoh et al. 2018). For instance, the impact of food insecurity will affect the health of people in sub-Saharan Africa. The growing body of knowledge on climate conditions has shown that its adverse consequences will affect the region adversely (Dube and Phiri 2013; Nyathi et al. 2018; FAO 2019). Due to climate change's direct impact on agriculture, people in the rural areas will be affected directly and indirectly since they depend upon it as source of employment (IPCC 2007; Eriksen et al. 2011). As a result of projected warming and rainfall deficit, climate change will impact negatively on the vulnerable populations in Sub-Saharan Africa. For instance, Hallegatte et al. (2016) have warned that climate change will affect poverty eradication objectives particularly the poor who are vulnerable to all shocks related to change (Fussel 2007; Hertel et al. 2010). There are a number of climate related shocks that contribute to household poverty. These vary from natural disasters; crop losses; food prices shocks; and health shocks (Scoones 1998). Not only does climate change exacerbate existing vulnerabilities but it has a negative impact on development by further reducing the capacity poor to diversify livelihoods.

2.1 Impact of Climate Change

The observations by Matsa and Mini (2014) show that the climate shocks and stresses can have devastating effects on poor people who live or whose livelihoods are based on farming and non-farming activities. This is further elaborated by Hallegatte et al. (2016) who posit that "people from the rural areas have little or no resources, they have less support from other family members, and have no means to cope, and adapt to climate related shocks." Involving households in agricultural activities can assist subsistence farmers to reduce their vulnerability to hunger and food insecurity. Climate has greatly affected food availability by transforming agricultural zones into arid areas with little yields and prolonged growing seasons. Hence, Manyeruke et al. (2013) argue that the potential for economic growth is hampered by climate change thereby exacerbating the economic conditions of the poor particularly in developing countries. In addition, the failure to adapt to climate change can increase the impacts of natural disasters and raise the costs for rehabilitating infrastructure. As a result, funds targeted for long term developments are sometimes diverted to repair the destruction caused by climate change. Therefore, the condition of the infrastructure is directly linked to access to food, safety of food and stability. For instance, “many countries in Africa are food-insecure and a large portion of the population rely on subsistence farming where farmers both consume their product and sell it in local markets” (Wlokas 2008). Natural disasters can lead to human losses, affect the economic activities and destroy infrastructure thereby reduce productivity in the important economic sectors such as agriculture which is sometimes the main economic activity in poor countries. Other challenges include social or political restrictions, which can also affect the underdeveloped countries’ capacity to adapt to climate shocks or stresses. Wide spread poverty, unequal distribution of land, poor governance and low levels of education can contribute to this problem (Tshuma and Mathuthu 2014). Furthermore, climate change has reduced water availability and storage which is critical for agricultural purposes in semi-arid tropics.

Dube and Phiri (2013) note that “climate change is projected to further reduce water availability in many water scarce regions, particularly in the subtropics, due to increased frequency of droughts, increased evaporation, and changes in rainfall patterns and run-off”. Scientists predict that warmer temperatures will increase crop water needs notwithstanding rainfall uncertainty. Hallegatte et al. (2016) conducted a study in Uganda and concluded that if there is a 10% reduction in water due to lack of rainfall, that is likely to reduces crop income by an average of 14.5% which can be as high as 20% for the poorest households. Thus, the world’s poor is already facing major problems regarding the scarcity of water. This implies that any reduction in access to water poses a real threat to food security in Africa and can affect people’s health negatively particularly the poor in many African countries. However, Eriksen et al. (2015) suggest that in order to improve crop production there is need to develop better methods for capturing and storing rainwater in the affected regions. However, technologies for harvesting and storing rainwater remain underdeveloped and the viability of such systems have not been explored. Nevertheless, their implementation will require heavy financial investment which is far beyond the capacity of most communities in rural areas (Adger et al. 2003; Menike and Arachchi 2016; Mekonnen and Kassa 2019). The unprecedented and immediate threat of agriculture is compounded stressed food systems that are failing to meet rural households needs. Henceforth, to many people who depend on the natural ecosystems and small scale fed agriculture for their livelihoods, climate change has become a threat. When combined with local stressors such as pollution and overuse, climate change threatens ecosystems which provide subsistence production and safety nets for many people in rural areas (IPCC 2007). Intensive ecosystem management (like crop cultivation and livestock) have been found to provide poor people with incomes as well as the extraction of non-cultivated ecosystem goods (like timber, plants, animals, and fish). The impact of climate change has affected poor communities who depend on ecosystem based activities for their livelihoods by cutting their subsistence production and removing their safety nets (Hallegatte et al. 2016).

2.2 Climate Change and Food Security

The frequency and the number of natural disasters triggered by climate change will have a severe impact on agricultural production and food prices. Most Afican countries that are food insecure are socially, environmentally and economically vulnerable due to climate change. As a result, this has the complicated situation and made it difficult to realise the goal of eradicating hunger and poverty in Africa. Dube and Phiri (2013) note that for most developing countries, the most important sector is agriculture. Agricultural growth has an impact on poverty reduction as well as food security. So, when we talk about food security, it is important to realise that it is a function of several interacting factors. The first one being food production followed by the purchasing power parity. Similar to the example given above about changes in water supply, in Africa, Asia and Latin America livestock activities and crop yields are projected to decrease (Hertel et al. 2010). As a result, the prevalence of hunger through direct negative effects of climate change will be worsened. Climate variability has devastating effects on crop failure, affecting yields and ultimately fluctuating food supplies. The negative effects of floods and droughts cannot only be seen on the destruction of crops but they increase the spread weeds that are evasive, worms, birds and locusts that destroy crops.

Physical, economic and social access to food can also be indirectly affected by climate change. For instance, a decrease in agricultural output can push the food prices upwards resulting in the decrease in purchasing power (Makadho 1996). Scholars have predicted that by 2030 a decrease in the production of food commodities may result in a decrease in the purchasing power. The problem is that a fall in agricultural output may result in the industry retrenching workers (Hertel et al. 2010). Thus an increase in unemployment will result in the majority of people being subjected hunger and being prone to malnutrition. In many developing countries, livestock is a vital asset as it directly and indirectly contributes to a variety of household livelihoods. There are many environmental factors that are caused by climate change such as climate sensitive livestock diseases. These livestock diseases may be very expensive to control due to high costs associated with their prevention and outbreak disease control. Furthermore, livestock farming can be affected by a number of factors such as quality and productivity of grazing land, stress caused by heat, and availability of water (Bird and Prowse 2008). As shortages progress, survival strategies become more desperate, resulting in overuse of domestic resources. Adaptation strategies become more constrained (IPCC 2007; Ombogoh et al. 2018). Therefore, this chapter seeks to interrogate the impacts of climate change on household food security and the adaptation strategies used by rural communities in dealing with climate induced food insecurity.

3 Study Setting and Methodology

Bulilima district is situated in Matabeleland South which is one of the eight provinces in Zimbabwe. The province boarders with South Africa on the southernmost side along the Limpopo River and to the west it shares the boarder with Botswana (Muchena et al. 2018). Bulilima district like other districts in the province is situated within the drought-prone area with less than 400 mm mean annual rainfall and the temperature can be as high as 40 degrees Celsius during summer months (Matsa and Mini 2014; Zimvac 2015). The district's agro-ecological characteristics makes it not suitable for crop and animal production. Despite the climate related limitations, crop and animal rearing remain the main livelihood options pursued in the area (Muchena et al. 2018). For Matsa and Mini (2014), the district is one of the Zimbabwe's most marginal regions socially, economically and infrastructural. There is hardly a tarred road in the district and the nearest urban area is Plumtree town with limited services and resources. The study was done in Gwambe and Nyele villages where data was collected between the 7th and 20th of January 2020. These villages were selected because of previous studies indicating their vulnerability to poverty and food insecurity challenges (Matsa and Mini 2014; Muchena et al. 2018).

In conducting the study, the researchers were guided by Stake (1995) and Yin (2003) who indicated that case study studies can best be done through the adoption of a constructivist philosophy. Since the truth is relative and it is dependent on one opinion, we adopted a qualitative approach to enable us to understand in-depth experiences of the participants (Crabtree and Miller 1999; Patton 2002) on the implications of climate change on household food security in the study areas. Participants of the study were purposely selected with the assistance of traditional local leadership and some key administrative informants. Purposive sampling was adopted for the identification and selection of information-rich cases related to the climate change and food security issue (Stake 1995). A rapid rural appraisal was done in the two study areas to enable the research team to familiarise themselves with the socio-economic and infrastructure development contexts of the areas. Data was collected using 8 key informants who comprised of traditional leadership, local authority representatives, Non-Governmental organisation field staff, and Agricultural Extension representatives. We also used in-depth interviews (30), focus group discussions (6) and document analysis. Given the qualitative nature of the gathered information, data was analysed using the content analysis approach.

4 Study Findings and Discussions

4.1 Drivers of Food Insecurity in the Study Areas

In order to understand climate change and food insecurity, both climate risk and climate resilience should be considered. The most climate risk that was noted was the increase in temperature. Thus, an increase in climate risk must be built through resilience that is measured through effective responses. Therefore, participants indicated that food insecurity is driven by several interrelated factors. In-depth interviews revealed that food insecurity in the two study areas emanates from a combination of two factors such as, a household's failure to produce for themselves and their inability to buy food at the market. Discussions uncovered that the two villages like the greater part of the district are vulnerable to drought, high temperatures and crippling rain-fed agriculture. This was further complicated by soil erosion, limited soil fertilities and lack of draught power. Engagements with participants revealed that most households have undeveloped farming systems that rely on family labour and limited adoption of farming technology. Limited adoption of technology was as a result of its unaffordability which has contributed to the reduction in farm household productivity. Participants also indicated that the migration of youths to towns and neighbouring countries was also creating challenges related to labour availability at household level. Most of the participants highlighted that the aged in the community could not produce enough food to feed their households. Furthermore, focus group discussions revealed that the HIV and AIDS pandemic has had a bearing on household food security in the rural areas. For instance, participants were concerned that the pandemic undermines household food and nutrition as it reduces the capacity to work, productivity and jeopardise household livelihoods. This was captured by one focus group discussion participant who noted that:

> Food security has been a challenge in this community. To answer your question there are so many factors at work. This area is drought-prone and rain-fed agriculture has been failing in the last three decades. This challenge has been complicated by poor soils, lack of agricultural inputs as well labour shortages. Young men in this community migrate to Botswana and South Africa leaving the aged to carry out agricultural activities. What we have seen especially amongst households headed by the aged is a yearly reduction in cultivated land culminating to reduced crop production.

Deliberations with key informants indicated that youths in the area were also being forced to migrate to the neighbouring countries in search for greener pastures as a result of the crippling implications of climate change on rural agriculture and subsequent loss of rural livelihoods and incomes. From the discussions with the participants, it was evident that the distress migration of the able bodied was making it impossible for the older generation to pass on their knowledge to the younger generation the culturally embedded smallholder agriculture memory. The results further reveal that climate change is breaking down the backbone of the food systems, livelihoods, and the ability to generate income amongst the small holder farmers. Inferences from the conversations with the participants show that climate change was affecting household dietary diversity, food prices and increasing malnutrition cases amongst children. The concerns raised by the participants were similar to a study that was conducted by Ziervogel and Frayne (2011) who concluded that "food availability depends on the production, distribution and exchange of food which includes the production of adequate crop, livestock and fisheries as well as the collection of wild foods and resources for migratory and indigenous communities". For instance, one of the key informants said:

> I have worked in Bulilima for more than ten years as a development practitioner. What I have realised is that household food security is driven by a number of internal and external factors. This community has succumbed to HIV and Aids. What we have seen here is that much of the time that should be taken for example working in the field is taken caring for the terminally ill. And money that has to be spent buying seed varieties and animal vaccines is spend on the health demands of the ill. We have also seen a low uptake of small grains that are drought resistant by most households in preference of maize. Food insecurity has also resulted from poverty, inability to buy food as well as lack of remittances. Households that receive some form of remittances in cash and kind are better off than those that do not receive such.

Based on the above notion, it was very difficult to analyse rainfall patterns since it is rare to find trends that are statistically significant (Gina and Ericksen 2010). Whilst there are changes in the average rainfall, the region has experienced long dry spells which are exacerbated by higher temperatures leading to increased evaporation. The findings are corroborated by Islam and Wong (2017) who noted that in rural areas there are two dimensions when it comes to the problem of food insecurity. They claim that lack of access and diminishing quality of productive resources affects households' ability to produce all its food requirements. They further claim that their inability to produce their food is a result of the environment that is not favourable or highly variable. As noted by Lal (2013), households have inadequate income to enable them to acquire food from the market and sometimes the food is delivered at very high prices which makes the market unreliable.

5 Implications of Climate Change on Agricultural Production and Food Security

Various studies (Vermeulen et al. 2012; FAO 2016) have concluded that the progress made in the fight against malnutrition and hunger has been reversed by effects of climate change. For instance, IPCC (2017) reported that the most vulnerable populations in developing countries are at risk of food shortages due to climate change. Similarly, discussions with the farming households revealed that the participants had in-depth knowledge about climate change and its effects on their agricultural production and food security. Participants were of the opinion that prolonged dry spells and droughts due to decreased rainfall have affected their crop production negatively. Decreased precipitation has affected their farm household grazing rangeland due to high temperatures. Overtime, subsistence farmers have suffered losses due to their livestock being prone to diseases such as the tsetse fly and the tick diseases. For instance, one participant lamented that:

> Climate change is killing our prospects in depending on smallholder agriculture for food security. We have experienced severe droughts in the last decades characterised by reduced precipitation and heat waves. This has led to crop failure resulting in acute food insecurity in some households. Cattle and small livestock rearing has also been affected by these changes. Famers have lost thousands of animals because of poor pastures and in some instances lack of water. Water scarcity has always been associated with countries such as Somalia. We are

> now experiencing it here in Zimbabwe. The capacity of a small holder famer to produce either crops or livestock is being handicapped by the repercussions of climate changes.

As can be seen above, small holder agriculture and livestock raring is one of the major activities for the people in Bulilima. But due to climate change, their prospects to access adequate food has been hindered. The results show that there is a relationship between poverty and vulnerability since they play a central role in food access and key component in determining the purchasing power of individual households and govern social dynamics access to food (Ziervogel and Frayne 2011). Most farmers depend on their harvests and livestock where they sell surplus production to the market. Thus, households cannot afford food due to limited allocation and preferences to translate their hunger into demand. Further deliberations revealed that climate change has impacted negatively even on forestry products such as the mopane worms which used to be abundant during rainy seasons. For instance, focus group discussions show that erratic rainfall and extremely high temperatures experienced by households had an effect in increasing the mortality of mopane worms. Further deliberations revealed that mopane worms play a significant role in-terms of household income and food security in Bulilima.

The results of this study are consistent with other studies that showed a direct relationship between a change in temperature, rainfall patterns and humidity. These variables were found to increase incidences of livestock diseases and reduced grazing area (Sirohi and Michaelowa 2007; Smith and Skinner 2002). For instance, Gina and Ericksen (2010) noted that when crops that are drought sensitive are grown, any increase in temperature and variable rainfall will increase the threat therefore, there is need to consider crops that are more appropriate for such an environment The literature (Gould and Lewis 2009; Vermeulen et al. 2012; Aggarwal et al. 2013) has shown that incidences of floods, droughts and other climate-related disasters is a result of climate change which has caused adverse impacts on both ecosystems. Climate change has devastating effects on human societies since they depend on farmlands, livestock and animal husbandry for agricultural purposes as their livelihoods. The results of this study are further substantiated by Islam and Wong (2017) who argue that poor agricultural output is a result of crop failure due to lack of water and droughts caused by climate change.

6 Households Coping and Adaptation Strategies Used to Deal with Climate Induced Food Insecurity

Rural people are often responsive to climate change rather than employ planned actions due to lack of capacity, inability to adapt to planned livelihoods options, lack of resources, and lack of capacity due to poverty and livelihoods shocks. (Scoones 1998; Smit and Skinner 2002; Osbahr et al 2008). Similarly, the results show that households respond differently to climate induced food insecurity. The study shows that the economic status of the household, assets and the size of household to a larger extent influenced the nature of the responses adopted. Income diversification to non-farm and off-farm activities such as small scale mining was mentioned as one of the activities that are important in increasing household incomes outside the struggling rain fed agriculture. In addition, most youths in the area have migrated to other areas that are embodied with gold as artisanal miners. One of the participants raised important insights into the link between small scale mining, household agriculture and food security. She hinted that:

> A substantial number of households now depend on small scale mining that gives us fast cash compared to farming. What we need to understand is that money got from small scale mining is not only used to buy food at the market but also in procuring better seed varieties, cattle stock feed and also in hiring labour to work the fields, which is critical for household food security.

The above assertion indicates that households look for ways to stabilise their food supply. Food stability can be affected by food supply variations, sources of income, climate variability, economic and political factors and fluctuations in prices (Ziervogel and Frayne 2011). Food supply stabilisation can take different forms including the pursuit of other on-farm activities and growing crop varieties (intensive high-value crops). Thus, the risks can be spread and give households an opportunity to test income generating capability of other activities (Gina and Ericksen 2010). Participants indicated that they are forced to eat fewer meals a day as a way of managing food insecurity. Hence, with a decline in community support, poor households are left to cope with price increases on their own. Nearly all households that participated in the study reported that they were forced to cut down on their food expenditure by eating cheaper and less nutritious foods. Although households have a tendency of protecting their assets, the results show that in extreme cases some households have been forced to sell livestock and some productive assets such as ploughs in order to generate income for buying food. For instance, some households were engaging in environmental detrimental activities including harvesting firewood in the rural areas to sell in nearby towns and cities (Plumtree and Bulawayo). Further enquiry also revealed that remittances from diasporas in South Africa, Botswana and the United Kingdom were handful in complementing food security requirements of some of the households. These remittances were coming in the form of groceries, money and in some instances capital machinery. However, the ever increasing food prices in the area has reduced the purchasing power of money remittances. Manual labour, especially amongst the youngsters, was mentioned as one of the coping strategies used in an attempt to earn an income to buy food. In one in-depth interview, a participant said:

> Households in this community adopt various strategies in trying to deal with climate induced food insecurity. Well to do households diversify their livelihoods and diet during hard times. Some households sell their livestock just to increase their purchasing power to buy their own food. Most well to do households in this community receive remittances as far as the United States of America and the United Kingdom, making it possible to buy their food needs. The only challenge is the increasing food prices. With regards to their livestock, we have seen some relocating or pen-feeding their animals. The situation is terrible when looking at poor households. Poor households eat once a day, sell fire wood, engage in manual labour and

in some instances their able-bodied are forced to migrate to nearby mines, towns, cities and even across borders.

Participants also highlighted that households were now tilting towards expanding small livestock production. The adoption of small grains was also mentioned by the participants although some were quick to object that they also succumb to erratic rainfall and extreme high temperatures. Some participants noted that small grains are labour demanding and are also affected by birds. Intercropping and crop diversification were also mentioned by some households as critical in coping with household food insecurity. Similarly, the IPCC (2007) reported that rural communities across Sub-Saharan Africa have employed different strategies in order to cope with food insecurity, respond to poverty and manage environmental stresses which are exacerbated by climate change and variability. Their strategies include adjusting planting dates and crop varieties, planting crops that are drought-resistant such as millet, rapoko and sorghum (Dube and Phiri 2013), disposal of assets, remittances from abroad (Nyathi et al. 2018), migration and food aid (IPCC 2007) amongst others. Vulnerability exposes people to external risks, shocks and stresses (Bird and Prowse 2008) and determines people's ability to recover and cope with the resulting impacts. However, coping mechanisms vary depending on the individuals within a household or groups within a community depending on their social standing and livelihood activities. There is agreement among scholars such as Chambers and Conway (1992), Scoones (1998) and Eriksen et al. (2011) on the range of coping strategies that people draw from when under stress. Nonetheless, the strategies that can be employed by the very poor are more likely to be naturally less resilient and restricted due to stresses on their livelihoods and lack of assets.

6.1 Adaptive Capacity of Households in Managing Climate Induced Food Security

The capacity to adapt inherently to climate change is influenced by the household's coping range and the ability to either move or expand the coping range using newly defined adaptations (Eriksen et al. 2015). Climate change adaptation is important in helping individuals and households to deal with climate change consequences. However, the changing climatic conditions have limited such adaptation especially in the rural global south (Osbahr et al. 2008; Bird and Prowse 2008; Eriksen et al. 2011, 2015). Discussions with the participants indicated that the adaptive capacity of households in dealing with climate induced food insecurity is influenced by a diverse number of factors. Participants highlighted household demographics as one of the key factors that are important in enhancing the household's capacity to have consistent access to enough food. For example, poor households with high dependency ratios were reportedly struggling to respond effectively to food insecurity. In contrast, households with a substantial number of able-bodied individuals and with few dependents were found to be able to pull resources together and increase their capacity to produce or buy food.

The ability to diversify livelihoods was also mentioned as one of the influential factors with a bearing on the household's capacity to deal with climate induced food security. Households that diversified into livelihood options were those that did not depend on rain-fed agriculture and they stood a better chance to increase their income and purchasing power parity. So, the study revealed that households with assets were able to venture into more lucrative livelihood options compared to their less resourced counterparts. Another important factor is the local access to services and infrastructure which is important in determining the adaptive capacity of a household to climate induced food security. The study has also shown that households were failing to cope with climate induced food insecurity as a result of lack of infrastructure. Rural development infrastructure was found to be an important element in enhancing climate change adaptation by facilitating climate change information dissemination, determining market behaviour and financial markets. The results also show that social networks are important in increasing household capacity to cope with food insecurity. In addition, money saving and lending clubs were seen as significant in increasing household income in times of a crisis. One of the participants indicated that the money club has assisted her to buy food and agricultural inputs. An interesting response on the adaptive capacity of households in dealing with climate induced food security came from one of the female participants who happens to be the head of a household. She pinpointed out that:

> The capacity of households to deal with the climate induced food insecurity depends on household assets. If you have nothing like some of us, you will have to wait for your day to die. If you have assets that can act as some form of collateral, you can secure a loan and start something to generate income. Those with reliable water sources are doing vegetable gardens and they have capacity to diversify their livelihoods to sustain their household food needs. I think most smallholder farmers lack information on climate change. To me l believe that has a bearing on their adaptive capacity. Smallholders need to be sensitised about climate change and its implications on their livelihoods and food security as it were. That understanding of the phenomenon will enhance their adaptive capacity. Government support is also needed to ensure successful adaptation to climate change.

Adaptation practices can be positively associated to access to credit, organizational membership and availability of extension services such as technology adoption (Adger et al. 2003; Aggarwal et al. 2013; Zimvac 2015; Siders 2019). Some studies confirm that there should be a relationship between adaptation strategies and the size of household (Croppenstedt et al. 2003; Deressa et al. 2009; Abid et al. 2015). In other studies, they have linked larger households to their ability to surplus labour. These have also been linked non-farm activities and the generation of income; and the investment of money generated from non-farm activities into climate change coping mechanisms (Reardon et al. 1992). For most small farmers, the sustainability of their livelihood is determined by climate change adaptive capacity and access to productive resources. Therefore, it is critical to have access to infrastructure and services in order to get the necessary materials and knowledge required to adopt technology which includes the smallholder farmers' adaptation options (Ali and Erenstein 2017).

As indicated above, dealing with climate induced food insecurity depends on household assets, those with nothing are likely to suffer the worst climate change effects. Those with assets can use them as collateral to borrow money and diversify their livelihoods in order to live healthy lives. Climate induced food insecurity adaptation can also be influenced by food utilization. Food utilisation is dependent on age and the health of the person. So, poor households who have low adaptive capacity are likely to suffer from poor health due to inadequate safety standards, poor sanitation and are likely to suffer from chronic illness due to insufficient nutrient intake which may compromise their digestion (Ziervogel and Frayne 2011).

7 Conclusions and Recommendations

Climate change is generating a vicious circle due to low agricultural output and deprivation that exacerbates the vulnerability of households, who are dependent on rain-fed agriculture to feed their families. Inadequate food supply and hunger is a major challenge in developing countries. Most households in the rural areas have no access to money to enable them to produce sufficient foods on their own. The quality of life of people who are poor depends on the environment and the weather conditions which can be invariably impacted by climate. Poor communities have no means of controlling rainfall, droughts, or cold from disturbing their livelihoods. Involving households in agricultural activities can reduce the vulnerability of subsistence farmers to hunger and food insecurity. Changes in climate has greatly affected food availability by transforming agricultural zones into arid areas with little yields and prolonged growing seasons. The capacity of households to adapt to the impacts of climate variability were mainly influenced by the social, human, physical, financial and natural resources and how well they were accessed and conserved. Households have resorted to the diversification of their livelihood portfolios in an attempt to deal with the reparations of climate change on food security. Adaptation to climate change requires households adopt a small number of livestock and grow small grain varieties given their resilience against the effects of climate change. Information on climate change should be continuously disseminated to mitigate household risks and vulnerabilities. The reduction of household vulnerability is important in managing all the effects of food insecurity and malnutrition. The government and its development partners should increase food security resilience through the use of multiple interventions that range from policies and programs designed to reduce poverty and vulnerability by promoting efficient labour markets, diminishing people's exposure to risks, and enhancing their capacity to manage economic and social risks to the collection of principles to apply for farm production processes to get better agricultural products and processes of identifying, assessing and controlling threats to an organization's capital and earnings. Rural populations should therefore, be given resources that support agricultural adaptation activities to enhance food supply by enhancing their adaptation to climate change. In conclusion, climate response strategies that can be adopted include the use of crops that are high temperature resistant and the promotion of adoption of technology that can promote access to productive resources, access to sufficient water and investment in household assets. For households to improve their livelihoods, they need to focus on portfolios that can increase their household income, access to and utilisation of food in order to recover and adapt to climate risks. In responding to climate change, the study recommends the exploration of ways in which rural poor communities could be provided with resources that support farm and non-farm activities to help them adapt and withstand climate vulnerability.

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Exploring Mechanisms of Using Seasonal Climate Information to Drive Humanitarian Logistics Preparedness

Minchul Sohn

Abstract This study aims to identify mechanisms behind the utilisation of seasonal climate forecasts when humanitarian organisations make preparedness measures in their supply chain to mitigate potential disaster risks. When putting such logistics preparedness measures, humanitarian organisations deal with great uncertainty due to the unpredictable nature of natural hazards. Food security is often threatened even under the recurring wet season as the variability and erratic characteristics of its onset, duration, and amount of rainfall bring considerable challenges to the management of supply chains to support food security. By analysing the organisations' use of seasonal climate information in logistics preparedness to support food security, this study identifies the underlying processes and recognisable logics created through various practices. This study contributes to the literature by discussing how such information can be better used to improve logistics preparedness decision-making and mitigate potential disaster risks.

1 Introduction

Food insecurity is a pertinent concern in many Sub-Saharan countries. Climate change is creating an additional burden due to projected increases in the risk of climate extremes (IPCC 2014). Humanitarian organisations make preparedness measures in their supply chain to mitigate potential risks of such climate extremes on food security. However, the variability and erratic characteristics of climate present increasing challenges in managing logistics and supply chains for humanitarian organisations. For example, erratic temperature and rainfall patterns of wet seasons are projected to increase the risk of crop failure in many developing countries, stressing the need for adequate logistics preparedness (Mubiru et al. 2018).

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_25

In the presence of the expected, yet uncertain, negative impacts of seasonal climate risks on food security, well-informed logistics preparedness is hugely critical. In other words, it is imperative to be 'climate-sensitive' (Hellmuth et al. 2007). To achieve this, it is the meteorological forecast information, an area that can be further exploited in managing humanitarian logistics. Galindo and Batta (2013a) asserted that meteorological forecast information must be utilised when conducting preparedness activities in order to prevent and mitigate the catastrophic consequences of potential disasters. Noteworthily, recent developments in seasonal climate information have enabled better knowledge of seasonal climate risks (Doblas-Reyes et al. 2013; Tozier de la Poterie et al. 2017). In preparation for such climate-related risks on food security, the utilisation of seasonal climate information within humanitarian logistics should not be overlooked.

Thus, it is critical to have a broader understanding of how seasonal climate information is consumed and understood for humanitarian logistics preparedness. In this study, such a mechanism is denoted as climate-based humanitarian logistics preparedness. This study addresses this issue of climate-based humanitarian logistics preparedness by looking at the practices of responding organisations in Zambia that seek to utilise seasonal climate information for humanitarian logistics preparedness and aims to answer the following two research questions:

- How aid organisations understand, perceive and apply seasonal climate information in humanitarian logistics preparedness to mitigate and respond to food insecurity?
- How can seasonal climate information be better used to improve humanitarian logistics decisions for seasonal climate risks?

This study contributes to the initial understanding of the mechanisms of using seasonal climate information in humanitarian logistics preparedness. The resulting framework provides a base that can be used to enhance and complement the current state of the application.

2 Humanitarian Logistics Preparedness Under Seasonal Climate Risks

The primary objective of humanitarian logistics preparedness can be defined as an assurance of adequate planning for necessary resource mobilisation in respect of the potential needs involved, including mitigation of disaster risks (Jahre et al. 2016). Studies have considered various operational processes, functions, and capabilities as making up the key elements of humanitarian logistics preparedness (Kunz et al. 2014; Jensen and Hertz 2016; Jahre et al. 2016), including the mobilising of physical but also intangible resources (Kovács et al. 2012; Kunz et al. 2014). One of the challenges facing humanitarian organisations is, however, high levels of turbulence and uncertainty. Several studies have examined decisions for humanitarian logistics

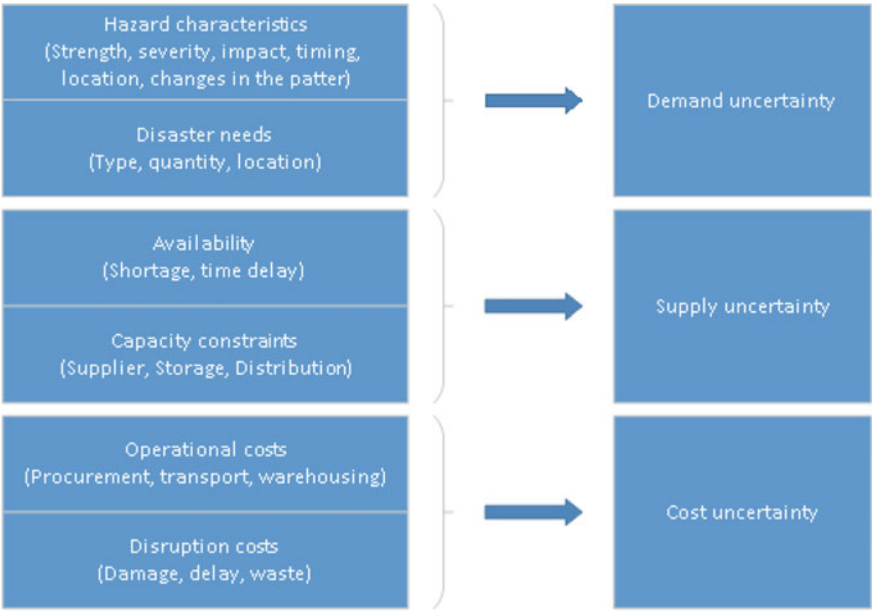

Fig. 1 Source of Uncertainty in Humanitarian Logistics

preparedness under uncertainty associated with the occurrence of a disaster and the resulting demands (Caunhye et al. 2012; Galindo and Batta 2013b; Gutjahr and Nolz 2016; Balcik et al. 2016). The main uncertainty in a humanitarian setting comes from three primary sources: demand, supply, and cost (Bozorgi-Amiri et al. 2013; Richardson et al. 2016). Figure 1 presents the different aspects of each uncertainty.

Arguably the most crucial source of uncertainty for humanitarian logistics preparedness is demand uncertainty (Bozorgi-Amiri et al. 2013). Demand uncertainty is associated with the characteristics of various hazards, together with the consequent characterisation of aid needs, answering questions related to what, where, when, and how much hazard impact is involved (Holguín-Veras et al. 2012). In particular, seasonal variability and shifting patterns of climate conditions also affect the demand uncertainty (Beck and Bernauer 2011; Thornton et al. 2014).

In the context of disaster preparedness for hydro-meteorological hazards, aid organisations will gain significant support by combining meteorological forecast information into humanitarian logistics preparedness planning, given that such information – depending on its accuracy – will complement existing data and the overall analysis result (Rodríguez-Espíndola et al. 2017).

The major benefits are threefold. First, identifying disaster characteristics through meteorological forecasts will help to increase the possibility of producing effective early warnings for logistical preparation, predicting the location, timing, and impact of the hazard, so allowing for an estimate of potential demands (Holguín-Veras et al.

2012). Aid organisations are expected to benefit from meteorological forecast information that will supplement the probability of disaster occurrence in a particular area, as opposed to relying on historical records (Davis et al. 2013). Second, by incorporating such information, relevant assessment and logistics preparation for the risk of extreme weather events (rare and improbable) can be planned in advance with longer lead-time, allowing for the determination of adapted tangible and intangible resource mobilisation. Third, meteorological forecast information is useful and important for an anticipatory and planned process of humanitarian logistics preparedness, factoring in potential changes in climate conditions, such as seasonal patterns (Tozier de la Poterie et al. 2017). Studies have underlined that the climate baselines are shifting but, at the same time, there is significant ‘abnormal’ climate variability, which is causing shifted climate patterns (Crane et al. 2011). A thorough assessment of such risk factors and vulnerability (Kumar and Havey 2013) is essential for any risk mitigation strategies in logistics management, e.g. postponement, speculation, and flexible supply base. This is because the logistics preparedness activities of many humanitarian organisations are critical for many vulnerable areas where climatic patterns are closely linked with agricultural production and/or distribution of infectious diseases.

This study argues that it is crucial to improve our understanding of how seasonal climate information is used and consumed by responding organisations. Doing so will allow for the better management of humanitarian logistics preparedness against climate extremes and associated disaster risks. As Jahre et al. (2016) pointed out, more research is needed to understand how the various mechanisms for humanitarian logistics preparedness are developed. In particular, the current study focuses on the process of utilising seasonal climate information in humanitarian logistics preparedness that remains as a ‘black box’. Therefore, this study aims to fill in a number of knowledge gaps in the literature: (1) an investigation of the mechanisms and processes of incorporating seasonal climate information into humanitarian logistics preparedness; (2) the utilisation of seasonal climate information in mitigative humanitarian logistics preparedness; and (3) an enhanced understanding of different practices and the possible elaboration of the mechanisms of using seasonal climate information in humanitarian logistics preparedness.

3 Data and Method

This study has made use of the qualitative approach (Caelli et al. 2003; Narasimhan 2014; Ketokivi and Choi 2014) to develop a holistic and contextualised analysis of the mechanisms of using seasonal climate information in humanitarian logistics preparedness. A qualitative approach is useful to identify different processes and patterns of interdependent activities (Eisenhardt et al. 2016) as well as to investigate their contemporariness and complexity (Meredith 1998; Voss et al. 2002). Thus, the primary focus lies in an in-depth understanding of mechanisms and/or logic (Aastrup and Halldórsson 2008) behind the utilisation of seasonal climate information in humanitarian logistics preparedness.

3.1 Research Setting

The research was conducted in Zambia, a landlocked, sparsely populated southern African country facing multiple challenges related to weather and climate (ADB 2019). Prone to both droughts and floods, Zambia has suffered in the past 30 years due to increasingly erratic rainfalls and longer spells of drought that have become far more frequent (Arslan et al. 2015). Strong seasonal distinctiveness in climate exists as wet and dry seasons; hence, seasonality is considered a regular phenomenon but is recurrent with variable degrees of climate shocks and extremity (Alfani et al. 2019).

In Zambia, the potential use of seasonal climate information is well understood by aid organisations due to regional/national emphasis on the value of such information. The information is widely accessible to the disaster preparedness and response community, including authorities from the government, major United Nations agencies, and non-governmental organisations (NGOs). In addition, seasonal climate information is used as a key component of national contingency plans (Hyvärinen et al. 2015). Therefore, Zambia provides a rich context for studying the utilisation of meteorological forecast information for humanitarian logistics preparedness in the context of recurrent seasonal climate variety.

3.2 Data Collection

The primary data for this study has been collected based on field research. Qualitative data were collected through observation, interviews, and a focus group discussion. In addition, some relevant organisational documents and reports obtained from the field were surveyed. These data provide rich information about the organisational practices of applying climate information within their seasonal planning activities.

The sampling strategy for this study followed the purposeful sampling suggested by Patton (1990). In contrast to random sampling, the organisations were deliberately selected in order to serve the purpose of the study. In this way, the study can ensure that the selected organisations are both relevant and appropriate for identifying humanitarian logistics preparedness practice with seasonal climate information.

The interview guide was created in the form of semi-structured questions, notably to act as a prompt, reminding the interviewer about all necessary topics, questions, and areas to probe. The interviews were ranging from 40 to 90 min and thoroughly explored the subjects at hand. Potential interviewees were contacted by email or telephone in advance and briefed about the project. In total, 25 interviews were conducted. The primary informants were managers/director of the organisations or programmes with active involvement in seasonal planning of aid operations.

3.3 Data Analysis

The data was analysed using a thematic analysis approach (Attride-Stirling 2001; Braun and Clarke 2006; Nowell et al. 2017). At the outset of the analysis, the characteristics, main activities, and involvement in seasonal mobilisation was classified for each organisation. Following that, descriptions of each organisation were developed that outlined the key decisions and outcomes that supported the respective groups' engagement with climate forecast information within the processes by which they prepared their seasonal logistics. The main focus of the analysis was on identifying the mechanisms and practices of actions (Näslund 2002; Borgström 2012) that the responding organisations employed to utilise seasonal climate forecasts within their humanitarian logistics preparedness activities.

During the iterative process of coding, existing literature was consulted on an ongoing basis to develop further insights into the key concepts that were emerging and to refine the constructs (Eisenhardt et al. 2016). Specific focus was placed on literature related to the application of seasonal climate forecasts (Lemos et al. 2012) and the cognitive processes that are involved in logistics management (Tokar 2010) and disaster preparation plans (Paton 2003; Weber 2006). The outcome of such an iterative process helped the researcher to scrutinise the actions that are employed to assimilate and utilise the forecast information that contributes to humanitarian logistics preparedness.

4 Findings and Discussions

This study explores the practices of aid organisations that seek to utilise seasonal climate information for humanitarian logistics preparedness. Three key processes are identified as a mechanism of using seasonal climate information in humanitarian logistics preparedness based on an analysis of organisations' engagement with seasonal climate information. The following processes were commonly employed by those that participated: (1) perceiving the needs of seasonal climate information; (2) establishing the relevance to humanitarian logistics preparedness; and (3) multi-sectoral networking when incorporating seasonal climate information into humanitarian logistics preparedness evaluations, decisions, and measures (Fig. 2).

The relevant practices in the first two processes reveal the distinct approaches toward seasonal climate information, resulting in the constitution of two archetypical logics of framing: simplification and actualisation. In the sections that follow, each process that contributes to the constitution of two archetypical logics will be further discussed.

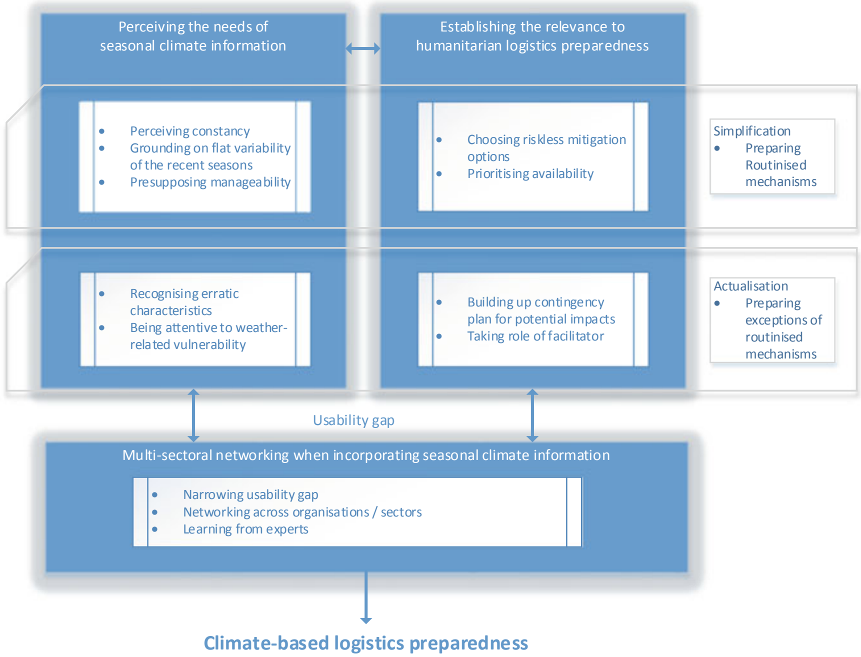

Fig. 2 Three key processes as a mechanism of using seasonal climate information in humanitarian logistics preparedness

4.1 Perceiving the Needs of Seasonal Climate Information

Different responding organisations have different perceptions of the climate and weather conditions they are up against, as their approaches must be based on the environment of the regions in which they have active programmes and operations. As the wet season approaches, organisations build different prospects for the upcoming wet season. Such difference contributes to the subsequent logic of information utilisation.

On the one hand, the use of climate information is simplified as responding organisations have strong perceptions about the constancy of seasonality. In other words, the rather flat variability of the recent seasons has contributed to the simplification logic. Based on this logic, organisations consider seasonal variability as a predictable phenomenon, behaving the same every year with expected consequences that require similar preparation.

This simplification logic is upheld by the responding organisations' assumptions that the seasonal climate risks are manageable. Some interviewees claimed that they tend to pay limited attention to climate information because seasonal variability never becomes an issue unless it is a crisis. They also commented that they consider erratic rainfalls as a part of the reality of working in the field, and those risks are manageable.

On the other hand, responding organisations succeed in extending their engagement with seasonal climate information, hence establish the actualisation logic as they recognise the erratic characteristics and changing climate conditions. Prolonged dry spells are widely recognised by organisations as an example of erratic and changing rainfall patterns, which is becoming increasingly common nowadays. Aid organisations also admitted that they must be prepared for other secondary effects that start coming as a result of the change in weather patterns, including weather-related vulnerability such as water shortages, major insect pests, and/or decreased crop yields. As organisations' concerns continue to grow, the managers are motivated to seek more climate information in order to mitigate the potential impacts of seasonal climate risks.

4.2 Establishing the Relevance to Humanitarian Logistics Preparedness

Logics of using seasonal climate information in humanitarian logistics preparedness are created through the different priorities that the responding organisations determine. The organisations exhibit the simplification logic by avoiding worst-case scenarios, such as being stock-out for critical resources. Therefore, securing the availability of supply stocks is highly prioritised for services that require a continuous stream of supplies. Agricultural inputs and commodities are provided by the push system, which distributes more stock in anticipation of disruptions based on historical data and experience.

In addition, simplification logic is supported by the preference for having risk aversion decisions. Hence, the responding organisations supply early-maturing varieties and/or promote early planting to avoid potential harvest loss from erratic rainfall and secure "at least something from the field" rather than as a means of expecting the maximum possible quantity. Organisations weigh up their options intending to achieve secure choices that involve minimal engagement with climate forecast information.

On the other hand, responding organisations realise the actualisation logic with seasonal climate information by relating to their tasks and aiming to balance the different potential consequences of seasonal climate risks on logistics preparedness. Depending on the seasonal climate information, certain needs are prioritised for particular areas, and relevant information is put in the contingency plan. Preparations are also in place for the pre-positioning of relief items and planning for evacuating affected populations but also for conveying the leading indicators of seasonal climate information to communities at risk. By doing so, the responding organisations act as facilitators, interacting with field extension officers, cooperatives, and leading farmers so that the information can be shared and channelled to grassroots levels.

Such practices help the responding organisations actively monitor and follow seasonal climate outlooks by searching, interpreting, and translating climate information for local communities. The responding organisations can plan ahead, therefore, mobilising community resources in advance to adapt their logistics decisions. These include specific sourcing decisions of agricultural inputs, estimations of the locations and sizes of populations in need of agricultural commodities (pre and post rainfall season), and preparations for effective control measures for infectious waterborne diseases (e.g. malaria and cholera) of which success measures are much affected by seasonal quality.

4.3 Multi-Sectoral Networking When Incorporating Seasonal Climate Information

The above discussion related to the previous two processes unveils how archetypical logics of framing occur. Challenges related to each logic are apparent. While the responding organisations with the simplification logic trail risk-averse decisions by prioritising availability, they may lose their sight of the resource efficiency as well as on managing exceptions. On the other hand, the actualisation logic can provide the responding organisation with considerable opportunities in process facilitation. However, it may be challenging to assure a tangible advantage. The biggest challenges for both simplification and actualisation logic lie in the limited usability of the information. This study confirms the findings from the previous research in the climate science literature, which highlighted this usability gap and particularly those barriers that affect usability (Lemos et al. 2012).

The usability gap is interlinked with the information fit regarding the accuracy, salience, and geographical specificity of the forecast information (Lemos et al. 2012). Due to the chaotic nature of the climate, complete accuracy will never be easily achieved; however, the usability of climate information depends on whether it can inform specific decisions (Thomson et al. 2003).

The third process, multi-sectoral networking, complements these challenges. In other words, by networking across organisations and sectors, responding organisations can organise and incorporate seasonal climate information that is available to them, shape their logistics preparedness decisions, and evaluate potential measures. The cases of multi-sectoral networking act as podiums, offering complementary goods for limited usability that responding organisations can then apply to their own logistics operations. It is undertaken in the form of a consultative forum, cluster meetings, and/or a coordinating committee among the UN system, international and local NGOs, and relevant government departments. These discussions are organised regularly (quarterly) but, in addition, meetings are held before the wet season as necessary. Topics and decisions that are made through such multi-sectoral discussions are pre-positioning, infrastructural damage assessment (to mitigate the effects of limited accessibility proactively), community engagement and aligning procurement/delivery system. Climate hazards are compared from different sectoral views, e.g. hydrological drought versus agricultural drought, based on the contribution of experts in each sector.

As one of the interviewees commented, seasonal climate information is not the only trigger for any preparedness decisions. But what is important is the discussion related to the implications of such information on different actors. Thus, the approach is based on bringing experts together to discuss the upcoming season, supporting community engagement in addressing vulnerability, assembling relevant information for use in seasonal logistics preparedness and identifying/coordinating what resources should be mobilised to mitigate and respond to a particular area of risk.

5 Conclusions, Contributions, and Future Research

Recent developments in climate science invite the possibility of extending our humanitarian logistics preparedness measures to a broader period of time, allowing for a shift of attention from managing disaster events to managing disaster risks. This study provides an insight into how seasonal climate information is incorporated into the humanitarian logistics preparedness of responding aid organisations that deal with seasonal climate risks on food security.

Based on a qualitative case study, this paper identifies the various mechanisms of using seasonal climate information in humanitarian logistics preparedness that aid organisations make to support food security. Three processes are revealed: (1) perceiving the needs of seasonal climate information, (2) establishing the relevance to humanitarian logistics preparedness, and (3) multi-sectoral networking when incorporating available seasonal climate information. These processes and associated practices enable humanitarian organisations to better implement climate-based humanitarian logistics preparedness.

Analysing the different practices of the first two processes reveals two different logics of seasonal humanitarian logistics preparedness: simplification and actualisation. These differing logics highlight the importance of establishing both context and meaning when considering climate information. Under the simplification logic, to address recurring disruptions, humanitarian organisations undertake a limited use of climate information while adopting a routinised mechanism for such recurring disruptions based on presumptions of constancy and manageability. The mobilisation of logistics resources is based on rather deterministic inventory management models and riskless options, while issues relating to stock availability are also prioritised. This simplification logic can be justified when climate patterns show no changes in trends, resulting in rather predictable climate variability.

In contrast, under the actualisation logic, responding organisations recognise erratic and changing patterns of climate conditions. They actively monitor climate information with a view to being able to mitigate, reduce, and respond to disaster risk but also to mobilise community resources. The primary objective is to prepare for 'exceptions' that routinised mechanisms of dealing with climate disruptions do not answer, such as where practices have become simplified. However, challenges exist when organisations strive to assure tangible advantages due to limited information usability, e.g. presentation, accuracy, and geographical specificity.

The evidence from the analysis of the third process suggests that seasonal climate information can be better used for the decision-making of humanitarian logistics preparedness, especially when it comes to multi-organisational and sectoral discussions. Challenges related to the usability of climate information are addressed through information sharing and mutual consultation. Hence, the involved parties can allocate resources as required and assign roles based on informed decisions. These aspects highlight the functional and strategic importance of coordination in climate-based humanitarian logistics preparedness. Therefore, reconciling the separation between meteorological information and sectoral priorities is critical. Such mutual consultation encourages organisations to adopt a climate-based approach and to make continuous monitoring of climate through collective actions.

As a practical contribution, this study will better inform decision-makers of the disaster management and food security that exist within aid organisations, especially regarding how available seasonal climate information is incorporated into their logistics preparedness measures. The research will hopefully stimulate a dialogue among aid organisations and scholars about the use of climate information for humanitarian logistics preparedness.

The current study is not without its limitations, however. First, given the focus on processes of climate-based humanitarian logistics preparedness, a thorough examination of performance outcomes is beyond the scope of the research. Moreover, in-depth financial evaluations of such decision-making have not been a common practice among the participating organisations in the field. Future research should focus on addressing ways to evaluate performance and provide cost–benefit analyses of actualising climate-based humanitarian logistics preparedness. Second, crucial contexts relating to the geographical and ecological characteristics of regions where these organisations operate have not been compared because all organisations have multiple programmes involved in more than one geographical area. Future research should explore conditions and constraints (e.g. feasibility and/or ease of implementation) on climate-based humanitarian logistics preparedness by studying programmes of different regions, hazards, sectors, or items. Finally, future research should further address intervention time windows for climate-based humanitarian logistics preparedness, as the timing of resource mobilisation based on robust climate information is critical for a successful implementation.

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Effects of Climate Change on Food Production in Semi-Arid Areas: A Case Study of Uzumba Maramba Pfungwe District, Zimbabwe

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Abstract The impacts of climate change are being experienced globally with negative impacts affecting mostly developing countries whose economies largely dependent on unstable rainfed agricultural food production systems. The instability manifests in changes in food access and prices. Zimbabwe is one such country in Sub-Saharan Africa where food production systems have been altered by climate change extremes with semi-arid regions like Uzumba Maramba Pfungwe (UMP) district being the worst affected given the fragile soils and low adaptive of smallholder farmers. The study therefore sought to provide evidence on the impacts of climate shocks on agricultural food production systems and their intersection with food security. A survey was conducted to gain insights into existing food production systems in UMP, how these were affected by climate extremes and community response to food security issues. Climatic data was analysed to understand climatic patterns relate with crop yields. Results showed that rainfed food production systems collapsed during droughts and severe dry spells leading to food shortages and reduction in meals consumed per day. While food prices increased, livestock prices slumped and pest and diseases increased affecting breeding. The quality and quantity of horticulture produce lowered, traditional crops were lost as well as legumes. Failure of food production in one season affected the choice of future climate change adaptation options. The study recommended that in order to stabilise food security in arid, adaptation options should be supported by enabling policies matched with appropriate technologies and market linked value chain systems.

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*,
Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_26

1 Introduction

The impacts of climate change are being experienced globally, with negative impacts having devastating effects in developing countries. Observed effects of past climates on crop production are evident in many parts of the world (FAO 2020) with negative effects being more frequently observed compared to positive ones (Porter et al. 2014). Africa is ranked high in terms of vulnerability to climate change yet many of the countries have economies largely dependent on rainfed agricultural systems (Boko et al. 2007). In Africa, rainfall has been projected to decline or become more erratic with areas which traditionally sustained rainfed crops not able to do so (Auerbach 2018). A decline in rainfall leads to decreased food production leading to increased demand and therefore increased food prices. Sustainable agricultural production is central to achieving global food security (Sundström et al. 2014). Food production is threatened by climate change manifesting as climate extremes such as floods, droughts, long and severe dry spells among others. Climate change projections for Sub Saharan Africa indicate reduction in cereal crop production (Mereu et al. 2015; Webber et al. 2014), for example maize yield was modelled to decrease by 3.8% while wheat would decrease by 5.5% on a global scale from the year 2000 to 2008 (Lobell et al. 2011). To compound the problems, environmental degradation, pests and diseases and lack of resources intersect with climate shocks further decimating food production levels. Increasing food production calls for an increase in yield and crop diversification in every season. However, climate change has continued to negatively alter food production systems especially for smallholder farmers who occupy fragile soils yet with limited capacity to cope with climate fluctuations. Semi-arid areas receive low rainfall and are more susceptible to climate shocks since the rainfall received is more often not enough to meet crop water requirements. In such areas, smallholder farmers are hardest hit given their limited capacity to absorb climate shocks. More often these farmers have limited access to technology, fertilizers, pesticides and hybrid seed (Issahaku and Maharjan 2014).

Like many other SSA countries, Zimbabwe relies on rainfed agricultural systems some of which are practised on fragile soils. The sector employs about two thirds of the population which directly or indirectly depend on it to meet household food security (WorldBank 2019). Agriculture is strongly tied to food security of the country especially maize production. Agriculture, the major economic activity used to contribute 20% of the Gross Domestic Product (GDP) a decade ago (WorldBank 2019), however the contribution shrunk to 10% in recent years due to a several factors which include the country's predisposition to climate extremes chief among them being droughts and long and severe dry spells. Food production systems are continuously being threatened and climate shocks exacerbates the inability of smallholder communities to build resilience or even mitigate the effects of extreme events. Future climate projections indicate a decrease in rainfall across the country with the months of October to December expected to experience 10–20% decrease in rainfall (Chuma 2012). A decrease in rainfall in semi-arid regions increases the probability of food insecurity given the already limited moisture available to crops. The semi-arid regions in Zimbabwe located over the north and south receive between 20 and 45% of the average rainfall (Bratton 1987; Nyamadzawo et al. 2013) and therefore reducing capacity to produce adequate cereal for consumption. Rainfall received in semi-arid areas is lost to runoff where loses sometimes reach levels of at least 50% (Nyamadzawo et al. 2012). Rarely is rainfall harvested for future use on crops. Wherever runoff is high, soil nutrient losses are also high. Erosion of already stressed soils further complicates crop production and this coupled with erratic rainfall and increased intra-seasonal dry-spells decimate crop yields. In order to improve food production, understanding micro-level impacts of climate change is an essential prerequisite for planning local level prioritization of resilient climate change adaptation strategies.

Climate change affects regions differentially and therefore any targeted interventions to improve food production systems can only be successful if they address local constraints. In Zimbabwe, the effects of climate change on food production have been analysed at higher scales and therefore appear rather generalised. Available research has focused on interventions to increase livelihood resilience through climate smart techniques such as conservation agriculture (CSA) (Makate et al. 2016; Marongwe et al. 2011), promotion of small grains (Phiri et al. 2020) and water harvesting (Nyamadzawo et al. 2013). Insights on food insecurity based on gender differences are reported in (Kairiza and Kembo 2019), while (Chanza 2018; Ndebele-Murisa and Mubaya 2015) found that the effects of climate change on livelihoods and coping strategies cause a complete breakdown of food production systems. The purpose of this paper is therefore to provide evidence on the effects of climate change on food productions systems in Zimbabwe and how they intersect with food security focusing on semi-arid areas in Uzumba Maramba Pfungwe (UMP) district. Empirical evidence was sought on the most affected food production systems, response to lean periods and ripple effects on recovery. The district was chosen for its lack of studies yet a experiencing myriad of climate challenges. The findings have potential to influence policy on agricultural development in semi-arid areas and assist in resource allocation for climate change resilience programs (Lal 2015).

2 Study Area

Uzumba Maramba Pfungwe is located to the northeast of Zimbabwe (Fig. 1). The district generally receives low rainfall with the bulk of the district lying in agro-ecological region IV (Fig. 1) and receiving rainfall less than 650 mm per year with the exception of southwestern areas in Uzumba area which receive up to 800 mm of rainfall. The district is not spared from climatic hazards such as droughts, dry spells and extreme temperatures (Gwenzi et al. 2020; Kwenda 2014). Farmers practice crop diversification and a variety of crops are grown which include cereals such as maize and small grains and legumes such as beans, ground nuts, cow peas and bambara nuts.

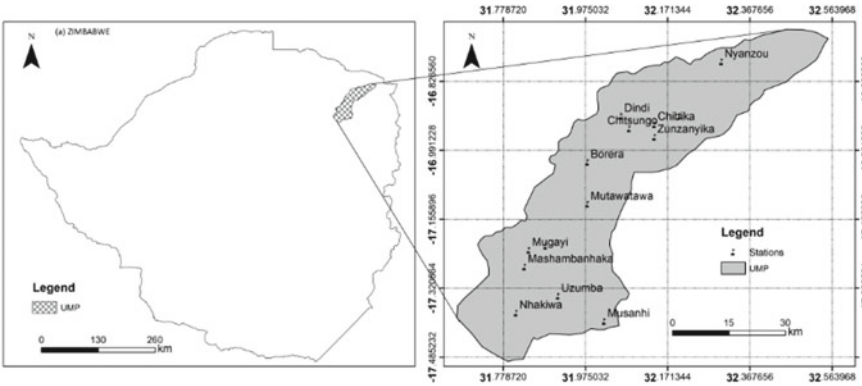

Fig. 1 Map of UMP district showing the location of UMP district in Zimbabwe and the stations where focus group discussion members were derived from

Subsistence farming is most common in UMP, however in good seasons, farmers sometimes sell surplus cereal when they produce excess. In Uzumba area which receives more rainfall, farmers have gardens in which horticulture crops such as tomatoes, leafy vegetables, sweet potatoes and onions are grown. Farmers in Uzumba (upper UMP) have a lot of mango trees and therefore the abundance of the fruit allow for road side sales during the months of December to February. Farmers also keep livestock such as cattle, goats and indigenous chicken however the numbers per household are low. Another common livelihood is road side sale of wild fruits such as sugar plum (*Uapaca kirkiana*) during the months of November to January. Most of food production systems in UMP are rainfed and therefore inherently suffer from climate shocks. In order to gain insights on how climate change affects food production in UMP, data was collected through surveys, observation and measurement of actual yield for 4 years. The details are provided in the methods section.

3 Methods

The natural hazards affect UMP differentially and these have been detailed in (Gwenzi et al. 2020).

To appreciate the farmers' perception on the effects of climate change induced shocks on food production in UMP, 200 household interviews (HHIs) were administered. Information sought included hazards experienced, coping strategies, access and use of weather and climate information in food production. A section in the questionnaire was included to extract information on (a) the major food production systems, (b) the years in which drought was experienced and impacts on food production systems, (c) crops completely lost and (d) other factors which intersected with climate shocks to limit food production. To improve the findings from the household interviews, Focus group discussions (FGDs) and key informant interviews (KIs) were conducted. A total of 6 FGDs were held, 3 in Pfungwe and 3 in Uzumba, one of which was for women only. The purpose of having a FGD for women only was to seek information on crops which were favoured by women yet forming part of the food basket for the families. FGDs were conducted in lower UMP (Pfungwe) and upper UMP (Uzumba) which are major food production areas in UMP. Key informants were drawn from the Ministry of Agriculture and Rural Development's Agricultural Technical and Extension Services Department (Agritex) and Social Welfare officers who had knowledge of food production systems in the district. Lead farmers in the district were also included either in FGDs or as KIs. A historical timeline was done with farmers where they highlighted major historical events that had a huge bearing on crop production in the district. Gauged data was available for a few years given the absence of a synoptic station in UMP. The period of study was extended using remote sensed data which was extracted from NASA POWER Agrometeorology website (http://power.larc.nasa.gov). Rainfall and yield data were analysed to determine the relationship between the 2 parameters. Zimbabwe rainfall is often influenced by the El Nino Southern Oscillation (ENSO) conditions and therefore seasonal performance was matched to different ENSO conditions for the period 2000 to 2017 in relation to the severity of conditions experienced by farmers however focusing on the period of study which was 2014 to 2017. ENSO conditions for previous rainfall seasons were obtained from the National Oceanic and Atmospheric Administration (NOAA) website (https://psl.noaa.gov/enso/past_events.html). The findings are given in the results sections.

4 Results: How Climate Change has Altered Food Production in UMP

In rainfed agricultural systems, food production correlates to rainfall sufficiency. A good rainfall season leads to at least average production holding all other factors constant. Any changes in rainfall amounts or pattern has a large bearing on food production. In this case food production is combining cereals, legumes and livestock. In UMP, climate change effects on food production were observed on quantity and quality and drought years resulted in low production leading to food insecurity. The following sections provide details on how climate extremes have affected food production in UMP.

4.1 Effects of Climate Change on Cereal Production

Farmers observed drought, long and severe dry spells coupled with high temperatures the as the main climatic hazards experienced in UMP. Farmers indicated a change from the year 2000 and excessive heating during rainfall season having been experienced since the year 2012. From the records maximum temperatures above 33 °C became more frequent, which was at least 1 °C more than the years prior to 2010. The historical timeline given by farmers indicated an increase in drought years which occurred sometimes over successive years, shifting from the 5 year cycle they had previously known. Since the year 2000 the farmers indicated an increase in the number of years in which low rainfall was received in UMP, leading to loss of some indigenous crops traditionally grown in the area which formed the food basket of many families. The seasons indicated as drought years in UMP are 2001/02, 2003/04, 2007/08, 2012/13 and 2015/16. A new rainfall pattern was noticed by many farmers as short wet spells were often punctuated by long and severe dry spells. Some portions in their fields would be swampy during the rainfall season and they would grow traditional rice however the crop had been lost completely from the district following dry conditions. From the historical timeline, droughts and dry spells caused low production or poor quality and small grain size in maize. Many traditional maize varieties grown by farmers in gardens for consumption as green mealies during the months of December into February when the main maize crop will not have matured were lost. Farmers continuously used retained seed given the non-availability of traditional seed shops. During severe droughts farmers faced total crop loss resulting in the extinction of major traditional maize varieties.

The 4 seasons for which data was available showed strong correlation between maize production and rainfall (Figs. 2 and 3). However Uzumba had higher yields in 2013 when just average rainfall was received due to good temporal distribution of the rains. In general Uzumba experiences more rainfall and therefore had higher chances of higher yields than Pfungwe. Prior to the year 2000, the farmers indicated they were able to produce food enough to last until the next harvest and when they experienced drought, the farmers were able to recover without much intervention from government or other relief agents. In recent years maize production remained generally low following low or poor temporal distribution of rainfall and therefore food insecurity continued to increase making the communities suffer from hunger more during lean periods.

From 2010/11 season some farmers kept personal records of rainfall. Poor temporal distribution was quite noticeable. The major drought years that the farmers could remember matched with El Nino and neutral ENSO conditions. Table 1 shows highlights of some historical climatic events provided by farmers and the related ENSO conditions. They likened 2015/16 season drought to 1977/78 and 1992/93 droughts when experienced total crop loss and lost many livestock. The loss in 2015/16 season had a ripple effect on cereal production in 2016/17 season as farmers had limited incomes to buy all the inputs they required.

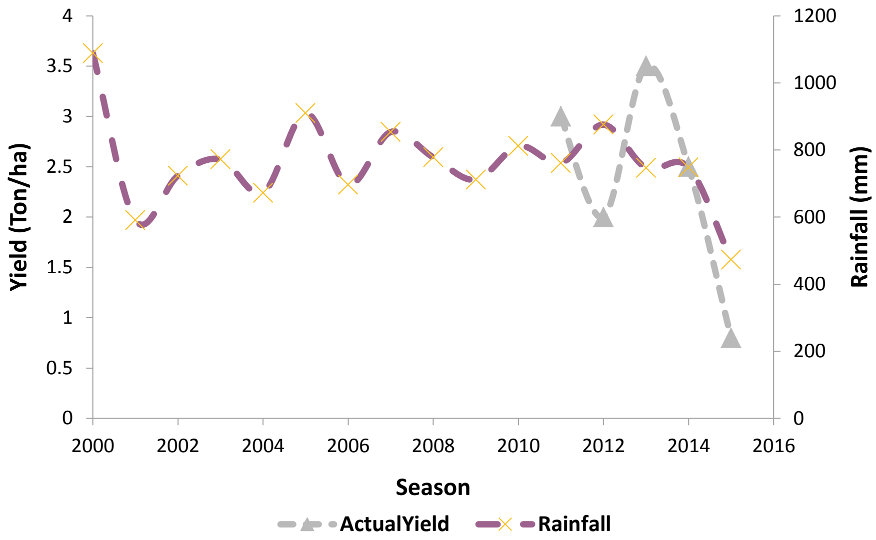

Fig. 2 Time series of maize yield in Upper UMP (Uzumba) for 4 seasons

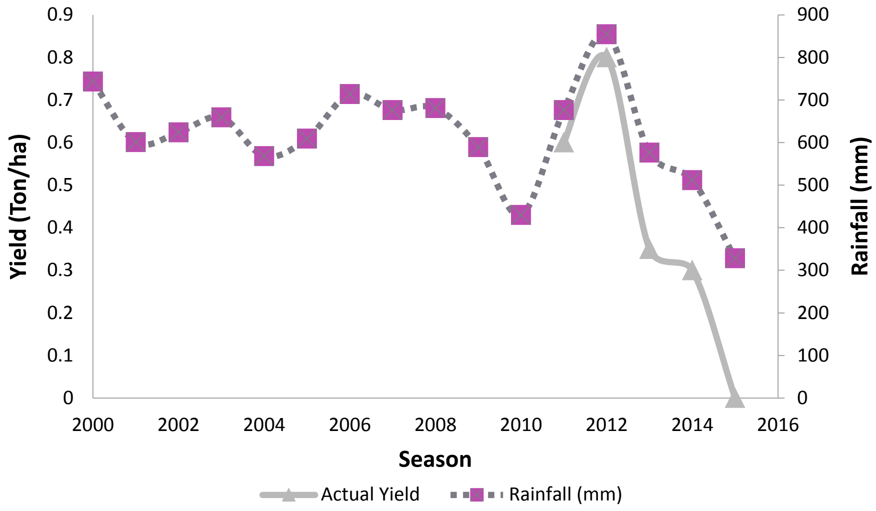

Fig. 3 Time series of maize yield in Lower UMP (Pfungwe) for 4 seasons

Among the cereals that are now popular in UMP are small grains especially sorghum. The government introduced small grains in 2004 following subsequent years of cereal deficits however many famers didn't adopt small grains immediately. In UMP small grains were adopted by many farmers as from 2010 an adaptation measure against climate shocks which continuously outpaced farmers' adaptive

Table 1 Historical climatic events experienced in UMP and the related ENSO conditions

Season	Seasonal conditions experienced and effect on cereal production	ENSO condition
2000–2001	More than average rainfall and good maize harvests	La Nina
2001–2002	Average rainfall and just enough production	Neutral
2002–2003	Low rainfall and poor harvests	El Nino
2004–2006	Poor rainfall distribution resulting in low maize production	Neutral
2007–2008	Low rainfall amounts, total crop loss	El Nino
2008–2009	Good rainfall and good harvests	La Nina
2009–2010	Harvests not enough to last the year	Neutral
2010–2011	Erratic rainfall, poor yields, adoption of small grains	El Nino
2011–2012	Good rainfall, yields low affected by the previous 2 seasons	La Nina
2012–2013	Rainfall concentrated in March, affected production	Neutral
2013–2014	Average and erratic rainfall, low production	Neutral
2014–2015	Low rainfall, low yields	El Nino
2015–2016	Low rainfall, total crop loss	El Nino
2016–2017	Good rainfall season though drier towards the end	La Nina

capacity. Small grains have high tolerance to low rainfall however crop stand establishment was poor. Droughts and dry spells decimated yields by at least 50% however in 2015/season there was little harvest to talk about following the severe drought that occurred. The increased frequency of poor rainfall seasons has resulted in reduced cereal harvests yet these are the staple food of every family. Combined, the cereals (maize and sorghum) fail to meet the food demand to last a full year in UMP and farmers diversified to have several crop production lines. Other crops grown in UMP are legumes.

Legumes such as groundnuts, bambara nuts and cowpeas which are synonymous with women are grown by many households as part of the food basket, however these are grown on small portions compared to cereals. With increased climatic shocks the legumes were aborting flowering whenever it coincided with excessive heating periods. If they reached physiological maturity, the legumes produced withered grain. Dried legumes provided backup to families during lean periods. Loss of harvest of legumes increases hunger periods. In the last decade farmers indicated they could harvest as much as 10 bags of groundnuts per household, however in recent years harvests have been halved or even less. Manifestations of aphids and other pests increased during drought and dry spells as observed in the 2015/16 season when cowpeas were affected across the district. Eventually little or no harvest was realised following the reinforcement of drought and aphids.

From December, farmers start enjoying leaf vegetables, some which grow naturally, however such vegetables were now becoming less common, or were available for short periods. These included pumpkin leaves (*cucurbita moschata*), amaranths (a*maranthus spp*), spider flower (*cleome gynandra*), cowpea leaves (*vigna unguiculata*) and okra leaves (*corchorus olitorius*). When in abundance, these vegetables are harvested and dried for future use especially during lean periods and are a major component of the family food basket in the rural areas. Farmers indicated the seasons 2007/08 and the recent 2015/16 season as the worst in recent years where they didn't harvest these vegetables following the drought. Long and severe dry spells had become more frequent in January and February, the months in which most of the vegetables would have matured for consumption affecting the quantity and quality. Farmers faced longer hunger periods where some relied mostly on starch as they could not enough vegetables for meals. This resulted in low production of all crop varieties. Pumpkins and water melons were taken as substitutes for afternoon meals and in many cases pumpkins substituted bread on morning meals. These were now rarely reaching maturity, if any they would be so few and would not last beyond harvesting time. The abundance of a variety of food which accompanied the rainfall season was now short lived creating food deficits that made communities exposed to longer periods of food insecurity.

4.2 Effect of Climate Change on Horticulture

In upper UMP, horticulture is a major livelihood activity. Droughts and dry spells affected the production of green vegetables, onions, tomatoes, and sweet potatoes commonly grown in gardens. Quality and quantity of vegetables were the most affected. Farmers supplemented organic manure with fertilizers. Under limited water availability, vegetables were watered less frequently and therefore growth was inhibited. During the 2012/13 and 2015/16 the leafy vegetables contained high levels of fertilizers and therefore bitter in taste. Tomato plants produced small and few tomatoes. Available water resources were reserved for domestic animals and some horticulture activities were abandoned or scaled down for example, vegetables and tomato production. Farmers had to deal with water shortages and aphids induced by excessive heating. Sweet potatoes were equally affected with yields significantly reduced.

4.3 Effect of Climate Extremes on Livestock

Smallholder farmers use cattle to provides the draft power. Effects of climate shocks on livestock has a huge bearing on crop production. Farmers highlighted livestock vigour as a major challenge that compromises food production. Climate shocks had introduced new and perennial diseases on livestock. Diseases such as red water, black leg, and January disease which previously were rare in the district were now common and lasting all year round. Smallholder farmers rely on animal draft power, therefore loss of livestock such as cattle led to reduced cropped areas as farmers had to outsource draft power. Pastures were severely diminished in drought years and recovery was not enough when the following season had average rainfall. The absence of enough pasture resulted in poor health in livestock causing reduced or no breeding, therefore livestock numbers remained low in the district. Health and more cattle offered such farmers an advantage of resting animals while others were used for ploughing.

4.4 Weakened Soils

Farmers highlighted that the soils in UMP were no longer producing higher yield as much as in previous decades. The district was experiencing higher run-off rates following short wet spells characterised by heavy rainfall. Soil nutrient was depleting yearly and application of fertilizers was not always possible due to limited financial resources to meet farm demands as farmers prioritised buying food to meet the gap from production. The greatest challenge was improving soil fertility using fertilizers in an area where moisture is already compromised. Farmers had turned to climate smart agriculture techniques however they could not get enough crop residue or tree leaves to use as mulch. With few livestock numbers, organic manure was not enough to cover the fields. While rainfall is a major factor in food production UMP, there are other contributory factors work to reinforce the effects of climate shocks on food production.

4.5 Other Factors Affecting Food Production Compounded by Climate Change

Several other variables intersect with lean years and livestock quality in production of food crops in UMP. Successive years of low production due to climate extremes lead to poverty. Where farmers' adaptive capacity is greatly compromised, vulnerability to climate shocks increase. Faced with food shortages, farmers concentrated on providing food, which was a more immediate needy than developing resilient farming systems. Drought years had ripple effects on food production in following seasons. Farmers were not able to purchase enough hybrid seed and use of farm saved seed resulted in low yields. Farmers used retained seed mostly for small grains and legumes more so because hybrid seed was not easily accessible from local shops.

Another factor which as an effect on food production is human health. Droughts and low adaptive capacity were reinforcing poverty among many smallholders. Poverty led to reduced access to food and in lean periods farmers resorted to reducing the number of meals. Food prices increased in such times as demand increased. An average beast was traded for only 8 bags of maize grain or $250. Such exchanges were not favourable for farmers and led to loss of livestock since the prices didn't allow farmers to purchase livestock in good rainfall seasons. The government provided relief targeting vulnerable households such as widows, child

Table 2 Household consumption patterns in UMP

Location	Number of meals	2014 (%)	2015 (%)	2016 (%)
Uzumba	3 meals	50	35	15
	2 meals	10	50	70
	1 meal	10	15	15
Pfungwe	3 meals	90	80	0
	2 meals	10	20	20
	1 meal	0	0	80

headed families and those with disabilities. To spread the food over a longer period, both those receiving relief and those self-reliant had to skip meals. However such feeding patterns didn't promote normal working capacity. Ultimately crop production was negatively affected. Table 2 shows the distribution of meals per household during the period 2014 to 2016.

5 Discussion

The findings revealed strong relationship between climate induced shocks and food production in UMP. While other factors exist, temporal and spatial distribution of rainfall within each season had a strong correlation with food production systems which are entirely rainfed. The level of household food security determines national food security, however climate shocks continue to affect efforts to build resilience. In UMP, successive lean years have resulted in low or insignificant incomes to hedge against the effects of climate extremes in achieving food security. The observations made by farmers on rainfall from the year 2000 agree with the available data. A comparison of farmers' records with ENSO conditions showed more manifestations of neutral or El Nino years than La Nina years. In Zimbabwe, though the relationship is not 1:1, it has been observed that neutral or El Nino conditions have resulted in low rainfall across the country in most of the cases (Mamombe et al. 2016; Manatsa and Mukwada 2012). Erratic rainfall punctuated by severe dry spells or occurrence of drought caused reduced cereal production over successive years. This has made it difficult for farmers to come out of the cycle of low production. With compromised agricultural production systems coupled low adaptive capacity, the farmers lagged behind in sustainable agricultural development as sources of income were used mostly for purchase of food. Natural resources are limited to provide other adaptation options in Pfungwe and therefore climate shocks have continued to decimate food production, a situation which may continue until decisive steps have been taken to improve such cereal production systems in arid areas.

Horticulture thrives under ideal conditions especially abundance of water. Severe dry spells and droughts in UMP intersect with already fragile soils to reduce food production thus increasing food insecurity. Uneven and under-watering in high temperatures cause plant stress and early maturation. This altered the taste making vegetables bitter. Community members shunned from buying the vegetables and farmers experienced loss of incomes meant to improve or develop resilient farming systems. Lack of climate information reaching grassroots contributed to poor crop management by farmers. Where the information reached the farmers extension agents needed further training focusing on climatic events. Response farming would help farmers mitigate the effects of climate shock on food production.

The dependence on animal draft power further complicates crop production in UMP. The vigour of animals is certain where there is enough pasture and enough water. The continued below average rainfall seasons resulted in weak animals. Such animals could not function as would be normally expected. Apart from being weak, breeding cycles were been affected and therefore livestock numbers have remained low in UMP. Therefore households burdened the same animals every year. Recovery periods for the animals were shortened. To further complicate the health of the animals, climate related diseases ravaged the animals. Livestock susceptibility to tick bone diseases increased due to increase in temperatures and infrequent dipping times worsened livestock health.

Once a drought occurred food prices increased, pastured depleted and livestock diseases increased. The sale of such livestock resulted in low income returns or a few bags of cereal not enough to last until next harvest for an average sized family of 6. Limited food options caused families to rely mostly on starch during drought periods. Barter trade for grain increased however exposing farmers to limited farm inputs in the following season. A drought year had ripple effects on family incomes such that many family struggled to buy hybrid seed for the following season. Remittances and money obtained from offering cheap labour was used only to buy food, without extra cash to maintain the health of livestock. Extreme weather events decimate family assets and the capacity to reinvest in agriculture leading to continuous food insecurity (Alderman 2010).

Successful food production in a region is influenced to a great extent by government support and policies in place. Enabling conditions and access to information that improve decision making in agriculture are a subset of successful smallholder crop production systems (Eriksen et al. 2011). The absence of targeted government programs in semi-arid areas compared to richer and wetter areas makes the smallholder farmers trail behind in adoption of new technologies which would otherwise help increase crop production. In Tsholotsho, farmers who have successfully grown small grains have accessed information and inputs from supporting agencies such as Environmental Management Agency and Agritex which provide agronomic information. This goes to show that farmers cannot independently succeed in building resilience to climate change without external support by the government (Phiri et al. 2020).

6 Conclusion

In recent years, food production is proving to be a more difficult process compared to past decades. The major threat to food production in UMP is climate change manifesting as climate shocks/extremes. Droughts and dry spells are common with lower UMP being the most affected and therefore getting lower yields compared to upper UMP. Yield is strongly correlated to rainfall therefore successive years of low rainfall have seen UMP losing traditional crops that support and increase variety in the family food basket. Such crops include legumes and rice. Leafy vegetables were found to be scarce and bitter in drought years further exposing families to nutrition insecurity.

UMP has huge potential to develop resilient agricultural systems for food production if supported by correct, accurate and timeous climate information and supported by capacitated extension agents and research. Climate information will evolve over time and farm management practices will need to reform and transform to match the changes (Lugen et al. 2018). The transformation calls for strong institutional support and willingness by farmers to positively adopt response farming. However instilling the knowledge, establishing capacity, building institutions and policies needed to deal with the climate of the future takes is a slow process. The study provides insights on the effects of climatic shocks on agricultural systems while seeking entry points to develop policies and capacitated institutions that supports development of resilient food production systems. Small grains and crop diversity have been promoted and successfully embraced by the communities, however marketing models available will need to match the effort and input costs used in production. The study did not include education and population dynamics as a limiting factor in crop production.

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Growing Climate Change Impacts on Hydrological Drought and Food Security in District Peshawar, Pakistan

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Abstract Hydrological drought, defined as a lack of water in the hydrological system, is a complex natural hazard that has a numerous effects on ecosystems and civilization. It decreases the soil moisture leading to decreased soil fertility ratio, crops productivity and groundwater levels, which results in increased food insecurity, physical and mental health problems, debts, while in some cases, people are forced to migrate owing to its associated problems. This study examines the impacts of hydrological droughts in one of the towns of District Peshawar, Pakistan. Three indicators were used to investigate hydrological drought in town IV district Peshawar; rainfall data, water table levels and stream flow of rivers were collected and a community survey was conducted to ascertain the hydrological drought parameters of the town. The reduction trend in water table varied from one to three feet per year in the study area, precipitation has reduced in the study area and stream flow discharges showed large differences in rivers capacity in the last two decades. Questionnaire survey from local population augmented the precipitation, water table and stream flow data. Analysis of the research results show that three main indicators for drought, which is precipitation, water table, and surface water availability have reduced in the study area. The study concludes by recommending measures in order to mitigate the impacts of the hydrological drought in town IV, district Peshawar. Government departments, NGOs, INGOs, and other stakeholders should take immediate steps in order to mitigate the hydrological drought impacts in this area, otherwise this may seriously affect the food security, social wellbeing and environment of the study area.

1 Introduction

Natural hazards (e.g. floods, earthquake, drought, cyclones, desertification, land sliding, volcanic eruption, etc.) are divided into four main categories; Hydrological Hazards, Meteorological Hazards, Geological Hazards and Biological Hazards. Meteorological hazards are those hazards which are related to weather phenomenon

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_27

like Cyclones, Hailstorm, Thunderstorm, etc. Hazards which are related to earth are geological hazards such as Land sliding, Earthquake, Volcanic eruption, etc., while, biological hazards are those hazards which are caused by living things like Epidemics, insect Infection, etc.. Hydrological hazards include water related hazards like Flood, Tsunami, Droughts, Desertification, etc.

A disaster may occur due to inability of a vulnerable community to cope against any hazard (Cutter et al. 2003). One of the hydrological hazards is drought. According to the Intergovernmental Panel on Climate Change (IPCC) assessment report, drought is a phenomenon which is frequently occurring all over the world (Pachauri and Reisinger 2007). Drought is not a disaster in and of itself; rather, it escalates into a disaster as a result of its harmful effects on the environment and the vulnerable population it affects (Wilhite et al. 2005). As this phenomenon grows and progresses slowly and gradually, it is considered as a slow onset disaster (Yun et al. 2012). Scientists have varying opinions about drought phenomenon. Drought is the natural insufficiency of rainfall for a period of time, resulting in a lack of water for survival (Adnan et al. 2015). The deficit of precipitation for long duration is the warning of drought. "Drought refers to a temporary reduction in water or moisture availability below normal or expected amount of water for a specific time period" (Khan and Khan 2015)."Drought is a climatic occurrence where the quantity of moisture is less than average rate for a constant period of time" (Anjum et al. 2012). Globally, drought is a complex and sneaking natural hazard (Paulo et al. 2012). Drought signs include short-term rainfall deficits, reduced water levels in ponds, reduced in-flows of watercourses, and decreased agricultural production (Wilhite et al. 2005).

Drought have both natural as well as social aspects (Wilhite et al. 2014). They have the capacity to damage the agriculture, environmental and economic sector as well as water resources and socio-economic conditions of the communities (Durrani et al. 2021). It is estimated that, 44 million people were effected due to meteorological droughts in 2013 all over the world (Miyan 2015). The price of maize increased significantly owing to the droughts in Kenya (Brahmbhatt and Christiaensen 2008). In 2002, India also suffered from severe drought conditions and its food grains decreased considerably as compared to yields of 2001 (Parida and Oinam 2015; Mishra et al. 2021). Pakistan faced severe drought from 1998 to 2002. Baluchistan, Southern Punjab, Tharparkar, and D. I. Khan were badly affected areas of Pakistan. In Khyber Pakhtunkhwa (KPK), thousands of hectares of land was effected due to hydrological drought (Khattak et al. 2019; Rahman et al. 2021).

a. Types of drought

According to the IPCC, variation in precipitation due to climatic variability, leads to dangerous event like flood, drought, and desertification. With every passing year, drought is becoming more risky phenomenon and an important climatic problem all over the world (Rogelj et al. 2012). Historically, many parts of the earth, especially Europe, Australia, Africa, North America, and Asia are facing more severe droughts as compared to past ten centuries (Dai 2011).

World Meteorological Organization indicates that climate and weather phenomenon is responsible for more than half of the natural hazards. Drought is occurring in arid and semi-arid areas and more number of people are exposed to this hazard other than any other natural hazards (Ren et al. 2014). The total losses due to drought were as high as US$6-8 billion all over the world (Wilhite et al. 2005). Droughts can be further sub divided into four different categories described as under:

(1) Meteorological drought

Drought is a meteorological phenomenon, where the affected areas suffer from extensive and severe moisture scarcity (Palmer 1965). Meteorological drought is reduction of precipitation in a specific region for longer periods (Eltahir 1992). Meteorological drought refers to reduction in precipitation from the normal amount which occurs for a specific time period (may be day, month, season or year/s) (Farooqi et al. 2005).This is the most severe types of drought and it starts in the sunny days and hot weather. This drought precedes other types of drought. Total rainfall and the amount of moisture in the soil is used to calculate meteorological drought (Allaby 2014).

(2) Hydrological drought

Hydrological drought affects soil moisture and ground water as a result of meteorological drought (Tallaksen and Van Lanen 2004). It refers to reduction in stream flow, lake levels, soil moisture, and underground water table etc., (Hoyt 1942)below a specified level for a specific time period (Van Loon 2015), resulting in shortage of water in the hydrological system (Dai 2011).

Hydrological drought is a natural hazard which is not specific for a region, but occurs all over the world and, consequently, its impacts are very high especially on people, whose livelihood is agriculture dependent.

(3) Agricultural drought

Agriculture drought refers to decrease in soil moisture accessibility below the normal level required for crop growth (Otkin et al. 2016). Such type of drought results into shortage of water for crops by negatively effecting the soil moisture conditions which is essential for crops growth (Xu et al. 2016). Agricultural drought leads to create famine like conditions, which is food shortage for long time period in a specific region (Rossato et al. 2017).

The inability of soil water to support crops due to the absence of regular precipitation for a specific amount of time can also be defined as agriculture drought (Wilhite et al. 2005). It is subsequent to hydrological and meteorological drought and may be called as the combination of hydrological and meteorological drought which damages crops production as well as food and farming (Rosenberg 1979).

(4) Socio-economic Drought

Droughts of this type are defined by the supply and demand of agricultural, meteorological, and hydrological elements such as grass, hydroelectric power, and water, which are weather dependent (Yevjevich 1967). It occurs as a result of hydrological drought, agriculture drought, and meteorological drought conditions which leads to adverse effects on the quality, quantity and demand of facilities and goods (Wilhite and Glantz 1985). Lack of water in the hydrological causes socioeconomic drought, affecting stream ecosystems, disrupting recreational activities, and impacting social and economic activities (Bazrafshan et al. 2014).

Socio-economic drought is distinct from other types of drought in that it represents the supply and demand for a commodity or economic product that is dependent on precipitation (such as water, cattle fodder, or hydroelectric power). Annually, supply changes due to precipitation or availability of water. As a result of expanding population, development, and other reasons, demand fluctuates and is frequently correlated with a positive trend. It is a situation in which the supply and demand of products and services are outstripped by weather and related deficiencies (Sandford 1979). It has a direct impact on the supply and demand of economic goods (Loukas and Vasiliades 2004).

b. Causes of drought

Water depletion is caused by a variety of factors, including decreased precipitation and climatic unpredictability (Brunetti et al. 2004). Drought is becoming more common and severe as a result of climate change, (Huntington 2006) and it is caused by a number of factors that naturally interact (Svoboda et al. 2004). Some of the causes of drought are as follows (Gupta et al. 2011).

(1) Reduced rainfall
(2) Poor infiltration
(3) High runoff and depletion of aquifers
(4) Poor catchment area
(5) High evaporation
(6) Reduction in soil moisture
(7) Depletion in ground-water and surface-water levels
(8) Increase in evapotranspiration
(9) Low vegetation cover.

According to some researchers (Rashid 2004), El-Nino and La-Nina can also lead to drought, since these phenomena effect the sea surface temperature as well as global atmospheric circulation leading to increased rate of carbon dioxide and other greenhouse gases contributing towards drought phenomenon. Increasing evapotranspiration and temperature may also increase intensity, frequency and magnitude of drought. According to Paulo et al. (2012) in addition to other climatic influences, atmospheric factors such as high wind, low humidity, and suspensions at the start of the rainy season influence drought in various parts of the world. As stated by (Mishra and Singh 2010), drought is caused by protracted periods of below-normal precipitation, as well as deviations or obstruction in river channels.

c. Drought Impacts

The impacts of drought are different on society, environment, and economy. There are two types of impacts, namely; direct impact and indirect impact. The direct impact include decrease in forest and crops land, increase in fire hazard, reduction in water level, increase in mortality rate, losses of wildlife and fish habitat (Wilhite et al. 2007). These impacts further cause indirect damages like joblessness, increased price of food items, reduced revenue collection, health problems as well as social damages including losses of life, social problems and migration (Logar and van den Bergh 2013). In addition, there are some examples of environmental impacts as well; frequently, drought disturbs forest, damages crops, results in loss of biomass, and leads to increased dust and pollution (Nguyen et al. 2009). Increased loss of different plants and animals and its species, reduction in water level, soil erosion due water and winds, shortage in water reservoirs, dirty water and polluted air are also some of the impacts of drought (Wilhite and Wood 1994). Socio-economic impact of drought lead to increased poverty, damages to forest and crops, decreased earnings, seeds shortage, and low quality and quantity production (Nguyen et al. 2009).

d. Drought in Pakistan

Pakistan is primarily a dry country with a temperate climate. A climatic gradient exists from the far north to the far south, from the mountains to the sea. Except in the northern highlands, average annual precipitation is less than 250 mm, and it decreases from north to south. Furthermore, more than a third of the country receives less than 250 millimetres of rain each year, which comprises the majority of the country's mountainous regions (Salma et al. 2012). Since the last decade, there has been extremely low rainfall in most of Pakistan's drought-prone areas (Adnan et al. 2018). To further aggravate this situation, very high temperatures have also been recorded. According to the natural phenomena, regular rain fall not only increases the moisture content on the surface but also results in recharging of the ground water aquifers. Unfortunately, actual conditions are entirely opposite to this situation. The amount of moisture lost from the earth's surface due to evaporation is larger than the amount of water received in the form of rainfall which is further exacerbated due to decreasing underground water levels making the areas vulnerable to droughts.

In Pakistan, a severe drought occurred from 1998 to 2001 (Anjum et al. 2012). The ecosystems of the impacted areas were influenced by the drought in a variety of ways, both short and long term. Agriculture productivity is heavily reliant on rainfall in most locations. Although the effects of droughts in Pakistan's impacted areas have been mitigated by the country's vast and unique canal network, nonetheless, in all the four provinces, droughts still remain chronic, in most of areas.

(1) Drought in Baluchistan and Sindh Provinces:

Baluchistan is extremely dry province of Pakistan, half of province is almost with less than 125 mm rainfall (Jamro et al. 2020). The other areas receive no more than 250 mm rainfall which is handicapped by adverse variability. Thar Desert is located beyond the left bank flood plain of the Sutlej and Indus rivers, where drought is severe and frequent. In the Baluchistan province, the drought prone areas have been developed through the traditional system of irrigation using karez tunnels which is ultimately rainfall dependent for recharging the aquifers. In some part of Makran and Quetta valley, where karez are dug from springs, and ground water is conveniently available to convey the water to the valley floor. Hoarders in the Thar and Baluchistan deserts used to graze their animals on desert plants and grow crops between the dunes. Drought has forced a big number of people to migrate to urban centres and other places over time (Solomon 2019). Reduced feed supply have resulted in widespread livestock losses. Drought has not been as severe in other parts of Pakistan due to a well-developed canal irrigation system and arrangements for food storage and supply. About 80% area of Baluchistan has been subjected to drought (Ahmed et al. 2016).

(2) Droughts in KP Province:

Large parts of the province are exposed to drought due to low rainfall from time to time, the most recent drought ending in 2001. Due to the absence of modern and extensive system of irrigation, Southern districts of KPK are prone to droughts, such as Tank, D.I. Khan, Karak and Lakki Marwat etc. Besides, in low rainfall situations, districts like Nowshehra, Kohistan, and Mansehra have occasionally been affected by droughts (Rahman et al. 2021). The districts like Peshawar, Charsadda, Mardan, Swabi, Kohat and Bannu which have relatively well developed irrigation system are still affected by prolonged droughts condition owing to water scarcity in irrigation wells etc. 1998–2001 drought greatly affected this province leading to water shortage for animal, crops and human beings.

(3) History of drought in Pakistan

Pakistan has a climate that is highly variable, with annual average rainfall of less than 250 mm, resulting in periodic droughts. Pakistan has also been subjected to droughts as a result of the El Nino and La Nina phenomena (Khan 2004). Pakistan has experienced severe droughts in 1881, 1899, 1920, 1931, 1935, 1947, 1951, 1971. Because of minimal rainfall, the drought of 1999-2001 was the worst in Pakistan's history (Naz et al. 2020). It resulted in negative growth of 2.6 percent, resulting in 51 percent water scarcity (40 percent greater than prior years) and reduced water flow in Pakistan's major rivers. In 2012, a state of emergency was issued in Tharparkar and Mirpur Khas due to severe drought (Miyan 2015).

Pakistan being an agriculture based economy relies heavily on rainfall. Baluchistan is extremely dry province since its twenty three out of twenty six districts are vulnerable to droughts. Due to the absence of modern and extensive system of irrigation in Southern districts of KPK are more vulnerable to droughts, while,Thar, Dadu and Thatta in Sindh; and Cholistan in Punjab are drought prone areas. Similarly, District Peshawar, which is the provincial capital of KPK is facing shortage of precipitation and due to its unusual geographic variability, is liable to severe and frequent drought phenomenon in the recent past. The issue is further aggravated owing to unplanned urbanization in the city and increasing population which in turn puts pressure on the drinking water requirements, besides increased irrigation water demand for agricultural purposes. In order to fulfill additional water requirements, excessive and unchecked ground water pumping further exacerbates the growing water scarcity in the area. The issue is further compounded by lesser rainfall and decreasing surface water availability making the area vulnerable to droughts. Owing to growing water scarcity problems in Peshawar city, as a case study, this research explored one of the four towns of this city (town IV) in order to ascertain hydrological drought phenomenon which is likely to cause food insecurity in the area in near future if the government fails to take immediate mitigation and adaptive measures to fight this looming threat.

2 Methodology

a. The Study area

The study area is town IV, Tehsil Peshawar, District Peshawar which is located about 160 km away in North-west direction from the Pakistan's capital, Islamabad. It shares border with Charsadda, Nowshera, Kohat, and District Khyber. Geographically, Peshawar district is one of the most populace district of KPK Province, having a density of about 3,400/km^{2}or (8,800/sq mi). Peshawar is covering an area about 1,257 km^2 (485 sq mi) and district Peshawar population is about 4,269,079. The district is divided into four towns, Town I, Town II, Town III, and Town IV. Town I and II are further subdivided into 25 union councils (UCs), and Town III and IV are further subdivided into 21 union councils (UCs). The total population of town IV (our study area) is 777,897.

b. Data Sources

Two types of data including, Primary data and Secondary data was used for this study. A comprehensive survey was conducted and data was collected through questionnaires. These questionnaires were filled from targeted population, while some data was collected from the local people, tube well operators and borrowing persons to ascertain the underground water table in the study area. The primary data was collected using random sampling, and field observations. The local people of the study area also gave some necessary information regarding the history of the underground water table, water purification and water quality, and also about the good and bad characteristics of water, as some areas have very good water quality for domestic purposes. The secondary data was collected from the various offices and departments including WSSP (Water Sanitation and Services Peshawar, PHED (Public Health Engineering Department), PMD (Pakistan Metrological Department), Irrigation Department, Agriculture Department etc. In addition, data from journals, reports, books, and research articles was also curated.

c. Data Analysis

Microsoft excel was used to analyze the obtained data. Excel was used to arrange the data and all the tables and graphs were created through these tools to achieve the objectives of the study.

d. Sample Size

For determination of sample size, we have different formulas and methods. We use a sample formula for sample size because our study population is predetermined. Yamane (1967) sample size formula was used for this purpose which was found to be 210.

e. Limitation of the study

No accurate data was available about current water table as well as reduction in water table per year with all those departments which are working on water supply and water sanitation like, WSSP, PHED and PDA (Peshawar Development Authority). The data collected in this regards was based on the people's perceptions obtained from questionnaire survey and from observation and interviews with the field staff of the above mentioned departments.

3 Results and Discussions

After thorough analysis of the responses obtained from the survey results, information gathered from the relevant departments and key personnel associated with water supply in the study area both from primary as well as secondary source, results are summarized as and explained as under.

a. Water Availability

Majority of the people (62%) in town IV District Peshawar are not satisfied from water availability, while some (38%) of them were satisfied. The major reasons for low water availability given by the community in the study area were attributed to less rainfall, followed by poor irrigation system, climate change and urbanization. Irrigation system is necessary for crops cultivation and more productivity. If proper irrigation system is available for crops; the quality and quantity of products should be better than the one which is rainfall dependent. According to the farmer's perceptions, there was annual change being experienced in the irrigation routine as the water quantity was decreasing over time in irrigation system as well as ground water table levels. Majority of them blamed lesser rainfall and climate change for the decreasing water levels. This decrease compels the farmers to explore other sources to meet their agriculture needs, and therefore, the ratio of people depending on the canal system decreased as they were diverted towards alternate sources including, tube well irrigation system, bore well irrigation system, and rain fall irrigation system. Around half of the population had to bank on rainfall, while almost one fourth depended on tubes wells, as well as bore hole to meet their irrigation requirements, in the absence of proper irrigation system and decreasing water availability in the canals in the area. Since, efficient irrigation system is necessary for crops cultivation and more productivity, the quality and quantity of products is badly hampered which might lead to food insecurity in the area.

b. Water Demand and Quality

Water is the foremost basic need for survival and without water, life is impossible. There are different water sources being used by the people in town IV in order to fulfill their drinking water demands, bore wells being the most prominent. Tube wells were being resorted to for irrigation purposes. Majority of the people were satisfied from the water quality, but expressed their concerns of deteriorating water quality as a result of rusted and poor quality distribution systems. They were also apprehensive about the mismanagement and carelessness of the concerned departments with regards to repair and renovation of the old deteriorating distribution system.

c. Climate Change Impacts leading to declining water table

The people's perception about decreasing water table every year had mixed opinions. Some opined that the water table fell below 100 ft in last ten years, while some felt that it was between 50 and 100 ft. Nonetheless, everyone was convinced on the fact that the water table is decreasing at a faster pace. All the farmers had the knowledge about droughts, but had varied opinions about its causes. Majority of the people believed that poor water management leads to drought, while others were confused between ground water extraction, climate change and environmental degradation. Television, was found to be the major source of knowledge and information as most of the people relied on it for getting all sorts of information including droughts (Table 1).

d. Climate Change led migration and reduction in cultivated areas & Food Insecurity

Almost half of the households (49.1%) living in the study area having varying family sizes had to migrate because of growing negative consequences of hydrological drought in town IV District Peshawar. Owing to weak economic conditions, many of these household were compelled to stay in this area as they could not afford to shift from this location. Due to prevailing conditions, majority of the population lost or had to sell their livestock, numbers ranging from less than 3 animals to more than 3 as 52%, 31% and 17% respectively. With regards to crop farming in the area, majority (51.4%) cultivated wheat, followed by maize (32%) and 13.2% other vegetables. Reduction in crop production was also explored, which was dependent on the farming area as well. The cultivated areas were significantly reduced owing to growing climate change impacts and varied from less than 2 to more than 2 acres, and the responses were equally distributed in

Table 1 Summary of survey data

AGE				
35-45yrs 31.4%	46–55yrs 35.2%	>55yrs 33.3%		
Education status of responders				
Metric 29.5%	Intermediate/High School 29%	Bachelors 21.9%	Masters 19.5%	
Land size for agriculture				
2 Acres 21.9%	3 Acres 16.7%	4 Acres 30.0%	>4 Acres 31.4%	
Satisfaction with water availability	YES 38.1%	NO 61.9%		
Source of irrigation	Canal system 23.8%	Tube well 21.9%	Bore well 23.8%	Rain fall 30.5%
Reason leading to change in irrigation routine	Water deficiency 45.7%	Weather effects 32.4%	Other 21.9%	
Change in the ground water level over last 10 yrs	<50ft 37.1%	Fell up to 50 feet 18.1%	Fell up to 100 feet 16.2%	>100 ft 28.6%
Do you know about drought	YES 100%	NO 0%		
How you know about drought	Radio 18.1%	T.V 70.5%	Self-Prediction 11.4%	
Frequently of listen	Daily 68.1%	Twice/Thrice in a week 28.1%	Weekly 3.8%	
Are you relocated due to hydrological drought	YES 58.1%	NO 41.9%		
Is crops insurance compulsory	YES 10%	NO 90%		

this case. This further lead to lesser crop production ranging between less than 300 kg/ acre to more than 300 kg/ acre, and again the consensus amongst the people was equally distributed with regards to decreasing crop production and growing food insecurity. For this reason, majority of the population (78.9%) had to change their cropping pattern owing to drought conditions. Climate Change was the major factor, followed by water scarcity to be responsible for changing cropping patterns.

e. Change in Cropping Patterns

Majority of the farmers who believed that they were compelled to change the cropping patterns found wheat (64.8%) and maize (35.2%) to be more vulnerable to drought conditions. Owing to climate change impacts and drought conditions in the area, people were becoming vulnerable to decreased agriculture income and increased food insecurity. In order to transferring this risk, consent for crop insurance options were explored from the community in the area. Almost all were of the view that crop insurance was not compulsory and were also reluctant to opt for this for multiple reasons, major reasons being corruption, lack of trust on government, difficult procedures and other causes (Table 1).

f. Health Issues

Besides, growing food insecurity in the area due to decreasing cultivated area, dropping crop production and migration of the people, the drought conditions have led to negative health impacts as well. Majority of the population (59.5%) blamed that frequent coughs can be owed to deteriorating water availability and droughts in the study area, while another (21.9% and 18.6%) put the liability on cholera and gastroenteritis, respectively, for this situation.

g. Major Findings from the data collected through survey

The key findings from the case study are tabulated in Table 1 which includes responses to classification questions in addition to information and various behavioral, knowledge and perception questions. Basically, income sources of the population of town IV was agriculture and livestock and accordingly, land size for agriculture was also explored and is represented in Table 1.

h. Water Table in Town IV

Water table data collected from WSSP and PHED. The departments identified that reduction occurred in water table from 2000 to 2018 (Idrees 2019). This data showed variability with regards to water table reduction in different areas of town IV, District Peshawar. Major depletion in water table (3 or more feet/year) was observed for Aza Khel, Mattani, Adezai and Sherkera. Water table depletion of 2–3 feet/year was found in Badhber Maryamzai, Badhber Harizai, Maryamzai, Mashogagar, and Nodeh Bala, while comparatively, lesser depletion (1–2 feet/year) was observed in Hazar Khawani I, Hazar Khawani II, Musa Zai, Urmar Bala, Urmar Miana, Urmar Payan. In case of rest of the UC's, the water table depreciation was less than 1 feet. The collected data showed seasonal as well as yearly decrease in water supply and depletion of underground water table.

i. Rain Fall Data from 1999 to 2018

Precipitation data was collected from PMD regional office Peshawar to identify as to how much reduction in rainfall was observed for the last two decades in Peshawar (Idrees 2019). There is only one met station in Peshawar which is responsible to collect weather related data in Peshawar. Highest precipitation was recorded in July 2010 which was 409 millimeter, while 0 mm was also recorded in many months during the last 2 decades. The data showing varying trends as the rain fall shows an increasing tendency from 1999 to 2010, while the trend is reversed during the years 2010 to 2018 (Fig. 1).

j. Bara River Discharge

Third indicator for drought is reduction in stream flow discharge, collected from Irrigation Department Peshawar (Idrees 2019). According to data collected, there was a huge difference of flow observed in capacity of the rivers. At present, there are three rivers in town IV; Bara River being the major river, while other two rivers have been converted to torrents. Bara River discharge level is also decreasing every year (Fig. 2).

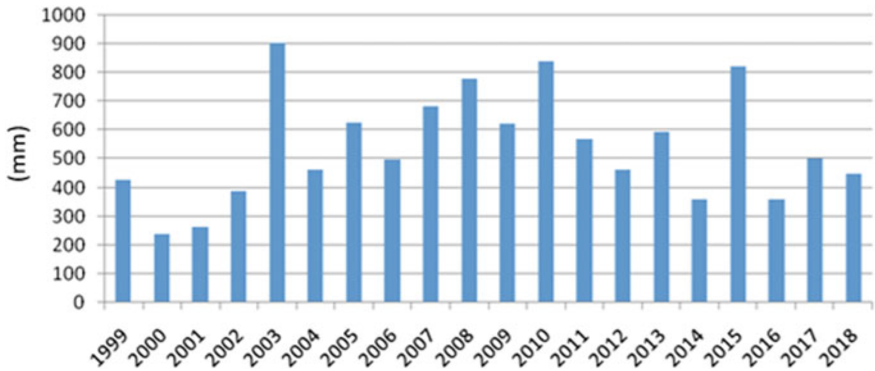

Fig. 1 Annual Rainfall Data 1999–2018

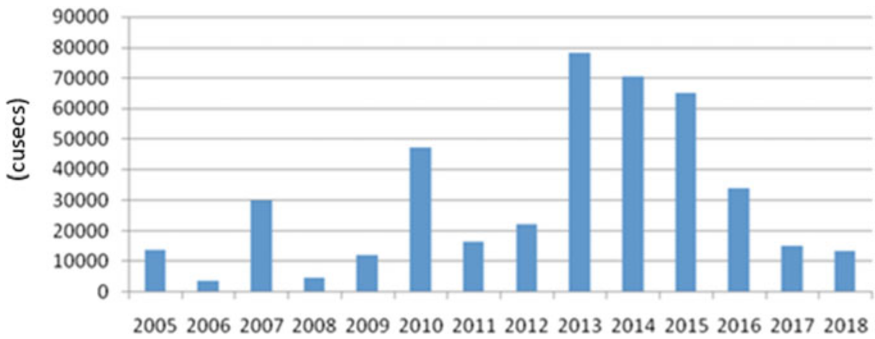

Fig. 2 Bara River annual discharge 2005–2018

4 Conclusions and Recommendations

This chapter shows that droughts are a major hazard prevailing in different parts of Pakistan. Town IV, Peshawar District, KPK Province was evaluated as a case study using three main indicators for drought namely, precipitation, water table, and surface water availability. The results showed that significant reduction and depletion was observed for all three factors in the study area which was supplemented through findings from the people's perceptions. This chapter concludes with recommendations from the international best practices to mitigate drought and its impacts. Primarily, this is the responsibility of government, NGOs, INGOs, and other stakeholder to take immediate mitigation measures to reduce drought impacts. Absence of such measures might lead to increased intensity and severity of droughts from moderate and severe in future. In order to overcome the adverse impacts of drought some recommendations are proffered. Training of farmers on drought mitigation techniques can equip the farmers and enhance the capacity to fight the impending challenges of drought. Furthermore, introduction of water-resistant crops to mitigate drought situation is desirable. Legislation to check illegal ground water abstraction and provision of funds for mitigation measures, reduction in water and industrial pollutants, and introducing easy agriculture loan and crop insurance schemes are all useful for mitigation. Following are the major recommendations proffered in order to mitigate the impacts of droughts.

a. Drought Management

There are three components of drought management.

(1) Monitoring and Early Warning System
(2) Risk and impacts assessment
(3) Mitigation and response

(1) Monitoring and Early Warning System

Preparedness and management against drought hazards are effective ways for reducing drought risks and consequently, the effects of droughts. The goal of drought early warning system and drought monitoring is to inform the people about the drought and its impacts, to sensitize Government and other Organizations to take measures to minimize the impacts of drought and maximize the coping capacities. The timely and effective dissemination of this information to decision makers and stakeholders is an equally critical aspect of drought early warning systems. A drought information system must incorporate information on the occurrence, severity, and length of droughts, besides other aspects. In drought monitoring, information and data is required to be collected from each relevant indicators, like precipitation, temperature, evaporation, snow peak, soil moisture, stream flow, groundwater, reservoirs, and lake level. There are some indices which are used to identify the severity of drought like; Palmer Drought Severity Index (Palmer 1965), The Standardized Precipitation Index, and Streamflow Drought Index (SDI).

(2) Risk and Impacts assessment

Drought risk is a result of hazard exposure. It is critical to understand the effects and causes of drought in order to lessen drought vulnerability. The US National Drought Mitigation Center has created a technique for analysing and mitigating the risks associated with drought. A risk assessment committee may be established on similar lines to identify elements at risk and understand as to why and how the communities are at risk. This committee should be made responsible to determine; groups of population, ecosystem, and most vulnerable sectors. Major goals should be risk identification and evaluation and to take suitable mitigation measures to reduce these risks.

(3) Mitigation and Response

There are some activities, short term and long term actions, programs, policies, and strategies to reduce risks associated with people, property, and environment before the drought is imminent. These types of mitigation actions for drought are different from any other natural hazards. Wilhite (2000) carried out a review of drought mitigation measures used by states in the United States in response to drought. These actions were divided into nine categories (adapted from Wilhite 2000):

(a) Monitoring and assessment
(b) Legislation and public policy
(c) Water supply augmentation
(d) Public education programs
(e) Technical Assistance
(f) Demand reduction
(g) Emergency Response
(h) Water conflict resolution
(i) Drought planning

b. Water Management and Conservation

Following measures need to be implemented in order to manage and conserve the water resources and control minor drought like situations from converting into drought disasters:

(a) Increase water storage capacity for agriculture as well as domestic purposes.
(b) To conduct scientific and research based studies that would be more helpful for appropriate mitigation measures.
(c) Training of farmers on drought mitigation measures to reduce its impacts on agriculture and raising awareness regarding drought resistant crops.
(d) To improve canal system for proper irrigation in the district.
(e) Use of modern irrigation techniques like, drip irrigation, laser leveling systems in the area.
(f) Legislation and strict control on unauthorized ground water pumping.
(g) Provision and allocation of dedicated funds for improving structural and nonstructural mitigation measures for drought risk reduction.

(h) Improvement in public private partnership and its relationship with community in context to reduce drought risks.
(i) Efficient water management system to check water quality and quantity and also ground water table.

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Climate Change and Food Supply Chain: Implications and Action Needed

Walter Leal Filho

Abstract This final chapter provides a review of how climate change impacts food security, assesses its implications outlines some future prospects.

1 Introduction: Climate Change and Food Security

Climate change is a global problem, whose impact is felt across many sectors. Its manifestations, such as variability in rainfall, fluctuating temperatures and increased frequencies of droughts/floods, impact many people and sectors. Indeed, changing climatic conditions have also been affecting food production processes, some of which (e.g. crop growth) are largely climate sensitive. The importance of a greater understanding of this process may be better understood if it is taken into account that rain-fed agricultural food production is the main source of nutrition in many middle- and low- income countries (Alemu and Mengistu 2019).

Moderates increases in temperatures may bring advantages for agriculture: a longer vegetation phase, for example, can enable vegetable farms to harvest several times a year. The faster ripening of maize has the positive side effect that higher yields can also be achieved.

However, there are also clear disadvantages: for example, earlier flowering makes fruit trees more susceptible to late frosts. Milder winters lead to a greater spread of plant-damaging fungi, viruses and insects. And the increasing number of hot days means significantly more stress for crops.

In general agricultural production is dependent on ecosystems that function under normal -i.e. specific- climatic conditions where levels of rainfall, temperature and humidity have a normal variation, without major extremes. Developing countries often endure variations on the levels of crop production, due to their geographical locations. An example is seen in African countries which- due to their locations near the tropics or semi-arid areas- face particularly high rises in temperature, and

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W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_28

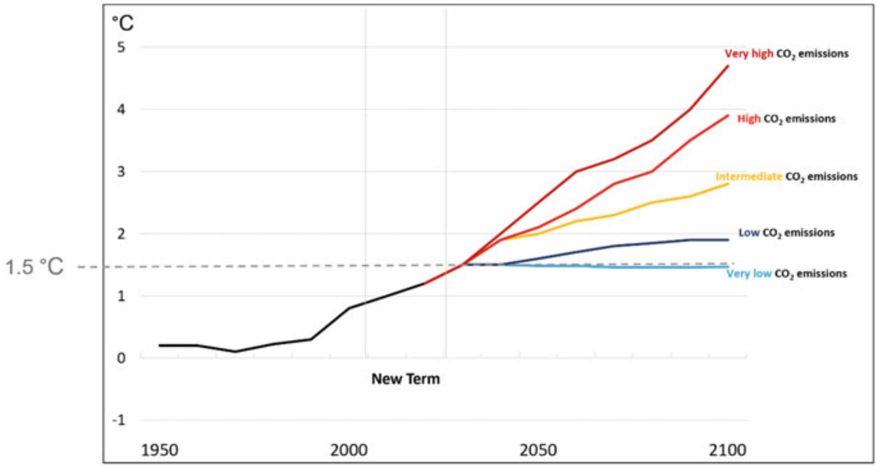

Fig. 1 Projected increases in temperature. *Source* IPCC (2021)

water shortages caused by droughts, which create unfavorable conditions for farming (Kogo et al. 2020). Additionally, it known that changes in CO_2 concentrations also affect plant development (Tito et al. 2018).

The current changes in the climate, especially -but not only- increased temperatures, are forcing many farmers to change their planting and harvesting periods, so as to ensure a good yield for their products (Rose et al. 2016). In other instances, farmers are changing the types of crops grown, so as to suit the new climatic conditions. This may often may require capital, so as to implement the changes and produce new growth protocols (Meng et al. 2014; Tito et al. 2018). Furthermore, some farmers need to the alter the locations for growing crops, for instance from lowlands to higher up areas, which is not always possible (Tito et al. 2018).

Figure 1, from the latest IPCC Report (AR6) illustrates the trends in respect of increased temperatures (IPCC 2021).

But even under a 1.5 °C projection, there are expected impacts on agriculture and, inter alia, on food production, especially in regions such as Africa, which are already suffering from a changing climate (Leal Filho et al. 2021).

2 The Many Impacts

Aside from crop farming, farming involving livestock is also significantly impacted by climate change. The variability in weather and atmospheric conditions, combined with temperature increases, may affect the lifespan of livestock. Furthermore, production of essential products from live stocks such as milk, is impacted by environmental factors. Variables such as humidity, wind speed and temperature affect the growth, reproduction and viability of animals. This, in turn, may result in low production of meat commodities or other by-products of livestock (Lal et al. 2011; Omotayo 2018).

Apart from reduced rainfall, food insecurity may also be amplified by excessive ones. In Nepal for instance, major increases in rainfall have led to floods, which have often resulted in landslides (Randell et al. 2021). Recent flooding events have led to a depletion of many crops, the blockage of transportation routes, and a prevention of the distribution of food aid to affected areas. These effects were worsened by the frequency of earthquakes experienced, leaving many civilians in a state of food insecurity. However, areas that were not affected by landslides saw positive effects on food security due to the rain aiding in crop growth (Randell et al. 2021). This example illustrates the complexity of the problem.

A further issue worthy mentioning, is that knowledge about climate change adaptation, which may play a major role in addressing food security, is often limited. Many people are not aware of the many adaptation methods they may use, which could help to reduce their vulnerability and increase their resilience. In Africa, for instance, the practices of bush burning, cutting of trees and intensive mono-farming, may lead to soil erosion and a reduction of soil fertility. This in turn worsens the already existing effects of climate change and leads to problems such as land degradation. The lack of land productivity, and the inability to support crops or live stock growth, may also lead to land abandonment, hence further reducing the options.

3 Conclusions

As this chapter and many chapters of this book have shown, climate change is expected to create great food insecurity in the affected regions. It is also expected to negatively influence the supply chain. A world suffering from global warming is a world where hunger may continue to prevail, since higher temperatures tend to endanger agriculture and lead to shortages in food production.

The resultant lack of food and water (caused by droughts) is also predicted to lead to adverse health outcomes to humans (Omotayo 2018). In countries vulnerable to reduced rainfall such as Iran, food insecurity has been highlighted as a national concern. Moreover, increases in populations also causes increases in food demand which, if not met, may lead to widespread food insecurity (Shayanmehr et al. 2020).

The impacts of climate change are expected to increase in the coming decades. Changes in temperatures, in precipitation and increased CO_2 concentrations, are changing the environmental conditions for plants, soils and livestock. This will have a direct impact on the yield and quality of agricultural products and is likely to influence supply chains in an unprecedent way. There is thus an urgent need for action, especially in developing countries.

Moving forward, there is a perceived need to promote simple adaptation strategies, which may be implemented with no major resources. For instance, farmers may better cope with increasing droughts, by selecting varieties that can better cope with long dry periods. Sorghum, for example, requires much less water than maize and could replace it as a raw material crop. Farming communities may also ensure that more humus accumulates in the soil, by using compost or green manure. Humus stores five times its own weight in water. It has also been shown that the formation of humus and the water-holding capacity of the soil are also promoted if the plough is not used when working the soil.

Similar solutions are needed, so as to prevent further deteriorations in food production. Of particular importance is the need to provide timely information on extreme weather events, which are often unpredictable and-as such- pose a planning risk for farming communities.

Some of the measures which may be deployed in order to address some of the problems related to food security in a climate change context are:

1. The award of a higher priority to food security issues in policy-making. Unfortunately, many developing countries are spending valuable resources with the military, neglecting the need to prioritise food security. This, in turn, makes them more dependent on food aid, and more vulnerable to climate change.
2. A greater emphasis to the conservation of ecosystems, particularly in the least developed countries, whose services also cater for food provision. This includes forests and woodlands on the one hand, but lakes and rivers on the other. They assist in the subsistence for local communities, especially those with no access to public services. They also provide a buffer to climatic variations, and a provision for possible alternatives should food production in one sector be reduced.
3. The combined pursuit of Sustainabie Development Goals 1 and 2, along with SDG13, bearing in mind that addressing hunger also depends on addressing poverty. Here, an inclusive approach is needed, since these goals are intimely associated.
4. More support to food-aid schemes such as those run by the World Food Programme, not only in respect of the provision of imported food, which is still widely needed in the short term, but also on long term strategies to reduce dependency on food imports. A sole reliance on food imports cannot be regarded as an adequate or even a long-term response to climate change. A pro-active approach is needed.

Finally, in conflicts prone countries, where climate change is further worsened by armed disputes, it is important that measures are put in place to guarantee access to food to the vulnerable groups, which offen do not contribute to these conflicts, but are severly affected by them.

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Correction to: Impact of Climate Variability on Maize Production in South Africa

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Correction to:
Chapter "Impact of Climate Variability on Maize Production in South Africa" in: W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_13

The author's name as "Terence Darlington Mushore" in Chapter "Impact of Climate Variability on Maize Production in South Africa" was incorrect in the initially published version. It has been corrected. The correct name is Terence Darlington Mushore. The auhtor name has been changed from "Terrerence Darling Mushore" to "Terence Darlington Mushore".

The updated original version of this chapter can be found at
https://doi.org/10.1007/978-3-030-87934-1_13

W. Leal Filho et al. (eds.), *Handbook of Climate Change Across the Food Supply Chain*, Climate Change Management, https://doi.org/10.1007/978-3-030-87934-1_29