Xavier Poshiwa
G. Ravindra Chary *Editors*

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Editors
Xavier Poshiwa
Great Zimbabwe University
Masvingo, Zimbabwe

G. Ravindra Chary
Central Research Institute for Dryland Agriculture
Hyderabad, India

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Contributing Staff Editor : Ms. Nidhi Utreja, Programme Officer, NAM S&T Centre

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Foreword

Most countries in Sub-Saharan Africa, including Zimbabwe, are plagued with recurrent food and nutrition insecurity emanating from the adverse impacts of frequent and extreme weather events such as droughts, cyclones, floods, pests and diseases which are associated with the phenomenon of climate change. Consequently, low crop yields and livestock production have been widely reported across the region's drylands. Rural communities are the most vulnerable due to low adaptive capacity. The need to build climate resilience and strengthen adaptive capacities in dryland communities cannot be overemphasized. To address the issues more efficiently, long-term adaptation and mitigation measures that link evidence-based research and development outcomes are preferred to short-term reactive rapid responses.

Based on the nature and context of vulnerabilities and challenges communities are facing, it is envisaged that in the long run, as enshrined in the Global Development Agenda 2030, partners should strengthen collaboration and establish functional facilities aimed at advancing innovation and increasing production in dryland farming. This will effectively serve as an instrument to catalyse change, strengthen the means of implementation and revitalize global partnerships to ensure food and nutrition security. In line with this, the Great Zimbabwe University (GZU), a state university under the Ministry of Higher and Tertiary Education, Innovation, Science and Technology Development (MHTEISTD), Zimbabwe; the Centre for Science and Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre), India; and other partners organized a virtual *International Conference on Dryland Agriculture (DA)* to provide a platform for scientists, development practitioners, policy-makers and farmers to showcase and analyse scientific innovations and strategies that can contribute significantly to the transformation and sustainability of dryland agricultural systems.

The conference has culminated in a book volume titled *Climate Change Adaptations in Dryland Agriculture in Semi-Arid Areas* which consists of 26 scientific papers contributed by authors who participated during the conference. The key issues addressed by the book focus on innovative strategies to turn around the development trajectory in dryland farming systems and ensure effective transformation and sustainability in the face of climate change.

On behalf of the MHTEISTD, We congratulate GZU and the NAM S&T Centre for bringing out this valuable book volume which will be of immense use to researchers, policy-makers, students, farmers and other stakeholders. We remain hopeful that the scientific recommendations made herein shall help to transform our drylands into greenbelts. We wish GZU and NAM S&T Centre the best in their current and future endeavours to enhance productivity in dryland areas.

Prof. Dr. Amon Murwira
Minister
Ministry of Higher and Tertiary
Education, Innovation, Science
and Technology Development
(MHTEISTD)
Harare, Zimbabwe

Preface

Many countries in the world have “arid” or “semi-arid” climates in which less than 800 mm of annual rainfall is received in more than 85% of the areas. For example, in the case of Zimbabwe, the rain is concentrated in five months from November to March followed by a marked dry season. Farmers in the arid and semi-arid regions are generally low on resources and face challenges related to erratic rainfall associated with long dry spells and or drought, poor soil fertility, poor crop establishment, pest infestation and a shortage of labour at times of peak demand. Given these conditions, it is important to develop farming practices that make efficient use of available resources and reduce risks. In the more arid and semi-arid areas, livestock provide a key mechanism for managing risks, but population increases are fragmenting rangelands in many places, making it increasingly difficult for pastoralists to gain access to the feed and water resources that they have traditionally been able to access. Post-harvest processing also poses a key challenge as small-scale farmers in the rural areas in the developing countries have very limited access to advanced technologies needed for enhanced value addition for sustained food security.

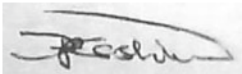
In addition, global climate change poses the greatest danger to world food security and sustainable development. This is also evident in the drylands of the world, as agriculture in the arid and semi-arid regions is adversely affected by the impending climate change phenomena, such as rainfall variability, changes in average temperatures and climate extremes (like heat wave, intense rainfall events, frost, cyclones, hailstorms and dust storms that lower yields of the crops) and also due to changes in atmospheric carbon dioxide. Agriculture in drylands also faces various other inherent abiotic and biotic limitations such as scarce water availability, declining soil quality and pest and disease infestations.

The potential rise in food insecurity during the “COVID-19 pandemic” together with the multiple crises in some countries resulting from more frequent extreme weather events (floods, droughts, etc.) and pests such as the current locusts plague accentuates the importance of raising crop yields and adaptation to climate. There is, therefore, an urgent need to assess the impact of climate change on dryland agricultural production systems and food security in specific regions of the world. Further, the design and implementation of effective coping mechanisms against biotic and abiotic stresses that impact crop productivity in these regions also require a clear and scientific understanding of the effects and impacts, so that appropriate adaptation measures can be formulated. The emphasis should also be on technological developments such as development and profiling of new plant and animal varieties/hybrids as well as breeds that are tolerant/resilient to biotic and abiotic stresses and identifying or development of agro-ecology-specific natural resource management practices for adaptation.

The present book titled "*Climate Change Adaptations in Dryland Agriculture in Semi-Arid Areas*" being published by Springer Nature, Singapore, is an initiative of the Centre for Science & Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre), New Delhi. It has a total of 26 chapters contributed by authors from six developing countries and classified under 4 areas: climate change adaptations in dryland agriculture (9 chapters); research and development in dryland agriculture (11 chapters); livestock feeding and alternative production systems in semi-arid areas (5 chapters); and risk coping in drylands (1 chapter).

We hope and are sure that the book will definitely help in bridging the knowledge gap present today in the area of dryland agriculture especially among the scientific community in the NAM and other developing countries.

We are grateful to Prof. dr. Amon Murwira, Hon'ble Minister of Higher & Tertiary Education, Innovation, Science and Technology Development, Zimbabwe, for kindly agreeing to write a "Foreword" for the book and for his strong support towards Research and Development on Dryland Agriculture. The editors also want to thank Prof. R. J. Zvobgo, Vice Chancellor, Great Zimbabwe University; Dr. Amitava Bandopadhyay, Director General, Centre for Science & Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre), New Delhi; and partner organizations for hosting and organizing the International Conference on "Climate Change Adaptations in Dryland Agriculture in Arid and Semi-Arid Areas".



Masvingo, Zimbabwe Xavier Poshiwa

Hyderabad, India G. Ravindra Chary

Introduction

It is well known that drylands represent more than a third of the world's land mass, 90% of which are in developing countries and rely mainly on degrading agricultural lands for their livelihoods. In fact, there are pronounced differences within drylands, particularly in terms of water availability, poverty, stage of development and sustainable intensification options.

Sadly, dryland farmers face multiple constraints due to poor soil, short growing seasons, low and uncertain rainfall, desertification and recurrent droughts along with poorer infrastructure and market access that affect their abilities to overcome chronic poverty and food insecurity.

Climate change and agriculture are interrelated processes that take place at a global scale. Climate change-related phenomena, such as changes in average temperatures, rainfall and climate extremes (like heat waves), and changes in atmospheric carbon dioxide-level and ground-level ozone concentrations, affect farming in several ways. Climate change is already affecting "dryland agriculture" with effects unevenly distributed across the globe. Higher temperatures eventually reduce the length of growing seasons and force large regions of marginal agriculture out of production, while encouraging weeds and pest proliferation. Also, heat waves cause lower yields of the crop and wilted growth in plants. In simple words, the overall impacts of climate change are expected to be significantly negative as it threatens the global food security.

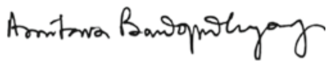
The impacts of climate change on agriculture in developing countries depend on the extent to which agricultural production in the semi-arid regions adapts to the influences of climate change. Therefore, in order to deliberate on how to avoid the short- and long-term effects of climate change and the adaptation strategies that can minimize such effects, the Centre for Science & Technology of the Non-aligned and Other Developing Countries (NAM S&T Centre), New Delhi, India, jointly with the Great Zimbabwe University (GZU), Masvingo, Zimbabwe, and the Ministry of Higher & Tertiary Education, Innovation, Science and Technology Development, Zimbabwe, organized an International Conference on *Climate Change Adaptations in Dryland Agriculture in Semi-Arid Areas* during 21–23 July 2020 in virtual mode.

As a follow-up, the NAM S&T Centre has brought out this book which contains 26 papers contributed by the participants of the conference from various developing countries and a few other eminent experts in this area. The volume has been edited by Dr. Xavier Poshiwa, Dean, Gary Magadzire School of Agriculture, Great Zimbabwe University, Masvingo, Zimbabwe, and Dr. G. Ravindra Chary, Project Coordinator, All India Coordinated Research Project for Dryland Agriculture (AICRPDA), ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, India.

I take this opportunity to thank Prof. Dr. Amon Murwira, Hon'ble Minister of Higher & Tertiary Education, Innovation, Science and Technology Development, Zimbabwe, for writing the "Foreword" of the book in spite of his extremely busy schedule. I would like to express my gratitude to Dr. Xavier Poshiwa, Corresponding Editor from Zimbabwe, and Dr. Ravindra Chary, Co-Editor from India, for their valuable contributions towards editing the book and coordinating all associated activities for bringing out this publication. We are thankful to Dr. Loyola D'Silva, Executive Editor, Springer Nature, Singapore, and Mr. Ramesh Kumaran, Project Coordinator—Total Service, Books Production, Springer Nature, Chennai, India, for their support and encouragement during the publication process.

I also acknowledge the interest and valuable efforts of the entire team of the NAM S&T Centre, especially Ms. Nidhi Utreja, Programme Officer, for compilation, proofreading and overseeing the publication process and Mr. M. Bandyopadhyay, Senior Adviser, for his guidance and supervision. I am also thankful to Mr. Pankaj Buttan, Data Processing Manager, and Mr. Rahul Kumra, Private Secretary, NAM S&T Centre, for their valuable support in bringing out this publication.

I am sure this timely and valuable publication will be a useful reference material that will help young researchers, scientists, government officials and policy-makers who are engaged in climate change adaptation and mitigation strategies in *Dryland Agriculture*.



Amitava Bandopadhyay, Ph.D.
Director General
NAM S&T Centre
New Delhi, India

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Climate Change Adaptations in Dryland Agriculture

Climate Resilient Rainfed Agriculture: Experiences from India

G. Ravindra Chary, S. Bhaskar, K. A. Gopinath, M. Prabhakar, J. V. N. S. Prasad, C. A. Rama Rao, and K. V. Rao

Abstract Rainfed agriculture is practiced in 52% of net cultivated area in India and contributes to about 40% of country's food production, thus important for country's food security and economy. Climate change impacts are evident in rainfed agriculture in India. Efforts have been made through national initiatives towards climate resilient rainfed agriculture and to enhance the adaptive capacity of farmers. On-farm participatory demonstration of climate resilient practices cluster village mode helped to cope with delayed onset of monsoon and in-season drought. Establishing village level institutions such as village climate risk management committees, custom hiring centres for farm mechanization, nutrient banks, seed and fodder production systems and mechanism for agro-advisories proved to be building climate resilient villages. It is also important to build resilience at agricultural landscape level (watershed) for sustainable and risk resilient rainfed agriculture. Capacity building of farmers enhanced their adaptive capacity. Preparation and implementation of Agriculture Contingency Plans enhanced the preparedness for weather aberrations and policy

G. R. Chary (✉) · K. A. Gopinath
All India Coordinated Research Project for Dryland Agriculture, ICAR-CRIDA, Hyderabad 500 059, India
e-mail: rc.gajjala@icar.gov.in

K. A. Gopinath
e-mail: ka.gopinath@icar.gov.in

S. Bhaskar
Natural Resource Management Division, ICAR, New Delhi, India

M. Prabhakar · J. V. N. S. Prasad · C. A. R. Rao · K. V. Rao
ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, India
e-mail: m.prabhakar@icar.gov.in

J. V. N. S. Prasad
e-mail: jasti2008@gmail.com

C. A. R. Rao
e-mail: car.rao@icar.gov.in

K. V. Rao
e-mail: kv.rao@icar.gov.in

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support. Several resilient technologies have been integrated into national, state and district programmes for achieving climate resilient rainfed agriculture. The proven climate resilient technologies in India could be upscaled in similar rainfed agroecologies in other countries. Climate resilience in rainfed agriculture can be better addressed through risk and vulnerability assessment at sub-district level; scaling out resilient technologies through government programmes, better preparedness for weather aberration and capacity building of stakeholders. The knowledge built and experiences gained in India trigger to propose a global programme for research and development in climate resilient rainfed agriculture and inter-governmental and multi-institutional arrangements for upscaling of proven climate resilient practices in the similar rainfed agro-ecoclogy domains in various countries. Further, development of regional centres of excellence in climate resilient rainfed agriculture for research and development and capacity building and human resources development is also suggested.

Keywords Climate Resilient Agriculture · Rainfed agriculture · Drylands · Contingency planning · India

Introduction

Rainfed-drylands are an important biome, occupying more than 41% of the global land area and comprising grasslands, agricultural lands, forests and urban areas. Drylands provide much of the World's food and fiber while maintaining habitats that supports biodiversity and provide ecosystem services (UNCCD 2017). Climate change, which is expected to manifest as increased frequency and intensity of extreme climate events including droughts (IPCC 2015), is particularly of concern in drylands where species and communities already have to cope with dramatic variations in temperature and droughts (UNCCD 2017). Climate change is a significant driver of land degradation in drylands. In some dryland areas, increased land surface air temperature, evapotranspiration and decreased precipitation amount, in interaction with climate variability and human activities, have contributed to desertification. These areas include Sub-Saharan Africa, parts of East and Central Asia, and Australia. About 25–30% of drylands already suffer some form of land degradation (Bai et al. 2008; Quang et al. 2014). In drylands, the most widespread form of land degradation is soil erosion with 87% of degradation being caused by water or wind (FAO 2005). Land degradation in drylands can also manifest itself through the loss of soil organic carbon (IUCN 2015). The depletion of water, either as soil moisture, groundwater, flowing rivers or reservoirs, disrupts water cycles and leads to water scarcity (Koohafkan and Stewart 2008; UNCCD 2017). Water scarcity affects among other things the length of growing season.

The climate change impacts are evident on agricultural production and productivity in general and rainfed agriculture in particular, in many countries. There have been many research, development and policy initiatives in many countries to address the impacts of climate in rainfed agriculture. However, the policies, approaches, programmes and activities vary to develop and implement strategies for achieving climate resilient rainfed agriculture across the countries. In the process, there could be huge knowledge, experiences, expertise and even shortfalls in addressing climate resilience in rainfed agriculture. Understanding all these and learning from each other's knowledge and experiences is necessary to concretize policies, programmes , long term and short term strategies and actions to achieve climate resilient rainfed agriculture. The aim of this chapter is to (i) share the experiences from India in addressing climate resilient rainfed agriculture through village/landscape level approaches/interventions, and (ii) sensitize the stakeholders about various initiatives, programmes, actions and strategies in India.

The human population in India accounts for 17.74% of World population, 4.2% of World's water and 2.4% of the World's total area. Agriculture in India contributes to 15.4% of GDP (Gross Domestic Product) and 10.6% earning of total exports. 52% of workforce is engaged in agriculture. 52% net sown area in India is rainfed. Rainfed agriculture is crucial to country's economy and food security since it contributes to about 40% of the total food grain production (85% of coarse cereals, 83% of pulses and 70.5% of oilseeds), supports two-thirds of livestock and 40% of human population. Furthermore, rainfed agriculture influences livelihoods of 80% of small and marginal farmers. Even if full irrigation potential is created, still 40% of net cultivated area will remain as rainfed agriculture which would continue to be a major food grain production domain (CRIDA Vision 2050; Ravindra Chary et al. 2015). In India, the estimated countrywide agricultural production loss in 2030 will be over $7 billion that will severely affect the income of 10% of the population. However, this could be reduced by 80%, if cost-effective climate resilience measures are implemented (ECA 2009).

The key challenges for Climate Resilient Rainfed Agriculture in India are briefly presented below:

- ***Climate change/variability impacts***: The rainfed agriculture is totally dependent on south-west monsoon and thus, is synonymous with risk due to erratic monsoon (Ravindra Chary et al. 2010). A decrease of one standard deviation from the mean annual rainfall often leads to a complete loss of the crop. Dry spells of 2 to 4 weeks during critical crop growing stages cause partial or complete crop failure (Rockstorm and Falkenmark 2000). Climate change and climate variability impacts Indian agriculture in general and more pronounced on rainfed agriculture. A district level climatic analysis in the country revealed spatial shifts of climate zones in about 27% of the geographical area in the country i.e. a substantial increase of arid region in Gujarat, a decrease of arid region in Haryana, and increase in semi-arid region in Madhya Pradesh, Tamil Nadu and Uttar Pradesh due to shift of climate from dry sub-humid to semi-arid. Likewise, the moist sub-humid pockets in Chhattisgarh, Orissa, Jharkhand, Madhya Pradesh and Maharashtra states shifted to dry sub-humid to a larger extent (Raju et al. 2013). These climate shifts in rainfed areas will have larger implications for crop planning, water resources assessment and prioritizing drought proofing programmes

. The Coupled Model Inter-comparison Project Phase 5 (CMIP5) based model ensemble, based on new-emission scenarios termed as Representative Concentration Pathways (RCPs), projects a warming of 1.5, 2.4, 2.8 and 4.3 °C for India under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, for 2080s (2071–2100) compared to the baseline period of 1961–1990 (Chaturvedi et al. 2012). The CMIP5 based ensemble projects an all-India precipitation increase of 6, 10, 9, and 14% increase under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, for 2080s compared to the 1961–1990 baseline. A consistent increase in seasonal mean rainfall during the summer monsoon periods has been projected. Instrumental records suggest, a significant negative rainfall trends in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of northwest and Northeast India and a small pocket in Tamil Nadu. Significant increase in rainfall is also evident in Jammu & Kashmir and in some parts of southern peninsula (Venkateswarlu et al. 2012). Rainfall is likely to decline by 5 to 10% over southern parts of India, whereas 10 to 20% increase is likely over other regions. There is a probable decrease in the number of rainydays over major parts of the country pointing at likely increase of extreme events. The recent ensemble models project that the frequency of extreme precipitation days (e.g. >40 mm/day) are likely to increase. Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature. Climatic risks like droughts and floods, poor water and nutrient retention capacity of soil and low soil organic matter (SOM) impact rainfed agriculture highly vulnerable, requiring a different outlook and strategy.

- ***Resource poor operational land resource base***: Out of 138.3 Million total operational land holdings in the country, 58.14 Million operational land holdings are totally unirrigated, out of which 85% account to marginal and small operational holdings (37.06 m marginal and 11.69 m small) while the total operational holdings under partly irrigated operational holdings are 17.21 m out of which 80% marginal (9.6 m) and small (3.49 m) operational holdings (DES 2011). The challenge is to sustain these unirrigated and partly irrigated operational holdings in respect of stabilized productivity and profitability along with enhanced livelihoods at the backdrop of the impacting climate change/variability.
- ***Bridging yield gaps***: The large yield gaps remain in several rained crops and regions between yields obtained at research stations and on farmers' fields (Ravindra Chary et al. 2012). In several disadvantaged areas, particularly in chronic drought prone areas, the yield gaps will continue to remain large even in 2050, both due to non-adoption of technologies and non-availability of tailor-made agro-ecology specific package of practices.
- ***Enhancing water productivity***: The basic resource which determines the success of rainfed agriculture is water availability. As the demand for water from non-farm sectors increases and availability to agriculture declines, the conflicts between upstream and downstream users may increase over time. Fallout of such process is the possible conversion of existing productive irrigated lands to rainfed lands

(Sikka et al. 2016). A 4 °C rise in temperature and a 10% decrease in rainfall is expected to reduce the stream-flow by 33% in mean annual, 15% in pre-monsoon, 35% in monsoon, 32% in post-monsoon and 21% in winter seasons. The National Water Mission, institutionalized under the National Action Plan for Climate Change, has set the target to improve the efficiency of water use by at least 20%. In a given land use setting, climatic variables especially temperature and rainfall regulate the irrigation water demand. At present in India, blue and green water availability is above the 1300 m^3/capita/year threshold. However, with climate change, blue-green water availability is estimated to decrease to less than 1300 m^3/capita/year, implying that by 2050, all of India could be exposed to water stress.

- ***Maintaining soil health and productivity***: The soils in rainfed areas belong to Entisols, Inceptisols, Vertisols, Alfisols, Aridisols and Oxisols and are characterized with multiple constraints that limit crop production and realizing optimum yields. Presently, on an average, the soil organic carbon is 5 g/kg in soils in rainfed areas whereas the desired level is 11 g/kg. Change in rainfall intensity could cause more soil erosion. Harnessing the synergy between soil moisture and applied nutrients in rainfed crops is a major challenge due to erratic distribution of rainfall.
- ***Low and skewed farm mechanization***: Farm mechanization in rainfed areas is very low due to small and marginal holdings, resource poor farmers etc. In view of the short window for sowing of rainfed crops and also for moisture availability period, farm mechanization in small farm holdings is very crucial in timely and precision agricultural operations and in large areas.

Materials and Methods

Climate risks are best addressed through adaptation which can bring immediate benefits and also can reduce the adverse impacts of climate change. Climate Resilient Agriculture (CRA) encompasses adaptation and mitigation strategies to meet the many challenges posed by climate change (Ravindra Chary et al. 2013). CRA means the incorporation of adaptation, mitigation and other practices in agriculture which increases the capacity of the system to respond to various climate related disturbances by resisting damage and ensures quick recovery. Such perturbations and disturbances can include events such as drought, flood, heat/cold wave erratic rainfall pattern, pest outbreaks and other perceived threats caused by changing climate. It is the ability of the system to bounce back and essentially involves judicious and improved management of natural resources, land, water, soil and genetic resources through adoption of best bet practices (NAAS 2013). The major initiatives launched in the domain of climate change research and climate resilient agriculture are briefly presented below:

i. ***Network Project on Climate Change (NPCC)***: The Indian Council of Agriculture Research (ICAR), Ministry of Agriculture & Farmers Welfare, Government of India launched Network Project on Climate Change (NPCC) in 2004 with the objectives of quantifying the sensitivities of food production systems to different scenarios of climate change, adaptation and mitigation strategies in agro-ecosystems and to provide policy support. The important outputs related to rainfed agriculture from NPCC indicated increased emphasis on soil conservation in peninsular and central India because of projected high run-off and soil losses due to changes in rainfall, and emphasis on agro-forestry systems in sub-tropical climates for maximum carbon sequestration potential (Naresh Kumar et al. 2012).

ii. ***National Mission for Sustainable Agriculture (NMSA)***: The National Action Plan on Climate Change (NAPCC) was formulated in 2010 consisting of 8 National Missions to represent multi-pronged, long term and integrated strategies for addressing climate change impacts. The National Mission for Sustainable Agriculture (NMSA), one of the eight missions of NAPCC, aimed at devising strategies to make Indian agriculture more resilient to climate change and to promote sustainable agriculture through a series of adaptation measures focusing on ten key dimensions encompassing Indian agriculture viz. improved crop seeds, livestock and fish cultures, water use efficiency, pest management, improved farm practices, nutrient management, agricultural insurance, credit support, markets, access to information and livelihood diversification. Subsequently, these measures had been embedded and mainstreamed into various Missions/Progammes/Schemes of Ministry of Agriculture & Farmers Welfare, Government of India with a special emphasis on soil & water conservation, water use efficiency, soil health management and rainfed area development.

iii. ***National Initiative on Climate Resilient Agriculture (NICRA)***: ICAR launched the flagship project on National Initiative on Climate Resilient Agriculture (NICRA) in 2011 (now called National Innovations in Climate Resilient Agriculture) with the objectives to undertake strategic research on adaptation and mitigation; to validate and demonstrate climate resilient technologies on farmers' fields; to strengthen the capacity of the stakeholders in climate resilient agriculture and to draw policy guidelines. The major components under NICRA are: (a) strategic research (b) Technology demonstration component, and (c) capacity building of stakeholders.

Results and Discussion

The experiences from various initiatives in India, particularly NICRA that could contribute to achieve climate resilient rainfed agriculture are briefly presented:

Strategic research: The state of art climate research facilities under NICRA were developed at ICAR institutes (Venkateswarlu et al. 2013; Climate Change Research Infrastructure 2019). District level vulnerability atlas was developed (Rama Rao et al. 2013) which guided NICRA-TDC programmes and many other climate research/policy programmes by national institutes, ministries/departments, state governments and non-government organizations. This atlas has been revised in 2020 by adopting IPCC AR 5 Report as Risk assessment of Indian agriculture to climate change (Rama Rao et al. 2019). Short duration drought tolerant varieties of rice and pulses were developed suitable for diverse rainfed agroecologies (Ravindra Chary et al. 2019a).

Technology demonstration: The TDC programme under NICRA is being implemented initially in 100 climatically vulnerable districts (Venkateswarlu et al. 2012). The programme is now being expanded to 151 village clusters (446 villages) representing 151 climatically vulnerable districts through Krishi Vigyan Kendras (KVKs) i.e. Farm Science Centres (FSCs), network centres of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and ICAR Institutes. A bottom-up participatory methodology was adopted for selection of villages' and implementing TDC programme in NICRA villages. ICAR/Central Research Institute for Dryland Agriculture (CRIDA) as lead institute had been planning, coordinating and monitoring TDC progaramme involving ICAR-Agriculture Technology Application Research Institutes (ATARIs) at Zonal level monitoring and KVKs/FSCs for implementing the programme in the villages. The programme in the villages is being implemented by establishing Village Level Institutions (VLIs) such as Village Climate Risk Management Committee, Custom Hiring Centre (CHC), seed production systems, fodder systems, nutrient banks and mechanisms for agromet-advisories.

The VCRMC is a unique institution formed with the approval of the village decision making body and played a greater role in identifying and implementation of need based climate risk resilient interventions. CHC enabled hiring of energy efficient, even gender friendly farm implements/machinery at affordable cost for timely and precision execution of agricultural operations in larger areas particularly in small farm holdings especially for sowing and intercultural operations as soil moisture status provides a limited sowing window in rainfed agro-ecosystems. The seed production systems by individual or community in the village served as an emergency seed supply system when farmers experienced shortage of seeds, where there is a need for re-sowing of crop. Further, this system provided timely availability of seeds of short duration drought tolerant varieties of rainfed crops in time and for faster seed replacement. The fodder production systems provided high biomass in short time and bridge the fodder scarcity during the annual dry seasons and also during the long dry spells and helped in the preservation and storage of surplus fodder, availability of nutritious fodder during the period of fodder scarcity and enhance nutritive value of crop residue and other cellulosic waste for animal feeding. Planting of high biomass yielding and fast-growing grasses and shrubs suitable for fodder not only increases fodder availability, but also reduces erosion. The concept of 'Nutrient Bank' is being evolved wherein the essential manures and fertilizers, soil amendments, foliar spray chemicals and biofertilizers are maintained locally and made available in time by the local community. The nutrient banks help farmers in restoring the productive capacity of soils and local environments. Other activities in the villages include issue of soil health cards to farmers for site-specific nutrient management, agromet advisories through centres of All India Coordinated Research Project on Agrometeorology (AICRPAM) and KVKs/FSCs.

The major interventions demonstrated to address the drought/dry spells were under four modules:

(i) *Natural Resources Interventions*—focused on *in-situ* moisture conservation (broad-bed and furrow, ridge and furrow, field bunds, contour bunding, compartmental bunding, conservation furrow/tillage, deep ploughing, trench cum bunding, mulching, tank silt application); *ex-situ* rainwater management (farm ponds, check dams, recharge of tube/open wells, community ponds/tanks, nala desilting), and efficient utilization of water through microirrigation systems; soil fertility improvement, improving soil carbon, site-specific nutrient management (soil health cards, soil reclamation, green manuring);

(ii) *Crop-based Interventions*—focused on introduction and demonstration of drought tolerant varieties, inter-cropping systems and crop diversification;

(iii) *Livestock-based Interventions*- focused on improved breeds, green fodder production, preventive vaccination, mineral mixture/concentrate feed, breed upgrading, backyard poultry, shelter management and silage/hay making; and

(iv) *Institutional Interventions*—focused on establishing village level institutions such as VCRMC, CHC.

Agroecology-specific rainwater management technologies are being developed and have larger scope in drought mitigation (Rejani et al. 2015; Ravindra Chary et al. 2016). Water harvesting facilities created in NICRA villages helped to enhance cropping intensity up to 140% in several villages. Timely agromet/agro-advisories were disseminated through messages, social media, WhatsApp web and electronic media. Seed banks established in NICRA villages produced huge quantity of seed of the resilient crops which helped in the spread of the promising varieties in the NICRA village clusters. Custom hiring centers supported farmers for timely field operations even during the lockdown. Several extension activities were taken up in NICRA villages, such as awareness programmes, field days, exposure visits and farmers days. Convergence with the ongoing national/state/district development programs are facilitated in upscaling of climate resilient practices. All these interventions, particularly, the NRM and crop based interventions, led to realizing better yields of rainfed crops and drought proofing even during deficit rainfall/drought years in various rainfall zones including the zones having less than 500 mm rainfall (Prasad et al. 2014; Ravindra Chary et al. 2019b).

Preparation and operationalization of District Agriculture Contingency Plans (DACPs): The DACPs were prepared for 650 districts in the country. Each DACP provides information on contingency measures to cope with delayed onset of monsoon, drought, flood, high intensity rainfall events, frost, heatwave, cold wave and cyclones in field crops, horticulture crops, and the coping measures were suggested to address before, during and after occurrence of extreme weather events in livestock, fisheries and poultry sectors. The farming situation-wise contingency measures to cope with delayed onset of monsoon (2,4,6, and 8 weeks delay) and early, mid-season and terminal drought for all the 650 rural districts in the country (Venkateswarlu et al.

2011; Umate et al. 2011; Rajendra Prasad et al. 2013; Prasad et al. 2012; Subba Reddy et al. 2008; Ravindra Chary et al. 2016). The DACPs are available on www.icar-crida.res.in; www.agricoop.in.

The challenge was operationalization of DACPs in various states/districts through agriculture departments. The Ministry of Agriculture & Farmers Welfare, Govt. of India and ICAR-CRIDA takes the lead through regular pre-monsoon and sometimes during monsoon (depending on the monsoon situation in the states/districts) state level interface meetings forsensitizing the state/district agriculture and allied sector departments (water resources, irrigation, watershed, animal husbandry, horticulture) for developing action plans for preparedness and real-time response to cope with delayed onset of monsoon and deficit/excess rainfall situations. The experience so far has been that the officials of state and district agriculture and allied departments were thoroughly sensitized for not only developing action plans but also were implemented particularly for arranging quality seed of drought tolerant varieties of rainfed crops, dissemination of agromet/agro-advisories, capacity building of department functionaries and farmers.

Real Time Contingency Planning (RTCP) implementation to cope with the drought/dry spells: Real Time Contingency Planning (RTCP) is conceptualized in All India Coordinated Research Project for Dryland Agriculture (AICRPDA) as "any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season" (Srinivas Rao et al. 2016) and implemented under NICRA in 54 villages in 14 states in diverse rainfed agroecologies (climates, rainfall zones, soil types and rainfed production systems) as two-pronged approach, i.e. (i) preparedness, and (ii) implementing contingency measures on real-time basis. The RTCP aims first to establish a crop with optimum plant population during the delayed onset of monsoon, to ensure better performance of crops during seasonal drought and extreme events, enhance performance, improve productivity and income, and to enhance the adaptive capacity of the small and marginal farmers. The preparedness emphasizes on a combination of tolerant variety/cropping system, rainwater/soil/crop/nutrient management practices along with timely availability of inputs while real-time basis implementation focus on the crop/soil/moisture/nutrient management measures to cope with delayed onset of monsoon, seasonal drought, floods and other extreme events (AICRPDA-NICRA Annual Reports 2012–13; 2013–14; 2014–15; 2015–16; 2016–17; 2017–18; 2019–20).

In the selected villages, the bottom-up process included baseline survey and PRA (Participatory Rural Appraisal) to document the initial details about the impacts of weather aberrations on agriculture and to understand the farmers' awareness about climate change/variability and also their traditional wisdom to cope with weather aberrations (AICRPDA-NICRA Annual Report 2012–13). To implement RTCPs, like in NICRA-TDC-KVKs villages, VCRMCs, CHCs, seed production systems, fodder production systems, nutrient banks (vermicomposting units) were established in the AICRPDA-NICRA adopted villages. These village institutions

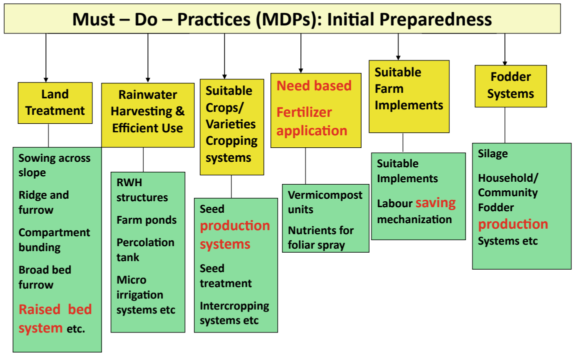

Fig. 1 The must-to-do practices for initial preparedness for RTCP implementation

played greater and decisive role in the initial preparedness and for real time implementation of contingency measures to cope with delayed onset of monsoon and early/midseason/terminal droughts during the cropping season. The must-to-do practices for initial preparedness or RTCP implementation (Srinivas Rao et al. 2016) are shown below (Fig. 1):

The key real-time interventions that helped to cope with delayed onset of monsoon were: introduction (Ravindra Chary et al. 2016) and identification of most suitable crops and short duration drought tolerant varieties and demonstration of cropping systems (Ravindra Chary et al. 2020), re-sowing within a week to 10 days with subsequent rains when germination is less than 30%, thinning; to cope with early season drought were—repeated interculture to break soil crust and remove weeds, avoiding top dressing of fertilizers till favourable soil moisture, *in-situ* moisture conservation through opening conservation furrows; to cope with mid-season drought were—avoiding top dressing of fertilizers till favourable soil moisture, *in-situ* moisture conservation through opening conservation furrows, surface mulching with crop residues, foliar spray of 1% KNO_3 or 0.5% water soluble fertilizers, and providing protective irrigation, if available; and to cope with terminal drought were harvesting crop at physiological maturity with some realizable yield or harvest for fodder, providing protective irrigation, if available or prepare for *rabi* sowing in double cropped areas.

Introduction of drought tolerant varieties gave about 15–35% higher yields compared to local/farmers' varieties (Ravindra Chary et al. 2020). The interventions to mitigate early season drought helped in adaptation of crops and realizing improved yields by 16–30% compared to no contingency measures. RTCP measures of foliar sprays of water soluble NPK (19:19:19) and KNO_3 in mitigating mid-season dry spells gave 15–25% higher yield in different crops compared to no spray. The effect of mid-season and terminal drought on different crops was mitigated mostly by supplementing irrigation from harvested rainwater in farm ponds, and foliar sprays. Supplementary irrigation improved yields by 20–25% in cotton, 40% in groundnut and 40–55% in soybean at different locations. Similarly, foliar spray of 1% KCl in rice during dry spell at flowering-milking stage increased yield by 25% compared to no spray (AICRPDA-NICRA Annual Reports 2013 to 2020). The experiences of RTCP measures implementation were included in the policy documents such as Revised Manual for Drought Management, Ministry of Agriculture & Farmers Welfare, Governmet of India (GoI), National Agriculture Disaster Management Plan, Ministry of Home Affairs, GoI, Revised Common Technical Guidelines for New Generation Watershed Management developed by National Rainfed Area Authority (NRAA) and Department of Land Resources, Ministry of Rural Development & Panchayati Raj, GoI.

Building resilience at Landscape level: On-farm participatory action research was undertaken to build resilience at landscape level in Kavalagi micro-watershed, Karnataka in Southern India by AICPDA centre, Vijayapura. The watershed is predominantly area is rainfed and cultivated with post-monsoon *rabi* crops viz. chickpea and sorghum. The watershed was characterized for land and soil resources and was mapped at 1:4000 scale. The soil units were delineated in to Soil Conservation Units (SCUs) considering soil physical parameters such as slope, depth, texture and erosion and Soil Quality Units (SQUs) were delineated considering the parameters such as EC, OC, pH and calcareousness. These two layers of SCUs and SQUs together were further delineated into homogeneous Land Management Units (LMUs). The on-farm trials on chickpea (cv. JG-11) and sorghum (cv.BJV-44 and cv.M-35–1) were conducted on LMUs-I, III, V and VII for 3 years wherein the seasonal rainfall varied and was deficit up to 30% compared to normal seasonal rainfall. Though, the rainfall was the same for entire watershed in 3 seasons, the yield of crops varied due to spatial variability in characteristics of LMUs. The yield of both chickpea and sorghum was higher on LMU-I > LMU-III > LMU-V > LMU-VII due to limitations in soil physical and chemical characteristics with LMU-I having more favourable land characteristics for crop growth (AICRPDA-NICRA Annual Reports 2017–18; 2018–19; 2019–20). The results revealed that the performance of crops vary due to spatial variability in land and soil characteristics in a landscape though the rainfall is uniform. Therefore, it is emphasized that building resilience of agriculture to be achieved at landscape level with suitable cropping in a favourable land and soil environment.

The experiences of RTCP implementation indicated many opportunities for developing adaptation strategies both as preparedness and real-time response such as: production of seed of alternate crops/varieties by State Seed Corporations, State Agricultural Universities (SAUs) and KVKs: have greater role to provide suitable drought tolerant and short duration seed material during the event of delayed onset of monsoon, establishment of community/village seed banks for production and distribution of quality seeds, promote use of appropriate sowing implements for timely and precision sowing, production of seed of alternate crops/varieties by state seed corporations, SAUs, KVKs, promote use of suitable farm implements for sowing/interculture, rainwater management interventions like water harvesting and storage structures are capital and labour intensive, thus, can be converged with national/state/district programmes, promote use of suitable farm implements for different operations. CHCs have a greater role to play in implementation of

RTCP measures including seed and fertilizer application, *in-situ* moisture conservation practices, water lifting with energy efficient pumps and efficient application, foliar sprays, residue incorporation, construction of farm ponds for efficient rainwater harvesting and reuse, efficient utilization of stored rainwater in farm ponds with micro-irrigation systems could be converged with national/state, timely procurement and supply of inputs like KNO_3, thiourea, KCl for foliar sprays, efficient recycling of crop residues for mulching between crop rows.

Capacity building: Capacity building is the key for adoption and upscaling of climate resilient practices in rainfed agriculture: Many capacity building programmes including customized training programmes, field days, exposure visits, diagnostic visits, scientist-farmers interaction meetings, exhibition stalls, were organized to sensitize both primary (farmers) and secondary stakeholders (engaged in rainfed agriculture development and policy) on various aspects of climate change/variability and impacts on agriculture and doable resilient practices leading to enhancement in adaptive capacity of the farmers and comprehensive understanding of the secondary stakeholders on the adaptation strategies for climate resilient agriculture.

The Central and state governments have been initiating many programmes /schemes that enable to achieve climate adaptation in rainfed agriculture such as Soil health cards, Pradhan Mantri Krishi Sinchai Yojana (PMKSY)—Micro Irrigation, National Mission on Sustainable Agriculture. Further, mainstreamed proven climate resilient practices in to various schemes/programmes such as Rashtriya Krishi Vikas Yojana, Mahatma Gandhi National Rural Employment Guarantee scheme, National Food Security Mission, Nanaji Deshmukh Project on Climate Resilient Agriculture (PoCRA), Govt. of Maharashtra, Programme on Climate Proofing of Watersheds, National Bank for Agriculture & Rural Development (NABARD) & ICAR- CRIDA (at action plan stage).

The overall experiences/knowledge gained in India through NICRA and AICRPDA on the approaches/frameworks/VLIs/interventions/impacts towards climate resilient rainfed agriculture have been continuously shared with and at international and national institutes, platforms and fora, such as CoP Meetings, United Nations Convention to Combat Desertification (UNCCD), World Resource Institute, G20 countries, Asian Development Bank, United Nations Environmental Programme (UNEP), The International Centre for Integrated Mountain Development (ICIMOD), International Water Management Institute (IWMI), Climate Change, Agriculture and Food security (CCAFS), Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) countries, South Asian countries, African countries and has been well recognized and appreciated, even to the extent of adoption of the approaches/methodologies/practices by some countries.

Conclusions

In India, rainfed agriculture plays a greater role in country's food security and economy. However, the rainfed agriculture is risk prone and challenged with many factors besides climate change/variability impacts that are already evident. Therefore, concerted efforts were needed to achieve climate resilient rainfed agriculture. Many national initiatives such as NPCC, NMSA, and NICRA have been undertaken to develop action plans/adaptation strategies and contribute to achieve climate resilient rainfed agriculture in India. A strong research network has been laid in the country with NPCC programme for assessing the impacts of climate change on Indian agriculture. NAPCC through its eight National Missions gave the much needed impetus to policy advocacy on addressing climate change in various sectors in India. NICRA established a strong research and extension and upscaling network involving National Agriculture Research System, Ministries, Departments, farmers and other stakeholders for developing climate resilient technologies to cope with droughts/dry spells and dissemination of climate resilient technologies and wider upscaling. A number of climate resilient practices and technologies for rainfed agriculture have been identified. The impacts and opportunities, of these particularly real-time response measures would certainly flag the path for climate resilient rainfed agriculture. The experiences gained in TDC through KVKs and RTCP implementation and building resilience at landscape level through AICRPDA centres for upscaling of climate resilient technologies have been worth emulating and being shared at international, national and state level platforms/fora. The national and state governments have already initiated mainstreaming of these practices and technologies into national/state/district programmes/schemes.

The climate resilience in rainfed agriculture can be better addressed through risk and vulnerability assessment at sub-district level, mainstreaming resilient technologies through strong convergence with government schemes and appropriate policy interventions, strong preparedness for weather aberration (based on long term experiences or trends) along with actually responding to the situation and capacity building of primary and secondary stakeholders. A global programme could be a proposal for research and development in climate resilient rainfed agriculture and inter-governmental and multi-institutional arrangements for upscaling of proven climate resilient practices in the similar rainfed agro-eoclogy domains in various countries. Further, there could be regional centres of excellence in climate resilient rainfed agriculture not only for research and development and also for capacity building and human resources development.

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Examining the Potential Impacts of Agro-Meteorology Initiatives for Climate Change Adaptation and Food Security in Bhutan

Tshering Wangchen and Tshencho Dorji

Abstract Bhutan is a small Himalayan kingdom with 53.7% of the total population engaged in agriculture. The contribution of the agriculture sector to the overall GDP of the country is 17.37%. The country aims to achieve food security and bring agriculture transformation through sustainable and innovative technologies. As a fragile mountain ecosystem, the country is extremely vulnerable to the impacts of climate change and already facing the brunt of climate change such as increase in surface temperature, changing rainfall patterns and frequent occurrence of extreme weather events. The National Center for Hydrology and Meteorology which is the nodal agency for climate studies, project an increase in surface temperature and varying rainfall pattern under diverse climate change scenario. In light of changing climate, the food security challenges can further be aggravated through reduced crop yield and loss of crops to insect, pest and diseases and natural disasters such as droughts, erratic rainfall, windstorms, flash floods and landslides. Climate change adaptation is therefore, extremely important to enhance food security of the nation. An agro-met decision support system was developed to generate, disseminate advisories to make informed decisions under a changing climate and eventually increase the crop productivity. Meteorological information is also used to manage Smart irrigation system to increase water use efficiency and address farm labour shortage issues. The agrometeorology program also started weather-based pest forecasting for sustainable crop protection. Implementation of numerous activities through the agro-met program of the department will moderate the potential impacts of climate change through provision of early warning information and preparation of contingency plans which contribute to overall enhancement of the food security of the country.

Keywords Agriculture · Food security · Climate change · Adaptation · Agro-meteorology · Agro-met decision support system · SMART irrigation system

T. Wangchen (✉)
Department of Agriculture, Thimphu, Bhutan
e-mail: tsheringwangchen@moaf.gov.bt

T. Dorji
National Center for Hydrology and Meteorology, Thimphu, Bhutan

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Introduction

Bhutan is small kingdom located in the southern slopes of the Hindu-Kush Himalayan Mountains also known as the Third Pole region. The country is situated between China in the north and India in the south, east and west. The country has a total area of 38,394 km sq which is characterized by steep and rugged topography that varies from 100 m in the south to over 7500 m in the north. The National Statistical Bureau (2018) reports a total population of 727,145 (380,453 males & 346,692 females) in the country as of 30 May 2017. The Bhutanese people depend on agriculture for their livelihood. About 53.7% of the total population is engaged in agriculture (National Statistical Bureau 2018). The share of agriculture sector towards the total GDP is 17.37%. The farming system is predominantly subsistence oriented but is now transitioning from a semi-commercial to commercial farming. About 7.8% of the total area is arable out of which only 2.75% is cultivated (Department of Forest and Parks Services 2017) of which 31% are on slopes with a gradient of more than 50%. According to the National Statistical Bureau (2018) the mean land holding is 2.22 acres per household with an average land holding of 2.91 acres in rural areas as compared to 1.04 acres in urban areas. Hence, the Bhutanese agriculture production system can be categorized into a “small holder system” by virtue of having farm size less than 10 hectares and farm characteristics of a small holder (Katwal et al. 2015). According to Katwal et al. (2015), rice, maize, wheat, barley, buckwheat and millets are major staple cereals cultivated by farmers.

Peljor and Minot (2010) support that food self-sufficiency is usually refers to either cereal self-sufficiency or rice self-sufficiency in Bhutan. In addition, Chhogyel et al. (2015), states that rice is equated with food security of the country and therefore indicates the importance of cereals in our food system. The domestic rice production barely meets about 50% of the total requirement and the rest of the demand is met from neighbouring countries mainly India (Chhogyel et al. 2015). A survey in 2007 reported that about 35% of the respondents faced food shortage during the year, and of this figure, 51% faced food shortage for more than 4 months while 49% had inadequate food for 3 months or less. As a result, the food security and food self-sufficiency are well enshrined in the food policy of Bhutan considering these scenarios. Early Five-Year Plans (FYPs) prioritized to achieve self-sufficiency in staple foods, while more recent FYPs focused on enhancing food security (Peljor and Minot 2010).

However, the food security goal is constrained by a number of issues and challenges. According to the Department of Agriculture (2016) the farming constraints experienced by the rural communities are farm labour shortages, human wildlife conflict, irrigation water scarcity, crop damage by insect pest and diseases, extreme weather events and occurrence of landslides. These barriers are often results of human induced climate change and the issues are interlinked with each other.

The aim of this paper is to examine future impacts of the agro-meteorology initiatives towards climate change adaptation and food security in Bhutan. This paper studies the climate of Bhutan, climate projections and risk and vulnerabilities of agriculture sector. Accordingly, initiatives of the Agro-meteorology Program were assessed in terms of its potentials to enhance food security. The paper also narrates the ability of the action plans to adapt to the vagaries of climate change.

Materials and Methods

This paper is based on the on-going initiatives of the Department of Agriculture (DoA) and National Center for Hydrology and Meteorology (NCHM). A desk study was carried out in order to participate in the "International conference of climate change adaptation in arid and semi-arid areas" organized by The Centre for Science and Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre), New Delhi, India. The literature review was done to comprehend future impacts of the agro-meteorology initiatives towards climate change adaptation and food security in Bhutan.

The following approach was used in the preparation of this paper:

- A review of the available climate data for Bhutan, scientific literature and technical documents to identify major climate characteristics and global influences affecting the climate of the country including an analysis of climate trends and climate variability in different agro-climatic zones of Bhutan.
- Review of reports produced by line departments, international organizations and academicians with regard to agriculture, climate change and adaptation action plans.
- An analysis of institutional arrangements for delivery of agro-met services.

Results and Discussion

Climate of Bhutan

Norbu et al. (2003) point out that the climate in general is wet and hot in the south, dry and cold in the north, dry and warm in the inner valleys, moist and cool on the N-S ranges and region. According to the National Centre for Hydrology and Meteorology (2017) there are two monsoon seasons in the country: Southwest and Northeast monsoon. Bhutan's climate is dominated by the Indian Summer Monsoon (ISM) which moves north from the Bay of Bengal and brings approximately 75% of annual rainfall between June and September. It usually brings significant amount of rainfall that causes rise in water levels, flooding and landslides. Northeast monsoon features cool and dry breeze with prolonged periods of successive cold days. It affects the country from November to February. Climate variability in the country is also brought about by El Niño Southern Oscillation (ENSO) and Western Disturbance (WD). ENSO is one of the sources of inter-annual variability of Bhutan's climate while heavy winter snowfall in the country is mainly related with Western Disturbances (National Centre for Hydrology and Meteorology [NCHM], 2017). The annual average rainfall was 1916.29 mm while the annual mean maximum and minimum temperature was 23.1 °C and 11.6 °C respectively. The highest temperature was recorded at Tangmachu with 36.5 °C and the lowest was recorded at Haa with −11 °C (NCHM 2017).

Climate Scenario, Trends and Projections

The consequences of climate change are already being felt. Number of studies show rapid changes in average temperatures, precipitation patterns, and increased risks of climate related hazards in the recent years. The Fifth Assessment Report (AR5) of the Inter-governmental Panel on Climate Change (IPCC) estimates an increase of global mean surface temperature by 4.8 °C by the end of the century. IPCC recommended that much more studies on climate change are required especially at the regional and national levels with high temporal and spatial scales.

Sivakumar and Hansen (2007) and Food and Agriculture Organization (2018a, b) point out that the key weather variables for crop production are rainfall, temperature and solar radiation. According to the NCHM (2019), the surface temperature is estimated to increase by 0.8–1.6 °C during 2021–2050 and by 1.6–2.8 °C towards the end of the century (2070–2099) under RCP 4.5 scenario. The overall surface temperature is projected to increase by about 0.8–2.8 °C during 2021–2100. Higher values are projected under the RCP 8.5 scenario with an increase in surface temperature by 0.8 °C to more than 3.2 °C towards the end of the century. These RCPs (Representative Concentration Pathways) are defined by their total radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter) pathway and level by 2100. The scenarios were used for climate change projection and simulation of global climate models.

The average annual rainfall is expected to increase in future. Under the RCP 4.5 scenario, the mean annual rainfall indicates an increase by about 10–30% on the mean annual scale, with summer (JJAS) rainfalls between 5 and 15%. Under the RCP 8.5 scenario, the mean annual rainfall indicates an increase of about 10–20% during 2021–2050 and with more than 30% increase all over Bhutan towards the end of the century (2070–2100). Under both scenarios, there is an indication of a marginal increase in rainfall trend (NCHM 2019). Drier winter conditions are also expected thus impacting the already retreating glaciers which is likely to affect the water sources.

Climate Risk and Vulnerabilities of the Agriculture Sector

Bhutan is highly vulnerable to the effects of climate change due to dramatic changes in topography and altitude over a small area (National Environment Commission 2011). Changing weather pattern, erratic weather events, retreating glaciers and the risk of Glacial Lake Outburst Floods (GLOF) have now become a glaring reality. The risk is further pronounced as more than 50% of its population depend on agriculture for livelihoods. Climate change is expected to disproportionately affect small holder farmers and make their livelihood even more precarious due to reduced adaptive capacity and higher climate vulnerability. A survey conducted by Katwal et al. (2015) shows that 94% of the respondents had the perception that local climate is changing while 86% responded that they are aware of the potential impacts of climate change on their livelihoods. Chhogyel et al. (2020) observed that for most of the Bhutanese farmers, climate change meant unpredictable weather, less or no rain, drying of irrigation sources, emergence of diseases and pests, high-intensity rain, less or no snow and shorter winter.

Terraced rice cultivation is commonly referred to as wetland farming, which constitutes 27.86% of the country's cultivable land (National Soil Services Centre and Policy and Planning Division 2010). Rice requires more water than any other crop thus making it the most vulnerable and highly dependent on climatic parameters, such as monsoon rains and temperature. Under both irrigated and rain-fed systems, rice farming stands out to be highly sensitive to climate change since it requires large quantities of water. Chhogyel and Kumar (2018) believe that the rice yield in the southern subtropical regions will be adversely affected by the heat waves, drought and erratic rainfall pattern. It has been reported that both rice yield and grain qualities were reduced under high temperature. A study conducted by Parker et al. (2017) indicates lower altitude areas in the south less than 1000 m above sea level (masl) will become unsuitable as a result of an increase in temperature.

The most prominent impact of climate change on water resource is the drying of water resources such as springs, lakes, ponds and marsh lands that feed the streams on which different sectors depend for their water needs. According to the Ministry of Agriculture and Forests (2016a, b) most of the existing irrigation facilities from the 1307 irrigation schemes are conventional open canal where water seepage and evaporation rates are very high resulting with conveyance efficiency of only 30 to 40%. A study conducted by Chhogyel et al. reported drying of irrigation sources as a result of climate change by 50% of the respondents. Further the increase in surface temperature will cause an increase in demand for water for crops as a result of increased evapotranspiration and will lead to more rapid depletion of soil moisture. This scenario may lead to more frequent crop failures (Food and Agriculture Organization 2013). 10–20% of crop loss was reported as a result of climate change corresponding to a crop damage of 8079–16,159 tonnes and 7202–14,405 tonnes in rice and maize respectively which is a substantial quantity for a small country with limited resources. Similarly, 10–20% crop damage was reported in cash crops such as potatoes, vegetables, apple and mandarins.

Table 1 Incidences of climate change impacts experienced in Bhutan. (Adapted from Chhogyel and Kumar 2018)

Extreme weather events	Year	Remarks
Glacial lake outburst (GLOF) flood	1994	Damaged 965 acres of agricultural land
Rice blast epidemic	1996	80–90% crop loss in high altitudes
Heavy monsoon in the country	2004	Damaged 39 irrigation schemes
Turcicum leaf blight in maize	2007	50% crop loss in high altitudes
Cyclone Aila/flash flood	2009	100 acres of land washed away
Hailstorm in Punakha	2012	30–40% rice crop damaged
High intensity rain and windstorm	2013	100 acres of maize crop damaged
Hailstorm/flash flood	2015	>100 acre rice crop damaged
High intensity rain	2016	>100 acre rice crop damaged

Upland mountain slopes is highly vulnerable to the vagaries of climate and weather events such as soil erosion, land fragmentation and nutrient loss and thereby impacting agriculture production. Loss of traditional genetic resources has been reported by Chhogyel and Kumar (2018) both in terms of crop species and varieties thereby increasing vulnerability to climate shocks. Loss of farm diversity and its susceptibility is obvious from the steady decrease in area and production of dry-land crops (Chhogyel et al. 2020). Some traditional crop varieties have been extinct due to incidence of insect, pest and diseases. Chhogyel and Kumar (2018); Ministry of Agriculture and Forests (2016a; b) highlight that plant diseases such as rice blast, Gray leaf spot in maize, citrus greening and diseases in cardamom and ginger have become very serious problems. Farmers in high altitude region lost 80–90% of the crop yield to rice blast in 1996 and similarly 50% of the maize farmers were affected by Turcicum leaf blight in 2007. Farmers also have reported cases of army worms and other insects. Such incidences of insect, pest and diseases are often a result of climate change. In recent times the country has also been experiencing frequent weather events causing widespread damages to crops and livelihood of the people. Some of the notable climate change induced impacts are shown in (Table 1).

Climate Change Adaptation Initiatives

The agriculture sector is one of the most climate sensitive sectors. Hence, climate change adaptation is of extreme importance in agriculture given the dependence on the sector on climate and weather elements. According to UNFCCC as cited in FAO (2017) climate change adaptation refers to "changes in processes, practices and structures to moderate potential damages from climate change, or to benefit from opportunities associated with such changes". FAO (2017) recommends that the climate change adaptation strategies and policies should be based on science while acknowledging the importance of indigenous and traditional knowledge. Adaptation actions should be mainstreamed into sectoral and cross-sectoral policy making and promote good adaptation practices to confront the heterogeneity and uncertainty of climate change impacts to contribute towards sustainable food production and food security for all. According to FAO (2012), adaptation strategies will be required to protect the livelihoods and enhance food security in many vulnerable developing countries to climate change.

Parker et al. (2017) states that many adaptation strategies in the agriculture sector are constrained by limited information on regionally specific climate change impacts on the main crops. They go on to state that past analysis of climate change impacts are generic and wider South Asian context has been taken as a reference for Bhutan.

Bhutan's first step towards climate change adaptation was when the National Adaptation Programme of Action (NAPA) was developed in 2006. The NAPA formed a set of objectives which included recognizing immediate projects and activities that can help communities adapt and to integrate climate change risks into the national planning process (National Environment Commission 2012). Although the provision of agro-meteorology services is clearly of national importance and was identified as one of the top six projects for implementation under the National Adaptation Program of Action (Bhutan NAPA-II 2006). Bhutan could not carry out timely actions as we were limited by funding support, human resources and institutional arrangements to provide comprehensive agro-meteorology services. Nevertheless, the country's first initiative in agrometeorology came through the Hydromet Services and Disaster Resilience Regional Project, funded by the World Bank in 2016. The Department of Agriculture is further supported by the Green Climate Fund (GCF) and Global Environment Facility (GEF) projects in order to support climate resilience and transformational change in agriculture sector in Bhutan.

Agrometeorology Program

According to Sivakumar et al. (2000) climate should be considered as the driving variable for management of soil, plant and animal resources. Therefore, climate services are essential for sustainability of agriculture farms. Climate Services refers to transforming climate data into climate information in a way that responds to user needs and helps in farm decision-making to reduce the impacts of climate-related hazards and increase benefits from favourable climatic conditions (WMO—Global Framework for Climate Services). Agro-meteorological services have become essential more than ever due to the challenges posed to agriculture production as a result of climate variability and extreme weather events. In order to provide climate services primarily vis-à-vis agro-met services, the agro-meteorology program was instituted under the Department of Agriculture in 2019. The institution of Agro-meteorology Program is a step towards enhancing climate change adaptation to ensure food security under a changing climate.

One of the main activities of the program is the development of agro-met decision support system (ADSS). The ADSS is a web portal to generate and disseminate farm advisories of specific crops of specific location based on machine learning algorithm. The decision support system can be accessed from www.agromet.gov.bt. The data is hosted with the government data centre. ADSS generates agro-met information products (crop advisories) based on the weather and climate forecast from the National Center for Hydrology and Meteorology (NCHM), Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) forecast and crop data to guide farmers in coping with weather and climate extremes.

Sivakumar and Hansen (2007) state that climate forecasts for agriculture must be interpreted in terms of production outcomes at the scale of decisions if the farmers and agriculture decision makers are to benefit. The provision of agro-meteorology services requires close collaboration between Department of Agriculture and National Center for Hydrology and Meteorology to enable the integration of user needs into the development of services and to facilitate feedback for their improvement (Fig. 1).

The ADSS integrates all information across a range of temporal and spatial scales and provides appropriate and actionable information for decision making which is crucial for effective delivery of climate services. The short-term weather forecasts, eg. 1–10 days rainfall and temperature will be useful to make farm decision such as cultivation, fertiliser application, transplanting, sowing, pesticide application and

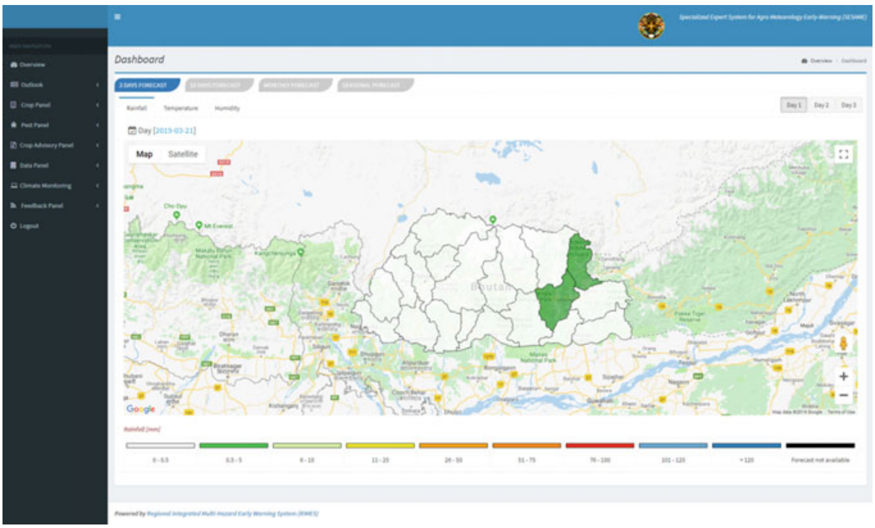

Fig. 1 The panel of the agromet decision support system

irrigation. For example, Lansigan et al. (2007) conclude that corn farmers in a site they studied reported 11–18% more yield by farmers who adopted planting date based on the climate forecast than farmers who planted based on farmers choice.

The erratic rainfall pattern and drying up of water sources as a result of climate change will add pressure to agriculture water management. Similarly, the increase in temperature will also result in increased evapotranspiration and thereby intensify the water demand required for irrigation. Agriculture Research and Development Centre, Wengkhar has developed a Smart irrigation system using an open source firmware and hardware solutions that integrates weather data (temperature, humidity, soil moisture, and rainfall) and accordingly schedules irrigation. This irrigation system increases the water use efficiency. In addition, the system is also accessible through internet and mobile apps which reduce the labour cost, a major farming constraint in the country. According to Agritask (2020) application of smart irrigation technology resulted in an increase of productivity by 5%, water and energy usage reduced by 30 and 20% respectively and 128 h of labour requirement saved in their business area. Currently, this technology is mostly centred in the east and there is a scope to widen its reach. The model needs to be upscaled in selected commercial vegetable sites and large-scale commercial fruit farms to adapt to the changing climate and enhance food security of the country.

Climate change is also expected to affect agriculture pest management. According to Strand (2000) agrometeorology for pest management is essential to enhance food security, reduce environment degradation and evaluate new risks at the backdrop of climate change. Accordingly, improved technologies to manage insect, pest and diseases will require weather information. The agrometeorology focal's based in the National Plant Protection Centre collected data for three main diseases: rice blast, potato late blight and apple scab and carried out weather-based forecasting for efficient crop protection.

Improved forecasts with longer lead times could decrease dependence on agrochemicals to manage some of the insect and diseases. Use of fungicide can be reduced through the use of disease forecasting or risk assessment models that evaluate suitable condition for disease infection (Strand 2000). Thus, pest management using agrometeorology information also adds value in the country's vision towards organic agriculture.

National Climate Outlook Fora

Other farm decisions such as what to plant, how much to plant, varietal selection need sub-seasonal and seasonal forecasts of rainfall and temperature. NCHM now conducts the national climate outlook fora annually wherein the national meteorology agency provides and communicates seasonal forecast to the users. The provision of seasonal forecast enables in preparing contingency for the community level users. The contingency action plans enable our farmers in reducing production risk and thereby enhance adaptation response.

Early Warning Information

Rice is the main staple crop and highly valued by the Bhutanese farmers. The rice cost of production is one of the highest mainly due to the high labour cost. However, rainfall coincided during harvesting in the popular rice growing belts in the past and reports of total crop damage appeared in the news. Such climate induced risk always dampened the hard work and discouraged the farmers. The National Center for Hydrology and Meteorology now provides 3–5 days weather forecast with warnings on extremes. This has really enabled farmers to make best farm management strategies based on their level of risk aversion in response to the forecast.

Automatic Weather Stations (AWS)

At present, NCHM operates and monitors 20 classes. A meteorological stations located in each of the 20 districts in the country. These stations are regularly monitored by trained meteorological technicians and data are recorded daily. Data is available from 1996 till date for most of the 20 meteorology stations. High quality data is needed for research and analysis in agriculture. Quality climate data will enhance the outputs of the studies in agriculture and help in delivering better services. According to De Pauw et al. (2000) sparce meteorological data networks can be addressed through automatic weather stations with data loggers and data transmission through telephone or satellite. Thus, DAVIS automatic weather stations were procured and installed in Agriculture Research and Development Centre's and some of the government farms.

The installed weather stations help in obtaining real time weather data. The site specific and real time meteorological information is indispensable to manage future irrigation projects effectively (De Pauw et al. 2000). Weather data is also used in the evaluation of climate resilient crop varieties, agrometeorological research and pest and disease forecasting. In addition, weather data (temperature, humidity, rainfall and soil moisture) from these AWS are integrated to the Smart irrigation system that modernizes the irrigation system. Consequently, such data indirectly translates in improving food security of the country and adaptation towards climate change.

Capacity Development

The Agro-meteorology Program is also taking the lead to enhance the capacity of plant protection officers to forecast pest and diseases. Capacity development is also prioritized for agrometeorology focal officers in crop modelling and simulations. Crop suitability models were generated in the past and such exercises assist in agriculture planning and decision making. In addition the department also agreed to be a part of FAO initiated Climate Change Platform for Risk Analysing and Agriculture Planning (C:PRAP), a Platform for analysing and visualizing risks and vulnerability of agriculture to climate change. The climate change risk and vulnerability information obtained from the platform will be helpful in designing climate change adaptation projects. Hence, C:PRAP will be useful to the policy makers, researchers, extension agents and so on. All these strategies and actions will enhance the resilience of our farming communities in light of the global climate change.

The country is also in the process of developing National Adaptation Plan (NAP) for medium to long term to reduce vulnerability by integrating adaptation into development planning and applying urgent adaptation actions. Agrometeorology initiatives are strongly featured in the NAP.

Institutional Arrangement

National Center for Hydrology and Meteorology

The National Center for Hydrology and Meteorology (NCHM) is an autonomous technical organization of the Royal Government of Bhutan. It is the nodal agency responsible for generation of information and delivery of products and services on weather, climate, cryosphere and water resources in Bhutan (National Center for Hydrology and Meteorology 2018). However, this mandate does not extend to formal engagement with the user community to identify climate needs in different sectors and to develop products specific to the needs of these sectors. The NCHM communicates crucial hydro-meteorological information to most of the users but there are still gaps that need to be addressed. The user community need to engage with NCHM to understand what climate information is available and how to interpret it correctly. Development and addressing gaps of climate services for agriculture is a priority of NCHM. The centre is also the national focal point for international organizations such as the World Meteorological Organization and International Panel for Climate Change.

Department of Agriculture

The Department of Agriculture (DoA) is one of the oldest government departments in the country. The department strives to achieve food and nutrition security, bring agricultural transformation through innovative and sustainable technologies. The department is assisted by four Agriculture Research and Development Centres, seven Central Programs and 20 Dzongkhag (district) agriculture sector in implementing various plans and programs to improve the livelihood of the rural communities. DoA is also one of the end users of climate services and DoA is working closely with

NCHM to co-produce the climate information in order to provide agro-advisories to the rural communities and enterprising youths engaged in agriculture. DoA also collaborates closely with NCHM to promote climate resilient agriculture practices (United Nations Development Program 2020). However, limited skills and knowledge in analysis and use of climate information services aggravate the growing problem.

Conclusions

Agriculture is one of the most important sectors providing livelihood to more than 53.7% of the total Bhutanese population and contributing 17.37% to the country's GDP. However, the sector is confronted with numerous farm issues and challenges with climate change posing one of the most serious threats particularly to the small holder farmers. We are likely to experience an increase in temperature, erratic rainfall pattern and the likelihood of extreme weather events will be more frequent affecting food and nutritional security of the country. Therefore, climate change adaptation is of extreme importance in agriculture given the dependence on the sector on climate and weather elements. Agro-meteorological services provided through the Agromet program of the department is one of the adaptation strategies and DoA and NCHM is working closely to generate crop advisories based on the weather and climate forecast and crop data. These farm advisories and early warning systems will enable farmers in reducing production risk, thereby enhance adaptation response and reduce the adverse effects of climate change through cross-sectoral engagement and enhanced investment in research and development and technology generation. Further, site specific weather information's are integrated to the Smart irrigation system to improve food security of the country and adaptation towards climate change.

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Climate Change Mitigation: In Situ Management Methods of Indigenous Fruit Trees in Chivi Communal Area, Masvingo Province, Zimbabwe

Marumure Jerikias and Makuvara Zakio

Abstract Greening of open spaces with indigenous fruit trees (ITFs) can play a significant role in mitigating climate change impacts via carbon sequestration and offer several co-benefits in rural areas. Most indigenous African fruit trees tolerate dry conditions, high temperatures and have a potential to improve nutritional status, food security and livelihoods for people that live in drier conditions. The main management strategies are based on exclusive harvesting of fruit trees, restrictions on cutting down of trees and collection of plant products for medicinal use. The study examined the in situ management strategies of indigenous fruit trees used in Chivi communal area to mitigate climate change impacts and sustain indigenous fruit tree resources. Data was collected through structured interviews and transect walks with key-informants. The results showed cultural practices, seed preservation and propagation and control of use by local community leaders as the main management strategies of indigenous fruit trees. Although cultural practices and seed preservation are critical in greening of open spaces, community leaders are at the fore front in the management of indigenous fruit trees. In line with these findings we recommend the inclusion of modern fruit tree management strategies in climate change mitigation.

Keywords Indigenous fruit tree · In-situ management · Food security · Climate change · Mitigation

Introduction

Climate change may significantly reduce the productivity of farms globally due to the effects of changes in temperature and precipitation patterns. Potential impact of climate change on farm productivity is a significant concern given that agriculture represents the primary livelihood strategy for the vast majority of rural poor in tropical developing countries, as this group typically has limited access to additional financial

M. Jerikias (✉) · M. Zakio
School of Natural Sciences, Great Zimbabwe University, Off Old Great Zimbabwe Road, P. Bag 1235, Masvingo, Zimbabwe
e-mail: jmarumure@gzu.ac.zw

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or biophysical resources to adapt to the predicted less hospitable weather patterns (Morton 2007; Bryan et al. 2013a). While climate change threatens agriculture, it also contributes to events such as increased temperatures described by global warming. Ambitious climate change mitigation scenarios aiming to limit global warming to 2 °C or less require very rapid reductions in greenhouse gas (GHG) emissions (Clarke et al. 2014; van Vuuren et al. 2013). However, even if stringent policies are adopted, it is likely that negative CO_2 emissions will become indispensable to achieve the Paris Agreement on climate. Agriculture, however, can help mitigate climate change. Agricultural mitigation can be realized through a variety of practices that increase carbon sequestration in soils and biomass (Scholes et al. 2014). This also involves carbon capture and storage through expansion of forest areas and proper management of the already available trees (both domestic and forest) as the favourable option. Establishment of new forest areas can be through planting and/or deliberate seeding. Recent studies stated afforestation as a major solution to climate change, with high potentials. Griscom et al. (2017) present a sequestration rate of 10.3 $GtCO_2$/year using 678 Mha by 2030, Lewis et al. (2019) find 154 $GtCO_2$ on 350 Mha over a time period of 70 years, and Bastin et al. (2019) show a potential of 752 Gt CO_2 using 900 Mha without specifying a time period. They assume that afforestation, despite its large extent, does not occur on agricultural areas and thus, do not affect food security. Even if it is done on agricultural lands it can utilize fruit trees hence providing food to the people.

Agro-forestry is an often named solution for the dual climate and other co-benefits (Dinesh et al. 2017) which includes food security, source of medicines, home gardens, windbreaks and livestock feed. The contributions of agro-forestry practices to the livelihoods of farmers are determined by local biophysical and socio-economic factors and need to be examined from their perspective (Dumont et al. 2017). However, the global benefit of regulating climate through carbon sequestration cannot be considered a motivating argument for smallholder farmers to invest in new farming practices (Bryan et al. 2013b). Therefore, mitigation efforts at smallholder farm level need to produce tangible and direct livelihood benefits for farmers, such as being a source of food, fuel or fodder with mitigation being a co-benefit of the improved agricultural practice (Ogle et al. 2014).

In support with the current drive to mitigate climate change and promote source of livelihoods of people living in semi-arid regions the study seeks to examine the in situ management strategies of indigenous fruit trees in these regions. A better understanding of the local strategies will inform researchers and policy makers on how greening of open spaces with indigenous fruit trees can be used as a potential climate change mitigation solution. Our current participation in research of this nature is viewed as one of the essential efforts to ensure food security in regions where crop production is immensely affected by low rainfall due to climate change.

Materials and Methods

Qualitative approach was used in this study in which non-numerical data was collected and analyzed to understand the common in-situ management methods used in rural communities. Transect walks through the community and structured interviews were used to collect data used in this study. The transect walks were conducted by the research team and key informants from the community. The key informants chosen were knowledgeable in identifying indigenous fruit trees and their common conservation methods. The information collected during the walks, through observing, asking questions and listening to what people say, were used in discussions held amongst the participants.

The study participants for the structured interviews were selected by means of purposive sampling of thirty men and thirty women. The researchers deliberately selected people with a long period of residence or permanent residents of Chivi communal area, aged 35 years and above (signifying knowledge of the natural environment). The interviews comprised of questions pertaining to the names of the indigenous fruit trees in the community, their importance and management methods applied to conserve them. Local names of the trees species were used in this study. The participants were not coerced to participate or paid for participating in the research. Consent of the participants to all the stages of study was sought. The information collected during the research was treated with confidentiality. Permission to carry out the research was sought from the local Chief through his headmen and kraal heads.

Results

The structured interviews and transect walks results showed the same types and importance of the indigenous fruit trees (Table 1).

The people in Chivi communal area value indigenous fruit trees as a source of food (96.54%), firewood (3.75%) and medicines (7.33%). Musau, muzhanje, muuyu, mutsubvu, mushuma, munyii and mutohwe are consumed by all the people in Chivi. Muuyu and Muhacha are completely not used as firewood in Chivi. Trees like mutohwe, mushuma, mupfura, mutsubvu and muzhanje had no known local medicinal properties.

The community shared the same practices and methods in managing its indigenous fruit trees (Table 2). The in-situ management methods for the indigenous fruit trees include; cultural practices, traditional beliefs (maintenance of indigenous fruit trees in sacred places, prohibition of cutting down of indigenous fruit trees associated with dead or spirit mediums), seed preservation and propagation and control by local community leaders (establishment and maintenance of sacred places, imposition of heavy penalties on offenders and education on conservation of indigenous fruit tree).

Table 1 Indigenous fruit trees and their cultural values

Scientific name	Local name	Cultural value (percentage)		
		Food	Firewood	Medicines
Strychnos spp)	Mutamba	95	3	27
Azanza garkeaena	Mutohwe	100	8	0
Ximenia caffra	Munhengeni	93	9	15
Berchemia biscolor	Munyii	100	2	2
Diospyros mespiliformis	Mushuma	100	5	0
Sclerocarya birrea	Mupfura	86	1	0
Vitex payos	Mutsvubvu	100	10	0
Parinari curatellifolia	Muhacha	88	0	1
Kigelia africana	Mumvee	2	2	23
Ziziphus mauritiana	Musau	100	2	3
Uapaka kirkiana	Muzhanje	100	3	0
Average (%)		96.54	3.75	7.33

Table 2 Management methods of indigenous fruit trees in Chivi communal area, Zimbabwe

Management methods	Responses out of 60 respondents	Percentage responses
Cultural practices and traditional beliefs: – Maintenance of indigenous fruit trees in sacred places [30] – Prohibition of cutting trees associated with dead or spirit mediums (Makamure and Chiminingе 2015)	44	73.3
Seed preservation and propagation:	5	8.3
Control by local community leaders: – Establishment and maintenance of sacred places (Akinnifesi et al. 2008) – Imposition of heavy penalties on offenders (Dinesh et al. 2017) – Education on conservation of indigenous fruit tree (Akinnifesi et al. 2004)	11	18.4

Cultural practices and traditional beliefs had the highest management methods for indigenous fruit trees of 73.3% and seed preservation and propagation had the least (8.3%).

Discussion

The interview and transect walks showed great cultural value (96.54% food, 3.75% firewood and 7.33% medicines) of indigenous fruit trees to people in Chivi communal area. This shows that indigenous fruit trees are playing a big role as a source of livelihood in semi-arid regions. Indigenous fruit trees were seen tall in the surrounding forests, in grazing areas, in fields or even at homesteads. In clearing land for agricultural and rural infrastructure, residents do not cut their preferred edible fruit trees (both for human and livestock consumption). This ensures a continual supply of fruits from their favoured species. This preservation of indigenous trees for their produce is commonly practiced in other parts of Africa (Kalaba et al. 2009; Akinnifesi et al. 2004). Economic trees like *Azanza garkeana (*mutohwe*)*, *Berchemia discolor (*munyii*)*, *Diospyros mespiliformis (*mushuma*)* and *Sclerocarya birrea (*mupfura*)* are now managed by some households in their home gardens as agroforestry plants (Maroyi 2012). The fruits collected from these indigenous trees besides being consumed locally they are also sold in local and roadside markets or even in Masvingo town. This alone is more than enough for the residents in Chivi communal area, a semi-arid area, to place great emphasis on keeping open spaces green with indigenous fruit trees, especially in times of food shortage.

Cultural practices and traditional beliefs are linked to indigenous fruit trees management methods in Chivi communal area though in some villages people were adopting other foreign cultures divorced from the community beliefs. However, most people are still guided by cultural practices embedded in traditional beliefs in the management of indigenous fruit trees. The indigenous fruit tree richness and abundance were mostly seen in sacred places or forests than in the culturally unprotected areas (Table 2). This might be due to traditional beliefs passed from one generation to generation which promotes sustainable harvesting of tree products. In addition, the beliefs restrict people from accessing sacred places and fruit trees of cultural values associated with the dead and spirit mediums (Tanyanyiwa and Chikwanha 2011). Although, the traditional beliefs were able to conserve the plant species in Chivi communal area there was no enough literature and scientific evidence to support it.

From the interview discussions with the elders and the community leaders the mention of the word sacred forest invokes different feelings in individuals. Imaginations can run wild, but in Chivi communal area forests played a very critical role in the sustenance of the livelihood of indigenous people through the provision of wild fruits and other materials. They are also a source of spiritual guidance and can entrench a culture of respect among the indigenous people, and hence, proper management of resources. The indigenous fruit trees were saved from defilement and deforestation by certain binding taboos shared by the people. Tatira (2000) reported that Shona people often use taboos as one of the ways of teaching young members of their society to positively relate to the natural environment. In other words, the taboos encouraged conformity to environmental expectations with regards to management and sustainable use of indigenous fruit trees. The elders further argued that failure to follow the taboos would anger the spirits and, offenders or the whole community would suffer the consequences of drought, sickness, or plagues such as the invasion of locusts, worms and birds in their fields. Additionally, the elders also pointed that certain rituals have to be performed to appease the angered spirits, and the offenders would be fined a beast, goat or chicken that would be released in the sacred forest and left to wander around on their own. The imposition of such heavy penalties on the offenders would deter them from cutting down the trees in future. This is supported by Risiro et al. (2013) who noted that access to sacred places was restricted as a way of respecting the dead buried in them and offenders were fined heavily depending on the gravity of the offense. Hence, the indigenous fruit trees are conserved or used sustainably.

According to elders and villagers who live near the sacred forests or places, those who try to clear the land for agricultural purposes in the sacred forest would get a rude awakening the next morning as the cleared and uprooted trees grew back in their same position they were cut. The Chief and his Headmen confirmed these stories and said such forests are not supposed to be used as arable land. In support, it is reported that religious beliefs, taboos, totems and sacred places are a scientific explanation of environmental degradation prevention (Makamure and Chimininge 2015).

The Chief in particular extended his authority duties to monitor compliance to the rules of management of indigenous fruit trees in the area of his jurisdiction. He prevents over-exploitation of the indigenous plant resources by preventing the felling of live species for fuel, and ensuring proper harvesting of fruits. A similar trend was reported by Rankoana (2016) in Mantheding Community, South Africa, in which local authorities play a leading role in biodiversity conservation and management. Discussions with the participants also pointed out the control by local community leaders as a major management method of indigenous fruit trees. They do so by establishment and maintenance of sacred places, fining offenders and educating people on the conservation of indigenous fruit trees and their importance. Local people are prohibited from cutting down any popular fruit trees. This correlates strongly with Maroyi (2012) who reported less cutting of preferred edible fruit trees, *Berchemia biscolor* (munyii), *Diospyros mespiliformis* (musuma), *Sclerocarya birrea* (mupfura), *Strychnos cocculoides* (muzhumwi), *Strychnos spinosa* (mutamba), *Uapaca kirkiana* (muzhanje) and *Vitex payos* (mutsvubvu*)* in Nhema communal area, Shurugwi district. The participants highlighted another common rule which prohibits cutting down of trees near burial sites as they are believed to be sacred since they harbour ancestral spirits. A number of graves in the area were ‘greened’ by patches of woodland trees, including indigenous fruit trees. Access to these areas is restricted. A similar trend was reported by Maroyi (2012) who found graveyards to be characterized by large trees, which usual circumstances would have been cleared.

In Chivi communal area, the indigenous fruit trees were protected from being cut down by cultural practices and traditional beliefs regarding trees used as firewood. Indigenous fruit trees, like the Muzhanje (*Uapaka kirkiana*), the Mutamba (*Strychnos species*), the Mutohwe (*Azanza garkeana*) and the Munhengeni (*Ximenia caffra*) were seen standing tall in the forests, in fields or even at people homes, providing them sheds and wind breaks. The trees were not used as firewood. The explanations given to the children by elders were that they burn badly; produce a lot of smoke and the smoke produced could choke. In addition, the wood could not last long on the fire and is associated with bad luck (Chemhuru and Masaka 2010). Interestingly, it is reported that these explanations were coined in order to protect these tree species and ensure a continuous supply of fruits that provided the indigenous people with food and natural sugar which were important for their health (Duri and Mapara 2007). Hence, traditional beliefs and taboos associated with natural vegetation are simply an attempt to sustainably protect nature's resources for the benefit of present and future generations.

According to the elders and villagers the tall indigenous fruit trees seen in the fields and the surrounding forests were regarded as sacred because they are thought to be inhabitants of the spiritual bodies. Trees like muhacha (mobola plum), muonde (Fig tree), mumvee (sausage tree), mukamba and mishuku (mahobohobo tree), mushozhowa (*Psudolachnostylis maprouneifolia*) were seen standing tall in the fields and it is reported that the Karanga people in Chivi perform some rituals (Makamure and Chiminge 2015). In addition, people are discouraged from unnecessarily cutting them down due to some associated traditional beliefs. For example, the Shona people believe that cutting down of *Parinari curatellifolia (*muhacha) would disturb rainfall pattern (Chemhuru and Masaka 2010). Even though the teachings of traditional beliefs are achieved through fear and indoctrination, they are meant to conserve the indigenous fruit trees.

The transect walks and interview discussions (Table 2) showed 5% of people practising seed preservation and deliberate propagation by the people for management of indigenous fruit trees in Chivi communal area. People of different age groups were involved in seed collection, preservation and propagation in their farms or near homes, leading to the domestication of trees which traditionally were seen only in forests. A similar trend was reported in other areas of Zimbabwe where indigenous fruits are propagated by dispersal of seeds in the homesteads for use by the family members (Rankoana 2016). The domestication of the wild indigenous fruit trees lead to some farmers to view the trees as new crops in semi-arid regions. Measures for the *in-situ* management of the trees on the farm were employed as a way of maximizing food security and capturing economic opportunities. For example, *Ziziphus mauritiana* (musau) from the Mashonaland parts of Zimbabwe were seen in Chivi communal area. The *Z. mauritiana* fruits are used as food for human consumption and livestock feed especially goats. This is not the first time where wild fruit trees are domesticated. The last two decades have witnessed increased interest in the conservation, domestication and commercialization of indigenous fruit trees indigenous fruit trees in the tropics (Akinnifesi et al. 2008). Significant progress has been reported in domestication strategies, including species priority setting, provenance trials, participatory clonal selection and development of new cultivars, nursery propagation techniques and field management. Unpublished reports indicated that some people in Chivi communal area are working closely with experts from Great Zimbabwe University

(GZU) to evaluate the effects of different seed pre-treatments on enhancing germination of selected indigenous fruit tree species (Makuvara and Marumure, *unpublished*). Significant improvement in seed germination and propagation in *Vitex payos* and *Azanza garckeana* was reported in Chivi communal area.

Conclusion and Recommendations

The people of Chivi communal area cherish a life of living in harmony with their natural environment and what it holds, as reflected by their tendency to manage indigenous fruit trees in a sustainable way and hence, ensuring food security and economic opportunities linked to fruit harvesting, storage and selling. Domestication and proper management of indigenous fruit trees led people living in such semi-arid regions to adapt to impacts of climate change. Indigenous fruit trees are generally resistant to low rainfall and high temperatures making them a reliable source of food and other materials in such areas. The conservation, protection and management of the environment have been the corner stone of their ethos, culture and traditions in most rural parts of Masvingo. They have developed heritage based solutions and maintained traditional knowledge and practices for the conservation and management of the natural environment. All these were fostered through their religious beliefs and education. This result in keeping their surroundings green with indigenous fruits, trees, and this might also aid carbon sequestration. Scaling of their efforts would result in mitigating challenges of climate change in a greater way. This can be done by empowering traditional leaders and spirit mediums through legislation as the custodians of traditions and indigenous fruit tree species within their communities. Government ministries that are responsible for the conservation must work hand in glove with local communities and traditional leaders on indigenous fruit and tree species conservation issues. Indigenous methods of conserving these tree species could be integrated with modern methods of conservation and propagation of the trees. The young generation needs to be educated and encouraged on adopting traditional cultural practices on issues of indigenous fruits and tree conservation, as a way of surviving in semi-arid areas and mitigating climate change impacts.

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The Effect of Temperature and Rainfall Changes on Biophysical and Socio-Economic Status of People in Northern Jordan Valley Drylands, Palestine

A. Rasem Hasan, Abdallah Alimari, Hanan A. Jafar, Amjad I. A. Hussein, and Ahmed A. Abu Shaban

Abstract Drylands, particularly in the developing countries are highly affected by climate change. Major devastating changes are expected to happen in dryland areas, ecosystem structures, productivity and socio-economic characteristics of inhabitants. This study aimed at investigating drylands' socio-economic and biophysical characteristics and assesses its vulnerability to changes in temperature and rainfall. The Northern Jordan Valley region, Palestine was selected as a pilot study area. Direct meetings and a questionnaire were used to collect socio-economic and agricultural data over the period February–July 2019. Soil samples were collected from representative fields in the study area to test the major soil chemical properties. A large climatic dataset (1970–2019) was analyzed to investigate changes in rainfall and temperature. Results show that the average households' monthly income in the study area was in the range US $440–900. A significant portion of households' monthly income was spent on water for domestic and agricultural purposes. Water harvesting was a predominant activity due to water scarcity in the study area. The chemical analysis of the soil samples revealed that the salinity in the irrigated area was more likely a result of the farmers' agricultural practices. Analysis of climatic data of the Northern Jordan Valley revealed a reduction in annual rainfall by 4.5 mm/decade during the period 1970–2019. In addition, the average monthly values of maximum and minimum temperatures of the same period have exceeded the long-term monthly

A. R. Hasan (✉) · H. A. Jafar
Water and Environmental Studies Institute, An-Najah National University, P.O. Box 7, Nablus, Palestine
e-mail: mallah@najah.edu

Civil Engineering Department, An-Najah National University, P.O. Box 7, Nablus, Palestine

A. Alimari
National Agricultural Research Center (NARC), Ministry of Agriculture, Jenin, Palestine

A. I. A. Hussein
Faculty of Medicine and Health Sciences, An-Najah National University, P.O. Box 7, Nablus, Palestine

A. A. Abu Shaban
Faculty of Agriculture and Veterinary, Al Azhar University—Gaza, P.O Box 1277, Gaza, Palestine

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average of maximum and minimum temperatures in the study area. These changes in rainfall and temperature has exaggerated water scarcity in the study area and provided strong evidence on climate change in the region. The high vulnerability of Northern Jordan Valley region to climate change has strongly impacted the livelihoods' of its inhabitants and forced many people to immigrate.

Introduction

Drylands are characterized by low unpredictable precipitation (annual average rainfall <200 mm (Gaur and Squires 2018), scarcity of water, large difference in temperature between day and night-time, low organic content in soil and relatively high evapotranspiration due to abundant solar radiation, low humidity and high temperature (Ji et al. 2015; Feng and Fu 2013). The main feature of drylands is water scarcity where negative water balance (the amount of water evaporates during one year is more than that precipitates) is predominant (Huang et al. 2016).

There are different definitions of drylands; the United Nations Environment Programme (UNEP) defines drylands according to the aridity index (ratio between average annual precipitation and potential evapotranspiration, AI) (Huang et al. 2016) where drylands are those lands with AI < 0.65, whereas the Food and Agriculture Organization (FAO) defines drylands according to the length of growing period (LGP), where drylands are areas with LGP of 1–179 day per year. Further, based on either AI or LGP, drylands are classified into hyper-arid, arid, semi-arid and dry sub-humid lands (see Table 1) (Yukie and Otto 2011; UNCCD 1994).

Drylands accounted for 44% of the Word's agricultural land, 41.3% of the planets land surface and 50% of the Earth's livestock (Schlaepfer et al. 2017; Reed et al. 2012). Drylands are considered the largest terrestrial biome on Earth; 38% of the world's population is supported by drylands (Huang et al. 2017a, b). The vast majority of drylands' population lives in the developing countries (Yukie and Otto 2011).

Table 1 Classification of drylands based on the United Nations Environment Programme (UNEP) aridity index (AI), and length of growing Period (LGP) according to Food and Agriculture Organization (FAO)

Classifications of drylands	Aridity index (AI) according to UNEP	Length of growing period in days (LGP) according to FAO—(Day/year)
Hyper-arid	AI < 0.05	–
Arid	0.05 < AI < 0.20	1–59
Semi-arid	0.20 < AI < 0.50	60–119
Dry sub-humid	0.50 < AI < 0.65	120–179
Total drylands	0.05 < AI < 0.65	1–179

Incredible diversity of specialized species is found in drylands due to the special climate conditions in these areas (Yukie and Otto 2011).

Drylands are highly vulnerable to human activities and climate change (Huang et al. 2017b; Zhou et al. 2015). The response of drylands to climate change is reflected by changes in the structure and function of their ecosystem and changes in their area and distribution (Huang et al. 2016). Many studies have investigated climate changes and its effects over drylands (Ryan and Elsner 2016; Ji et al. 2015; Feng and Fu 2013).

Due to climate change, the global drylands have shown a surface warming of 1.2–1.3 °C over the past century, indicating 20–40% more surface warming over drylands than humid-lands (Huang et al. 2017a; IPCC 2013). The semi-arid regions have shown the largest expansion of global drylands (more than 50% of the total expansion of drylands over the World (Huang et al. 2017b). Climate change and human activities (such as—over cultivation, inadequate irrigation system and overgrazing) have led to desertification in many drylands around the World (Delgado-Baquerizo et al. 2013; Yukie and Otto 2011). Desertification is a major threat to the ecosystem of drylands and its inhabitants (Huang et al. 2017b; Gornish and Tylianakis 2013). It could lead to reduction in the carbon sinks and increase the emissions of greenhouse gases to the atmosphere, loss of livelihoods, salinity of soil and reservoirs, diminishing food production and increased flooding (Yukie and Otto 2011).

Many models predicted an increase in the aridity with climate change during the twenty-first century, particularly in the World's drylands. Any increase in aridity is predicted to negatively affect the soil content of total nitrogen (N) and organic carbon (C), and positively affect the soil inorganic content of phosphorus (P). This indicates that aridity may favor the dominance of physical processes (such as weathering of rocks) over biological processes (such as decomposition of litter). In turn, the key services that are provided by drylands' ecosystems will be negatively affected (Delgado-Baquerizo et al. 2013).

The scarcity of water in drylands have exacerbated as a result of changing in rainfall patterns, increasing surface air temperatures and weather extremes (e.g. droughts) (Ryan and Elsner 2016). These changes can damage vegetation and cause loss in livestock (Dawson et al. 2016; Ravi et al. 2010). In turn, this will add an additional stress on the availability and stability of food resources in drylands, leading to severe imbalances in natural production systems and consequently lower income of drylands' inhabitants and higher poverty rate (Schlaepfer et al. 2017). Under the stress of poverty and low income per capita, inhabitants of drylands particularly males are forced into either internal or external (cross boarder) migration to support their families (Yukie and Otto 2011).

Without agricultural innovations and adaptation for the rapidly growing population and changes in the land use around the world, 31% of the World's population will be food insecure (Dawson et al. 2016). When climate change is taken into the scenario, this percentage increases by 21% putting 4.2 billion people at the risk of undernourishment by the year 2050 with the vast majority of these in the developing countries (Dawson et al. 2016). All in all, climate change in drylands threatens food security, regional economics, energy production, public health (Yukie and Otto 2011) and may cause social and political conflicts leading to a global crisis (Markkanen and Anger-Kraavi 2019; Gaur and Squires 2018).

This study aims at investigating the effect of climate change on the biophysical and socio-economic characteristics of the drylands in Palestine; a developing country in the Middle East region.

Palestine is under the threat of desertification due to unsustainable management of resources (such as—urbanization, over grazing of land, excessive use of agro-chemicals and over pumping of ground water), Socio-economic factors (including poverty and food insecurity, land tenure and fragmentation), Institutional and legal factors (e.g. Weak institutional capacities), natural factors (like—climate change and population growth), Israeli occupation related factors (e.g. Israeli settlements, separation wall, control over natural resources and uprooting of trees) (UNDP 2011). The major consequences of desertification and land degradation include decrease in soil productivity and fertility, increase negative impacts of climate change, increased rain water runoff, less food production and increased food insecurity, increased financial and security burdens, and increased soil erosion and loss (UNDP 2011).

As part of the Middle East region, Palestine has been and will be subjected to many serious climate changes that include increases in temperature and sea level rise, reduction in the annual rainfall, shifts in rainfall patterns as well as hydro-meteorological dangers such as heat waves, droughts, floods, and storms.

Materials and Methods

Study Area

Palestine consists of two separated land masses; the West Bank and Gaza Strip (Fig. 1) with total area of 6257 km^2 of which 5840 km^2 the area of the West Bank including East Jerusalem and the rest is the area of Gaza Strip.

The total population of Palestine is 4.8 million; 2.9 million live in the West Bank and 1.9 million live in Gaza Strip. The Palestinian population is considered young as 69% of the population is below the age of 29 (PCBS 2018). Around 26.9% of the Palestinian population is unemployed of which 44% of the Palestinian women (UN Country Team 2016). According to the statistics of International Labour Office in 2014, around 34% of Palestinian households were classified as food insecure; this percentage jumped to 57% in Gaza Strip due to humanitarian and socio-economic conditions (International Labour Office 2014).

The main water resources in the West Bank are the western basin, eastern basin, north-eastern basin, springs and mekorot (national water company of Israel), whereas the major source of water in Gaza strip is the coastal aquifer; in fact, 85% of these resources is under the control of the Israeli occupation (UN Country Team 2016). The annual water share of Palestinians is less than 200 m^3/capita which is 300 m^3/capita

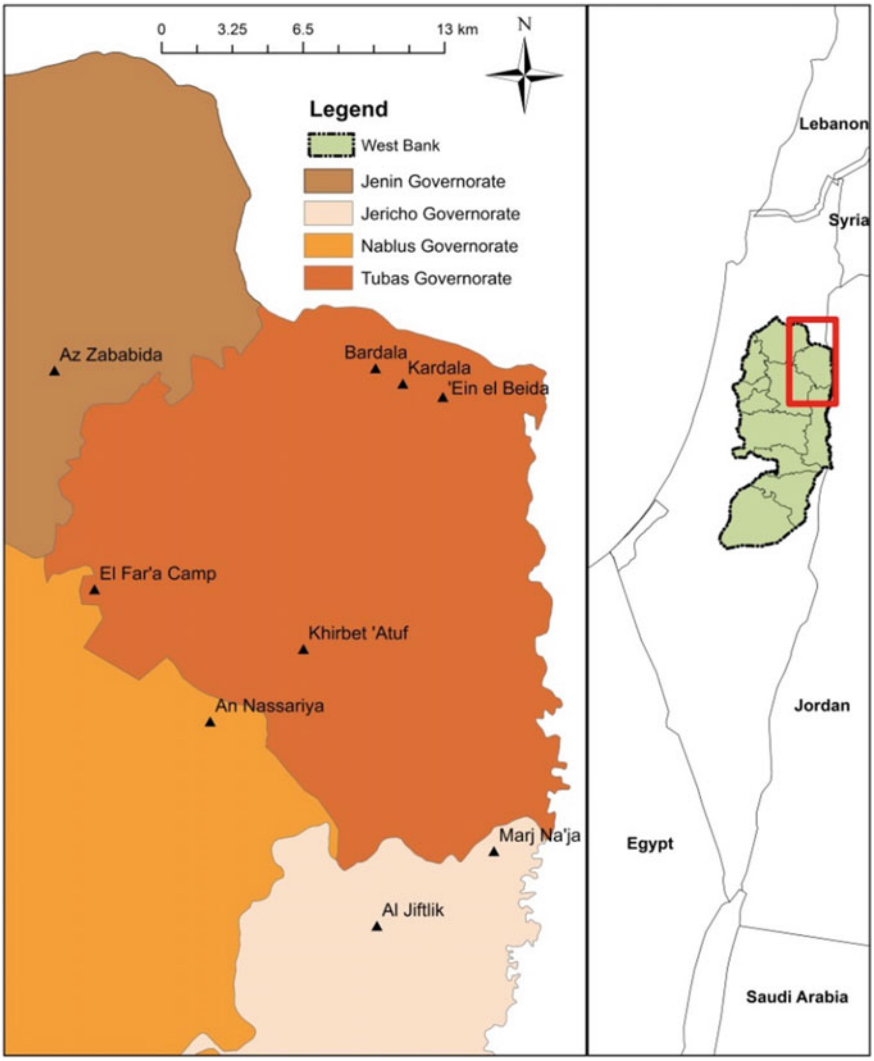

Fig. 1 Map of the study area

below the water scarcity limit of the World Health Organization (WHO) (MoFA Netherlands 2018).

Palestine is one of the most vulnerable drylands in the Middle East region due its political situation, limited water resources and bio-physical and socio-economic vulnerability to climate change (ARIJ 2013). The number of droughts has increased in the last few years (200–2010); consequently, the rate of vegetation has decreased in 42.7% of the West Bank area, especially in the Jordan Valley region (which is the most impacted area of land degradation in Palestine). Approximately 22.3% of the Jordan Valley area is under the effect of active degradation (ARIJ 2013).

Nine Locations in the Northern Jordan Valley region were selected as a pilot study area. These locations are: 'Ein el Beida, BradalaKardala, MarjNa'jeh, Al Zubaidat, AlJeftlik, An Nasariya, Alfara'a and Atoof as illustrated in Fig. 1. The Northern Jordan Valley region is considered historically as the food basket for the Palestinians. Although of its aridity, the region is known for its massive production of agricultural products due to fertility of its lands, availability of ground and drainage water, and elevated temperature all year around in comparison to the rest of Palestine and all Middle East countries, also due to its topographic settings, as most of the area is located around 350–370 below sea level (ARIJ 1995).

This study was conducted to assess the biophysical and socio-economic characteristics of the Northern Jordan valley due to the importance of this region on all levels. Geographically, this area is an International boundary among different neighboring countries; Culturally known for its importance to the three main faiths in the region; Economically as introduced to be a food basket in addition to its touristic attractive value; and Politically is an area of conflict, wherein current Palestinian citizens face deportation and annexation due to the dominant political conflict in the region.

Based on the UNEP AI; 44.4% of the West Banks' area is semi-arid, 30% is arid, 21.6% is dry-subhumid, and 4.0% is hyper-arid. Figure 2 shows that all of the study locations except for Al Fara'a are located in the arid zone where $0.05 < AI < 0.20$. As could be seen in Fig. 3 the dominant land use in the area is rough grazing/subsistence farming. The major economic activity in the Northern Jordan Valley region is agriculture. The average annual rainfall at the Jordan Valley region is only 100–200 mm (MoFA Netherlands 2018). The main water supply is Palestinian Water Authority through the West Bank Water Department that purchase bulk water from the Israeli Mekorot Company; other sources include groundwater and springs which are mainly used for agricultural uses (ARIJ 2012a, b, c). The Israeli occupation adds an additional stress to the problem of water scarcity in the area; inhabitants are neither allowed to construct or develop groundwater wells nor maintain old ones (ARIJ 2012a, b). Additionally, the water supply is not stable and is totally controlled by Israel.

The study was implemented over the period February to July 2019. Direct meetings were conducted to collect data regarding crops, irrigation intervals and quantities from farmers in the pilot study area. Soil samples were collected from representative fields in the study area to test the major soil chemical properties: salinity, pH, total nitrogen content (TN), calcium content (Ca), magnesium content (Mg), chlorine content (Cl), sodium content (Mg), Potassium content (K), phosphorus content (P), soil organic matter (OM) and sodium adsorption rate (SAR). The samples were composite samples where, each sample was composed of 10 samples in the field. Official methods of analysis of AOAC international and ICARDA referenced methods were used or soil analysis (Ryan et al. 2001; AOAC 1998). Parameters mean values were used to perform principal component analyses (PCA) along with the correlation analyses to test whether the variables are correlated or not was used. Level

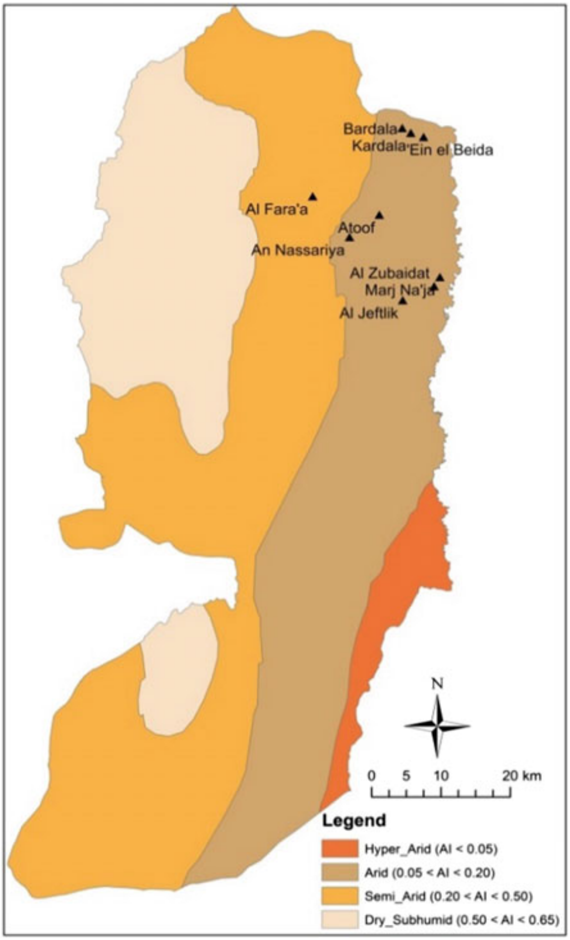

Fig. 2 Aridity map of the West Bank

of significant ($p < 0.05$) was estimated for all of the tested variables using crosstab (Chi-square).

For socio-economic data, a questionnaire was developed and tested to collect the data from a representative sample consisting of 180 rural households. The questionnaire covered various socio-economic topics such as household monthly expenditure, livestock holdings, land tenure and women contribution to agricultural work.

ArcMap (GIS 10.1) was used to create all the maps presented in this study, the shape files were provided by An-Najah National University (ANU). While the statistical analysis of socio-economic and climatological data was carried out using Microsoft Excel 2016. The dataset of annual mean temperature in Palestine over the period 1843–2013 was downloaded from (https://stat.world/en). The dataset is limited for this period (1843–2013), whereas the meteorological data for the study area was provided by the Palestinian Meteorological Department. The census data

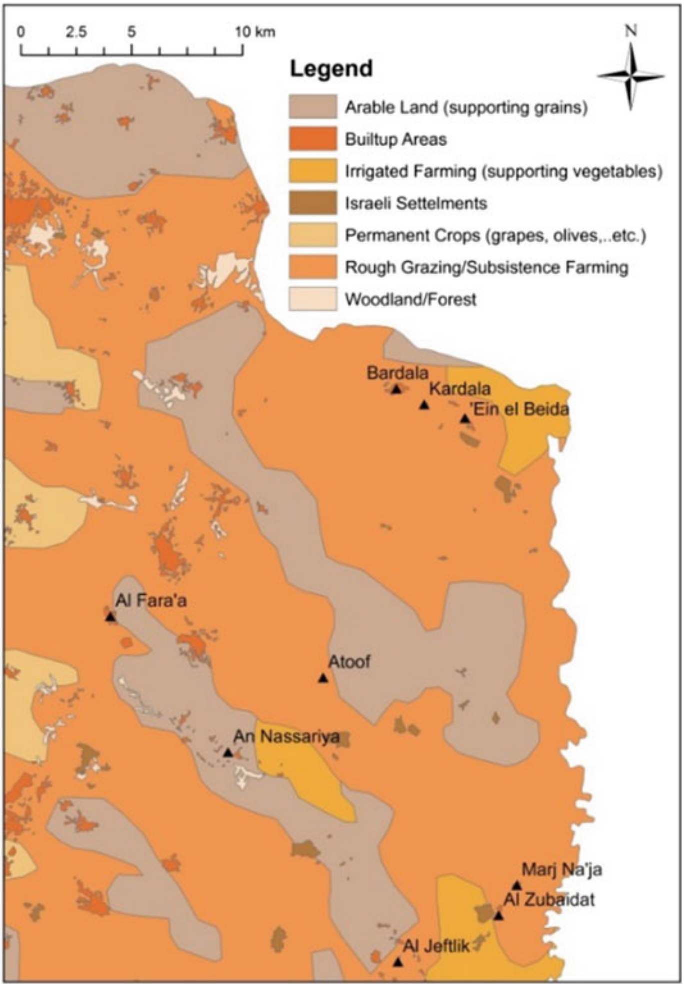

Fig. 3 Land use map

for the population in the study locations were drawn from The Palestinian Central Bureau of Statistics (PCBS) reports (PCBS 2018, 2008, 1999a, b, c). The forecasted population for the year 2017 was predicted using Equation (1):

$$P_p = Pe^{rt} \tag{1}$$

where, P_p is the predicted population, P is the present/past population in a specific year, r is the rate of natural increase and t is the time period between the P_p and P. According to the PCBS, the natural growth rate in Palestine is 2.8% (PCBS 2016).

Results and Discussion

Socio-Economic Characteristics

Climate change is seen as the consequence of complex social, economic and environmental interactions.

Climate change and geological processes contribute in reducing soil fertility and degradation, and have particularly serious consequences in the developing World, where millions of people are undernourished (Fischer et al. 2005).

The study findings revealed that, the average households' monthly income in the study area was US $440–1000 with animal production, labour farming wages and plant production as main sources of agricultural income. This agreed with (Kanafani 2016) where he found that the poverty line in Palestine for a family of 5 members was estimated at US $668 per month, and the deep poverty line at US $534 per month.

Furthermore, the survey showed a significant portion of households' monthly income was spent on water for domestic and agricultural purposes. Another major contributor to household monthly expenditure was animal feeds. Rubhara et al. (2020) found that the animal feed is a major contributor to household monthly expenditure. A strong presence was found for women contribution to agricultural income particularly in animal production sector. Women make essential contributions to agriculture in all developing countries. Rural women often manage complex households and pursue multiple livelihood strategies (SOFA Team and Doss 2011). The study also revealed that the majority of vegetable farmers (80%) and livestock farmers (77%) reported that agricultural inputs are most of the time accessible in terms of quality, quantity and prices. The results revealed that (65%) of the farmers receive extension services from the ministry of agriculture (MOA), (10%) from nongovernmental organizations (NGOs), (15%) from private companies, and 10% from other sources. More than 58% of farmers sell their agricultural products to wholesale market, 22% to traders, 5% to other farmers, 7% directly to consumers and 8% to others.

Moreover, water harvesting was a predominant activity in the area due to water scarcity in Palestine in general and the study area in particular, where the average annual rainfall is less than 200 mm. Rain is the cheapest source of water for agricultural purposes. In many dry regions of the World, there is no alternative but a better and more effective use of rain to increase and secure food production (Koohafkan and Stewart 2008).

Biophysical Characteristics

pH and Salinity, the pH level in the soil ranged from 7.9 to 8.6. In such type of soil (alkaline soil), phosphorus and most micro-nutrients become less available (Alvey et al. 2001). The salinity level of the soil in the root zone ranges from 1.5 dS/m up to 2.5 dS/m. According to the soil salinity classification it indicates that salinity is not an expected problem in the root zone in this area. This is due to the leaching of excess salts from the root zone. In many countries, the land is destroyed by salt accumulation each year. This rate can be accelerated by climate change and excessive use of groundwater (Machado and Serralheiro 2017) (Fig. 4).

Macronutrients, Potassium (K) ranged from 30 to 450 ppm. Bardala sample show very high level of K whereas Aljeftlik is very low and all other samples is within the normal range. Phosphorous (P) content in all sites is very high. Total Nitrogen (TN) percentage in all sites is very low (0.2 to 0.7 ppm), Magnesium (Mg) level from 20 to 170 ppm. In Aljeftlik and Alzubaidat Mg level is low and the level is high for Atoof (Fig. 5). Normally farmers apply excessive fertilizers and the soil environmental problems caused by these methods are substantial (Zhang et al. 2016). In the process

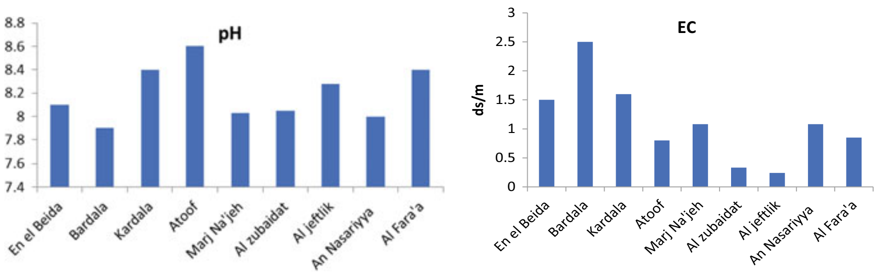

Fig. 4 pH and salinity of the tested soil samples

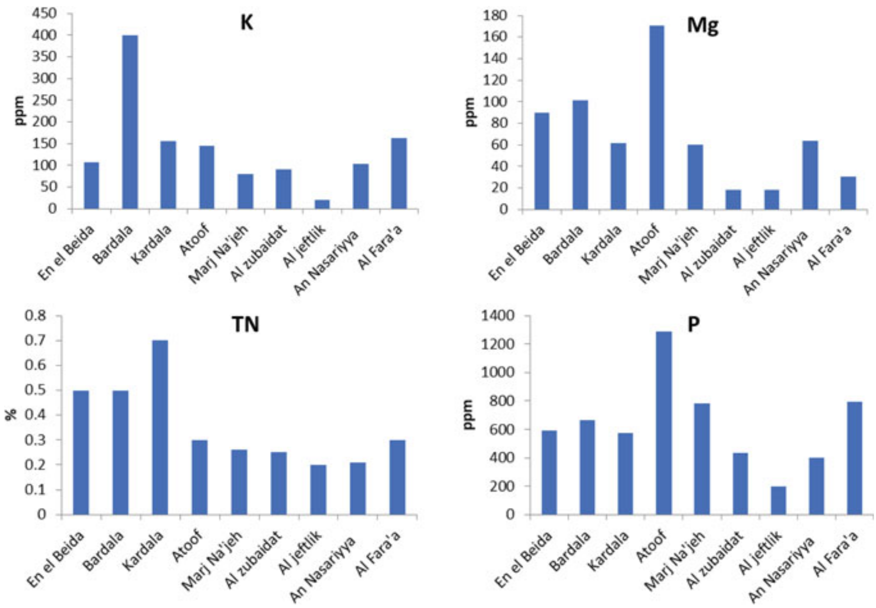

Fig. 5 Macronutrients level in the tested soil samples

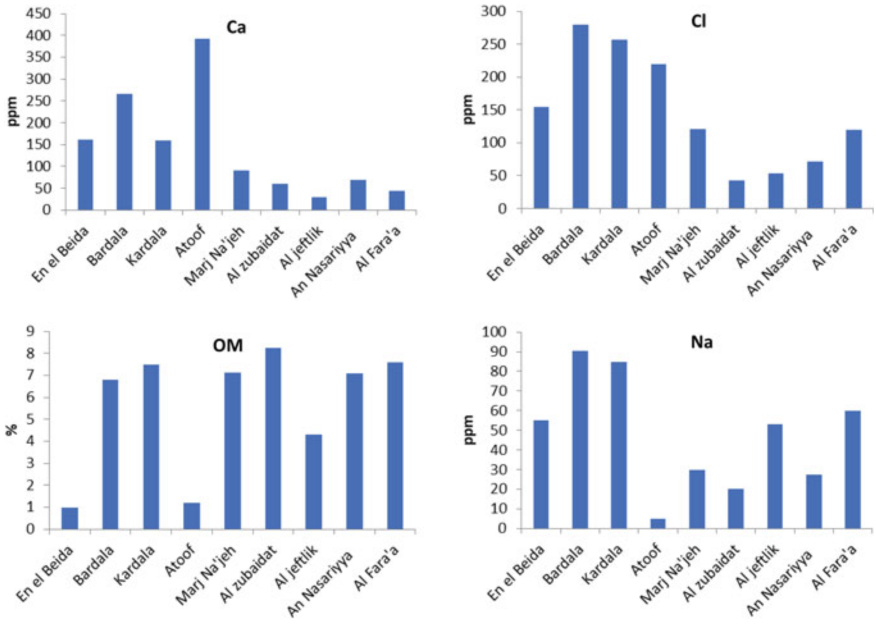

Fig. 6 Ca, Cl, Na and OM in the tested soil samples

of the growth and development of crops, the absorption and utilization of the nutrients are limited. Excessive nutrient application can inhibit the quality and yield of fruits and vegetables, leading to soil degradation (Dong et al. 2014).

Calcium (Ca), Chloride (Cl), Sodium (Na) and Organic matter (OM), Ca level in soil is low in all of the samples (ranged from 25 to 390 ppm). Calcium-deficiency is an economic problem for commercial vegetable growers due to the use of more intensive production practices (Olle and Bender 2009). The concentrations of Cl and Na in the soil samples were normal. The percentage of OM in the soil samples is normal and it ranged from 4 to 8%. OM affects crop yield by supplying nutrients and by modification of the soil physical properties for stimulating plant growth (Chang et al. 2007) (Fig. 6).

Principle Component Analysis (PCA)

The results of PCA matrix analysis showed that the first three axes, accounted for 90% of the total cumulative variation. This indicated a wide spectrum of the variation between the locations. As illustrated in Table 2, Cl, Ca and Na have a strong loading on the first principal component. While OM and TN have the strongest loading on the second principal component and pH has the strongest loading on the third component (Table 3).

Table 2 PCA matrix for the nutrients in the soil samples

Nutrients	Component		
	1	2	3
p	0.355	0.788	0.004
pH	−0.089	−0.017	0.985
EC	0.930	0.184	−0.275
OM	−0.230	0.913	−0.031
Ca	0.930	0.063	−0.302
Mg	0.825	0.330	−0.444
Cl	0.960	0.188	0.087
TN	0.882	0.960	0.345
NA	0.907	0.346	0.184
K	0.756	0.328	−0.301

Table 3 Correlation matrix for the nutrients in the soil samples

	P	OM	Ca	Mg	Cl	TN	Na
OM	−0.155						
Ca	0.555	−0.320					
Mg	0.646*	−0.382	0.946**				
Cl	0.662*	−0.098	0.642	0.676*			
TN	0.056	0.198	0.369	0.251	0.676*		
Na	−0.252	0.452	0.121	−0.015	0.368	0.778**	
K	0.212	0.221	0.530	0.401	0.643*	0.491	0.676*

* Correlation is significant at the 0.05 level (P<0.05)
** Correlation is significant at the 0.01 level (P<0.01)

Correlation

Different soil parameters were significantly correlated with each other. Strong positive correlation was found between Mg and Ca, Na and TN, K and Cl, K and Na, Cl and Ca. Other parameters showed weak negative correlation such as in the case of OM and P, Na and P, Cl and OM, and Mg and Na.

Variation Between the Sites

Significant variations ($p < 0.05$) were found between the sites for OM and for macro and micro nutrients (Table 4). The variation in the nutrients revealed the differences in agricultural input use by the farmers.

Table 4 Analysis of variance for tested sites for macro and micro nutrients

		Sum of Squares	df	Mean Square	F
Ca	Between groups	226,259.061	9	25,139.896	948.872
	Within groups	264.945	10	26.494	
	Total	226,524.006	19		
Mg	Between groups	36,965.368	9	4107.263	512.000
	Within groups	80.220	10	8.022	
	Total	37,045.588	19		
Cl	Between groups	148,008.347	9	16,445.372	49.135
	Within groups	3346.981	10	334.698	
	Total	151,355.327	19		
TN	Between Groups	0.434	9	0.048	123.755
	Within groups	0.004	10	0.000	
	Total	0.438	19		
Na	Between groups	17,536.745	9	1948.527	861.227
	Within groups	22.625	10	2.263	
	Total	17,559.370	19		
K	Between groups	172,581.138	9	19,175.682	852.253
	Within groups	225.000	10	22.500	
	Total	172,806.138	19		
P	Between groups	2,260,597.016	9	251,177.446	211.912
	Within groups	11,852.895	10	1185.290	
	Total	2,272,449.911	19		
OM	Between groups	21.286	9	2.365	29.703
	Within groups	0.796	10	0.080	
	Total	22.082	19		

Vulnerability to Climate Change

The analysis for the long-term annual average temperature of Palestine over the period 1900–2013 shows a clear increasing trend in the annual average temperature in Palestine as indicated in Fig. 7.

Focusing on the past century (1900–2000), the mean annual temperature in Palestine has increased at a rate of 0.082 °C/decade (Fig. 7a). While over the period (1984–2013) the mean annual temperature has increased at a rate of 0.27 °C/decade (Fig. 7b), this result is in line with the findings of UNDP (2010) and El-Kadi (2005) where both of the studies indicated an increasing trend in the mean temperature in Palestine and Gaza Strip, respectively.

Concerning the Northern Jordan Valley area, the monthly average maximum and minimum temperature in the study area has increased over the period 1975–2019

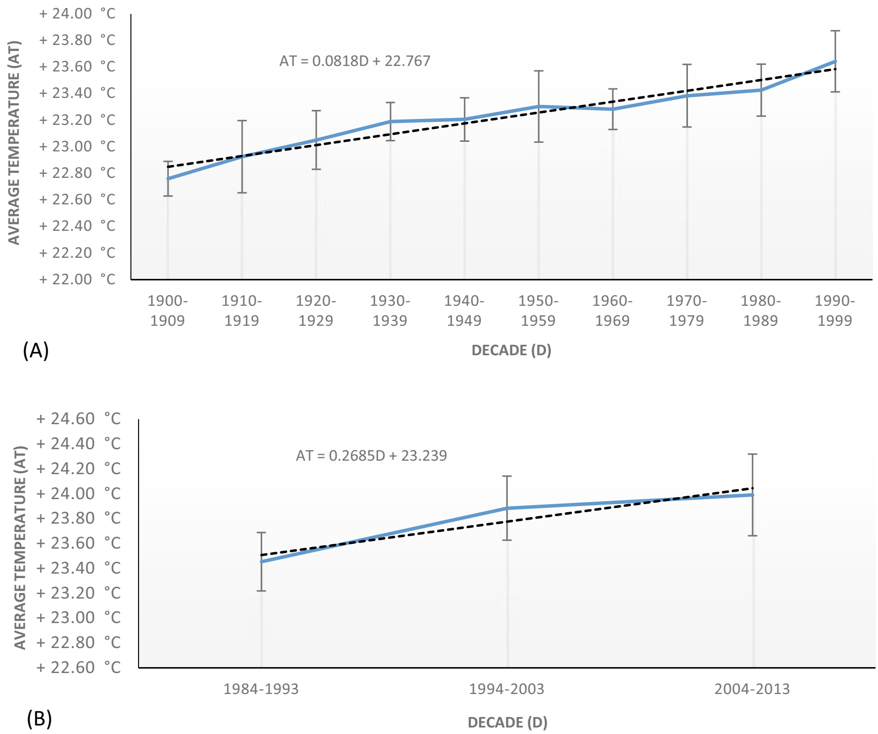

Fig. 7 Trends in mean annual temperature in Palestine: **a** over the twentieth century, **b** over the period 1984–2013

(Fig. 8). Moreover, the average monthly values of maximum and minimum temperatures of the period 1976–2019 in the study area have exceeded the long-term monthly average of maximum and minimum temperatures as illustrated in Fig. 9.

Concurrent with the increasing trend in temperature, more frequent heat waves have been observed in the last few years, especially in the Northern Jordan Valley region (ARIJ 2013). This region in particular is under risk because it usually has elevated temperature all year around in comparison to the rest of Palestine and all Middle East countries, due to its topographic settings, as most of the area is located around 350–370 below sea level (ARIJ 1995).

The average annual rainfall of the Northern Jordan Valley region showed a decreasing trend over the period 1970–2019 (Fig. 10). The ten-year moving average of rainfall revealed a reduction in annual rainfall by 4.5 mm/ decade for the same period (Fig. 11). The risk of droughts and aridity in the region will increase due to the predicted reduction in annual precipitation rates (MoFA Netherlands 2018).

Besides other political and natural factors affecting water resources in the study area, climate change has exaggerated water scarcity because of changing in the amount and patterns of precipitation (Fig. 10). Rainfall season in Palestine lasts

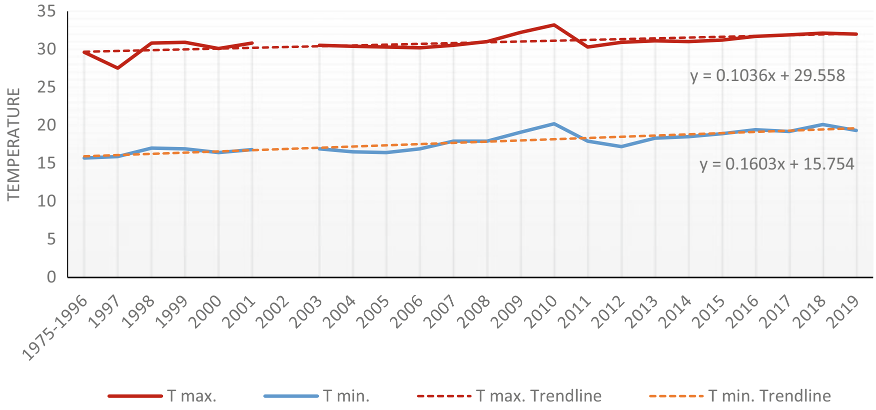

Fig. 8 Monthly average maximum and minimum temperature in the study area over the period 1975–2019

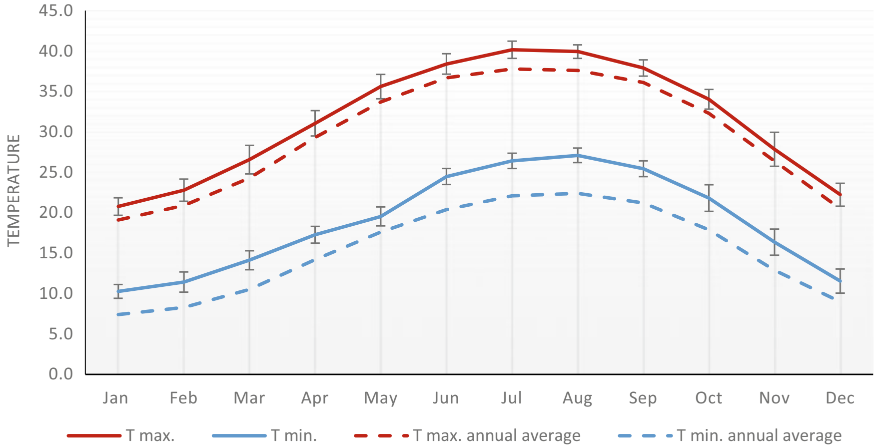

Fig. 9 Monthly average maximum and minimum temperature over the period 1976–2019 in the study area

from September to May, and usually reaches its peak in the period from December to March each year. However, due to climate change the rainfall season has been shifted to later summer months with dominant higher temperatures, which in turn has led to increase in the evapotranspiration rate and has reduced surface and groundwater supply in the Northern Jordan Valley region. Consequently, this has exacerbated the water crisis in the study area.

As a result of the combined effect of climate change (increased temperature, change in rainfall patterns and amount, heat waves and droughts) and human activities (e.g. intensive agriculture and rough grazing) the rate of vegetation has decreased in

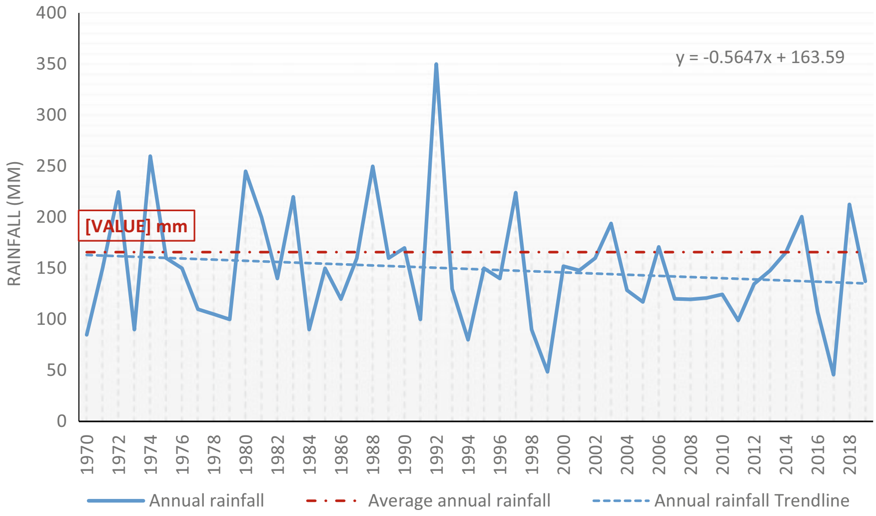

Fig. 10 Annual average rainfall over the period 1970–2019 in the study area

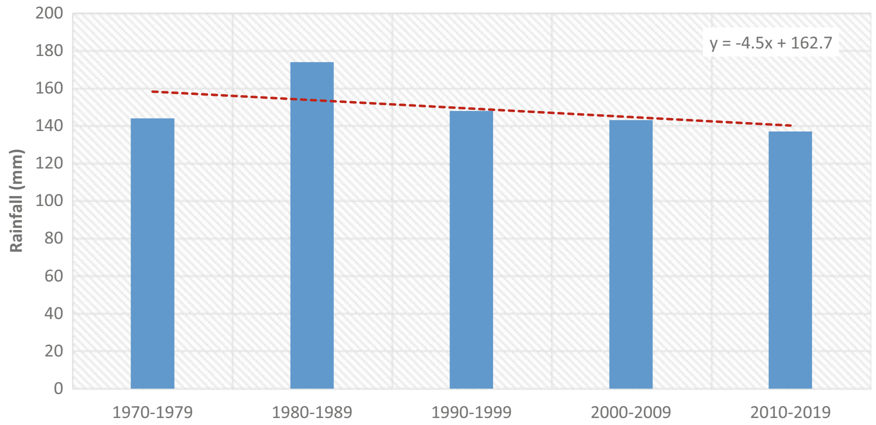

Fig. 11 Ten-year moving average of rainfall over the period 1970–2019 in the study area

42.7% of the West Bank area, especially in the Jordan Valley region (which is the most impacted area of land degradation in Palestine).

Approximately 22.3% of the Jordan Valley area is under the effect of active degradation (ARIJ 2013). Agriculture has been badly affected by climate change; the growing season has become shorter, water requirements for crops have increased and stocks and grazing range has declined, consequently the food prices has become higher (UNDP 2011; MoFA Netherlands 2018).

Compared to the past years, in recent years, salinity of groundwater has increased due to over-pumping, and reduction in groundwater recharge due to periodic shifting

Table 5 Population of the study locations in 1997, 2007 and 2017

Site	Population in 1997	Population in 2007	Population in 2017	Predicted Population in 2017 using Eq. (1)
Bardala	1154	1637	1607	**2166**
Kardala	121	307	203	**406**
Ein el Beida	791	1163	1138	**1539**
Al Fara'a	1713	2730	3998	3612
Atoof	76	171	216	226
An Nassariya	1010	1585	1889	2097
Al Jeftlik	3177	3714	3100	**4914**
Al Zubaidat	968	1421	1679	1880
MarjNa'ja	554	715	828	946

of rainfall resulted from climate change. This has led to another shift in cropping patterns, where farmers replaced historical cultivated species with more salinity tolerant ones. Quality and quantity of this shifting in crops is still not satisfactorily measured.

The high vulnerability of Northern Jordan Valley region to climate change has strongly impacted the livelihoods of its inhabitants as they are suffering from high production cost as they need to pay for animal feeds, fertilizers to meet the crops requirements of nutrients and increase their production, and water requirements due to water scarcity in the area. Furthermore, the lower production means lower income for inhabitants as agriculture supports most of the households in the area (e.g. 97% of Al Zubaidat's inhabitants are working in agriculture (ARIJ 2012b). All of this besides other political factors has forced many people to migrate causing a decline in the population of the Northern Jordan Valley region (Table 5). This could be clearly seen from the decreasing trend of population in certain locations of the study area during the period 2007–2017 (Fig. 12).

The impacts of climate change are expected to exacerbate threats to public health where many people will be food insecure and suffer from nutritional deficiencies, waterborne diseases due to low quality of drinkable water, and be at risk of other diseases related to lack of water such as dehydration, diarrhea and cholera (UNDP 2010; MoFA Netherlands 2018). This could be very dangerous in a population feeling insecure by all means.

Conclusions

The study findings revealed that the average households' monthly income in the study area was in the range (US $440–1000) with animal production, labour farming wages and plant production as main sources of agricultural income. Furthermore,

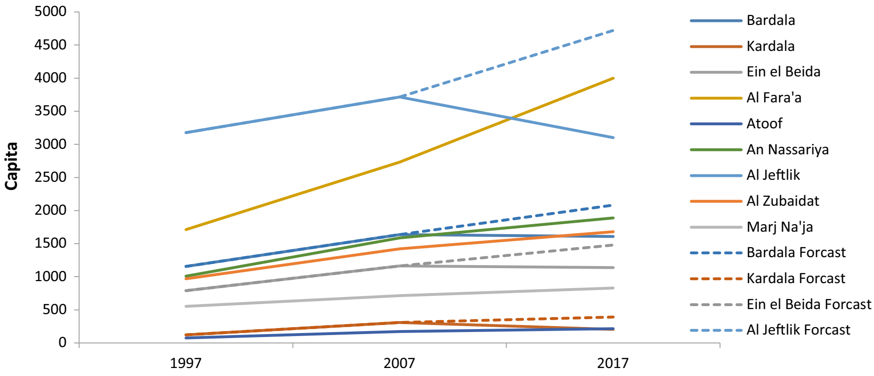

Fig. 12 The population of the study area by location

the survey showed a strong presence of women contributing to agricultural income particularly in animal production sector. A significant portion of households' monthly income was spent on water for domestic and agricultural purposes. Another major contributor to household monthly expenditure was animal feeds. Water harvesting was a predominant activity in the area due to water scarcity in Palestine in general and the study area in particular.

The chemical analysis of the soil sample revealed that the salinity problems in the irrigated area are not permanent problem, in fact, the problem is coming from the farmer practices and the irrigation management. Furthermore, the analysis results revealed that the fertilization efficiency was low and fertilizers losses were high.

Analysis of climatic data showed an increasing trend in the mean temperature in Palestine as a result of climate change where the mean annual temperature has increased at a rate of 0.27 °C/decade over the period 1994–2013. Analysis of climatic data of the Northern Jordan Valley announced a reduction in annual rainfall by 4.5 mm/ decade during the period 1970–2019. In addition, the average monthly values of maximum and minimum temperatures of the same period have exceeded the long-term monthly average of maximum and minimum temperatures in the study area.

Without appropriate adaptation strategies to climate change the existing problems at the northern Jordan Valley region are expected to increase. The significant warming, decreased rainfall amount, heat waves and droughts will cause environmental and social crisis, threaten food security and make water resources scarcer. Species and people won't be able to cope with climate extremes. The population in the arid area will decrease at an accelerated rate as more people will move to other places away from the vulnerable area. To avoid this, the Palestinian authority should adopt a clear strategy to combat and adapt to climate change, empower local communities, and attract agricultural investments in the region, and have a policy and strategy for management of drylands with clear development and investment plan. Strong collaboration between all stakeholders in the society is required for building resilience to climate change.

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An Assessment of Meteorological Drought Variability in Representative Areas of Rajasthan

Era Upadhyay and Jhumoor Biswas

Abstract Drought is one of the major disasters in India farmers are exposed to, due to inconsistent rainfall and changes in precipitation patterns. The inter-annual and inter-seasonal variabilities in rainfall patterns can increase vulnerability towards drought conditions. This study has been carried out to explore the variabilities and patterns of rainfall, to understand the natural causes underlying drought and to determine the indicators such as change in level of agricultural output and to take a holistic view on drought management over the years. Ultimately, mitigating approaches such as early warning systems and crop insurance for farmers are needed to minimize the impact of drought. The precipitation and temperature data of four major drought areas of Rajasthan (Barmer, Hanumangarh, Jaisalmer and Jodhpur) were considered for the past 41 years (January 01, 1979 to June 20, 2020). The highest annual rainfall was recorded in Barmer and Jaisalmer in 2006 due to flood. The months of January, March, April, September, October, November and December were with less or no precipitation while light to moderate rainfall (0.10–15.71 mm) occurred during the months of July and August at all sites. Standardized Precipitation Index (SPI) was used as a primary tool for drought analysis by calculating monthly rainfall for all sites across all the years. The years 1986 and 2002 stand out as extremely dry years for all the four districts as there was a prolonged dry condition prevailing during the monsoonal season for that year. July, August and September had highest SPI values (−1.0 to 2.0), whereas winter months had low SPIs (1.5–1.99). The various types of analysis conducted in this study will enable to understand the comprehensive nature of drought impacts.

Keywords Drought · Standardized precipitation index · Cost–benefit analysis · Weather forecast

E. Upadhyay (✉)
Amity University Rajasthan, Jaipur, India

J. Biswas
Indian Institute of Social Welfare and Business Management, Kolkata, India

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Introduction

Drought is characterized by insufficient precipitation for a prolonged period of time, resulting in hydrological imbalance (Zhang et al. 2015). Based on measurement, drought may be categorized as meteorological, hydrological, and agricultural as a physical phenomenon, while fourth category, socio-economic drought relates to supply and demand reflects from socio-economic system (Wilhite and Glantz 1985; American Meteorological Society 2004). Meteorological drought occurs due to lack of precipitation over a region for a period of time (Estrela et al. 2000) while hydrological drought is the result of inadequate water resources over a period of time (Clausen and Pearson 1995). Subsequently, a decline in soil moisture to a period may cause agricultural drought.

Although past studies have applied various methods to determine different drought characteristics, precipitation based drought investigation was found more appropriate for this study because rainfall deficiency is the main reason causing drought (Gocic and Trajkovic 2013). The distribution of rainfall across the world is affected by the magnitude and direction of air circulation through the atmosphere. Due to anomaly in surface temperatures, air circulation patterns are altered which change the patterns of precipitation falls (Chang and Wallace 1987).

The new weather patterns may affect the surface and groundwater resources and can cause reduced attributes like water supply, crop yield, power generation, habitats, cropping systems, livestock and adverse effects on socio-economic activities (Riebsame et al. 1991; Olesen et al. 2011). Adverse effects on plant growth due to drought resulting from water deficiency reduced the crop yield (Karl et al. 2009). During severe drought in Bikaner of Rajasthan, the cropped area was reduced 12% and productivity was reduced about 85% while moderate drought reduced yields by 55%, but the cropped area was reduced by 8%. This result reveals that even under moderate to severe droughts, farmers in the Bikaner region are committed to planting this drought-hardy arid legume (Narain et al. 2001).

Drought may reduce crop yields due to inadequate water and availability of soil moisture for crop growth. During draught episodes, farmers have to adopt favourable cropping system and may consider only drought tolerant crops. Therefore, different water resource management strategies are required to regularize the crop system. However, it is imperative to understand the spatio-temporal variability of drought to formulate and mitigate its potential adverse effects on agriculture. Thus, this study has been carried out to explore the variabilities and patterns of rainfall, to understand the natural causes underlying drought and to determine the indicators such as change in level of agricultural output and water availability to take a holistic view on drought management over the years. Early warning systems and seasonal weather forecasts are required to mitigate the impact of drought. The various types of analysis conducted in this study will enable to understand the comprehensive nature of drought impacts.

Materials and Methods

Study Area

Rajasthan state in the North-Western part of India comprises 11% of the total geographical area of India and located between 23°30′ and 30°11′ North latitudes and 69°29′ and 78°17′ East longitudes. The state is surrounded by Aravalli Mountain stretching from southwest to northeast which play a major role in the climatic pattern of Rajasthan. The Arabian monsoon strikes the Eastern slope of Aravalli consequently sufficient rainfall occurs in Eastern part, whereas the Western part remains arid. The South-Eastern part of Aravalli is characterized by humid climate and subsequent green vegetation, whereas, North-Western part has desert or semi desert areas. The state follows two crop patterns based on seasons-monsoon dependent Kharif crops which are sown in summers (June–July) and harvested in the months of September and October, another is Rabi crops sown in winters (October–November) and harvested in the months of March–April. In this study, four districts (Barmer, Hanumangarh, Jaisalmer and Jodhpur) of Rajasthan have been selected to understand the drought patterns and associated issues. These four districts are declared as drought prone areas by the state government (http://www.dmrelief.rajasthan.gov.in/index.php/9-news/170-samvat-2072) (Fig. 1).

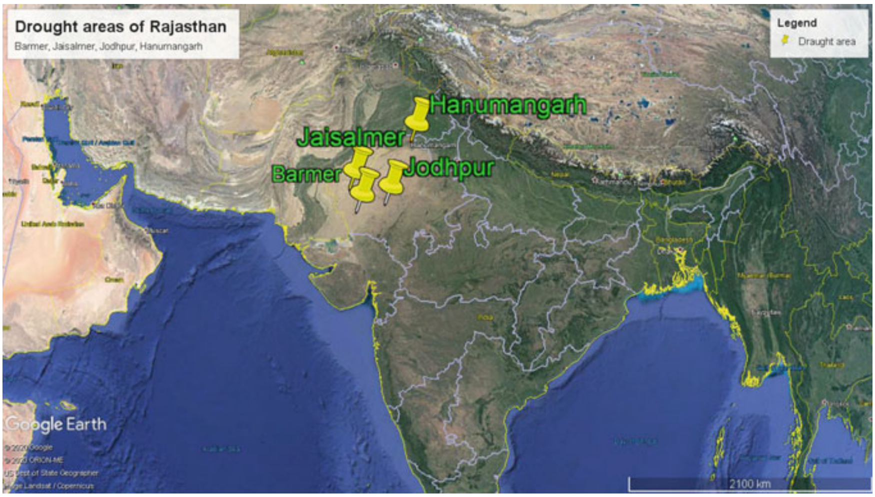

Fig. 1 Study area

Table 1 Location of stations

Station	Latitude	Longitude	Elevation (m)
Barmer	25° 45′ 11.35″ N	71° 25′ 5.02″ E	173
Hanumangarh	29° 34′ 29.2800″ N	74° 19′ 58.7172’″ E	182.23
Jaisalmer	26° 54′ 56.7″ N	70° 54′ 30.04″ E	238.21
Jodhpur	26° 16′ 06″ N	73° 00′ 21″ E	237

Data Collection

Daily precipitation, minimum temperature and maximum temperature data were collected from CPC Global Unified Precipitation data provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, from their website at https://psl.noaa.gov distributed in study area (Fig. 1) for the period 1979–2020. The geographical location of the selected stations is given in Table 1.

Data Analysis

Monthly averages, annual averages, mean deviation and standard deviations were calculated for determining the inter-annual and inter-seasonal variabilities in rainfall and temperature patterns. Correlation analysis was applied to monthly precipitation and temperature time series of each station across all years. Drought analysis was conducted by calculating the monthly rainfall and temperature data for past + 40 years using Standardized Precipitation Index (SPI). The SPI is a meteorological drought index which has been frequently used by decision makers for measuring and monitoring the intensity of meteorological drought events. SPI is also useful for identifying spatio-temporal extent of long term historical droughts (Mckee et al. 1993). In this study, SPI was used to identify the incidences of meteorological drought, its intensity and spatio-temporal extent across drought districts of Rajasthan. SPI was calculated using software SPI calculator, DrinC—Drought Indices Calculator version: 1.7 (91); it reads from standard input and writes to standard output. SPI values generated by software further classified according to Table 2 followed by the droughts classification.

Table 2 SPI drought classification

SPI values (Range)	Type of drought
>2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
>−2	Extremely dry

Results and Discussion

Inter Seasonal Variability and Trends

Figure 2 illustrates that the months of January, March, April, September, October, November and December are with less or no precipitation while light to moderate rainfall (0.10–15.71 mm) occurred during the months of July and August at all sites. Low precipitation was also observed by Schafer in March, October, and December while highest in January, June, and July (Schafer, 2001). However, the distribution, and direction of the trends varied from month to month for each site. A sharp rise in precipitation can be seen in the month of August, 2006 for Barmer and Jaisalmer. Barmer received 714 mm rainfall/22 days against 238 mm seasonal mean and Jaisalmer received 477 mm rainfall/22 days against the seasonal mean of 150 mm. This continued rainfall resulted in a flood in the Thar Desert. Usually, the rainfall exceeding 100 mm/day with 3–5 day long wet spell causes a potential risk of flood, however, the total amount of precipitation may vary in the range of 250–600 mm (Kar 2011).

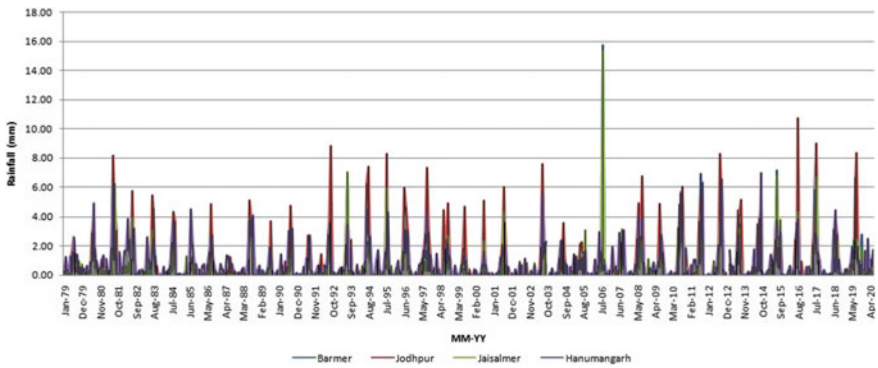

Fig. 2 Inter seasonal variability and trends in precipitation of Barmer, Hanumangarh, Jaisalmer and Jodhpur (1979–2020)

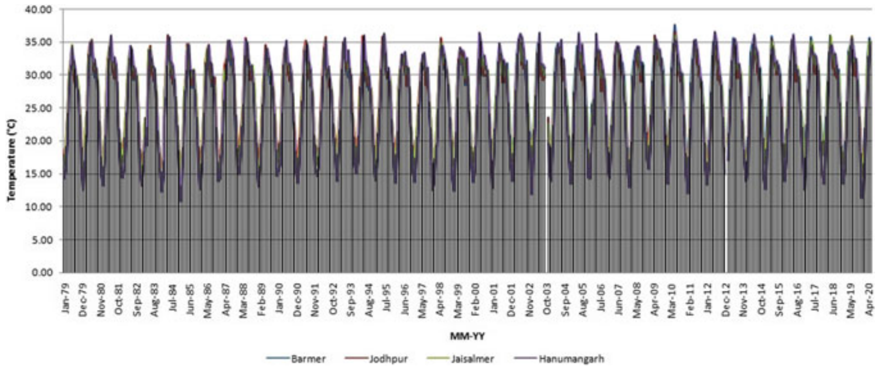

Fig. 3 Inter seasonal variability and trends in temperature of Barmer, Hanumangarh, Jaisalmer and Jodhpur (1979–2020)

The maximum monthly averages of temperature occurred in the months for May and June while minimum temperatures are obtained in the month of January (Fig. 3). Also, in a study with 41-year temperature data, the maximum mean average temperature was found in pre-monsoon followed by monsoon season and the average minimum temperature was observed in the post monsoon season (Deoli and Rana 2019).

Inter Annual Variability and Trends

There was inconsistent pattern of rainfall distribution that can be noticed over time and space (Fig. 4) during January 1979–June 2020. Schafer also found inconsistent

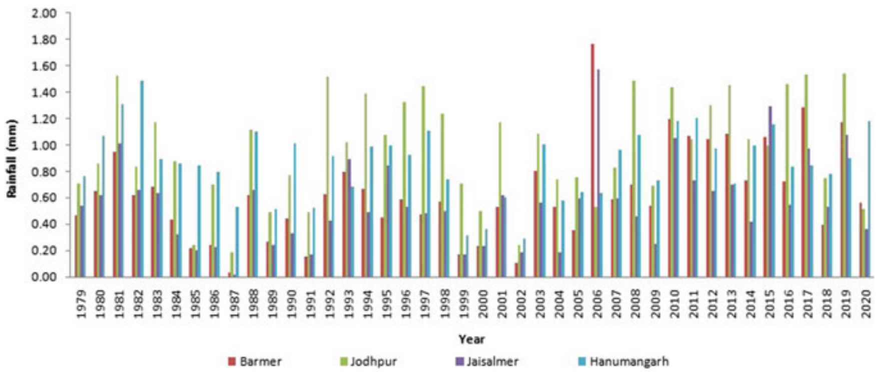

Fig. 4 Interannual variability and trends in precipitation of Barmer, Hanumangarh, Jaisalmer and Jodhpur (1979–2020)

annual precipitation trend patterns with positive trends in some parts of the middle and lower catchment since 1951 (Schafer 2001).

The minimum annual averaged precipitation occurred in 1987 in Barmer, Jaisalmer, Jodhpur (0.01–0.18 mm) and Hanumangarh (0.29 mm) in 2002. Maximum annual averaged precipitation has been observed in Hanumangarh (1.48 mm) in 1982, Barmer and Jaisalmer (1.57–1.77 mm) in 2006 followed by Jodhpur (1.54 mm) in 2019. Thus highest annual rainfall was recorded in Barmer and Jaisalmer in 2006 due to floods. Similar trend of total annual rainfall was observed at Jaisalmer as the area received 513 mm/16 days and 759 mm/24 days for Barmer in 2011 (Kar 2011).

About 59% for Barmer, 68% for Hanumangarh, 67% for Jaisalmer and 57% for Jodhpur of annual averaged precipitation across the years (1979–2020) lie between mean and standard deviation (Table 2). Therefore, Hanumangarh is driest and Jodhpur is observed with higher precipitation amongst drought filled districts. The drought in western part of Rajasthan is observed very frequently (once in 3–4 years) and once in 5–6 years in the Eastern part of Rajasthan (Dutta et al. 2015).

The years of lesser rainfall (lower annual average) below (0.615, ±0.344) were recorded 1985, 1986, 1987, 1989, 1991, 1999, 2000, 2002, 2006 for Barmer; 1987, 1989, 1991, 1999, 2000, 2002 for Hanumangarh (below 0.838, ±0.266), 1985, 1987, 1991, 1999, 2002, 2004, 2006 for Jaisalmer (below 0.55, ±0.331) and 1985, 1987, 1989, 1991, 2000, 2002, 2006 for Jodhpur (below 0.9617, ± 0.4029). The rainfall was recorded below 56% particularly in the month of July lead to a severe drought over most of the regions and India experienced approximately 21.5% deficit of rainfall during the year 2020 (Bhat 2006).

The results of correlation analysis with annual averaged daily maximum temperatures for the years 1979–2020 are shown in Table 3. A uniform correlation curve was found for all four regions which show slight variability in temperatures. A negative correlation with the Indian monsoon was observed due to the effect of El-Niño Southern Oscillation phenomenon and the Himalayan/Eurasian snow cover on Asian monsoon (Kripalani et al. 2003).

Table 3 Mean deviation, Standard deviation and correlation analysis for Barmer, Hanumangarh, Jaisalmer and Jodhpur (1979–2020)

Station	Mean		Standard deviation		Correlation
	Precipitation	Temperature	Precipitation	Temperature	Precipitation versus Temperature
Barmer	0.615	33.43	±0.344	2.83	0.22
Hanumangarh	0.838	32.00	±0.266	2.88	0.19
Jaisalmer	0.55	33.49	±0.331	2.87	0.19
Jodhpur	0.9617	33.17	±0.4029	2.85	0.16

Drought Analysis Using SPI

Drought event occurs when SPI is continuously negative and reaches an intensity of −1 or less while positive SPI indicates the ending. The spatiotemporal pattern of SPI reveals Jodhpur having highest count of near normal precipitation conditions (−0.99 to 0.99 SPI) for most years followed by the other drought districts. 1986 and 2002 stand out as extremely dry years for all the four districts as there was a prolonged dry condition prevailing during the monsoonal season for that year. July, August and September have highest SPI values (−1.0 to 2.0), whereas winter months have low SPIs (1.5–1.99). Mundetia (2014) also reported the mild to severe drought (0.0 to −1.99) covering all study sites of this study for similar time period.

Impact of Drought on Crop Yield

Based on agricultural droughts, crop yield can be investigated. Several studies carried out in the last decade links crop yield with drought conditions. The crop production was investigated and yield was found according to the results of this study. Less than 35% vegetation cover over most of the areas of Rajasthan indicating drought related stress during year 2000 (Dutta et al. 2015) while lowest Irrigated and rainfed crop yields were observed in 2011 (Ram et al. 2018). A correlation was observed between sorghum yields and southern oscillation (SO) in Argentina, Australia, India, and Texas (Keplinger and Mjelde 1994) while a close relationship between SO and Australian crop yield was recorded by Nicholls (1985). SO effects are also related to precipitation patterns (Woolhiser and Keefer 1993).

Similarly, the recorded increasing yields of corn (49%) and sorghum (108%) showed the positive responses to annual rainfall (250 mm) during 2011–2013. In contrast, Ray et al. (2018) reported slight decrease in yields of corn and sorghum crops during 2015 and 2016 due to floods. In terms of crop yields, 1987 was the worst year which experienced severe drought subsequent to poor moth bean crop yield. Our analysis shows up the year 1987 with lower annual averaged precipitation values for all the four sites. Usually the crops yields were adversely affected due to severe to moderate agricultural droughts in each alternate year (Pratap et al. 2001). A significant correlation between temperature and the maize yields was reported (Cane et al. 1994). As per the intensity of drought, the cropped area and productivity of arid legume was reduced by 12% and 85% respectively due to severe drought while moderate drought diminished yields by 55% and 8% cropped area in Bikaner (Pratap et al. 2001).

Conclusions

On the basis of inter seasonal, inter annual variability, standard deviation, correlation in the multisite of precipitation and temperature, and drought analysis in this study area during January 01, 1979–June 20, 2020, the following conclusions can be inferred from this study:

- The precipitation and temperature patterns and drought behavior at monthly, seasonal, and annual time scale in four areas of Rajasthan were analyzed and annual means, variabilities and correlations were determined.
- The months of January, March, April, September, October, November and December are with less or no precipitation while light to moderate rainfall (0.10–15.71 mm) occurred during the months of July and August at all sites.
- The distribution and direction of the trends varied from month to month for each site. The maximum monthly averages of temperature occurred in the months for May and June while minimum temperatures are obtained in the month of January.
- There was inconsistent pattern of rainfall distribution noticed over time and space during January 1979–June 2020.
- The minimum annual precipitation averages occurred in 1987 in Barmer, Jaisalmer, Jodhpur (0.01–0.18 mm) and Hanumangarh (0.29 mm) in 2002. Maximum annual precipitation average has been observed in Hanumangarh (1.48 mm) in 1982, Barmer and Jaisalmer (1.57–1.77 mm) in 2006 followed by Jodhpur (1.54 mm) in 2019. Thus highest annual rainfall was recorded in Barmer and Jaisalmer in 2006 due to floods.
- About 59% for Barmer, 68% for Hanumangarh, 67% for Jaisalmer and 57% for Jodhpur, precipitation across the years (1979–2020) lie between mean and standard deviations.
- A uniform distribution curve was found for all four regions with annual averaged daily maximum temperatures which show slight variability. Correlations between temperature and precipitation are poor as expected which is also reflected in annual productivity of crops.
- The years 1986 and 2002 stand out as extremely dry years for all the four districts as there was a prolonged dry condition prevailing during the monsoonal season for that year. July, August and September have highest SPI values (-1.0 to 2.0) whereas winter months have low SPIs (1.5–1.99).
- Overall, results suggest larger impact of drought on the yield of crops. This study may be helpful for farmers in drought areas of Rajasthan to consider reducing crop areas during drought periods and planting more drought-tolerant crops.
- Drought events can be mitigated by several management decisions related to water resource management such as sprinkler and drip irrigation methods and rain water harvesting. These decisions have to be taken by farmers at community level and regional decisions to promote awareness and aid to farmers must be taken by governments or state agencies.

Recommendations for Future Research

Since drought is a common risk in agriculture and severe draught may trigger famine, a detailed research is requiring in continuation of preliminary analyses conducted in this study. In the immediate perspective, spatio-temporal analysis of drought districts versus non-drought districts of Rajasthan may be performed to understand sensitivity of meteorological parameters leading to drought related conditions. Further, effectiveness of early warning systems such as seasonal weather forecasts needs to be evaluated to mitigate the impact of drought. Statistical forecasting methods using rainfall data from previous years may be used to forecast rainfall for future years for creating an effective roadmap for potential drought management measures. Also, the effectiveness of cost–benefit analysis is required for allotting crop insurance to farmers for economic relief due to crop failure.

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Building Resilience to Climate Change: A Case Study of Female Headed Households in Arid Region of Buhera District, Zimbabwe

L. Ruparanganda and C. Nyoni

Abstract Climate change is increasingly recognised as a global phenomenon with potentially far reaching implications. Sub- Saharan Africa has already started experiencing climate change. It is threatening food security with vulnerable groups who include female headed households most likely to suffer due to their heavy reliance on rain-fed systems to supplement household food security. This paper sought to explore strategies employed by female heads in building resilience to the effects of climate change. This was done by analyzing adaptation strategies employed by female heads in responding to climate change induced food insecurity as well as limitation to adaptation. An approach based on the understanding that resilience is a function of adaptation. The study is based on the action oriented theory of adaptation by Klaus I, 2011 as basis for understanding social action processes shaping climate change resilience building processes within female headed households. It makes use of the qualitative research approach through application of case study research design in which in-depth interviews, key informant interviews and focus group discussions were used to collect data. Findings from the study reflect that whilst female headed households have adopted numerous coping and adaptation mechanisms in building resilience to the threats of climate change on food security which include cultivation of traditional grains, shifting planting dates and diversifying livelihoods through participation in community savings groups and extraction of non-timber products for sale. Female heads remain constrained in their ability to adopt a wide range of local available adaptation strategies due to existing socio-cultural barriers, lack of resources and gender imbalances. Hence, the importance of designing policies, programs and implementation strategies that is gender sensitive for maximum benefit by female heads.

L. Ruparanganda (✉)
School of Social Work, Midlands State University, Harare, Zimbabwe

Present Address:
300 Sunway City, Ruwa, Harare, Zimbabwe

C. Nyoni
Department of Social Work, Bindura University of Science Technology, Bindura, Zimbabwe

X. Poshiwa and G. Ravindra Chary (eds.), *Climate Change Adaptations in Dryland Agriculture in Semi-Arid Areas*, https://doi.org/10.1007/978-981-16-7861-5_6

Keywords Adaptation · Climate change · Food security · Female headed household · Gender · Resilience

Introduction

Climate change is increasingly recognised as a global phenomenon with potentially far reaching implications (IPCC 2007, 2012, 2014). Sub-Saharan Africa has already started experiencing climate change (Holmgren and Öberg 2006). In Zimbabwe communities have already started reporting gradual changes in climatic conditions experiencing climate change marked by changes in rainfall patterns and increase in frequency of droughts (Brown et al. 2012). These gradual climate changes and extreme weather events are already undermining gains of agriculture research and development designed to secure household food security among smallholder farmers (Karfakis et al. 2012; Nelson et al. 2010). Ludi (2009) cites UNDP (2008) which notes that the impacts of climate change such as sea level rise, droughts, heat waves, floods and rainfall variation—could, by 2080, push more than 600 million people into malnutrition.

Changes in climate conditions will potentially impinge on the food security of smallholder farmers within the Sub-Saharan Africa because farming systems is heavily reliant upon rain-fed agriculture to supplement household dietary requirements (Nyantakyi-Frimpong and Bezner-Kerr 2015; Schulze 2010; Kotir 2011). Also due to the high poverty levels that typify the rural small-scale farmers their adaptive capacity remains low (Kates 2000). Among smallholder farmers, female headed households will be hardest hit as they already considered "to be the poorest" (Buvinic and Gupta 1997: p. 266) and "more food insecure" (Mallick and Rafi 2010: p. 593).

Several arguments are already being drawn as to why smallholder female heads are likely to be at danger of climate change induced food insecurities (Lambrou and Nelson 2010; Molua 2011; Twyman et al. 2014). These are centered around already existing gender related social, economic and cultural barriers such as insecure property rights, lack of or few assets, limited access to credit, extension services, weather information and an overburden of social caring roles (Alhasan et al. 2019; Tibesigwa et al. 2015; Alem et al. 2010; Hisali et al. 2011; Babugura 2010; Buvinic and Gupta 1997; Wanjiku et al. 2007). For example, in the event of a drought it has been argued that male heads of households are more likely to take up other off-farm opportunities, which may include temporary migration while women remain behind to care for the family (Kakota et al. 2011, Buvinic and Gupta 1997). This implies that their adaptive and mitigation options are lower than those of men (Bene et al. 2012; Lambrou and Piana 2006; Carr 2008; Eriksen and Silva 2009).

Zimbabwe records large proportions (40%) of female-headed households residing in rural areas (Agritex 2002) with the majority (nearly three quarters) of them living below the national poverty datum line (Horrell and Krishnan 2007). These are reported to experience challenges in financing agricultural activity, making them highly susceptible to households' food insecurity (Nyikahadzoi et al. 2012a, b). The food insecurity situation will likely worsen in the face of climate-change (Brown et al. 2012). Despite all this, and Zimbabwe's continued exposure to climate-related shocks, there remains limited literature on social processes shaping adaptation processes and challenges encountered by female heads. Instead most studies on climate change tend to broadly cover rural livelihoods and agricultural productivity (Bhatasara 2017; Brown et al. 2012; Mutekwa 2009; Bhatasara 2015) with little attention paid to understanding dynamics shaping climate change adaptation for rural female heads. The few studies that incorporate a gender lens (Musiyiwa 2014; Gusta 2017) remain strongly inclined to rural livelihoods concepts omitting the food security discourse. This situation hinders design of policies and implementation of programs that address unique needs of the specified group.

This study draws from the social action group of theories, particularly the action-oriented theory of adaptation as propounded by Klaus and Stecker (2011) in pursuit to understand social processes shaping climate change adaptation processes and associated challenges for improved household food security for female heads. A theory that seeks to explain the relationship among variables shaping adaption to changing environments which include stimulus, the receptor, resources used to shape change process and the associated outcomes.

Materials and Methods

Study Area

The study was conducted in Buhera District, Ward 30 in Manicaland Province of Zimbabwe. The province generally houses majority female heads (41.8%) in comparison to a national average of around 35% (Zimstat 2012). Ward 30 of Buhera District falls in Agro-Ecological Natural Region V of Zimbabwe. An area that falls within arid region characterised by erratic rainfall below 450 mm per annum and occupying low land area below sea-level (500 m). It is marked by little irrigation infrastructure development and experiences recurrent crop-failure and food shortages (Oxfam-UNDP/GEF 2015). The area is suitable for extensive production and game-ranching (Anderson et al. 1993). Hence, the combination of such agro-ecological and socio-demographic characteristics provided fertile ground to how female heads in arid conditions are building resilience to the threats of climate change on household food security.

Study Approach and Design

The study adopted qualitative research approach using case study research design in which in-depth interviews, focus group discussion and key informant interview were used as data collection methods. Purposive sampling strategies were applied throughout study processes in selection of all study participants. This was meant to ensure inclusion of persons with interests and knowledge deemed relevant to the research issues. In-depth household interviews were conducted with thirty female heads and three focus group discussions at community level. The focus group discussion comprised female heads grouped by age in the following categories 18 years to 35 years, 36 years to 59 years and the 60 years and above to capture variances in experiences for three categories namely youth, middle aged and the elderly. Each focus group discussion comprised 8 to 10 participants. Focus group discussions were meant to gain in-depth insight on experiences of female heads in coping and adapting to climate induced food insecurity. Key informant interviews were also conducted with representatives from various government departments (4 agricultural extension workers, 3 provincial and district administrative officials, 1 district environment specialist), local leadership (1 councilors, 2 village heads). Key informant interviews were meant to generate expert knowledge on how female-headed households were coping with effects of climate-change on households' food security and the challenges that they faced based on the expert's day-to-day interactions with this group including support programmes provided. All interviews were tape recorded to obtain the actual narratives from interviewees (Patton, 2002). Applied thematic analysis was used to analyse data. Specifically, data analyses process included transcription of narratives, coding of data and grouping of recurring issues into themes that guided the writing up of the findings (Guest et al. 2011). A process facilitated by application of the Statistical Package of Social Sciences Software (SPSS) in managing the data.

Ethical Considerations

Social science raises ethical issues (Creswell 2014). Schutt (2013) describe ethics as standards, principles and guidelines that have been followed when carrying out research. This study adhered to ethical standards and principles of research. The researcher took a number of steps to adhere to principle of confidentiality, informed consent, voluntary participation and giving feedback to participants after the study was concluded. The study was cleared by the Bindura University ethics clearance committee.

Results and Discussion

The findings of this qualitative study show that female heads are engaged in various climate change adaptation strategies centred on livelihoods diversification, adoption of new farming practices and increased reliance on external support in the form of social assistance programs and remittances. Adoption of the various strategies are meant to maintain household income, improve access to credit, and sustain agricultural productivity and secure alternative food sources.

Livelihood Diversification Strategies

Livelihoods diversification emerged as part of climate change adaptation strategies employed by female heads for sustained household food security. Participants explained that most female heads were increasingly depending on forestry products, adopting small livestock and enrolling in community based savings as livelihood diversification strategies in managing and coping with persistent climate change induced household food inadequacies. These themes are discussed in more detail below.

Reliance on forestry products

The study identified increased reliance on forestry products as part of climate change adaptation strategies employed by female heads. According to key informant participants, most female heads now resort to collection of forestry fruits and wild vegetables, hunting wild birds (quail) and extraction of salt from the Save river for sell or consumption as means of managing any weather induced household food gap. The *Adansonia digitata* fruit, *Ziziphus mauritiana* fruit, *Amaranthus hybridus* leaves, *Clome gynandra* leaves and *Bidens pilosa* leaves, and quail bird form common fruits, vegetables and birds, sought after by female heads during drought. The wild vegetables of *Amaranthus hybridus*, *Clome gynandra* and *Bidens pilosa* are harvested in abundance during rainy season and preserved through natural drying processes for use later in dry months of the year; a trend that has become common post year 2000. These wild vegetables which were once consumed for their medicinal properties now provide source of vitamins in the form of relish among female heads. Female heads are finding it difficult to sustain cultivation of exotic leafy vegetables-*Brassica oeracea* (chomolia) and *Brassica napus* L. (rape) as most shallow wells used in irrigating household gardens now dry earlier. Additionally, the *Adansonia digitata* fruit, quail birds and salt are sold and or traded for grain to migrants from surrounding towns and city. Reliance on forestry products is evident from the following comments by participants:

> "For the past five years or so the rains have continued to fail us. I have had to gather the *Adansonia digitata* fruit which we sell or exchange for grain with traders from Birchenough, Murambinda, Chipinge, Mutare even Harare". (Participant 5)

Similarly another participant said:

> "Unlike other households [male-headed] who can sell their cattle and secure grain for longer periods. For most of us it's a story of making use of what is available- the quail bird, *Adansonia digitata* fruit [baobob fruit] or salt from Save river. We now use the powder from *Adansonia digitata* fruit to make porridge for the young ones". (Ward 30, FGD Female Head Participants)

One other participant said:

> "In most cases female heads have very few livestock (Maybe 5 or 6 goats). Due to persistent low rains these have also not been reproducing that much. You cannot be found always selling them as it has become a yearly problem that there are no rain and harvest are poor. You have to look for other ways to also help and for us it's the *Adansonia digitata* fruit. Harvest, sell and buy food or get grain". (Key Informant Participant 7)

From the participants comments above it is clear that female heads have adopted reliance on forestry products as means of securing income and food during drought periods. Droughts have become a common feature in the area with the coping strategy becoming a way of life for the vulnerable female heads. The finding reflects usefulness of natural resources in aiding vulnerable communities' secure alternative sources of livelihoods as threatened by climate change. However, if unregulated the practice have the potential of not only negatively affecting the ecological system of a community but also contribute to accelerated climate change.

Adoption of small livestock

From the participants narratives, it is also evident that female heads are increasing adoption of small stock particularly goats and traditional chickens as means of managing the decline in harvest due to continued low rains. Whilst traditionally such livestock has been synonymous with women, female heads described them as cheap to purchase, fast to reproduce, easy to manage and quick to sell, making them a suitable climate change adaptation strategy for female headed households whose majority live within limited resources. The following remarks bring out female heads increased adoption of small livestock as a climate adaptation strategy:

> "It has continued to be dry and we are finding it better to use income that you may have to purchase goats. They are not affected that much by drought as with the cattle. These I sell in exchange for food or money when drought hits. They have helped us a lot. The past two years I have had to sell one or two per year to secure food". (Participant 3)

Another elderly female head narrated:

> "Most of the cattles that my husband owned died as a result of these droughts. I am now left with chickens and goats. I have been selling these or exchanging them for grain for the past three years. Any money I get I make sure I buy at least 1 or 2 chickens especially the Boschveld variety. It multiplies fast, produces more eggs which has been useful in managing this new problem of hunger. Chickens and goats do not require additional labour. I can always manage on my own. I just make let them out and as I do other chores they are browsing or looking for food in nearby surrounding". (Female Head Respondent 7)

An agricultural extension worker had this to say *"We are encouraging households to adopt small livestock particularly goats and traditional chickens as these are more drought tolerant in comparison to cattle. They are also easy to manage and are quick to dispose. Most female heads have taken heed of this call and whenever they secure some small funds are now resorting to investing in goats and traditional chickens. Whilst it has been difficult for household to find extra income to buy such livestock as they continue failing to make much due to low yields. Participating in community based savings groups has helped in providing access to income for purchasing small livestock. Additionally some NGOs continue to come with some pass small livestock* *projects targeted at female heads. This has improved their situation"* (Key Informant Respondent 2).

The above narrative of female headed households and key informants present the notion that small livestock have become a more attractive adaptation choice among female heads whose majority have limited income and labour resource. This can act as both a source of protein and means of cushioning households in dealing with household food deficit needs especially during severe drought periods as they can be exchanged for grain or sold for such purposes.

Enrolment in community based savings groups

Enrolling in community based savings and commodity groups emerged as one other climate change adaptation strategy common among female heads. The strategy provides female heads opportunities to save and have access to credit useful in managing household emergencies such as food shortages as opposed to local loan sharks who usually charge higher interest rates. Additionally money borrowed has been useful in providing start-up capital for income generating projects contributing to establishment of diversified livelihoods among households. They also noted ability of commodity groups to act as food reserve which they always find useful in covering any food needs as a result of weather related crop failure. Enrolment in community based savings groups as climate change adaptation strategy in arid regions by female heads is evident through the following narrations by respondents:

> "I joined the community savings groups and the profits are used to purchase household food items such as cooking oil, sugar and rice. A hamper is given out to every member at the end of year. Depending on amounts one can receive upto 20kgs of rice. This has been useful in covering for the poor harvests. Thus I always make sure to look for the $1 monthly subscription fee so I know I am guaranteed of something to feed my family in the next year even though there is a drought". (Female Head Respondent, 15)

Another female head respondent narrated:

> "The continued drought years have made it difficult for us as female heads to raise money for inputs for the next season. Being a member of the internal savings and lending club has at least guaranteed my household seed and fertiliser which I can use in the fields. This year is a bad year and I am planning to borrow some money to start some Boschveld chicken raring project". (Female Head Respondent, 27)

One other respondent had this to say: "*At times as female heads you have no one to quickly come in and rescue you following a drought. By joining the savings groups I know I can easily get a loan to buy food while I wait to sell that chicken or receive some remittances. As rains continue to be erratic, you need to be part of such groups. The monthly subscriptions are manageable especially for most of us who always find it difficult to raise large sums of money"* (Female Head Respondent, 10).

The above narrations thus confirm participation in community based savings groups as one other resilience strategy adopted by female heads. The findings confirm finding by Alhassan (2019) where female heads in Ghana were reported depending on savings to borrow money to cover food needs in times of drought. Members can also make use of loans secured from savings groups to finance a household project thereby promoting livelihood diversification a recommend approach to building resilience. For example in one similar study in Zimbabwe women tended to invest proceeds earned from communal savings groups to finance a new non-farm small business venture as means of building resilience against any future household shock including drought and floods (Gash et al. 2020).

Adoption of New Farming Practices

Adoption of new farming practices also emerged as part of the climate change strategies adopted by female heads in dealing with sustaining agricultural productivity so as to maintain household food security. This includes shifting planting dates, reducing land area cultivated and adoption of drought tolerant crops which are influenced by continued increase in dry spell, reduced amounts of rainfall, disappearance of winter rains which mark land preparation time, delayed onset of first rains and shortened agricultural rainfall season.

Shifting planting dates

Female headed households reported shifting planting dates from the traditional mid-November to mid-December to match changes in onset of first rains. The disappearance of winter rains have also made it difficult for the majority of female heads who depend on manual labor to prepare land before the first rains. Most female heads also solely depend on rain-fed system promoting the need to alter farming practices in accordance with changes in rainfall patterns. The following are a sample of participants' utterances pertaining shifting of planting date:

> "The rainfall trend for the past 10 years or so has been coming in first week of December. In the 1990s by mid-November you would expect the first rains. For most of the female heads that depend on rain-fed agriculture we have had to adjust accordingly. We now plant in December and this can be upto mid-December". (Female Head Respondent, 4)
>
> "Initially I continued dry planting in the last week of October or First week of November expecting rains to fall immediately. I realized I was now missing it as the rains would come in December and may start of in the low range. So crops that would have been dry planted do not germinate. Instead the seed would rot and forcing you to buy again or look for someone to give you. So I now plant when I see there has been enough rains to allow germination, which is anytime from mid-December. That way you are assured of some harvest". (Female Head Participant, 20)
>
> "Traditional leaders and lead farmers now encourage us to plant late. That is what we have adopted. Previously it was November/October now it's in Dec". (Female Head Participant, 1)

From the participants' narratives above, it is clear shifting planting dates is a common strategy that female heads are adopting in response to changing climatic patterns such as delays in onset of first rains. The strategy depicts application of incremental approaches to climate change adaptation processes as identified by Kates et al. (2012). An approach characterized by adoption of minor and small scale adjustments by communities to tradition social and ecological systems with a focus on building resilience to climate change impacts. Additionally, the finding reflects the value of tradition leaders and extension staff as agents of resilience building process.

Reducing land area cultivated

Reducing land area cultivated came out as one other strategy that most female heads have adopted. Female heads narrated that whilst other communal member has access to irrigation plots in government irrigation schemes. Most of female heads lost such plots upon death of spouse or did not get first preference during allocation as they were considered able to migrate upon marrying or remarrying. Those with irrigation plots whilst they have adopted reduction of land area cultivated they have maintained better leverage in terms of land size area cultivated. Hence, whilst, this has been the most notable option to match changing rainfall patterns it has come with some disadvantages as the option has failed to guarantee improved yields. The following provided narratives from key informants as well as female head participants:

> "Rain now comes late in December and by January they are gone and then again during March for a very short period. I have had to reduce the area that I cultivate for crop production by more than half. When the rains eventually fall there is very little time to prepare and plants. While this helps me at least secure some harvest things could be better if I had a plot in the irrigation facility which could continue to provide water for my crop during dry spell. Those in the irrigation scheme usually perform better". (Female Head Participant, 3)

Another respondent had this to say: "*For most female heads it has become challenging. I have no draught power and when the rains come late in the season I just manage with what I have. So with my two children in primary school we know we can only cover a small area"* (Female Head Participant, 7).

Another key respondent had this to say: "*Rains have become more and more erratic. They also come late in the season. Hence most households with limited labour particularly elderly and young female heads have been forced to reduce the size of plots they cultivate. In some cases it has yielded favourable results. If many of them had some plot in the irrigation facility reducing land area cultivated could have more sustained benefits as some harvest could be guaranteed from the non-rain fed plot. But as it is at there are no guarantees. In severe dry years no harvest may be realised."* (Key Informant 4).

It is clear that female heads make use of reducing land area cultivated as one of the coping strategies in managing delays in onset of first rains and shortening of the rain season which has been negatively affecting yields. These findings affirm previous studies in Ghana, Ethiopia and Cameroon which also identified reducing land area cultivated as common climate change adaptation strategy among peasant communities (Alhasan et al. 2019; Gebrehiwot et al. 2013; Deressa et al. 2009). A coping strategy common among communities is lacking technical and financial capacity to respond in different ways.

However, as depicted in the above narrations, reducing land area cultivated is proving useful among female heads, it bears some limitations as it remains a rain fed approach to farming which provides no guarantees to securing harvest. Access to irrigation plots would bring more sustained benefits yet these remain limited due to traditional customs around allocation of land in the area which do not favour women. Such systemic constraints around traditional land tenure and user rights are posing as limitations to female heads ability to acquiring sustainable resilience capacities. An important area to consider in climate change policy is review and programing especially for the food security sector.

Increased cultivation of drought tolerant crops

Findings form the study also point to increased adoption of drought tolerant crops among female heads in managing changing climatic conditions for improved food security. There is an acknowledgement that the area is arid and has always been suited for drought tolerant crops. Female heads note abandoning common practice of cultivating beans and maize in garden plots which they would irrigate using shallow wells and resorting to cultivation of small grains-*Panicum miliaceum*, *Eleusine coracana* and legumes-*Vigna unguiculata*, *Arachis hypogea* and *Vigna subterranea* which are drought tolerant. These findings are made explicit by the following narration as explained by participants:

> "In the early 2000s I would also grow maize and beans on the garden plot. I used to make use of the shallow well in the garden to irrigate the crops. I no longer cultivate such crops as the shallow well I use to water the crops now dries early since each year we are receiving low rainfall. I now concentrate on growing *Vigna unguiculata*, *Arachis hypogea* and *Panicum miliaceum.* At least you are guaranteed of some harvest". (Female head participant, 22)
>
> "These years I now plant *Eleusine coracana* for grain and *Vigna unguiculata*, *Arachis hypogea* for legumes. With these ones you do not get disappointments. With *Vigna unguiculata*, I also dry the leaves for use as relish later in the year. With continued low rains and shortening of the season I now prefer these". (Female Head Participant, 3)
>
> "If you are fortunate you may secure contract farming with some private companies to cultivate small grains such as the *Panicum miliaceum* variety which they in turn use to brew beer. Hence, I choose adopting small grains". (Female Head Participant, 26)

Key Informant Respondent

> "Most female heads like any other member of the community are finding it beneficial to stick to drought tolerant crops. Apart from their drought tolerance qualities they offer room to use of retained seed which can also be a product of pass on with one guaranteed of a harvest. They also do not require much fertiliser. Even where there is no or little feeding one can secure some harvest". (Key Informant Participant, 11)

The above participant narrations point to adoption increased cultivation of small grains and drought resistant legumes as common among female heads. The adoption of drought tolerant crops among communal farmers as a climate change strategy has been affirmed by other studies (Fagariba et al. 2018; Alhasan et al. 2019) These small grains (*Panicum miliaceum*, *Eleusine coracana*) and legumes (*Vigna unguiculata*, *Arachis hypogea* and *Vigna subterranea*) which are drought tolerant have several benefits for female heads. Firstly, by ensuring continued availability of carbohydrates and protein content in female headed households. Secondly, as depicted from the narratives, production costs are lower as even were retained seed has been used and no fertiliser applied there is guarantee of some harvest. This makes them best suited for female heads who usually find it difficult to finance agricultural activities. Thirdly, the possibilities of securing contract farming opportunities also offers added advantage of providing sustainable livelihood opportunities for vulnerable households. This not only aids in incremental approaches but enhances female heads transformation capacities in resilience building. As the opportunity bear potential to addressing systemic barriers in financing the adoption of strategies through forming of partnerships with the private sector.

Reliance on External Support

Interviews with female heads participants, local leadership other stakeholders from various government department, the private sector and non-governmental organisations pointed to reliance on external support in the form of food aid, cash transfers, food for work, food for assets, seed packs and remittances as one other strategy adopted by female head. The narratives below provide evidence on this strategy.

> "Most elderly female headed households are continuing to find it difficult to cope with changing climatic conditions. The shift in dates of onset of first rains, the shortening of the season is something making it difficult guarantee enough harvest to feed the family. Some of the new farming techniques such as conservation agriculture are proving labour intensive for female heads with no additional labour. So they wait for NGO or government food assistance programs to feed their families". [Extension Officer Key Informant Participant, 2]
>
> "It has been difficult for me as an elderly person. I tried farming using conservation farming method. I could not bear it. It left me with terrible back aches. So I now wait for government food assistance program. My brother here and there also sends some money to buy grain". [Female Head Participant, 20]
>
> "Most drought years I have had to be on school feeding program. So I can have one meal per day but the children are guaranteed of a second one from school". [Female Head Participant, 14]
>
> "Most of us have now been participating in drought relief programs". [Female Head Focus Group Participant 1]

It is clear from the above narrations that reliance on external support forms one of the strategies to managing climate change common among female heads. For the Buhera community, this takes the form of NGO support and remittances from kinship members. A finding that affirms previous studies (Tibisegwa et al. 2015). This approach takes the form of a coping strategy. It reflects the value and importance of social capital (internal and external) in managing climate change related household food gaps. However, the strategy also reflects confinement of female heads to use of the local structures and systems in adapting to climate change which in most cases may fail to build on adaptive capacities of such vulnerable households. A different approach for men is at liberty to migrate and explore other opportunities which may have higher returns.

Additionally, the findings reflect the need to invest in technically appropriate climate smart technology that match various socio-demographic characteristics of different categories of people in society i.e. female headed characterised by labour constraints and the elderly who can no longer meaningfully engage in livelihood activities.

Conclusion

It can be drawn that female heads are adopting several strategies in building resilience to climate change. These include livelihoods diversification, changing farming practices and depending on external support. The strategies take the form of coping and incremental approaches and are proving useful in strengthening the households' absorptive and adaptive resilience capacities. The strategies focus on sustaining agricultural productivity, maintaining household income, improving access to credit and securing alternative food sources. For female heads such resilience building strategies remain localized and based on traditional practices of sustaining livelihoods. Kinship ties and community stakeholder support plays a significant role in facilitating the resilience building process. However, this offers opportunities for layering of sustainable development programs including enforcement of regulations to control practices with potential of environment degradation. The poor socio-economic resource base characterizing female heads compromise their ability to adapt. Additionally gender norms and traditional customs i.e. on land tenure presents systemic constraints to climate change adaptation process within female heads. Hence this paper recommends application of pro-active approaches in the design of climate change policies and programs that are gender sensitive and seek to address any existing socio-economic and cultural barriers for the creation of resilient communities.

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Halophytes of Semi-Arid Areas: Resources for Mitigation of Climate Change

Doongar R. Chaudhary

Abstract Halophytes grow in coastal areas of the semi-arid regions are often exposed to intense and varying environmental stresses (especially salinity). India has a total coastline of 7516.6 km and Gujarat enjoys the distinction of having the longest coastline (more than 1650 km) in India. The vast coastal area of Gujarat falls under semi-arid climatic zone and is mostly made up of mudflats and sandy loam soil. The impact of tides that ranges from about 3 m to a maximum of 10 m is quite high along the coast. The coastal area of Gujarat consists of different halophytes (*Salicornia*, *Arthrocnemum*, *Haloxylon*, *Sesuvium*, *Suaeda*, *Aeluropus*, *Heleochloa*, *Atriplex*, and *Salvadoraetc*), which have potential economic importance (food, fodder and natural products) along with environmental and ecological benefits. The rise in sea levels, increasing salinity and droughts are the main effects of climate change in many parts of the world. Halophytes are extraordinary plants to tolerate the salinity that other species cannot survive. Halophytic plants have different physiological and molecular mechanisms (salt excretion, accumulation and avoidance) to survive under extreme salinity. Succulent halophytes have a higher Na^+/K^+ ratio (accumulator) in the shoot and root which are potential plants to be used for bioremediation of salt-affected soils. The rhizosphere of halophytes is a potential source of plant growth-promoting bacteria which can be used for the development of salinity tolerance in the crop plants apart from gene resources for the development of the transgenic plants. Therefore, halophytes have a special place in assisting our understanding of salinity tolerance and important for climate change challenges.

Keywords Halophytes · Salinity tolerance · Coastal ecosystem · Inter-tidal zone

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D. R. Chaudhary (✉)
Division of Plant Omics, CSIR-Central Salt and Marine Chemicals Research Institute, Bhavnagar, Gujarat 364002, India
e-mail: drchaudhary@csmcri.res.in

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Introduction

To achieve the World's food production for the need of an increasing population is very challenging because of decreasing availability of arable land resulting from urbanization and land degradation by soil salinization/other degrading processes. Soil salinization is expected to rise in the present scenario of global climate change (Shabala et al. 2014; Flowers and Muscola 2015). Soil salinization has become a serious global issue due to the changing climate and anthropogenic activities which not only reduces soil quality and agriculture productivity but also continuously decreasing the agricultural land area (Bhaduri et al. 2016; Shao et al. 2019). Soil salinization and increasing drought will be the main contributing factors to increase the soil salinity in the arid and semi-arid regions of the World. Additionally, the area of salt-affected land is increasing year by year because of high evapotranspiration, less rainfall, use of poor-quality water, poor irrigation practices and human-made activities (Shao et al. 2019). Seven percent of the total land and one-third of irrigated land of the World are affected by the salinity (Flowers and Colmer 2008). According to NHO (National Hydrographic Office, Dehradun, India), the revised coastline length of India is 11,084.50 km which is shared by 13 different states and union territories (Gujarat, Maharashtra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Goa, Daman & Diu, Puducherry, Andaman and Nicobar Islands, and Lakshadweep & Minicoy Islands) (CWC 2016). Gujarat has the longest coastal line among the different states of India. With the considerable coastline, India has 6.72 m ha salt-affected soil and Gujarat alone has the largest salt-affected area of 2.22 mha (Mandal et al. 2009). Despite the advancement of technologies and techniques, genetic-engineering and breeding of salt-tolerant plants require many years to achieve (Flowers and Muscola 2015). Another approach may be the domestication of halophytes which have inherent genetic makeup to tolerate high salinity with economic values (Glenn et al. 1999) and can be alternative crop plants for cultivation in salt-affected lands.

Halophytes are defined in numerous ways with time and the advancement of research in the field of halophytes. Halophytes are the plants which are capable of growing at 0.5% sodium chloride content (Chapman 1942). Later, the plants grow and complete their life cycle in high salt content (Waisel 1972). Similarly, Breckle (1995) also suggested that plants that grow and complete their entire life-cycle in saline habitats are halophytes. Halophytes are the plants which survive to reproduce in environments where the salt concentration is around 200 mM NaCl or more (Flowers et al. 1986; Flowers and Colmer 2008). Recently, salt-tolerant plants (halophytes, including salt marsh and mangrove plants) are highly evolved and specialized organisms with well-adapted morphological and physiological characteristics allowing them to survive in the soils possessing high salt concentrations as defined by Khan and Duke (2001).

Effect of Soil Salinity on Plants

Among all salts, sodium chloride is highly soluble and found in higher concentrations in saline soils. Thus, sodium (Na^+) ion plays the primary role in the ionic toxicity in the plants growing on saline soils (Munns and Tester 2008). The movement of different salts into the plant is caused by the transpirational flux that is required for maintaining the water potential in the plant (Mahajan and Tuteja 2005). The Na^+ is highly toxic in a cytosolic concentration of about 100 mM. Na^+ shows cytotoxic effects in dual ways: firstly, it has a high charge to mass ratio (in comparison to K^+) which disrupts water structure and lower down hydrophobic interactions within proteins (Pollard and Jones 1979; Jones and Pollard 1983) and secondly, Na^+ inhibits enzyme activity, either directly through binding with inhibitory sites or indirectly through displacing $K^+$from its activation sites (Serrano 1996). In both cases, competition between Na^+ and K^+ ions is critical, and Na^+ to K^+ ratio in the cytosol is the main determining factor for Na^+ toxicity (Amtmann and Sanders 1998). There are protein transporters at the root epidermis which transport Na^+ and K^+ but when Na^+ present excessively in the soil which competes with K^+ ions for intracellular influx (Amtmann and Sanders 1998; Blumwald et al. 2000). The K^+ ion transporter has an affinity for Na^+ ions called Na^+/K^+ symporters (Blumwald et al. 2000). So, high soil Na^+ content negatively affects intracellular K^+ influx because most of the cells retain high K^+ and low Na^+ concentration in the cytosol accomplished by the coordinated regulation of different transporters for proton, potassium, calcium and sodium (Mahajan and Tuteja 2005). The influx of Na^+ causes many harmful effects on plants by dissipating the membrane potential, affecting the functions of some enzymes, generating the reactive oxygen species and reducing the photosynthesis process (Hasanuzzaman et al. 2014; Himabindu et al. 2016; Mishra and Tanna 2017). Additionally, higher sodium influx cause osmotic imbalance, disorganization of the membrane, inhibition of cell expansion and division, and in severe stress condition, it causes plant death (Niu et al. 1995; Yeo 1998).

Mechanisms of Salt Tolerance in Halophytes

Halophytes have evolved salt tolerance mechanisms operating at various levels, anatomical, morphological, physiological, molecular and ecological levels that help plants to cope with salty conditions (Hasanuzzaman et al. 2014; Flowers and Muscola 2015). These plants have adjusted well to complete the life cycle under the saline environment with different types of adaptation mechanisms such as ion compartmentalization, succulence, osmotic adjustment, regulative ion transport and uptake, production of osmolytes, maintenance of energetic and redox status, and salt excretion or inclusion (Lokhande and Suprasanna 2012) (Fig. 1). For salinity tolerance,

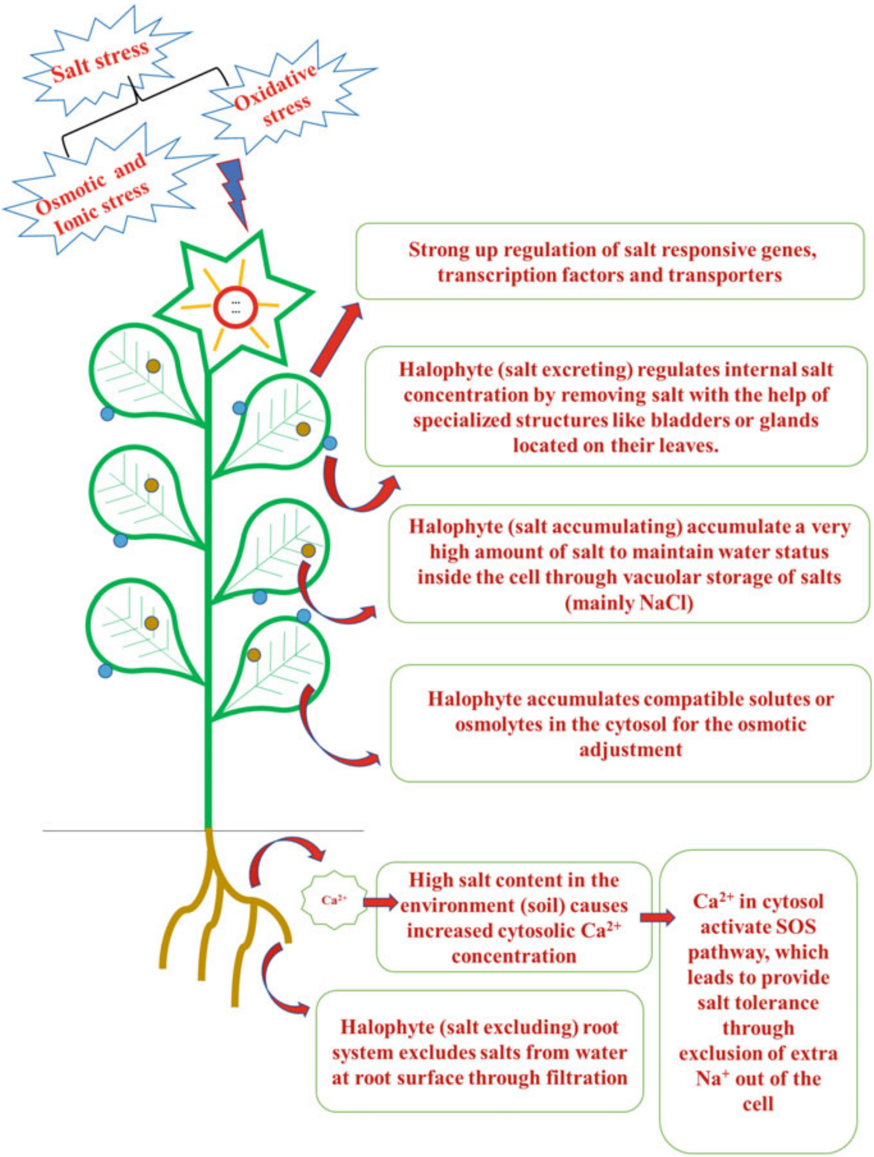


Fig. 1 Adaptive mechanisms employed by halophyte for salt tolerance

halophyte species also synthesize compatible solutes for protecting cellular structures and maintaining water potential inside the cell (Schat et al. 1997; Sharma and Dietz 2006).

Halophytes are extremophiles; these are found in salt marshes and other salty environments like saline depressions, inland deserts and rocky coasts or sand dunes.

Based on the different salt adaptation mechanisms (Fig. 1), halophytes have been classified into three categories: (a) salt excluding, (b) salt excreting and (c) salt accumulating. Salt excluding plants have evolved with a particular type of root system that works based on the ultrafiltration mechanism. Their root system excludes salts from water at the root surface through filtration (Kim et al. 2016). The *SOS1* gene (salt overly sensitive) is mainly expressed in the root cell membrane and plays an important function in Na^+ extrusion (Sreeshan et al. 2014). The *SOS* pathway is activated by Ca^{2+} ions and Ca^{2+} ion significantly provides salt tolerance to plant (Knight et al. 1997; Mahajan and Tuteja 2005). The high salt content in the environment causes increased cytosolic Ca^{2+} concentration which is released from the apoplast and intracellular compartments (Knight et al. 1997). The *SOS* pathway causes the exclusion of extra Na^+ out of the cell with the help of plasma membrane Na^+/H^+(*SOS1*) antiport and supports to maintain homeostasis of cellular ions. There are three proteins such as *SOS1*, *SOS2* and *SOS3*, work in a coordinated manner in the *SOS* pathway for reducing the salinity effects (Mahajan and Tuteja 2005). Salt excluder halophytes include *Kandelia candel, Avicennia marina, Bruguiera gymnorrhiza*, *Ceriops candolleana* and *Rhizophora mucronate* (Drennan and Pammenter 1982; Waisel et al. 1986; Hasanuzzaman et al. 2014). Salt excreting plants regulate internal salt concentration by removing salt with the help of specialized structures like bladders or salt glands located on their leaves, such as: *Acanthus ilicifolius, Aeluropus lagopoides, Aegiceros corniculatum, Acanthus ilicifolius* and *Aeluropus littoralis* (Barhoumi et al. 2007; Hasanuzzaman et al. 2014; Sanadhya et al. 2015). Salt accumulator plants accumulate a very high amount of salt to maintain water status inside the cell. Halophytes have evolved with the mechanism of osmotic adjustment through vacuolar storage of salts (mainly NaCl) and organic molecules accumulation in the cytosol. The mechanism of Na^+ and Cl^- entry in halophyte cells is not fully known but might involve different types of ion channels, transporters and pinocytosis (Hasanuzzaman et al. 2014). The Na^+/H^+ antiporters are required for the uptake of Na^+ ions into the vacuoles and this transporter gets energy with proton motive force producing H^+-ATPases (proton-adenosine triphosphatase) and H^+-PPases (proton-pyrophosphatase) (Bassil et al. 2011; Munns and Tester 2008). It is also reported that halophytes often possess large vacuoles such as in the case of *Suaeda maritima*, 77% volume of mesophyll cells are occupied by vacuoles (Hajibagheri et al. 1984) which makes them efficient for accumulating about 500 mM salt in the cells (Dracup and Greenway 1985). Although the amount of salt accumulated in shoots is not the same for all halophytes, this depends on the adaptive strategies occupied by different species of halophytes for salt tolerance (Fig. 2). This accumulated salt causes the development of succulence in the halophytes, such as *Sonneratia acida*, *Sonneratia apetala, Sonneratia alba*, *Excoecaria agallocha*, *Limnitzera racemose, Salvadora persica*, *Suaeda nudiflora, Sesuvium portulacastrum*, *Pentatropis siansh, Suaeda maritima*, *Clerodendron inerme, Ipomoea pes-caprae, Heliotropium curassavicum, Salicornia brachiata, Salicornia persica, Halimocnemis pilifera* and *Sporobolus arabicus* (Ravindran et al. 2007; Hasanuzzaman et al. 2014; Rathore et al. 2016; Mangalassery et al. 2017).

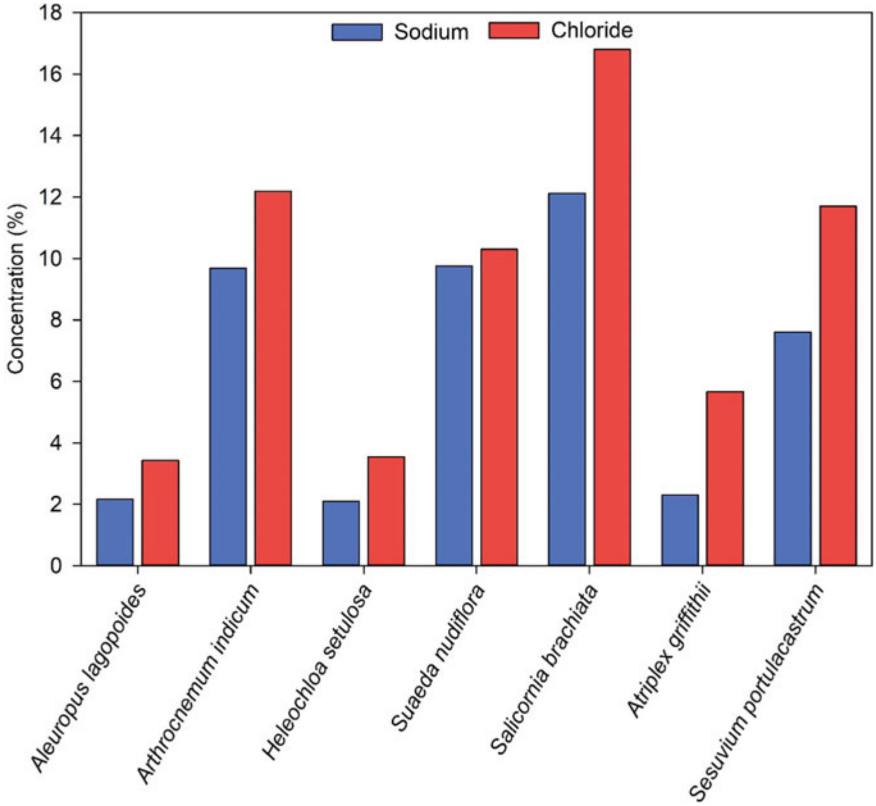
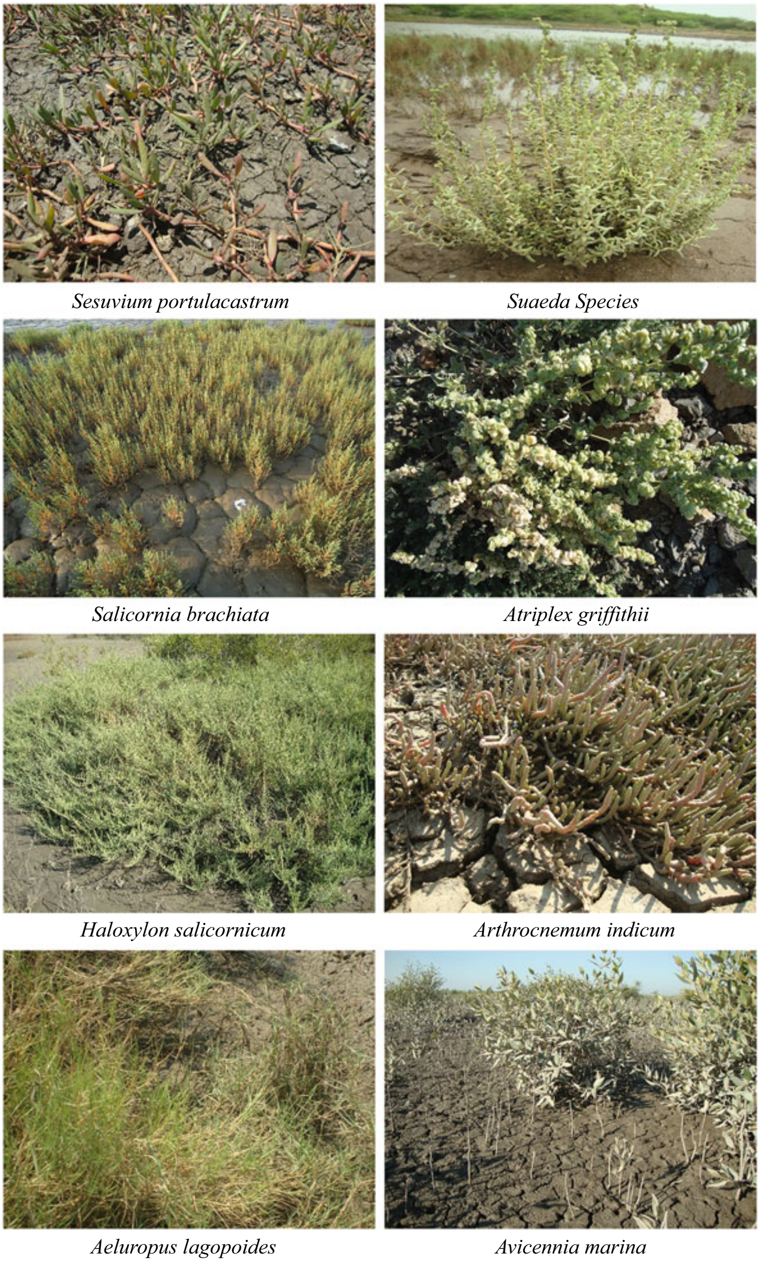


Fig. 2 Sodium and chloride content in the shoots of halophytes growing in coastal saline soils of Gujarat, India

Halophytes of Gujarat Coastal Area

Due to favourable climatic and soil conditions of the coastal area of Gujarat which is habitat for different vegetation, comprises of mangrove and halophytes (Fig. 3). Joshi (2011) divided halophytes occurring in Gujarat into three main categories: (1) succulent halophytes, *Salicornia brachiata* Roxb., *Arthrocnemum indicum* (Willd.) Moq., *Haloxylon salicornicum* Bungeex. Boiss., *Salsola kali* Linn, *Sesuvium sesuvioides* Fenzl., *Sesuvium portulacastrum* (L.) Linn., *Suaeda fruticosa* (L.) Forssk., *Suaeda maritima* (L.) Dumort., *Suaeda monoica* Forssk., *Suaeda nudiflora* (Willd.) Moq. (2) Non-succulent halophytes *Aeluropus lagopoides* (L.) Trin. ex Thw., *Heleochloa setulosa* Trin., *Juncus maritimus* Lam., *Sporobolus virginicus* (L.) Kunt. (3) shrubby halophytes *Atriplex griffithii* Moq., *Limonium stocksii* Boiss., *Salvadora persica* Linn., *Tamarix aphylla* (L.) Karsten. In coastal saline areas, halophytic plants are one of the most important contributors to the proper functioning of the coastal ecosystem (Joshi 2011; Rathore et al. 2017).



Sesuvium portulacastrum | *Suaeda Species*

Salicornia brachiata | *Atriplex griffithii*

Haloxylon salicornicum | *Arthrocnemum indicum*

Aeluropus lagopoides | *Avicennia marina*

Fig. 3 Halophytes growing at the coastal region of Gujarat (India)

Halophyte for Amelioration of Saline Soil

The acreage of saline soils in the world is expanding day by day due to climate change and there is an urgent need to develop salt-tolerant crops to survive with the adverse condition of soil salinity. The amelioration of salinity has been predominantly achieved through washing and leaching of salt with excessive amounts of good quality water. However, mostly saline soils occur in arid and semi-arid regions, where rainfall is scanty and the availability of good quality waters is limited. Therefore, other biological remedial measures can be used, such as plantation/cultivation of salt-tolerant plants that can take up salt from the soil and reduce the soil salinity. For this purpose, halophytes are the candidate plants that have the capacity to accumulate and remove the salts from the soil and can effectively remediate the salt-laden soils (Hasanuzzaman et al. 2014). The halophytic plant can grow satisfactorily under higher soil salinity and they have many applications as food, fodder, oil, cosmetics, pharmaceutical, nutraceutical, industrial, ecological and agricultural. Sometimes, the productivity of halophytes is equivalent to conventional agricultural crops. *Kosteletzkya virginica*, a grain-crop for seawater-based agriculture, yielded 957 kg ha^{-1} seed containing 20.64% oil (Ruan et al. 2008). *Salicornia bigelovii* (a highly salt-tolerant stem succulent annual halophyte) is suggested as oilseed crop, since it produces a high yield of seeds (2t ha^{-1}) with a high protein (31%) and oil (28%) content which is similar to soybean yield potential and quality of seed (Glenn et al. 1999). *Salicornia brachiata*, an oilseed halophyte, yielded 4.5–7.1 t ha^{-1} dry biomass and 0.49–0.91 t ha^{-1} seeds (Pandya et al. 2010). It can accumulate 30–40% salt of its dry weight (Jha et al. 2009). The biomass of *S. brachiata* is used for the production of high-valued vegetable salt (Ghosh et al. 2005) and seeds are used for oil production (Fig. 4). The seeds of *S. brachiata* produce a special type of oil which is high polyunsaturation

Fig. 4 Edible oil (rich in PUFA) from seeds of *Salicornia brachiata* and vegetable salt from biomass of *S. brachiata*

and rich in linoleic acid (essential amino acid) that shows similarity with safflower oil (Eganathan et al. 2006; Pandya et al. 2006). *Chenopodium quinoa* is a facultative halophyte, an important grain cash crop that can yield 441 kg ha^{-1} under saline soil conditions with 13.45% protein content (Eisa et al. 2017). Oil content in the seeds of *Arthrocnemum indicum*, *Alhaji maurorum*, *Cressa cretica*, *Halopyrum mucronatum*, *Haloxylon stocksii* and *Suaeda fruticosa* varied from 22 to 25% with unsaturation of 65–74% (except in *A. maurorum*) and suggested that *S. fruticosa* can be used as a source of oil for human consumption (Weber et al. 2007). Few halophytic plants are good source of fodder for animal feeding in the coastal area but those may cause nutritional barriers owing to high salt concentration and antinutritional compounds. Common grasses found in the area of salt-affected soil are *Leptochloa fusca*, *Lasiurus scindicus*, *Panicum turgidum*, *Dactyloctenium sindicum*, *Cynodon dactylon*, *Paspalum vaginatum*, *Sporobolus marginatus*, *S. ioclados*, *Chlorisgayana*, *Chloris virgata*, *Echinochloa turnerana*, *Echinochloa colonum* and *Puccinellia distans* which can be used to feed the animals (Khan and Qaiser 2006). *Aeluropus lagopoides* had better ion uptake, ion partitioning and forage quality traits (protein, proline, fiber, ash and sugar content) which is found to be an ideal forage grass for saline agriculture on saline black soils (Rao et al. 2005).

Hamidov et al. (2007) investigated the ability of *Portulaca oleracea* to remove salt from the soil and reported that it could remove 570 kg ha^{-1} salt with biomass production of 3.25 t ha^{-1}. It was observed that *Suaeda maritima*, *Sesuvium portulacastrum*, *Excoecaria agallocha*, *Clerodendron inerme*, *Ipomoea pes-caprae* and *Heliotropium curassavicum* can remove 504, 474, 396, 360, 325 and 301 kg ha^{-1}salt, respectively from saline soil in 4-month growth time (Ravindran et al. 2007). Above ground biomass of *Salicornia brachiata* can remove 334 kg ha^{-1} sodium and 493 kg ha^{-1} chloride from inter-tidal soils of coastal Gujarat, India (Chaudhary et al. 2018). Bioaccumulation factor (BF, ratio of the content of Na^+ in aboveground parts to that in soil) and translocation factor (TF, ratio Na^+ content in aboveground parts that in the belowground parts) varied from 2.23 to 16.15 and 1.03 to 5.34, respectively in the *Salicornia brachiata* (Chaudhary et al. 2018). Plants with higher BF (> 1) and TF (>1) for Na^+ are reliable candidates for remediation of saline soils (Table 1). *Salicornia brachiata* maintain a higher Na^+/K^+ ratio in shoots compared to roots due to shoot succulence (Table 2) and reduce the soil salinity (Table 3) along with improvement in microbial activity (Table 4). Ouni et al. (2013) found that *Tecticornia indica* and *Suaeda fruticosa* produced 7.4 t ha^{-1} and 2.2 t ha^{-1} dry biomass, respectively with 0.75 t ha^{-1} and 0.22 t ha^{-1} sodium accumulation, respectively at Soliman

Table 1 Bioaccumulation factor (Na^+) and translocation factor (Na^+) of *Salicornia brachiata* (Mean ± standard error, n = 108)

Factor	Value
Bioaccumulation factor	8.90 ± 2.22
Translocation factor	3.66 ± 0.69

Table 2 Na^+/K^+ ratio in *Salicornia brachiata* (Mean ± standard error, n = 108)

Plant part	Na^+/K^+ratio
Aboveground	14.05 ± 2.97
Belowground	5.02 ± 1.51

Table 3 Effect of *Salicornia brachiata* on soil characteristics and nutrient contents (Mean ± standard error, n = 108)

Soil characteristics	*Salicornia* root zone soil	Control soil (without vegetation)
pH	8.28 ± 0.01	8.17 ± 0.03
EC (dS m^{-1})	20.49 ± 0.47	29.28 ± 0.84
Organic carbon (%)	0.70 ± 0.02	0.71 ± 0.01
NO_3^--N (mg kg^{-1})	1.38 ± 0.08	2.88 ± 0.18
NH_4^+-N (mg kg^{-1})	5.65 ± 0.32	6.67 ± 0.41
P (mg kg^{-1})	14.97 ± 0.47	13.98 ± 0.64
Na^+ (g kg^{-1})	17.01 ± 0.41	23.93 ± 0.75
K^+ (g kg^{-1})	1.69 ± 0.02	1.56 ± 0.03

Table 4 The concentrations of fatty acid methyl ester (FAME) microbial biomarkers in the soil influenced by the *Salicornia brachiata.* (Mean ± standard error, n = 108)

FAME (nmol g^{-1})	*Salicornia* root zone soil	Control soil (without vegetation)
Total FAMEs	37.98 ± 1.83	22.22 ± 1.29
Total Bacterial	16.35 ± 0.88	9.30 ± 0.64
Gram-positive	6.44 ± 0.34	3.81 ± 0.21
Gram-negative	10.38 ± 0.58	5.47 ± 0.42
Fungal	1.73 ± 0.15	0.77 ± 0.05
Actinomycetes	2.12 ± 0.11	1.23 ± 0.07

sabkha (North-East Tunisia). In another study, *Arthrocnemum indicum*, *Suaeda fruticosa* and *Sesuvium portulacastrum* could remove sodium 2504, 711, 802 kg ha^{-1}, respectively and significantly reduced the soil salinity (Rabhi et al. 2008). Among *Tecticornia pergranulata*, *Sclerolaena longicuspis* and *Frankenia serpyllifolia* cultivated on brine-affected soil, *T. pergranulata* showed the highest shoot Na^+content (98 g kg^{-1}), bioaccumulation (14.21) and translocation (23.09) factors for Na^+ with higher remediation potential of brine affected soil (Shaygan et al. 2018). Plantation of *Atriplex halimus* decreased electrical conductivity for saline-sodic soil from 39.2 to 26.5 dS m^{-1} and from 6.2 to 4.9 dS m^{-1} for saline soil; furthermore, sodium adsorption ratio was also significantly reduced (Abdul-Kareem and Nazzal 2013). *Suaeda monoica* was evaluated for the amelioration of paper mill effluent treated soil and it was observed that electric conductivity of soil was reduced from 4.75 to 2.10 dS m^{-1} with an accumulation of 172.20 mg NaCl g^{-1} (Malik and Ravindran 2020). *Sesuvium portulacastrum* had reduced the soil salinity (from 7.1 dS m^{-1}

to 4.9 dS m^{-1}) and sodium adsorption ratio (20.9–13.5) in 90 days growth which produced biomass of 8.1 t ha^{-1} and removed 595 kg Na^+ ha^{-1} (Lokhande et al. 2009). Halophytes improve fertility as well as the microbial quality of soil under saline conditions (Tables 3 and 4). Remediation of saline soils by the halophytes is an economical method since chemical and water availability for leaching in arid and semi-arid regions are expensive. It has been proven that many halophytic plants have the potential to accumulate a substantial quantity of salt (hyper accumulator) and have great potential to ameliorate the saline soils of arid and semi-arid regions (Chaudhary et al. 2018; Rathore et al. 2016).

Plant Growth-Promoting Rhizobacteria from Halophytes

Salt tolerant plant growth-promoting rhizobacteria (PGPR) isolated from the rhizosphere of halophytes have the potential to ameliorate salinity stress in crop production through physiological and molecular mechanisms (Arora et al. 2020) which is an alternative to the plant breeding and genetic engineering approaches. Halophytes are valuable bio-resource for halotolerant bacteria with plant growth-promoting traits (Fig. 5) which accelerate the growth of plants and increase the tolerance in agricultural crop plants for enhancing productivity and soil fertility (Etesami and Beattie 2018; Egamberdieva et al. 2019) which is an eco-friendly and sustainable approach. Salt tolerant PGPR efficiently improves the growth of plants under salt stress conditions by various mechanisms include improvement in nutrient availability (biological N_2, solubilization of phosphorus, potassium, chelation of iron and zinc by siderophores), production of phytohormones (indole acetic acid, gibberellins and cytokinins), protection from salt toxicity through activation of antioxidant enzymes (superoxide dismutase, peroxidase, catalase, ascorbate peroxidase, guaiacol peroxidase and ACC deaminase), production of osmolytes (soluble sugars, amino acids, polyols and glycine betaines), increased expression of salt overly sensitive genes and transporters, control of phytopathogen and production of secondary compounds (exopolysaccharides which reduce Na^+ accumulation and uptake by the roots, increase soil aggregate formation and water retention) (Shahzad et al. 2017; Etesami and Beattie 2018; Arora et al. 2018; El-Esawi et al. 2018; Egamberdieva et al. 2019; Arora et al. 2020).

Jha et al. (2012) isolated the PGPR (*Brachybacterium saurashtrense* sp. nov. and *Pseudomonas sp.*) from roots of *Salicornia brachiata* that were halotolerant and improved the growth of *Salicornia* under salt stress conditions. *Klebsiella*, *Pseudomonas*, *Agrobacterium* and *Ochrobactrum* were isolated from the roots of *Arthrocnemum indicum* with growth promoting traits (*nifH* gene positive, indole-3-acetic acid production, phosphate solubilisation activity, 1-aminocyclopropane-1-carboxylate deaminase activity and capable of reducing acetylene) (Sharma et al. 2016). The ACC deaminase producing PGPR, *Arthrobacter soli*, *Bacillus flexus*, *Isoptericola dokdonensis* and *Streptomyces pactum*were isolated from *Limonium sinense* which stimulated the growth of the host plant and also influenced the

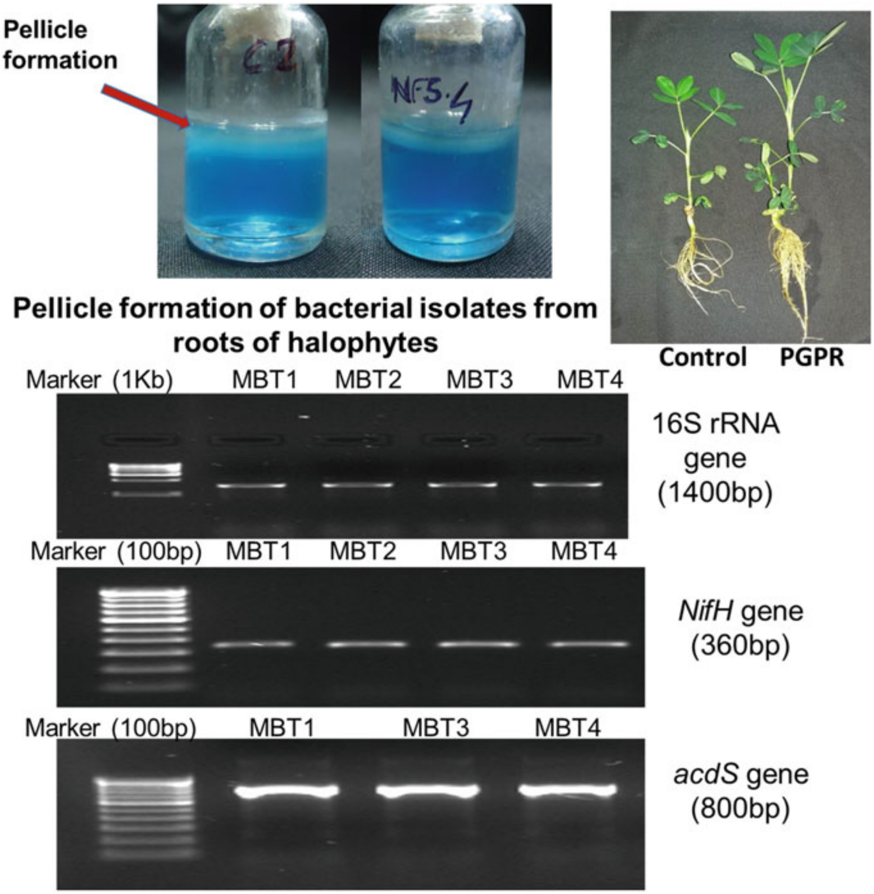


Fig. 5 Halotolerant plant growth promoting rhizobacteria isolated from halophytes

flavonoids accumulation (Qin et al. 2014). The five PGPR isolates (*Bacillus endophyticus*, *Bacillus tequilensis*, *Planococcus rifietoensis*, *Variovorax paradoxus* and *Arthrobacter agilis*) were isolated from *Salicornia europaea* which had PGPR properties (1-aminocyclopropane-1-carboxylate deaminase activity, indole-3-acetic acid and phosphate-solubilizing activities) and significantly stimulated the growth of the host plant (Zhao et al. 2016). Zhou et al. (2017) identified three PGPR (*Micrococcus yunnanensis*, *Planococcus rifietoensis* and *Variovorax paradoxus*) from halophytes with the ability to secrete 1-aminocyclopropane-1-carboxylate deaminase as well as other plant-growth-promoting traits which enhanced salt stress (NaCl concentrations 50–125 mM) tolerance of sugar beet as well as enhanced the seed germination and plant biomass, higher photosynthetic capacity and lower stress-induced ethylene production. The PGPR (*Bacillus sp.* and *Arthrobacter pascens*) were isolated rhizospheric soils of *Atriplex leucoclada* and *Arthrobacter pascens* plant growth-promoting traits (phosphate solubilization, bacteriocin and siderophore production) and inoculated to maize under induced salinity stress which increased fresh and dry weight of shoot and root with increased accumulation of osmolytes (sugar and proline) and antioxidant enzymes (superoxide dismutase, peroxidase, catalase and ascorbate peroxidase) activities (Ullah and Bano 2015). Mukhtar et al. (2020) isolated the five PGPR (*Bacillus safensis*, *Bacillus pumilus*, *Kocuria rosea*, *Enterobacter aerogenes* and *Aeromonas veronii*) from rhizospheric and nonrhizospheric soils of halophytes (*Salsola stocksii* and *Atriplex amnicola*) and inoculated to maize, all bacterial isolates positively affected the maize growth under salinity stress resulted in high concentrations of proline, glycine betaine and malondialdehyde.

Stress Tolerant Genes from Halophytes

Halophytes complete their life cycle under extremely saline soil conditions and are bioresources of salt-tolerant genes and give tools for developing transgenic crops with improved stress tolerance for saline agriculture. A large number of transporters, including antiporters (*NHX*, *SOS*, *HKT*, *VTPase*), ion channels (Cl^{-1} channels, water channels, Ca^{+2} channels); assisted genes (*APX*, *CAT*, *GST*, *BADH*, *SOD*) and stress-inducible promoters have been identified from the different halophytes (*Salicornia brachiata*, *Aeluropus lagopoides*, *Populus euphratica*, *Thellungiella halophile*, *Chenopodium quinoa*, *Puccinellia tenuiflora*, *Atriplex gmelini*, *Suaeda salsa*, *Salicornia europaea*, *Aeluropus littoralis*, *Spartina anglica*, *Salsola soda*, *Suaeda corniculata*, *Phragmites australis*). These genes were over-expressed in model plants and many agricultural crops (tobacco, rice, alfalfa, soybean, jatropha and cotton) (Himabindu et al. 2016; Mishra and Tanna 2017; Khedia et al. 2018; Jha et al. 2019) for improved stress tolerances. Salt responsive genes family adopt a different strategy for stress tolerance. Among different strategies; Na^+ efflux, sequestration of Na^+ in cell-organelles such as vacuoles, loading of Na^+ on xylem and inhibition of Na^+ influx are the most common strategy which is commonly regulated by a single gene or by a multigene family. Promoters and transcription factors also play a vital role in stress tolerance by activating series of adaptation/ tolerance pathways, following two major routes, either ABA-dependent or ABA-independent pathways. Signal transduction plays a vital role in the activation of gene cascade following the phosphorylation of genes using protein kinases. Antioxidant encoding genes are also involved in imparting stress tolerance by quenching reactive oxygen species and protecting plants from oxidative damages.

Conclusions

Soil salinity problem is increasing throughout the world and there is an urgent need to search for improved saline soil and alternative approaches to meet the global food security challenge. Halophytes have anatomical, physiological and biochemical mechanisms to cope with severe adverse conditions of soil salinity and these have the potential applications for food, fodder and industries which could be efficiently used for amelioration of saline soils because of higher accumulation of salt. However, the selected halophyte should have the capability to produce higher biomass with higher salt content simultaneously should have economic values. Salt tolerant plant growth-promoting rhizobacteria is an emerging biological tool for mitigation of salt stress in the crop plants and halophytes are resources for the developmentof novel bioinoculant/bioformulation for saline agriculture.

Halophytes are sources for identification and isolation of novel salt responsive genes and promoters which can be explored for the development of transgenic crops and plant genetic engineering for stress tolerance.

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Selection of Resilient Crop Species for Cultivation Under Projected Climate Change

Deepa Shree Rawal

Abstract Plant species response to projected climate change would be diverse and dependent on species site specific climate. Therefore, information on species site specific response will be required to build regional species specific adaptation plan. For this identification and implementation of tools and techniques that can predict plant responses to projected climate change would be crucial. There are various methods that can be employed to model species response and mechanistic model is one of the reliable models that can predict the impact. Mechanistic model Tree and Climate Assessment- Germination and Establishment Model (TACA-GEM) has largely been used to predict the climate change impact on wild and agricultural species by identifying resilient species for plantation and cultivation under projected change. TACA-GEM was utilized to predict the impact of climate change on agricultural species in three ecological zones representing eastern mountain, hilly and tropical (Terai) regions considering eight cereals and lentil species in Nepal. Species physiological and phenological parameters with germination experimental data were used to calibrate the model to a range of climate change scenarios by the 2050s. The findings indicate that rainfall is one of the primary factors influencing species germination probability and timing. Moderate rainfall with warm climate projected benefitted germination in tropical site (Saptari) while higher rainfall and colder climate projected was adverse to the germination of most of the species in Bhojpur. The germination probability displayed by wheat and chickpea suggests that these species are the most resilient to projected climatic conditions by the 2050s across all the sites. The study successfully demonstrated site specific species vulnerability to a range of climate conditions. Thus, similar research activity can be employed in different land types to identify resilient crop species for future cultivation.

Keywords Environment · Influence · Agricultural crops · Response · Modeling · Vulnerability

D. S. Rawal (✉)
Nepal Academy of Science and Technology, P. O. Box 3323, Khumaltar, Lalitpur, Nepal
e-mail: deepa.rawal@nast.gov.np

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Introduction

Global temperature is expected to rise 1.1–2.6 °C by the 2100s, and this may likely change the natural biological systems of the World (IPCC 2013). Climate change will alter the temperature, rainfall, radiation and humidity (Olesen and Bindi 2002), consequently changing the physiological and phenology of species (Hughes 2000). Phenological change is the change in the timing of developmental phases of species like seeding/sowing, germination, budding, leafing, stem growth, flowering/fruiting, seed maturing, senescence and harvesting. Therefore, changes in physiological and phenological events in agricultural plants could alter yield and can have greater economic impact (Chmielewski et al. 2004). Information on crop-weather relationships help farmers in decision making and in building strong adaptation strategies (Chmielewski 2013).

There is a growing trend of using phenological response for climate change assessment studies (Chmielewski et al. 2004) that would provide adaptation guidance aiding in the selection of resilient species for future cultivation. Phenological study can help in identifying the optimal cropping area, species and varieties for plantation in changed climate conditions (Chmielewski 2013) that can help in building regional adaptation plans. However, for this species response, modeling is required for the assessment of species resilience to climate change. There are various methods that can be adopted to model the response and mechanistic models have been highly used for the prediction of climate change impact. Phenological models are largely used to study the impact of climate change on natural, managed ecosystems (Chmielewski 2013) and agricultural lands (BC and Rawal 2017). Plants have a definite temperature requirement 'heat sum' before they attain certain phenological stages (Rajput et al. 1987; Sikder 2009). Generally, for field crops Growing Degree Day (GDD) or Heat Sum Models (HSM) are used to calculate the timing of the consecutive phenological stages (Chmielewski 2013). Mechanistic models TACA (Nitschke and Hickey 2007; Nitschke and Innes 2008; Nitschke et al. 2012) and TACA-GEM (Mok et al. 2012; Rawal and Bharati 2015; BC and Rawal 2017) were used to assess the vulnerability of wild and agricultural plant species to climate change. This model primarily utilizes species physiological and phenological parameters to show germination probability, timing shift, and seedling establishment under projected climate conditions, further aiding in identifying resilient species and implement adaptation measures (Rawal et al. 2015; Rawal and Bharati 2015; BC and Rawal 2017).

Effect of climate change is evident in Nepal and may adversely affect various sectors like forestry, agriculture, livelihoods and many other resources affecting the country's economy (Alamgir et al. 2014). National Adaptation Program of Action (NAPA) shows that Nepal is extremely vulnerable to climate change impacts because its economy heavily depends on natural resources, particularly water, soils, and forests (MOE 2010). Nepal has diverse agricultural zones like plains (Terai), hills, mid hills, high hills and mountains and cropping pattern varies across agricultural zones (Malla 2008). Climate change leading to warmer temperature coupled with rainfall decline is the key determinant that alters the timing of phenological events

(Wheeler et al. 1996; Chakrabart et al. 2010; Amgain 2011a, b) that may negatively affect the yield of rice, maize and wheat (Wheeler et al. 1996; Tao et al. 2006; Lobell and Field 2007; Subash et al. 2011). Increase in temperature can cause more damage to the agricultural sector of the tropical 'Terai' region of Nepal. For example, temperature rise of 4 °C reduced rice and wheat production in the Terai region even as production in the hills and mountains rose, while for maize, production declined in the Terai and hills but increased across the mountains (Malla 2008). Hence, climate change and its effects on crops are of particular concern for the World especially in the arid regions.

Climate change induced production decline has led farmers to seek adaptation measures such as changing the agricultural calendar and cropping patterns (Karn 2014). Climate change can influence the choice of crop species, as poorly adapted species can show higher fluctuation and declinein yield even under a small change in the growing season length (Chmielewski 2013). Temperature rise and changed rainfall pattern can alter present soil condition and evaporation (Fennessey 1994; Falloon and Betts 2010) consequently shifting the timing of germination, growth, flowering and fruiting of crop species affecting the yield and the economy. In such situation, vulnerability identification and risk assessment would be critical for better management of agriculture (Reilly and Schimmelpfennig 1999; IPCC 2014). Furthermore, understanding climate variability, its effect on individual crop species and their response can provide valuable information and guidelines for farmers and decision makers.

Therefore, a key challenge ahead is to identify a suitable resilient species and varieties for future plantation in a particular region. Plant species show diverse response to projected climate change that is dependent on individual species site specific climate. Thus, information on species site specific response will be required to build species specific regional adaptation plans. For this identification and implementation of tools and techniques that can predict plant responses to projected climate change would be crucial.

Modeling tools and techniques are largely been implemented to assess species response to climate change. TACA-GEM has been widely used to predict impact on species abundance under projected climate change. This model can be implemented to predict site specific species response that can help in building regional adaptation plans and has been implemented in Nepal to identify site specific species response to climate change scenarios by the year 2050 for wild and agricultural species (Rawal and Bharati 2015; BC and Rawal 2017). This paper basically relates a novel technique adopted in case of Nepal by Rawal and Bharati (2015) which could largely be employed as an innovative approach for the identification of resilient crop species to projected climate change in different regions across the world.

Materials and Methods

Site and Species Selection

Three districts Sankhuwasabha, Bhojpur and Saptari districts representing three ecological zones hill, mountainous and plain (Terai) of the Koshi river basin in Nepal that has been characterized with high climatic and geographical variability (Sharma et al. 2000; Bharati et al. 2014) was selected for the study. This study was conducted by International Water Management Institute (IWMI) under the Koshi Basin Programme, led by the International Centre for Integrated Mountain Development (ICIMOD), that was supported by the Australian Government through the Sustainable Development Investment Portfolio for South Asia.

Eight species of cereal and lentil viz. *Oryza sativa* L. (two varieties), *Triticumaestivum* L., *Zea mays* L., *Paspalumscorbiculatum* L. and *Vignamungo* (L.) Hepper, *Glycine max* (L.) Merr., *Cajanuscajan* (L.) Millsp., *Cicerarietinum* L. (see Appendix 1 for species details) were selected for the study. These species were selected based on the estimated area of cultivation and amount of production in each district (Central Bureau of Statistics 2013). All the selected species are cultivated across three sites except pigeon pea and chickpea, which are only cultivated in Sankhuwasabha and Bhojpur.

Germination Experiment and Statistical Analysis

Seeds used for the germination experiment were mainly accessed from the seed supplier companies that supply seeds to the farmers and some of the seeds were directly accessed from the local farmers (see Appendix 1 for seed source and varieties). Seed germination experiment was conducted at the Seed Science and Technology Division of National Agricultural Research Centre (NARC), Khumaltar, Lalitpur, Nepal in a randomized factorial design in controlled seed germinator chambers following the guidelines of the International Seed Testing Association (ISTA 2011). Sample consisted of four replicates of 100 seeds for each species. Seeds of *Oryza sativa*, *Zea mays*, *Paspalum scorbiculatum*, *Vigna mungo*, *Glycine max*, *Cajanus cajan* and *Triticum aestivum, Cicer arietinum* were germinated at the average temperature of 25 °C and 20 °C, respectively, under dark conditions. All the species were germinated between the papers (A grade germination paper), and *Paspalum scorbiculatum* was germinated in petri dish lined with filter paper (Whatman 150 mm). Moisture was maintained by adding distilled water every day (ISTA 2011). Seeds were carefully observed for epicotyl hook emergence for each day. Base temperatures used for calculating Growing Degree Days (GDD, Shahba and Qian 2008) are provided in Table 1.

Table 1 Species specific germination parameters and climatic origin taken for the calibration of TACA-GEM model

Parameter	Millet	Rice 4	Rice 11	Maize	Wheat	Pigeon pea	Chickpea	Soybean	Black gram
Habitat									
Soil texture[a]	SL[a]	C[e]	C[e]	CL[a]	S[k]	L[a]	SL[q]	L[q]	L[q]
Seedfall Julian date (days)	120[a]	180[a]	180[a]	95[h]	120[m]	120–140[o]	150l	150[r]	90–120[l]
Rooting zone depth (m)	0.1[ab]	0.1[ab]	0.1[ab]	0.1[ab]	0.1[ab]	0.1[ab]	0.1[ab]	0.1[abs]	0.1[ab]
Coarse fragment (%)[b]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Probalistic Germination Functions thresholds of polynomial regression for germination based on GDD									
Minimum GDD threshold (days)	20	30	20	30	30	30	30	30	20
Maximum GDD threshold (days)	180	190	200	140	110	170	170	130	120
Minimum temperature (°C)	20[a]	20[a]	20[a]	18[a]	15[a]	18[a]	15[a]	20[a]	22[a]
Maximum temperature (°C)	35[a]	30[a] or	30[a] or	33[a] or	27 [a] or	38[a]	29[a]	33[a]	35[a]
b0	−0.0705	−0.2284	−0.2708	−0.3903	−0.6028	−0.2156	−0.4103	−0.4369	−0.2169
b1	0.0066	0.0112	0.0117	0.0220	0.0384	0.0243	0.0202	0.0248	0.0149
b2	−5.39E−05	−9.3E−05	9.04E−05	−0.0002	−0.0005	−0.0005	−0.0002	−0.0003	−0.0002
b3	1.1E−07	2.1E−07	1.9E−07	5.9E−07	1.6E−06	3.2E−06	4.3E−07	8.2E−07	5.9E−07
Other germination parameters									
Germination moisture threshold (MPa)	−1.0[c]	−1.0[f]	−1.0[f]	−2.0[j]	−2.3[m]	−1.0[p]	−1.70[j]	−1.0[s]	−2.0[u]
Physiological base temperature (°C)	5.1[d]	8[g]	8[g]	6.1[i]	2[n]	10	5.49[j]	5[t]	8[a]

GDD, growing degree days; [a] www.fao.org, [b] Mok et al. (2012); [c] Kader and Jutzi (2003); [d] Russell and Webb (1976); [e] Anonymous 3 (2005); [f] Chauhan and Johnson (2009); [g] Yoshida (1981); [h] Anonymous 2 (2008); [i] Itabari et al. (1993); [j] Finch-Savage (2005); [k] Anonymous 1 (2008); [l] www.nfsm.gov.in; [n] George (1967); [m] Wuest et al. (1999); [n] Khah et al. (1986); [o] Sheahan (2012); [p]Briede and McKell (1992); [q] Heuzé et al. (2012b, 2013a); [r] Usual Planting and Harvesting Dates (1997); [s] Vieira et al. (2004); [t] Covell et al. (1986); [u] Pratap and Sharma (2010)

To determine the relationship between optimum time and temperature needed for germination, germination percentage was analysed as a dependent variable of GDD accumulation using non-linear polynomial regression analysis (McDonald 2009).

Mechanistic Model and Climatic Parameters

The mechanistic model TACA-GEM (Mok et al. 2012), a modified version of TACA (Nitschke and Hickey 2007; Nitschke and Innes 2008; Nitschke et al. 2012) was used to model the species-specific germination responses to climate variability. Species-specific germination parameter GDD thresholds and GDD functions identified from the germination phenological experimental components were used for TACA-GEM calibration (Table 1). Details of the model can be found in Rawal et al. (2015), Mok et al. (2012) and Nitschke and Innes (2008).

For the simulation of past climate conditions (PCC), climate inputs from the ten-year reference period was inputted to TACA-GEM. The climate data include the minimum and maximum temperature (T_{min} and T_{max}), rainfall (R_{mean}) and solar radiation (SR) on a daily time step (*source:* Department of Hydrology and Meteorology, Nepal). The climatic data, climatic points and the years used for each site are provided in Appendix 2. For the site Bhojpur, the R_{mean} values were considered from the climate station 1325 (Dingla, Bhojpur). The temperature data representing Bhojpur (station 1324, Bhojpur, Bhojpur) has a large number of missing T_{min}, T_{max} and R_{mean} data, and climate station 1325 (Dingla, Bhojpur) lacks temperature data. Significant higher correlation exists between the T_{max} ($r \leq 0.87$, $P < 0.0001$) and T_{min} ($r \leq 0.91$; $P < 0.0001$) between the climatic stations 1324 (Bhojpur, Bhojpur) and 1303 (Chainpur, Eastern Sankhuwasabha). Hence, the climate variables T_{min}, T_{max} of the station 1303 (Chainpur, Eastern Sankhuwasabha) has been used to represent the temperature of Bhojpur. Where the missing values exist, the monthly mean of the climatic variables T_{min}/T_{max}/R_{mean}/SR were added. When monthly SR values were missing, the monthly mean of previous or subsequent year was used for the interpolation.

The projected climate model simulations in the Fifth Assessment Report of the IPCC (2014) are based on the Representative Concentration Pathways (RCPs, Moss et al. 2010). Four projected climatic conditions—wet-warm (CanESM2-r4i1p1), wet-cold (CCSM4-r5i1p1), dry-cold (GISS-E2-R-r4i1p1) and dry-warm (IPSL-CM5A-LR-r4i1p1)—that represent 'RCP 45' (Immerzeel and Lutz 2012) were considered for TACA-GEM model simulation. Monthly delta change approach (in detail, Immerzeel and Lutz 2012) has been used to build these four scenarios, which project the temperature and precipitation change by the 2020s–2050s, corresponding three selected sites. The base reference years used to make the four climate projections were from the period 1998–2008 for each site. This delta change approach is considered an efficient way to assess climatic changes (Deque 2007; Kay et al. 2008). Based on the present and the four projected climatic conditions, TACA-GEM output provides germination shift in days and germination probability score ranging from 0–1, indicating total failure (0.0) to 100% success (1.0) in germination.

Average of climatic factors (T_{min}, T_{max}, R_{mean}) used to calibrate the TACA-GEM for PCC and the projected climate change conditions by the 2050s (wet-warm, wet-cold, dry-cold, dry-warm) is provided in Table 2. Analysis of variance (ANOVA) of mean annual T_{min}, T_{max} and R_{mean} of PCC and projected climatic conditions (wet-warm, wet-cold, dry-cold, dry-warm) was carried out to show the climatic differences among the sites Sankhuwasabha, Bhojpur and Saptari. Mean annual T_{min}, T_{max} and R_{mean} of PCC and the four projected climatic conditions (wet-warm, wet-cold, dry-cold, dry-warm) differed significantly ($P \leq 0.001$) across the sites. Bhojpur is significantly wetter and Sankhuwasabha significantly drier while rainfall was moderate at Saptari across PCC and projected climatic conditions. Saptari is significantly warmer than the other two sites across all the climatic conditions and temperature conditions are similar between Bhojpur and Sankhuwasabha. T_{max}, T_{min} and R_{mean} are lower under PCC than the four projected climatic conditions across all the sites (Table 2).

Table 2 Average of climatic factors (T_{min}, T_{max}, R_{mean}) used to calibrate the TACA-GEM for PCC and the projected climate change conditions by the 2050s. Climatic means followed by different superscripts indicates significant differences ($P \leq 0.05$) in climatic conditions (PCC, wet-warm, wet-cold, dry-cold, dry-warm) among the sites Sankhuwasabha, Bhojpur and Saptari

Site	T_{min}	T_{max}	R_{mean}
Sankhuwasabha			
PCC	13.0^a	24.7^a	4.2^a
Wet-warm	14.0^a	25.7^a	5.0^a
Wet-cold	13.7^a	25.4^a	5.0^a
Dry-cold	13.7^a	25.4^a	5.1^a
Dry-warm	14.0^a	25.6^a	4.9^a
Bhojpur			
PCC	13.0^a	24.7^a	6.8^b
Wet-warm	14.0^a	25.7^a	7.8^b
Wet-cold	13.7^a	25.4^a	7.8^b
Dry-cold	13.7^a	25.4^a	7.8^b
Dry-warm	14.0^a	25.6^a	7.5^b
Saptari			
PCC	19.3^b	32.3^b	5.4^c
Wet-warm	20.3^b	33.2^b	6.1^c
Wet-cold	20.0^b	32.9^b	6.0^c
Dry-cold	20.0^b	32.9^b	6.2^c
Dry-warm	20.2^b	33.1^b	5.9^c

Results

The model results demonstrate that species germination response was generally influenced by climatic condition of individual site. However, germination probability of wheat and chickpea were similar across all the sites. Species germination probability was higher across all the climatic conditions projected by the 2050s in Saptari. The result also demonstrates that projected climatic condition of Bhojpur was not favorable for most of the species as germination probability declined.

Site specific species response suggests that at Sankhuwasabha all four climatic conditions were favourable for the germination of wheat, chickpea and soybean. However, the projected dry-cold conditions severely affected the germination probability of millet, rice 11, maize, pigeon pea and black gram while rice 4 was affected by wet-warm conditions (Table 3).

The model results suggested that at Bhopur, PCC is generally more beneficial for germination than projected climate conditions for all the species except rice varieties at this site. Among the projected climate conditions, higher rainfall coupled with cold conditions projected were more detrimental to the germination of most of the species. Across the projected climatic conditions wet –warm condition was more favourable for the germination of all species. Under wet-cold and dry-cold conditions the germination decreased across all the species and germination potential of millet, soybean and black gram declined more sharply than for other species (Table 3).

Moderate rainfall and warmer conditions projected in Saptari mostly benefitted species germination across all the projected conditions. However, the germination of two rice varieties declined under the wet-warm conditions indicating germination vulnerability of rice under warmer condition. Although the germination probability under PCC is lower for wheat and chickpea, projected climate conditions benefitted germination (Table 3).

Discussion

Species Vulnerability

Plant species show various degree of regeneration change under climate changed conditions (Rawal et al. 2015). In this study, the germination response displayed by the species under varied climatic conditions helped in determining the species risk to projected climatic conditions. The germination capacity of wheat and chickpea were not much affected by projected climatic conditions thus displayed wider degree of plasticity. Species demonstration of wider regeneration niche than that of the existing one may provide a larger degree of plasticity (Aitken et al. 2008; Cochrane et al. 2011). Such plasticity was not demonstrated by all the species under projected climatic condition by the 2050s which may risk the germination capacity and seedling establishment. This study therefore, suggests that wheat and chickpea demonstrated

Table 3 TACA-GEM model results of germination probability score (0 − 1 indicating no to successful germination) for the study species under PCC (past climate condition) and projected climatic conditions wet-warm, wet-cold, dry-cold and dry-warm by the 2050s

	Millet	Rice 4	Rice 11	Maize	Wheat	Pigeon pea	Chickpea	Soybean	Black gram
Germination probability score (std dev.)									
Sankhuwasabha									
PCC	0.62(0.33)	0.77(0.28)	0.52(0.48)	0.96(0.12)	1.00(2.2E−09)	0. 89(0.15)	0.99(5.4E−05)	0.55(0.41)	0.70(0.31)
Wet-warm	0.78(3.3E−03)	0.69(4.0E−03)	0.59(0.004)	0.99(5.2E−05)	1.00(3.9E−10)	0.96(7.0E−04)	0.99(1.1E−07)	0.65(4.0E−03)	0.76(4.0E−03)
Wet-cold	0.80(0.03)	0.92(1.0E−03)	0.81(3.0E−03)	0.99(1.0E−04)	1.00(4.2E−11)	0.97(6.0E−04)	0.99(3.6E−08)	0.70(4.0E−03)	0.78(3.0E−03)
Dry-cold	0.50(3.0E−03)	0.77(3.0E−03)	0.46(5.0E−03)	0.94(1.0E−03)	1.00(3.4E−10)	0.87(2.0E−03)	0.99(1.6E−08)	0.60(5.0E−03)	0.69(4.0E−03)
Dry-warm	0.86(2.0E−03)	0.97(6.0E−04)	0.92(1.4E−03)	0.99(1.7E−05)	1.00(2.4E−12)	0.97(5.0E−04)	0.99(8.1E−08)	0.77(4.0E−03)	0.85(2.0E−03)
Bhojpur									
PCC	0.71(0.22)	0.78(0.34)	0.67(0.44)	0.99(0.02)	1.00(2.0E−07)	0.86(0.13)	0.99(6.0E−04)	0.57(0.39)	0.79(0.20)
Wet-warm	0.70(4.1E−03)	0.81(3.0E−03)	0.72(4.0E−03)	0.95(1.0E−03)	1.00(4.5E−09)	0.83(3.0E−03)	0.99(4.2E−06)	0.57(5.0E−03)	0.68(4.0E−03)
Wet-cold	0.51(5.0E−03)	0.77(3.0E−03)	0.66(4.0E−03)	0.89(2.0E−03)	1.00(7.7E−09)	0.76(3.0E−03)	0.99(8.2E−05)	0.34(4.0E−03)	0.49(5.0E−03)
Dry-cold	0.51(5.0E−03)	0.81(3.0E−03)	0.67(4.0E−03)	0.94(1.0E−03)	1.00(7.2E−10)	0.76(4.0E−03)	0.99(9.1E−07)	0.40(5.0E−03)	0.53(5.0E−03)
Dry-warm	0.61(5.0E−03)	0.77(4.0E−03)	0.65(4.0E−03)	0.89(2.0E−03)	1.00(4.4E−09)	0.78(3.0E−03)	0. 99(6.3E−05)	0.49(5.0E−03)	0.59(5.0E−03)
Saptari									
PCC	1.00(3.3E−07)	0.87(0.17)	0.99(0.00)	1.00(1.7E−09)	0.47(0.44)	0.99(2.9E−06)	0.95(0.06)	0.99(4.5E−05)	0.99(7.7E−05)
Wet-warm	1.00(1.4E−10)	0.74(4.0E−03)	0.69(3.0E−03)	1.00(7.2E−14)	0.99(1.3E−09)	1.00(4.6E−10)	0.99(4.2E−06)	1.00(3.9E−09)	0.99(1.7E−08)
Wet-cold	1.00(6.1E−10)	0.99(4.6E−05)	0.99(9.5E−05)	1.00(1.9E−13)	0.99(8.2E−06)	0.99(1.6E−07)	0.99(5.8E−07)	0.99(2.5E−07)	0.99(5.9E−08)
Dry-cold	0.99(3.7E−08)	0.99(5.2E−05)	0.99(0.0001)	1.00(5.9E−15)	0.99(5.4E−06)	0.99(4.5E−07)	0.99(3.4E−07)	0.99(1.7E−07)	0.99(9.1E−07)
Dry-warm	1.00(1.3E−10)	0.99(5.9E−05)	0.99(6.8E−05)	1.00(3.3E−15)	0.99(8.6E−06)	1.00(6.6E−10)	0.99(1.5E−06)	0.99(5.9E−08)	0.99(2.4E−08)

higher degree of resiliency that can adapt future changes and can be considered as the most suitable species for future plantation across all the sites. Wheat is grown across a wider range of environments and has greater capacity for adaptation (Anonymous 1, 2008) than any other cereal crops. In the case of chickpea, the species is drought tolerant (Heuzé et al. 2013a) and is distributed across a wide climatic range, from arid, semi-arid, tropical and temperate (www.fao.org). However, chickpea is not currently cultivated in hilly areas like Sankhuwasabha and Bhojpur but this study indicates that chickpea may germinate well in hilly areas as well which also explains the resiliency exhibited by chickpea. Additionally, Covell et al. (1986) suggests introducing chickpeas in new areas as the species is capable of germinating over a wider range of temperatures. Moreover, Venkateswarlu and Shanker (2009) also argue that introducing and cultivating resilient species and varieties that are suitable for a new agricultural system is an adaptation technique.

Millet and maize are highly diverse and are found in different climate zones from temperate to tropical (www.fao.org). This study demonstrates that maize and millet can be resilient to projected climate conditions in Saptari, but the declining germination probability exhibited in Bhojpur and under dry-cold conditions in Sankhuwasabha suggests that these species may become vulnerable at these sites. Maize is a species of warm climate and requires adequate moisture, and hence does perform well in semi-arid or wet climate (Purseglove 1972). Meanwhile, millet can thrive in dry conditions but has limited drought tolerance (Heuzé et al. 2012a; www.fao.org). Hence, the response displayed in Saptari indicates that warm and moderate rainfall conditions projected at this site maintained the germination capacity while extremely wet conditions in Bhojpur and extremely dry conditions in Sankhuwasabha posed germination risk for both the species.

In this study, two rice varieties exhibited varied germination response under similar temperature conditions of Bhojpur and Sankhuwasava. Germination capacity and yield of rice is directly linked to the rainfall condition. Rice plants require less water during nursery stage and high rainfall and excess moisture during this stage may result in lower germination and yield (Karn 2014). Under climate changed condition dry-warm conditions are more prevalent at dry sites due to temperature rise (Dixit et al. 2009; Karn 2014) and such conditions were found to be favorable for germination of rice 4 and 11 in Sankhuwasabha and Saptari. Generally, germination potential for rice needs to be 70% (www.fao.org) for quality assurance. Germination potential (<70%) exhibited by rice 11 across all the projected climatic conditions and sites indicates that this rice variety is relatively more vulnerable than rice 4 variety. Therefore, this study recommends extensive investigation of responses within species, i.e., populations/varieties, to identify suitable population/variety for future plantation.

Among the lentil species, high rainfall in Bhojpur was adverse to the germination of soybean, pigeon pea and black gram indicating that these species require moderate rainfall conditions for germination. Soybean, pigeon pea and black gram all these species perform well in warm, moist and well-drained environments (Arora and Mauria1989; Heuzé et al. 2013b) which explains the species germination resiliency under warm and moderate rainfall conditions in Saptari. Moreover, Soybean is a drought-tolerant species suitable for semi-arid areas and can survive dry spells and recover once favorable conditions resume (Heuzé et al. 2012b).

Spatial Vulnerability

This study demonstrated that species germination potential relied on spatial climatic conditions and germination phase is largely controlled by rainfall. Rainfall variation was the key factor that determined the species germination potential. Temperature conditions are similar in Sankhuwasabha and Bhojpur; however, the varied species responses across the site suggest that higher rainfall in Bhojpur lowered germination capacity for most of the species indicating vulnerability to projected climatic change at this site. However, lower projected rainfall benefitted germination in Sankhuwasabha, indicating lower susceptibility of the species to climate change at this site relative to Bhojpur. Optimum temperature and soil water availability are the principal environmental factors that influence seed germination and emergence (Lindstrom et al. 1976; Fyfield and Gregory 1989). This is consistent with our study findings, which indicated that moderate rainfall with warm climatic conditions in Saptari benefited germination indicating resilience to climate change; although wet-warm conditions may adversely affect two rice varieties. However, uncertainties do exist and irrespective of future climate change, our study indicates that germination of the selected crop species may not be vulnerable to climate change in Saptari by the 2050s.

Furthermore, climate change is expected to affect agriculture very differently in different parts of the World (Parry et al. 1999; Vaghefi et al. 2013). Hence, spatial climatic pattern and its impact and adaptation planning at the regional level have become a key issue (Tao et al. 2008). Therefore, this study was an example to show how modeling tools can be implemented to predict species spatial vulnerability to projected climate change that may help in building adaptation plans that can suit a particular region. This type of modeling tools can be utilized in various land types like moist, arid semi-arid etc. as site specific climate scenarios and environmental factors are utilized to calibrate model for the prediction of plant response. Such studies should be promoted and implemented to assess vulnerability and to devise adaptation plans in regional scale.

Conclusion

This study was able to demonstrate that species exhibit unique germination responses, and such divergent responses are likely to be influenced by regional climatic conditions indicating species vulnerability is reliant on spatial climatic condition. The study was successful in providing some primary insights on how projected spatial climatic variability may affect species germination, thus helping to identify species resiliency to climate change. This study was an example to initiate the use of such models for the prediction of species spatial vulnerability and to identify resilient species for cultivation under climate change. Thus such studies may ultimately help to better predict future consequences and help manage and improve agricultural production at the regional level.

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Appendix 1: Scientific Name, Common Name, Seed Variety and Source of the Selected Species

Species	Common name	Seed varieties and source
Paspalum scorbiculatum	Millet	Personal communication with a farmer from Kavre
Oryza sativa	Rice 4 (Jeeramansuri)	Khumal 4 (Everest seed company, Khumaltar)
Oryza sativa	Rice 11(Taichin)	Khumal 11 (Everest seed company, Khumaltar)
Zea Mays	Maize	CTake 940 (Everest seed company, Khumaltar)
Cajanus cajan	Pigeon pea	Personal communication with a farmer from Koshi basin
Cicer arietinum	Chickpea	Personal communication with a farmer from Sindhuli
Triticum aestivum	Wheat	WK 1204 (ATC scientific seed conservation center, Khumaltar)
Vigna mungo	Black gram	Personal communication with a farmer from Kavre
Glycine max	Soybean	Sathiyakalo (Everest seed company, Khumaltar)

Appendix 2: Station Number, Site Name and Past Years of Climate Data (T_{max}, T_{min}, R_{mean} and Solar Radiation) Accessed for Three Sites

Site	Geographical position	Station name and code used for T_{max}, T_{min}, R_{mean}	Station name and code used for solar radiation	Past years of climate taken for model input
Saptari	26.53° N 86.73°E	1202 (Phatepur)	1206 (Okhaldhunga)	1994, 1997–1999, 2001–2002, 2006–2009
Sankhuwasabha	27.30 °N 87.32 °E	1303 (Chainpur)	1307 (Dhankuta)	1999–2003, 2005–2009
Bhojpur	27.16 °N87.05 °E	1303 (T_{max} and T_{min}, Chainpur) 1325 (R_{mean}, Dingla)	1307 (Dhankuta)	1999–2003, 2005–2009

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Livestock Based Production Systems for Climate Adaptation in Dryland Areas

D. B. V. Ramana

Abstract Climate change would impact and destabilize livestock production systems in drylands through crop failures, fodder scarcity, low (milk, meat and egg) production and increased incidence of endemic animal diseases. Adaptation strategies like enhancing fodder production, scientific feeding of livestock, protection from extreme weather events through proper shelter, disease surveillance and timely immunization against endemic diseases, integration of livestock production systems with agriculture and allied sectors would help in reducing vulnerability of livestock and ecosystems to climatic changes. Introducing subsidies for fodder production, establishment of complete feed mills, insurance of animals, income diversification practices and establishing livestock early warning systems and other forecasting and crisis-preparedness systems could strengthen adaptation efforts. Capacity building of livestock producers to understand and deal with climate change impacts and mitigation of GHG emissions, further reduces the magnitude of climate change impact on livestock-based production systems in the long run.

Keywords Climate change · Drylands · Integrated farming systems · Adaptation strategies · Fodder production systems · Livestock production

Introduction

In tropical countries like India, climate change has been, and continues to be the most important cause of instability in dryland production systems and the dependent livelihoods. Climatic related risks like extreme weather events (heat stress/cold stress), drought and floods, are expected to rise sharply in near future as global average surface temperature is predicted to increase 1.8–4.0 °C by 2100 (IPCC 2007). These changes would destabilize the dryland production systems through crop failures, fodder scarcity, low livestock production and increased incidence of endemic animal diseases. Along with crops and tree plantations, livestock also contribute to human

D. B. V. Ramana (✉)
ICAR-CRIDA, Hyderabad 500059, India
e-mail: ramana.dbv@icar.gov.in

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food supply. It converts low-value crop residues and byproducts, inedible or unpalatable for human, into milk, meat, and eggs and directly contributes to nutritional security. Nearly two-thirds of farm households are associated with livestock production as a resilient mechanism to the crop production and 80% of them are small landholders (≤2 ha) (Birthal 2008). Besides contributing over one-fourth to the agricultural GDP, livestock provides employment to 22.45 million people in principal or subsidiary status in India (Kumar et al. 2015).

At present, resource depletion and climate change in dryland areas driving the farmers gradually towards more resilient livestock based production systems. Climate change would also impact severely the economic viability and production of these integrated production systems. Drought and high ambient temperatures in particular, affects production of milk, meat and egg, reproduction, health of animals and condition of pastures. Changes in pasture and crop biomass availability and quality affect animal production through changes in daily or seasonal feed supplies. To mitigate the adverse affects of extreme weather events and cope with changing climate, much precised resilient basket of options suitable to local conditions and resources are needed. Hence, one should be critical in recommending resilient production systems in view of much diversified and heterogeneous group of farmers and the resources accessible to them in dryland areas. This will help in sustaining the productivity in dryland areas and profitability to the farmers even in the era of climate change.

Impact of Climate Change on Livestock Production Systems

Dry matter intake decreases especially in high yielding milk cattle and buffaloes exposed to heat stress. In addition, there can also be a decrease in the efficiency of nutrient utilization and increased loss of sodium and potassium electrolytes. Sudden changes in temperature, either a rise in T max (>4 °C above normal) during summer i.e. heat wave or a fall in T min (<3 °C than normal) during winter i.e. cold wave cause a decline in milk yield of crossbred cattle and buffaloes (Upadhyay et al. 2007). The estimated annual loss due to heat stress at the all-India level is 1.8 million tonnes, that is, nearly 2% of the total milk production in the country (Upadhyay et al. 2007). Global warming is likely to lead to a loss of 1.6 million tonnes in milk production by 2020 and 15 million tons by 2050 from current level in business as usual scenario (Upadhyay et al. 2007). The decline in yield varies from 10–30% in first lactation and 5–20% in second and third lactation (Srivastava 2010). Northern India is likely to experience more negative impact of climate change on milk production of both cattle and buffaloes due to higher variation in day and night temperatures (Naresh Kumar et al. 2012).

The decline in milk production will be higher in crossbreds (0.63%) followed by buffalo (0.5%) and indigenous cattle (0.4%). A rise of 2–6 °C due to global warming (time slices 2040–2069 and 2070–2099) projected to negatively impact growth, puberty and maturity of crossbreds and buffaloes (Naresh Kumar et al. 2012). Heat stress induced by climate change has also been reported to decrease reproductive performance in dairy animals. Time to attain puberty of crossbreds and buffaloes will increase by one to two weeks due to their higher sensitivity to temperature than indigenous cattle. The main effects include decrease in the length and intensity of the oestrus period, decreased fertility rate, decreased growth, size and development of ovarian follicles, increased risk of early embryonic deaths and decreased fetal growth and calf size. Decrease in weight gain and alterations in reproductive behaviour were also observed in small ruminants (Ramana et al. 2013). Lack of prior conditioning to weather events most often results in catastrophic losses in the domestic livestock industry. Further, intensive livestock and poultry production systems rely heavily on food grains as their principal feed type will be the most affected. Since climate changes will have the potential to affect the crop production it will put pressure on livestock industry as a whole.

Besides the direct effects of climate change on animal production, there are profound indirect effects as well, which include climatic influences on quantity and quality of feed and fodder resources such as pastures, forages, grain and crop residues and the severity and distribution of livestock diseases and parasites. Climate change will have a substantial effect on global water availability also. Not only this will affect livestock drinking water sources, but it will also have a bearing on livestock feed production systems and pasture yield. Rising temperatures increase lignification of plant tissues and thus reduce the digestibility and the rates of degradation of plant species. Dryland areas which receive relatively low rainfall are expected much reduction in herbage yields especially in dry seasons. Incessant rains during 2010 monsoon in India have indicated increased incidence of epidemics of blue tongue disease outbreak in costal districts of Tamil Nadu, Karnataka, and Andhra Pradesh due to heavy breeding of the vector *Culicoides* species (Venkateswarlu et al. 2011). Temperature and humidity variations could have a significant effect on helminth infections also. Thus, in general, climate change-related aberrations will have adverse impacts on animal health and production systems.

Adaptation Strategies for Optimum Production from Livestock-Based Systems

Adaptation helps in reducing vulnerability of livestock and ecosystems to climatic changes, and mitigation reduces the magnitude of climate change impact in the long term. Livestock keepers, especially resource poor farmers have a key role to play in promoting and sustaining a low-carbon rural path through good management practices. The capacity of local communities to adapt to climate change and mitigate its impacts will also depend on their socio-economic and environmental conditions, and on the resources available and extent of accessibility for the resources.

An adaptation strategy augment tolerance of livestock production systems and enhances ability to survive, grow and reproduce in conditions of deprived nutrition, high incidence of parasites and diseases under extreme weather events. There is no one-size-fits-all solution for adaptation; measures need to be tailored to specific contexts, such as different species of animals, production level, ecological and socioeconomic patterns, and to geographical location and traditional practices. The foremost adaptation strategy that help in reducing the vulnerability of livestock production systems in dryland areas include enhancing feed and fodder base both at household and community level. This can be achieved by intensive irrigated fodder production systems with high yielding perennial (hybrid napier varieties like CO-3, CO-4, APBN-1 etc.,) and multicut fodders varieties (MP Chari, SSG etc.), intensive rainfed fodder production systems by growing two or more annual fodder crops as sole crops in mixed strands of legume (Stylo or cow pea or hedge lucerne etc.) and cereal fodder crops like sorghum, ragi in rainy season followed by berseem or lucerne, in rabi season, short duration fodder production from tank beds with sorghum and maize fodder, sowing *Stylosanthes hamata* and *Cenchrus ciliaris* in the inter spaces between the tree rows in orchards or plantations as hortipastoral and silvopastoral integrated fodder production systems, fodder production systems through alley cropping, perennial non-conventional fodder production systems with deep rooted top feed fodder trees and bushes such as *Prosopis cineraria, Hardwickia binata, Albizia* species, *Zizyphus numularia, Colospermum mopane, Leucaena leucocephala, Azadirachta indica, Ailanthus excelsa, Acacia nilotica.* Use of unconventional resources form food industries like—palm press fibre, fruit pulp waste, vegetable waste, brewers' grain waste and all the cakes after expelling oil as feed. Further, fodder production at homesteads through Azolla, hydroponic Fodder Production with barley, oats, lucerne and rye grass, year-round forage production with suitable perennial and annual forages like growing annual leguminous fodders like cowpea or horse gram etc. inter-planted with perennial fodders like Co-3, CO-4, APBN-1 varieties of hybrid napier in kharif and inter-cropping of the grasses with berseem, lucerne, during rabi season would also increases resilience of livestock production systems through continuous supply of nutritious fodder.

Substantial fodder can be produced through prior contingency planning. During early season drought, short to medium duration cultivated fodder crops like sorghum (Pusa Chari Hybrid-106 (HC-106), CSH 14, CSH 23 (SPH-1290), CSV 17) or Bajra (CO 8, TNSC 1, APFB 2, Avika Bajra Chari (AVKB 19)) or Maize (African tall, APFM 8) which are ready for cutting in 50–60 days and can be sown immediately after rains under rainfed conditions in arable lands during kharif season results in optimum fodder production. If a normal rain takes place in later part of the year, rabi crops like Berseem (Wardan, UPB 110 varieties), Lucerne (CO-1, LLC 3, RL 88) can be grown as second crop with the available moisture during winter. In waste lands fodder varieties like Bundel Anjan 3, CO1 (Neela Kalu Kattai), *Stylosanthes scabra* can be sown for fodder production. In case of mid season drought, suitable fodder crops of short to long duration may be sown in kharif under rainfed conditions. Mid season drought affects the growth of the fodder crop. Once rains are received in later part of the season the crop revives and immediate fertilization help in speedy recovery. If sufficient moisture is available, Rabi crops like Berseem (Wardan, UPB 110 varieties); Lucerne (CO 1, LLC 3, RL 88) can be grown during winter. In waste lands fodder varieties like Bundel Anjan 3, CO-1 (Neela Kalu Kattai), *Stylosanthes scabra* can be sown for fodder production. As late season drought affects seed setting, normal short duration fodder crops may be sown. Avoid multicut fodder varieties under rainfed conditions as they require some sort of irrigation after each cutting. All the available fodder must be harvested before drying out to preserve nutritive quality. Depending on availability of moisture, Rabi fodder crops especially low water requiring varieties of lucerne may be planted. In wastelands, grasses like *Cenchrus ciliaris*, *C. setigerus, Chloris gayana, Panicum maximum, Desmanthus virgatus, Stylosanthes scabra* can be taken up to increase forage production. In areas that receive north east monsoon rains, multi-cut fodder varieties of sorghum (CO 27, Pant Chari-5 (UPFS- 32), COFS- 29 or pearl millet (Co-8) or maize (African tall) are recommended. In areas that receive summer rains, fodder crops like cowpea and maize are best suited.

The second most important in building the resilience of livestock-based production systems in drylands is development and promotion of integrated farming systems. Integrated farming system besides generating higher productivity, it also produces sufficient food, fruits, vegetables to the farm families.

Scope and Prospects of the Livestock Based Production Systems

India has 228 million ha (69%) of the total geographical area (about 328 million ha) is under dry lands (arid, semi-arid and dry sub-humid) and is affected by the unpredictable nature of rainfall during the monsoon and aberrant weather situations like long gaps in rainfall, delayed start of monsoon and early cessation of rains leading to ambiguity in production, low yields per unit area and low income. Further, these areas incidentally are highly populated which makes the people vulnerable to environmental stress and impacts livelihoods directly. In these areas, agro-ecologically sustainable livestock based production systems with different species of livestock including poultry and fishery has a lot of scope in enhancing the productivity and profitability, minimizing risk and improving the livelihoods of millions of rural population dependent on dryland agriculture. Livestock has always provided the much needed resilience to dryland farming in most drought-prone regions of the country. Livestock serve not only as an effective enterprise in terms of converting the cereal crop residues into nutritious protein (milk or meat), but also recycles the nutrients to the soil through farm yard manure for sustainable agricultural production. In the distressed and resource-poor dryland agro-eco systems, the role of livestock is all the more important since they provide year-round liquidity that meets the domestic and farm needs of the agriculturists. Livestock builds resilience to the production systems by providing daily income through sale of livestock products (milk, meat and eggs), annual income through sale of manure and as liquid asset through sale of livestock and also provides draft animal power in agriculture especially for farmers with less than one hectare farm size. Increasing demand for livestock products further necessitates more and more livestock based farming systems and this can be evidenced from increasing in per capita milk (91–115 kg/year), meat (2.8–5.4 kg/year), eggs (23–53 number per year) and fish (4.0–6.2 kg/year) consumption of rural and urban households during 1987–88 to 2009–10 in India (NCAER 2014). Further, the future demand for the available farm yard manure as organic fertilizer under national programme for organic production seems to be immense and plays a vital role in reclamation of soil organic carbon in poor dryland soils for enhancing the productivity of crops.

Considering the resource base available in the country, prospects are much better for livestock than any other component for integration in cropping systems. The extent of land available for grazing like forest area, fallows, wastelands and specified grazing/pasture lands forms the major source of forage for both small and large ruminants in rural areas. Dry fodder resources like cereals and millets in addition to the groundnut and pulses grown by farmers serves as source of roughages in the form of stover, straw, haulms and other materials and forms the major portion of dry fodder for livestock. Green fodder resources like annual (sorghum, maize, bersem, lucerne, cow pea, horsegram) and perennial fodder (Co-3, Co-4, APBN-1) grown by farmers in cultivated lands serves as source of green fodder for livestock.

Types of Livestock Based Production Systems and Domain Areas

There are many livestock based production systems that do exist in different agro-ecological regions under rural conditions. These systems comprising enterprises viz. field and horticultural crops, poultry, fishery (0.20 ha) and apiary (5 bee hive boxes) in 0.6 ha area in Chintapalli of high altitude and tribal zone of Andhra Pradesh recorded a net income of Rs. 29, 102 and B:C ratio of 1.83 with productivity of 14.40 (t ha^{-1}) and 464 man days/ha/year over arable cropping returns (Rs. 14500/ha) and B:C ratio (1.47) with less productivity (7.50 t ha^{-1}) (Sekhar et al. 2014). A production system with field crops (Rice) + poultry + fish + horticultural crop (banana) resulted in highest system productivity (14.90 t ha^{-1}) in terms of rice grain equivalent yields. This system besides generating higher productivity, also produce sufficient food, fruits, vegetables etc. to the farm families. It recorded 99.3% more productivity over cropping alone. Similarly, fish + horticulture + apiary system recorded 96% higher productivity (14.40 t ha^{-1}) than rice-rice alone. Paddy-fish-horticultural system gave 88.3% higher productivity over conventional cropping. Several livestock based production systems like (A) crop + poultry (20) + goat (4); (B) crop + poultry (20) + goat (4) + dairy (1); (C) crop + poultry (20) + goat (4) + sheep (6); and (D) crop + poultry (20) + goat (4) + sheep (6) + dairy (1) were studied. Among the models examined, model (D) recorded a maximum net income of Rs 52,794/ha, with maximum employment generation (389 mandays/ha/year) (Solaiappan et al. 2007).

Some suitable livestock based production systems for different agro-ecological regions of the country are as follows:

Crop-Livestock Integrated Farming System

In this type of integration, mostly dairy animals like cows and buffaloes are integrated with cropping system for milk production and is more common in rural India. Residues from the *Kharif* crops like paddy, sorghum, groundnut forms the basal diet for the dairy animals and these animals are supplemented with green fodder from grazing or cultivated lands along with household or purchased bran and or cake during milking. Depending on the availability of crop residues and also purchasing capability of the farmers, the type and number of milch animals varies from farmer to farmer. This type of integration is mostly market driven and more common in peri-urban than remote areas and is suitable for all the agro-climatic zones depending on the demand and market for the sale of milk. In order to exploit full potential of dairy animals reared under these systems, incentives like subsidized fodder seed, concentrate mixture, mineral mixture, silage bags, shelters for storing crop residues etc., are required. Integrated farming system has a combination of crop and livestock enterprises and in some cases may include combinations of aquaculture and trees. It is a component of farming systems, which comprehend the concepts of minimizing risk, increasing total production and profits by lowering external inputs through recycling and improving the utilization of organic wastes and crop residues. It provides a steady and stable income, rejuvenation/amelioration of the system's productivity and also improves space utilization and increase productivity per unit area.

A long-term experiment with farming system modules on micro-watershed basis in a watershed (13,964 m^2 area) at HRF with a total of 23 crops (4 field crops, 9 vegetables, 2 fruit crops, 3 grasses/fodder, 2 tree crops, 2 bush crops and 1 essential oil yielding crop) were studied. The main advantage of this FSM was production of fodder from diverse sources and this was integrated with ram lamb fattening (Fig. 1).

The available fodder would meet the nutritional requirements of 10 ram lambs for a period of 5–6 months. Through this system, 1.2–1.5 t of organic fertilizer in the form of sheep faeces can be produced to improve fertility of soil. An additional income of 12,000–15,000 would be possible with integration of small ruminants through lamb fattening in addition to the income from crop production.

Crop-Livestock-Poultry Integrated Farming System

Livestock like cattle or buffaloes or small ruminants especially sheep are integrated with crop production. Benefits of integration are synergistic rather than additive. Crop

Fig. 1 Nellore (Brown) sheep grazing on established pasture in a micro watershed

and livestock components may benefit to varying degrees to the overall profitability of the system. Crop residues, otherwise which goes as waste form the feed for livestock along with natural and cultivated forage and produces primarily milk or meat in addition to the farm yard manure for soil application. Integrated farming system offer a pragmatic solution to meet the increasing demand for food, diversification in food habits and stabilizing the income thus improving the nutrition of the small-scale farmers with limited resources. Further, integration of different farm components i.e., crops + horticultural crops (fruits and vegetables) and livestock along with vermi-composting as value addition practice has been found to have maximum gross and net returns with maximum net returns of Rs. 42,610 (51.7%) from livestock, including vermin-compost (AICRP-IFS 2013). Local non-descriptive cows and buffaloes are recommended for marginal and small farmers who have limited feed, fodder and financial resources, whereas graded buffaloes and crossbred cows are recommended for medium and large farmers who have sufficient feed, fodder resources along with supplement feed purchasing capacity. Small ruminant (sheep and goat) production is more in resource-poor areas (Hanumantha Rao 1994) and it is not high among resource-poor farmers. This is because of the need of more grazing resources like forest/fallow/CPR lands for rearing small ruminants and this can be integrated with coarse cereal crop production systems. Inclusion of 10–20 synthetic poultry breeds like Giriraja/Vanaraja/Gramapriya/Rajasree at backyard with available food grain wastes/grain byproducts (broken rice/rice bran) from the cropping system will also provide additional income through sale of eggs and chicken. All these types of systems are suitable for the scarce rainfall zone where the rainfall is 500–750 mm.

Integration of high yielding graded Murrah buffaloes and crossbred cows with cropping systems should be recommended for the areas having some irrigation facilities and or receiving above 1000 mm rainfall. These areas generally produce surplus crop residues besides allocation of some cultivated land for fodder crops and purchase of feed supplements. In these systems inclusion of 10–20 synthetic poultry breeds like Giriraja/Vanaraja/Gramapriya/Rajasree etc. at backyard will further boost the income of the farmers.

Crop-Livestock-Poultry-Fishery Integrated Farming System

These types of systems are mostly suitable for high rainfall areas, where paddy is cultivated both in *Kharif* and *Rabi* seasons. Cows and or buffaloes are maintained at backyard with crop residues and supplements. Fish is reared in farm ponds and poultry is maintained in cages over the pond with grain and bran supplementation. The droppings of poultry serve as feed for the fish in the pond. These types of systems are suitable for the areas where assured canal irrigation is available. These integrated systems are also possible in dryland areas with little modifications like rearing poultry at backyard and raising yearlings for 4–5 months in water harvesting farm ponds developed under watershed for life saving irrigation to the crops. These systems are most suitable for North-Eastern states.

Silvo-pastoral Systems

It is an efficient and integrated land use management system of agricultural crops, tree fodder species and or livestock simultaneously on the same unit of land which results in an increase of overall production. Inter spaces between fodder trees species (*Leucaena leucocephala*) are utilized for cultivation of grasses and grass legume mixtures (*Cenchrus ciliaris* and *Stylosanthes hamata* or *scabra*), which provides a two tier grazing under in situ. One year after establishment of fodder species the small ruminants are allowed to graze (Fig. 2). During rainy seasons the animals prefer to graze green grass, but during dry seasons when there is no blade of grass available, they utilize foliage of the trees along with crop residues. It involves interaction of woody perennials ecologically and economically with the crops and or livestock. This type of systems provide Rs. 25,000–30,000 income per ha (Ramana et al. 2000) and helps in reclamation of soil in waste lands and are more suitable for rearing small ruminants (10–12 animals/ha) in degraded waste lands under dryland conditions in Scarce rainfall zone.

Fig. 2 Deccani sheep grazing in silvo-pastoral system

Horti-pastoral Systems

In these systems, the inter tree spaces in the mango/lemon/sweet orange orchards are utilized for cultivation of grasses and grass legume mixtures (*Cenchrus ciliaris* and *Stylosanthes hamata* or *scabra*) along with one side boundary plantation of fodder trees species (*Leucaena leucocephala*). One year after establishment of fodder species, 2–3 lambs (mostly ram lambs) per ha are introduced (Fig. 3) and reared for 5 months (August to December). Cultivated fodder and weeds serve as feed for the animals. Integration of lambs provide Rs. 4000–5000 additional income per ha through sale of animals, control weeds by grazing/browsing and also improve soil fertility through faeces and urine (Ramana 2008; Ramana et al. 2011). These types of systems are suitable for areas where orchards exist. A number of factors need to be considered while integrating livestock with crop and or orchard farming. It includes the type of livestock (cattle/buffaloes/sheep/goat/poultry), stocking density, palatable and nutritious feed supply, possible damage to the crops/plants and security. If goat is integrated with orchards, it is recommended that the lower most branches of the trees should be above 1 m from the ground. It should be emphasized too that livestock integration alone will not ensure successful harvest from crop/orchard farms. Many factors, including climate, farming practices, cost of inputs and market etc., impacts production and profitability.

Fig. 3 Nellore (Zodpi) sheep grazing in horti-pastoral system

Management Alterations Needed to Combat Climate Change Impacts on Livestock Production Systems in Drylands

Modifications in feeding, breeding and shelter management would enhance resilience of livestock production systems. This includes: (i) modifying grazing practices (rotational grazing and or restricted grazing); (ii) introducing especially during lean period, such as stall-fed systems through cut and carry fodder production; (iii) better feeding management through conventional and unconventional feed resources (iv) providing proper shelter and adequate wholesome water throughout the year (v) identification and promotion of local high productive resilient breeds that have adapted to local climatic stress and feed sources; (vi) improvement of local animals through cross-breeding with heat and disease tolerant breeds and (vii) synchronization of oestrus based on the availability of feed resources and favourable climatic conditions, (viii) supplementation of micro minerals and vitamins especially during lean season, (ix) Eradication, containment and surveillance of endemic animal diseases.

Pre-requisites or Support Systems for Livestock-Based Production Systems in Drylands

Livestock-Crop relationship could be competitive or complementary depending on the level of harmonization of resources use and also availability such as land, labour, capital etc. Livestock density is much higher in most of the dryland areas compared to their carrying capacity and most of the traditional intercropping systems are rapidly transformed to intensive commercial mono cropping and affected fodder and feed security of livestock in the last decade. Further, distribution of waste lands and shrinking of CPRs reduces the land available for growth of natural and cultivated pasture and or grain and fodder producing crops thus creating competition between crops, animals and humans for natural resources.

Collection of available crop residues and or green fodder and proper preservation in the form of hay or silage and its subsequent utilization in efficient manner along with byproducts of grains plays a vital role in enhancing productivity of livestock component and its contribution to the overall profitability of integrated farming system. Further, continuous supply of green fodder in the form of forage or silage is prerequisite for profitable livestock based integrated farming systems. Hence, the farmer should have some land for cultivation of fodder. Infrastructure like chaff cutters, silage bags and supplements like mineral mixture and concentrate mixture should be made available in the village for the farmers on subsidy. Establishment of community operated complete feed mills at each 4–5 cluster of villages covering a radius of 5–10 km will further help the farmers in efficient utilization of unconventional crop residues like red gram stalks as feed for livestock.

The small size of backyard poultry flocks confined overnight for manure collection limits their impact in even a small fishpond. Moreover, variations in flock size and structure greatly affect actual waste availability throughout the year. Increasing flock size so that more waste is available for fertilizing fishponds requires improved availability of supplementary feed and a reduction in mortalities, particularly among young poultry. Hence, some infrastructure facilities for brooding, vaccination seems to be essential along with supply of poultry feed on subsidized rates for integration of poultry and fishery in wetland cropping systems. Least-cost production techniques that depend on using several combinations of ingredients, rather than a single high-cost compounded feed, is a relevant strategy for both livestock and fish production.

Assuming 50 households in each village are small and marginal, an amount of Rs. 5–10 lakhs for infra structure and 20–25 lakhs for supplements would be required as additional budget for upscaling the livestock based integrated farming system.

Probable Scenario in the Next 15–20 Years with the Livestock Based Production Systems

Livestock based production systems helps in many ways to the farmers. It could be agronomic- management of soil fertility through organic resources and animal power to agricultural operations or it could be more economical—nutrient flow of feed and fodder to the animals through crops residues and byproducts from agriculture produce. Livestock based systems with efficient resource use lead to high and sustained production levels, while minimizing the negative impacts of intensive farming and conserving natural ecosystem.

Demographic patterns, especially rapid developing era and mounting resource demands which, in the cases of food and natural resources like land and water, might lead to severe scarcities. These trends, which are virtually certain, exist today, but during the next 15–20 years they will gain a great deal of momentum. Recently introduced National Livestock Policy, aims at increasing livestock productivity and production in a sustainable manner, while protecting the environment, preserving animal bio-diversity, ensuring bio-security and farmers livelihood. Further, under 12th plan proposal, many initiates on fodder development in the country like mapping of ecologically sensitive pastures and development of rehabilitation packages, rehabilitation and productivity enhancement of degraded grazing lands, promoting fodder species under agro-forestry initiatives, developing seed/germplasm banks/nurseries of native species for rehabilitation of grazing lands, developing fodder storage/value addition facilities, capacity building of Managers/Community Groups have been introduced. National grazing-cum-fodder and pasture management policy and national centre of excellence (CoE) for fodder and pasture land management have been proposed and emphasized for encouragement and establishment of cooperatives for fodder and pasture management and these would enhance the availability of fodder for livestock. Hence, livestock-based production systems would certainly reduce the competition and demand for natural resources and produce more food for ever growing population in the country. These systems would increase efficiency of production systems and reduce pressure on natural resources and ultimately result in sustainable agriculture with assured food and livelihood security in future. It would increase the income by 25–30% and provide livelihoods to more than 60% of population and also contributes to soil reclamation and organic food production.

Conclusions

Livestock based production models suitable to the agro-climatic zones will vary with location depending on natural resources (grazing lands, water, rainfall and other climatic factors, soil types) and crop residues, byproducts and forage availability and market demand for the produce. It helps in recycling and improving utilization of organic wastes and crop residues and lowers external input requirements, minimizes risk, increases total production and profit. Livestock based production systems interact eco-biologically, in space and time, are mutually accommodative and depend on each other in additive fashion and results in more efficient use of their marginal small holdings with less external inputs, improve their economic gains substantially and pays path towards achieving a more sustainable agricultural food production systems in drylands.

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Research and Development in Dryland Agriculture

Aqueous Leaf Extracts of Sunflower (*Helianthus annuus*) for Weed Management

K. Makaza, M. Matigimu, and N. Sakadzo

Abstract Allelopathy is a phenomenon which has both beneficial and detrimental effects amongst plants within the same community. The concept is gaining popularity as a sustainable weed management tool in agro-ecosystems because of its potential to create eco-friendly products as compared to synthetic herbicides which have risks to human health and environment. A laboratory experiment was conducted at Great Zimbabwe University to evaluate the allelopathic effect of crude leaf aqueous extracts of sunflower (*Helianthus annuus* L.) on germination and early seedling growth of black jack (*Bidens pilosa* L.) seed. Four concentrations of shade dried sunflower leaf extract (2%, 4%, 6% and 8%) (w/v) were evaluated against distilled water (0%) as the control. Ten black jack seeds were sown in each petri dish per treatment and arranged in a Completely Randomized Design (CRD), replicated thrice. Results showed significant ($p < 0.05$) inhibitory effects on mean germination percentage, mean plumule and radicle length. Mean germination percentage of black jack treated with crude aqueous extracts concentrations were significantly ($p < 0.001$) lower than the control. Similarly, plumule and radicle elongation were significantly ($p < 0.001$) inhibited by the various sunflower leaf extracts concentrations. The inhibitory effect increased with increase in sunflower extract concentration. The 6% and 8% treatment concentrations had the highest inhibitory effects on all parameters as compared to the control, although they were not significantly different from each other. Whilst 4%, 6% and 8% treatment were not significantly ($p > 0.001$) different from each other on mean germination, their inhibitory effect were highly significant ($p < 0.001$) as compared to other lower treatments. Therefore, aqueous leaf extract of sunflower is allelopathic as it inhibited germination, plumule and radicle growth. The 6% concentration is recommended for use as pre-emergence herbicide against black jack. Further research using organic solvents to extract non-polar allelochemicals and efficacy of different plant parts is recommended.

K. Makaza (✉) · M. Matigimu · N. Sakadzo
Gary Magadzire School of Agriculture, Department of Soil and Plant Sciences, Great Zimbabwe University, P.O. Box 1235, Masvingo, Zimbabwe
e-mail: kmakaza@gzu.ac.zw

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Introduction

Allelopathy is a natural and environmentally friendly technique which proved to be a unique tool for weed control for increasing crop yields (Sharma and Satsangi 2013). The term allelopathy was coined by Molisch in 1937 and derived from two Greek words 'allelon' which means each other and 'pathos' means to suffer or the injurious effect of one upon each other (Rawat et al. 2017). It is the biological phenomenon where the development of one plant interferes with the physiological processes of other growing plants within the same community. Pejman et al. (2011) defined allelopathy as the inhibitory or stimulatory effects of a plant or microorganism on other plants or microorganisms through the release of chemical compounds into the environment which are known as allelochemicals. Allelochemicals are biomolecules or secondary metabolites which are produced as by products by plants during their different physiological processes and they have a role in plant-plant, plant-soil, plant-pathogen, plant–insect and plant-predator interactions that may be beneficial or detrimental to the plant (Sharma and Satsangi 2013). These allelopathic compounds are non-nutritional and can be found in any part of the plant i.e. from leaves, stem, root, flower and seeds of living or decomposing plant material and they can be released to the environment as leachates, root exudates, volatiles and from decomposed material (Qasem 2012; Sharma and Satsangi 2013; Bonanomi et al. 2016). Allelochemicals can affect growth and development of plants by having multiple effects on photosynthesis, respiration, cell division, pigment synthesis, protein synthesis, production of plant hormones, membrane permeability, nitrogen fixation, germination of pollen grains and several enzyme activities (Nivas et al. 2017). They may cause necrosis of the root, poor germination, curling of the root axis, discoloration, reduced weight accumulation and lowered reproductive capacity (Mukondwa et al. 2019). The allelopathic effect between plants exists in wide array of interactions in agro-ecosystems and types of allelopathy are basically categorized with respect to the relationship between the plants species involved and these include: crop-crop, crop-weed, weed-weed and tree-crop (Signh et al. 2012).

Weeds are among the pests which are of great economic importance in the agriculture sector all over the world. These are plants that exist on undesirable location, not valued for its use or beauty but regarded as hindering the growth of the superior vegetation sown by men. Generally, crop yields are very low in communal farming sector of Zimbabwe due to crop- weed competition which result from ineffective weed control and poor timing of weed removal (after 4–6 weeks in maize) (Mukondwa et al. 2019). Black jack is one of the common problematic weeds found in arable lands of Zimbabwe. To alleviate the yield losses, most farmers are now relying on synthetic herbicides due to their high efficacy. However, the use of synthetics may have drawbacks to the environment and also cause health problems to people. Crops have been grown since ancient years without damage to the environment but the use of synthetic herbicides during the short span of the last 50 years have raised serious doubts about their continuous use (Rawat et al. 2017). Synthetics are not easily biodegradable in the environment; hence, they cause environmental pollution which may cause adverse effects on the life of natural ecosystems. Hand weeding using a hoe is the commonly practiced weed control method in small farming sector in Zimbabwe. Mandumbu et al. (2013) propounded that weed control using hand weeding is uneconomical due to higher costs of labour and resultant low yields in the communal farming sector of Zimbabwe. A lot of time and energy is expended on removal of weeds by hand or short handled hoes. About 70% of the time of a farmer from the beginning to the end of the season is being spent on weeding (Mukondwa et al. 2019). As a result, the operation becomes monotonous and back breaking. In addition, Gianesse (2013) reported that availability of labour for hand weeding is decreasing and costs of labouris increasing, resulting in inconsistent weed control and poor crop yields.

A potential alternative for overcoming the use of herbicides and labour shortage related problems is to use allelopathic strategies in weed management for sustainable agriculture (Mukondwa et al. 2019). For sustainability, future weed control practices might consist of multiple integrated strategies of which one might be making crops suppress weeds themselves by improved allelopathy and competition and minimize or stop the use of herbicides (Rawat and Maikhuru 2012). According to Rawat et al. (2017), sustainability emphasise on optimal crop production with minimal external inputs, reducing dependence on commercial inputs (fertilizer and pesticides) and substituting them with internal resources and relying on sustainable practices which maintain the productivity over long periods. According to Farooq et al. (2011), wise exploitation of allelopathy in cropping systems may be effective, economical and natural method of weed management and a substitute for chemical control and hand weeding in improving crop productivity for communal farmers. Allelopathic crops offer strong potential for the development of cultivars that are highly weed suppressive (Pejman et al. 2011).

Sunflower has been reported to have allelopathic effects on other plants and has the potential for achieving sustainable weed management, (Sharma and Satsangi 2013). The bioassays of leaf aqueous extracts show strong inhibition in germination and root length of many weeds and crops (Rawat et al. 2011; Pejman et al. 2011). Macias et al. (2002) propounded that there are 25 natural allelopathic compounds that are phytotoxic towards many plants from different sunflower cultivars. Further studies showed that sunflower contain 16 sesquiterperne, 14 *bisnorsequiterpenes* and *sesquiterpenehilannulos* for its toxicity (Rawat et al. 2017). Leaf aqueous extracts of sunflower were found to contain five new guananolides and the annuolides possesses allelopathic activity (Rawat et al. 2011). Heliannuols, terpenoids and flavonoids are the most common important allelopathic compounds isolated from sunflowers (Pejman et al. 2011). The heliannuols and all guananolides proved inhibitory to dicot weed species, hence they may be an excellent source as a pre- and post- emergence herbicide to dicotyledons species (Rawat et al. 2011; Rawat et al. 2017; Pejman et al. 2011).

Allelopathic material from sunflower can influence the antioxidant systems in target plants causing cell membrane permeability and cellular damage, reducing the target plant's ability to germinate and causing a gradual loss of seed vigor (Pejman et al. 2011). The most frequently reported gross morphological effects on plants are inhibited or retarded seed germination and effects on coleoptiles elongation shoot and root development (Kruse et al. 2000). According to Bogatek et al. (2006), sunflower extracts completely inhibited seed germination of white mustard. Kamal (2011) reported that, sunflower extract was inhibitory to germination, shoot and root length of wheat, maize and species of weeds. Sharma and Satsangi (2013) observed that, the leaf extract of sunflower show more inhibitory effect on the growth (seed germination, plumule length, radical length) of *Parthenium hysterophus* in comparison to stem and root extract. Pejman et al. (2011) postulate that *Lolium rigidum* is sensitive to extracts of sunflower cultivars as sunflower extract reduced all traits in this weed. The aqueous extracts as well as growing plants inhibits the seed germination and seedling growth of *Abutilon theophrasti*, *Datura stramonium, Ipomoea* spp., *Brassica kaber* and also reduced the germination by 36–56% and seedling growth with 22–57% of *Trianthema portlacastrum* and *Amarantus vidris* (Rawat et al. 2017). Therefore, this study was to determine the allelopathic effects of crude aqueous leaf extracts of sunflower on germination and early seedling growth of black jack.

Materials and Methods

The study was conducted in 2020 at Great Zimbabwe University main campus in Masvingo, Zimbabwe (latitude 20°7′ 17S and longitude 30°49′ 58E; altitude of 1034 m above mean sea level) located in the agro-ecological region (IV). The study area is characterized with an annual average annual rainfall of 600 mm with mean temperature of 28 °C. Average temperature during the study was 17 °C. The lab studies were conducted at Great Zimbabwe University Chemistry laboratory in June 2020.

Sunflower variety Sy 4200 was planted at recommended spacing of 75 cm inter-row and 25 cm intra-row. During planting, Compound D was used as basal dressing at the rate of 250 kg/ha. The leaves of sunflower were harvested at 40 days after planting (Kamal 2011) and were dried for 30 days under room temperature, then powdered to increase the surface area for the particles and to speed up the extraction.

Preparations of Leaf Extracts

The powder was soaked in water in different beakers with different concentrations ranging from 2 to 8%. The concentrations were prepared as described by Sakadzo et al. (2018) by adding 2 grammes of sunflower leaf powder to 100 ml of distilled water to give 2% concentration of aqueous and 4, 6 and 8% concentrations were prepared in the same manner. Treatment with 0% was the control with 20 ml of distilled water. The prepared extracts concentrations were left for 48 h. The solutions were filtered and stored under temperatures below 5 °C (refrigerated) until use to prevent contamination by pathogens and the conversions of crucial chemicals under high temperatures (Kamal 2011).

Experimental Design

The laboratory experimentwas conducted in a Completely Randomized Design (CRD) with five treatments (0% (control), 2%, 4%, 6% and 8% sunflower aqueous leaf extracts) replicated thrice.

Weed Germination and Seedling Growth

150 healthy seeds of black jack were collected from arable land. 10 seeds were grown in Petri dishes of 9 cm diameter replicated 3 times in completely randomized design. Cotton wool was used as the medium for germination.

Data Collection

Germination of seeds was counted after 6 days after soaking (DAS) and was expressed as a percentage. The seeds were considered germinated when the radicle and plumule started to show, following imbibition which was evidenced by an increase in seed size. Radicle and plumule length were measured in cm using a ruler at day 6 and 7.

Data Analysis

Data were analysed using Genstat version 14.1 and means were separated using Fisher's protected least significance difference (LSD) at 5% significance level.

Results

Effect of Sunflower Crude Aqueous Leaf Extracts on Mean % Germination on 7 DAS

The 4–8% sunflower extract concentration significantly ($p < 0.05$) inhibited black jack seed germination more than 2% and the control (Table 1 and Fig. 1), although

Table 1 Effects of different sunflower crude leaf aqueous extracts concentrations on mean germination, radiclelength and plumule length of black jack at 7 days after sowing (DAS)

Leaf aqueous extracts concentration (%)	Germination %	Plumule length (mm)	Radicle length (mm)
0	96.67^{c}	4.267^{d}	6.700^{c}
2	20.00^{b}	2.667^{c}	3.833^{b}
4	6.67^{a}	1.333^{b}	2.667^{b}
6	0.00^{a}	0.000^{a}	0.000^{a}
8	0.00^{a}	0.000^{a}	0.000^{a}
Grand mean	24.7	1.65	2.64
F probability	<0.001	<0.001	<0.001
LSD	10.50	1.187	2.001
% cv	23.4	39.5	41.7
Significance	**	**	**

Means followed by the same letter in the same column are not significantly different at 5% level according to Fishers protected least significant different test
ns represents non-significance, * shows significance, ** shows very high significance

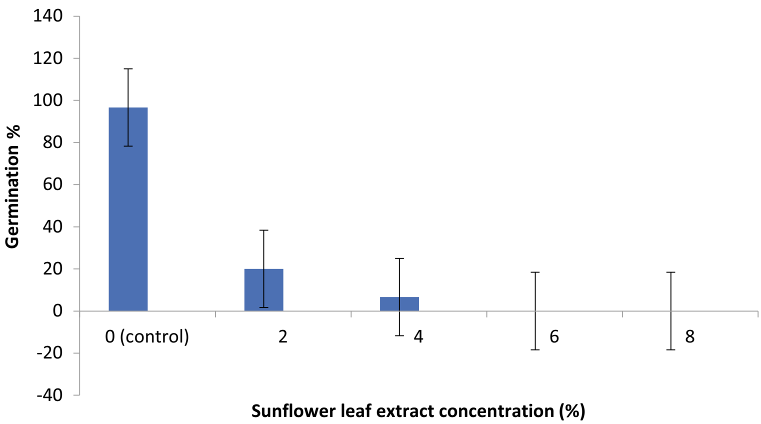

Fig. 1 Effects of sunflower crude leaf aqueous extracts on mean germination percentage of black jack seeds 7 DAS.
*Error bars which do not overlap shows significant differences and those that overlap shows no significant differences at 5%

there were no significant differences ($p > 0.05$) among themselves. Overall, germination percentage at day 7 follows a definite trend with treatment 1 (control) having the highest mean germination percentage (96.67%). 2% sunflower aqueous concentration had 20% and 4% sunflower aqueous concentrationhad 6.67%, whereas treatment 6% and 8% concentrations didn't germinate, having 0% germination mean.

Effect of Sunflower Crude Leaf Extract on Mean Plumule Length of Black Jack Seedlings 7 DAS

There were highly significant ($p < 0.001$) differences on mean plumule length due to sunflower crude aqueous extracts concentrations (Table 1, Fig. 2). The control (0%) had the highest plumule length (4.267 mm), which was significantly ($p < 0.001$) higher than 2% treatment (2.667 mm) and 4% treatment (1.3333 mm). However, the plumule length mean for 6% and 8% treatments was not significantly different.

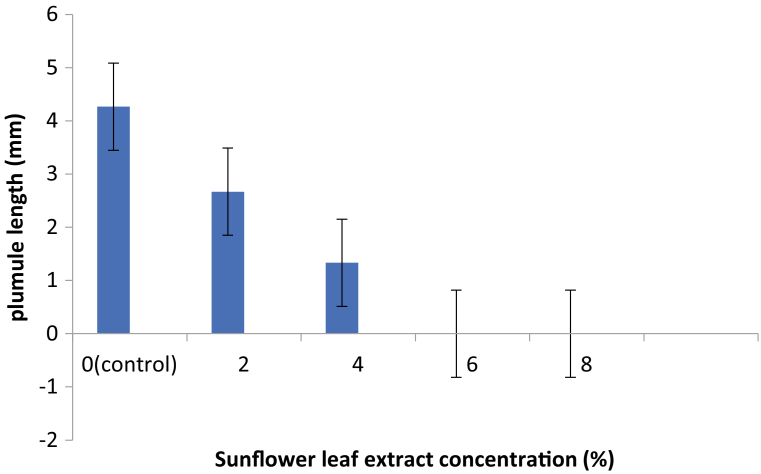

Fig. 2 Effect of sunflower crude leaf aqueous extracts on mean plumule length of black jack seedlings 7 DAS.
*Error bars which do not overlap shows significant differences and those that overlap shows no significant differences at 5%

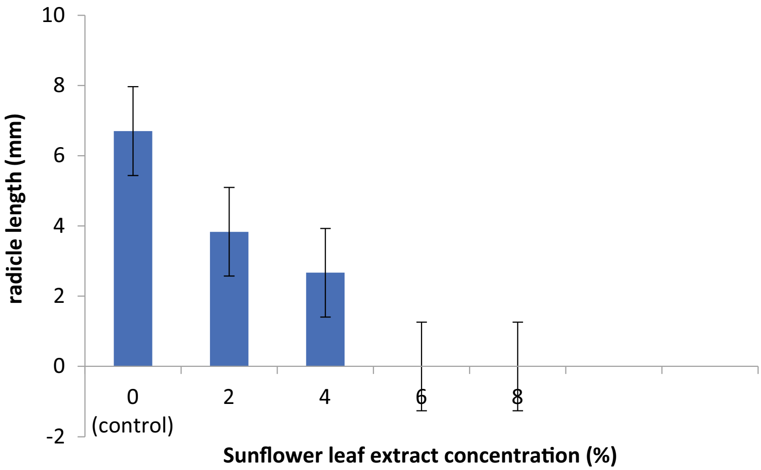

Fig. 3 Effect of sunflower crude leaf aqueous extracts on mean radicle length of black jack seedlings 7 DAS.
*Error bars which do not overlap shows significant differences and those that overlap shows no significant differences at 5%

Effect of Sunflower Crude Leaf Aqueous Extracts on Mean Radicle Length of Black Jack Seedlings on 7 DAS

The difference in mean radicle length of black jack was highly significant ($p < 0.001$) affected by sunflower crude leaf aqueous extract (Table 1 and Fig. 3). The increasing concentration of aqueous extract drastically reduced the radical length. Treatment 1 (control) had the highest mean radicle length (6.700 mm) which was significantly ($p < 0.001$) higher over rest of the treatments. Treatments with 6 and 8% aqueous concentrations were not significantly different ($p > 0.05$).

Discussion

There was highly significant difference among the treatments means on germination percentage at 7th day. The control black jack seeds were characterized by germination ability of 96.67% which was significantly higher ($p < 0.001$) than sunflower leaf extract treatments. The aqueous extracts from sunflower leaves showed inhibitory effect on black jack weed germination. The degree of inhibition increased as concentration increases. 6% and 8% treatments with the highest sunflower crude leaf extracts inhibited seed germination completely whereas 20% and 6.67% mean germination were detected in the presence of 2% and 4% leaf extract, respectively at day 7. This revealed that sunflower leaf extract successfully suppressed seed germination of black jack. Bogatek et al. (2006) also observed that germination of mustard seeds were inhibited as concentration of sunflower extract increased, and in the presence of high concentration of sunflower leaf extracts, germination was almost inhibited completely. This means that, the higher the concentration, the more the toxic compounds such as phenolics which causes osmotic stress resulting in loss of membrane intergrity and enhancing loss in germinability. The loss in seed germinability may be a result of an increase in lipid peroxidation due to increase in malondialdehyde (MDA) which increases as concentration of sunflower leaf extract increases. In support, Bogatek et al. (2006) observed that, two cultivars of sunflower affected lipid peroxidation of mustard seed in the same way. This result reveals that loss of seed germinability is associated with membrane lipid peroxidation. Also, loss of germinability may be due to toxic interference with respiration resulting from reduced production of ATP and RNA synthesis or disturbances in the functions of secondary messengers necessary for germination (Muhammad and Majeed 2014).

This implies that, germination alterations are not only due to water stress and lipid peroxidation but the inhibition in seeds germination was greatly influenced by the presence of high concentration of toxic allelopathic compounds such as phenolics, alkaloids and flavonoids which are present in sunflower (Muhammad and Majeed 2014). This was in agreement with the research by Bernat et al. (2004) who concluded that, the lower water availability for seed germination due to binding of water molecules by compounds present in extract of sunflower leaves plays a minimal role in reducing seed germination, but the action of sunflower allelochemicals is mainly due to their toxic nature.

Sunflower leaf extract highly significantly ($p < 0.001$) suppressed the plumule growth of black jack as compared to the untreated control under laboratory conditions (Table 1 and Fig. 2). The inhibition of plumule growth was concentration depended. Similar results by various workers revealed that aqueous leaf extracts of sunflower potentially reduced the development of early seedling growth on different crops and weeds (Bogatek et al. 2006; Kamal 2011; Sharma and Satsangi 2013). Sunflower aqueous leaf extracts has been reported to be rich in toxic substances such as flavonoids, alkaloids and phenolics which altered cell division patterns, physiological function and interferes with water and mineral uptake capacity of seedlings (Muhammad and Majeed 2014). Reduced germination and delay in germination time reduced growth of the plumule.

The phytotoxicity of aqueous extracts of sunflower leaf was significantly increased as their concentration increase due to presence of high allelopathic toxic compounds (Kamal 2011; Sharma and Satsangi 2013). The leaf of sunflower has high concentration of phenolic compounds such as polyphenols, tannins and flavonoids and these substances affect phytohormones such as gibberellic acid (GA) and indole acetic acid (IAA) which are essential growth hormones, resulting in reduced growth of seedlings (Kamal 2011). Besides that, the allelochemicals of sunflower interfere with mitosis in the root apex by inhibiting enzymes necessary for adenosine triphosphate (ATP) and ribose nucleic acid (RNA) synthesis (Muhammad and Majeed 2014) and this causes cell death in roots of early seedlings, resulting in retarded growth. In support, Levizou et al. (2002) reported that sunflower leaf extracts retarded mitosis in the root apex of lettuce seedlings.

Conclusion

Sunflower aqueous leaf extracts significantly inhibited germination; plumule and radicle elongation of black jack in petri dishes.There is need for further investigation of suflower allelopathy in pots, micro pots and field situations. The study will help in developing low cost adaptation strategies for climate resilient agriculture thereby promoting an economic and eco-friendly environment to small holder farmers.

Future Research

To focus on the effects of sunflower aqueous extracts on other common arable broad leaf weeds including monocotyledonous species in Masvingo;

- Allelopathic effects of organic solvent extracts as opposed to aqueous extracts on various weeds.
- Studies on the allelopathic effects using fresh and dried morphological parts (root, stem, leaves) of sunflower in weed management should be conducted for comparison.
- Field trials and green house experiments in pots are suggested for further elucidation of allelopathic activity of sunflower on *Bidens pilosa* and other arable weeds.
- Foliar spray studies to evaluate potential of extracts as an early post emergence herbicide
- Identification and purification of allelochemicals from different parts of sunflower.

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Food Systems in Dryland Communities: Challenges and Opportunities in Gutu District, Masvingo Province, Zimbabwe

Tendayi Mutimukuru-Maravanyika, Lazarus Chapungu, and Felix Majeke

Abstract Despite several efforts to reduce hunger, the number of people suffering from hunger in the World has been growing over the years, and the number of undernourished people has also been increasing. The situation is worse in most regions of Africa where the number of children under five years of age suffering from stunting and wasting, has been rapidly increasing. Other forms of malnutrition have been experienced with an increase in adult obesity, and anemia in women. Understanding food systems is therefore a critical step in influencing the food security and nutritional status of communities. Improvements in efficiency and productivity of food systems have been found to result in successes around the World in reducing the prevalence of hunger and improving nutrition status of populations. Identifying major areas of weaknesses in food systems is therefore critical for shaping interventions for alleviating food-related illness. This study aimed to understand the food system challenges in Gutu communal areas of Zimbabwe, and come up with ways for dealing with these. The study used a case study approach, as well as a mixed participatory research approach for data collection and analysis. Both quantitative and qualitative data collection techniques were employed. The study unveiled a myriad food system along the entire value chain in Gutu communal area. Crop sector challenges include, expensive inputs, poor productivity, limited processing and value addition, and seasonal production of crops. Livestock sector challenges ranging from input supply, production as well as value addition and processing. The paper ends by discussing various strategies that can be employed to effectively deal with these challenges and turn the drylands into bread baskets.

T. Mutimukuru-Maravanyika (✉)
Gary Magadzire School of Agriculture, Great Zimbabwe University, P. O Box 1235, Masvingo, Zimbabwe
e-mail: tmaravanyika@gzu.ac.zw

L. Chapungu · F. Majeke
School of Natural Sciences, Great Zimbabwe University, P. O. Box 1235, Masvingo, Zimbabwe
e-mail: lchapungu@gzu.ac.zw

F. Majeke
e-mail: fmajeke@gzu.ac.zw

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Keywords Food systems · Food system challenges · Agriculture · Communal areas · Zimbabwe

Introduction

New evidence show a rise in world hunger with the number of people who suffer from hunger growing over the past three years (FAO et al. 2018). The number of people in the World suffering undernourishment, is estimated to have increased from around 804 million in 2016 to nearly 821 million in 2017 and the situation is worsening in most regions of Africa (FAO et al. 2018). Despite progress made in reducing child stunting, over 22% of children under five years of age in the World are still affected. Other forms of malnutrition are also growing with an increase in adult obesity in countries irrespective of their income levels. Several countries in the World still suffer from other forms of malnutrition including anemia in women, and child stunting and wasting.

In Zimbabwe, about 1.1 million people were estimated to be food insecure in 2018 and thousands of rural dwellers are threatened by malnutrition (WFP 2018) and projections showed that about 2.5 million people were at risk of food insecurity and malnutrition if the existing food systems were not improved (WFP 2018). Research carried out show that (MAMID, WFP and FAO 2013):

- 56% of children 6–59 months old are anemic.
- 28% of women & 14% of men are anemic.
- 1 in 3 women are overweight, 11% of women are obese
- Less than 10% of Zimbabwean children under the age of 2 receive the recommended minimum acceptable diet–eggs, meat, milk products, and legumes are rarely included in the diets of young children.

Several challenges to food security were identified: high food prices, climate change, lack of holistic planning, small farmers switching to cash crops such as tobacco, lack of market/value addition, lack of robust extension services, poor watershed management practices, lack of credit facilities, high costs of labour, high cost of farming inputs such as lime, seeds, fertilizers, limited irrigation development/rehabilitation and post-harvest losses. Projections showed that many poor households especially in deficit-producing areas in the south (Gutu included), west, and extreme north would experience food security challenges mainly because of a poor 2017–18 cropping season and increasing macroeconomic hardships in the country (e.g. the increasing non-staple food and other commodity prices) making it difficult for poor households to access food (FEWS NET 2018).

Understanding the challenges in communal food systems is critical (Chase and Grubinger 2014) as improvements in efficiency and productivity of food systems have resulted in successes around the World in reducing the prevalence of hunger and improving nutrition status of populations. Understanding food systems and the major areas of weaknesses helps in devising interventions to alleviate food-related illness.

Food security exists, when all people have physical and economic access to sufficient, safe and nutritious food that meet their dietary needs and food preferences for an active and healthy life at all times (MAMID, WFP and FAO 2013). Community food security exists when all members obtain a safe, personally acceptable and nutritious diet through a sustainable food system that maximizes healthy choices, community self-reliance and equal access for everyone.

Food systems are an inter-connected web of activities, resources and people that are involved in the provision of human nourishment and sustaining health (Tansey and Worsley 2008). These activities include production, processing, packaging, distribution, marketing, consumption and disposal of food. Production includes activities involved in producing plants and animals for food and other related products; distribution includes the networks of people, companies and institutions and processes involved in transporting food from places of production (e.g. farms, factories) to places where it can be purchased, used, or consumed e.g. wholesalers, farmers markets and retail stores; processing includes activities that add value to food or transform food into various food products such as slaughtering, butchering, packaging; and consumption refers to all activities and processes by which an individual or group acquire and utilize food after it has been produced and distributed (Hanna et al. 2012). Food systems also include other issues such as: governance and economics of food production; its sustainability—the degree to which food is wasted, and how food production affects the natural environment; how food affects health and well-being—including nutrition and food safety; and finally inputs and products of each of the steps (Grubinger et al. 2010). In a nutshell, a food system is made up of the environment, people, institutions and processes by which agricultural products are produced, processed and brought to consumers.

There is need for a deeper understanding of the food systems to identify the main challenges faced so that they can be addressed in order to strengthen the food security situation in the communities. This is what this study aimed to do. Specifically, the main objectives of the study were to:

- Assess the challenges that are faced in the Gutu food systems
- Identify and recommend potential areas for intervention to deal with identified challenges to food system.

The Study Site

The study was carried out in four wards of Gutu District namely: ward 2-Tongogara resettlement, ward 14-Mataruse communal land, ward 16-Mutambwi communal land and ward 30-Nerupiria mixture of resettlement and communal land] (Fig. 1). Gutu district, is one amongst several districts in Zimbabwe where malnutrition is high, hunger is rife and poverty is a norm (FNC 2018).

Gutu District is the third largest district in Masvingo Province, southern Zimbabwe, after Chiredzi and Mwenezi. It is the northernmost district in the province. Climatically, the area falls under Natural Regions III and IV. Natural Regions (NRs)

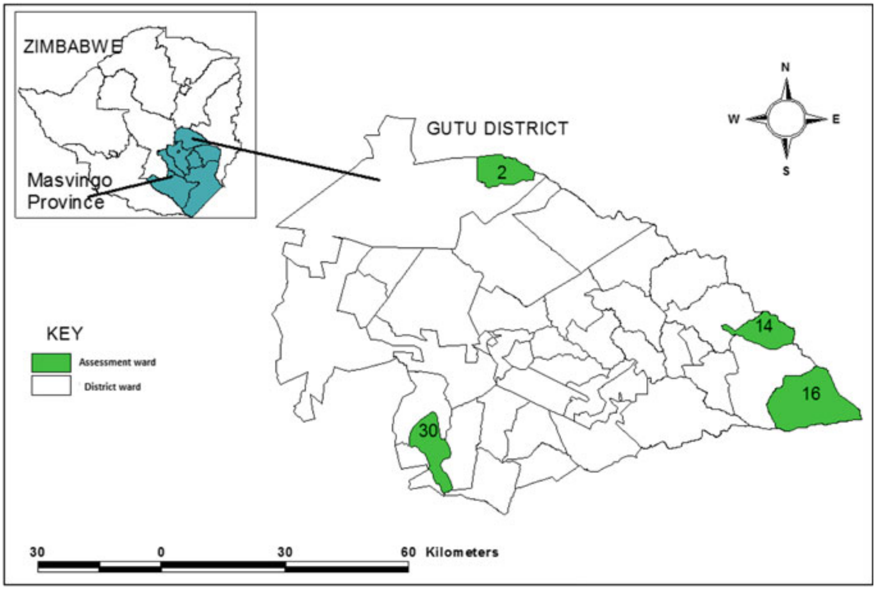


Fig. 1 Map of Gutu district showing the study sites

in Zimbabwe's context are areas delineated on the basis of soil type, rainfall and other climatic factors. It is one of the few districts in the country that suffers from over-population. It has a population of 203 083 people with a density of 22.08 per square kilometer (Zimbabwe National Statistics Agency 2014).

Access to safe drinking water is 60.4%. Poverty prevalence is 66.8%. The high poverty prevalence rate, lack of access to water, dry climate in collaboration with other related factors influence the food security situation in the district. Thus generally the district is classified as acutely food insecure, facing up to four months of food deficits per year (ZimVac 2017). As a result, it is amongst the districts with the highest prevalence rates of stunting for children of 6–59 months of age in Zimbabwe (MAMID, WFP and FAO 2013). Gutu district is amongst the most nutritionally starved districts in the country, partly because of inefficient food systems. It is for this reason that any study that seeks to understand the prevailing food systems in the district merits attention.

The selected wards (Fig. 1) present areas of different land tenure systems and it is assumed they have different food system scenarios. Thus, the wards are representative of some of the key tenure systems in the district. This will provide better understanding of the district's food systems.

Materials and Methods

The study was undertaken with a multi-sectoral/multi institutional and multi-disciplinary approach in close interaction and collaboration with local NGOs (e.g. Zimbabwe Council of Churches), government departments including the Ministry of Health and Child Care, the government extension organization, AGRITEX, the local governance structure—Gutu Rural District Council and the traditional leadership authority.

A mixed methods design was adopted as the strategy of inquiry and made use of both quantitative and qualitative methods (Gary 2011). The quantitative approach is rooted in the positivist paradigm (Collins 2010) while the qualitative approach is grounded in the phenomenological philosophy (Corbetta 2003). (Morgan 2008) postulates that the mixed methods design emanates from the pragmatic school of thought and is being widely used by researchers from various disciplines. The approach is also rooted in the argument that knowledge is generated from activities, circumstances and consequences and not antecedent conditions as in the positivist philosophy (Sango 2013). The choice of the mixed methods design was based on the sense that it reduces the weaknesses of each of the research paradigms by capitalizing on the strengths of both. (Punch 2011) reiterates that the mixed method design is highly pragmatic and convenient as it allows the researcher to use quantitative and qualitative techniques either interdependently or independently. Thus, it is vastly flexible and can be used in diverse research projects. While quantitative methods focus on the collection of facts, qualitative methods place prominence on the meanings derived from the facts. Figure 2 shows the methodological approach used in this study.

The choice of the mixed methods approach was dependent on a variety of reasons. These include, *inter-alia*; to analyses problems from different standpoints to develop

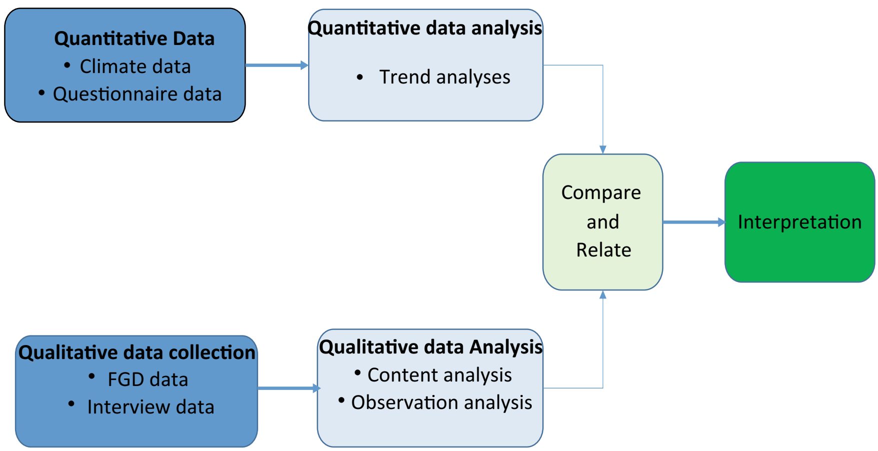


Fig. 2 The mixed method approach adopted in the study

and understand the meaning of a singular perspective, to make use of both quantitative and qualitative data to better understand a problem; to develop a complementary picture; to compare, validate, or triangulate results; to provide illustrations of context for trends; or to examine processes/experiences along with outcomes.

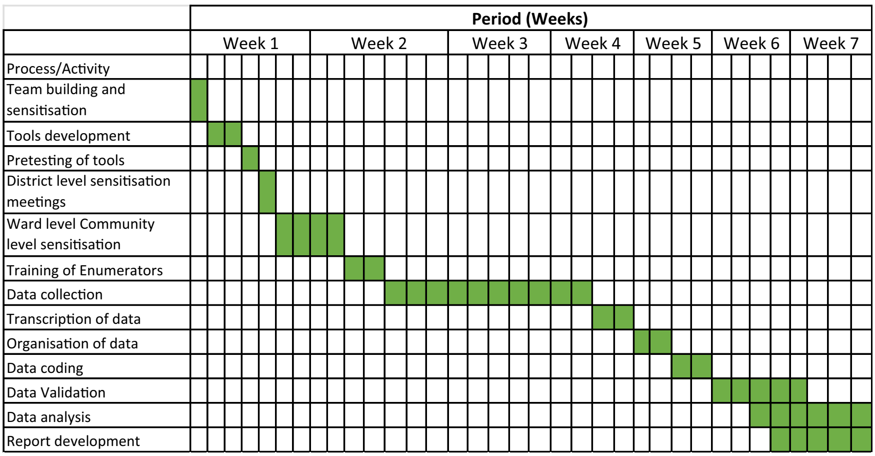
Data Collection

Data collection involved a number of processes and activities that were performed over time. Each activity and process was assessed in terms of appropriateness, efficiency and effectiveness in achieving the intended goal and specific objectives of the assessment. The processes and timeline for the participatory situational assessment are shown in Table 1.

Different tools were used to develop a shared understating of the local food system including the livelihoods mapping, transect walks, key informant interviews, secondary data collection, historical trends, FGDs.

Rainfall and temperature data were obtained from weather stations within Masvingo province operated by the Meteorological Services Department of Zimbabwe. The trends of climate and ascertain the effects on food systems since crop production in the region is dependent on meteorological conditions was assessed. Other data was obtained from the National Climate Data Centre (NCDC), National Oceanic and Atmospheric Administration (NOAA) programs for preserving, monitoring and provision of climate and historic weather data (www.ncdc.noaa.gov). The assessment tested if there was a significant change in precipitation and temperature variables over a 40 year period using the Mann–Kendall (MK) trend test (Hirsch et al. 1993). An add-in of Microsoft excel, XLSTAT 2015 was used to

Table 1 Study activities and timelines



carry out this test due to its ability to take into account and removing the effect of autocorrelations.

Sampling Design

The maximum variation purposive sampling design was employed in this assessment. In this approach, study participants are purposively selected to provide a diverse range of cases relevant to a particular phenomenon or event. The purpose of this kind of sample design is to provide as much insight as possible into the event or phenomenon under examination. Local actors were purposively sampled based on their contribution to the understanding of food systems in Gutu district. Actors who were involved in the study include the Provincial Administrator; the Provincial Crop and Livestock Officer; the Provincial Social Services Officer; the Provincial Gender Officer; the Provincial Environmental Health Officer; the Provincial Nutrition Officer; the District Administrator; the District Crop and Livestock Officer; the District Social Services Officer; the District Environmental Health Officer; the District Nutrition Officer; local Chiefs and Headmen; ward councilors for the 4 wards; village health workers for the targeted wards; women, men, youths, people with disabilities representatives in the target communities and agro dealers in the respective committees.

Local councilors assisted in the process of purposively identifying participants for interviews, focus group discussions and questionnaire surveys. Key informant interviewees were also purposively sampled considering their roles in the community with regards to food systems.

Data Analysis

The data collected during assessment was organized and analyzed to draw conclusions on the food systems. The deductive approach was used.

Results

The communities in Gutu District were mainly involved in crop and livestock production—both were basically for subsistence and crop production was mainly rain-fed. Although community members in the study sites had access to land for crop production, the sizes of the land has been shrinking over time due to increasing population. Although limited, community members also had access to wetlands, rivers and boreholes and dams.

Crop Food Systems

The major crops grown are maize, sorghum and pearl millet grown extensively largely for subsistence. Surplus food produced (Maize and Sorghum) is however sold for cash to meet other household needs. Groundnuts, roundnuts (bambara), finger millet, cow peas are also grown to a lesser extent by a few individuals.

The study also revealed that most households produce vegetables in small individual gardens either at their homesteads or along streams and rivers and in wetlands. Vegetables produced include leafy vegetables, onions and tomatoes. The most common farming method is conventional with few farmers practicing conservation farming. This is mainly because conventional farming is deemed easy, fast and less labour intensive compared to conservation farming. Despite the fact that most households do not own livestock for draft power, conventional land preparation is common to most of the household through hiring draft power.

Several challenges were identified related to crop production including the following.

- ***Pest outbreaks***: The past two years recorded incidences of fall armyworm with devastating effects on mostly maize and sorghum production. Lack of proper pest control measures as well as lack of extension advice was said to have resulted in farmers losing their crops.
- ***Poor soils***: Most of the soils were said to be sandy soils of granitic origin which exhibit poor characteristics in terms of fertility, water holding capacity and structure. This had been worsened by continuous mono-cropping practices of cereals (maize and small grains).
- ***Lack of draught power***: Farmers reported increased livestock deaths due to disease outbreaks like anthrax, foot and mouth and tick bone diseases (such as the January Disease). It was reported that some households did not own livestock and hence this made it difficult for them to prepare land for crop production. Such households were said to only produce crops on very small pieces of land.
- ***Climate change***: Farmers indicated that they were no longer able to predict the advent of rains like before. They said that sometimes they experienced early rains, while in other times they had late onset of rains, with delays going to as far as January. Incessant, very low and erratic rains, caused by La Nina and El Nino respectively, are experienced. The farmers also said that sometimes they were experiencing too much rains, resulting in water logging of crops. They also said that there were cases when they experienced prolonged dry spells resulting in permanent wilting of the crop.
- ***Poor transport systems.*** Farmers reported poor transport networks—most roads in the district were in a poor state making it difficult for them to transport their produce to the market. The transport systems were also said to be unreliable, making it difficult for them to market their crops.
- ***High input costs.*** Farmers blamed the declining economic condition in the country for the rapidly increasing input costs. Many farmers said that they were no longer able to afford the improved hybrid seeds and were therefore using retained seed

of various crops in their production process—this was one of the reasons they were obtaining very low yields. In addition, despite the poor soils in their area, farmers said they were unable to purchase fertilizers due to the high costs and this was also a major contributor of the low yields of their crops. Pesticides were also said to be expensive and some farmers were said to be resorting to traditional methods such as hand picking and use of ethnobotanical such as spraying crushed aloe vera plant, and using raw tobacco leaves dipped in water.

- ***Water shortages for production with farmers resorting to rainfed agriculture***. Farmers said that they were mainly doing rainfed agriculture and there were limited options for irrigation in the district.
- ***Limited value addition to produce***. Farmers reported that value addition to the crops was very limited (see Table 1). This was mainly because of lack of technologies for processing and adding value to the produce. Small grains for instance were processed using the traditional pounding, which is tedious and laborious, and consequently discouraging the production of these crops. The products made from the current processing of crops was limited as well (see Table 2).
- ***Increased post-harvest losses***. Farmers indicated that they were losing their grain due to post harvest pests such as weevils, rodents and termites. They said that

Table 2 Processing of crops in Gutu district

Produce	Post–harvest handling and storage methods	Value addition processes	Consumers/markets
Maize	Thrashing, application of pesticides	Making of samp	Mainly household consumption, Local buyers from local households
	Packaging in 50 kg bags		
Groundnuts	Stored in an unshelled state in 50 kg bags	Making of peanut butter	Household consumption
Finger millet	Packaged in 50 kg bags	Pounded to make mealie meal for sadza and making of traditional beer	Household consumption, local buyers
Beans	Packaging in a bucket	Boiling to make delicacy	Local buyers, household consumption
Vegetables	Sun dried vegetables	Drying and mixing with tomatoes	Local buyers, household consumption
Sweet potatoes	Not usually stored	Boiling and addition of salt	Mainly for household consumption
Round nuts	Packaged in 50 kg bags	Unshelled and boiled to make a delicacy (mutakura)	Household consumption
Tomatoes	Sun drying	Sun drying and mixing with vegetables	Local buyers

pesticides were expensive and they could not afford them. They also indicated a general lack of knowledge on post-harvest storage and handling technologies that can help them to preserve their crops.

Livestock Food Systems

The common livestock in Gutu communities are cattle, goats, sheep, indigenous chicken, turkeys, donkeys, pigeons and guinea fowls. Many of the livestock were kept on extensive systems, with very limited/ minimal supplementary feeding. Almost all households owned chickens and goats, though in varying numbers. A few households owned cattle. Production of livestock by farmers was said to be mainly for subsistence.

Challenges faced in livestock food systems are:

- ***Livestock diseases***: The main diseases threatening cattle and goats included heart water, red water, foot and mouth, lump skin and January disease (*Theileriosis*). Tick bone diseases were said to have become a menace to the whole district—with many farmers losing entire herds. The reason why they were having challenges with *theileriosis* was mainly because there was a general lack of acaricides for dipping animals as well as lack of water to fill in the tanks—over the years, the government veterinary department has failed to purchase the required acaricides and most farmers, who rely on the public dipping facilities had no other options. Cattle in the districts were said to go for more than three months without dipping, causing a buildup of tick population in the area. Poultry in the communities was said to be affected by pests like fowl tampans and diseases like swollen eyes, new castle disease and bird flu and over time, the number of chickens owned per household had declined by 60% across the district.
- ***Droughts***: Farmers said that the frequent occurrence of droughts had affected the availability of grazing material for livestock. Livestock production was thus affected by food shortages resulting in poor productivity. Wetlands which used to provide abundant grazing material for livestock for the greater part of the year were said to be drying up. Most of the rivers which were perennial and could supply water for livestock throughout the year were also said to have turned seasonal.
- ***Predation***: Most areas in the district were said to be mountainous and rocky inhabited with wild animals like hyenas that prey on livestock, reducing livestock numbers significantly. Goats were said to be mainly targeted by hyenas.
- ***Lack of value addition to livestock products***. The livestock production was said to be mainly for subsistence. Selling of livestock was done mainly to neighbors and other farmers in the areas and there was limited value addition as most animals were sold alive. In an event that an animal got sick or injured, the owner would then kill it and sell it as meat (this is the little value addition that farmers were said to be doing). Meat drying using smoke was said to be a common practice by farmers to preserve meat for household consumption.

Cross Cutting Issues Influencing Crop and Livestock Food Systems in Gutu

Ineffective agricultural extension services: Although public extension providers were said to be present in the communities, many of them were said to lack basic resources for them to do their work. They were also said to be demotivated due to poor remuneration from the government and hence they were not providing much assistance to farmers.

Climate Change: Results from the Mann–Kendall trend tests show statistically significant ($p = 0.001$, $\alpha = 0.05$) changes in monthly mean maximum temperatures in the district for the period 1974 to 2014. The trend is shown in Fig. 3. The linear model presented shows an increase in mean maximum temperatures from 1974 to 2014.

Analysis of the total annual precipitation (the sum of all precipitation received and recorded throughout the year under consideration) over a forty year period (1974–2014) for Masvingo province show that there is a statistically significant ($P = 0.049$, $\alpha = 0.05$) trend (Fig. 4). The trend line equation shows that the amount of rainfall recorded throughout the year decreased with time over the period.

Temperature is increasing whilst annual rainfall is decreasing over time. The trends shown in Figs. 3 and 4 show high variability. Such trends have influence on crop production, post-harvest processes and food management in general. Climatic changes have had some impact on livelihoods. Table 3 shows selected climate change variables and their influence on livelihoods.

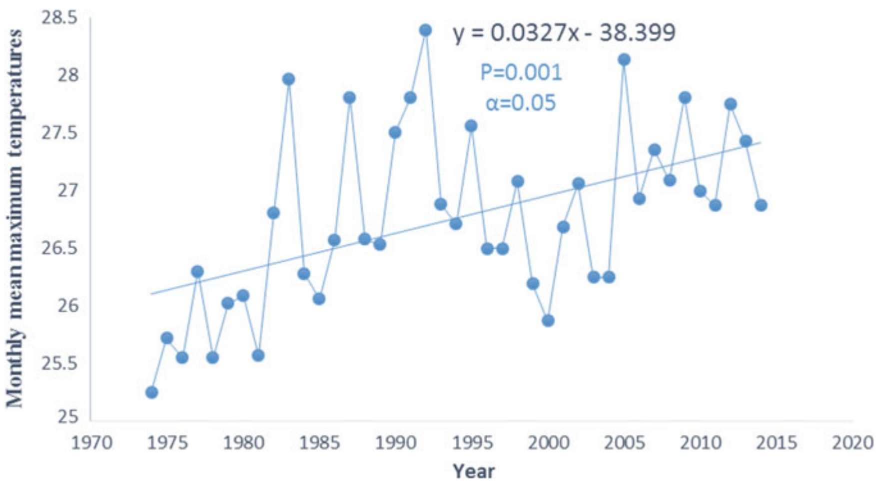


Fig. 3 Monthly mean maximum temperatures

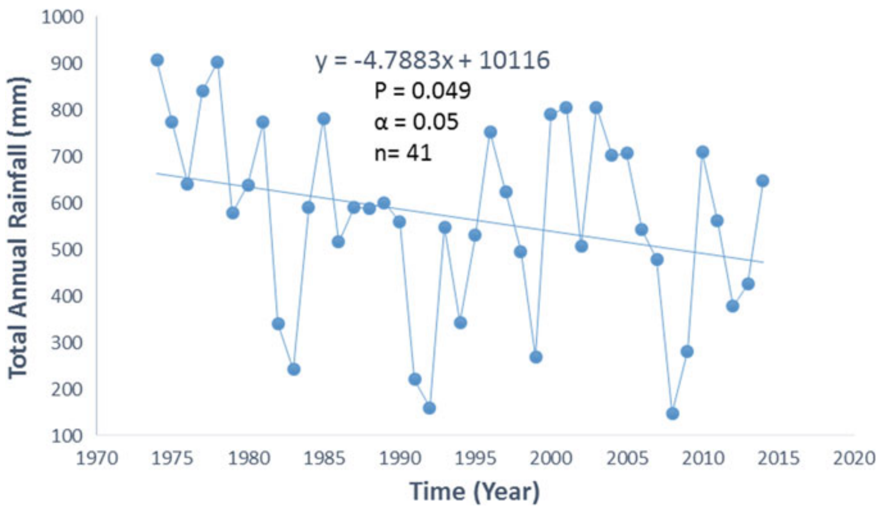


Fig. 4 Total annual rainfall (mm)

Table 3 Climate change impacts

Climatic changes	Impact of hazards
Low and erratic rainfall (prolonged mid-season droughts)	• Rivers are now seasonal, hence fish are now rare • Recurring droughts • Livestock deaths and reduced productivity • Wetlands dried up hence the community's farming is now seasonal • Change of crop mix where brown rice which used to be grown abundantly in the areas could not be grown due to dryness
Increase in temperature	• Rivers are now seasonal, hence fish are now rare
Incessant rainfall	• Land degradation • Stunted growth of crops resulting in low crop yield • Rapid dam siltation
Late onset of crop growing season	• Farmers are not able to properly plan for farming

Gutu Food Security Situation

Farmers said that food availability in wards 2, 14, 16 and 30 of Gutu Rural District was highly seasonal and hunger was experienced from September/October to March. A summary of food availability calendar is represented in Fig. 5.

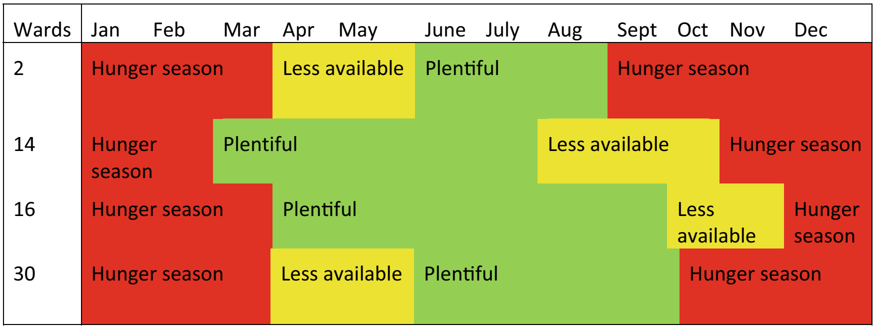


Fig. 5 Seasonal food availability

Discussion

Results have shown a myriad of challenges faced by small holder farmers along the entire value chain, from input supply, production, processing and post-harvest handling and marketing. With regards to input supply, farmers in the district are unable to access critical inputs like seeds and fertilizers and this greatly affect their productivity. Production challenges as seen above are linked to input supply—with poor inputs, coupled with poor soils, productivity is greatly reduced. Livestock production in the district also face many challenges that have seen a reduction in livestock numbers over time. Post-harvest handling, processing and value addition were said to be almost non-existent for most of the produce, both crop and livestock.

These challenges are not new and have been there for many years. Dealing with these challenges requires one to think '**outside of the box**' in order to come up with lasting solutions to these challenges. Efforts to deal with these food system challenges should include:

- ***Promotion of adoption of precision agriculture farming by farmers***. Farmers need to embrace new digital technologies such as satellite farming and the use of GPS systems. Precision farming is a farm management concept that is based on observing, measuring and responding to inter and intra field variability (Dwivedi et al. 2017). Precision agriculture has many advantages including: improvements in efficiency, reduction in costs of production, increased yields, improved decision making by farmers and reduced environmental impacts (Dwivedi et al. 2017).
- ***Revamping the extension provision system to make it vibrant and efficient***. Having an effective extension system with effective extension provision will go a long way in helping farmers deal with the production challenges they face. Extension providers need to be capacitated to ensure that they are up to date with current developments and new technologies. Updating extension providers' skills and knowledge on new developments (e.g. in environmental changes taking place in the district), helps them to provide appropriate support for improving the production, processing and storage processes by local communities.

- ***Developing affordable technologies for post-harvest handling and processing of agricultural products***: Currently farmers have periods of plenty and periods of hunger. Developing simple and affordable post-harvest processing technologies should be a priority. With processing, it is possible to preserve food so that it can be used during the lean times. For example, simple technologies for processing tomatoes into tomato paste and drying fruits (e.g. mangoes) for future use are necessary. Capacity development for farmers in recipes for processing fruits (e.g. mangoes) into pickles, making fruit jams and many other processed foods that can be canned and stored for a long way will help improve community food safety situation.
- ***Developing affordable irrigation technologies for farmers***. Current irrigation facilities (e.g. drip irrigation technologies) are expensive and unaffordable, a reason why farmers continue to rely on rainfed agriculture. There is need to come with cheaper more affordable irrigation technologies so as to promote production throughout the year. Such technologies should be powered by solar energy that is so abundant in the country.
- ***Developing and promoting low cost and effective rainwater harvesting technologies***. From the farmers' perceptions as well as the climate analysis done, climate has been changing with more climate extremes such as droughts and floods. There is need for water harvesting technologies that can help farmers to preserve the little water they get and put it to productive use. Several techniques for rainwater harvesting by farmers have been shared widely in literature, from in situ conservation that makes efficient use of rain in the field, concentration of runoff to crops in the field, to collection and storage of rainwater in different structures (Farooq and Siddique 2017). In addition, technologies that can help farmers to also tap into ground water will also go a long way in reducing the impacts of droughts and this will for sure help to improve the food security situation as well (Farooq and Siddique 2017). Farmers in Zimbabwe can learn about technologies for tapping into ground water from countries such as United Arab Emirates that depend mostly on ground water for their agricultural production, to avoid reinventing the wheel (FAO 2008).
- ***Promoting collaboration amongst various stakeholders along the value chain***. The challenges farmers face will require a value chain approach as they are interlinked and connected..Dealing with the challenges as a piece meal will not help at all. This requires a multi-stakeholder approach with NGOs, community based organisation (CBOs), private sector players, academic institutions, government departments joining hands and pulling resources together to deal with challenges identified.
- ***Exposure trips to promote learning from successes***. Proposal for change, even when the change is good, always meets resistance—many are always happy to remain with the status quo. To transform production systems in Zimbabwe's communal areas, there is need for a complete change in mind-set for all stakeholders including farmers and their support institutions. Changing mind-sets is not an easy task and one way to do this is to facilitate exposure trips to places where similar challenges have been successfully dealt with (e.g. to Brazil, Israel,

United Arab Emirates) where farmers are employing efficient technologies for soil and water conservation. Local look and learn tours (e.g. to Zvishavane to the late Mr Phiri's homestead—who is known for harnessing water using local technologies) are also critical for enhancing learning and stimulating farmers in dry areas such as Gutu District to venture into new ways of doing farming.

Conclusions

Many challenges that farmers face in Gutu food systems have been there for time immemorial and it is high time to rethink African agriculture and come up with solutions that will bring an end to poor agricultural performance. Communal farmers in Zimbabwe and many other African countries are highly endowed with huge land resources that are rare to find in other continents like Europe, for instance. Armed with this resource, there is need for a complete rethinking of current production processes to new ways that can turn the precious land resources into highly productive landscapes. With commitment and effort from various actors, it should be possible to turn these low productive drylands into '**bread baskets**' that can support many livelihoods.

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Potential of In-Field Rainwater Harvesting to Improve Resilience of Dryland Cropping in Smallholder Farms of Zimbabwe: A Review

Misi Amos Manyanga, Gabriel Soropa, and Munjonji Lawrence

Abstract Sustainable agriculture for food security and improved livelihoods in Zimbabwe has been greatly impacted by frequent droughts and prolonged mid-season dry spells due to climate change and variability. These impacts are further exacerbated by the farmers' limited capacity to adapt to these climatic shifts. Over the past years, different in-field rainwater harvesting technologies have been promoted to help farmers especially in arid and semi-arid regions to capture, store and utilize rainfall for improved crop yields. This article reviews different in-situ rainwater harvesting technologies implemented and promoted in some parts of Sub Saharan Africa, for suitability to the Zimbabwe context. The most common in field rainwater harvesting technologies promoted in parts of Zimbabwe and parts of Sub Saharan Africa include planting pits, contour ridges with infiltration pits, tied ridges, ridges, fanyajuu and zai pits. Farmers tend to adopt permanent and semi-permanent in-field rainwater harvesting structures with labour requirements being the main hindrance to adoption. In most cases, insitu rainwater harvesting strategies were found to significantly improve crop yields. In-field rainwater harvesting structures can thus be used for climate change adaptation in Zimbabwe. Rainwater harvesting structures are effective when integrated with soil fertility management. Structures such as modified planting pits (tumbuzika) need to be evaluated locally for their impact as rainwater harvesting strategies under different soil types and topographic conditions in the smallholder farming sector of Zimbabwe. There is need for policy formulation with regards to climate change adaptation strategies such as in-field rainwater harvesting if they are to be a success.

Keywords Dry spells in-field water harvesting · Small holder farms

M. A. Manyanga (✉)
Department of Soil and Plant Sciences, School of Agriculture, Great Zimbabwe University, P.O. Box 1235, Masvingo, Zimbabwe

G. Soropa
Department of Crop Science and Post-Harvest Technology, School of Agricultural Sciences and Technology, Chinhoyi University of Technology, P. Bag 7724, Chinhoyi, Zimbabwe

M. Lawrence
Risk and Vulnerability Science Center, P. Bag X1106, Sovenga 0727, South Africa

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Introduction

Climate change has negative effects to various sectors of economic development including natural resources, agriculture and food security, forestry, tourism, manufacturing and health (IPCC 2007). Changes in rainfall distribution, increasing number of seasons with below normal rainfall and increased temperatures lead to extensive droughts and heat stress and lowers crop productivity (Komba and Muchapondwa 2012). In Zimbabwe, rainfall is becoming erratic and highly variable both spatially and temporally (Nyagumbo et al. 2009). In the semi-arid regions of the country, delayed on-set and premature end of the rainy season are experienced. The rainfall often occurs as high intensity short duration convective storms (Nonner 1997) giving rise to severe soil erosion especially in the early cropping season when the ground is bare. During the cropping season, longer intra-seasonal dry spells are common and their impact on crop production is often severe, especially if they coincide with critical stages of crop development (Rockstrom et al. 2002). Africa is already suffering from food insecurity and malnutrition, (IPCC 2007). About 23 million people in 11 African countries being affected by acute food insecurities and facing malnutrition. This shows climate change in this continent exposes smallholder farmers to worse hunger scenarios (Apata 2011). In an effort to adapt and mitigate the effects of climate change, farmers have adopted different strategies that include use of drought tolerant crop varieties, crop diversification, changing planting dates (Darwin 2004; Ubisi et al. 2017) and practicing in-field rainwater harvesting.

Broadly, rainwater harvesting (RWH) is defined as the collection and concentration of runoff water for productive purposes such as crop, fodder, pasture or tree production, livestock and domestic water supply (Ngigi 2003). RWH covers techniques and strategies to intercept and use rainfall near to where it first gets into contact with the earth surface (Hatibu and Mahoo 2000). If RWH is well utilized and applied in the right environment, it is a cheap and sustainable source of water to most of the smallholder farmers in drylands (Singh et al. 2019). In principle, rainwater harvesting is a simple low-cost technique which requires little expertise or knowledge and indeed it offers many potential benefits (Otti and Ezenwaji 2013). According to Mwenge et al. (2005), the advantages of RWH include increased income, improved food security and reduction in malnutrition besides moisture retention. In contextof the erratic nature of rainfall patterns being received, it is important to capture as much water as possible within the crop fields using in-field RWH structures. In-field RWH helps to increase water infiltration leading to improved groundwater recharge and preserves the soil moisture for crop use. Rainwater harvesting is applicable over a wide range of conditions especially in areas where seasonal average rainfall is insufficient to meet the crop water requirements (Oweis et al. 2001). In many localities, direct rainfall is insufficient to meet crop water requirement (Oweis and Hachum 2006). Therefore, increasing the amount of water available through RWH seems to be the most appropriate way of ensuring sustainable dryland crop production, increasing agricultural productivity, improving food security and alleviating poverty.

A number of in-field RWH technologies have been developed, tested and adopted by smallholder farmers across Sub Saharan Africa (SSA). The technologies being promoted are infiltration pits (Maseko 1995); cross-tied graded contours, deepened contours and fanyajuus (Hagmann 1994), no-till tied ridging, mulch ripping, clean ripping and hand hoeing (Nyagumbo 1999).The water harvesting projects have been set up in sub-Sahara Africa since the 1970s and 1980s in response to widespread droughts that left a trail of crop failures (Hatibu and Mahoo 1999; Ngigi 2003). Tolossa et al. (2020) also expressed that there are several in-field water conservation practices that have been used in several regions of Africa, including earth bunds, planting pits or planting basins, mulching, dead level contours and their modifications. Unfortunately, a few of these practices have succeeded in combining technical efficiency with low cost and acceptability to the local farmers. For example, experimental research on infiltration pits in Zimbabwe produced mixed results, and available information is inadequate to explain the causes of the differences in results (Nyakudya et al. 2014). This paper reviews some of the studies that have been done on in-field RWH in Zimbabwe and other parts of SSA in order to get a perspective of future research needs. The review mainly used secondary data from research done in parts of SSA such as Zimbabwe, Kenya, Tanzania and Malawi.

Materials and Methods

This chapter is a review of information collected from journal papers as well as conference, workshop proceedings and technical reports on in-field rainwater harvesting.

Results and Discussion

Rainwater Harvesting Strategies Promoted in Sub Saharan Africa (SSA)

Across SSA, various in-field rainwater harvesting structures have been promoted and extensive research efforts have been done on in-situ RWH strategies such as infiltration pits (Maseko 1995); cross-tied graded contours, deepened contours and fanya juus (Hagmann 1994). In Zimbabwe success stories have been documented (Nyagumbo 1999; Twomlow and Bruneau 2000; Rusike and Heinrich 2002; Motsi et al. 2004; Mugabe 2004). However, it is worth to note that planting pits resemble zai pits and in West Africa it is common and mostly adopted by many smallholder farmers across different agro-ecological farming zones (Twomlow et al. 2008). Planting pits are planting holes dug using hand hoe as part of the conservation farming system (Mupangwa et al. 2012). Water collected in the pit is retained by the effect of a

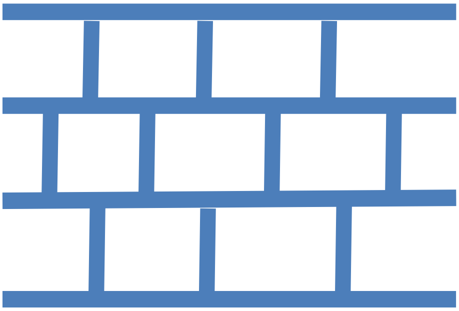

Fig. 1 An Illustration of how tied ridges are constructed for infield rainwater harvesting

structure created by the soil from the pit that is placed at the downstream side. The planting pits use a spacing of 0.9 × 0.6 m and the size of each planting pit is 0.15 × 0.15 × 0.15 m (Twomlow et al. 2008). In Rushinga, a semi-arid area of Zimbabwe, smallholder farmers modified contour ridges traditionally used for rainwater management by digging infiltration pits inside contour ridge channels for improving the amount of water retained in the crop fields (Nyakudya et al. 2014).

Tied Ridges

Tied ridges are rows of soil hipped to form lines and then tied in between in order to trap water thereby increasing infiltration and reducing runoff. To prevent possible erosion, the lower ridge is tied starting from the point between the above tied ridge such that tying is not perpendicular giving a pattern similar to a brick stretcher bond used in house construction (Kathuli and Itabari 2014) as illustrated below (Fig. 1).

Tumbuzika

Tumbuzika are very common in Kenya. They are enlarged planting pits which are 0.6 m wide and 0.6 cm deep. While using Tambuzika strategy, the top 0.2 m soil is mixed with manure or compost prior to planting. For example, 5–7 maize seeds are sown per pit with the pits spaced at 1 m row to row and 0.75 m pit to pit (Kathuli and Itabari 2014) (Fig. 2). Most of the smallholder farmers in sloppy areas of Kenya rely on fanya juus for cropping. Fanya juu, implying' throw it up' in Swahili, and it is the process of digging ditches and throwing soil upslope to form an embankment. The bank prevents the runoff water while the furrow, which is dug along the contour, retains water. Over time, well-formed and flat terraces develop naturally (Ngigi 2003). In some localities, fanya chinis which are the opposite of Fanya juus (here the soil is thrown down slope instead of up slope) are used but still works the same way.

Fig. 2 Maize in planting pits at an experimental station in Zimbabwe

Zai Pits

Another technique which has been promoted for RWH in Kenya and Tanzania are the zai pits. Zai pits which are similar to planting pits (basins) in Zimbabwe are a simple and effective form of RWH. They are small holes dug in the ground to capture and retain rainfall. The pits allow little water to escape and therefore enhance rainfall productivity (Black et al. 2012).The zai pits are shallow and wide pits that are about 0.3 m wide and 0.15–0.2 m deep, in which four to eight seeds of a cereal crop are planted (Fig. 3) (Mati 2005). Soil fertility can be improved through addition of organic manure and compost or even inorganic fertilizers into the pit. This technique works through water harvesting as well as conserving moisture and fertility in the pit. In southern Tanzania's Njombe district, the pits are made bigger and deeper (at least 0.6 m deep), and 20 L volume of manure is added. Since the area receives an annual rainfall of around 1000 mm, the farmers plant 15–20 seeds of maize per pit and the yield is more than double the conventionally tilled land (Mati 2005).

In Tanzania, many RWH techniques exist such as conservation tillage, pitting, contour barriers, strip catchment tillage and basin system (Hatibu and Mahoo 2000). The basin systems commonly known as the "negarim" micro-catchment technique is perhaps the best known RWH system. It is also known as the "meskat" system. In this system, each micro-catchment feeds runoff to a discrete cropped basin. The basin size is typically in the range 10 m^2 to 100 m^2 and is surrounded by an earth bund approximately 0.3–0.4 m high. They are particularly well suited to tree crops, but other crops can be grown successfully under non-mechanized farming systems. There is a long tradition of using this system in arid regions (Oweis and Taimeh 1996). Many farmers recognize the natural redistribution of runoff that occurs in the farming landscape and adjust their management to reflect differences in soil-moisture availability. Planting pits are also a common RWH technique in Tanzania. A notable example is the 'ngoro' technique which is common in the Mbinga District. In this semi arid region of Tanzania, pits are typically about 30 cm diameter and 20 cm deep.

Fig. 3 Planting pits for water harvesting and conservation at a farmer's field in Zimbabwe

The system is well adapted to hand cultivation and is beneficial to most smallholder farmers who are usually resource constrained especially in areas where soil surface capping is a problem.

Benefits of In-Field Rainwater Harvesting

Utilization of RWH has the potential to conserve rainfall especially in threatened environments resulting in increase in crop yield and reduced risk of crop failure (Oweis et al. 2001; ATPS 2013). Increased crop productivity and yield among smallholder farmers due to adoption of RWH will motivate and incentivize them to invest in more soil nutrient enhancement. In- situ rainwater harvesting technologies often serves primarily to recharge soil water for crop and other vegetation growth in the landscape. Malesu et al. (2006) argues that in-situ technique emphasizes on water management and conservation which are mostly traditionally considered for soil moisture conservation. This approach aims at maximum infiltration and minimum surface runoff to achieve better yields where soil moisture is a constraint. Different strategy for in-situ water harvesting resulted in increased retention of moisture, through reduction in run-off from fields and improved infiltration enhancing groundwater recharge. Therefore, improved in-field water harvesting can increase the time required for crop moisture stress to set in and thus can result in improved crop yields, food security and livelihood among households (Nyamadzawo et al. 2013).

In Zimbabwe, infiltration pits dug in contours were found to increase soil moisture content significantly from the centre of the infiltration pits up to 3 m down the slope compared to contour ridges only (Nyakudya et al. 2014). Infiltration pits help reduce soil erosion and high value horticultural crops can be grown inside and close to the pits (Nyakudya et al. 2014). Ndlovu et al. (2020) studied climate change adaptation by smallholder farmers in Gwanda district, Zimbabwe and noted that water harvesting techniques such as planting pit, mulching, deep tillage, dead level contours, ephemeral stream diversion and ridges/furrows reduces surface runoff thereby promoting water conservation and soil fertility. However, the authors noted that although in-field rainwater harvesting techniques have the potential to improve yields and crop production, there are a number of pertinent factors that affect and influence the adoption of these water harvesting techniques by smallholder farmers in the study area. These include the availability of household labour, technical know-how and farmers' perceptions. Such factors should be taken into consideration while designing and implementing strategies for upscaling the adoption of water harvesting techniques.

In Dodoma, Tanzania, runoff water was harvested, stored and later used to irrigate during a serious drought year and resulted in rice yields of about 1.5 t/ha while no yield was observed in plots where there was no supplementary irrigation (Kaumbutho and Simalenga 1999). In Malawi, simulation results showed that tied-ridges reduce surface runoff and this increased rainwater retained in the field (Wiyo et al. 2000). However, the same study showed that tied-ridging is not likely to benefit maize crop grown in coarse-textured soils regardless of seasonal rainfall. In Kenya, tied-ridges coupled with soil fertility improvement were found to increase crop yields by 100–300% (Kathuli and Itabari 2014) which is a very significant increase. In a study in Niger, Olaleye et al. (2006) reported higher yields on zai treatments compared to flat planting and this was attributed to a build-up in the soil organic matter contents which may have increased the soil water holding capacity in the zai treatments. The common idea behind all these structures is to retain runoff water and increase water use efficiency.

Farmer Adoption and Knowledge of Rainwater Harvesting Strategies

According to Critchley and Siegert (1991), the main problems associated with adoption of the water harvesting structures are that they are difficult to construct, have high labour requirements and have no room for mechanization. A clear example on effects of labour issues on adoption of rainwater harvesting strategies in Zimbabwe were pronounced on the basin tillage system (makomba), which are a modification of the zaipits which were widely promoted under Precision Conservation Agriculture

(PCA), half moon basins and shallow planting furrows using a hand hoe (Twomlow et al. 2008). Though these basin tillage were adopted by some farmers, challenges still persist due to perennial high labour demand required on establishment to the extent that they have been given a nickname, “digaufe” in vernacular language which translate to “dig and die” (Nyamadzawo et al. 2015). This clearly shows that to promote farmer adoption, technologies should be cautiously promoted to avoid stigmatization. However, a study done by Mutekwa and Kusangaya (2006) in Chivi district in Masvingo Province showed some encouraging levels of adoption with infiltration pits being the most commonly adopted RWH techniques adopted by 61% of the household respondents while tied ridges were adopted by 27%. The same authors also quoted a farmer’s perception about RWH technonologies as follows. ‘*These technologies have taught us to work together. We learn from each other, share labour and tools. We have already formed permanent labour clubs. Otherwise as individual households, we would not manage*’. About 89% of the RWH farmers indicated that they are now able to grow at least 2 crops on a rotational basis in one calendar year showing that the farmers are now able to intensively utilise their land (Mutekwa and Kusangaya 2006). This also shows that farmers know that these technologies work and to be successful and effective, they need to work together due to limited availability of the tools and labour required to make these structures. This assertion was also observed by Munamati and Nyagumbo (2010) whose study found that resource ownership is also a key factor in farmers’ ability to scale out water harvesting technologies with performance significantly linked to resource status. This is also a clear indication that with proper promotion, adoption of RWH strategies by many farmers is a great possibility. Literature showed that farmers tend to adopt more of permanent rainwater harvesting structures. Hagmann and Murwira (1996), reported that farmers in semi-arid areas showed more interest in large, semi-permanent to permanent water harvesting structures. Nyamadzawo et al. (2013) also expressed that more permanent water harvesting technologies may be a solution to the problems of perennial high labour requirements and there is a need to promote them. Semi-permanent to permanent water harvesting structures helps to harvest the runoff after in-situ soil moisture storage and stores it for providing supplemental irrigation to crops using efficient water application methods to save the crops during prolonged dry spells which are very common in recent years due to the impacts of climate change.

In Kenya, variability of rainfall due to climate change has triggered a sprout of a myriad of RWH strategies to mitigate drought and water shortages (Aroka 2010). However, despite many efforts being put in place to adopt RWH projects there is lack of tangible evidence on the significance of RWH on human welfare and sustainable development (Ngigi 2003). Moreover, RWH projects have not received enough attention to warrant widespread adoption and implementation (Kenya Rainwater Association 2010). There is need for twin effort by researchers and policy makers to promote efforts for adoption of different RWH strategies by smallholder farmers who are more prone to climate change in different cropping regions of Kenya. A complimentary study done by (Mang’era, 207) noted many deterrents to effective RWH in Kenya that include poor technical designs for rainwater capture and storage, inadequate investment, failure to apply water supply standards, perceptions about the non-potability of rainwater, and poor linkage and coordination of efforts at local through national levels of social organization. The researcher also identified some key factors responsible for successful RWH projects which included: social capital, local knowledge and capacity, and establishment and enforcement of property rights. Therefore, there is need for efforts to promote effective rainwater harvesting strategies through building capacity of project groups at the local level, developing effective RWH policies, institutions and creating RWH coordination networks at local level through national and international collaborations.

In Tanzania, it was observed that farmers already know the importance of water conservation and harvesting and interestingly they have been implementing these practices. Farmers effectively utilize soil moisture through proper cropping system with less water demanding crops such as millet being cropped on upper slope while maize and other crops that require more water were planted on lower slope positions. Adoption of these water harvesting practices was found to improve farmer's income and reduced poverty (Kaumbutho and Simalenga 1999). Another study done by Gowing et al. (1999) assessed the extent to which different RWH are used in Tanzania and reported widespread adoption of RWH techniques. However, the authors noted that farmers are faced with shortage of appropriate technologies and knowledge suitable for their areas. They concluded that there is a need to identify and disseminate appropriate technologies that will reduce vulnerability to rainfall variability and scarcity especially in the semi-arid areas of Tanzania. Therefore, specific regulations are imperative for guiding and enforcing the adoption and attainment of the targeted technology potential. These should be recognizable at national level through national RWH technology guidelines and standards (Mwamila et al. 2016).

Conclusions

Many farmers in selected areas of SSA observed significant benefits by adopting different RWH strategies. This clearly shows that in-field RWH can be acritical climate change adaptation strategy in Zimbabwe. In-field rainwater harvesting coupled with good soil fertility management practices can help to increase crop yields significantly through increased water use efficiency and thereby, helping in climate change mitigation and adaptation. Furthermore, for rainwater harvesting to be effective and successful, there is need for farmers to work collectively taking into consideration of the farmers' resource endowment. The problem of resource endowment can be countered through formation of labour working groups in order to reduce the amount of time spent during the initial establishment of the RWH technologies. More studies need to be done to explore the benefits of rainwater harvesting in Zimbabwe in order to come up with proper more adaptable strategies for climate change adaptation. Moreover, advocacy for adoption of different rainwater harvesting strategies to smallholder farming communities, both at policy and lower levels should be done for adaptation to climate change.

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Developing Pathways for Sustainable Agricultural Development in Zimbabwe by 2030

Sabine Homann-Kee Tui, Gevious Sisito, Elisha N. Moyo, Thulani Dube, Roberto O. Valdivia, Malgosia Madajewicz, Katrien Descheemaeker, and Alex C. Ruane

Abstract Agricultural production systems in Zimbabwe are facing high intensity of climate change impacts. Stakeholders require actionable information to direct investments towards a climate resilient future. The Agricultural Model Inter-comparison and Improvement Project, Climate Change Adaptation and Resilience (AgMIP CLARE) uses an integrated multi-modeling approach to support policy-level decision making and priority setting for sustainable development and climate adaptation with the goal of improving farmers' livelihoods, food and nutrition security and gender equity. The Zimbabwe Vision 2030 was used to co-develop, with stakeholders' and experts, plausible future scenarios of the agricultural sector in Zimbabwe. For systems like in Nkayi district, the simulation results illustrate that investing in a sustainable

S. H.-K. Tui (✉)
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Box 776, Matopos, Bulawayo, Zimbabwe
e-mail: S.Homann@cgiar.org

G. Sisito
Matopos Research Institute, PB K 5137, Bulawayo, Zimbabwe

E. N. Moyo
Climate Change Management Department, Ministry of Environment, Climate, Tourism and Hospitality Industry, 11th Floor, Kaguvi Building, Harare, Zimbabwe

T. Dube
Department of Development Studies, Lupane State University, Bulawayo, Zimbabwe

R. O. Valdivia
Department of Applied Economics, Oregon State University, Corvallis, USA

M. Madajewicz
Center for Climate Systems Research, Columbia University, New York, NY, USA

K. Descheemaeker
Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK Wageningen, Netherlands

A. C. Ruane
National Aeronautics and Space Administration Goddard Institute for Space Studies, New York, NY, USA

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future, yields more favourable outcomes than investing in 'high emission' economic growth: pro-active diversification and intensification of small (traditional) grains and legumes and integration with livestock, supported by inclusive, functional value chains and access to information leads to higher returns per unit land on farm. Policies and interventions that promote a switch to more legumes in the farming systems, and make the uptake of productivity enhancing technologies more attractive, achieve greater food and nutrition security and increase social and economic equity, offset the impacts of climate change and improve farmers livelihoods. Importantly, to make effective investments there is need to create incentives for all farmers to invest; under a sustainable future, vulnerability is less and the poorest benefit more. Deciding for one future helps prioritizing what it would take in terms of policies and investments to achieve the vision 2030. Testing technologies and adaptations under different possible futures, integrating socio-economic and agro-ecological dimensions across different scales, simulation experiments helps stakeholders and experts to design and evaluate policies aimed at meeting sustainable development, climate and food security goals.

Keywords Climate change adaptation · AgMIP CLARE · AgMIP representative agricultural pathways · Zimbabwe

Introduction

Climate change amplifies challenges in agriculture, particularly in drylands, where water is already scarce, bio-diversity dwindling, against an ever raising pressure to nourish human populations. Dryland areas in Zimbabwe cover more than two thirds of the country, facing high intensity of climate change impacts (Moyo 2012). Given the levels of risk and uncertainty, there is need for science to serve decision purposes, direct policy investments, on what to put in place towards a climate resilient future (Lipper et al., 2014). Science informed decision making is increasingly becoming important, to improve agricultural systems, in their function to deliver food and nutrition, as changes take place in agriculture, climate and socio-economic conditions, now and in the future (Antle et al. 2015).

The main reason why agricultural development pathways are being created is to shape policy and investment decisions on how Zimbabwe can best achieve sustainable agricultural development and how to achieve the set goals of its vision 2030. Researchers engage with stakeholders and sectoral experts in an iterative process, to bringing in different sources of knowledge that inform the dialogue on major drivers for agricultural production, their interactions and how those might influence the state of the future. Development pathways are based on sound baseline analyses of current policy, institutional and socio-economic conditions and different trajectories representing development goals, policy implementation and challenges. These pathways allow to assess the potential impacts and trade-offs associated with the scenarios which can be used to support decisions, planning and investment. Climate policy plays a key role on the ability of the country to implement adaptation and mitigation strategies conducive of achieving climate goals and international commitments (e.g. Paris agreement). Therefore, climate policy assumptions along the pathways create the different scenarios to assess the changes in the farming systems. This informs actionable climate change adaptation options, tailored to areas with similar bio-physical and socio-economic conditions and accounting for plausible futures that cannot be measured and tested using traditional methods of field experimentation.

Research outputs include:

1. Pathways for agricultural development validated with stakeholders and experts, representing impacts of climate and other socio-economic influences, and how changes in policies are likely to impact on agriculture and the wider food systems.
2. Consolidation of policy packages for sustainable and resilient agri-food systems, costs, feasibility and impacts, supporting desirable transitions based on sound policy analyses and requirements.
3. Actionable information on how pathways can be implemented, as to where to transition from, where to go, based on well aligned priorities and entry points.
4. Analyses of the consequences (impacts) if sustainability goals are different or implementation of sustainable development policies are not fully implemented.

In this chapter, the advancement in creating and implementing development pathways within an integrated modeling approach to inform policy decision processes in Zimbabwe is reported. The chapter draws on a case study within the global Agricultural Modeling Intercomparison and Improvement Project (AgMIP, www.agmip.org).

Addressing systemic challenges to agriculture and climate change adaptation:

Policy and decision makers in the Zimbabwe agriculture sector face daunting task to enable sustainable increases in productivity and nourish a growing and developing population under a changing climate, and growing regional and global challenges (Mbow et al. 2019). To achieve its vision 2030 of being a prosperous and empowered upper middle income society, the agricultural sector must fulfil key goals (Fig. 1a).

Policy decisions must transform agricultural production systems, with more efficient resource utilization, water and input use, improving soil health and rangeland bio-diversity, decreasing green-house gas emissions, facilitating economic growth in a way that it engages women and youth.

Climate change acts as risk multiplier (Moyo and Nangombe 2015). Climate change enhances the urgency of transforming to a more inclusive, competitive and sustainable agricultural system (Rickards and Howden 2012; Kates et al. 2013). Food, nutrition and income challenges are wide spread, affecting the rural and urban poor. Drylands are projected to have most negative impacts. There are many uncertainties for a range of intertwined impacts that affect agricultural systems differently (Garrett et al. 2017). Impacts vary by geographical, bio-physical, and socio-economic conditions, which render it difficult to make decisions regarding the development of the sector.

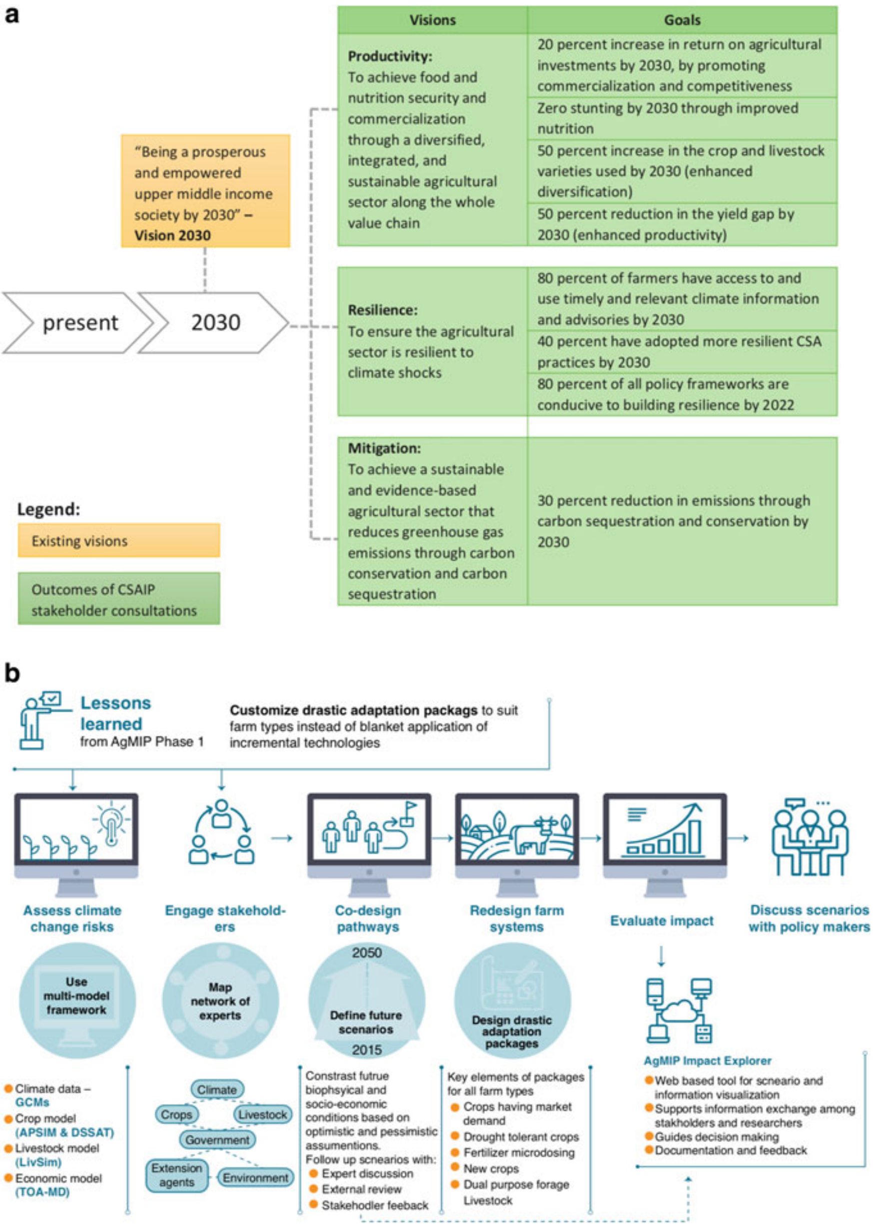

Fig. 1 **a** Vision and goals to achieve Zimbabwe's' vision 2030, as defined by the climate smart agricultural investment plan (World Bank 2019). **b** Customized climate change adaptation packages to suit particular farming systems, AgMIP RIA process. *Source* Adapted from ICRISAT (2016) and Valdivia et al. (2019)

Stakeholders and policy makers need better decision-making support that allows them to make effective investment (Bößner et al. 2018; Holman et al. 2019). Risks and uncertainty are however difficult to digest for decision processes. Strategies and programs must reflect the needs and priorities of the agricultural sector. Available information on climate dynamics and climate change impacts is however often not appropriate or available for guiding decision processes on agricultural policies and investments (Hansen et al. 2011). Given the complexity of problems in the agricultural sector, generating supportive evidence is difficult. There are influences by the multiple goals from within the sector and also other sectors, and inconsistencies in the implementation of policies from national to local levels. Most studies on climate change impacts focus on single technologies and interventions, e.g. crop or livestock species, and come up with aggregated outcomes. Neither do they measure climate change impacts on farming systems and agro-ecological zones; hence, they do not represent vulnerability adequately.

Most approaches for collecting information on climate change impacts and vulnerability fail to adequately represent the heterogeneity of the sector, and hence are not suitable to inform targeted climate change adaptation. Furthermore, they mostly consider the impacts of climate change under current conditions, but do not figure out the likely influence of future socio-economic and bio-physical conditions.

Agricultural Development Pathways for Science-Based Policy and Decision Making

To prepare for an unknown future, agricultural development pathways in combination with farming systems modelling can inform likely impacts of climate change, within given national policies, and how those national policies impact on climate change responses (Whitbread et al. 2010; Antle et al. 2017). AgMIP Representative Agricultural Pathways (RAPs) provide qualitative and quantitative information to characterize the state of a future World under which a particular farming system might operate (Valdivia et al. 2015, 2020).

The RAPs co-design process brings science and policy development closer together to inform what investments, institutional mechanisms and capacity would be needed to support an envisaged future, while acknowledging that there are uncertainties. Evaluation of possible policy decisions and adaptation measures using simulation experiments makes it possible to compare both short and mid-term adaptation strategies, at local and national scales. This provides critical insight for the design of policies, how they can meet sustainable development goals, mitigation and adaptation objectives.

The AgMIP RIA approach uses 6 critical principles:

1. **Coherent framework** to describe how the future of agriculture might look like. Given uncertainty there is need to present plausible future World conditions, based on robust assumptions. Here we compare different pathways and integrate multiple methods to assess most plausible changes in future. Global emission (Representative Concentration Pathways, RCP) and socio-economic scenarios (Shared Socio-economic Pathways, SSPs) provide global trends and parameters,

which influence local context specific projections, as defined in the RAPs. This acknowledges that global drivers impact on local action. The IMPACT global economic model provides price and productivity trends. Climate, crop, livestock and economic models integrate multiple components to represent local farming systems. They simulate farming systems changes and climate impacts under current as well as under future conditions, in this case by 2030.

2. **Science in collaboration with stakeholders and experts** to integrate science with local knowledge, through learning processes. Experts and stakeholders from different disciplines bring intrinsic knowledge about causalities and relationships to create future worlds that represent real possible change, which modeling alone cannot comprehend. Generating inputs for and revising outputs with experts also brings out more comprehensive explanations, e.g. why technologies were not being taken up, what underlying causes needed to be addressed, how the results could help to match prioritizing interventions with future conditions and needs, how research could help accelerating decision processes.
3. **Impact assessment and trade-off analyses** to project likely impacts of policy packages and adaptation interventions under future conditions with climate change. Decision makers might want to know about the levels of vulnerability of different parts of the communities along different development pathways, what interventions can provide sustainable benefits to farmers and other agriculture sector stakeholders, what are the likely consequences and what incentives are needed to achieve broad adoption of sustainable agricultural approaches, which might pan out differently in other agro-ecological regions.
4. **Delineating areas with similar response to climate change** to reduce complexity and provide suites of adaptation packages for geographical areas with similar conditions and climate change impacts. This requires characterizing areas and production systems that are more vulnerable to climate change, identify hot spots of climate change and their distribution, and how they would affect farming systems.

Methodology

The AgMIP Regional Integrated Assessment (RIA) follows a rigorous protocol based multi-model approach (climate, crops, livestock and economics) to improve information for actionable decisions that make agricultural systems more resilient to climate change. It measures changes in farm components, on individual farms and how they are distributed in heterogenous farm communities. That helps to understand better how agricultural systems could respond to climate change under future bio-physical and socio-economic conditions.

Participatory and modelling methodologies are used to measure the likely vulnerability of agricultural systems to climate change, and the possible impacts of adaptation strategies on those systems (Valdivia et al. 2015, 2020). Linking the analyses to national and global scales helps to understand, for instance, how inconsistency in the implementation of national policy interventions, as well as global markets and programs, might affect these systems (O'Neill et al. 2017).

What makes the approach unique is that it allows policy and decision makers to develop and test specific questions and story lines on investments and interventions ex ante, e.g. which populations are most vulnerable, what adaptations would benefit most farmers while building a more sustainable agricultural system, and what technology, institutional and policy gaps need most urgently to be addressed.

In Zimbabwe, AgMIP-RIA was implemented as part of a journey of multiple projects and collaborations (Masikati et al. 2013; Homann-KeeTui et al. 2013, 2020; Dube et al. 2014). Building on lessons, networks and data through earlier crop livestock projects was clearly an advantage for contextualizing the results. Initial AgMIP-RIA multi-modeling experiments, following a Business As Usual pathway with isolated technical improvements (fertilizer application, improved varieties, forage production) showed limited impact on poverty reduction, economic gains and overall livelihoods improvement (Masikati et al. 2015). The interventions increased agricultural production and food security, however, remained insufficient to meaningfully improve smallholder livelihoods. The research team therefore engaged with stakeholders and experts in another cycle to develop more transformative pathways and adaptation strategies to be tested using the AgMIP modeling approach.

Figure 1b summarizes the 6-steps:

1. **Assess climate risks**: The multi-model framework was set up for the mixed crop livestock systems in Nkayi district. It links climate models (5GCMs with contrasting temperature and rainfall, under RCP 4.5 (low emissions) and RCP 8.5 (high emissions); Ruane and McDermid (2017), with crop models (DSSAT and APSIM; Jones et al. 2003; Holzworth et al. 2014), a livestock model (LIVSIM; Descheemaeker et al. 2016), and an economic model (TOA-MD; Antle et al. 2014; Antle and Valdivia 2020a). Household data were used from an earlier baseline surveys (n = 168) to identify farm types and farm management parameters (Homann-KeeTui et al. 2015, 2020). Global price and productivity trends were taken from IMPACT projections (Wiebe et al. 2015). Experimental data were used to calibrate the crop and livestock models (Masikati et al. 2013; Descheemaeker et al. 2018).
2. **Engage stakeholders**: Stakeholders and experts from multiple disciplines were involved at early stage. The purpose and activities were shared early in the process, building on what had been done before. Researchers, stakeholders and experts co-designed the pathways and adaptation packages and analyzed simulation results and their meaning. This iterative process provided valuable inputs to modify or adjust model parameters and for validation of simulation results. Stakeholders also advised on how best to endorse the research in national planning processes. National research and government organizations were part of the team, as part of building capacity on applications for future uses.
3. **Co-design pathways**: A Business as Usual Pathway and 2 contrasting pathways, sustainable and non-sustainable development, were co-designed. In a series of 2-day workshops, engaging 10 provincial-level experts, the likely changes

(direction and magnitude) of key drivers anticipated by 2030 were identified and quantified, for each pathway. Quantitative parameters (family, farm and herd size, input and offtake levels), global prices and productivity trends, were fed into the simulation models. The process of developing RAPs narratives and storylines helped to identify policy priorities for sustainable agricultural systems.

4. **Re-design farming systems**: Typical agricultural systems and farm types were characterized. Climate change adaptation packages were developed with experts, taking into account future temperature, rainfall, water, soil nitrogen content and CO_2. Adaptation packages were verified with rural communities and local stakeholders to ensure that they respond to context specific conditions and were realistic. Taking into account complex changes, participants were asked to imagine future worlds where barriers had been removed, as the conditions for farming would have been improved over time.
5. **Evaluate impacts**: In an iterative process, modeling results were illustrated to stakeholders and experts. Impacts of climate change and the potential benefits of the adaptation packages to the farm types under different development pathways were discussed. Key messages were generated and prepared to be presented in user friendly formats. Data and story lines and results are available in AgMIP's Impacts Explorer, a web-based platform available to users (http://agmip-ie.wenr.wur.nl/home2).
6. **Discuss scenarios with policy makers**: The contrasting scenarios on what could happen under different future conditions were discussed with policy makers to identify and endorse policy and intervention priorities that lead to transformation of farming systems towards more sustainable development. Contrasting the pathways helped to bring out critical steps.

This 6-step approach can be adjusted to specific needs. There can be need for revision after dramatic changes in the socio-political environment or unexpected shocks, e.g. COVID-19 or a sudden government and regime change.

Drylands in Zimbabwe: Impacts of Climate and Climate Change Adaptation

Current Farming Systems

Land use in Nkayi district is extractive and dependent on nutrient depleted sandy soils with limited response to soil amendment. Higher temperatures, deficit rainfall and delays in the start of the rainy season make agriculture more risky.

Farmers grow mostly maize, with yields below 1t/ha (Homann-KeeTui et al. 2015). Agricultural productivity is low, and with production levels harvest outfalls are endemic. Only few farmers invest in livestock feed, despite feed shortages. Most farmers are resource poor (extremely poor farmers: 43% of the population, with no cattle, and on average 1.4 ha land; poor farmers: 38% of the population, with 5.4 Tropical Livestock Units (TLU) and 2 ha land). The other farmers are 19% of the population, with 13.9 TLU livestock and 2.7 ha land.

Unless government, financial partners and support agencies create a more conducive environment for agriculture and market oriented support systems, climate change means greater food and nutrition insecurity for large parts of the population. Potential success depends on changing the deeper structures in the agricultural set up and not on technical change alone.

Sensitivity to Climate Change Impacts

Climate projections vary by climate models and location reflecting uncertainty on how climate change impacts could pan out (Moyo et al. 2018). The projections of contrasting climate models were averaged to come up with recommendations for climate change adaptation. In this case, the climate projections to 2030 foresee increased temperatures by 2–3%. Precipitation projections are more variable, a decrease in rainfall of 25% seems possible. Furthermore, climate risks vary by crop type, crop types being differently sensitive to these changes in climate. Maize was most sensitive (−25 to 6% change in maize yield); sorghum and groundnuts varied similarly (−21 to 13% and 18% change in sorghum and groundnut yield, respectively). Cattle production was highly sensitive to climate impacts (−8 to −1% change in offtake, −22 to −4% in milk production) due to the compounded effects of climate change, reduced crop biomass production and reduced biodiversity on rangelands compromising feed quality.

Benefits to Adaptation

Farmers extremely vulnerable to climate change have greater potential for improving their livelihoods (Homann-KeeTui et al. 2020). Adaptation packages were designed assuming that various barriers to adaptation such as access to seed, markets, knowledge and services, were removed or improved. The packages were designed and evaluated assuming different degrees of implementation and considering the different farm types. Figure 2 summarizes the 3 step adaptation packages:

- Step 1 improved cereal management
- Step 2 Intensification and expansion of legumes
- Step 3 Improved feed for livestock and increased commodity prices as incentive for farmers to make these investments.

Highest returns were obtained with the full implementation of the adaptation package (step 3, Fig. 3). The majority of farms would find it economically advan-

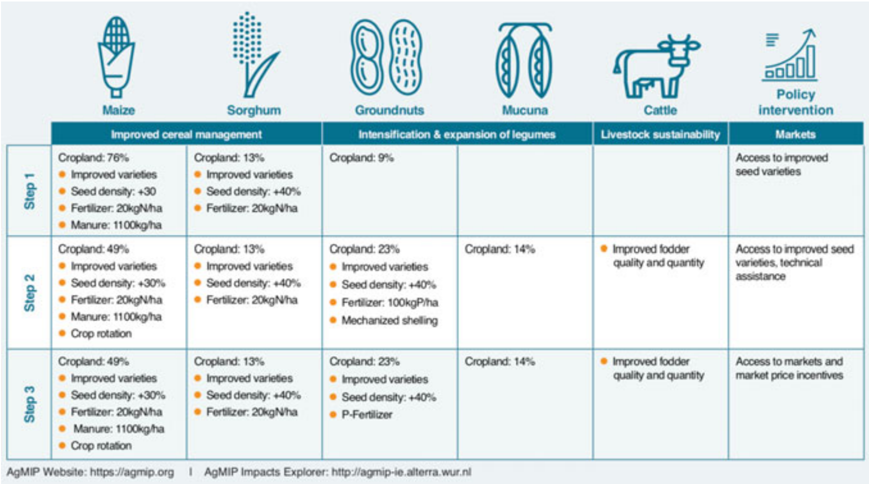

Fig. 2 Climate change adaptation packages developed for Nkayi district. *Source* Adapted from Valdivia et al. (2019) and Homann-KeeTui et al. (2020)

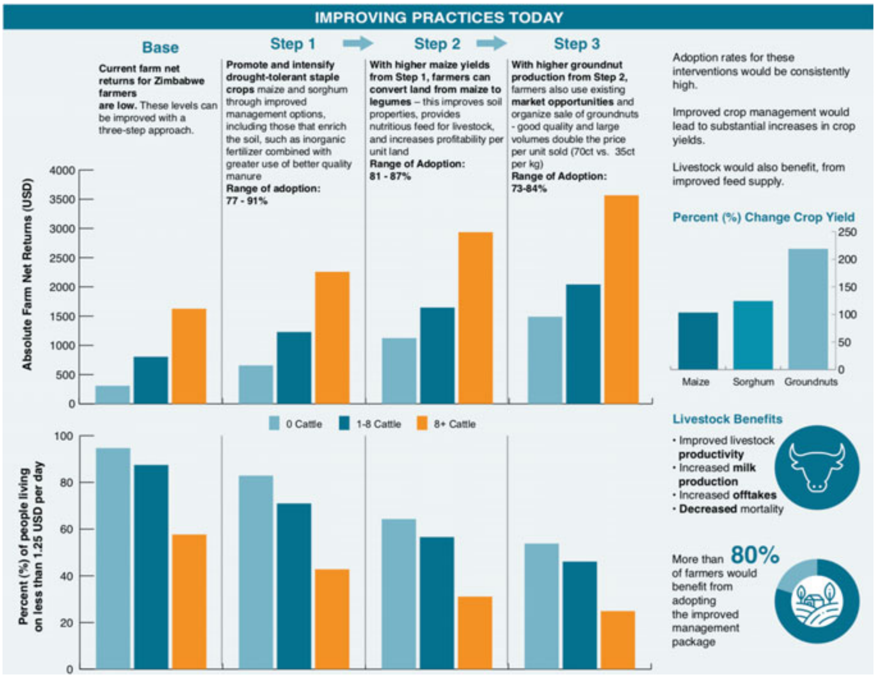

Fig. 3 Impact of adaptation options on different farm types. *Source* Adapted from AgMIP (2017)

tageous to adopt the packages, increased crop production and integration with livestock, along with market improvement. Technically, climate change adaptation can substantially improve agricultural production, if inputs and services are given and coupled with market mechanism.

For extremely poor farmers, without livestock, promoting legumes was most important as a way to increase the net returns per unit farm land, balance the negative climate change effects on maize, and sustain nutrition. For poor (<8 cattle) and non-poor farmers (≥8 cattle) with the highest risk for cattle production converting land from maize to fodder legumes would counteract climate change impacts.

Agricultural Development Pathways

Development pathways project conditions to the future, where we can assess the impacts of climate change and adaptation under those conditions. Stakeholders and experts co-designed contrasting pathways that Zimbabwe could take: what if Zimbabwe followed a sustainable inclusive economic development, or alternatively what if a priority was given to an economic growth fossil fuel intensive pathway. Analysing these futures and likely impacts, what can we learn from the pathways and what measures can be taken to ensure sustainable development and climate mitigation and adaptation goals are achieved?

Figure 4 summarizes the economic impacts of the different pathways:

Green Road—Sustainable development: Investing in a sustainable future had clear advantages: inclusive markets and access to information created incentives for all farmers to invest; farmers set more land in value, diversified and intensified crops, increased herd sizes. Policies enabling infrastructure investment and development, human and institutional capacity, R&D, technical innovations and delivery services, were aligned to transform the agricultural sector.

Grey Road: Economic growth, fossil fuel intensive: This future reminded of the past, better-off large scale commercial farmers expanded and invested, whereas the many poor would rely on off-farm income, often become suppliers of cheap labour to agro-industries, and maintain small plots on for supplementary nutrition. Poverty and malnutrition increased. With low priority for environmental and social concerns, this resulted in reliance on natural resources, and caused widespread degradation.

In both futures, agricultural productivity increased substantially. However, it is important to highlight that the impacts of climate change on crops depend on soils fertility. Crop responses to climate change impacts were low on the nutrient depleted soils; yet grain yield reductions due to climate change were higher on better soils with higher nutrient supplies than on the poor soils. However, on better soils yields were higher even when reduced by climate change, as compared to poor soils, for all crops. Soil available water partially negated the negative impacts of increased temperature. Integrated soil fertility management with more organic inputs buffered and reduced the negative effects of climate change on crop production. There is hence

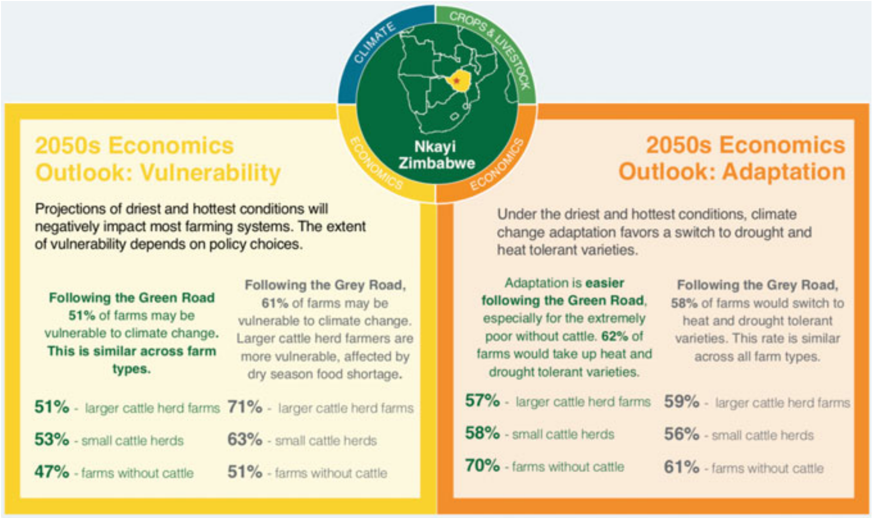

Fig. 4 Economic impacts of sustainable vs fast economic development. *Source* Adapted from AgMIP (2017)

need for holistic approaches that advance knowledge and learning about the multiple benefits and increase uptake of integrated soil fertility improvement.

Farmers with large cattle herds are most affected by climate change due to the effects of higher temperature on the biodiversity of rangelands as prime source of feed and the reduced feed quality. Supplementary feeding buffered the effects of climate change. The results highlight the utmost importance of creating decentralized feed and fodder markets, improving access to affordable stock-feed of high quality, while also investing in conservation of rangeland resources through economic incentives.

Given that in these futures agricultural productivity would increase substantially as result of more drastic agricultural investment programs, dealing with improved soil productivity and livestock feed, the main issue for climate change adaptation would be to switch to heat and drought tolerant varieties. Heat and drought tolerant varieties would benefit more under the sustainable future, and the poorest farmers would benefit more in relative terms. This is a strong argument for crop improvement programs to engage in within consultative approaches, targeting climate change and specific user needs.

An important observation was that where poverty rates are high like in the case of Nkayi district, following the sustainable development road can reduce vulnerability and half poverty by 2050. This can result in lower vulnerability and poverty, and greater benefits from adaptation, especially for the extremely poor. Investment in sustainable development supported gender equity, food security, nutrition priorities. Under the economic growth road, vulnerability would remain higher; farmers with large herds were stricken most by feed gaps. Investment in sustainable development hence paid off, it was less risky and better for the poor.

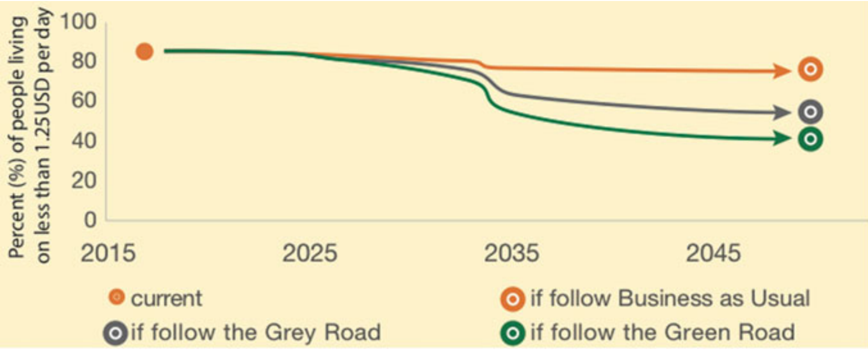

Fig. 5 Impact on poverty reduction following different development pathways. *Source* Homann-KeeTui et al. (2018)

The results also indicate that in either sustainable development or high economic growth pathway, a large proportion of farmers would remain below poverty line (Fig. 5). This means that by all means future agricultural and climate change programs have to cater better for the extremely poor. This involves creating off-farm income options, e.g. in decentralized agricultural input and output services, and improving the access to affordable nutrition and health services, to buffer their vulnerability to climate change impacts.

Discussion and Conclusions

Development Pathwaysand Trade-Offs to Support Climate Change Initiatives and Action

The strength of co-creating agricultural development pathways lies in the integration of science and stakeholder-based knowledge that yields information that enables priority setting and support to decision-making processes (Valdivia et al. 2020). Consequences of development pathways can be quantified to identify trade-offs and synergies between socio-economic and environmental outcomes. Accounting for these dimensions and complexities can accelerate transformation to sustainability (Antle and Valdivia 2020b).

Results from this study can motivate an informed dialogue through broad collaboration and engaging a broad range of stakeholders when developing national plans and help to tighten the measures required to move up from business as usual towards a sustainable development pathway (Berkes 2009; Garrett et al. 2017). The way knowledge is produced, prospective action and policy packages evaluated through ex ante impact assessments with stakeholders and experts, influences how it can serve national purposes and guide climate adaptation planning.

A major challenge lies in the availability and coordination of data that are relevant for decisions at national level and for particular farming systems. The scenario approach integrates information about farming systems and how they respond similar to climate change, at the level where climate change and adaptation happen. The learning process with local stakeholders and experts in the analyses of modeling results, can inform scaling of adaptation strategies (Holman et al. 2019).

Lessons from Using Development Pathways for Informing Adaptation Decisions

Integrated assessment approaches as shared in this chapter, development pathways with multi-disciplinary simulation models and tools, can lead to informed decision and actions, to more resilient futures for agriculture (Dimes et al. 2009; Whitbread et al. 2010, Antle and Valdivia 2020a). They help to understand how food systems might adjust in future to achieves social and environmental goods and goals, how shocks could impact those systems, and where interventions would need to set in. However, to convert modeling to action there is also need to understand what road blocks prevent using the information. For instance linear paradigms towards food security might prevent wider societal goals such as gender equity, food justice or shaping a change in attitudes towards the environment. There are also important dimensions that are not yet sufficiently being addressed, for instance, how gender, indigenous knowledge and wider environmental implications can be incorporated (Dube et al. 2017).

As much as modeling exercises have demonstrated that interventions, such as adaptation packages, can reduce yield gaps and poverty levels, the question is why these have not been implemented. One important insight was that for the many farmers at rock bottom poor state, limited yield response locked these farms at low productivity; improved management to amend poor soils is most imperative for them (Tittonell et al. 2010). Understanding the interplay between higher level and local-level drivers is critically important for developing sustainable adaptation options. Consistency between national level policy formulation and local level implementation could address some of the institutional and structural barriers to improve farming systems.

Capacitation of national staff in climate modeling and scenarios development, broadening the use of these approaches, and the learning from application and validation would be an important attribution to support national climate adaptation plans.

Priorities for Policy Support

Stakeholder and expert reflections around these pathways created urgency for policy support:

- **Building adaptive capacity**: Consultative, decentralized policies need to be implemented in a context of improved human and social capital. Infrastructure development, including seed systems and market access, ITC for digitalizing agriculture and early warning systems, are critical investments to help the high and increasing number of vulnerable smallholder farmers to adapt to climate variability and change. Considering the role women have to play in decision processes, establishing equal control over production factors remains critical; positive impacts on food security and nutrition to be expected.
- **Integrated soil fertility amendment**: Given the high risk particularly in drylands, and the need to regenerate depleted soils, promoting farmer practices of organic soil improvements and integration of crops and livestock seemed to pay off more than high levels of inorganic fertilizer. Agro-ecological approaches for enhanced soil quality would go along with crop improvement for varieties to respond to user demands, and being drought and heat tolerant.
- **Feed and fodder production**: Climate change impacts on those farmers with many cattle highlighted risks that can be mitigated through proactive promotion of feed and fodder technologies (seed availability, mechanization, decentralized feed and fodder processing and market units).
- **Revitalization of food and feed legume value chains:** Especially poor household increased their farm net returns and improved nutrition benefits through legume expansion. Considering that legume value chains have been dilapidated, ensuring functional and safe legume seed systems, production, and grain production to marketing directly benefits rural communities.
- **Confidence in promoting small grain value chains:** As drought and heat tolerant crops, nutrition dense staple, with potential strong response to management improvement, investment in production to processing technologies likely impacts rural communities positively.

Upscaling Using Agro-Similarity Approaches

An important challenge is leveraging on the uptake of technologies and caters for most critical bottleneck situations. There is need to delineate predominant farming systems for which climate impacts are similar and for which similar development pathways would be relevant. As work in process, AgMIP is working on an agro-ecological similarity approach. It maps out the distribution of most critical climate change indicators, where climatic pressure on farming systems is likely to pan-out. This involves the responsiveness of soils to climate impacts under soil fertility improvement, and the conditions under which climatic impacts would require a move towards diversified and nutrient-dense cropping systems. Complementary to the integrated assessments, this will help to identify zones of highest priority for investment in adaptation to climate change, e.g. hot spots of feed shortages, critical changes in agro-biodiversity, and bottlenecks for increasing systems productivity.

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Role of Soil Survey and Soil Testing for Agricultural Development in Zimbabwe

Misi Amos Manyanga, Emmanuel Chikwari, and Tonny Phirilani Tauro

Abstract Land productivity of smallholder farming systems is determined by underlining pedological characteristics and soil fertility status. Understanding relationship between soil survey, irrigated land use, soil testing, water testing and irrigation is critical in developing strategies for increasing crop production in Zimbabwe. Soil survey involves understanding of soil formation, site characteristics, soil chemical properties and physical properties and limitations, which are critical for scientific land use planning such as irrigation development for crop production and achieving higher water productivity. Water quality analysis is necessary to reduce risks of water induced soil degradation and fertility problems. Soil testing determines nutrient-supplying power of a soil for crop production while reducing the risk of nutrient mining and soil degradation. A desktop study of available data was conducted to evaluate the trends in soil survey and soil testing in Zimbabwe and to identify problems in pedological and nutritional analysis. Several cases have been noted in which crop production enterprises especially under irrigation schemes and in greenhouses have been initiated without soil background information. The number of soil surveys within Chemistry and Soil Research Institute conducted has been declining since 2000. Consequently, the following soil problems were observed at different irrigation schemes. These include heavy metals toxicity, poor drainage, crusting, salinity, acidity and shallow soil depth. Furthermore, in some cases water being used for irrigation was found to cause salts accumulation, for example at Musikavanhu irrigation scheme. Cost of pedological and nutritional analysis, plus lack of knowledge on their importance are major reasons for decline in requests for soil survey and testing. There is need for soil survey and testing for all agricultural projects to ensure improved food security.

M. A. Manyanga (✉)
Great Zimbabwe, School of Agriculture, Department of Soil and Plant Sciences, P.O. Box 1235, Masvingo, Zimbabwe

E. Chikwari
Chemistry and Soil Research Institute, Department of Research and Specialist Services, Fifth Street Extension, P.O. Box CY550, Causeway, Harare, Zimbabwe

T. P. Tauro
Department of Natural Resources Management, Marondera University of Agricultural Sciences & Technology, P.O. Box 35, Marondera, Zimbabwe

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To improve utilization of land resource, there is need to put in place an agricultural development policy guided by an Act of paliament which will make it mandatory to carry out soil survey and soil testing for individuals and or institutions who envisage utilising land for agricultural development.

Keywords Soil survey · Soil testing · Crop production · Food security

Introduction

Household food security is mostly dependent on maize production and productivity since it is a widely grown crop in Zimbabwe and other parts of Sub-Saharan Africa. Unfortunately, maize yields in Zimbabwe have remained <1 t ha^{-1}, (Gotosa et al. 2021) threatening household food security for over 70% of the rural population primarily drawing their livelihoods from agriculture (Smaling et al. 1997). Apart from soil nutrient deficiences, unavailability of mineral fertilizers and suitable crop varieties at affordable prices, most of the farmers are not adopting improved varities and nutrient managment practices for inherently low fertile soils in low rainfall areas (Mapfumo and Giller 2001; Nyakanda et al. 2002). In the face of climate change impacts due to increasing temperatures, inter and intraseasonal rainfall variability, decrease in annual rainfall and long dry spells, food security is likely to be affected (IPCC 2013). This necessitates to find out alternative ways and strategies to improve crop production to achieve food security in Zimbabwe.

Irrigation development is one of the key options for enhancing agricultural production and to achieve food security. However, for successful implementation of irrigation schemes a number of prerequisites such as availability of adequate water, suitable soils for irrigation, and skilled personel are to be met. According to Manzungu (1995), Mutambara irrigation scheme, the oldest smallholder irrigation project, was developed mainly due to abundance of water and initiative of the farmers following a severe famine of 1912. As such most irrigation schemes in Zimbabwe are proposed and or established near dams and rivers. With increasing need for food, some irrigation systems use ground water in some parts of Zimbabwe. Besides availability, water should of be of high quality otherwise it can cause soil salinity (Nyapwere et al. 2018) which inturn affects crop production.

To understand the suitability of a piece of land, suitability for irrigation, a soil survey must be conducted prior to project development. Knowledge of soil types and their characteristics is important for taking up sustainable land-use management decisions (Brevik et al. 2017) and Pereira et al. 2017). In Zimbabwe, the need to apply such knowledge led to the establishment of a Pedolgy and Soil Survey section (P&SS) within the Chemistry and Soil Research Insititute (CSRI). Apart from P&SS who are mandated to conduct national soil surveys, universities with soil science departments and private consultants with the requisite experience also conduct soil surveys in Zimbabwe. However, CSRI is the main soils referal centre storing most of the available data in their archives. The Zimbabwean approach for soil survey work utilises the Zimbabwe soil classification system that is mainly based on parent material with four taxonomic levels influenced by degree of weathering and leaching. The system goes on to identify the soil in its respective group out of the eight, based on clay activity and soil chemistry influenced by the weathering and leaching processes. World Reference Soil Base (WRB 2014) classification system is also used in the classification process in order to harmise with international systems.

The guidelines by Bennet (1985) are utilized during land capability assessment for irrigation development. In addition to checking for the suitability of the soil for irrigation, water is also analysed as outlined by Tauro et al. (2011). This is required in order to reduce soil degradation as a result of irrigation with salty water. The final report will combine field soil mapping report, pedological analytical and water analysis results to provide soil classification, irrigability classes, water quality assessment and a map for the survey area (Manyanga and Chikwari 2019). Soil maps include information on the most relevant physical and chemical soil properties in order to meet the demands of site-specific land use and management (Geitner et al. 2017). To achieve best management recommendations, soil fertility aspects need to be combined with pedological soil characteristics obtained from soil surveys.

Therefore, to understand the fertility status represantative soil samples have to be collected from fields for chemical analysis. Chemistry and Soil Research Insititute provides national soil testing and advisory services to farmers throughout Zimbabwe. Integrating soil analysis report and soil survey report might be a solution to various challenges being faced in soil fertility related problems under rainfed and irrigated soils in the country. However, utilisation of this government service by famers still remains very low. Information on soils is critical for a wide range of land-use planning and management activities that aim to be sustainable and resource efficient (Geitner et al. 2017).There is need for effective dissemination of soil resources information to benefit the farmers across the country. This desktop study aimed to (i) assess the demand and importance of soil survey and soil testing services (ii) identify potential threat and risks of undermining soil survey and testing services in relation to national food secuirty (iii) chat way foward for sustainable agricultural development and improving food secuity in Zimbabwe.

Materials and Methods

Data used for this desktop study was collected from various soil surveys, soil testing reports and records from CSRI and other literature. CSRI has three sections namely Pedology and Soil Survey section (PSS), Crop Nutrion section (CNS) and Soil Productivity Research Laboratory section (SPRL). Crop Nutrition section is mandated to provide soil testing servces to advice on lime and fertilizer recommendations to farmers, researchers and a wide range of other stakeholders. It also diagnoses plant nutrient deficiencies by analyzing foliar samples for all crops. The section houses laboratories which analyze soil samples for nitrogen, phosphorous and bases (calcium, magnesium and potasium) as well as pH.

PSS carries out soil surveys for agricultural development, land use planning and natural resource assessment. The information gathered is used for developmental purposes such as irrigation, forestry, national parks and other developmental work. Pedology and Soil Survey section also provides advisory assistance for soil related problems such as land reclamation and management of problem soils including sodic and saline soils. It endeavours to map out all the soils in Zimbabwe including land use capability evaluation and classification. The soil survey work is complimented by the Soil Chemistry and Physics laboratories that analyse the soil as well as the Geographical Information systems unit that manipulates data for map production and database development.

Results

Need for More Soil Surveys

An analysis of the numbers of samples being submitted for soil and pedological analysis shows that since the begining of the twentieth century, few soil samples are being analysed. Given that agriculture plays a critical role in the economy of Zimbabwe this is a worrying trend. Clearly there is need for more soil surveys and mapping to better inform farmers on best farm sites that are productive in order to optimise production. There is dire need for extensive mapping of Zimbabwean soils. This would culminate in development of a national soil information ssystem, a key development for offering effective advisory services.

Cases of Soil Fertility and Other Soils Related Problems Identified in Different Areas

Following a soil survey done at an already established Bannockburn irrigation scheme, soils in some parts of the area were found to be ultramafic. These have an inverse calcium to magnesium ratio (Table 1). The effects of this problem were evident as shown by the poor maize crop planted before a soil survey was done on the irrigation scheme. These soils were found to have the following limitations: (a) inverse calcium (Ca): magnesium (Mg) ratios, (b) high nickel (Ni) and cadmium (Cd) contents, (Table 1.) (c) very low concentrations of macro nutrients (N, P, K), (d) management problems (drainage and trafficability) (Table 2) and (e) shallow soils.

Soils in the areas from the Tonhorai, Gudyanga, Maunganidze and Musikavanhu B irrigation schemes (Nyapwere et al. 2018) were also found to have salinity problems mostly due to use of saline irrigation water as well as surface sealing which resulted in gradual yield decrease in different crops grown as reported by affected farmers. In some parts of the fields, accumulated salts could visually be observed on soil

Table 1 Soil problems at some existing and proposed irrigation scheme sites in Zimbabwe

Name of irrigation scheme or site	Total area (ha)	Area affected by limitation (ha)	Main limitation	Sources
Bannockburn-Zvishavane	450	435	Inverse Ca:Mg	Munjonji et al. (2006)
	450	96	High Ni and Cd	
Bruton Chipa	1067	211	Severe surface capping	Gotosa et al. (2003)
Mundi-Mataga-Zvishavane	126	ND	Poor drainage	Nyapwere and Manyanga (2011)
Musikavanhu-Chipinge	1300	205	Water induced salinity	Nyapwere et al. (2018)
Mabwematema-Zvishavane	350	12	Sodicity	Manyanga et al. (2016)
Kanyemba-Dande	280	200	Sodicity	Manyanga et al. (2019)
Rupangwana-Chiredzi	130	75	Extremely shallow soil depth	Manyanga et al. (2018)

ND means total area not determined

Table 2 Heavy metal and Ca:Mg ratios of selected sites at Bannockburn (Mhondongori) Irrigation scheme

Profile	Soil depth (cm)	Ca:Mg ratio	Nickel (ppm)	Cadmium (ppm)
26/ZZ/06	0–23	0.7:3.4	146	10
27/ZZ/06	0–23	2.4:7.2	114	10
28/ZZ/06	0–19	1.8:3.2	170	8
29/ZZ/06	0–22	7:22	240	8

Source Soils of the proposed Bannockburn (Mhondongori) Irrigation Project, Report No. A684

surface. Salt accumulation could also be due to the fact that most irrigation schemes are found in dry regions where salts often tend to concentrate in the root zone due to high evapotranspiration. In areas with surface salts, the leaves of crops are dying back and stunted. Soil crusting observed at Bruton Chipa irrigation scheme resulted in poor crop emergence leading to poor crop establishment (Manyevere et al. 2015). Another major soil problem was sodicity which was observed at the proposed Mabwematema irrigation scheme in Zvishavane with exchangeable sodium percent (ESP) ranging between 36 and 70% (Manyanga et al. 2016), parts of Musikavanhu irrigation scheme where ESP was between 10 and 20% (Nyapwere et al. 2018) and also in almost all of the proposed Kanyemba irrigation scheme soils (Manyanga and Chikwari 2019). For the established irrigation schemes such as Tonhorai, Gudyanga, Maunganidze and Musikavanhu B, the water was of high salinity with electrical conductivity ranging between 800 (microsiemens/cm) to 1700 (microsiemens/cm) (Nyapwere et al. 2018) (Table 2).

The problems of soils in most of the farms were related to soil acidity, acute nutrient deficiencies and inverse Ca:Mg ratio (Table 3). These problems were indentifed while making lime and fertilizer recommendations from submitted soil samples while others were from client requests linked to low productivity. Poor nodulation and growth of legumes, low fruiting of fruit tress, low and poor quality of the produce were some of the clients concerns in most field investigations that were initiated. Some farmers would over apply fertilizers with the hope of increasing crop productivity unaware of the actual limitations (Table 3). In most cases, most clients only visited CNS for consultation upon noticing problems in thier field following huge investments in time, labour and inputs (chemicals and fertilizers). However, in most cases the problems like soil acidity might not be corrected following crop establishment. The majority of cases with inverse Ca:Mg ratio (Table 3) were of soils found along the great dyke of Zimbawe which is also known to be rich in heavy metals (Munjonji et al. 2006).

Discussion

Soil survey is very important in identification, characterisation and classification, understanding of distribution and establishing relations between natural resources and soil for guidance in resource management (Dudal 1987). The most critical information gathered is on soil formation and the inherant soil status which is influenced by various soil forming factors and soil forming processes. This is critical in assigning the soils to their most suitable uses thereby preventing land degradation hence helping reduce problems such as poor drainage, heavy metal contamination, erosion and subsequently siltation of water bodies. Lack of knowledge on the importance of soil surveys among farmers, relatively higher costs of carrying out soil survey as well as ignorance by some decision makers are some of the reasons behind decrease in demand for soil surveys in Zimbabwe. Some decision makers within planning institutions leterally think soil surveys are not important hence the establishment of some agricultural developmental projects without soil surveys being done often with negative consequencies such as development of drainage problems and poor siting of some projects. Soil surveys help identify some of the potential problems of soils and ensure informed decisions for land development.

High concentrations of heavy metals observed at Bannockburn irrigation scheme are related to the parent material since this scheme is situated along the Great dyke which is generaly rich in heavy metals. Parent material largely influences heavy metal content in many soil types, with concentration sometimes exceeding the critical

Table 3 Selected sites with various soil fertility problems

Name of site or farm or source	Affected crop at the site	pH (CaCl)	After incubation N (ppm)	Available P (ppm)	Exchangeable cations Mg equivalents/100 g			Main limitation
					K	Ca	Mg	
CSRI 40/SQ (Nyamadzawo farm, 2016)	Maize	3.8	69	187	0.08	0.53	0.22	Soil acidity
CSRI (Mudau farm, 2006)	Soyabean	3.5–4.2						Soil acidity
CSRI (Kamunda investment, Block A, 2007)	Peach	4.0	78	198	0.62	2.43	1.04	Soil acidity
CSRI (Dunmangalss farm, Land 1, Tauro et al., 2010)	Most crops	4.7	47.2	37.8	0.46	13.94	5.24	Parent material induced soil acidity
CSRI (Dodhill Horticulture, A, 2010)	Vegetables	5.2		1	0.25	5.61	5.50	Acute P deficiency
CSRI (Matlala FARM, F3 C.M.M, 2014)	Most crops	5.6	10	3	0.08	3.98	14.34	Acute P deficiency and inverse Ca:Mg
CSRI (Matlala farm, F4 C, 2014)	Most crops	7.2	7	7	0.05	0.95	21.38	Acute P deficiency and inverse Ca:Mg
CSRI (Sigauke farm, Sample 2 (west), 2012)	Most crops	4.3	29	2	0.14	2.21	2.35	Soil acidity and acute P deficiency
CSRI (Mazibuko farm, 2/RN, 2009)	Most crops	5.3	58	7	0.10	2.61	13.49	Acute P deficiency and inverse Ca:Mg
CSRI (Runyemba farm, 80/SQ, 2012)	Most crops	3.8	21	6	0,0.10	0.77	0.47	Soil acidity and acute P deficiency

(continued)

Table 3 (continued)

Name of site or farm or source	Affected crop at the site	pH (CaCl)	After incubation N (ppm)	Available P (ppm)	Exchangeable cations Mg equivalents/100 g			Main limitation
					K	Ca	Mg	
CSRI (Chako farm, Garden, 2008)	Vegetables	3.8	44	4	0.07	0.62	0.32	Soil acidity and acute P deficiency

values (Palumbo et al. 2000). At Bannockburn irrigation scheme Ni and Cd concentrations were higher than critical values. According to CCME (1999), maximum permissible limit of Ni in soil is 131.9 ppm whilst World Health Organization (WHO), Food and Agricultural Organization (FAO) and Ewers U, Standard Guidelines in Europe indicates 50 and 3 ug/g as maximum permissible limits of Ni and Cd respectively (Chiroma et al. 2014). Inverse Ca: Mg ratio is very much associated with high heavy metal concentration and it is a bigger problem when the ratio is less than or equal to 1:1. At this ratio there is magnesium toxicity and reduced uptake of calcium by plants. Heavy metals present in the soil environment pose serious ecological problems (Tandi et al. 2004; Aekola et al. 2008).

Soil crusting and surface sealing observed at Bruton–Chipa was largely influenced by soil structure as indicated by water stable aggregates, infiltration and, to a lesser extent, fine sand fraction, which is derived from weathering of the Zambezi metamorphic belt (Manyevere et al. 2015). According to Nyamapfene (1991), soil crusting and surface-sealing pose management and economic challenges to agriculture thus such soils can also be classified as problematic soils. Crusting can significantly reduce rate of water infiltration and crop emergence which negatively affect establishement and subsequent yields. Other problematic soils observed from different soil analysis and soil surveys are saline, alkaline, saline-sodic, and sodic soils. Saline soils affects osmotic potential of soils resulting in crops wilting even with enough moisture in the soil. Sodic soils have poor structure due to clay dispersion caused by sodium resulting in reduced water infiltration rate.

The knowledge of soil fertility status and nutrient management practices is importanat since they influence agricultural productivity with implications on food security and livelihoods of rural households (Mapfumo and Giller 2001). Soil testing helps farmers to obtain information on soil fertility levels which will help determine on the type and amount of fertilizers to apply. It is critical for farmers to fully understand the potential productivity and limitations of soils and take correct remedial action. Huge losses can be incured if a problem is noticed during the production cycle as some issues like pH correction are best managed before crop establishment while alternative options are expensive for smallholder farmers. Farmers have to simultaneously manage the soil not only to get the highest possible crop yields but also to maintain its long-term sustainability (Beringer 1985). This requires tools to effectively measure nutrient status in soil. According to Beringer (1985), soil and plant analysis are essential in predicting fertilizer requirements. For example soils with inverse Ca:Mg ratio less than or equal to 1:1 experience magnesium toxicity and reduced uptake of calcium by plants. McLean et al. (1983) showed that the Ca:Mg ratio alone does not affect crop yields but emphasis should be placed on supplying adequate and not excessive amounts of either of the nutrients. This would therefore require a robust soil analysis service. In Zimbabwe, low soil fertility is one of the major constraints in agricultural production. It is important to note that management of soil fertility was found to increase yields for example by 32% in cassava (Henry and Gottret 1996). Results from soil and plant analysis coupled with other factors help in improving crop production and productivity.

Most of soils of communal lands in Zimbawe are sandy with inherant low fertility resulting from differences in parent material and catenal position (Masvaya et al. 2010). Lack of appreciation of the importance of soil testing is one other factor affecting crop yields. Communal farmers in parts of the country are not aware of the benefits of soil testing compared to commercial farmers. Extension service has to be strengthened in order to be effective in helping farmers in soil soil sampling for routine soil analysis.

Lack of policy on soil survey and soil testing means project developers and farmers respectively are not obliged to do any before initiating their projects. However, failing to manage soils will foster low output and low return of any agricultural investment. On the other hand, some developers want their projects to be commissioned without doing proper checks on soil properties which have an impact on the sustainability of such projects. Irrigation schemes are the worst affected projects as their failure impact heavily on food security at household and natioanal level.

Way Foward

It is encouraging to note that the Ministry of Lands, Agriculture, Fisheries, Water and Rural Resettlement is raising awareness on soil sampling and analysis in its Agricultural Recovery Plan. Such a positive initiative will ensure sustained agricultural productivity and production for improved national food security. There is need for policy formulation and an Act of Paliament on agricultural land use which will make it mandatory for farmers or any organisation to have their land surveyed and/or soils tested for sustainable agricultural development. There is need for national soil mapping to obtain soils information for developing a national soil information service. Such proper planning will help in reductution of land degradation. For farmers to appreciate the importance of soil survey and soil testing, there is need for information dissemination most critically through establishing farmer learning schools and demonstration sites across the country. Another way of information dissemination is through awareness programmes on both print and electronic media. Through these farmers will have practical exposure and appreciate importance of soil testing and soil fertility management.

Conclusion

The diverse soil chemical and physical problems associated with most of agricultural projects developed in Zimbabwe highlight the importance of carrying out soil survey and soil testing for effective utilization of soil resources. Soil survey ensures that soils are put to the most suitable uses thereby helping prevent and or reduce soil degradation due to poor land use. Soil and land use survey gives critical inputs to the policy makers. For most effective and efficient fertilizer use, soils should be tested for fertility and balanced nutrition, optimum crop yields and environmental protection. Soil surveys must be carried out before any land is used for agricultural purposes. Soil surveys are also important for soil resource information such as kinds and extent of land degradation and soil processes in climate change impact perspectives, sustainable land use planning and developing climate change adaptation and mitigation strategies. There is need for an agricultural development policy guided by an Act of paliament which will make it mandatory to carry out soil survey and soil testing for all agricultural projects.

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Potential Blue Zone Status of the Dryland Area of Buhera District in Zimbabwe: Development of a Hypothesis

I. Nyambiya

Abstract Science has shown that the damage to our DNA happens especially because of the lack of micronutrients such as minerals caused by eating devitalised food hence the existence of low life expectancy in most of Africa. This hypothesis suggests that inspite of the Buhera district being in the agro-ecological region V of Zimbabwe which is a dryland region; the people in that area seem to live the longest when compared to the rest of the country. It is postulated here that this might be because of the practice of dryland agriculture in certain sections of Buhera South where dryland traditional crops and grains such as sorghum, millet and Bambara nuts are grown and consumed. Additionally, the people in the region have adapted to the consumption of drought resistant traditional fruits such as baobab and marula which are endemic to that region. Observational studies and informal discussions with some residents of Buhera conducted over a period of five years suggest that the longevity of residents could be influenced by the consumption of a traditional diet of these nutrient dense traditional foods. This hypothesis awaits systematic study and validation of all the parameters which contribute to a region being labelled a blue zone. This subject is important to implement health reforms, combat diseases, and improve quality of life of the people.

Keywords Blue zone · Dry region · Millets · Sorghum · Buhera · Quality life · Health reform

Introduction

Zimbabwe is a semi-arid country (Government of Zimbabwe 1998) comprising some regions which are drier than others and as such has been divided into five agro-ecological regions of I–V, with the later receiving the least rainfall (Chikodzi et al.

I. Nyambiya (✉)
School of Natural Sciences, Great Zimbabwe University, Off Old Great Zimbabwe Road Box, 1235 Masvingo, Zimbabwe
e-mail: inyambiya@gzu.ac.zw

X. Poshiwa and G. Ravindra Chary (eds.), *Climate Change Adaptations in Dryland Agriculture in Semi-Arid Areas*, https://doi.org/10.1007/978-981-16-7861-5_15

2013). About 41% of the world's landmass is covered by drylands which feed an estimated 2 billion people (Solh and Van Ginkel 2014).

Buhera located in the eastern part of Zimbabwe is the largest district in the country and is classified in the Natural Regions III, IV and V (Mvumi et al. 1998) with temperatures reaching as high as 40 °C and annual rainfall between 400 and 600 mm (Lindahl and Matenga 1995). It is a dryland region where drought tolerant crops such as pearl millet *(Pennisetum glaucum),* finger millet *(Eleusine coracana L.),* sorghum (Sorghum bivulgare) and Bambara (*Vigna subterranea* (L.) Verdc.) nuts have been successfully cultivated as a mitigation strategy against droughts and climate change (Wood et al. 1996) compared to other food crops such as maize *(Zea mays* L.) which are less drought tolerant.

Indigenous fruits found in this region include baobab *(Adansonia digitata L),* *m*arula *(Sclerocarya birrea)* and African Snot apple (*Azanza garckeana*) tree which have been successfully adapted for diet and other non-food uses such as traditional medicines and production of commercial household artefacts like mats (Kozanayi 2018). Concomitantly it has been observed that some residents of Buhera seem to live a longer life, with a recorded case of 107 years. Research on the topic of blue zones, the areas of the world where people live the longest suggests that 80% of a person's longevity of life is influenced by their lifestyle and environmental factors than their genetic make-up (Buettner and Skemp 2016) as also revealed by a Danish Twin Study (Herskind et al. 1996). Lifestyle medicine which includes the use of a correct diet has been touted as the next frontier for treatments of disease and improving human health (Bodai et al. 2017).

In this context, a preliminary investigation was carried out to understand the phenomenon of the unusual longevity of life in the Buhera district of Zimbabwe in the counter-intuitive background of Buhera being a poor and a dryland region compounded by Zimbabwe being classified as one of the low income countries in the world (Celik et al. 2019). The reliance of the residents of Buhera on small grains from crops which are drought tolerant in an arid and semi-arid environments, wild indigenous fruits and indigenous leafy green vegetables which are endemic to the regions and have a micronutrient-dense profile is suggested as one of the reasons for a possible blue zone phenomenon in this region.

Literature Review

Climate Change Adaptability

The people who live in the arid and semi-arid regions of Zimbabwe and depend on rainfed agriculture have recognised the adverse phenomenon of climate change and variability prompting active responses to mitigate against these events (Bhatasara 2015). There is also consensus that sub-Sahara Africa is increasingly more impacted by climate change because of reduced capacity for mitigation due to poverty and poor governance systems among other constraints (Manyani 2017). Buhera is considered as one of the poorest districts of the country excercebated by the unfavorable climatic conditions which have prompted some development agencies to seek ways for on-going active involvement in the region beyond just providing food aid. (Mafuta and Kamuzhanje 2020).

A range of mitigation strategies have been demostrated to work globally for improving livelihoods in dryland areas especially as these regions are impacted upon by the effects of climate change (Kumar et al. 2019). Methods for mitigation which include *in-situ* water harvesting have been practiced in dryland areas such as Gwanda in Zimbabwe (Munamati et al. 2009). A myriad of coping mechanisms practiced in other regions of Zimbabwe include cultivating drought tolerant crops coupled with diversification, and consumption of cereals and endemic wild fruits (Campbell 1987) within dryland regions such as Zambezi valley (Mavhura et al. 2015). Investigations have also revealed that the use of organic manures, inorganic fertilizers and crop rotation with leguminous crops followed by sorghum can help improve the yields for the small grain crops (Ncube 2007). In Malawi for instance, the baobab fruit, a dryland fruit tree has been used as a supplemenary food during periods of scarcity (Darr et al. 2020), whilst in the lowveld south east of Zimbabwe, another arid part of the country, the processing of baobab fruits, leaves and fibre has been used to combat the effects of poverty (Mugangavari 2019).

Ironically, in some dryland parts of Zimbabwe, the communities worst affected by climate change have shifted to the cultivation of crops such as maize (Murungweni et al. 2016) while the communities in drought-prone regions like Mutoko have resorted to the cultivation of sorghum and millets along with practising adaptation strategies such as mulching, creating walls on river banks as well as better facilities for food storage (Mugambiwa 2018). Pearl millet is still largely grown in West Africa whilst maize has superseded the indigenous millets in Southern Africa because of the commercialization of maize (Azare et al. 2020).

Traditional Grains and Legume Cultivation

As a dryland region, Buhera is vulnerable to droughts which are becoming more frequent and thus affecting crop productivity (Mutasa 2010). The studies indicate that the region is among the top three districts in Zimbabwe with poor seasonal vegetation health index and an average of 6.84 drought events over the past 30 years (Frischen et al. 2020). Women are particularly affected in the district compounding a *status-quo* of poverty and prevalence of obstacles for livelihoods in a country where most subsistence farming is practiced by women (Maruzani 2014).

Millets are indigenous to Africa and have a better adaptability for arid and semi-arid regions with pearl millet now considered as the 6th most important grain globally (Garí 2002). These crops have been demonstrated to improve food security in Buhera and other dryland regions of Zimbabwe such as Mangwe in Matebeleland South (Muzerengi and Tirivangasi 2019). The profile of the crops which are grown in the

Manicaland province where all the natural ecological regions from I to V are found is given in Fig. 1 below (Chingarande et al. 2020). The dryland districts in this province are Buhera and Chipinge. There is a propensity by the dryland regions to grow sorghum, millet and cowpea all of which are drought tolerant crops. Whilst it has been shown that climate change is affecting the growth of crops such as maize, a preferred staple in Zimbabwe (Makadho 1996), sorghum and millet offer better alternatives because of their resilience to drought risk (Mukarumbwa and Mushunje 2010). In another study, Chikodzi notes that groundnuts followed by sorghum and lastly maize are least sensitive to climate variability which explains why there is preference for the small grains in Buhera (Chikodzi 2016). Other leguminous varieties such as cowpeas are also preferred in Buhera with higher tonnage in this district compared to the wetter districts of Chimanimani, Makoni, Mutasa and Nyanga which are in region I, II and III (Fig. 1). This is because cowpeas also have the capacity and ability to grow in challenging climatic conditions of water shortage coupled with sandy soils (Nkomo et al. 2020). The distribution of tonnage of the grains grown and harvested in Buhera: Whilst maize constitutes about 51% of the grain probably cultivated in the region III part of Buhera, the small grains and drought resistant legumes remain an important component for militating against the extreme climate conditions for regions IV and V of Buhera district (Fig. 2).

Bambara nuts (*Vigna subterranea* (L.) Verdc.) which originated in West Africa have also become a common cash crop in semi-arid regions of Africa including Zimbabwe because of its resistance to moisture compared to even sorghum another dryland crop (Hillocks et al. 2012). Villagers in the semi-arid Buhera have as such

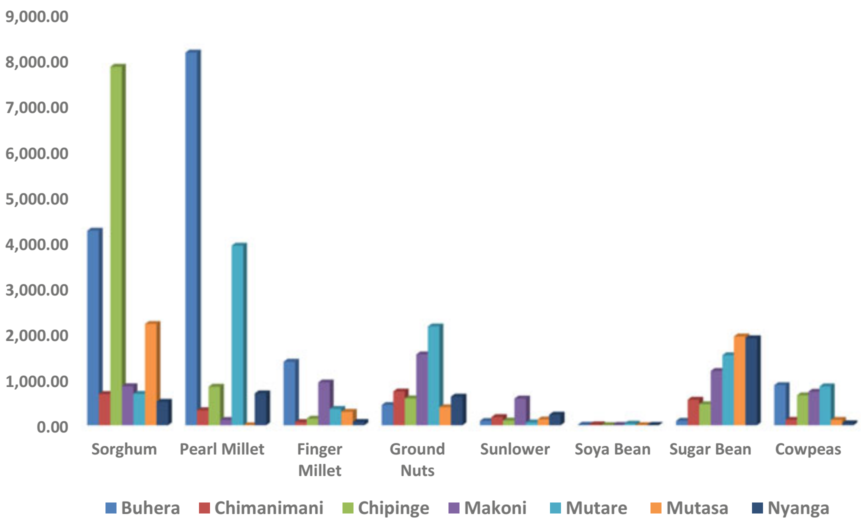

Fig. 1 Tonnage of harvested crops in 7 districts of Manicaland province where Buhera is located (original data obtained from USAID) (Chingarande et al. 2020)

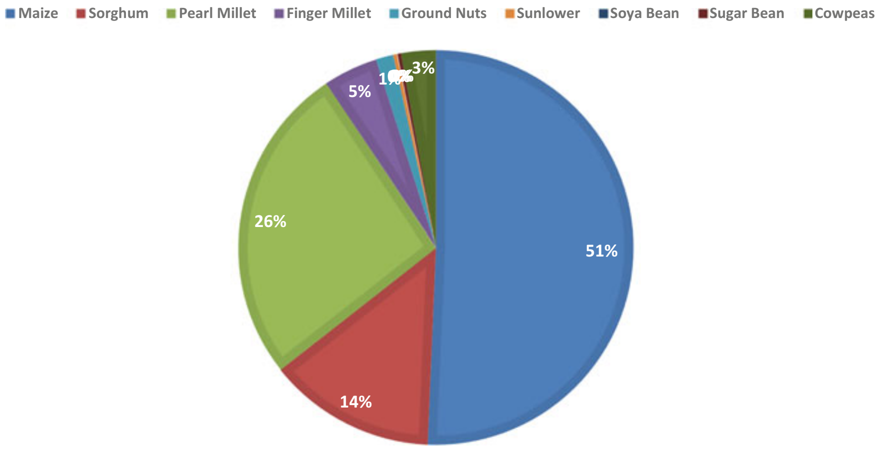

Fig. 2 The proportion of grain crops which were harvested in 2019 cropping season in Buhera (original data obtained from USAID) (Chingarande et al. 2020)

also resorted to the cultivation of Bambara nuts for its nutritive value where other sources of protein are low (Mubaiwa et al. 2018).

Though pearl millet, finger millet and sorghum are the crops which are grown successfully under rainfed in Buhera (Lindahl and Matenga 1995), there is a resistance by smallholder farmers for cultivation of these crops due to the perception that these crops need high labour, vulnerable to bird pests such as quelea (Phiri et al. 2019).

The Use of Green Leafy Vegetables

Studies reveal that 92% damage to our DNA happens especially because of the lack of micronutrients such as minerals caused by eating devitalised food (Ames 2006) and the lack of consumption of leafy greens (Amazing Discoveries and O'Neill 2017) and hence the existence of low life expectancy in most of Africa and in other regions of the world. About 40 micronutrients are required by the human body, deficiency of which may lead to DNA damage which triggers chronic disease (Ames 2001). For instance selenium as a nutrient is needed for DNA repair (Bera et al. 2013) and as such strong associations (Tang et al. 2008) have been established between the pathogenesis of diseases, morbidity and mortality, and the inclusion or lack thereof of vegetables and fruits in diet (Collins et al. 2012). These articles of food which are micronutrients and mineral dense. Minerals are important for several structural and physiological functions (Soetan et al. 2010) in the human body particularly to prevent chronic conditions such as cancer. The residents of Buhera are known to supplement their diet with the consumption of wildgreen leafy vegetables from such plants as cat's whiskers *(Cleome gynandra)*, smooth pigweed *(Amaranthus hybridus)*, baobab *(Adansonia digitata),* black jack (*Bidens Pilosa*) which have been found to have a better nutritional content that the conventional non-indigenous varieties such as spinach and lettuce (Chipurura et al. 2013; Muchuweti et al. 2009). Villagers in Buhera are well versed in the processing of indigenous vegetables for sale to traders (Mukwereza 2002). The care should be taken not to overcook since it reduces the nutritional quality of these vegetables (Chipurura 2010).

Water Conservation Systems

Because of the erratic rainfall pattern in Buhera district, villagers have resorted to water harvesting techniques to the extent that 72.9% of water in Buhera is obtained from wells whilst boreholes constitute 21.6% where there is no canal water irrigation to support rain-fed agriculture (UNESCO & Ministry of Lands AgricultureWater and Rural Resettlement 2019). Farmers have also resorted to the use of shallow hoe-dug furrows for planting small grains like sorghum in Buhera without prior ripping and ploughing as a method to manage soil moisture content (Zimbabwe Conservation Agriculture Task Force 2009). In drylands of Chiredzi the yield of pearl millet increased from 1.67 to 3.29 t/ha, hence shift towards climate-smart agricultural practices in uplands and wetlands may be promoted (Murungweni et al. 2016). In collaboration with international agencies, the local people have been able to grow exotic vegetables such as kale and cabbage in trenches loaded with manure while the soil from the trenches was used to grow potatoes, beans and other legumes whilst making sure to use crop residues from other crops like maize and sorghum to retain moisture and for weed management (USAID 2017).

Bioprocessing

The processing of crops as an indigenous heritage in Buhera reveals how its citizens have adjusted to living in one of the hottest regions of Zimbabwe. For instance, Bambara nuts are not only grown as a cash-crop for local consumption and also export sales in Buhera. The residents have adapted this hard-to-cook legume (Mubaiwa 2018) for easy consumption by soaking and sometimes grinding and milling before cooking it into a snack used as replacement for starchy foods (Hillocks et al. 2012). The use of a rock salts called *gowa* sourced from Buhera including sodium hydrogen carbonate at an experimental level by some researchers suggest that such methods might have been practiced in Buhera (Mubaiwa et al. 2019).

The Use of Traditional Fruits

The additional advantage of Buhera district is that it is home to endemic species of indigenous fruit trees unique only to this region including the marula, baobab, snot apples, wild grapes among others (Shava and Garden 2005). Since many years, the residents from and around Buhera have used the ancient Baobab tree to make products such as salt-containers called *gumbu* (Kozanayi et al. 2014) and other non-food item including mats. The use of baobab which is indigenous to Africa (Rahul et al. 2015) includes exploitation of its dried fruit pulp and leaves in Buhera and this is partuclualy important as the fruit can be stored for a long time and as such an important source of nutrients such as potassium (Chipurura 2010) and vitamin C (Mpofu et al. 2014). *Mutandabota*, a local probiotic made out of baobab pulp contains milk up to 79% (Anita et al. 2014; Mpofu 2015; Mpofu et al. 2014, 2016) is also consumed in Buhera even though no documented work can be found concerning its bioprocessing and value addition practiced in Buhera.

The Marula (*Sclerocarya birrea* subsp. *caffra*) is a sub Saharan (Sinthumule and Mashau 2019) tree which is capable of surviving in the marginal areas such as Buhera has also been used as adaptation strategy by harvesting its fruits and non-edible parts. Although the research information on this in Buhera is not available, villagers are known to mix marula juice, baobab pulp and millet flower to prepare a fermented non-alcoholic beverage safe for consumption by pregnant mothers and children (Nyambiya 2020b). Residents in Buhera have subsisted on wild fruits such as Hanza (*Boscia senegalensis), Indian plum (Ziziphuis Mauritania), Jiga tree (Maerua crassifolia)* and the fresh fruits of Sugar plum (*Uapaca Kirkiana) which* have been known to supplement food reserves during the lean months in Buhera just before the onset of rains.

Potential Blue Zone Status

The informal observational studies seem to suggest a relatively longer longevity index for some residents in the Buhera district; this needs a systematic study of the demographics of the region, the food security analysis especially with regards to the consumptions of "small" or traditional grains and indigenous fruits upon which this hypothesis depends. The global burden of disease resulting in early mortality (Lopez et al. 2002) is directly correlated with lifestyles (Hurst and Siddharthan 2020) even now in Africa (Zumla et al. 2015) where statistics of lifestyle diseases such as obesity, heart disease and diabetes are increasing as in the rest of the world.

Five regions around the world have been designated as Blue Zones (Buettner & Skemp), meaning they possess the largest number of people who live the longest because of their lifestyle which forms part of the environmental factors that affect longevity of life (Poulain et al. 2004) and perhaps because of genetic factors. None of these regions are in Africa and to the best of the author's knowledge no suggestions or systematic studies have been done where longevity factors have been observed. These areas are Loma Linda in California where the Seventh Day Adventists practice the eight laws of health (Kent 2017) particularly a plant based diet (Snowdon and Phillips 1985) to prevent disease (Fraser 1999; Girko 2016) and stay healthy from non-communicable diseases (Kim et al. 2018). The residents of Okinawa in Japan are known to live longer (Willcox et al. 2008) because of a life of good diet and calorific restriction (Willcox et al. 2007) a practice called temperance in health reform (White 1949). The studies in Nikoya in Costa Rica and Ogliastr in Sardina regions, Italy have revealed a largely plant-based diet as positively correlated with the phenomenon of longevity of life in both regions (Nieddu et al. 2020). The residents of Ikaria in Greece also live longer (Chrysohoou et al. 2011; Stefanadis 2011) because of a Mediterranean type of diet (Lăcătușu et al. 2019) besides other factors. Lifestyle medicine for managing health and disease is now slowly entering into the public domain globally (Bodai et al. 2017) and it has been demonstrated through the very recent field of epigenetics (Moosavi and Ardekani 2016) that environmental factors such as diet through methylation at the gene level influence the emergence of disease even in monozygotic twins who are identical at the gene sequence level (Esteller 2008).

Methodology

The methodology involves hypothesis development based on the scientific method of enquiry (McLelland 2006) leaning heavily on the definition of a hypothesis as "an idea or postulate that must be phrased as a statement of fact, so that it can be subjected to falsification…constructed in advance of the experiment" (Glass and Hall 2008). Observational studies over a period of about five years (Nyambiya 2020a) seem to suggest that there is a relatively larger population of people who live beyond 80 years in Buhera (Nyambiya 2020b) which is counter-intuitive given that Buhera is one of the driest regions in the country and they are regarded as poor. Additionally, it also appears that the larger proportion of these individuals are women.

Regions of the world such as Nikoya in Costa Rica have revealed a similar phenomenon of poverty negatively correlated with longevity of life giving credence to the hypothesis that it is not necessarily wealth that leads to long term health (Rosero-Bixby 2008; Rosero-Bixby and Dow 2016). The observations made at a farm at which the author lived for about four years seem to suggest that rodents such as the African rat when naturally feeding have a preference for the so-called superfoods (See Fig. 3) in the order of linseed, millet, soybean ending with non-superfoods such as sugar-bean and maize (Nyambiya 2019). As such any regions of the world where these foods are preferred in greater proportion could contribute to a greater longevity index as found in the regions already studied deriving from their own unique circumstances.

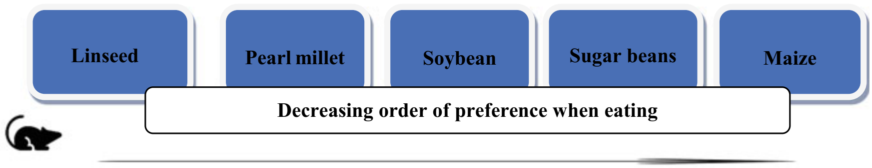

Fig. 3 Some feeding habits of the African rat

More animal studies can be performed to validate the claim for rodents having a "superior wisdom" of subsistence on crops which humans have chosen to have less regard for in spite of knowledge of their superior nutritional value.

The Hypothesis

This chapter proposes an hypothesis that there seems to be a larger proportion of Buheraeans living longer which could be their larger reliance on sorghum, pearl millet and finger millet as the staple food in their diet (Lindahl and Matenga 1995) given these crops' ability to thrive under hot and arid conditions (Padulosi et al. 2015) such as in Buhera (John Wood 2005). Millets are known to have good nutritional content which reduces oxidative stress or damage (Devi et al. 2014) the cause for premature aging. Research has demonstrated that foods like millets contain isoflavones including genistein (Russin et al., 2006) essential for reducing inflammation (Yu et al. 2016) associated with reactive oxygen species (ROS). The oxidative stress hypothesis posits that the continual loss of bodily and organ function and vitality due to the accumulation of ROS (Liguori et al. 2018) leads to disease and death which can be countered by a supply of antioxidants found in appropriate plant based-based diets (Madigan and Karhu 2018) from crops such as millets (Devi et al. 2014; A. Kumar et al. 2018; Nani et al. 2015; Saleh et al. 2013), linseed (Ayelign and Alemu 2016; Goyal et al. 2014; Kajla et al. 2015; Mishra 2013; Garnorka & Jain 2013) and polyphenol-containing soybean (Chao 2008; Radd 2000). In spite of the fact that Buhera is a poor semi-arid and arid region in Africa, the reliance of the population on indigenous crops and fruit trees seems confer better lifestyle attributes.

Discussion

The population in the dryland regions in Zimbabwe such as Beitbridge (Murungweni et al. 2016) Chiredzi, Muzarabani (Manyani 2017) Mutoko (Bhatasara 2015), Bulilimamangwe (Muzerengi and Tirivangasi 2019), the Wengezi and Gudyanga areas in the south-east lowveld of Zimbabwe (Mugangavari 2019) including Buhera (Chikodzi 2016) have adopted resilient strategies to combat the effects of climate variability and climate change, and as such subsist on drought resistant crop varieties and indigenous fruit trees among other coping mechanism. Whilst maize has been consumed in Africa for over 500 years (Kodamaya et al. 2007) from its deemed origins in Mexican (Benz 2001), it remains a non-indigenous crop especially in Sub Saharan Africa to the detriment of the local populations especially as health reform recommends the consumption of foods which are native to a particular region for the benefit of the local populations (White 1905). Such diets have been known to boost the base immune system for the local people helping to fight disease (Akinola et al. 2020). For instance pearl millet has an iron content of 74.9% compared to the 20.0% for maize (Devi et al. 2014). Millets are known to contain selenium (Liu et al. 2016) an important antioxidant which prevents gene mutation (Ames 2001). It is in this respect it is proposed to carry put systematic studies into healthy lifestyle habits in the African regions for health reform.

The work suggested in this chapter awaits systematic and rigorous investigation and validation. It borrows heavily of various works which have already been undertaken on the current blue zones determining such parameters as spatial and longitudinal mortality patterns of the residents of Buhera over a determined period of time and cross-sectional comparison of biomarkers, diet and other health risk factors as has been studied elsewhere (Rosero-Bixby et al. 2014). Interesting statistics in the AKeA2 study have shown women living longer when they have fewer children with the last born coming at an advanced age (Lipsi et al. 2015). Already observations seem to suggest such a phenomenon in Buhera. The so called trait resilience has also been touted as a factor for longevity (Fastame e et al. 2018) contributing to the phenomenon of successful aging (Rowe and Kahn 1987). Perhaps science can learn from the story of the Biblical Moses of the Book of Exodus who is said to have lived to 120 years and his eye sight was good nor his natural force abated (King Henry VIII, 1611b). For forty years in the Wilderness, a dryland area region of the Middle East, the Israelites subsisted on manna a plant based "pastry" which tasted of coriander seed and honey (King Henry VIII, 1611a).

Studies involving determination of extreme longevity have to be carried out meticulously to avoid the errors of myth (Perls et al. 2010) and age inflation (Rosero-Bixby 2008) associated with poor data from self-reporting of the ages of participants in any cohort study. The preliminary studies would involve the analysis of census data to determine the proportion of long-lived individuals whether alive or deceased, and compare this with information from *bonafide* birth registration records (Perls et al. 1999). Research on nutrition is particularly useful as this has yielded important correlations and associations before, such as the prevalence of cancers associated with the consumption of processed and red meats (Rohrmann et al. 2013; Tong et al. 2019) whilst a vegetarian Mediterranean diet has been associated with a better quality of life (Thompson 1993) leading to longevity. Interestingly researchers have gone on to the extent of describing the so-called epidemiology of longevity (Newman and Murabito 2013) as if to suggest the condition as a disease when this can be celebrated as successful aging in which exogenous factors such as nutrition, exercise and the psychosocial environment play a critical role in the quality of life (Rowe and Kahn 1987).

The dryland region of Buhera presents an opportunity for the study of the parameters which make for successful aging and a poor region of the world where intuition and science would suggest the opposite. To the best of the author's knowledge, this hypothesis and the research which will follow it constitute the first attempt at characterising any region in Africa as a blue zone. This is also because the nomenclature of the blue zone is a fairly recent phenomenon (Blue Zones Project 2020) with the usual tendency of the African continent lagging behind on global trends. As such the study aims to therefore recommend the mainstreaming of the cultivation of "small" grains not just as drought resistant crops, not only as part of a health reform agenda (White 1866), good health (Dunn 1959a) in a positive sense and wellness (Dunn 1959b) but combating the global burden of disease especially in the era of viral pandemics such as COVID-19 in which the intemperate use of food (Nabi et al. 2020) is correlated with disease (Sharif-Yakan and Kanj 2014). Further, this study also helps in identifying and promotion of climate adaptation and resilient strategies and practices in dryland agriculture.

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Optimizing Productivity in Semi-Arid Dryland Agriculture for Developing Countries: Insights from Zimbabwe

E. Dahwa, C. P. Mudzengi, M. Mubvuma, T. Maravanyika, L. Chapungu, and E. Chikodza

Abstract In Sub-Saharan Africa, lack of adequate water during the growing season is the major constraint to crop and livestock production in the semi-arid dryland farming systems. Dryland farming systems are characterized by a strong dependence on rainfed agriculture, high population growth rates, and unstable economic and policy conditions. The study uses Zimbabwe, a developing country as a case study. We sort to conduct a review of the existing key drivers of growth namely technology, innovations, water productivity, policy, research and extension services. Information was collected through workshop discussions, internet and author personal experiences. It is imperative to identify crucial areas where technological interventions can be prioritized to improve productivity in drylands. Use of water conservation techniques such as zero tillage, winter ploughing, contour ridges, tied ridges, terracing and mulching are important strategies that may improve water productivity. Engaging farmers in processes for developing innovations is critical for adoption. Agricultural research seeks to generate new information and develop new technologies, inputs, and techniques of production. A key driver of increasing productivity and growth in drylands is to re-think and adopt new production technologies along with institutional, infrastructural and policy interventions. Without serious investment in these, it is likely that developing countries in Sub-Saharan Africa will continue to experience chronic food deficits well into the future.

Keywords Dryland agriculture · Innovation · Productivity

E. Dahwa (✉) · C. P. Mudzengi · M. Mubvuma · T. Maravanyika
Garry Magadzire School of Agriculture, Great Zimbabwe University, P.O. Box 1235, Masvingo, Zimbabwe
e-mail: edahwa@gzu.ac.zw

L. Chapungu · E. Chikodza
School of Natural Sciences, Great Zimbabwe University, P.O. Box 1235, Masvingo, Zimbabwe

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Introduction

The year-to-year variability of rainfall is a significant constraint to the sustainability of dryland agriculture systems in developing countries in sub-Saharan Africa (SSA) (Unganai 2000). Drylands are regions classified climatically as arid, semi-arid, or dry subhumid, based on the length of the growing period for annual crops (FAO 2009). A strong dependence on rainfed agriculture, high population growth rates, and unstable economic conditions compound the sensitivity to climatic variations and extremes (Martin et al. 2000). As such, dryland agriculture farming systems are characterized by risk which needs to be effectively managed (Unganai 2000). The semi-arid Natural Region V (NRV) of Zimbabwe (Fig. 1) occupies about 30% of the country. Twenty seven per cent of smallholder farming areas is found in this region (Whitlow 1980). The outstanding three percent is occupied by wildlife reserve areas. The major constraint to crop and livestock production in NRV is lack of adequate water during the growing season (Nyamudeza 1999). For this study, dryland agriculture is principally referred to as farming in the absence of irrigation in an arid to semi-arid region where lack of moisture limits crop or pasture production during part of the year (Stewart et al. 2006).

In Zimbabwe agriculture uses the bulk of the country's water resources. Sustainable use of this resource cannot be over-emphasized. Part of the solution lies in the availability of technologies that can make this possible (Manzungu 1999). There is scope in exploring rainwater management technologies to reduce the impact of dry spells in dryland agriculture cropping systems. Vincent and Thomas (1960) notes that rainfall received in this region was too low for reliable production. This would categorically include even the drought resistant fodder and grain crops. In

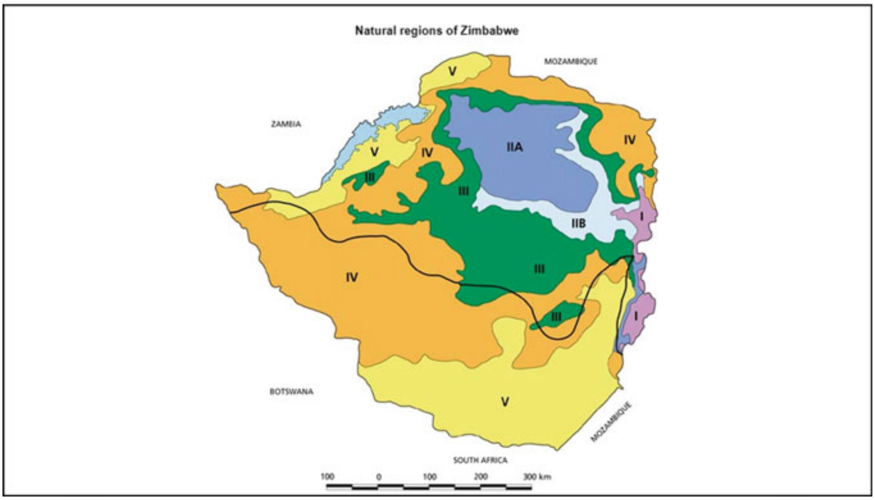

Fig. 1 Zimbabwe's natural farming regions (Vincent and Thomas 1960)

contrary to this, Staples (1962) notes that the same region was only suitable for cultivation of extremely drought resistant varieties of sorghum and pearl millet. Following these propositions, two decades lapsed with little or no documented research in dryland agriculture in Zimbabwe. These two rather opposing views were not really put to a test. It would appear, however, that for reasons that had to do more with conventional wisdom than technical considerations, the recommendation by Vincent and Thomas (1960) triumphed. In 1980, the Southern African Development Coordination Council (SADCC) invited The International Crops Research Institute for Semi-arid Tropics (ICRISAT) to set up a major Research Center in the region, embracing the five crops in its mandate. ICRISAT was then established in Zimbabwe, Matopos. After careful deliberation, ICRISAT decided to concentrate on three crops—sorghum, millet and groundnuts—that historically had been neglected by the British, Portuguese, and German colonial research services in Africa (Eicher 1984). In 1982 work on dryland agriculture was initiated at Chiredzi and Chisumbanje Research Stations (Nyamudeza 1999). Moving forward, there has been growing research interests in semi-arid dryland agriculture farming systems (Clatworth 1985; Mudhara 1990; Nyamapfene 1991; Nyamudeza 1999; Mupangwa et al 2011).

Farmers practicing dryland agriculture in semi-arid regions have been growing crops and livestock since time immemorial. This has taken place in the absence of adequate innovation, technical and policy support. Crops grown mainly include sorghum and millets, while livestock includes cattle and goats. However, although sorghum has been well grown and recognized in most cases the yields are very low even under the present day farming system. Irrigation has been widely recommended as the best way to grow crops in this region. However the cost of setting up such and or maintenance remains high for most smallholder farmers. Most irrigation schemes established within the last three decades remain dysfunctional and or underutilized owing to several factors. Due to these and other reasons, farmers will continue to depend on dryland agriculture. This means that success in cropping depends on using agronomic techniques which conserve or use water sparingly in order to permit regenerative production.

In this paper, we discuss key drivers to unlock productivity in dryland agriculture farming systems. These include water productivity, technologies, innovations, policy, research and extension. We conclude by drawing on important lessons learnt in Zimbabwe and our propositions on the future of dryland farming in the entire Sub-Sahara African region.

Objectives

The overall objective of the study was to conduct a comprehensive scoping and assessment of key drivers of productivity in dryland agriculture systems. This study uses Zimbabwe (a developing country) as a case study. We sort to conduct a review of the existing technologies, innovations and policies and analyze gaps on how to improve productivity.

Methods

The study used a number of methods in data collection and analysis. An internet-based literature survey was used to find out the meaning and scope of dryland agriculture in the international arena. We also gathered information through discussions on preliminary findings at a Dryland agriculture validation workshop hosted by GZU and attended by 40 participants. Participants included individuals who represented stakeholders from the government, non-governmental organisations, farmers, research (national), private sector and development agencies. The authors also used their personal experiences in project management and development in dryland agriculture. Using the information and our experience, we identified four key drivers that need redressing inorder to enhance productivity in dryland agriculture. We discuss the potential of these key issues on improving productivity for developing countries in semi-arid dryland agricultural systems.

The Zimbabwean Context

Zimbabwe is largely a semi-arid and agro-based country. The country's populace largely lives in rural areas. The agricultural sector plays a key role in the country's economic growth, food security and poverty reduction. More than 70% of the population depends directly or indirectly on agriculture as a source of livelihood (CIAT 2017). The population is reliant on a climate-sensitive, dryland agricultural system (ZIMSTAT 2015). Sector contributes an average of 11.3% (2012–2016 average) to annual Gross Domestic Product (GDP) and 16% of the country's export earnings (UNDP 2017). The country's main agricultural products are maize, sorghum, millet, wheat, cassava, cotton, tobacco, coffee, sugarcane, peanuts and livestock (cattle, goats, sheep, pigs, chickens). The main agricultural exports include tobacco, sugarcane, maize and cotton. Tobacco and cotton contribute 25 and 12.5% respectively to GDP. Unstable macro-economic environment together with effects of climate extremes such as droughts, floods and COVID-19 have had significant agricultural losses. As a consequence, food imports (particularly maize, wheat and rice) have been recently on the increase. In the 2018/19 season, 6 million people across the country needed food aid (UN 2019). Other numerous "lesser known crops" such as legumes (Bambara/round nuts, peas and ground nuts), tubers (potato and sweet potato), leafy green vegetables and beans (sugar) are critical for food security and nutrition and mainly produced by smallholder farmers.

The high dependence on dryland agriculture by most of the population renders farming a risky business for many (Unganai 2000). The uncertainties inherent to the natural and man-made circumstances are the major drivers of risk in agriculture. According to (Ruud et al. 2000) 'Risk is inescapable in life but it is, however, not to be feared'. This is so because; return is the compensation that an investor is rewarded with for taking on a risk. Every practitioner in agriculture must assume some carefully assessed level of risk if they expect to reap profits from their business activity. The old adage "High risk, high return" is also applicable to farming business. From an investment perspective, one of the primary responsibilities for a farmer of any category is to manage agricultural risk. Now, risk management entails identifying sources of events that may negatively affect future returns, quantifying the impact of such occurrences and taking appropriate measures to mitigate, or possibly eliminate the effects of these possible adverse developments. In general, the major sources of risk in agriculture are: production, marketing, financial, institutional and human. In this paper we focus mainly on risk pertaining to production.

Key Technological Issues in Dryland Agriculture

It is imperative to identify crucial areas where technological interventions can be prioritized to improve productivity in drylands. According to Nagaraj et al. (2011), one key technological area that needs attention to address challenges related to dryland agriculture is natural resource conservation and management. Focus is on rainwater harvesting, efficient water utilization, efficient soil fertility and nutrient management. Another key technological area is focusing on selection of most suitable crops and cropping systems as per land capability class and rainwater availability, selecting early maturing and drought resistant crops. There is also need to look at livestock strategy when determining technologies for dryland agriculture. Focus should be directed towards feed (fodder and/or forage) development and management, development of appropriate grazing practices, development and introduction of improved breeds and also integration of livestock and crop production.

Agroforestry is yet another area that needs consideration. It integrates crop-livestock production; conserves soil water, assists in supplying energy and improves soil fertility.

However, the key question of whether the technologies are bringing the required change still remains.

The major critical constraints in the dryland areas are related to water stress, low soil fertility and other factors related to crop management. The first priority should be to identify the principal agronomic and other constraints, then improve the environment. It is only then that improved varieties would be used to increase production, when it is relevant to exploit their genetic potential. Although there have been many research activities which demonstrate that the integrated approach, combining improved varieties with agronomic practices, improve crop productivity (Kidane 2019; Miller and Kebede 1984), this has not been used as a package for farmers in dryland areas of Zimbabwe.

Focus on Screening Early Maturing Crops

The crop improvement programs of Zimbabwean drylands have concentrated on screening early maturing varieties for drought tolerance. This is a good approach, however even during the short growing period in the dryland areas; the distribution of rainfall is highly variable within the season. Therefore, even a short cycle crop could be exposed to water stress at any time during its life cycle. Development of drought resistant crops and varieties is another technological development in dryland systems of Zimbabwe which has positively influenced crop production. However, lack of post-harvest management technologies has resulted in the shunning of drought resistant crops owing to difficulties associated with their processing. Other scholars have pointed to the need for improvement on palatability of small drought resistant varieties. Thus, there is still a technological gap with regards to varieties, pre-harvest processing and post-harvest processing of crops grown in drylands.

Technologies to Reduce Evaporation Loss

Soil moisture is the most limiting factor in dryland agriculture. It is lost as evaporation from the soil surface and as transpiration from the plant surfaces. Evaporation has to be arrested as it is not directly related to productivity whereas transpiration can be reduced to some extent without affecting productivity of plants. The evaporation losses can be reduced by mulches, anti-transpirants, wind breaks and weed control. About 60–75% of the rainfall is lost through evaporation. These evaporation losses can be reduced by applying mulches.

Mulch is any material applied on the soil surface to reduce evaporation and improve soil water balance. Application of mulches results in additional benefits like soil conservation, moderation of temperature, reduction in soil salinity, weed control and improvement of soil structure. If the surface of the soil is loosened, it acts as mulch for reducing evaporation. This loose surface soil is called soil mulch or dust mulch. Intercultivation creates soil mulch in a growing crop. Some non-governmental organisations such as Zimbabwe Council of Churches are involved in projects that improve infiltration and storage of rainwater in soils using vertical mulches. This consists of digging narrow trenches across the slope at intervals and placing the straw or crop residues in these trenches. The pruned plant material is placed in contour trenches formed between rows or in trenches around the plants in concentric circles each year in one circle.

Techniques to Reduce Transpiration Losses

About 99% of the water absorbed by the plants is lost in transpiration. If transpiration is controlled, it may help in maintenance of favourable water balance. Antitranspirant is any material applied to transpiring plant surfaces for reducing water loss from the plant. These include stomatal closing, film forming, reflective, growth retardant. Most of the transpiration occurs through the stomata on the leaf surface. Fungicides like phenyl mercuric acetate (PMA) and herbicides like atrazine in low concentrations serve as anti-transpirants by inducing stomatal closing. PMA was found to decrease transpiration to a greater degree than photosynthesis in a number of plants. Plastic and waxy materials which form a thin film on the leaf surface retard the escape of water due to formation of physical barrier.

In addition, growth retardent chemicals reduce shoot growth and increase root growth and thus enable the plants to resist drought. They may also, induce stomatal closure. Cycocel is one such chemical useful for improving water status of the plant. Antitranspirant generally reduce photosynthesis. Therefore, their use is limited to save the crop from death under severe moisture stress. If crop survives, it can utilise the rainfall that is received subsequently. Anti-transpirants are also useful for reducing the transplantation shock of nursery plants. They have some practical use in nurseries and horticultural crops.

Wind breaks are any structures that obstruct wind flow and reduce wind speed while shelterbelts are rows of trees planted for protection of crops against wind. The direction from which wind is blowing is called windward side and direction to which wind is blowing is called leeward side. Shelterbelts are planted across the direction of wind.

They do not obstruct the wind flow completely. Depending upon their porosity, certain amount of wind passes through the shelter belts while the rest of it deflects and crosses over the shelterbelts. It thus reduces wind speed without causing turbulence. The protection offered by the shelterbelts is dependent on the height of central tree row in the shelterbelts. Generally, shelterbelts give protection from desiccating winds to the extent of 5–10 times their height on windward side and up to 30 times on leeward side. Due to reduction in wind speed, evaporation losses are reduced and more water is available for plants. The beneficial effect of shelterbelts is seen more clearly in drought years. In addition, shelterbelts reduce wind erosion.

Prompt weed control eliminates the competition of weeds with crops for limited soil moisture. Transpiration rate from weeds is more compared to crops. Effective weed control in dryland agriculture leads to increasing availability of soil moisture to crops. This is the most useful measure to reduce transpiration losses. Nutrient solution spray is recommended in the event of revival of rain and release of moisture stress. Urea or DAP spray (2% solution) is useful for quicker regeneration of crops like legumes (e.g. Castor bean) after rain.

Livestock Management Challenges in Drylands

There are some indigenous knowledge systems and practices developed by traditional herders which have been tested and found useful. It is vital that this knowledge be documented and synthesized for widespread use under dryland agriculture. Some of the livestock keeping communities may require new technologies, while others need to build on traditional technologies and practices. The major areas that require technological improvements in dry areas include:

Scarcity of feed: the feed resource base for livestock production in drylands of Zimbabwe is natural grazing and crop residues. The quality and supply of these resources is seasonally variable. Grazing resources are waning due to expansion of cropping land and bush encroachment.

Lack of infrastructure: the infrastructure necessary to transport livestock or livestock products from remote rural communities, where production is concentrated, to urban markets is lacking. Livestock are forced to trek long distances to markets usually without adequate water and feed. They also trek long distances in search of heterogeneous feed and water resources. There are very limited market centers and stock routes with the necessary facilities such as feeding and watering points.

High mortality rates: A significant number of young domestic animals born die due to various causes. This is a very important constraint limiting productivity. The high mortality is also a result of inadequate veterinary coverage: resulting in high mortality and morbidity.

Long marketing channels and lack of market information: Producers do not have access to market information; consequently, the system lacks market orientation, which is an important driving force for increased production. Low product quality: Poor quality of live animals and small ruminant meat and meat products prevents penetration into many export markets.

Absence or inadequate provision of credit services: Livestock owners have difficulty obtaining credit to begin or expand production, purchase inputs and increase stock. Critically, farmers lack access to finance from banks and microfinance institutes. The lack of land tenure security for smallholder farmers who acquired land under the Fast Track Land Reform Program (FTLRP) constrains access to finance, as this land cannot be used as collateral. The lack of title is a limiting factor for agrarian investment in A1 and A2 farms across the country.

Water Productivity

Water productivity (WP) is widely used in monitoring crop and livestock performance and is derived as a relationship linking carbon gain to evapotranspiration (Albrizio and Steduto 2003). WP may be analysed based on the relationship between agricultural output (Y_i) and cumulative water use, as illustrated in Eq. (1).

$$Y_i = \int WU \cdot \varepsilon \Delta t \tag{1}$$

where, έ is the water productivity; determined as the slope of the graph representing the relationship between Y_i and accumulative water use with change in time (Δt) from sowing to crop maturity (Sinclair et al. 1984) or from birth to physiological maturity in case of livestock (Peden et al. 2007). Water use is the water lost through evapotranspiration process in crops or lost through various forms of excretion by livestock or during processing of livestock products (Peden et al. 2007).

Descheemaeker et al (2013) defined WP as the amount of agricultural output per unit of water depleted and suggested that it can be assessed for crops, trees, livestock and fish. Thus WP may be categorized as either Crop Water Productivity (CWP) or as Livestock Water Productivity (LWP), the latter being defined as the ratio of livestock products and services to the water depleted and degraded in producing these products, and may include water lost in slaughter houses and milk processing facilities (Peden et al. 2007). CWP is defined as the biomass or grain yield per unit of crop water use (Sinclair et al. 1984), and is influenced by crop physiological traits such as biomass accumulation and daily transpiration or water use.

Water productivity has been reported to vary spatially with respect to water use. Considerable variation in WP has been observed indifferent crops and between genotypes of the same species. For example in maize, WP ranges from 1.2 to 2.3 kg/m^3, chickpea, 1.3–6.4 kgha^{-1}, wheat 0.6–1.9 kg/m^3, rice 0.5–1.1 kg/m^3, and forage sorghum from 7 to 8 kg/m^3 (Mubvuma et al. 2018; Siddique et al. 2001; Ogola et al. 2002; FAO 2009).

Ways to Improve Water Productivity in Dryland Regions

It is clear from Eq. (1) that any crop, tree, livestock or fish management practice that increase WU or duration of crop growth may increase Y_i. Unlike WP which is robust and tend to be generally constant across organisms of the same species, WU has been reported to vary with crop cultivars, tree species, livestock breeds, environmental factors and seasons. Therefore, use of any management strategy that improves WU may also improve agricultural output and WP. At farm level, several strategies have been developed to improve WP (Steduto et al. 2006). For example, Mubvuma et al. (2018) reported manipulation of planting date as a strategy to increase WP in a small grain legume crop, whilst Ogola and Thangwana (2013) reported use of optimum planting density to improve WP. In dryland agriculture, better agronomic management that ensures a healthy vigorous growing crop that is free from weeds, pests and diseases may promote higher dry matter accumulation and hence increase WP. Thus, use of water conservation techniques such as zero tillage, winter ploughing, contour ridges, tied ridges, terracing and mulching are important strategies that may improve WP, particularly in water limiting conditions. In addition, use of rain water harvesting techniques coupled with use of efficient irrigation technology (drip irrigation) at farm level has been reported to improve WP. Timely and correct application of fertilizers in crops may improve CWP. Application of nitrogen fertilizer in crops has been reported to improve WP.

Moreover, agroforestry cropping systems have been reported to enhance resource utilization by improving temporal and/ or spatial complementarities in resource capture (Ong et al. 2007), this in turn improves WP in trees species. However, the major challenge in agroforestry is to develop a combination of tree and crop species that optimizes WP. Furthermore, research on livestock-water nexus to improve LWP is still limited. There is need to develop livestock breeds that grow efficiently from the little available water.

In much of southern Zimbabwe, both CWP and LWP has been reported to be low, particularly in Chivi, Chiredzi and Gutu districts mostly because of water stress and poor soil fertility levels. The region is prone to drought occurrence in two years out of every five years. Food security situation is low and malnutrition is prevalent. However, several strategies have been developed to improve resilience of both crops and livestock to the hash climatic conditions. These interventions include conservation farming technology that combines zero tillage and 100% mulching to conserve moisture. In smallholder farming community areas where such interventions have been implemented, CWP and LWP has started to improve.

Research Development and Extension Services

In terms of research, The Department of Research and Specialist Services (DRSS) is the main government agricultural department focusing on crop and livestock. Universities such as Great Zimbabwe University, University of Zimbabwe, Chinhoyi University of Technology, Midlands State University and many others also conduct agricultural research. Other research actors include CGIAR centers such as the International Maize and Wheat Improvement Center (CIMMYT) who have been largely focusing on the development of drought-tolerant maize varieties. The International Livestock Research (ILRI) focuses on livestock. Other international organizations such as the Food and Agriculture Organization (FAO) and the United Nations Development Program (UNDP) support government initiatives to build necessary policies and frameworks for agricultural development, investment and implementation.

The major factors contributing to decreases in agricultural productivity in dry lands include inappropriate livestock breeds and crop varieties, particularly in consideration of the prevailing change and variability in climate, which also leads to decreases and unreliability in precipitation, shifts in geographical occurrence of pests and diseases, and variable temperatures. Agricultural research and extension therefore play a pivotal role in increasing agricultural productivity in these areas. Agricultural research seeks to generate new information and develop new technologies, inputs, and techniques of production (Maiangwa 2010). On the other hand, agricultural extension is concerned with the transfer of these scientific research findings and new technologies to farmers.

This can be through on farm demonstrations, trainings, lead farmer participation or any other such educational platforms. It has been predicted that by the turn of the twenty-first century, there will be few areas in most African states where agricultural production can be increased by expanding the area under cultivation (USDA 1984). As a result, the focus of agricultural research and extension programs will have to shift to yield increasing- biological and chemical technology.

The main goal of agricultural research and development is increasing agricultural productivity, enhancing food security and income generation, consequently improving rural livelihoods. However, challenges in research and extension in most developing countries include low and unpredictable budgets, dilapidating and outdated infrastructure and equipment, shortages of competent scientific and technical staff, as well as lack of clearly defined research priorities (Maiangwa 2010). The ensuing low quality of service provision has facilitated the involvement of commercial and voluntary agencies in the provision of research and extension services, which traditionally was a mandate of the public sector. These different entities, however, have varying objectives. For instance, while government aims at achieving national policy goals, nongovernmental organizations and related voluntary agencies are guided by the social well-being of families, and commercial entities have profit considerations (Adebayo et al. 2016). However, it has been noted that research models supported by many funding agencies remain semi-colonial in nature and foreign domination in setting research priorities and project management tends to have high probability of negative consequences which outweigh the apparent benefits of the research findings (Costello and Zurnla 2000). It is therefore imperative to develop more efficient and effective research frameworks to increase agricultural productivity.

Zimbabwean government's investment in agricultural research continues to dwindle. The countries' budget allocations for agriculture have consistently gone down, and the country's allocation of 6 percent is below the recommendation in the Maputo Agreement (Sukume 2016). If research is to be translated into practice there should be increased funding for research by international and national research centres, improving the relevance and responsiveness of research to clients and making the institutional base for agricultural research more pluralistic (Costello and Zurnla 2000; Maiangwa 2010). Additionally, emphasis should be placed on getting research findings into policy and practice as well as development of national research capacity.

Innovation Processes and Productivity

Perceptions on innovation and diffusion processes have evolved dramatically. Earlier studies on adoption and diffusion of technologies, conducted during the period 1950–1980, were mainly centered on understanding adoption of technologies developed by researchers and transferred to farmers by extension agents. Studies have revealed that adoption of innovations has stages. The widely used characterization makes use of the model developed by Rogers (1962, 1983) and consists of the following stages: awareness, interest, evaluation, trial and adoption. Later on Rogers (1995)

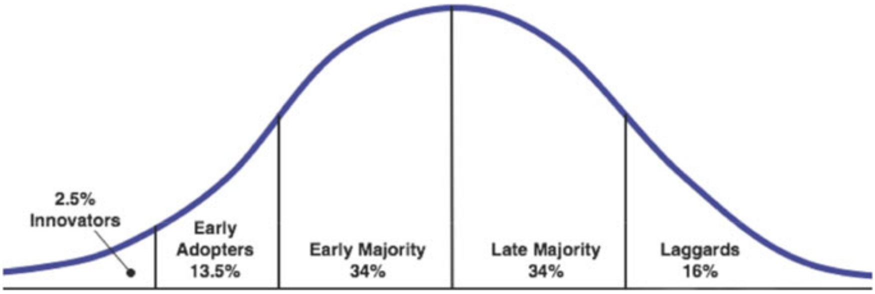

Fig. 2 Category of adopters

proposed different stages including: knowledge, persuasion, decision, implementation and confirmation. Some studies have also revealed on speed of adoption, some people quickly adopt whilst others are slow at adopting new innovations. Such studies classified people into five different categories (Fig. 2), innovators (making up 2.5% of total people), early adopters (making up 13.5% of total people), early majority (making up 34% of total people), late majority (making up 34% of total people), and then laggards (making up 16% of total people).

While other factors influencing adoption and diffusion of innovations are important, opinion leaders have been found to play a key role in the adoption process. Extension workers are highly recommended to target them with interventions in order to quickly promote adoption. Important variables identified to influence the adoption rates include: the perceived attributes of the innovations, the type of innovation decision, the communication channels used and the effort of the extension worker in promoting the innovation.

The adoption and diffusion of innovation perspectives of the earlier scientists have over the years have been highly criticized due to its top-down approach. The approach would assume that innovations promoted by extensionists were appropriate, relevant to the context applied. In the process, new ideas were generated on innovation and diffusion processes. New research on innovation and diffusion processes, began to ask the following questions—why and how do innovation processes unfold? What characteristics of innovation processes lead to emergence of new technologies? And what are the new roles of extension and research in the innovation processes? With the new way of thinking, there is a strong belief that the process of change (the innovation process) is often affected by complex inter-dependencies, unintended and unforeseen developments and interactions and hence cannot be facilitated in a linear top-down way. The new understanding is that innovation is not a linear process of science developing new knowledge and transferring it on to extension for wider dissemination to farmers. Rather, central to the process of innovation development are the interactions among a large number of actors having complementary knowledge and expertise. This process should be facilitated as actors often need an initial push to work together, jointly act, share and learn in what have been increasingly referred to as innovation platforms.

New perspectives reveal that innovation as a process of constant learning and adaptation and the capacity to learn to work in new ways and to build new competencies is an important part of innovation development process.

Processes for Promoting Innovations

In Zimbabwe, several organizations have been involved in promoting innovations to tackle challenges farmers face. In this section, a case study of organizations that promoted innovations in Zimbabwe's communal areas will be provided. These include ICRISAT and its work on small grains; AGRITEX work on promoting soil and water harvesting technologies in Chivi District and DR&SS work on promoting drought tolerant crops in Zimbabwe; CARITAS/ ILRI's work on promoting goat farming in Beitbridge; Heifer International work on promoting cattle production in the communal areas of Zimbabwe; and finally the promotion of contour ridges by agricultural extension during the colonial era. Integrating Crops and Livestock for Improved Food Security and Livelihoods in Rural Zimbabwe (ZimCLIFS) project to strengthen synergies in crop-livestock farming systems through innovation platforms.

The ZimCLIFS Project was implemented in 2012 in Gwanda and Nkai Districts. The project aimed to strengthen synergies in crop-livestock farming systems in four districts of Zimbabwe. The project was funded by the Australian Aid Program through the Australian Centre for International Agricultural Research (ACIAR). It was implemented by the International Livestock Research Institute (ILRI) (lead agency) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT); the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); Australia's Commonwealth, Scientific and Industrial Research Organisation (CSIRO) Ecosystem Sciences; University of Queensland; Zimbabwean non-governmental organizations; Community Technology Development Organization (CTDO) and Cluster Agricultural Development Services (CADS); and several departments within the Zimbabwe Ministry of Agriculture, Mechanization and Irrigation Development.

The project used the 'Innovation Platform' approach, to introduce high protein, drought-tolerant legume fodder crops like *Mucuna pruriens* to promote both crop production and livestock marketing. The Innovation Platform (IP) is an inclusive, participatory space/opportunity through which agricultural stakeholders (including farmers, agriculture extension workers, traders, NGOs, development workers and government personnel) come together to identify market opportunities and adopt innovations to solve real life challenges they are facing. IP therefore enable various stakeholders to meet and discuss key challenges they face. The IP meetings not only foster innovative ideas that break socio-economic barriers but are also critical in building confidence whilst simultaneously helping farmers to come to consensus about key issues being discussed.

The project initiated several community meetings in the two Districts of Nkayi and Gwanda, with various stakeholders. The purpose of these meetings was to identify key problems faced in the districts as well as come up with solutions to these problems. The project then identified and trained lead farmers on production technologies, marketing and self-organization. After the lead farmers were trained, a farmer-to-farmer training approach was used and the farmers also engaged in their own experimentation by planting mucuna in rotation with cereals. About two years after planting mucuna, farmers realised that their soils had significantly become fertile and had become resistant to the Striga weed which helped to bring down production costs. This information was shared by various stakeholders during the IP meetings. As time went on, the farmers realised that mucuna seeds also had a market and started selling to other farmers and development organisations and this also helped them to generate the much needed income. Prices of mucuna seed ranged from USD 1.5 to USD 3 per kg and excess seeds were crushed/roasted and preferentially fed to weak cattle and those recovering from diseases like foot and mouth disease. The success of the mucuna technology has since triggered other innovations in the two Districts namely solar driven fodder gardens, infrastructure rehabilitation for pen feeding cattle and marketing.

Before the project was implemented, farmers' food security was threatened and opportunities for improving their livestock farming were limited. Through innovation platforms, the project managed to promote the production of mucuna crop as an innovation to improve market-oriented crop-livestock integration. The innovation platform approach has helped in improving technology uptake as farmers got opportunity to experiment with the technology and experience its benefits. The project benefited 60,000 farmers in the two districts.

Agricultural Policy

The last agricultural policy framework for Zimbabwe was developed in 1994 to cover the period 1995–2020. With many changes in the agricultural and socio-political context, this policy is now irrelevant in many facets of the Zimbabwean agricultural sector. At present, the Ministry of Lands, Agriculture, Water, Climate & Rural Resettlement is in the process of drafting a National Agricultural Policy Framework 2018–2030 (NAPF). The country also is in line with a number of regional and international policy frameworks. Examples include the Maputo Declaration (2003) and Malabo Declaration (2014) which commit all African Countries to the implementation of the Comprehensive African Agriculture. The country also became a member of the World Trade Organization (WTO) in 1995 with a number of agreements in Agriculture in place. More importantly, the FTLRP of year 2000 significantly altered the agrarian structure. It is against this background that the country needs a robust policy framework that supports land capacity utilization, production and productivity.

Over the last three decades, Zimbabwe has been experiencing a declining trend in production levels with a deteriorating general trend for maize and wheat, but also for cash crops such as cotton and soybean (FAO 2010). The government has responded through direct inputs assistance to farmers, provision of extension services, and liberalization and deregulation measures, as well as increased investments in irrigation development. However, the financial constraints faced by the government, together with a number of weather-related shocks, have considerably limited the impact of these measures on turning around agricultural production and development.

Despite numerous water resources in the country, there is still a heavy dependency on rain-fed agriculture. In light of this and other challenges, we propose that to strengthen the resilience of dryland agriculture, there should be a deliberate policy focus on dryland agriculture recognizing the fact that it is practiced in different natural farming regions. Dryland farmers in NRV and NRII are faced with different scenarios that influence decisions to invest in farming. There should be a specific focus on soil rehabilitation, water and biodiversity conservation to offset the high rate of natural resource degradation brought about by agriculture. Experiences from other countries suggest that resilience can be achieved through a combination of new climate-smart technologies and institutional and policy reforms, including improved extension strategies and safety nets for farmers (CIAT, World Bank 2017) particularly those in marginal areas who are most threatened by crop and livestock failures.

Considering these challenges and constraints, as well as the fact that the country's current economic recovery is still fragile, it is critical for the Government of Zimbabwe to identify appropriate policies and investments aimed at stimulating sustainable agricultural growth and unlocking the country's agricultural potential.

Lessons Learnt and the Future

Engaging farmers in processes for developing technologies/innovations to solve their self-identified problems is critical for adoption of technologies. When farmers actively participate in the development of technologies, the resultant technologies are relevant and widely adopted. Outsiders are therefore rarely able to determine technologies for solving farmers' problems on their own.

Productivity growth is fundamental to the long-term success of Sub-Saharan Africa's predominantly dryland agriculture. Recent evidence suggests that productivity growth is going down over the past few decades. Among other drivers, farmers' capacity to adapt, adopt and apply innovations. More importantly there is need to rethink on new models for production, extension, research, innovation processes and technology transfer supported by infrastructure and policy. Without serious investment in these, it is likely that developing countries in Sub-Saharan Africa will continue to experience chronic food deficits well into the future. As such, they will require food imports on a concessional basis for many years to come. Dryland agriculture still offers potential economic opportunities for ensuring food security.

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Land Use Systems and Soil Quality Indicators in a Fersiallitic (5e) Soil at Matopos Research Farm in Zimbabwe

Jephias Dera, Canisio Mataga, and Neil Mandinyenya Zhou

Abstract This study investigates soil texture and chemical properties on different land use systems in order to determine soil exchange characteristics that influence land quality. In order to assess the effect of land use over time some soil samples were taken to determine the soil quality for agricultural purposes. The experiment was carried out at Matopos Research Institute located at longitude 28°29′ E, latitude of 20°24′ S. A completely randomized block design (CRBD) was used for collecting soil samples for laboratory analyses from four land use systems namely rain-fed fields, irrigation land, fallow and grazing. Data was analyzed using ANOVA. There were significant ($P < 0.05$) differences for the soil properties: soil texture, N, P, K, and Mg in different land use systems. N, P, and K levels were relatively high on land under irrigation compared to other land uses. Exchange properties: Cation Exchange Capacity (CEC), and calcium magnesium ratios had significant ($P < 0.05$) differences among land use systems. From the findings of this investigation, it was therefore concluded that farmers periodically need to fallow their lands to sequester organic matter, stabilize soil aggregates, improves nutrient cycles for sustainable agricultural production. In addition, for best responses for land management it is important to send soils for analysis for correct fertilizer recommendations.

Keywords Soil quality indicator · Land use systems · Land use intensity

Introduction

The sustainability of crop and soil management practices to improve or maintain soil quality depends on the understanding of how soils respond to different site-specific cropping and land-use practices (Tesfahunegn et al. 2020). Site-specific data on soil properties could also support to dealing with spatial variability of soil nutrients

J. Dera (✉) · C. Mataga
Agronomy Research Institute, Matopos Research Station P Bag k5137, Bulawayo, Zimbabwe

N. M. Zhou
Midlands State University, P Bag 9055, Senga, Gweru, Zimbabwe

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and physical indicators and their influencing factors. Such information is important to formulate appropriate sustainable cropping systems and land-use type strategies (Negasa et al. 2017; Trivedi et al. 2016). Thus, it necessitates knowing the extent of soil quality degradation in terms of soil physical and chemical properties and nutrient stocks under different management practices such as irrigation and rain-fed cropping and other land-use systems and soil management practices (Tesfahunegn et al. 2020).

Assessing land use-induced changes in soil properties is essential for addressing the issue of agro-ecosystem transformation and sustainable land productivity (Yao et al. 2010).

The soil quality concept that provides a tool to help quantify the physical response of soil to land use changes and soil/crop management practices is the soil physical quality (SPQ) indicators. It primarily refers to soil strength, fluid transmission and storage characteristics in crop's root zone. Land use changes and soil management practices can potentially alter SPQ thereby, influencing basic soil functions such as: moderating and partitioning water, solute movement, and their redistribution and supply to plants; filtering, buffering, immobilizing organic and inorganic materials; promoting and providing resistance to erosion (Karlen et al. 1997).

It is apparent that soil is one of the most important and determinant factors that strongly affects crop production. Soil is the foundation resource for nearly all land uses, and the most important component of sustainable agriculture (Mulugeta and Karl 2010). Therefore, assessment of soil quality indicators with respect to land use types, management practices and slope classes is useful and primary indicator for sustainable agricultural land management. Understanding the effect of these factors on soil properties is useful for devising land management strategies. The information can also be used to forecast the likely effects of any potential changes in land use types and management practices on soil properties. It is apparent that the destruction of vegetative cover can promote soil erosion, which eventually increases the magnitude of soil related constraints to crop production. Generally, a sound understanding of land use and management effects on soil properties provides an opportunity to evaluate sustainability of land use systems (Woldeamlak 2003).

Many smallholder farmers practice subsistence farming that is characterized by continuous cultivation and grazing of very high land use intensities. They fail to produce enough to feed their families because their lands and soils have become aged and infertile. Replacing this with virgin land is almost impossible because the land has become a very scarce resource due to urbanization and increase in populations. It is necessary to investigate the status of soil quality and how it is influenced by the way farmers use the land. So far, very few quantitative studies have been done for example to assess the effects of soil depth on soil. It has already been noted that soil degradation is compounded by shortage of additional arable land for expansion and intensification especially on smallholder farms. Research has revealed that prolonged and intensive cultivation resulted in deteriorating plant nutrients (Admas 2018).

The main objective of this study therefore, was to investigate the impact of four different land use patterns namely rain fed cultivation, irrigation, grazing and fallow on soil physical and chemical characteristics in order to identify critical soil quality indicators for management. Specific objectives were:

i. To examine the effects of land use systems on soil quality based on soil pH, cation exchange capacity (CEC); exchangeable sodium percentage (ESP): exchangeable potassium percentage (EKP) and Calcium to Magnesium (Ca: Mg) ratios in the soil at Matopos.
ii. To suggest suitable land management practices that would improve soil quality in small holder farming.

Materials and Methods

Study Area

The experiment was carried out at Matopos Research Institute (28°29′ E and 20°24′ S) in Zimbabwe approximately 1340 m altitude in agro-ecological region IV (Vincent and Thomas 1961). Rainfall is both limited and variable (250–1400 mm per year, median 570 mm) and occurs between October and April. October is the hottest month (mean maximum 29.4 °C). The soil type is called Fersiallitic soil (5E) that is medium Sandy Clay Loam (mSaCL) or Clay Loam (CL) textured with dark reddish brown or brown colour (10YR 4/3 Munsell soil colour notation) of good permeability and drainage, derived from or mafic (basic) rocks known in Zimbabwean soil literature as epidiorite. The area has a mosaic vegetation type made up of Tree Bush Savanna (TBS) of varying densities, with the most dominated tree species being *Acacia karoo, Acacia gerrardi, Acacia rehmanniana, Acacia nigrescens and Maytenus senegalensis* in combination with a continuous and discontinuous cover of commoner grass species that include *Heteropogon contortus, Cymbopogon plurinodis, Themeda triandra* and *Hyparrhenia filipendula* (Zhou 2004).

Experimental Description

The experiment was arranged in four land use patterns with depths for top soil (A horizon); upper sub soil (B horizon) and lower sub soil (BC horizon) having soil samples taken from them. A completely randomized block design (CRBD) was used for collecting soil samples in each of the four representative land use systems selected namely: rain fed fields, irrigation land, fallow land and grazing area.

Procedure for Soil Preparation

The targeted soil for study was the fersialitic 5E soils at Matopos Research Station. These soils do reflect diverse physical, chemical and biotic properties but the scale is small (Zhou 2004). For many years Matopos and the local small holder farming community soils under different land use systems have not been sent for laboratory analyses to check for soil quality which is a key in deciding land management and improving soil productivity. This involves an assessment of “the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation” (Doran and Zeiss 2000). Soil samples were collected from different land use patterns (rain fed fields, irrigation plots; fallow land and grazing area) using an auger from three different horizons namely top soil (A horizon); upper sub soil (B horizon) and lower sub soil (BC horizon) and then prepared for laboratory analyses at the Department of Research and Specialist Services (DR and SS) in Harare. Data analysis was done using Analysis of Variance (ANOVA) in Genstat 19th edition.

Results

The results for the four-land use systems are shown in tables and graphs.

Soil Physical Properties

There is no marked variation in soil texture as indicated by the soil textural classes as these generally range between sandy clay loam and clay loam especially in fallow and grazing land use systems. However, there are some discernible differences in textural classes between irrigated and rain fed, and fallow and grazing (Table 1) possibly due to different land use intensities with soil cultivation in irrigation and rain fed and not in the other two land use systems (Table 1).

The highest sand content across all sand types (fine, medium and course) and land use patterns was obtained in irrigation, this may be associated with continuous

Table 1 Soil texture in different land use patterns

Soil texture	Fallow	Grazing	Irrigation	Rain fed	P level
Fine sand (%)	18.7	20.0	25.0	21.3	Not significant
Medium sand (%)	5.67^{a}	7.00^{a}	21.67^{b}	3.00^{a}	<0.001
Coarse sand (%)	4.67^{a}	9.00^{b}	11.33^{b}	2.00^{a}	0.003
Silt (%)	33.33^{b}	25.67^{a}	20.67^{a}	43.00^{c}	<0.001
Clay (%)	37.67^{c}	38.33^{c}	21.33^{a}	30.67^{b}	<0.001
Soil textural class	SaCL	CL	m Sa L	Si CL	

Notes f Sand = fine Sand; m Sand = medium Sand; c Sand = coarse Sand; CL = clay loam; Sa CL = sandy clay loam; m Sa L = medium sandy loam; c Sa CL = clay sandy clay loam; Si CL = Silt clay loam cultivation using inorganic fertilizer for long-time in which such practices aggravate erosion that erode fine soil particles and leaves coarser particles. As for clay content, the highest value (up to 38.33%) was obtained in grazing and fallow fields. Irrigated land had the lowest clay content of 21.33%. There was a significant ($P < 0.05$) difference on the clay content among the different land use patterns (Table 1).

Soil Chemical and Exchangeable Properties

ANOVA results for N, P, K and magnesium assessed showed significant ($P < 0.05$) differences for all the four land use systems (Table 2). Soil pH appears to be within slightly acidic range notably under rain fed cultivation and irrigation. The soil pH did not vary between the land uses systems.

The chemical properties of soils in the study areas as shown by Total Exchangeable Bases (TEB) and CEC of the soil vary with position along the catena. High values of TEB and CEC are found in the lower parts of the catenas and in the sub soils where clay content is higher and drainage is poorer than in the top parts of the catenas (Zhou 2004). Generally, CEC was high in all land use systems with highest figure of 21.94 c mol c/kg on grazing land which is similar to fallow land (Tables 2 and 3).

Table 2 Chemical characteristics (N, P, K, Mg ad Na) of soils in different land use systems

Soil nutrient	Fallow	Grazing	Irrigation	Rainfed	P level
N (ppm)	20.00^{a}	28.67b^{c}	26.67^{b}	23.00^{a}	<0.017
P (ppm)	20.0^{a}	8.7^{a}	88.3^{b}	14.7^{a}	<0.001
K (c mol c/kg)	0.363^{b}	0.200^{a}	0.257^{a}	0.167^{a}	<0.047
Mg (c mol c/kg)	8.10^{c}	9.62^{d}	5.55^{a}	7.03^{b}	<0.001
Na (c mol c/kg)	0.077	0.093	0.067	0.077	Not significant
Ca (c mol c/kg)	13.36	12.02	10.33	11.68	Not significant

letters $^{a–d}$ are for the separations of means, means with same letter are similar while different letters denotes significant difference of the means

Table 3 Changes in soil pH, CEC, ESP and Ca: Mg ratios as indicators of soil quality in different land use systems

Soil characteristic	Fallow	Grazing	Irrigation	Rainfed	P level
pH	6.10	6.53	6.37	6.00	Not significant
CEC (c mol c kg^{-1})	21.91^{b}	21.94^{b}	16.74^{a}	18.95^{a}	<0.003
ESP (%)	0.363	0.423	0.397	0.403	Not significant
Ca:Mg (ratio)	1.667^{b}	1.253^{a}	1.860^{b}	1.667^{b}	0.002

letters $^{a, b}$ are for the separations of means, means with same letter are similar while different letters denotes significant difference of the means

Discussion

Land Use Systems Influence Soil Characteristics

Total nitrogen was significantly different ($P < 0.05$) among the land uses. High nitrogen was noticed on grazing land and this could be associated with the relatively high organic carbon which in turn resulted from plant and root biomass as well as residues being returned in the soil system (Chemada et al. 2017). Total nitrogen was found to be low on fallow land and this could be due to the fact that it has lost most of the nutrients and need to be reclaimed. The principal cause for lower contents of total nitrogen comes from biomass removal during crop harvest and insufficient replenishment through organic and or inorganic fertilizers. Available phosphorous was higher on irrigated land presumably due to continuous application of inorganic fertilizers like Single Super Phosphate. The lower P levels on grazing land might be due to phosphorous fixation (Nedessa et al. 2005). Potassium significantly varied across land use types. The higher K content was noticed in fallow land. The lower K^+ in the rain fed land and grazing land could be probably due to soil degradation and losses by leaching as the rain fed and grazing land were devoid of vegetation cover. Possibly, continuous cultivation practices, excessive precipitation and application of inorganic fertilizer could be responsible for the reduction of pH in the soil in these land use systems (Ahmed 2002).

Percentage of clay is the most variable soil physical characteristic in the granite soil. Of the chemical characteristics measured, soil pH is the least variable characteristic of the granite soils. Cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) in the A and B-horizons are the most variable characteristics (Zhou 2004). For all the four land use systems assessed at Matopos, most of them were medium to coarse textured with low ESP relative to other cations which indicate good soil quality as shown by a low sodicity hazard and presumably low salinity problem and dominance of soluble sodium in the soil. The major issue arising from high sodium levels relative to the other exchangeable cations is on the physical properties of soil. In surface soil layers, this imbalance in the ratio of cations results in poor soil structure (Rengasamy et al. 2011). This is evidenced by surface soil crusts or the setting of soil into large blocks or columns on drying. Additionally, the poor soil structure leads to a decreased permeability to water and thus poor soil drainage.

Land Use Systems and Soil Quality Indicators

A Land use planning system in smallholder farming is the centre of attention in Zimbabwe as this has a direct influence on soil quality. Evaluating soil physical and chemical characteristics in various land use systems in a farm is therefore essential in order to understand soil quality in soils under different land use and management systems especially in rural areas. Studies in soils and agronomic practices in crop production in Zimbabwe are abundant but investigations to compare the impact of different land use systems followed by small holder farmers on soil quality and management are lacking. Soil quality indicators at Matopos were assessed and described. It was noted that soil pH as a total integrator of chemical properties was rather less variable and low with soils tending to be slightly acidic especially in those land use systems that involve tillage of the land. Due to high level of urea and ammonium phosphates for agriculture in Matopos, the cultivated soils are made acidic in nature thereby reducing soil quality.

Many farmers rely on CEC to assess soil quality in their fields as an important parameter of soil because it gives an indication of the type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental behavior change (Landon 1991). Generally, the chemical activity of the soil depends on its CEC. However, although the CEC of a soil is strongly affected by the amount and type of clay, and amount of organic matter present in the soil (Lal 2006) the way land and soil are being used affects soil quality. There appears to be a diminutive effect of land use systems on soil quality in terms of CEC an indication of good natural potential of the soils to supply nutrients to growing plants at Matopos. Through a judicious liming and land management practice, levels of calcium could be raised in the soils to boost CEC and increase calcium to magnesium ratio thereby reducing possibilities of poor soil quality through heavy metal toxicities as well as other nutrient deficiency conditions in the soil. Good grass cover and organic matter in fallow, grazing and forest land should be maintained as this will improve soil quality in terms of CEC. Recent research (Admas 2018) indicated that incorporation of black carbon significantly increases soil CEC. It is noted that, for Matopos, continuously cultivated land without incorporation of black carbon will affect soil quality by lowering CEC but good soil management practices on cultivated land could influence the amount, quality and turnover of soil organic matter of the land (Nedessa et al. 2005) thereby improving soil quality.

The lowest mean CEC was observed in the irrigation land with 16.74 c mol c/ kg. This might be due to uptake of basic cations (Mg and Ca) through crop harvest and soil erosion. Calcium to magnesium ratio appears to be quite lower than ideal values of 3:1 or 4:1 for the reddish brown Fersiallitic soils across all land use systems at Matopos. Exchangeable sodium percentage (ESP) was low indicating that soils are not sodic.

Poor soil quality in land use systems due to soil chemical degradation involves depletion of essential nutrients for plant growth, salts and heavy metal accumulation to toxic amounts levels, washing away of basic soil nutrients and loss of soil organic matter. Continuous cropping with no or sub-optimal nutrients addition, disposal of toxic wastes and use of poor-quality irrigation water are some of the major contributors to soil chemical degradation in cropping systems.

Conclusions and Recommendations

It is concluded that land use systems at Matopos influence soil quality indicators. The assessed land use systems especially rain fed fields and irrigation does seem to influence and exchangeable bases and CEC. The research findings also reveal that fallow and grazing land had the highest CEC due to the accumulation of litter on the surface of the soil which recycles nutrients and makes them available in the soil. Therefore, farmers need periodically fallow their lands to sequester organic matter, stabilize soil aggregates, improves nutrient cycles for sustainable agricultural production. It is recommended that use of dolomitic lime (Mg CO_3), gypsum (Ca SO_4) be made to boost the level of calcium and magnesium in the soil thereby increasing capacity of the soil to supply nutrients. This must be coupled with a careful education and training program for local farmers in various techniques that are critical for soil conservation and land management.

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The Effect of Ridging and Phosphorus Application on *Neorautanenia Brachypus* (Harms) Vegetative Growth and Tuber Development

C. Pisa, D. Sibanda, X. Poshiwa, and T. P. Tauro

Abstract Diseases, droughts and prolonged dry-spell conditions are set to increase as climate change is increasingly becoming a threat to livestock survival. The use of *Neorautanenia brachypus* both for medicinal purposes and as livestock feed seems to be potential strategy in overcoming these threats and prompting the domestication of *N. brachypus*. Nutrient management in *N. brachypus* production is an important strategy for increasing productivity. A study was conducted at Marondera University of Agricultural Sciences and Technology (MUAST) to assess the effects of ridging and phosphorous application on the growth and yield performance of *N.* brachypus over two seasons. During the first season, plant height and leaf number were determined from 3 weeks after emergence (WAE) to 3 months after emergence (MAE) while aboveground biomass and tuber initiation distance were determined at 3 and 18 MAE. At the end of the 2018/19 season tuber weight was determined. Data was subjected to analysis of variance (ANOVA) and means separated using least significant difference (LSD).*N. brachypus* percent emergence, plant height, above ground biomass and weight were significantly higher on ridged land than flat land at all P levels. Tuber initiation distance of *N. brachypus* was shorter on ridges than flat land at all P levels. Significantly, higher plant heights and above ground biomass were attained when P was applied on ridges at 30 kg ha^{-1}. Incremental addition of P on ridges produced shorter tuber initiation distance and heavy tuber weights. *N. brachypus* can be domesticated and growing it on ridging and P application at 30 kg ha^{-1} is recommended to increase the growth rate and reduce time to harvest.

C. Pisa (✉) · T. P. Tauro
Department of Natural Resources Management, Faculty of Earth and Environmental Sciences, Marondera University of Agricultural Sciences and Technology, P O Box 35, Marondera, Zimbabwe

D. Sibanda
Department of Animal Science, Faculty of Agricultural Sciences and Technology, Marondera University of Agricultural Sciences and Technology, P O Box 35, Marondera, Zimbabwe

X. Poshiwa
Gary Magadzire School of Agriculture, Great Zimbabwe University, P.O. Box 1235, Masvingo, Zimbabwe

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Keywords Drought · *Neorautanenia brachypus* · Phosphorus · Ridging

Introduction

Cattle play a pivotal role in the livelihoods in many African communities (Oba 2001). About 40% of the income from agriculture is accounted by livestock worldwide (McDonald et al. 2011). The number of cattle one owns in many rural areas of Africa determines the wealth and dignity of a household (Murungweni et al. 2012). Animal products are very critical to the food security, livelihoods, nutrition, and resilience of many people all over the world. Livestock specifically cattle are a source of meat, milk, leather and other products (McDonald et al. 2011). Further, cattle provide manure that build and maintain fertility and productivity of soils (Oba 2001). Cattle performance for milk and beef production is highly determined by the availability and accessibility of feed.

Adverse conditions like drought, results in reduction of feed and water in the veld. Feed security for livestock during the drought period for both large- and small-scale farmers in Zimbabwe has been a huge problem. The animal performance, health condition, birth rate, milk production are reduced while death rate increases during drought (Tavirimirwa et al. 2013). Hence, feed shortage is associated with food insecurity, starvation, malnutrition, hyper-mortality rate, draining of fiscal resources and poverty. Shortage of feed during drought has led to the cultivation and domestication of pastures like katambora (*Chloris gayana*) and star grass (*Cynodon nlemfuensis*) (Murungweni et al. 2012).

In Chikombedzi rural area of Masvingo Province of Zimbabwe, livestock farmers discovered *Neorautanenia brachypus* (Harms) (Zhombwe) in the veld and fed it to their cattle during drought years. The farmers discovered that *Neorautanenia brachypus* was an essential medicinal feed aiding in cattle survival during drought. The indigenous perennial, erect forage shrubby legume has been reported to have several uses that include treating bad wounds, harvesting fish and feeding animals. Animal performance, survival rate and the body condition score of animals improved when cattle were fed on Zhombwe (Murungweni et al. 2012).

N. brachypus has been nicknamed "God given life saver" in Chikombedzi district due to its benefits to animals. *N. brachypus* grows in the wild and it takes long to reach maturity (Murungweni et al. 2012) and this could be attributed to limited nutrients and water in addition to the hard-compact soils found in Chikombedzi. Plant growth vigor is affected by the environment in which it grows in terms of soil nutrient status and the soil conditions (Martin and Jones 2000). *Neorautanenia brachypus* is a rainfed summer tuber legume crop which grows in a range of soils. The tubers are harvested from the veld and fed to animals as a way to mitigate the drought effects of reduced animal performance, health condition, birth rate, milk production. The tubers can weigh up to 45 kg (Murungweni et al. 2012) and currently there is no information on the number of years required to reach that weight. Increased exploitation of the tuber from the veld poses the risk of Zhombwe extinction. Zhombwe takes long to mature under natural conditions, hence there is a need to identify the nutritional and environmental needs to reduce the time to maturity.

Inadequate soil moisture can result in the deterioration of the nutritive status of the veld and absence of palatable plant species. Plant species can accumulate anti-nutritive factors like tannins and lignin. Acid detergent fibres decrease the digestibility of the feed components thereby reducing the food conversion rate resulting in decreased animal performance. *Neorautanenia brachypus,* however, can withstand drought conditions and the tuber that forms underground enables the harm to extract a lot of moisture from the soil and store it in the tubers. *N. brachypus* therefore, provides livestock feeding on it with water. Animals fed on Zhombwe tubers are capable of sustaining for some days without water as compared to those animals that feed on grass or browse (Murungweni et al. 2012). It is also believed that the Zhombwe tuber can reduce the internal parasites in the animal gastric intestinal tract. Despite many benefits, farmers have great challenge with the harvesting of Zhombwe as it is difficult to dig out from the flat lands in the wild. As such there is need to identify options which can reduce the labour associated with the harvesting process. Production of Zhombwe on ridges is one alternative given that other tuber crops (sweet potato, Irish potato, cassava) are grown on ridges and their harvesting is relatively easy. Most pasture legumes have failed to be established in nutrient depleted soils of the veld and *Neorautanenia brachypus* (Harms) is not an exception. These soils lack the major plant nutrients nitrogen, phosphorus and potassium. Being a legume *Neorautanenia brachypus* (Harms) can fix its own nitrogen. Phosphorus in an essential nutrient required in tuber crops for increased tuber yield and quality. Phosphorus deficiency appears to be the most limiting nutrient to legume establishment, biomass productivity and fixation (Giller 2001, Malwanda et al. 2002). This necessitates the need to identify nutritional needs of Zhombwe for domestication and multiplication of the precious pasture. Adequate domestication conditions will mean adequate nutrient supply, early physiological maturity and reduced harvesting labour. Hence, a study was conducted aiming at determining the effects of the propagation of *Neorautanenia brachypus* (Harms) on ridges and fertilizer P applications.

Materials and Methods

Description of the Site

The study was carried out at Marondera University of Agricultural Sciences and Technology (MUAST), Dozmery campus. The area is located in agro-ecological zone 11b with sand to sandy loam soils derived from granite. These soils have low inherent fertility, poor water holding capacity and low organic matter content. The climate in this area is characterised by hot summers from October to December with a maximum temperature of 28 °C and cold winters from May to July with temperatures that can go as low as 6 °C in June. The average annual rainfall is 800 mm and follows a unimodal pattern with rains between November and April.

Land Preparation and Planting

Land preparation was done after the first effective rains in mid-November using a tractor drawn disc plough. Soil samples were taken at a depth of 0–0.15 m and analysed for texture, pH, N, P, K, Ca, Mg before planting. Plots 5 m by 5 m were demarcated with 1.0 m pathways in between to avoid inter-plot treatment effects. The experiment was laid out in split plot design with Randomised Complete Block Design (RCBD), with slope as blocking factor. Land preparation was the main factor while P fertilizer application was the sub-factor. Land preparation consisted of ridged land and flat land. The P fertiliser treatments consisted of 0, 10, 20 and 30 kg P ha^{-1} which were replicated three times. Ridges of a height of 0.10–0.15 m and a spacing of 0.50 m were made as per treatment. Planting of mechanically scarified seed was done at the end of November and phosphorous (SSP) was applied at sowing as per treatment requirement. Seeds were mechanically scarified by nicking the seed coat with a knife and planted immediately in moist soils (Tauro et al. 2019). A single seed was planted at a planting station with spacing of 0.6 × 0.30 m on both ridges and on the flat. Weed control was done by hand hoeing.

Data Collection

The data was collected for the growth parameters plant height, above ground biomass, distance to tuber initiation and tuber weight. Seedling emergence was determined at 7 and 14 days after planting. Plant height was measured from 3 weeks after emergence (WAE) and weekly thereafter up to 3 months after emergence (MAE). Above ground dry matter biomass was determined 3 MAE by cutting the whole plant at 1 cm from the soil surface and oven drying at 65 °C to a constant weight. Tuber initiation distance was determined by randomly selecting plants for destructive sampling and measuring the length between tuber and the point where plant root was in contact with the soil surface. The tubers weight at 3 and 18 MAE was determined.

Statistical Analysis

The data obtained during the study were subjected to GENSTAT 14th edition for analysis. Analysis of variance (ANOVA) was done using general ANOVA. The Least Significant Difference (LSD) at $P \leq 0.05$ was used to separate means utilizing Minitab version 16.

Results

Tuber Establishment and Development

Neorautanenia brachypus emergence, plant height and above ground biomass were significantly ($P < 0.05$) higher on ridged land than flat land at all P levels (Figs. 1, 2 and 3). Ridging and P application significantly ($P < 0.05$) increased emergence of N. brachypus. The 10, 20 and 30 kg P ha^{-1} differed significantly ($P < 0.05$) from the control that did not receive any P (Fig. 1). No significant seed emergence differences were observed on the flat for the different P rates. Under both land preparation treatments, there was a general increase in plant height with increasing P application rates in the growing period (Figs. 2 and 3).

Aboveground biomass differed significantly ($P < 0.05$) among treatments. Biomass was highest at 30 kg P ha^{-1} and lowest at 0 kg P ha^{-1} for both ridged and flat land. At both 0 and 30 kg P ha^{-1} the biomass on ridged land did not differ

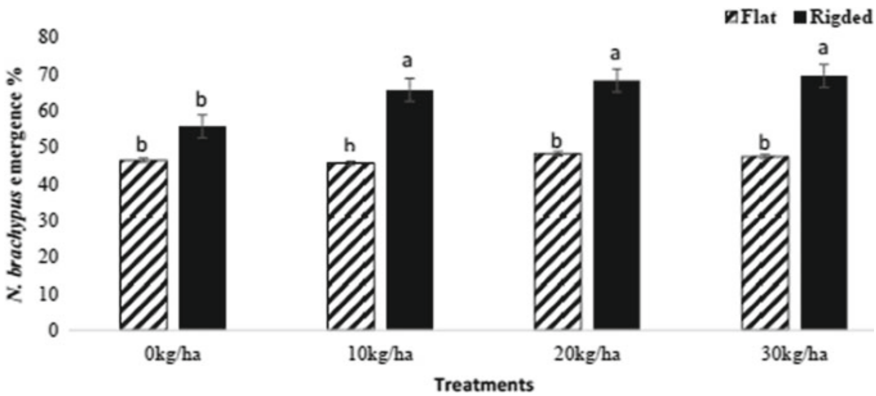

Fig. 1 Emergence of *Neorautanenia brachypus*at two weeks after planting during 2017/18 season

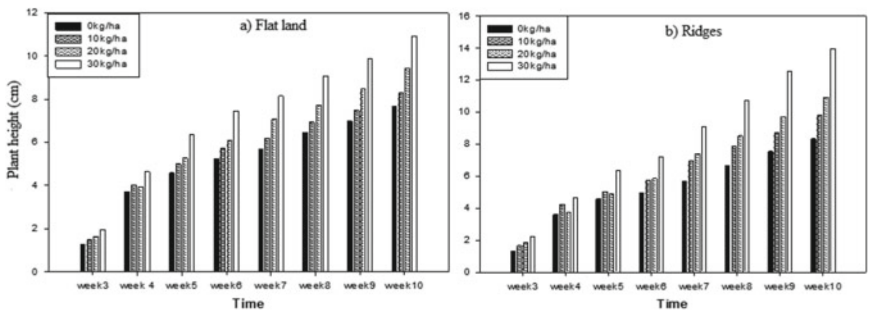

Fig. 2 Plant heightof *Neorautanenia brachypus* over the 2017/2018 season

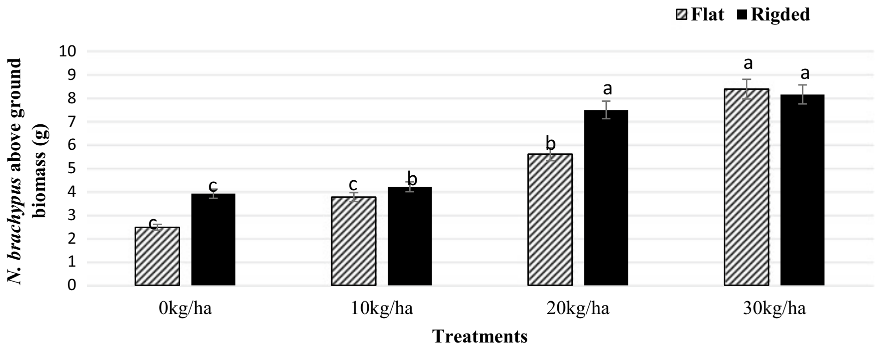

Fig. 3 Aboveground biomass of *N. brachypus* at 3MAP during 2017/18 season (Means followed with the same letter are not significantly different ($P \leq 0.05$))

significantly from that attained on the flat. At 10 and 20 kg P ha^{-1}, however, the ridged land produced significantly more biomass than the flat. Biomass on ridged land did not differ significantly at 20 and 30 kg P ha^{-1} while it did not differ on flat land for the 0 and 10 kg P ha^{-1}.

The Effect of Ridging and Phosphorus Application on Tuber Initiation Distance

Ridging significantly ($P < 0.05$) reduced the tuber initiation distance across all P treatments in the first year. There was a general decrease in tuber initiation distance with an increase in P application under both the flat land and ridged land. The shortest distance was attained on ridges at 30 kg P ha^{-1}. Tuber initiation distance did not differ when 10 and 20 kg P ha $^{-1}$ were applied on ridged land and when 0, 10 and 20 kg P ha^{-1} were applied on the flat (Fig. 4). In the second year, tubers had significantly ($P < 0.05$) grown deeper into the soil profile under ridges expect under 20 kg P ha^{-1} (Fig. 5). The tubers deepened by a factor of 2.8, 2.1, 1.4 and 2.1 under the control, 10, 20 and 30 kg P ha^{-1} respectively in the second year. Tubers were located at a depth of 19.3, 13.2, 7.8, and 10.7 cm for the control, 10, 20 and 30 kg P ha^{-1} respectively (Fig. 5).

The Effect of Ridging and Phosphorus Application on Tuber Weight

Tuber weight was significantly ($P < 0.05$) higher on ridged land than on the flat across all phosphorus treatments though at 0 kg P ha^{-1} ridged or flat land did not effect

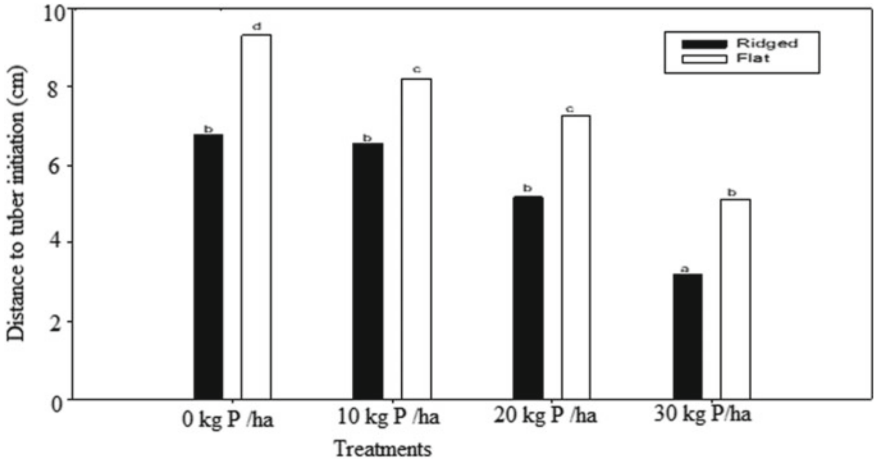

Fig. 4 Tuber initiation distance from soil surface in the first year

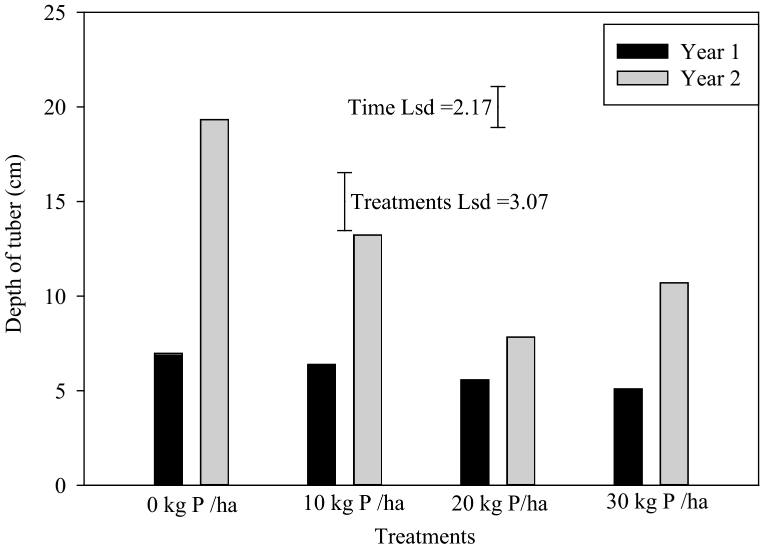

Fig. 5 Tuber initiation distance from soil surface (in the second year) under ridges

significant differences ($P > 0.05$) in tuber weight. Application of P on both ridged and flat land significantly ($P < 0.05$) increased tuber weight with the 30 kg P ha^{-1} having significantly ($P < 0.05$) higher tuber weight than the other P levels (Fig. 6). In the second year, the tuber weight was significantly ($P < 0.05$) higher than in the first year across all P treatments (Fig. 7).

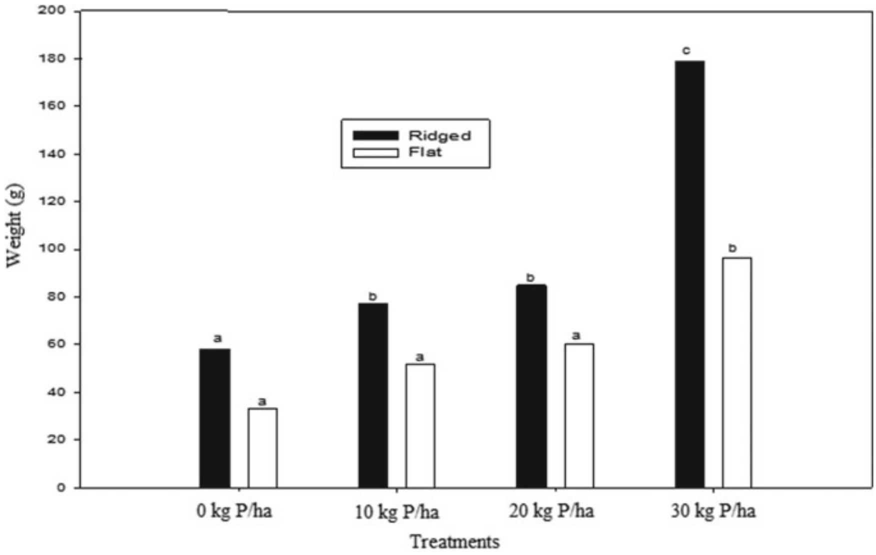

Fig. 6 Tuber weights after one year under ridged and flat land

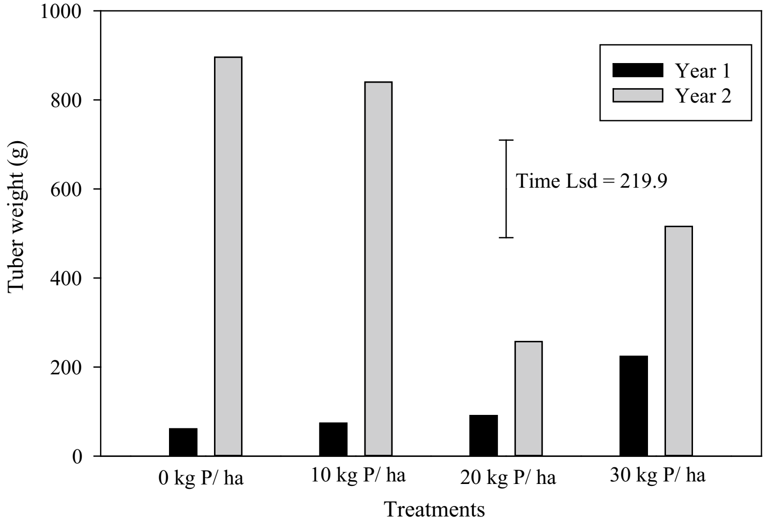

Fig. 7 Tuber weights under ridges over two years

Discussion

Benefits of Ridging and P Application During the Establishment of Neorautanenia Brachypus

Soil moisture management through improved in situ moisture conservation practices such as ridging is important in dryland crops to cope with dry spells during cropping season. *Neorautanenia brachypus* emergence was enhanced on ridged than flat land. Flat land tends to lose more water and have high soil temperatures. Ridging conserves moisture in the soil by reducing evaporation. Ridging has shading effect on one side of the ridge from sunrise to mid-morning and late afternoon to sunset which can reduce the rate of evaporation from the soil thus encourage faster germination as soil moisture is conserved. Beside moisture conservation, ridging creates a fine tilth (Tsuno and Fujise 1999) which encourages good soil aeration and ease of seedling emergence than on flat land where the soil can be compact and/ or be capped. Though ridging is labour intensive and time consuming for farmers, it allows for a good crop stand which is beneficial to farmers in attaining high crop biomass. Ridging concentrates nutrients in the soil resulting in increased crop establishment as there are readily available nutrients in the soil when the seedling exhausts seed stored nutrients. Ridging reduces crusting in soils (Manyevere et al. 2015) and benefits in crop emergence (Rodrigues et al. 1990).

Phosphorus is required for root development and therefore should be available in early plant development to ensure crop establishment. This is noted from the high emergence on ridged land that received 10 kg P ha^{-1}. Despite *Neorautanenia brachypus* having been termed large seeded with high food reserve for germination and emergence (Tauro et al. 2019), this study has indicated that seed P can be limiting. Therefore, ridging and P requirement contribute to the pathway of domestication particularly during the establishment stage, building on the need for mechanical scarification highlighted by Tauro et al. (2019).

Plant growth was good with combined effect of ridging and P application as shown by greater plant height and number of leaves on ridged land. Ridging and application of 30 kg P ha^{-1} recorded the highest growth parameter every week may be because of more availability of nutrients (Tsuno and Fujise 1999). Ridging that enhances nutrient availability via moisture conservation. The improved growth consequently increased biomass production. The benefit of P addition on plant growth and biomass productivity is well reported (Giller and Wilson 1991; Hikwa et al. 1998; Giller 2001; Malwanda et al. 2002). Biomass increased with P application to 20 kg P ha^{-1} beyond which there was no significant difference in biomass. Application of P to *Neorautanenia brachypus* is critical as it is a legume which fixes N. Legumes has high demand for energy during nitrogen (N) fixation with products channelled towards biomass production. Since nitrogen fixation is an energy consuming process, the supply of P must be proportional to the rate of nitrogen fixation and plant growth. Similar indigenous legumes that were harnessed from natural system also responded to single super phosphate fertilizer application in terms of biomass productivity and

N fixation (Tauro et al. 2010). However, according to Ritchie and Tilman (1995), other nutrients such as calcium and manganese may be critical for the development of wild legumes. Ridging concentrates nutrients within the soil (Tsuno and Fujise 1999), such that a crop will benefit from the localised fertility on the ridge which in this study translates to high biomass and increased height of *Neorautanenia brachypus.* This is why biomass under flat land responded to high P addition from 20 kg P ha^{-1} while under the ridges the benefit of P was noted at 10 kg P ha^{-1} as nutrient had already been localised.

Tuber Development Attributes of Neorautanenia Brachypus

Ridging and P application reduced distance to tuber development and increased the weight of the tuber. Given that ridging conserves moisture and creates fertility hot spots, the tuber developed near the soil surface and at a fast rate. Earlier we noted that 10 kg P ha^{-1} was sufficient for biomass development under the ridges, but for tuber initiation and development, 30 kg P ha^{-1} is (Mapfumo and Giller 2001) critical in the first year. However, in the second year under ridges, tubers went deep under the control, 10 and 30 kg P ha^{-1} while it was not so deep for the 20 kg P ha^{-1}. Growth of tubers to deeper depth is an indication that most of the P was used in the first year and in the second year the roots had to grow deeper in search of nutrients. It could also be that since initially the trial was established in the rainy season moisture was readily available. As the season changed to the dry season, soil water content decreased and the roots had to grow deeper in search of both water and nutrients. It is also important to note that the tubers are formed from the tap root.

In this study it was noted that tubers development required more P than above ground biomass. Phosphorus is critical for root development for most of the crops (Brady and Weil 2008; Kahsay and Moral 2019). *Neorautanenia brachypus* tubers like all other tubers are developed from assimilates from photosynthesis which are combined with various soil nutrients to manufacture medicinal compounds, high crude protein, fat and energy reserve noted by Murungweni et al. (2012). A number of studies have reported that ridged land has been reported to produce high tuber yield. Similarly, Martin and Jones (2000) and Onwueme and Sinhar (2002) reported higher tuber yield when potatoes are grown on ridges and attributed this to nutrient concentration effect of ridges. Results in this study indicated that P application was critical in the first year but in the second year all the tubers across the treatments had similar weight, thus indicating that other nutrients other than P were limiting tuber development basing on Sprengel–Liebig law of the minimum (Ritchie and Tilman 1995; van der Ploeg et al. 1999; Ferreira et al. 2017). Apart from P, potassium applied in high amount for crops such as potatoes and sweet potatoes to help is tuber development and might also be required by *Neorautanenia brachypus.* The high tuber weight when 0 and 10 kg P ha^{-1} were applied on ridges indicate that the tubers were storing nutrients for later use as conditions were no longer optimal for plant growth. This is any plant survival mechanism under low water nutrient status. Such an efficient nutrient mobilisation system might be a strategy allowing *Neorautanenia brachypus* and other indigenous legumes to establish under natural veld under various soil types (Mapfumo et al. 2005; Murungweni et al. 2012).

Conclusions

Phosphorus application at 30 kg ha^{-1} promoted plant growth and reduced tuber initiation distance. Both ridging and P fertilizers might reduce the waiting period to harvesting but further studies need to be done. The labour of harvesting is likely to be reduced on ridges than on flat but might need to be verified with further studies. It can be concluded that *N. brachypus* can be domesticated and grown on ridges with P fertiliser application. The effects of other nutrients like K are also critical for tuber development need to be exploited for a complete recommendation. Thus, improved moisture and nutrient management could help in devising and developing climate resilient agriculture practices in dryland areas.

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Effects of Different Seed Pre-treatments on Enhancing Germination of Selected Indigenous Plant Species in Chivi District, Masvingo, Zimbabwe

Zakio Makuvara, Jerikias Marumure, and Pardon Chidoko

Abstract One of the most important management strategies of indigenous plant species in Zimbabwe is based on seed preservation and propagation. Although seeds of some indigenous plants easily germinate, many native plant species in Zimbabwe have one of several types of dormancy. To this end, the present study examines different pre-treatment methods for seed germination improvement of *Vitex payos* and *Azanza garckeana*. In this investigation, six treatments (T) were applied to randomly selected viable seeds: T1 untreated seeds (control), T2 pre-chilling for 6 h, T3 boiling for 5 min, T4 filing, T5 soaking in 98% concentrated sulphuric acid for 5 min and T6 soaking in 0.1% potassium nitrate for 5 min. For each of the six treatments, 12 seeds were used and three replicates were done. The pre-treatment responses of seeds were compared with control responses (T1). Three germination indices (final germination percentage (FG), mean daily germination (MDG) and germination rate (GR) were observed daily for 35 days. Results show that germination indices were significantly ($p < 0.05$) enhanced by treatments. Percentage germination varied significantly ($p < 0.05$) between pre-treatments, with T5 recording the highest mean germination for *V. payos* (41.6%) and T3 recording the highest for *A. garckeana* (47.2%).We therefore, recommend acid pre-treatment of *V. payos* and boiling for *A. garckeana* seeds for breaking seed dormancy.

Keywords Seed dormancy · Germination indices · Pre-treatment · Seed preservation · *Vitex payos* · *Azanza garckeana* · African tree species · Agroforestry

Z. Makuvara (✉) · J. Marumure
School of Natural Sciences, Great Zimbabwe University, P. Bag 1235, Masvingo, Zimbabwe
e-mail: zmakuvara@gzu.ac.zw

P. Chidoko
Gary Magadzire School of Agriculture, Great Zimbabwe University, Masvingo, Zimbabwe

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Introduction

Forests are endowed with many tree species of socio-economic importance that are capable to produce a variety of edible, highly nutritious and medicinal fruits, seeds, leaves, twigs nuts and bark (Omokhua et al. 2015; Stuart et al. 1998). Forests serve as substantial forms of sequestered carbon and therefore they reduce greenhouse gases (Stuart et al. 1998). The global importance of forests cannot be overemphasized as they play an important role in maintaining basic ecological processes, sustaining livelihoods, and supporting economic growth. The current alarming rates of forest loss across Sub-Saharan African countries have further increased the fragmentation of multitudes of populations and the reduction of species biodiversity (Iakovoglou and Radoglou 2015; Omokhua et al. 2015). Most of the natural plant communities are endangered because of ongoing overgrazing, overcutting, and uprooting (Belal et al. 2015). Reforesting a site for increasing genetic diversity is normally by direct seeding or seed-derived seedlings (Belal et al. 2015).

In Zimbabwe and many other African countries, conservation of indigenous plant species is normally achieved through management of these plant species in their natural habitat (in situ) and away from their field habitats (ex-situ) (Marumure and Makuvara 2020 *unpublished*). Ex situ management strategies, are applied in facilities such as botanical gardens, seed gene banks, in-vitro gene banks, and field gene banks. Fredrick et al. (2017) noted that seeds of most arid and semi-arid tree species take time to germinate even if exposed to conditions suitable for germination because of a hard impermeable seed coat. In line with this limitation, nurseries generally focus on producing seedlings from species where dormancy is not an obstacle and sometimes seedlings are propagated vegetatively. Artificial propagation of seedlings ultimately decreases species biodiversity at the regenerated site (Duncan et al. 2019; Iakovoglou and Radoglou 2015). However, success of management strategies relies on availability of adequate and viable seeds among other factors (Amusa 2011). Although seeds are key elements in both in-situ and ex-situ *indigenous* plant species management, propagation of most African indigenous tree is constrained by seed dormancy (Amusa 2011).

Seed dormancy is a temporary failure of a mature viable seed to germinate when exposed to all environmental conditions necessary for germination (Fredrick et al. 2017). Dormancy manifests differently across species depending on adaptation to a prevailing environment (Duncan et al. 2019). The determination of various forms of seed dormancy is important in successful propagation of tree species in dry lands. An identification key for seed dormancy is based on different traits as described by Luna et al. (2014). Although seed dormancy limits seed plant propagation, it is imperative in many woody plant species. Seed dormancy allows synchronization of germination with optimal conditions for the survival of the resulting seedlings. Moreover, seed dormancy prevents germination of seeds to coincide with adverse environmental conditions such as frost and drought (Fredrick et al. 2017). However, traits such as low seed dormancy are main causes of pre-harvest sprouting and poor harvested seeds quality (Née et al. 2017). In the light of this, there is need to develop an appropriate pre-treatment technology for breaking dormancy and regularizing germination (Amusa 2011). More importantly, analysis and examination of dormancy will generate useful information on ecological understanding of tree species (Née et al. 2017).

Overcoming seed dormancy plays a significant role in the regeneration potential of tree species and it makes the basis for agroforestry (Fredrick et al. 2017; Née et al. 2017). The conditions necessary to overcome dormancy and promote germination greatly vary among species, within a species and among seed sources of the same species (Fredrick et al. 2017). Seed dormancy can be broken by several methods, including heat treatment, pre-chilling, chemical treatment (sulfuric acid and potassium nitrate), and mechanical scarification. In addition, smallholder farmers in overcoming effects of drought, salinity, and temperature variability can apply physiological strategies such as seed priming (Ali et al. 2020; Awodoyin et al. 2015; Omokhua et al. 2015). Quite a number of pre sowing seed treatments, such as chemical and physical treatments were examined and scarification at the radicle end increased the germination of seeds (Ali et al. 2020; Collen et al. 2015; Fredrick et al. 2017). Studies have indicated that seed pretreatment may significantly promote seed germination of various tree species. Seeds of species with hard seed coat need to be subjected to physical and chemical treatment to break dormancy and obtain uniform germination (Fredrick et al. 2017).

Germination is a critical step in plant natural life cycle and for any seed to initiate this process, it has to imbibe enough water under suitable conditions (Al-ansari and Ksiksi 2016a, b). The studies on seed germination were identified as crurial tools for conservation and management of many plant species. Of particular importance is the knowledge on natural regeneration processes and possible causes of species decline, persistence in changing landscapes and response to global climate (Iralu and Upadhaya 2018). The conditions necessary for seed germination can be highly variable among tree species (Fredrick et al. 2017; Luna et al. 2009). Temperature variations, oxygen levels, water availability, and absence of inhibitory factors influence seed emergence (Al-Ansari and Ksiksi 2016a, b). Germination is affected by critical factors such as time, rate, homogeneity, and synchronization of seed emergence. The establishment and survival of seedlings soon after germination could be better predicted using appropriate germination (Al-Ansari and Ksiksi 2016a, b). Germination process is directly linked to the dormancy releasing factors, which are two fold in their effect on the fate of the seed (termination of dormancy or initiation of germination) (Bareke 2018).

Germination process generally occurs in three phases and the first phase involves rapid absorption of water. The absorption of water by seeds initiates the hydration of cell walls and seed intercellular storage (Née et al. 2017). Water absorption in this initial phase is accompanied with biochemical events such as membrane restoration and DNA repair commence. In phase two the first step of protein synthesis (transcription) of genes responsible for plant regulator metabolism occurs. Metabolism of plant growth regulators plays a critical role in determining a balance between seed dormancy and germination. Phase three involves a rapid increase in water uptake and radicle emergence (Née et al. 2017; Raji and Siril 2018). Sustenance and distribution of underutilized African indigenous tree species is hindered by fragmentation of land and anthropogenic activities. Plant species found in dry lands of Africa require suitable propagation and management methods for their large-scale production through agroforestry, social forestry, home gardens and on-farm cultivation (Raji and Siril 2018).

Indigenous African plant species play significant roles in the lives of people especially those in rural areas. Of particular importance are indigenous fruit trees, although undomesticated play many important roles as traditional sources of nuts, fruits, spices, leafy vegetables, edible oil and beverages. Indigenous fruit trees are mainly used during periods of seasonal food shortages (Kimondo et al. 2011; Michael et al. 2015). As observed in many African countries, in Zimbabwe introduced fruit species rather than the indigenous species are grown for large-scale production and distribution. This phenomenon as resulted in rapid decline in the cultivation and knowledge of indigenous plant species known to the local people (Awodoyin et al. 2015). In Zimbabwe indigenous fruit trees *A. garckeana and V. payos* bear fruits even if arable agriculture fails, thereby improving food security for rural households. It is important to note that growing of these fruit trees reduces overdependence on arable agriculture and this decreases environmental degradation.

Indigenous fruit trees play an important role in rural Zimbabwe, but their domestication and utilization is limited. Plant seed traits and germination were identified as central in plant community dynamics and providing insight into the utilization and domestication of plant species. Duncan et al. (2019) highlighted that there are limited studies on effects of seeds traits and germination on plant community ecology. In addition to this, information on propagation and management strategies of indigenous plant species is scantily available (Marumure and Makuvara 2020; *unpublished*). Domestication of indigenous trees species requires knowledge on regeneration and aspects of the plant seed biology. Pre-treatment of seeds is important towards germination and establishment of most African native plants (Bernard et al. 2019), nonetheless, there is paucity of information on the effect of pre- sowing treatment on germination of indigenous plant species in Zimbabwe. This study therefore, sought to assess the impact of pre-sowing treatments on the germination *V. payos* and *A. garckeana.*

Materials and Methods

Study Area

The experiment was conducted at the School of Natural Sciences Laboratories at Great Zimbabwe University, Masvingo, Zimbabwe. Seeds were collected from Chivi district, Masvingo, Zimbabwe [20° 2′ 44″ south, 30° 29′ 22″ East]. Chivi district is a dryland region with a diversity of indigenous plant species including *V. payos* and *A. garckeana* which are conserved naturally using mainly in-situ methods.

Table 1 Seed pre-treatments

Number	Pre treatment	Description	Code
1	Untreated	Seeds not treated	T1
2	Pre-chilling	Seeds exposed to 4 °C for 6 h	T2
3	Boiling	Seeds boiled for 5 min	T3
4	Filing	Seeds scarified using a file	T4
5	Acid	Seeds soaked in 98% concentrated sulphuric acid for 5 min	T5
6	Nitrate	Seeds soaked in 0.1% potassium nitrate for 5 min	T6

Seed Collection and Viability Test

Mature and fully ripened fruits of *V. payos* and *A. garckeana* were collected from Chief Madyangove community near Mandamabge in Chivi district (Northern part), Masvingo province, Zimbabwe. All the fruits were cracked and the collected seeds were shade dried for ten days. Seeds were weighed and those with almost the same weight within each plant species were selected for further analysis. Of the 540 seeds collected from the cracked fruits, 90 (45 seeds from each plant species) were sampled for a seed viability test using 1, 2, 3 triphenyl tetrazolium chloride (TTC). Seed viability involved the removal of a seed coat and opening of embryos using a pair of forceps. The exposed embryos were incubated in 1% TTC at pH of 7 for 3 h in total darkness. Three replicates with 15 dissected embryos for each plant species were examined. Pink embryos were considered as viable and mean percentage seed viability was calculated for each plant species.

Experimental Design

Prior to pre-sowing treatments, seeds were cleaned with distilled water. Seeds were then subjected to five pre-treatment methods with the untreated seeds as control as indicated in Table 1. The pre-treated seeds were sown in trays (60 × 45 × 30 cm) three-quarter filled with topsoil. Trays were arranged in a completely randomized design with 24 seeds per tray. Each pre-treatment method (12 seeds of each plant species) was replicated in three trays. Seed trays were watered once in three days and weeds were controlled by hand.

Data Collection and Analysis

Number of seeds emerged was recorded daily per seed tray for 35 days. Percentage seed Germination (PG) and Germination Rate (GR) and Mean Daily Germination

Table 2 Comparison between V. payos and A. garckeana in terms of grand mean of final percentage germination, mean daily germination, and germination rates

	V. payos	*A. garckeana*	*P level*
Final germination (%)	24.06 ± 0.82	27.30 ± 0.36	0.013
Mean daily germination	0.13 ± 0.04	0.15 ± 0.01	0.169
Germination rate	1.05 ± 0.11	1.26 ± 0.02	0.124

(MDG) were calculated. Data set on the three germination parameters was subjected toAnalysis of Variance (ANOVA) and Student t test. Analysis of all data was done with help of Genstat 14th edition.

Results

Viability Test

The percentage viability of V. payos and A. garckeana was 92 ± 0.45 and 89 ± 0.25, respectively.

Comparison of Germination Characteristics of V. payos and A. garckeana

See Table 2.

Significant ($p < 0.05$) differences between *V. payos and A. garckeana* in terms of final percentage germination was observed. However, there was no significant ($p > 0.05$) difference between germination rates and mean daily germination of *V. payos* and *A. garckeana* seeds. The differences between treatments and between two plant species and treatments in terms of all the germination parameters were significant ($p < 0.05$).

Effects of Pre-treatments on Germination Characteristics

Treatment 5 and 6 resulted in relatively higher percentage germination in the two plant species. However, treatment 3 recorded the highest percentage germination differencebetween *V. payos* and *A. garckeana.* In addition, a significant difference in

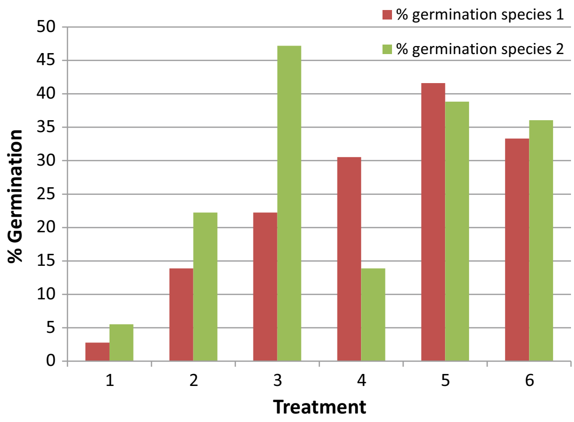

Fig. 1 Effects of pre-treatments on percentage germination of species1 (*V. payos* seeds) and species2 (*A. garckeana* seeds)

percentage germination was recorded in treatment 4. The control (T1) recorded the least percentage germination in both plant species (Fig. 1).

Discussion

Degree of seed dormancy varies in many tree species and no single pretreatment technique has been found to be equally effective for all seed species (Amusa 2011). This idea corroborates with the findings of this study since there were variation in response to different pretreatments within species and between species. Although percentage germination was relatively low, the highest percentages recorded for *V. payos* and *A. gerckeana* were 42% with treatment 5 and 47% with treatment 3, respectively. Percentage germination and germination rate of *V. payos* and *A. gerckeana* varied with different treatments except for treatment T4 and T6 for *V. payos*. These results therefore indicate differences in the degree of dormancy and effectiveness of pretreatments.

Potassium nitrate treatment promotes the seed germination of many plant species and extensively utilized chemical for promoting germination. The accepted concentration of potassium nitrate in germination testing ranges from 0.1 to 0.2% (Bareke 2018). The findings of this study indicated that potassium concentration of 0.1% significantly increase percentage germination of both *V. payos* and *A. garckeana* seeds. However, lower concentration of potassium nitrate (<1%) was reported to inhibit germination and a typical for example was the inhibition of *Salvia cyanescens* seeds (Bareke 2018). In studies by Amoakoh et al. 2017; Dewir et al. 2011, it was concluded that potassium nitrate concentration of 4% significantly increase germination of *Thrinax* seeds compared to the control, but lower concentrations did not improve germination. In this study, it was concluded that seeds of *V. payos and A. garckeana* are associated with physiological dormancy since they both responded to potassium nitrate treatment.

In this study acid treated seeds of both plant species gave higher percentage germination, mean daily germination and germination for seeds of V. payos was recorded with T5. These findings are similar to those reported by Collen et al. (2015), who reported that sulphuric acid promoted highest germination in *Acacia angustissima*. This is in line with reports by Fredrick et al. (2017), who reports that the period of dormancy in seeds is reduced due to pretreatment of seeds in sulphuric acid. Fredrick et al. (2017) also stated that acid treatment of seeds removes waxy layer of the seed coat by chemical decomposition of seed coat component. According to Majd et al. (2013), acid treatment is efficientin enhancingseed germination of species with hard impermeableseed coat and is dependent on seed exposure time to sulphuric acid and concentration of sulphuric acid used. Decreasing germination at longer periods in acids is attributed to possible damage of embryo (Majd et al. 2013). Exposing the seeds to highly concentrated sulphuric acid can also have a negative effect on the germination of the seed. High percentage germination was recorded for acid treated *Prosopis caldenia* seeds with 45 min exposure time. It is believed that the length of time seeds need to be soaked in sulphuric acid depends on the hardness of the seed. Acid treatment may also enhance germination capacity by accelerating the leaching of plant growth inhibitors from the seed (Collen et al. 2015; Raji and Siril 2018). Different species have varying rates at which their seed coat is permeable to water and gases (Amusa 2011).

In the current study pre chilling improved germination of *V. payos* and *A. gerckeana* seeds, but the percentage germination were relatively low (Table 3 and 4). Our results are contrary to research findings by Amoakoh et al. 2017; Amusa 2011), where seeds of *A. Africana and P. campachiana* seeds in control treatment gave a higher germination percentage. However, the results of pre chilling of seeds in this study is similar to what was reported for *Azadirachta indica, Adansonia digitata*, and

Table 3 Effects of seed pre-treatment on germination characteristics of *V. payos*

	Germination characteristics		
Treatments	Final % germination	Mean daily germination	Germination rate
T1	2.77[e]	0.0167[c]	0.138[d]
T2	13.90[d]	0.0767[b]	0.639[cd]
T3	22.23[c]	0.1233[b]	1.036[bc]
T4	30.53[b]	0.1767[a]	1.476[ab]
T5	41.60[a]	0.2233[a]	1.878[a]
T6	33.30[b]	0.1800[a]	1.183[bc]
Grand mean	24.06	0.1328	1.058
LSD at 5%	7.148	0.05099	0.6045
CV%	16.3	21.1	29.1
P value	<0.001	<0.001	0.001

Different superscript letters in the same column indicate significant ($p < 0.001$) differences

F. albida (Amusa 2011; Fredrick et al. 2017). Boiling was found to be suitable for germination *A. garckeana* seeds, recoding the highest percentage germination. Heat treatment depends on seed exposure time. Generally, boiling of seeds removes waxy and creates cracks that improves gaseous exchange and water uptake. However, prolonged heat contact could be linked to seed embryo damage and poor germination (Amusa 2011; Fredrick et al. 2017). In two separate studies, the effect of hot water on the seeds of *F. albida* provenances and *A. Africana* resulted in poor germination (Amusa 2011; Fredrick et al. 2017).

All treatments had significantly ($p < 0.001$) higher final percentage germination and mean daily germination as compared to control (T1).Treatment 4 (T4) and T6 had almost the same final percentage germination and mean daily germination and therefore no significant ($p < 0.001$) differences. Although mean daily germination of seeds exposed to T5 had no significant differences with that of T4 and T6, T5 recorded a significantly ($p < 0.001$) higher final percentage germination than any other treatment. Germination rate was highest in T5 and lowest in the control (T1).

All treatments had significantly ($p < 0.001$) higher final percentage germination and mean daily germination as compared to control (T1) except for T4. Although T3 had a significantly ($p < 0.001$) higher final percentage germination than any other treatment, T5 and T6 recorded high and almost the same final percentage germination and mean daily germination. Mean daily germination of seeds exposed to T5 and T6 had no significant ($p > 0.001$) differences. Germination rate of all treatments was significantly ($p < 0.001$) higher than that of treatment 1 (T1) except for T4 and the highest was recorded for T3.

Physical scarification of the seed coat filing and using abrasion paper can improve germination of seeds (Amoakoh et al. 2017). Our results show that percentage germination for filing (T4) was higher than that of T1. Although there was an improvement

Table 4 Effects of seed pre-treatment on germination characteristics of *A. garckeana*

	Germination characteristics		
Treatments	Final % germination	Mean daily germination	Germination rate
T1	5.53^{d}	0.0317^{d}	0.264^{d}
T2	22.23^{c}	0.1367^{c}	1.122^{c}
T3	47.20^{a}	0.2800^{a}	2.320^{a}
T4	13.90^{cd}	0.0800^{d}	0.682^{cd}
T5	38.83^{ab}	0.2267^{b}	1.878^{ab}
T6	36.07^{b}	0.1900^{b}	1.284^{bc}
Grand mean	27.3	0.1575	1.258
LSD at 5%	9.04	0.04879	0.7128
CV%	18.2	17.0	28.1
P value	<0.001	<0.001	<0.001

Different superscript letters in the same column indicate significant ($P < 0.001$) differences of germination in response to T4, the percentages of both plant species were generally low. Germination was found to be faster in mechanically scarified seeds and this indicates that when the seed coat is ruptured, rate of germination increase. This is in accordance with fact that hard seed coats prevent the entrance of water and exchange of gases. Amoakoh et al. (2017) reported no significant difference between the control and the mechanically scarified *P. campachiana* seeds.

Conclusions

Seeds of most arid and semi-arid tree species such as of *V. payos and A. garckeana* rarely germinate when exposed to conditions necessary for germination due to impermeable seed coat. Since the seed coats *V. payos and A. garckeana* are hard, they take long to emerge from the soil and are associated with poor germination in nursery establishment. This study indicated the existence of considerable variation in germination in these two plant species with respect to germination percentage, mean daily germination, and germination rate when subjected to different pre sowing methods. Acid treatments and boiling are the most effective methods in improving seed germination of *V. payos* and *A. garckeana* respectively. The findings of this study will enable selection of the most suitable pretreatment method for the two plant species and allow their establishment in plantations, propagation and domestication. We recommend that more and simple pretreatment methods for these plant species be explored.

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Impact of Mobile Night Kraals on Soil PH in Crop Fields—A Pilot Study

Rutendo P. C. Nyamusamba

Abstract Soil productivity is positively related to soil pH. Animal manure is good alternative for improving soil pH over time. "Impacting" is a term used to refer to the establishment of mobile kraals in crop fields, creating a nutrient hot spot. This pilot study sought to assess the effect of impacting on soil improvement. The study was carried out at the research and learning plot of Lupane State University, Zimbabwe. A randomized complete block design with two treatments was used: Kraal and no Kraal treatments.Soil samples were collected before planting. Data were analysed using the unpaired t-test. The pH in kraal treated plots averaged 6.0, while that of the no-kraal plots, averaged 4.8. Impacting can improve soil pH in one season. More research is needed on the impact of kraal duration on soil compaction and its effect on crop growth and development.

Keywords Cattle kraal · Impacting · Soil pH · Sustainable crop production

Introduction

Soil productivity in most of African communal and smallholder crop fields continues to decrease. Soil productivity is positively related to soil pH (Mukungurutse et al. 2018). Soil pH is mostly influenced by soil parent material, percentage of sand and fertilizer application. In Lupane and most of Zimbabwe communal and smallholder farms, soils are predominantly sandy and are acidic (Shoko and Moyo 2011; Mukungurutse et al. 2018). In addition, over the years, the use of acidifying fertilizers has been mismatched with liming requirements (Nyamangara and Mpofu 1996). Acidic soils are less productive: Nutrients are not readily available and microbial activity in the soil is reduced (Mukungurutse et al. 2018). The combined effect of poor soils and changing climate patterns increases crop stress resulting in reduced productivity and sustainability of farming. Liming is required at above 500 kg/ha to improve soil productivity (Shoko and Moyo 2011). Liming products are not readily available

R. P. C. Nyamusamba (✉)
Great Zimbabwe University, Main Campus, P O Box 1235, Masvingo, Zimbabwe
e-mail: rnyamusamba@gzu.ac.zw

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to communal and smallholder farmers both affordability and availability. Animal manure is good alternative for improving soil pH over time (Whalen et al. 2000; Naramabuye et al. 2008). In communal areas, application of animal manure follows a gradient with the fields close to the homestead getting more manure than those further away from the homestead. The use of mobile night cattle kraals in crop fields (impacting), is a possible method of improving soil pH with accessible resources (Chinyere et al. 2015).

"Impacting" is a term used (by those implementing the technology) referring to a crop-livestock integration technology where mobile kraals are placed in crop fields and cattle spend several nights before the kraal is moved to a new location within the field. Both solid and liquid excreta from the cattle are left where the kraal was placed creating a nutrient hot spot.

Communal grazing of livestock in rural areas presents an opportunity to improve crop-livestock farming systems through impacting. Impacting has the potential to improve soil health in crop fields (Chinyere et al. 2015). The technology reduces labour needed to carry manure from permanent kraals into the crop field. Some farmers in Hwange, Zimbabwe and other parts of the country have started using the technology and are pleased with the improved yield in one season implementation (personal communication). There is need to understand the changes taking place when impacting crop fields. This study seeks to assess the effect of impacting on soil pH in crop fields.

Materials and Methods

The study was carried out at Lupane State University research plot in Lupane, Zimbabwe. The soils are predominantly Kalahari sands. A randomized complete block design with two treatments was used: Kraal and no Kraal treatments. In 2016/17 season, three kraal treatments were established and in 2017/2018 season, thirteen kraal treatments were achieved. For the kraal treatments, eighteen cattle spend the night in one kraal for 7–10 days, and then moved to the next plot. Each plot was 8 m by 8 m. Soil samples were collected before planting to a depth of 20 cm and sent for analysis. Each impacted plot had the kraal placed once during off-season. Data were analysed using the t-test in Numbers Version 3.1 (1769).

Results

Soil pH was significantly ($P < 0.05$) different between the kraal and no-kraal treated plots in both 2016/17 and 2017/18 seasons (Table 1). The pH in kraal treated plots averaged 6.0 for the two seasons while for the no-kraal plots, it averaged 4.8 (Table 1).

Table 1 Soil pH results for the kraal and no kraal treated plots

	Kraal	No-Kraal	P-value
2016/17 season	6.4	4.8	0.026
2017/18 season	5.6	4.8	0.016
Average	6.0	4.8	0.001

Discussion

Soil pH is a good indicator of how suitable a soil is for sustaining crop growth. Soil pH of 6.0–7.5 is considered best for most crops including maize. Without kraal treatment, pH was acidic at 4.8. Nitrogen, phosphorus, potassium, sulphur, calcium magnesium and molybdenum are largely unavailable when pH is below 5.5. Manganese, copper, zinc and boron are moderately available. Only iron is available in acidic soil. At pH of 6.0, nutrients are available or moderately available (United States Department of Agriculture Natural Resources Conservation Service [USDA-NCRS] 2014). Most communal and smallholder farmers do not lime their crop fields. Generally, input schemes avail seed and fertilizer to communal farmers without much consideration for soil pH. Therefore, the fertilizer, although applied, is still not available to the growing crop. Thus, a poor crop yield is obtained. One week of kraal treatment might have increased nutrient availability by correcting soil pH to 6.0 from 4.8 within the same season. Applying cattle manure improves soil pH (Whalen et al. 2000; Mtangadura et al. 2017; Chinyere et al. 2015) but it comes with increased labour requirements and also causes nutrient gradients when applying manure to crop fields.

Conclusion

The use of impacting technology can improve soil pH in one season and make nutrient available for plant uptake. Research on the impact of kraals in crop fields will continue. Focus will continue on soil nutrient changes, soil compaction issues and the growth and development of the growing crops.

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Statement of Competing Interest
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Livestock Feeding and Alternative Production Systems in Semi-arid Areas

A Strategic Livestock Feeding Framework for Semi-Arid Areas

Clarice Princess Mudzengi, Everson Dahwa, and Clayton Simbarashe Kapembeza

Abstract The unpredictable and erratic rainfall characteristic of semi-arid areas often affects the growing season, hence rangeland productivity. Strategic management is therefore necessary for sustainability of extensive livestock production systems in these areas. A seasonal calendar for fodder and feed availability in a semi-arid landscape was synthesized based on a survey and focus group discussion. Point Centred Quarter method was used to identify the browse species in the area. There was a depletion of the grazing resource in the dry season, but an abundance of highly nutritive browse species. Cereal crop residues were also highlighted to predominate during this season. There were general decreases in crude protein (CP), and dry organic matter digestibility (DOMD) from the wet to the dry season, whilst acid detergent fiber (ADF) and dry matter (DM) increased. However, despite the decrease, CP of all browse species was higher than the minimum levels required for maintenance. A significant difference ($P < 0.05$) in ADF and DOMD was observed among the species during the dry season, but not in CP and DM ($P > 0.05$). In the wet season, only ADF significantly differed ($P = 0.006$) among the species. In order to address challenges due to the temporal variations in both quality and quantity of livestock feeds in semi-arid areas, it is proposed to develop a strategic feeding plan based on a wide range of socio-ecological practices; home based rations, and feed improvement techniques. Other veld management, rehabilitation and restoration methods are recommended.

Keywords Semi-arid areas · Ruminants · Animal feeds · Rangelands · Sustainable production

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C. P. Mudzengi (✉) · E. Dahwa
Department of Livestock, Wildlife and Fisheries, Gary Magadzire School of Agriculture, Great Zimbabwe University, P. O. Box 1235, Masvingo, Zimbabwe

C. S. Kapembeza
Division of Livestock Research, Department of Research and Specialist Services, Grasslands Research Institute, P. Bag 3701, Marondera, Zimbabwe

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Introduction

The livestock sector plays a key role in poverty alleviation and national nutritional security in most developing countries since livestock are a source of meat, eggs and milk. This sector also contributes towards employment and income generation for better livelihoods in semi-arid areas. In Zimbabwe, the greatest proportion of livestock is found within the semi-arid regions, under extensive production systems (Mudzengi et al. 2020). However, in these areas, range land productivity is affected by long dry seasons, frequent droughts, and unpredictable and low rainfall. Droughts have adverse effects on livestock production. For instance, droughts reduce the ability of cows to cycle, reduce pregnancy rates and increase calving intervals (Dzavo et al. 2019). The grazing resource remains the major feed resource in semi-arid areas as the cost associated with supplementary feed is unsustainable. This situation is exacerbated by challenges of management and utilisation of common pool resources (CPRs) such as rangelands, resultantly culminating in increased susceptibility of livestock to poor nutrition related deaths and low productivity (Ngongoni et al. 2009). It is therefore important for nutritionists and ecologists to explore the possibility of utilizing alternative feeding strategies.

Unlike the Sourveld which receives between 600 and 1000 mm of rainfall, and is mainly composed of perennial grass species which lose nutritive value and palatability during the dry season, the biggest challenge in the Sweet veld during the dry season is normally the decrease in feed quantity leading to nutritional stress in livestock (Tavirimirwa et al. 2019). In prolonged dry periods or droughts this can result in chronic malnutrition. Affected animals exhibit poor body condition which enormously compromises animal productivity. Therefore, it becomes logical under such circumstances to heavily supplement animals with concentrates. However, supplementary feeding constitutes more than 75% of the total variable costs of livestock production, which is expensive and beyond the affordability of most farmers (Matope et al. 2019). In most remote areas the feeds may also not be readily available due to poor accessibility. In this regard, it would then be necessary to shift towards low cost, locally available feed resources to ensure feed availability even during the dry season. Consequently, this would reduce the need for purchased feeds, and improve livestock production through increases in fecundity, weight gains, and improved health condition.

Previous studies have listed some of the livestock feed resources in rural areas (Ngongoni et al. 2007; Dzavo et al. 2019; Mudzengi et al. 2020). There have also been many innovations and technologies developed for feed production (Murungweni et al. 2004; Burque et al. 2008; Murungweni et al. 2012). However, there is lack of a strategic feeding framework based on locally available feeds, which results in inefficient use of these resources, and shortages in the most critical times. There is also limited information on trends in seasonal variation of the nutritive value of these feed resources. We postulate that determination of changes in quality of feed resources across seasons would result in development of more effective supplementation programmes.

The main aim of this study was to develop strategic feeds and feeding systems for livestock in semi-arid areas. Specifically, a seasonal calendar of fodder and feed availability in semi-arid landscapes was synthesized. The seasonal variation in crude protein, dry matter (DM), acid detergent fibre (ADF) and dry organic matter digestibility (DOMD) of selected key browse species was also determined. Based on this, a strategic livestock feeding framework was developed which may be helpful for strategic nutrient management under climate variability.

Materials and Methods

Study Site

The study was carried out in Malipati, a communal area at the periphery of Gonarezhou National Park in the South East Lowveld of Zimbabwe (Fig. 1). Malipati is located at an altitude of 300 m to 600 m above sea level, and it experiences mean maximum and minimum temperatures of 21.8 °C and 13.3 °C, respectively. Rainfall is low, erratic and unpredictable, with the highest of about 158 mm being received in December normally. *Colophospermum mopane* is the dominant tree species in the

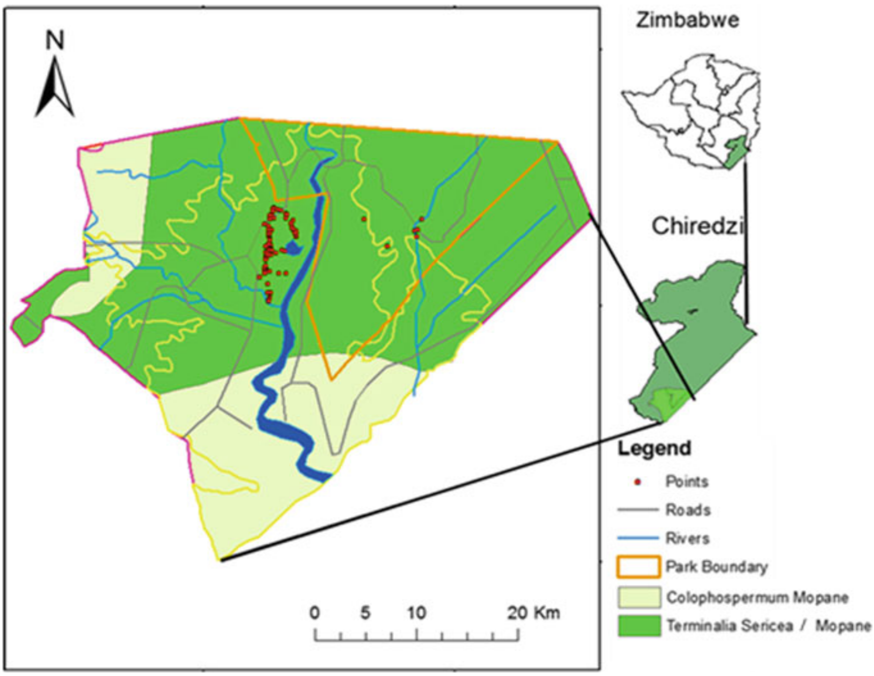


Fig. 1 Location of study area

area (Zengeya et al. 2013). Malipati falls in the Sweet veld, with *Urochloa mozambicensis* and *Aristida congesta* as the dominant perennial grasses. The Sweet Veld refers to a vegetation type in Southern Africa that retains palatability for livestock across seasons.

Data Collection

Survey and Focused Group Discussion

Individual questionnaires were used in a survey involving 138 respondents (12% of total households) randomly selected from all villages of Malipati. Information collected from the survey included socio-demography and livestock feeds and the feeding systems used by the farmers in the area. To further deepen our comprehension of livestock production and productivity in the area, as well as to get feedback on some of the issues arising from the survey, a focus group discussion (FGD) was also conducted involving 7 members (3 females and 4 males). The members included seasoned livestock farmers, traditional leaders and government extension officers from the Department of Veterinary Services.

Chemical Analysis of Key Browse Species

Using the Point Centered Quarter Method (Bryant et al. 2005), samples of foliage of 7 key browse species were collected during the dry (June and September) and wet (November and March) seasons. The species selected as key for livestock as suggested during the FGD were *Salvadora persica, Xanthocercis zambesiaca, Boscia albitrunca, Loncocarpus capassa, Hippocratea crenata, Colophospermum mopane* and *Dichrostachys cinerea.* Species verification was done at the National Herbarium, Harare, Zimbabwe. The fresh foliage was weighed using a scale, and it was air dried under shade, ground to powder and stored in air tight bags. AOAC procedure (AOAC 1990) was followed for determination of crude protein (CP), acid detergent fibre (ADF), dry matter (DM), and dry organic matter digestibility (DOMD) of the key browse species across seasons. Ash was determined by incineration at 600 °C for 24 h, and DM by drying to constant weight at 70 °C for 24 h in a forced air oven. The Kjeldahl method was used for CP, and a method by van Soest and Robertson was used for ADF. DOMD was calculated using the formula

$$\%\text{DOMD} = \frac{\left[\text{OM in sample} - (\text{OM in esidue} - \text{OM in control residue})\right] x100}{\text{OM in sample}}$$

Data Analysis

IBM SPSS (2012) was used for statistical analysis.

Results

The grazing resource is the major feed resource during the wet season (November–March). During this period the grass will be of high nutritive value. However, although there might still be some standing hay from April to August, this will be of low nutritive value. On the other hand, browse species such as *X. zambesiaca, B. albitrunca* and *H. crenata* provide highly nutritious foliage across seasons. As illustrated in Fig. 2, CP of the browse species decreases from the wet to the dry season, but does not fall below 10%. A similar observation is also made for DM. However, ADF generally increases from the wet to the dry season (April–October). The trends in chemical composition of the browse species are illustrated in Fig. 2.

From June to September livestock can also eat pods from these trees. It is observed that after crop harvests in April, cereal and legume crop residues are also available as

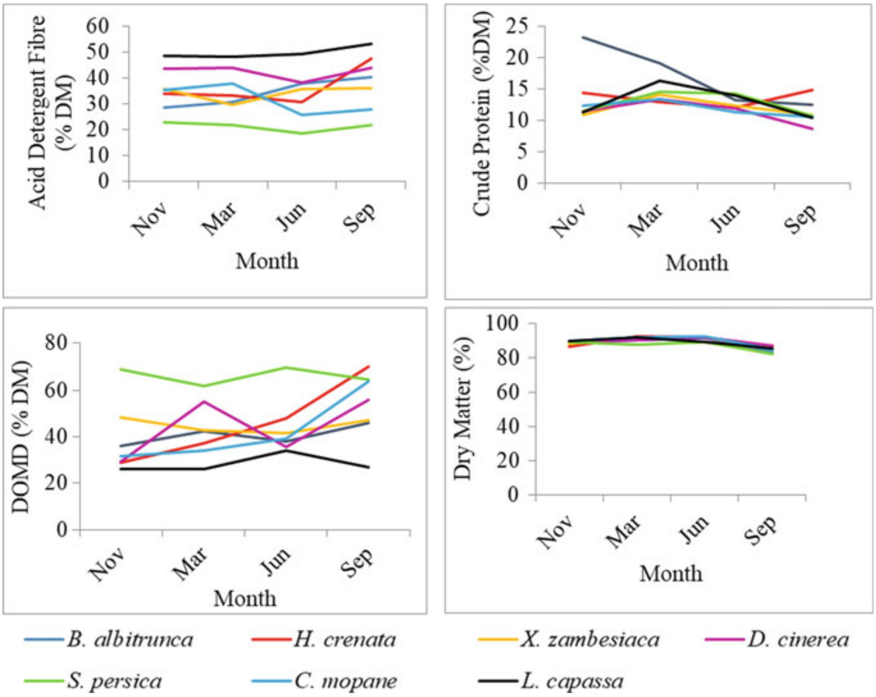


Fig. 2 Chemical composition of the browse species from wet to dry season

supplementary feed. However, unlike haulms from groundnuts and other legumes, maize stover and other cereal crop residues are of low nutritive value. A calendar summarizing seasonal availability of livestock feeds in semi-arid areas is given in Table 1.

Based on the calendar of seasonal feed availability (Table 1), a strategic feeding plan is developed (Table 2) with possible strategies of feed production, as well as the logical times of production and feeding. This plan does not include December, January and February as the grazing and browsing resource will be in abundance,

Table 1 Seasonal livestock feed availability

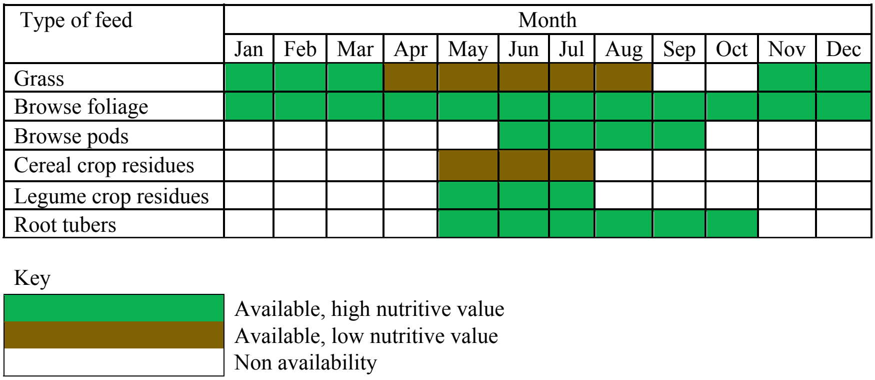
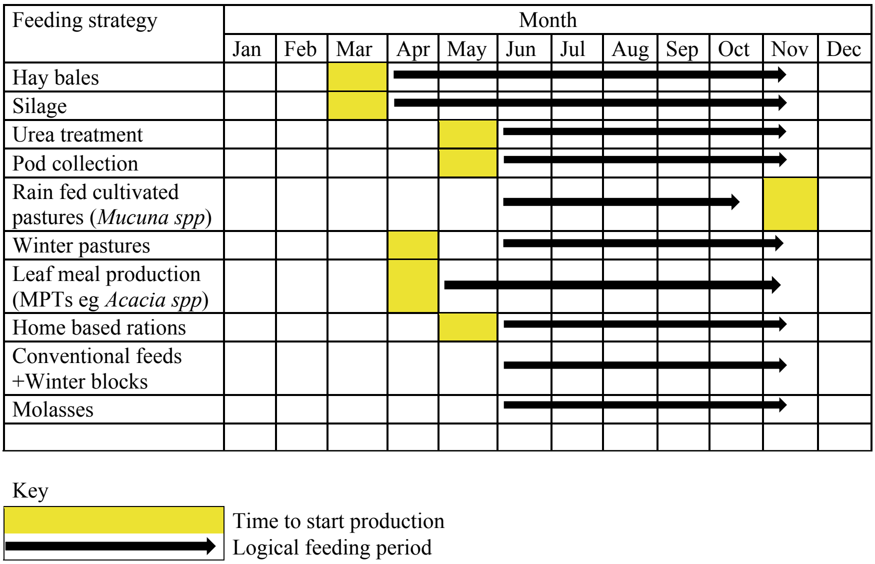


Table 2 Livestock supplementary feeding strategies for semi-arid areas



providing feed for the animals as indicated in Table 1. This plan also indicates that it is logical to make supplementary feeds just before the dry season.

Apart from strategic utilisation of feeds, proper rangeland management is also important. We recommend veld assessment as the first step, after which, according to the state of the range, any of the following practices can then be used: range fertilization, reinforcement, rehabilitation, control of undesirable plants and improved grazing management. These practices are aimed at increasing forage yields and quality, hence livestock production.

Discussion

The feed resource base in dry areas, if strategically utilised, can cater for the nutritional requirements of livestock throughout the year in semi-arid areas. For instance, the grazing resource is available, with high CP and low ADF from November to March. Thereafter, as the dry season progresses, CP of both grass and browse decreases, while DM and ADF increase due to lignification. This reduces feed digestibility and feed intake by animals. However, browse is still abundant during the dry season. Moreover, despite a decrease in CP from the wet to the dry season, our findings showed that the browse species with the lowest CP was *D. cinerea* at 8.72%, which is still adequate enough to provide minimum ammonia levels required for maximum microbial growth in the rumen. Such results have also been reported earlier (Ouédraogo-Koné et al. 2008). However, although this indicates that browse species can alleviate protein deficiencies for improved livestock production, especially in semi-arid areas, knowledge of inherent anti-nutrients would also be important as they affect digestibility.

The study also highlights some feeding strategies, as well as technologies for feed production. For instance, apart from direct consumption by animals, foliage of browse trees can be preserved as leaf meal through drying in cool shade, while pods of trees such as *D. cinerea* or root tubers like *Neorautanenia brachypus* can be incorporated into home based rations. There are also different techniques such as urea treatment which can be used to improve feed intake in animals fed poor quality stover of cereals like maize. However, as illustrated in this study, not only is it vital to know the different technologies of feed improvement or production, but correct time of feeding, as well as knowledge of the groups of animals in critical need of supplementation at different times of the year is also important. For instance, animals should be grazed during the wet season when the grass is still high in nutritive value. Preparation of home based feeds can then commence at the end of this season, for feeding during the dry period. Browse which persists across seasons can also be consumed by animals throughout the year, but would be more beneficial from June to November. Supplementation can then be targeted at pregnant heifers and cows, or sick animals. Additional essential programmes in the late dry season include vitamin injections and dosing since drinking water might be from contaminated sources.

Rangeland productivity is also dependent upon proper management, which starts with veld assessment to ascertain the composition, health, structure and abundance of vegetation available. As per the need, rehabilitation, fertilization or reinforcement may be done for rangeland improvement. For instance, fertilization is supplementing the existing soil with additional needed nutrients to increase yield, quality, and profit (OSU 2021). This study is unique in synthesis of a seasonal livestock feed availability calendar from which a strategic feeding framework was subsequently developed. However, the seasonal variation in quality for grass species is to be determined. In addition to analysis of CP, DOMD, ADF and DM, the analysis of otherparameters like energy, neutral detergent fibre and ether extracts is important. Efficient and effective supplementary feeding can improve livestock production and productivity during dry seasons in semi-arid areas.

Conclusion

In the Sweet veld, the dry season normally presents challenges in livestock feed availability, while it is less so for quality. The feed resource in semi-arid areas, if strategically utilised, can satisfy livestock nutritional feeds throughout the year. During the dry season, browse and residues of cereal and leguminous crops can be utilized as feed sources. Browse retains high nutritive value across seasons. In order to improve poor quality feeds like maize stover, a variety of technologies which include urea treatment can be employed. All the available information, technologies and indigenous knowledge on appropriate rangeland management practices can lead to sustainable livestock production in semiarid dryland areas.

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Feed Management for Smallholder Pig Farming Systems in Zimbabwe

Chipo Gombwe, Ngavaite Chigede, Tinoziva Hungwe, Rumbidzai Blessing Nhara, Everson Dahwa, Prosper Bright Muvhuringi, and Brighton Emmanuel Maburutse

Abstract Higher costs of commercial feed coupled with a hyper-inflationary environment in Zimbabwe is impeding developments in the pig industry. The performance and economic effect of substituting commercial feed with iso-nitrogenous and iso-energetic on-farm diets in smallholder pig production systems was investigated. Two diets (sorghum-soyabean and sorghum-sunflower) were compared with commercial pig grower feed to weaner pigs with feed change overs made fortnightly. Diets were restricted at 1.2 kg per pig per day during the first 14 days and adjusted to 1.5 kg per pig per day for the next 28 days. Average daily weight gains were significantly ($p < 0.05$) different between treatment diets: 300.0 g; 571.4 g; 757.1 g for sorghum-sunflower diet; sorghum-soyabean diet and commercial pig grower meal diet, respectively. Feed cost analysis indicated that, sorghum-sunflower diet cost US $3.38 to gain a kilogram of live weight, while that of sorghum-soyabean diet was US $1.79 per each kilogram live weight gain against a US $3.01 per kilogram with commercial feed. On-farm feeds can be used in pig production achieving the same performance goals under smallholder pig farming systems. Substitution of commercial pig feeds with on-farm protein and energy alternatives improves gross margins. On-farm feed management is instrumental to the smallholder sector as it cushion them from climate change induced feed challenges and inflationary price increases.

Keywords Pig farming · Feed management · Iso nitrogenous diets · Iso energetic diets · Smallholder farm · Zimbabwe

C. Gombwe
Zimbabwe Prisons and Correctional Services, Mutimurefu, Masvingo, Zimbabwe

C. Gombwe · N. Chigede (✉) · T. Hungwe · R. B. Nhara · E. Dahwa
Livestock, Wildlife and Fisheries Department, Great Zimbabwe University, Masvingo, Zimbabwe
e-mail: nchigede@gzu.ac.zw

P. B. Muvhuringi
Animal Science Department, Africa University, Mutare, Zimbabwe

B. E. Maburutse
Animal Science Department, Marondera University of Agricultural Sciences and Technology, Marondera, Zimbabwe

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Introduction

Feed is one of the most critical contributors to costs of pig production contributing up to 75% of total costs (Alagawany et al. 2015; PIB 2018). Feed challenges are exacerbated by seasonal variability and climate change (Rauw et al. 2020) which can take extremes either cold or hot. Feed intake is affected in both cold and hot climatic conditions as the thermoneutral zone of pigs is affected (Babinszky et al. 2011). In cold conditions feed intake increases whereas in hot conditions it decreases reducing growth performance of pigs. Energy and amino acids are the most costly components of pig diets (Lange and Birkett 2005) with energy constituting approximately 87% of the total cost (Noblet 2007). Thus, it is key for farmers to estimate precisely the energy value of feeds for less costly feeds. A guaranteed on-farm feed supply is a prerequisite in determining success of a piggery enterprise. With the adverse effects of climate change coupled with high feed costs, smallholder farmers should adapt to feeding low cost feeds which are formulated from ingredients which are less affected by changes in climate, such as sorghum which uses C_4 photosynthesis pathway (Babinszky et al. 2011). The quantity and quality of feed ingredients especially those of plant origin are affected by a combination of temperature and carbon dioxide increases as well as variation in precipitation (Ume et al. 2018). Commercial farmers can afford to purchase commercial feed for their piggery enterprise but not the smallholder farmers in rural areas as they have low capital base. Smallholder farmers rely on a variety of feed resources, using what is available at a particular time. On-farm feed mix can be done using climate adapted on-farm produced feed resources and cut on feed costs for the resource constrained smallholder farmers.

Feed given to pigs must provide energy, amino acids and minerals in their rightful proportions. On-farm energy sources come from cereal grain crops like maize, sorghum and wheat. In pig diets, corn is the widely used energy source in Zimbabwe because of its availability country wide (Mungate et al. 1999). However, due to incessant droughts, availability of corn for the feed industry is limited as the human demands takes center stage and gets first priority. Sorghum is commonly grown in low rainfall regions because of its drought tolerance (Seed Co 2019), for human consumption, livestock feed and ethanol extraction. Low-tannin and correctly processed sorghum (*Sorghum bicolor*) can replace corn in pig diets without reducing growth performance of pigs at a reduced feed cost (Cousins et al. 1981). These merits make sorghum grain an excellent constituent of on-farm feedstuff in dryland agriculture that can be used as the primary energy source in swine diets. Sorghum has 85–96% of the feeding value of maize (PIB 2018).

On-farm protein sources include crushed oil seeds (Whittemore et al. 2001): soyabean meal, cotton seed meal, sunflower seed meal, copra and canola meal (Bell 1993). Soyabean and sunflower are common among the Zimbabwean smallholder farmers. Stein et al. (2007) revealed that dehulled and non-dehulled soyabean meals are excellent sources of protein in pig production because of its excellent balance in essential amino acids. Soya bean requires roasting to inactivate the trypsin inhibitors it contains which bind protein digesting enzymes resulting in poor growth of pigs as protein availability will be reduced for body building (Goebel and Stein 2011). Overheating will result in reduced digestibility of lysine and other amino acids (Gonzalez-Vega et al. 2011). Sunflower (*Hellanthus annus*) meal composition depends on whether it contains the hulls or not. Hulled sunflower meal is of lower nutritive value and this affect palatability and digestibility which affect both voluntary feed intake and growth performance than dehulled meal (Alagawany et al. 2015). However, sunflower meal can be used in pig diets because of its sweet taste which appetize pigs (Mavromichalis 2014) and also low cost compared to soyabean meal and absence of anti-nutritional factors (Alagawany et al. 2015). Mavromichalis (2014), asserted that pigs will readily consume diets based on sunflower meal, if upper crude fiber limits are not exceeded.

Climate change induced feed shortages as a result of recurrent droughts calls for adaptive measures especially to the smallholder sector. High performing sows are sensitive to environmental changes, irrespective of their genetic make-up (Rauw et al. 2020). Production of feed from drought tolerant crops like sorghum and sunflower under smallholder farming systems goes a long way in mitigating pig feed challenges. In this context, a study was carried out targeting smallholder pig farmers, with sorghum as an alternative energy source and either sunflower or soyabean as the protein source. The objectives of the study were to assess potential of on-farm diets based on sorghum to promote growth in mixed breed weaner pigs under smallholder farming systems in a changing climate and to compare economics of on-farm sorghum based diets.

Materials and Methods

Study Area

The research was conducted at Mutimurefu[1] Prison farm which is situated 23 km East of Masvingo town, Zimbabwe. The farm is located under agro-ecological region IV of Zimbabwe and characterized with an average annual rainfall of 650 mm (Vincent and Thomas 1960), mean annual temperature of 18 °C with a range of 0 to 28 °C, light frost confined to low lying areas, shallow sandy clay soils with effective depth of less than 1 m and with natural vegetation of *Acacia sp, Combretum*, on shallow stony grounds. *Peltophorum africanum, Isoberlina globiflora, Number-jacks, Brachystegia glaucescens* on higher crest and slope areas. The predominating grasses are *Aristida sp mixed* with *Tragus sp.*

[1] Mutimurefu prison farm is a government institute under the department of Prisons and Correctional Service under the Ministry of Justice in Zimbabwe.

Health and Welfare of Pigs

Pigs were checked to assess thermal comfort (shivering and panting), diseases (labored breathing, coughing, diarrhoea, nasal discharge) and lameness (claw damage) during feeding time. Dry grass bedding was provided in the sties to insulate the floors and cushion pigs from temperature drops. Pigs were washed with soapy water at the beginning of the experiment. Hand spraying was done at weekly intervals alternating Triatix dip and Tickbuster acaricides as a preventive measure against the mites (*Sarcoptes scabiei*). A total of six eight weeks old Large white cross weaner pigs (initial weight 19.33 kg ± 1.03) were selected. Weaner pigs were randomly allocated to three pig sties with an area measuring 3 m × 2.35 m. Dry grass bedding was spread on the rough floors. The sties were well ventilated with built in feed and water troughs. Pigs were weighed individually on weekly basis. Records of weights including the induction weights were kept. Clean water was supplied ad libitum.

Preparation of Diet Constituents

All the feed ingredients were coarsely ground using a grinding mill with a screen size 2 to achieve a homogenous particle size. Sorghum variety, Marcia was used in the study. Reducing particle size is of great importance in improving feed efficiency (Healy et al. 1994). The grain size was reduced to produce a coarse meal which became more palatable to weaner pigs. Soyabean seeds were roasted on fire until the outer shell turned golden brown. Overheating was avoided as it has been shown to reduce digestibility of lysine and other amino acids (Gonzalez-Vega et al. 2011). Roasting was done to inactivate trypsin and chymotrypsin inhibitors found in raw soybeans (Goebel and Stein 2011). Roasting the soyabean produced an aromatic meal which was later on mixed with other feed constituents. Sunflower seeds were crushed making them more palatable to the pigs.

Feed was formulated using Pearson square method with two ingredients targeting a final diet with 18% crude protein. Sorghum meal used had 8.4% CP, soyabean meal 44% CP and sunflower meal 30% CP. Sorghum and Sunflower meal based diet was mixed using a ratio of 1 part protein to 1.25 parts energy source by weight while sorghum and soyabean meal based diet was at a rate of 1 part protein to 2.7 parts energy source. The commercial diet i.e. pig grower meal with crude protein content of 18% from a feed company was used as control.

Feeding of Weaner Pigs During the Experimental Period

The experimental period was split into three phases, with each phase being two weeks long. The first week was used for adaptation to the new diet and clearing of residual feed in the system of the pig. Weight changes were recorded during the second week of each phase. All the weaners received the same quantity of feed for two weeks period at a rate of 1.2 kg of feed per pig per day which was split by half and given twice daily, during morning, 0700 h, and late afternoon, 1500 h. Feeding times were consistently followed. In the first day of the experiment feed was gradually changed from pig grower meal to either sorghum-sunflower or sorghum-soyabean diet to prevent stomach upsets. During the second and third period of the experiment, feed quantity per pig was adjusted to 1.5 kg of feed per day to match increase in body size. Observations on voluntary feed intake were made 30 min after every feeding session to assess on intake of the formulated diets.

Experimental Design

A Latin square design, replicated twice, was used with the diet and time period as sources of variation. Three diets were allocated randomly to the pigs in the pens. Randomization was done such that each treatment diet occurred only once in each column and row. Feed was rotated after every two weeks in a cross over fashion (Table 1).

A standard model for Latin Square Design used: $Y_{ijk} = \mu + R_i + C_j + T_k + e_{ijk}$

Where, Y_{ijk} = growth of pig in the ith row, jth column subjected to kth treatment

μ = the overall mean of all observations

R_i = added effect common to ith row

C_j = added effect common to the jth column

T_k = added effect of the kth treatment

e_{ijk} = a random error.

Induction weights and weekly weight changes were measured using an analogue scale. Average daily gain (ADG) and feed conversion ratio (FCR) were computed.

Table 1 Layout of the design and treatment randomization

Period	Pen		
	1	**2**	**3**
1	T1	T2	T3
2	T2	T3	T1
3	T3	T1	T2

There were two weaner pigs in each pen
Key: Treatment diets: T1—Sorghum meal with soya bean meal; T2—Sorghum meal with sunflower meal; T3—Pig grower meal

Table 2 Average weight gain (kg)

Period	Pen		
	1	**2**	**3**
1	T1(5.5)	T2(3.0)	T3(10.5)
2	T2(1.2)	T3(1.25)	T1(3.05)
3	T3(4.0)	T1(3.5)	T2(2.0)

Treatments key: T1: Sorghum-soya bean meal; T2: Sorghum-sunflower meal; T3: Pig grower meal
The commercial diet produced a higher average weight gain, followed by sorghum-soyabean, and lastly sorghum-sunflower (Table 3)

Feed cost per weight gain was also computed to give an indication of fattening costs associated with each diet. Voluntary feed intake was checked.

Statistical Data Analysis

Two way analysis of variance was carried out, using Genstat 18th edition. Microsoft excel was used to compute cost of each live weight gain based on current prices of the on-farm feeds. Significant differences were indicated by a *p* value less than 0.05. Means were separated using Fisher's protected l.s.d.

Results

Average weight gain in each pen at a given period (6 weeks) is indicated in Table 2. Despite the diets being iso-nitrogenous, sorghum-sunflower meal diet had the lowest gains ($p < 0.05$) across the three phases whilst sorghum-soyabean meal diet produced similar growth performance to commercial diet in phases 2 and 3 (Table 2).

Discussion

In the face of climate change, feed supremacy need to be exhibited in terms of reduced stress to animals by environmental factors like increased ambient temperature and decreased feed quality. Sorghum-sunflower meal diet had the lowest gains during period one (Table 2). During period two, pigs fed sorghum-soyabean diet outperformed pigs on the other diets. However, all diets produced weight gains which were below the national average of 650 g per day (Kagande 2014). Commercial feed produced good weight gain in phase three followed by sorghum-soyabean meal. Despite the diets being iso-nitrogenous, sorghum-sunflower meal diet had the lowest

Table 3 Treatment means

Diet	Mean weight gain (kg)	ADG (g)	Cost/kg LW (US$)
Sorghum-sunflower	2.07[a]	300	3.38
Sorghum-soya bean	4.02[ab]	571.4	1.79
Pig grower meal	5.25[b]	757.1	3.01
Grand mean (kg)	3.78	542.8	
LSD	2.481		
***p* value**	$p < 0.05$		

On-farm feeds cost source: AGRITEX monthly reports. Mean weight gains with different superscripts indicates significant differences. ADG—Average Daily Gain.
Groups with the same superscript are statistically similar when using l.s.d to separate the means, thus [a] is not significantly different from [ab] and [b] from [ab]

gains ($p < 0.05$) across the three phases though a good voluntary feed intake was displayed by the pigs. The low performance of pigs fed sorghum-sunflower diet may be attributed to high fibre in sunflower meal (Alagawany et al. 2015; Mavromichalis 2014) as hulled sunflower seed was used to make the meal. The high fibre in the diet may reduce energy digestibility impacting negatively on weight gain of pigs relying on such diets (Li et al. 2018). Climate change, due to increased mean temperatures, support C_4 type of plants (Babinszky et al. 2011, p. 167) which are high in fibre component (Barbehenn et al. 2004). The current findings resemble utilization of such high fibre locally available feed components in pig production to economize piggery under a changing climate.

The low performance from sorghum-sunflower diet noted in this study is in line with findings from Green et al. (1988), who reported higher apparent digestibility coefficients (AD) of nitrogen (N) and amino acids for soyabean than sunflower meal fed to growing pigs. However, Green and Kiener (1989), reported similar amino acid digestibility of the sunflower meals and soya-bean meal and also asserted that digestibility of sunflower was not influenced by dehulling. There is need to limit the inclusion level of hulled sunflower meal in diets of growing pigs. Sunflower meal may perform better if mixed with other protein sources such as soyabean meal or when it is dehulled (Li et al. 2018). On the other hand, hulled sunflower has a higher dietary thermic effect[2] which does not go well with conditions of increased average temperatures due to climate change effects, hence reduced performance was observed from pigs fed a high fiber diet.

The weight gain produced from sorghum-sunflower diet was 46% of the standard weight gain considering a national average gain per day of 0.65 kg. This below average performance can be explained partly by the high dietary fibre, 25%, (Mavromichalis 2014) which is rich in lignin, an indigestible component associated with hulled sunflower meal (Goff et al. 2002). High fibre diets can reduce the apparent faecal digestibility of other dietary nutrients like crude protein and fat (Noblet 2007).

[2] Dietary thermic effect: refers to heat produced in the course of digestion and conversion of the dietary nutrients in an animals' body.

Sorghum-soyabean meal diet produced a gain which was 88% of the standard weight gain per day. The sorghum-soyabean results testify the potential of on-farm feeds under smallholder farming systems if ingredients are processed considering their limitations.

The cost to fatten pigs using sorghum-sunflower meal was high. The costs come in the form of housing, labour and feed costs as the pigs have to eat more and stay for more days to reach the desired weight gain. Sorghum-soyabean meal diet produced the gain with low cost compared to commercial feed. The low cost of on-farm feeds maybe partly due to no transport cost as they were on the farm.

Conclusions

On-farm feeds from drought tolerant crops such as sorghum can be used to fatten pigs. Sorghum is a C_4 plant which can do well with high carbon dioxide, a common feature with climate change, therefore, smallholder farmers can make a shift from maize to sorghum based diets in the face of adverse climatic changes. Sorghum-soyabean based diets perform better than sorghum-sunflower diets. Low weight gains are experienced when using hulled sunflower meal as the sole protein source and a limit has to be put on its inclusion level. Overall, on-farm feeds are cheap to use when rearing pigs.

Further research may be carried out on performance of pigs when fed with compound diet based on sorghum, sunflower and soyabean meal, on effects of partial substitution of commercial diet with on-farm feed to achieve cost effective and efficient diets and metabolism trials may be taken up to ascertain degree of use of the nutrients in the on-farm diets. To develop climate resilient pig farming, there is need for further studies on how best the higher fibre component in sunflower can be utilized. There is a need to study on impacts of using feed additives, such as enzymes, need attention with regards to fibre utilization for climate resilient pig production under smallholder systems. Most importantly, adaptive capability of different pig breeds need to be ascertained.

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Utilisation of Cactus (*Opuntia ficus-indica*) in Mitigating Drought Effects on Livestock in Matabeleland South Province of Zimbabwe

M. Banga, B. E. Maburutse, C. J. Mugova, T. P. Tauro, and C. Pisa

Abstract Seasonal droughts and erratic rainfall patterns are a major challenge in rearing livestock for smallholder farmers in Zimbabwe and the situation might worsen in the wake of climate change. A survey was carried out to determine the utilisation of cactus in mitigating drought effects on livestock in six districts of Matabeleland South of Zimbabwe. Informant interviews and questionnaires with both closed and open-ended questions were used as data collection tools. Survey data was analysed using Statistical Package for Social Sciences (SPSS) version 21. The survey showed that 35.58% farmers used cactus in mitigating drought effects on livestock. The rest depended on renting grazing lands (25.2%), selling livestock (16.02%), migrating to areas with water and forage (16.02%) and use of formulated feeds (7.18%). The survey revealed that 51 (79.7%), 6 (10.9%), 4 (7.8%) and 3 (4.7%) fed cactus to their goats, cattle, sheep and donkeys respectively. The farmers also indicated that the major challenges with using cactus were, lack of information, injuries associated with the cactus spines and unknown diseases in the production of cactus. It was also observed that cactus adoption had been increasing since 2010 with the highest number of adopting farmers recorded in 2016. The spineless variety was the most popular. It was also observed that many farmers got to know about cactus from other farmers. The study showed that cactus could be used as feed for livestock but adoption for use is curbed by lack of knowledge. There is need for more extension work to encourage the use of cactus in drought years to reduce livestock loss by farmers. Nutritional and feeding value of cactus varieties for different livestock species is also recommended.

Keywords Animal feed · Cactus · Drought and climate change mitigation · Livestock

M. Banga · B. E. Maburutse · C. J. Mugova
Department of Animal Science, Faculty of Agricultural Sciences and Technology, Marondera University of Agricultural Sciences and Technology, P O Box 35, Marondera, Zimbabwe

T. P. Tauro · C. Pisa (✉)
Department of Natural Resources Management, Faculty of Earth and Environmental Sciences, Marondera University of Agricultural Sciences and Technology, P O Box 35, Marondera, Zimbabwe

X. Poshiwa and G. Ravindra Chary (eds.), *Climate Change Adaptations in Dryland Agriculture in Semi-Arid Areas*, https://doi.org/10.1007/978-981-16-7861-5_23

Introduction

Livestock play very important economic and socio-cultural roles for the welfare of household livelihoods. They are a source of food (meat and milk), income, employment to stockmen, manure, transport, agricultural traction and act as asset savings (Bettencourt et al. 2015; Randolph et al. 2007; Murungweniet al. 2012). Cattle, sheep and goats are pivotal in augmenting incomes from other ventures and enhance food security. Cattle provide milk, manure and draught power (Masikati 2011; Khombe 2002) as well as meat and hides as terminal products (Mavedzenge et al. 2006). In the rural areas of Africa, herd size determines the wealth status and dignity of an individual household (Murungweni et al. 2012; Maburutse et al. 2012) making livestock production critical particularly in the semi-arid regions where crop production is limited by rainfall (Chitonga 2013).

Global animal production has been on the increase since 1961 (Liu et al. 2016) with Africa lagging behind. Small scale farmers in Africa have small herds of cattle, very few goats and chicken and this is attributed to a number of problems. The challenges faced by these farmers include, lack of investment, limited working capital and little to no access to credit facilities, insufficient farm size, poor access to extension officers who, in turn, are often under-resourced. Poor knowledge of pasture and animal management, poor veld condition and variable climate (MacLeod et al. 2008) negatively influence livestock production for small scale farmers. Massive livestock deaths have been observed in the lowveld of Zimbabwe as a result of feed challenges as the region receives erratic and subnormal rainfall amounts. Livestock become malnourished leading to the manifestation of different diseases and conditions which pose threats to the animals.

During the 1991 to 1992 drought in Southern Africa, 23% of the national cattle herd (Tobaiwa 1993) and 4500 (FAO 2011) goats were lost in Zimbabwe alone. Repeated droughts and intra-season dry spells have led to massive livestock mortality due to extreme shortages of water and starvation in the semi-arid areas of Zimbabwe (Timpong-Jones et al. 2014) and the frequency has since been increasing over the past 5 years. Over the years, climate change has exacerbated drought leading to more compound effects on livestock because of lack of adequate feed resource bank in the veld especially in the communal areas thus the need for alternatives.

Ruminant animals are dependent on forage and fodder crops for their productivity (Shiawoya and Tsado 2011), making forage and fodder crops, central to the development of the livestock industry. This feed resource, which consists mainly of grasses, legumes, browses, and cereal crop residues, varies widely across the major agro-ecological zones of Zimbabwe. However, during drought years, there is little forage feed and thus communal farmers tend to cull poorly performing animals, so as to reduce nutritional requirements of the herd and provide more feed for the younger and productive cattle (Lawton et al. 2012; UGA Cooperative Extension 2019). Calves are also weaned early so that the nutrient load is lightened on the cow for it to maintain its condition. Some provide supplementary feed or ship the animals to where there is feed which is very costly and most smallholder farmers are not resource endowed. While these strategies mitigate the effects of drought on livestock, many face challenges with these techniques thus have resorted to some non-conventional strategies like feeding their animals with cactus (*Opuntia ficus indica*) (Zimmermann et al. 2008).

Out of desperation, farmers in Matabeleland South province started using cactus and observed a reduction in disease incidences and mortality. Cactus has antioxidants in the vegetative parts making it a medicinal feed supplement. It also provides the animals with enough water due to its high moisture content of 80–90% (Tesoriere et al. 2008; Felker et al. 2012). Cactus has good regeneration ability relative to other drought tolerant fodder crops in arid and semi-arid areas and can withstand severe defoliation thus making it for a good animal feed resource. Cactus has the potential to produce more than 20 t DM ha^{-1} $year^{-1}$ and provide 180 t ha^{-1} $year^{-1}$ of fresh good-quality water stored in the cladodes for the livestock (Dubeux et al. 2015). This productivity is enough to produce forage to sustain five adult cows per year, at least 60-fold increase over rangeland productivity (Dubeux et al. 2015). Gusha et al. (2015a) reported that cactus production can be done on a tenth of land reserved for the pasture. Because of their crassulacean acid metabolism CAM (Guevara et al. 2011), cacti can produce 4–5 times dry matter for every millimetre of rainfall (Degu et al. 2009). This plant has photosynthetic metabolism consisting opening of stomata to capture atmospheric CO_2 only at night, as the air temperature is lower and humidity higher, reducing water loss to the environment (Nefzaoui et al. 2014). The extensive, well-developed root system and absence of leaves of cactus allows it to withstand harsh climatic conditions such as extremely high temperatures (Singh 2009). These characteristics make it potential non-conventional forage to incorporate in livestock farming during drought in Matabeleland. However, the extent and methods of utilisation of cactus in Matabeleland South Zimbabwe is however undocumented. The study therefore sought to assess the adoption and utilization of cactus as a feeding strategy in Matabeleland South province of Zimbabwe as farmer livelihoods are largely dependent on livestock production.

Materials and Methods

Site Description

The study was conducted in the Matabeleland South province of Zimbabwe. The area lies in the lowveld of Zimbabwe in the agro-ecological Natural Region IV (Vincent and Thomas 1961), which receives an annual rainfall of 450 mm to 650 mm and has a temperature range of 6–28 °C. The area is dominated by infertile sandy soils with low organic matter, making crop production risky and therefore more suitable for extensive livestock production. Common grasses dominating the veld include

Table 1 Distribution of farmers who rear livestock (cattle, sheep and goats) in the areas where cactus is predominantly used

District name	Population of livestock farmers	Sample sizes (n)
Esigodini	29	16
Shangani	65	37
Mangwe	59	33
Kafusi	27	15
Bulilima	68	38
Filabusi	72	42
Total	320	181

Eragrostis viscosa, *Chloris virgata*, *Aristida adscensionis* and *Dactyloctenium giganteum*. A variety of shrubs and trees are also found inclusive of *Grewia monticola*, *Colophosphermum mopane* and other species of *Acacia* and *Combretum*.

Sample Selection

The study population targeted livestock farmers from different districts within the province who were selected using the snowball sampling technique. Data for areas where cactus is predominantly used was collected from AGRITEX officers (Table 1). Sample sizes for each area were then calculated using Raosoft sample size calculator using the parameters; population size: 320; margin error: 5%; confidence level: 99%; response distribution: 50% to give a total of 181 sample units (Table 1).

Data Collection

Key informant interviews and questionnaires with both open-ended and closed-ended questions were used as data collection tools. A pragmatic approach was taken as it sought to understand farmers' experiences and perspectives and capture all important aspects by virtue of using the qualitative as well as the quantitative data for authentication. Before the actual survey, pre-testing of the questionnaire was done for validation purposes. Extra data was collected via standardized or open-ended interviews for the exploratory survey. Triangulation technique was used to verify findings generated by different data collection tools.

Data Analysis

Survey data was cleaned coded and analysed using Statistical Package for Social Sciences (SPSS) version 21. Content analysis was used for the responses from the semi structured interviews with similar messages. The analysis involved generating descriptive statistics of interviewees and logistic regression analysis was used for factors influencing cactus utilisation and use.

Results

Mitigation Strategies

Respondents reported risk aversion strategies they were using in mitigating drought effects on livestock. Famers used five risk aversion strategies which included use of supplementary feed, migration to areas were feed was available, renting of grazing land in commercial farms, selling of livestock and feeding cactus to the animals. Among the five strategies reported by farmers 35% of the farmers used cactus, followed by renting grazing lands from commercial farms (26%). Smaller percentages of farmers sold their livestock (16%) or migrated to areas with water and forage (16%) with the least percentage (7%) of farmers using formulated feeds (Fig. 1). However, cactus non-users constituted 64.64%, whilst 35.36% of the farmers used cactus.

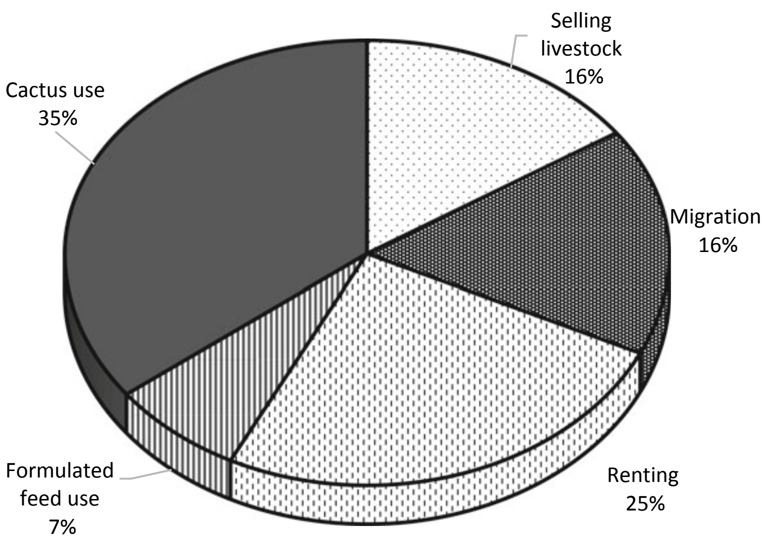

Fig. 1 Proportion of farmers' mitigation strategies for drought on livestock in Matabeleland South

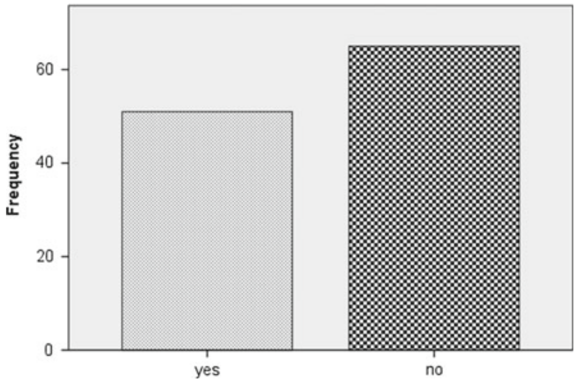

Fig. 2 Awareness of cactus use as feed in livestock farming

Awareness of Cactus Use as Feed for Livestock

The survey revealed that 65 (55.6%) of interviewed farmers who did not use cactus as animal feed had no idea about cactus as livestock feed while 52 (44.4%) of cactus non-users knew about it (Fig. 2).

Sources of Information

Twenty-eight (43.8%) of the 64 farmers interviewed mentioned that they got to know about cactus from other farmers who used cactus to feed their livestock (Fig. 3). Those

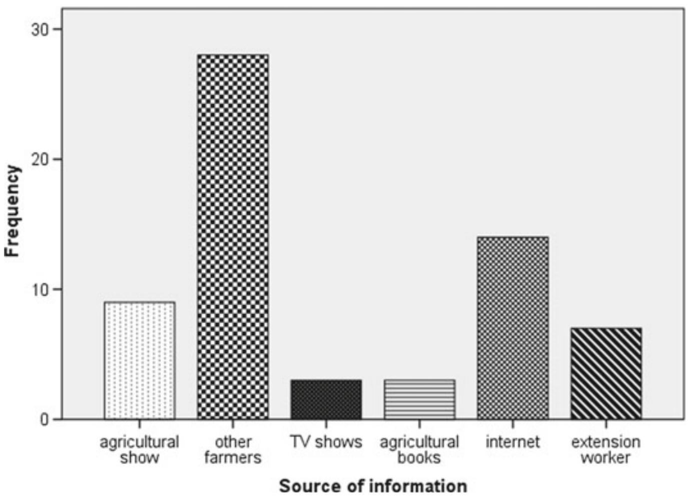

Fig. 3 Sources of information on cactus use

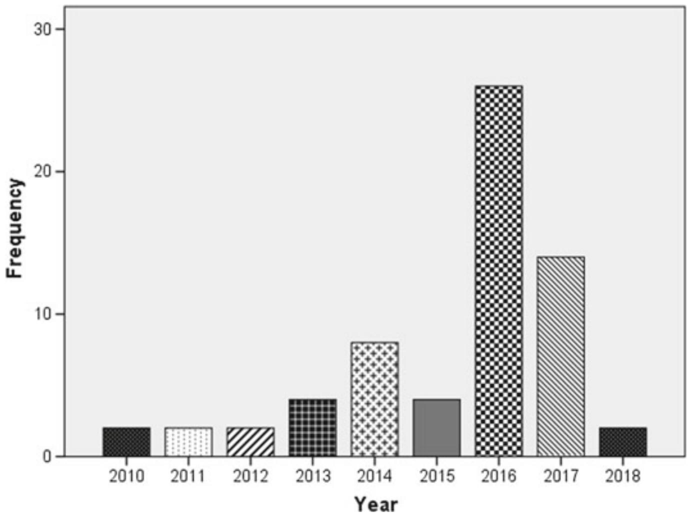

Fig. 4 Cactus adoption as drought mitigation strategy for livestock in Matabeleland South

who got the information from the internet, agricultural shows and extension workers constituted 21.9, 14.1 and 10.9% respectively. A small percentage of farmers got the information from television shows (3%) and agricultural books (3%).

Cactus Use Adoption by Year

Before 2012 farmers were not keen in utilising Cactus in their farming system. However, in 2013 and 2014 there was a rise in utilisation of the natural resource as a livestock feed with 6% and 12% more farmers starting to use cactus respectively. It was noted that the majority of the farmers started utilising Cactus for their livestock in 2016 with 40% more farmers joining the group of cactus users while another 22% also adopted it in 2017. However, only 3.1% of the interviewed farmers had started using cactus in 2018. (Fig. 4).

Livestock Feeding on Cactus

Cactus users reported on livestock species that commonly consumed cactus. The survey revealed 51 (79.7%), 6 (10.9%), 4 (7.8%) and 3 (4.7%) fed cactus to their goats, cattle, sheep and donkeys respectively (Fig. 5).

Direct grazing, silage plus cut and carry were utilisation methods used by farmers to feed cactus to their livestock. Out of 64 cactus users, forty-one of farmers use

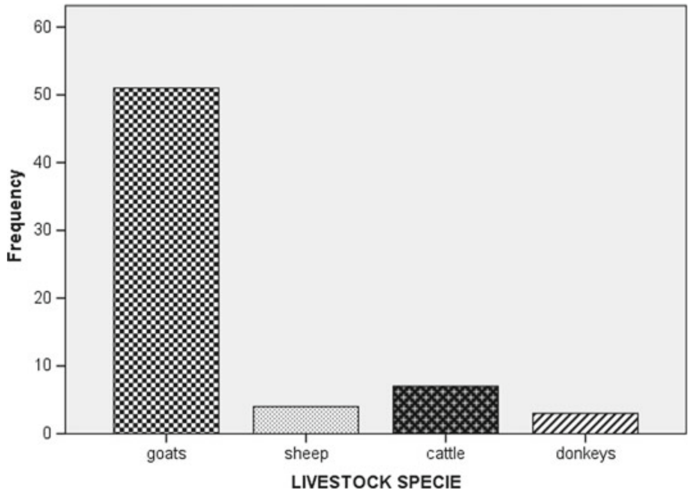

Fig. 5 Livestock species feeding on cactus

direct grazing (64%), 17 (26.6%) made silage and 9.4% (6) used the cut and carry method, (Fig. 6). Different reasons were cited for the different feeding methods.

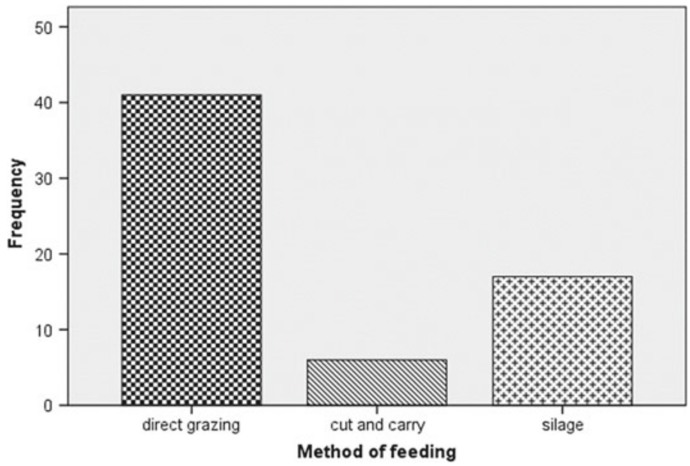

Fig. 6 Cactus utilisation strategies by farmers

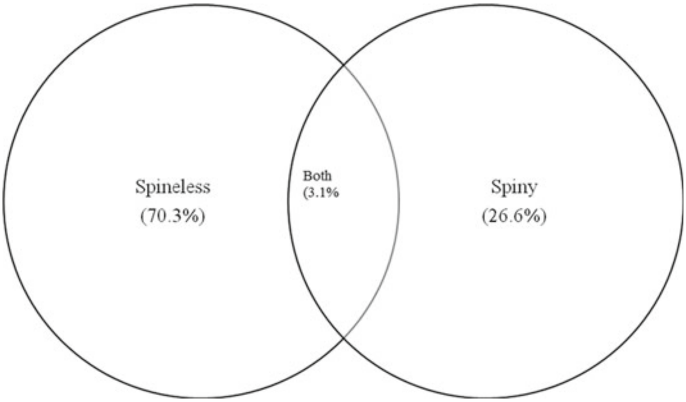

Fig. 7 Cactus varieties used by farmers in livestock farming

Cactus Varieties Used by Farmers

Two cactus varieties were used in Matabeleland south as livestock feed. 70.3% of the 64 cactus users used spineless or thorn less varieties to feed their livestock while 26.6% used spiny or thorny varieties (Fig. 7). A smaller proportion of farmers used both varieties (3.1%).

Challenges Faced in Using Cactus as Livestock Feed

Cactus users reported challenges they are facing in using cactus in mitigating drought effects on livestock. Of the 64 cactus users, twenty-six (40.6%) reported that unknown diseases were affecting the cactus (Fig. 8). Some farmers lacked information on how to grow, maintain and utilize cactus (32.8%). A smaller proportion of farmers (26.6%) reported that spiny cactus caused injuries and deaths of livestock when directly grazed.

Barriers to Cactus Adoption by Cactus Non-users

Cactus non-users reported they lacked information on the establishment and management of cactus (36%) and did not have enough space to introduce cactus in the production system (18%). The invasive nature of cactus deterred 20% of the farmers from using cactus as feed (Fig. 9). Ten percent of the farmers reported that cactus was affected by diseases which are difficult to control. Some farmers (14%) did not

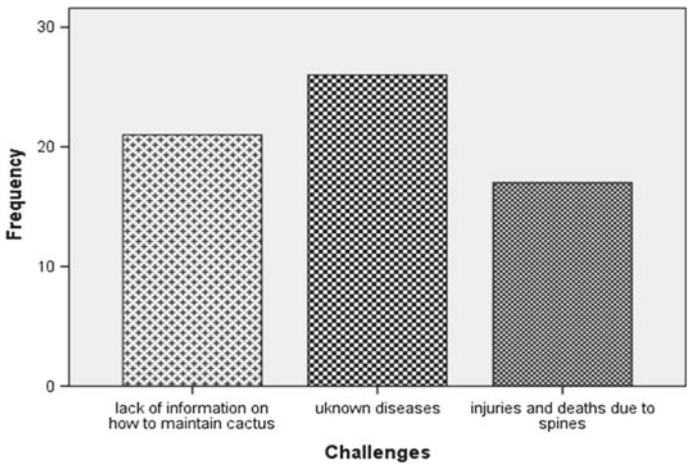

Fig. 8 Challenges faced by farmers due to use of cactus as livestock feed

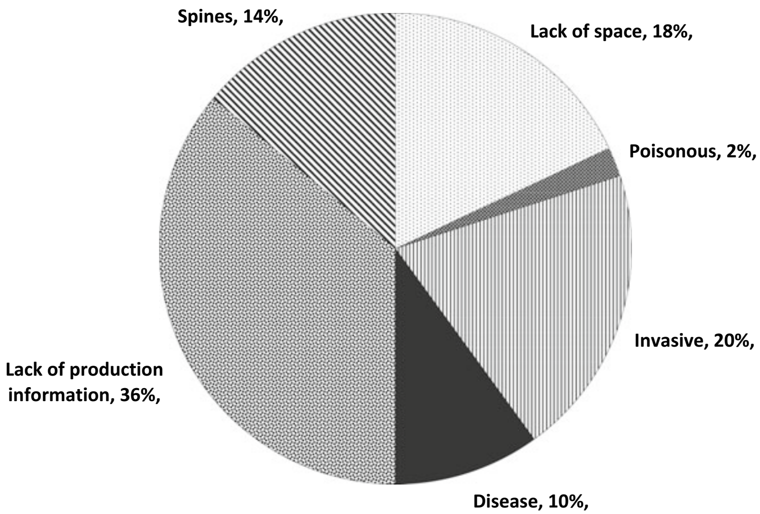

Fig. 9 Barriers to adoption of cactus use by cactus non-users who are aware of cactus use as livestock feed

want to use cactus since it is spiny, caused injuries to animals and 2% thought it was is poisonous.

Discussion

Mitigation Strategies

Cactus use as a feed shortage mitigation strategy in the face of climate change was most popular among farmers in Matabeleland South. The cactus users claimed that cactus improved livestock production during drought years. This could be attributed to the nutritional status of cactus. Cactus cladodes are high in soluble carbohydrates (640–710 g/kg DM) and calcium (40–80 g/kg DM), crude protein (25–60 g/kg DM), high in calcium and β-carotene, but low in fibre (NDF, 170–280 g/kg DM) (Ben Salem and Abidi 2009; Ben Salem and Makkar 2010). Cactus has considerable palatability, tolerance to salinity, high digestible energy content and high content of mucilage.

The survey however revealed that most farmers (64.64%) were not aware of the use of cactus as animal feed therefore relied on the other strategies of renting grazing lands on commercial farms, selling livestock, buying formulated feeds and migrating to areas with water and forage which was costly for them. For instance, when drought causes the farmers to cull their herds usually there is a flood of supply to cattle markets which can cause prices for cattle to drop significantly (Scasta et al. 2016) and thus farmers lose a lot of revenue as they are later forced to buy replacement animals at higher prices. There were however some farmers who were aware of cactus use but still did not adopt the technology due to lack of space as the plant is believed to be invasive. Some did not adopt due to the perception that it could be poisonous. This notion could have been brought about from observations that cactus can have laxative effects especially when fed alone due to the high moisture content in the cactus cladodes (Souza et al. 2009; Santos et al. 2010; Gusha et al. 2015b).

The survival strategies used by cactus non-users have a number of challenges with farmers who sent off their livestock to areas with water and forage facing predation problems. Predation was quantified as a great cost to them through veterinary services and financial loss especially in areas in close proximity with national parks such as Matopos. Anderrson et al. (2013), reported that areas with high ground cover near parks experienced a 1% probability of lion and/ or hyena kills per annum per household which was higher than the kills in areas located further away from the park (0.2%). Loss of one cow to predation every year per household translates to a loss of approximately US$400 for a mature beast (Anderrson et al. 2013). Other than predation as a cause of death, diseases are a major threat to livestock production. During migration of animals, transmission of corridor diseases from carrier buffaloes that came in to contact with livestock could also result in more deaths (Anderrson et al. 2013).

Some farmers used formulated feeds for their livestock during the period of feed deficit and this proved costly. High feed production costs due of competition for raw materials such as maize which are also used for human consumption resulted in the high costs of feed. Continual renting of grazing lands on commercial farms resulted in more costs being incurred. However, the total cost and frequency is determined by the herd size (Wagner 2008).

From this research, it was determined that farmers chose cactus over other mitigation strategies because it was cheaper as most of the households used family labour to grow it. Cactus production costs also averaged US$17.50 per 1 tonne of herbage. Other than drought as a cause of death, diseases are a major threat to livestock production. Cactus users however, affirmed that feeding their animals to cactus decreased veterinary costs on livestock by more than 50%.

Source of Information on Cactus Use

Farmers in Matabeleland South acquired the cactus information as an animal feed from various sources. There was indication of great farmer interaction as 43.8% (Fig. 3) of the farmers sourced drought mitigation strategies in livestock farming from fellow farmers. Farmers in Matabeleland were seen to embrace Information and Communications Technology (ICT) in livestock farming as 21.9% got to know of cactus via the internet. This could promote livestock production because it enables farmers to get current production information (Chhachhar et al. 2014).

Agricultural shows and extension workers constituted lower percentages, 14.1% and 10.9% respectively, because agricultural shows are done once a year and farmers did not meet extension officers often as the extension workers did not have adequate resources to cover their assigned areas. Other sources which included television shows (3%) and agricultural books (3%) played a minor role in informing farmers about cactus use. This was so because most of the communal farmers have no televisions and few books were published due to lack of information about the plant.

Adoption of Cactus by Year

In 2016, the water holes dried up and the pastures dwindled leaving farmers unable to feed their livestock and sell them for much (Christenhusz and Byng 2016). Maize prices were high making it expensive for farmers to make on-farm feeds. The price of a 20-L bucket of maize was as high as US $9.00 (Christenhusz and Byng 2016). Farmers in Matabeleland South province therefore adopted cactus as animal feed to prevent deaths of livestock due to starvation. These farmers constituted 40.6% of cactus users.

In 2017, more farmers adopted the use of cactus as an animal feed but the rate had decreased due to use of other drought mitigation strategies like migration to areas with good rangeland and watering points. During the 2017/2018 season alone Zimbabwe lost 20 000 cattle with Matabeleland South alone losing more than 4000 cattle and approximately 3 000 cattle in Masvingo. Farmers who adopted cactus use in 2017 constitute 21.9%. Only 3.1% of the farmers adopted cactus in due to lack of adequate knowledge on how to grow, maintain and utilize the plant. The low percentage recorded could also have been due to the fact that the survey was done in the first half of the year when feed was still in abundance and a lot of farmers were still dependent on the veld.

Cactus is affected by unknown diseases which are difficult to control and has resulted in some farmers unwilling to venture into cactus production. Also, most communal areas farmers do not have enough cropping land thus they are failing to introduce cactus due to shortage of land (FAO 2009).

Livestock Feeding on Cactus

Most farmers fed cactus to their goats which are the most versatile ruminant animals. The unique saliva of goats has a variety of enzymes which make them efficiently utilize cactus and any type of plant (Ceballos et al. 2009). Cactus has considerable palatability, tolerance to salinity, high digestible energy content and high content of mucilage (Gusha et al. 2015a) and thus can be used as forage by a number of livestock such as goats, cattle, sheep and donkeys. Most of these animals were seen to graze cactus directly.

Direct grazing of spineless was reported to be the most common method (64%) used by farmers in feeding cactus to livestock. The spineless varieties did not harm to animals when they are directly grazed. Arakaki et al. (2017) reported that the spiny cactus variety caused injuries and consequently deaths especially to young animals. Direct grazing also allows farmers to reduce labour costs as compared to use of silage and cut and carry method. The cut-and-carry method was used by 9.4% of farmers and was labour intensive as it required chopping and carrying the pads to a different location before feeding livestock. Use of direct grazing also saved time as there is no need to process the green forage, unlike, in silage making.

Some farmers (26.6%) preferred making silage from cactus due to its high sugar (0.79–1.9%) and water content making it suitable for a fermentation process (Arakaki et al. 2017). Silage making increases the palatability of cactus therefore increasing intake by livestock. Gusha et al. (2015) observed increased nutritional status when the silage was made from cactus and leguminous biomass like *Leucaena leucocephala* and *Acacia angustissima*. The cut-and-carry method was beneficial in that it prevented overutilization or overgrazing of cactus allowing quicker rejuvenation (Jeong et al. 2009).

Cactus Varieties Used by Farmers

Larger proportion of cactus users adopted the spineless varieties (70.3%) while 26.6% used the spiny varieties and 3.1% used both varieties. Most farmers reported shunned the thorny variety as it required removal of spines by burning therefore more labour.

It could not be grazed directly and thus farmers were forced to use the cut and carry method which is labour intensive. The burning of spines is done using propane which is expensive and requires skilled prevent over burning of the cactus pads (Jeong et al. 2009). Though the spines could be removed by a chopper, such tools are expensive for the smallholder farmers. Direct grazing of the spiny cactus caused mechanical injuries to livestock increasing the susceptibility of animals to diseases and stress resulting in reduced feed intake and growth due to wounds on the mouth.

Challenges Faced in Using Cactus as Livestock Feed

Farmers (40.6%) that used cactus to feed their livestock reported that, cactus was being attacked by unknown diseases which were difficult to control leading to extensive degradation of cactus plants resulting in continual shortage of feed. The lack of adequate information on how to grow, maintain and utilize cactus also posed a great challenge for cactus user. The farmers were not aware of the best propagation and management methods for a successful establishment cactus rangeland.

The smaller percentage (26.6%) of farmers using thorny varieties of cactus faced challenges of injuries and deaths of livestock when they directly grazed the cactus. The thorns are mostly damaging the mouth parts and eyes thus reducing feed intake and eventually death. However, this challenge could be overcome by fencing the thorny cactus preventing direct grazing. Positive impacts have been noted on livestock due to use of cactus for instance better growth rates (Zimmermann et al. 2008) and reduced veterinary costs.

Awareness of Cactus Use and Barriers to Its Adoption

Though a large percentage (55.6%) of the cactus non-users knew of cactus as a drought mitigation strategy they did not adopt the technology. They cited lack of knowledge and accurate information on how to grow maintains and utilize the versatile plant (36%), they lacked space (18%), spiny (14%) and invasive (20%) nature of cactus varieties as some of the reasons for not using cactus. Some thought cactus was poisonous 2%. The idea of cactus being poisonous could have been brought about by the fact that cactus can have a laxative effect on livestock (Menezes et al. 2010). Arakaki et al. (2017) reported that many of the diseases that affect cactus are not known and the farmers lack information on the epidemiology and aetiology of such diseases, thus, they are difficult to eliminate.

Conclusions and Recommendations

The study showed 35% of smallholder farmers in Matabeleland South used cactus to feed their animals during drought years and some had already started establishing it in their fields to ensure availability. The spineless varieties were most preferred as they had less challenges in terms of animal injury and could be grazed directly reducing labour requirements for feeding. The major challenges in cactus use included lack of sufficient information, cactus diseases and animal injuries. Non cactus users shied away from cactus mainly due to invasive and spiny nature of cactus, disease and lack of space for production. Cactus has a great potential in alleviating effects of drought on livestock and thus more research on the agronomic requirements of cactus to enable its multiplication and ensure feed availability for livestock at all times is needed.

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Potential of Triploid Rainbow Trout (*Oncorhynchus mykiss*) Under Cage Culture in Afromontane Reservoirs of Eastern Highlands, Zimbabwe

Tinashe Chapinduka, Everson Dahwa, Rachel Gwazani, Clarice P. Mudzengi, and Banele T. Maya

Abstract Rainbow trout, a sport fish naturally grows well in cool and flowing water. However with decreasing water flows and pollution in many rivers due to climate change and variability, suitability of the natural habitat is threatened. Alternative production systems can be necessary to mitigate the negative impact. In this study we aimed to test the production potential of trout using cages in an inland dam. We selected fingerlings weighing 94 ± 5 g and compared production of trout in floating cages versus raceways with flowing water. Using non-parametric methods, we tested if there were differences in feed and growth patterns on fish in raceways and cages. Mann–Whitney U test showed that there was no significant difference (U = 40, $p = 0.118$) between feed intake for race ways and cages. Feed conversion ratio differently increased but did not differ among the two groups. Mann–Whitney U test showed that there was no significant difference (U = 87, $p = 0.410$) on overall fish mortality between raceway and cage groups. While care is needed on the initial handling of fingerlings and stocking to reduce mortalities, cages provide an alternative inexpensive method for growing trout in cool temperature environments.

Keywords Rainbow trout · Cage · Raceway · Fish · Climate change

Introduction

Rainbow trout is a cold water fish native to North America and belongs to the Salmonidae family. It has a fusiform body and blue to olive green colour with pink lateral line (FAO 2012). Globally Rainbow trout is used as a sport fish and its pink and white flesh is highly valued. The species require pristine, well oxygenated unpolluted and flowing water (Picker and Griffiths 2011). Minimum required amount of water

T. Chapinduka · E. Dahwa (✉) · R. Gwazani · C. P. Mudzengi
Department of Livestock, Wildlife and Fisheries, Great Zimbabwe University, P. O. Box 1235, Masvingo, Zimbabwe
e-mail: edahwa@gzu.ac.zw

T. Chapinduka · B. T. Maya
Zimbabwe Parks and Wildlife Authority, Nyanga National Park, Nyanga, Zimbabwe

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in a through flow system to raise a tonne of trout is 600 L per minute. A through put less than 600 L per minute will reduce the stocking density which will automatically reduce the final yield (Boujard et al. 2002). However, due to climate change and variability, human and animal population pressure on inland water resources, the conditions for optimum production for trout are quickly diminishing. Decreasing rainfall due to climate change has reduced the flow of water in many inland water systems.

The species was introduced in Zimbabwe in early twentieth century initially for recreational purpose but later on adopted for commercial aquaculture (Skelton 2001). It was tried in various parts of the country before the seed was planted successfully in the headwaters of Nyangani Mountain where there is abundant pristine rushing water (Jonnalgada and Mhere 2001). Despite the lucrative remuneration potential that can be offered by culturing rainbow trout (Singh et al. 2016), there are few trout farms in Zimbabwe. Reasons commonly cited include high investment capital, lack of good sites, lack of good feed and seed as well as knowledge (Wallat et al. 2004; Maleri 2009). On the basis of these reasons, it is thus important we explore alternative and sustainable ways of producing trout fish to possibly enhance adoption as a farming venture.

Cage culture is an alternative method gaining attention and enhancing adoption of trout culture in various parts of the world (Offori et al. 2010) mainly due to its low capital demand for use in existing water reservoirs. Cages also allow agro diversification in a water conservative way. According to Maleri (2009) small scale cage culture in Western Cape, also sub-Saharan Africa has increased adoption of trout by small scale farmers contributing to high yield, poverty alleviation and food security. However, the inherent weakness of cages is their failure to fully protect the ecosystem. For instance, rainbow trout is carnivorous and invasive, if allowed to escape the cages they can threaten endemic species. Sterile triploid rainbow trout can be used instead but reported to be a poor adaptor to some conditions (Galbreath et al. 2006).

Production performance of triploid rainbow trout under cage culture in a temperate-afromontane inland water body was evaluated. Since large water bodies in cooler environments have an enormous surface area for gaseous exchange, they should have the potential to support trout production. Specifically we examined if growth patterns of fish reflect the success of using cages in inland water bodies. The expectation was that there would be no variation between cages and the conventional raceways.

Materials and Methods

Study Area

The study was done in an Afro-montane reservoir (Rhodes dam) and raceways at Trout Research Centre, located in Nyanga National Park, Zimbabwe. Altitude is

1500 m above the sea level, cool montane/temperate climate with mean annual rainfall >1200 and mean annual temperature of 20–25 °C prevail in the region (Meteorological Department 2010). The region has ultra-oligotrophic lotic and lentic waters. Little anthropogenic pollution and geochemistry of the watershed reduce eutrophication and maintain the pristine status of the reservoirs (Nhiwatiwa 2017). Zimbabwe's Eastern Highlands has biodiversity legacy harbouring threatened native and exotic endemic aquatic fauna (Kadye and Magadza 2008). Also the agro-climate of the area is congenial for cold water aquaculture including rainbow trout farming (Blow and Leonard 2007). Numerous reservoirs in this region were constructed for agricultural purpose, domestic and for recreational use.

Research Design

A quantitative research design was used whereby measurable data was collected and analysed to determine the potential of triploid rainbow trout under cage culture in Eastern Highlands. Two treatments that are cage culture and conventional raceways were set, replicated twice. Raceways (conventional system) were used as a bench mark for comparison with the cage system. Two small cages (1.80 m^2 each) were launched in the dam using judgmental selection of the site. Also two raceway compartments (3.6 m^2 each) arranged in series were used. Following sections describe in detail the methodology procedures that were used in site survey, stocking, feeding, data collection and procession.

Site Survey and Cage Launching

Criteria that were used to select the site for launching the cages include security, water depth, water exchange capacity and accessibility. Illegal harvesting of cages is one of the social constraints and can result in loss to the farmer (Ofori et al. 2010). Site of water depth of at least 2.5 m was selected. Water depth is important in disposal of uneaten feed and faecal wastes from the cage (Maleri 2009; Murathan et al. 2007). Site free from water plants was also selected. Densely vegetated areas are not suitable for launching the cages.

Stocking

Triploid rainbow trout fingerlings with an average weight of 94 g were obtained from the hatchery at Nyanga Trout Research Centre. The fingerlings were transported to the dam in polyethylene plastic bags. The plastic bags were filled with about 9 L of water and oxygen was added. Each replicate was stocked with 500 fish using a density of 277.78 and 138.89 fish per cubic meter in cages and raceways respectively. Different stocking densities were deduced based on literature guidelines for cage cultures and raceways. Stocking density determines fish welfare, production as well as the economics of the culture system being used (Boujard et al. 2002). Wallat et al. (2004) suggested that a profitable stocking density in cages range from 200 to 600 fish per cubic meter. However, the stocking densities used in this research were determined by minimum stock required to break even after considering input cost of feed and seed only.

Feeding

Extruded commercial feed supplied by ProFeeds Company was used throughout the project. Growers 1 & 2 pellets with a crude protein content of about 35% were used until harvest. Fish were fed three times a day following recommendations by Sung-Yong and Venmathi (2015). Satiation feeding method was used whereby feed was weighed before and after feeding to determine the amount of feed given to the fish. During feeding the feed would be broadcasted manually in the cages and raceways whilst observing fish response. Fish were fed up to 75% satiation.

Data Collection

The project focused on live weight increment (growth parameters), feeding efficiency and mortality of triploid rainbow trout reared in cages and raceways.

Growth: Fish growth was observed through weight gain. Fish were weighed on two weeks interval using an electronic scale. During fish weighing, a bucket was filled with water up to ¾ full. The bucket placed on the switched on scale. The scale would then be tarred to determine only the weight of fish. Fish were then caught using a scoop/hand net and put in the bucket. The total weight recorded on the scale representing fish weight only was divided by the total number of fish (sample number) put in the bucket. Thus how average body weight was obtained. The following formulae were used to compute growth parameters;

$$\mathbf{AG} = \mathbf{Y_2} - \mathbf{Y_1} \tag{1}$$

where AG is the absolute growth; Y_2 is the final weight and Y_1 is the initial weight. (Lugert et al., 2016)

$$\mathbf{AGR} = (\mathbf{Y_2} - \mathbf{Y_1})/(\mathbf{period}) \tag{2}$$

where AGR stands for absolute growth ratio; Y_2 is the final weight, Y_1 is the initial weight. (Lugert et al., 2016).

Feed efficiency: Feed intake was recorded on daily basis. Since satiation method was being used, feed was weighed before feeding and after feeding to determine amount of feed given to the fish. Feed was weighed using an electronic scale.

Feed conversion ratio was calculated as the fraction of feed used and weight gain. It was calculated using the following formula

$$\mathbf{FCR} = \mathbf{FC}/(\mathbf{W_2} - \mathbf{W_1}) \tag{3}$$

where FCR stands for feed conversion ratio, FC is the feed consumed, W_2 is the final weight and W_1 is the initial weight.

Mortality: Dead fish were picked from the experimental units. In cages some floated and some sank at the bottom and were removed using a harpoon. Dead fish were counted and recorded for each replicate. Mortality was then expressed as the percentage of the initial stock.

Temperature: Temperature was recorded using a water thermometer in cages and raceways during the culture period. The daily maximum and minimum recordings were averaged to determine daily average temperature. The daily average temperature was then recorded.

Data analysis: Data for growth, feed efficiency and mortality were captured in excel, sorted and statistically analysed in SPSS version 20. Data exploration was done to test for normality. A Mann–Whitney U then done to test for differences between the two test groups (Raceways and Cages) since date failed the normality test even after data transformation.

Results

Feeding Efficiency

Feed intake: Mann–Whitney U test showed that there was no significant difference ($U = 40$, $p = 0.118$) between feed intake for race ways and cages. Feed intake over the experimental period is illustrated (Fig. 1).

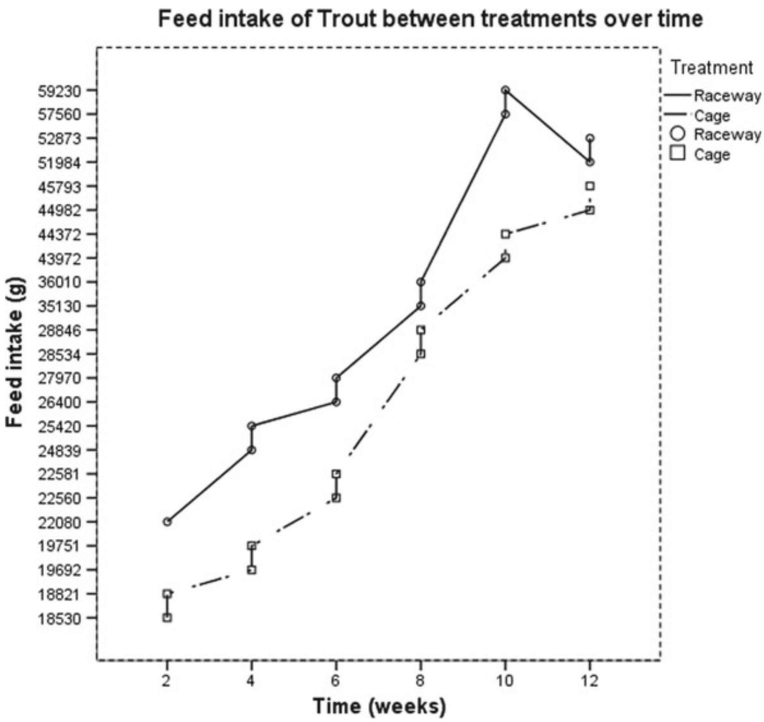

Fig. 1 Feed intake between treatments over time

Feed Conversion Ratio (FCR): FCR Mann–Whitney U test showed that there was no significant difference (U = 70, $p = 0.932$) between feed conversion ratio for fish in race ways and cages.

Temperature: Mann–Whitney U test showed that temperature did not differ (U = 84, $p = 0.514$) between the categories of race ways and cages.

Absolute growth (AG): Fish in raceways were slightly heavier (261, 5 g) than fish in cages (232, 8 g). However, Mann–Whitney U test showed that there was no significant difference (U = 61, $p = 0.551$) between these final weights for fish in race ways and cages. Weekly growth rate of trout over the experimental period is illustrated below (Fig. 2).

Mortality: Mortality was recorded throughout the experiment in both treatments (Fig. 3). Highest number of dead fish in cages was recorded within the first two weeks of stocking adding up to 8 fish in cages and 6 fish in raceways. Mann–Whitney U test showed that there was no significant difference (U = 87, $p = 0.410$) on overall fish mortality between raceway and cage groups.

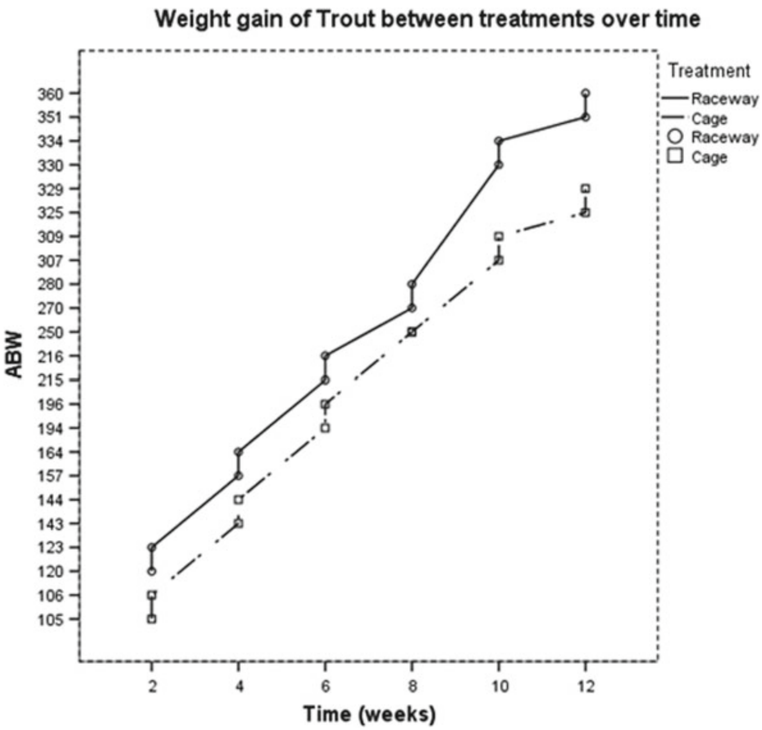

Fig. 2 Weight gain in cages and raceways over time

Discussion

Growth

Growth is one of the productivity factors measured to determine success or viability of the culture method with regards to fish farming economics (Baer et al. 2010). Growth can be defined as the gradual increase in the living system of an organism over time (Lugert et al. 2014). In this study, growth performance of triploid rainbow trout in cages was compared to the conventional raceway method. Results indicated that fish in both cages and raceways surpassed the market size (200 g) during the culture period of 90 days. In this study, individual fish gained more than 2 g per day. Findings of this study fall within the range of 2–6 g reported by Maleri (2009) for Trout cage culture in Western Cape, South Africa. Since temperature is one of the critical factors that determine performance of triploid fish (Cotter et al. 2002), it remained in the ideal range that made it possible to achieve such Absolute growth ratios in both cages and raceways.

Although the market size was achieved in both treatments, cages had a slightly lower growth rate than the raceways throughout the culture period. Possible factors

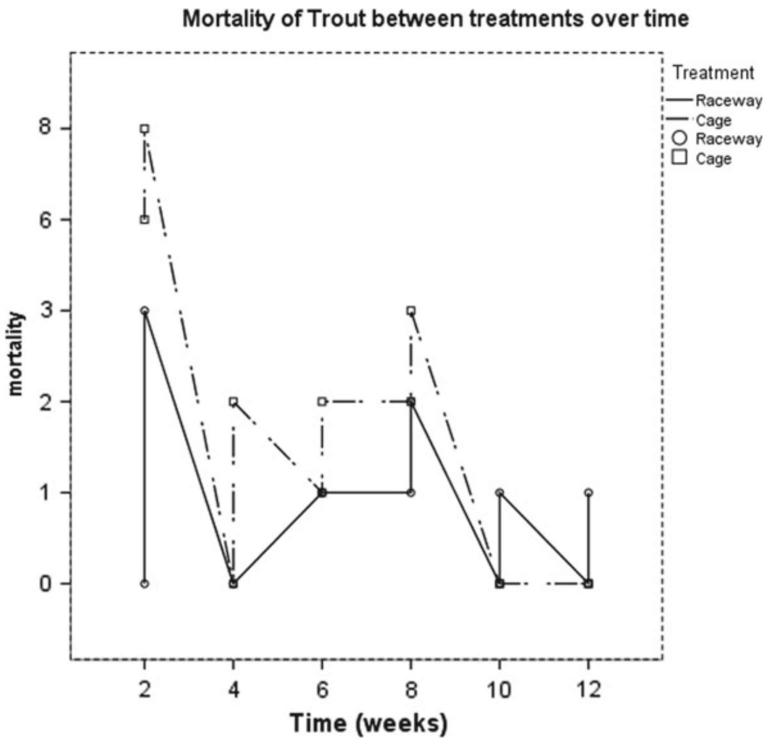

Fig. 3 Mortality of triploid rainbow trout between treatments over time

that might have contributed to the slight growth variation between the groups include slow adaptation of the fish in cages during the first days after stocking. This is indicated by low feeding intake (18,675.5 g), low weight gain (11.45 g) and high slightly higher mortalityin the first two weeks after stocking in cage treatment. The fingerlings that were used in this study were taken from the raceways. Raceways generally have got higher water flow and exchange rates than cages (FAO 2011). The batch that was taken for cage stocking took some time to adapt whilst the batch that was stocked in raceways had their environment maintained and did not reduce their feeding rate very much as in the case of the cage stock.

Again, the capturing and transportation of the cage stock may have contributed to the poor performance during the first days. The fingerlings were transported a distance of 8 km in polyethylene plastic bags filled with water and additional oxygen whilst those stocked in the raceways were moved by hand nets from their previous raceway to the experiment compartment. Although, fish were handled anaesthetically as recommended by Wallat et al. (2004) to reduce stocking stress, the above low growth performance was observed and linked to the factors described.

Feeding Efficiency

Amount of feed used by the fish gradually increased with period in both cages and raceways, although the former had a slightly lower total feed intake at the end of the experiment the groups did not differ. The temperature during the experimental period remained ideal and did not differ for the two groups. Temperature affects functioning of the enzymes for digestion and can as well influence release or suppress anti-stress hormones (Guderly and St-Pierre 2002). Since there was no variation in temperature between the treatments during the culture period it is assumed that the culturing environment were similar in terms of temperature hence similar digestion and quest for feed. More importantly, the water conditions in which the cages were launched are relatively good quality. Limnochemistry studies by Nhiwatiwa (2017) showed that reservoirs in Nyanga have good condition that is high oxygen, clear water and very little pollution since most of the water originates in Nyangani Mountain which does not have any agriculture or industries nearby.

Temperature determines feeding rate of fish. Fish are poikilotherms and the environmental temperature has effect on their homeostatic functioning. It therefore explains why low feeding rates were observed during the morning (before 10:00 h) and late afternoon (after 15.00 h) which was suspected to be correlated to the low temperature <14 °C. Stickney (2000), states that trout do not feed well when the temperature is very low or too high. The feeding frequency was then adjusted to two times a day in both cages and raceways to avoid feed loss. Variation of feed intake between recorded intervals was the effect of growth. As the fish grow the amount of feed that is consumed increase as well. Young fish have low feed intake whilst older fish have high feed intake, this was also observed in this study.

Feed conversion ratio (FCR) is an indicator for fish farm success (Murathan et al. 2007). FCR determines production cost and farm profitability. A high FCR indicates poor feeding efficiency and it means that more feed is required to achieve a small weight. In this study, feed conversion ratios 1.66 and 1.70 were observed in cages and raceways respectively. Our results are consistent with FCR of 1.63 reported by Murathan et al. (2007) but higher than the 0.92 observed by Kljajić et al. (2016). Maleri (2009) also reported an FCR range of 1.1 to 2.5 for fresh water small scale trout cage culture of studied farms in Western Cape. Eighty per cent of the studied farms achieved FCR less than two which indicated viability of the farms. FCR during the culture period in both treatments was within the widely observed and FAO (2011) recommended range of less than 2. Quality of the feed used (35% crude protein) and pristine water condition as well as maintenance of congenial temperature (15–21 °C) during the culture period can be credited for achieving good FCR in cages.

Mortality

Mortality rate can determine the yield obtained at the farm. It is also used as an indicator for culture method viability. Mortality can be density dependent or independent (occur due to lethal temperature or poisoning). In this study mortality of 5.4% and 1.8% were recorded in cages and raceways respectively. Mortality in cages recorded was higher than other findings such as 2.9% (Murathan et al. 2007); 2.28% (Kljajić et al. 2016). Wallat et al. (2004) reported survival rates of 96.7% and 94.2% for low and high stocking densities in trout cage culture. The high mortality in cages occurred in the first two weeks and this is possibly linked to handling myopathy. As also noted by Kljajić et al. (2016) high stocking mortality can occur due to the handling and transportation stress.

Conclusion

The study showed that triploid rainbow trout can be grown successfully using cage culture in small reservoirs in Eastern Highlands. The fish achieved the market size within the culture period. Farmers can adopt the system in order to maximize use of the existing reservoirs and generate more income. However, farmers are required to follow anaesthetic procedures in handling of fish during transportation and stocking to reducing stocking mortality. Again farmers are recommended to observe fish response when feeding especially during harsh weather conditions as this can raise the feed conversion ratio. Future research can focus on possibility of growing trout in cages during winter in marginal areas of Eastern Highlands that cannot support trout farming throughout the year.

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Author Contributions Tinashe Chapinduka conceptualised, conducted field work and developed the script, Everson Dahwa analysed the data, interpreted the results and helped to draft the manuscript. Rachel Gwazani Supervised the research process and assisted in drafting script. Clarice Mudzengi helped in drafting the script. Maya co supervised the process. All authors revised the manuscript, read and approved the final version and takes accountability of for the contents in this article.

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Availability of Data and Materials The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate Approval to carry out the survey was granted through the Zimbabwe Parks and Wildlife Authority. Great Zimbabwe University approved the research proposal through its Departmental panel of examiners.

Competing Interests The authors declare that they have no competing interests.

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Seaweed Biostimulants for Climate Change Adaptations in Dryland Agriculture in Semi-arid Areas

Vijay Anand K. Gopalakrishnan and Arup Ghosh

Abstract The effects of climate change are now being overtly felt. Apparently this is manifested by more occurrences of tropical cyclones, uneven rainfall distribution, leading to transient drought conditions and higher temperatures. With the increase in population, it becomes even more difficult to guarantee food security as the effect of climate change would be severe on agricultural production. Climate change adaptations thus have to be sought in the field of agriculture. Some of the strategies to enhance the agricultural productivity would be to genetically engineer drought tolerant plants, but that has regulatory hurdles across the globe. Other way is to devise treatments that bring about tolerance to abiotic stress by regulating the genes responsible for drought tolerance in plants and bolster the antioxidant system in plants. In this context, seaweed based biostimulants have shown enormous potential of mitigating climate change effects by imparting drought tolerance in crops. Life cycle impact assessment across several environmental categories have been carried out and lower greenhouse gas potential per unit of crop yield has been reported with *Kappaphycus alvarezii* sap as biostimulant. Carbon foot prints of the biostimulants have been found to be very low and thus these can be potential organic products. Studies have also been carried out to empirically prove the beneficial effect of seaweed extracts on soil moisture deficit which is a condition very much prevalent in drylands in semi-arid tropics. The seaweed biostimulants were found to withstand soil moisture stress and helped reduce the yield loss to a significant extent. It also prevented deterioration of soil microbial flora under drought condition. This chapter provides a quantitative view of how seaweed biostimulants can mitigate climate change effect and why it should be a policy of the state to encourage such green products.

Keywords Life cycle assessment · Seaweed extracts · Sustainability · Kappaphycus · Maize · Sugarcane

V. A. K. Gopalakrishnan · A. Ghosh (✉)
Applied Phycology & Biotechnology Division, CSIR-Central Salt & Marine Chemicals Research Institute, GB Marg, Bhavnagar, Gujarat 364002, India
e-mail: arupghosh@csmcri.res.in

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Introduction

Food security is of paramount importance to the existence of mankind in order to feed its burgeoning population which is expected to double by 2050 (FAO 2018). Although agricultural productivity has kept pace with the ever increasing demand for food and feeds, thanks to the use of synthetic N inputs but recent trends have shown stagnation in yield increase in major crops (Smith et al. 2014). Yield gaps between potential and real yields in the different geographies of the world have been steadily increasing. This has been predominantly attributed to the deterioration in the soil quality manifested by intensive agriculture. The environmental trade-offs of increasing agricultural productivity using synthetic N fertilizers is two pronged as both their production and use phase contribute significantly to global warming. This situation is further stressed by climate change which leads to erratic weather conditions such as increase in temperature in certain areas, changes in precipitation. The latter results in transient drought conditions which greatly affect productivity in rain-fed agriculture, the most prevalent form of agriculture practiced in major cultivating areas. In addition, increase in temperature has also been reported to reduce global yields of major crops (Zhao et al. 2017). In this context, sustainably increasing crop productivity without having any detrimental effects on environment is a challenge which needs to be addressed by the scientific community. Among various alternative practices that have been employed to overcome the above challenge plant biostimulants have been recently reported to be a promising candidate for sustainably increasing crop productivity. The scope of the present article is to highlight the benefits of using biostimulants obtained from seaweeds such as *Kappaphycus alvarezii* and *Gracilaria edulis* in increasing productivity of some of the major food and cash crops like rice, maize and sugarcane and their potential benefits on the environment.

Seaweed Based Biostimulants and Its Environmental Foot Print

Seaweeds are a phylogenetically diverse group of macro-algae which grow both in temperate as well as tropical marine environments. The extracts from these seaweeds have been reported to contain many physiologically active constituents such as plant growth regulators (Stirk and Van Staden 2014), phenolics (Rengasamy et al. 2015), quaternary ammonium compounds (Mondal et al. 2015), polysaccharides such as carrageenans (Shukla et al. 2016) and serve as biostimulants.

Biostimulant means compounds, substances and products including microorganisms whose functions when applied to plants, seeds, rhizosphere is to regulate and enhance crops physiological processes independent of the products nutrient content to improve input, use efficiency, growth, yield, quality and/or stress tolerance. There are different techniques of obtaining the extracts and the type of extraction profoundly influences the chemical composition. By virtue of containing the above mentioned physiologically active ingredients they have been reported to enhance productivity in a number of crops such as soybean (Rathore et al. 2009); in wheat (Zodape et al. 2009); rice (Sharma et al. 2017); rice-potato-green gram cropping system (Pramanick et al. 2014) and in maize (Singh et al. 2016) either alone or in combinations. In addition, these active substances have been shown to impart biotic and abiotic stress tolerance in crops (Trivedi et al. 2018a, b; Agarwal et al. 2016). *K. alvarezii* and *G. edulis* are seaweeds native to tropical waters. The former is a carrageenophyte which has been predominantly grown for its phyco-colloid carrageenan while the latter is an agarophyte cultivated mainly for its agar. In 2005, the advent of a process involving simultaneous production of biostimulant and carrageenan *K. alvarezii* resulted in a significant value addition of the down-stream product (Eswaran et al. 2005). Use of these biostimulants in conjunction with recommended rate of chemical fertilizers (RRF) not only resulted in increase in crop productivity in range of 10–36% in various crops (Singh et al. 2016; Trivedi et al. 2018a, b; Sharma et al. 2017; Singh et al. 2018) but also led to notional savings in the use of chemical fertilizers that would have been otherwise required to enhance the yield. Further, it was also evident that yield responses in the treatments involving reduced RRF applications at 50% had parity with control (Singh et al. 2016, 2018). This would result in direct savings in the form of chemical inputs required for achieving the target yields.

Mariculture of seaweeds in open sea in spite of being less sophisticated does not require any nutrients or fertilizers (Ghosh et al. 2015). In addition, it does not compete for arable land resources with practically no freshwater requirements (Layek et al. 2015). Although less sophisticated, the cultivation of macro-algae entails certain material and energy inputs and the production of biostimulant may account for environmental impacts as it involves mechanical extraction. Thus to unequivocally prove that the use of seaweed based biostimulants in enhancing agricultural productivity is indeed environmentally sustainable, life cycle assessment for the production and transport of *K. alvarezii* and *G. edulis* biostimulants have been carried out (Ghosh et al. 2015; Anand et al. 2018). The modeling and scenario analysis was done using GaBi (now Thinkstep®) version 6 software. Eighteen different environmental impact categories were assessed using the ReCiPe method with hierarchist perspective. The carbon footprint of the biostimulants extracted from *K. alvarezii* and *G. edulis* was found to be 118.6 and 73.1 kg CO_2 equivalents, respectively per kiloliter of their production at factory gate following price allocation (Ghosh et al. 2015; Anand et al. 2018). Deducing the carbon foot print of the product is essential as it is a prerequisite for estimating environmental impacts *vis-a-vis* chemical fertilizers when the biostimulants are employed in an agricultural practice for improving crop productivity. Additionally, the other advantage that these biostimulants have is that they do not account for emissions in their use phase (Ghosh et al. 2015). Because of their very low N content (>100 mg L^{-1}) it was hypothesized that these biostimulants when applied as a foliar spray may be directly absorbed by the plants. On the contrary, the use phase of the synthetic N fertilizer contributes to the bulk of the emissions due to both direct and indirect emissions.

Environmental Benefits of Biostimulant Application on Crops

The benefits of employing seaweed based biostimulants in increasing grain production in an environmentally sustainable manner can be best illustrated using some of our earlier studies in rain-fed maize (Singh et al. 2016), rice cultivated in lateritic soils (Sharma et al. 2017) and in Sugarcane (Singh et al. 2018). Rice, maize and sugarcane are major crops that not only occupy bulk of the cultivated area but also are significant contributors to the global warming in the agriculture, forestry and land use (AFOLU) sector. The carbon foot print for the cultivation of maize on one hectare of land entails 599 kg CO_2 equivalents on account of fertilizer production and transport even without accounting for farm emissions from soil after application [with recommended rate of fertilizers being 150:60:40 kg N: P_2O_5: K_2O ha^{-1} applied through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP)]. In contrast, foliar spray of 142.5 L of *Kappaphycus* based biostimulant significantly increased the grain yield of maize by 21.4% over and above the recommended rate with an emission of 25.65 kg CO_2 equivalents per hectare (assuming transport through rail for a distance of 1500 km). This was a mere 4.3% addition of impacts under climate change impact category over that produced on account of the required fertilizer inputs (Singh et al. 2016).

It is well known that rice production contributes to the bulk (55%) of the agricultural greenhouse gas emissions in the world (Alam et al. 2016). Further, synthetic fertilizers contribute to approximately 50% of the total carbon foot print during rice production (Yan et al. 2015). Cultivating rice in red and lateritic soils poses an additional challenge due constraints imposed by the edaphic factors. Even under these challenging environments, the efficacy of the biostimulants obtained from *K. alvarezii* and *G. edulis* in improving rice productivity was demonstrated (Sharma et al. 2017). Foliar application of *Kappaphycus* seaweed extract (KSWE) and *Gracilaria* seaweed extract (GSWE) significantly enhanced grain yield of rice by 29% and 28% in relation to control when applied at 15% concentration. Notably, the yield of rice in the treatments involving combination of these biostimulants with 50% RRF was statistically at par with control. Life cycle impact assessment revealed the benefits of using these biostimulants in agricultural practice wherein, maximum reductions of 11.4% and 14.8% in climate change (CC) impact category per tonne of rice were obtained in treatments involving combination of RRF with 15% KSWE and 10% GSWE, respectively in comparison to the control. Interestingly, treatments involving 50% RRF + SWEs brought about at least 43% reduction in CC impact per tonne of rice, which amounts to savings of about 35 kg CO_2 equivalents per tonne of rice.

Sugarcane cultivation also contributes significantly to the emissions owing to high application rates of synthetic N-inputs in certain geographies like India, China (Thorburn et al. 2011). Thus sustainably increasing cane productivity without having any detrimental effect on the environment is challenging task. The efficacy of biostimulant obtained from *Kappaphycus* in increasing cane productivity in an environmentally friendly manner was demonstrated using field trials (Singh et al. 2018). Foliar application of *Kappaphycus* seaweed extract (KSWE) at 5% concentration enhanced cane productivity by 12.5 and 8%, respectively, in plant and ratoon crops. Interestingly, the treatment involving 6.25% KSWE + 50% RRF showed yield parity ($p < 0.05$) with control (water + 100% RRF) in ratoon while there was 7.9% reduction over control in plant crop with a concomitant savings of 50% RRF. The potential of the KSWE in lowering GHGs is manifested by the way of saving at least 260 kg CO_2 equivalents ha^{-1} when applied at 5% concentration.

Biostimulants and Alleviation of Abiotic and Biotic Stress

It is well known that biostimulants mitigate abiotic stress like drought due to the presence of stress alleviators like—glycine betaine, mannitol, sugars etc. as well as by modulating abscissic acid homeostasis (Sharma et al. 2019; Santaniello et al. 2017; Shukla et al. 2018; Trivedi et al. 2018a, b). The evidence of exogenous application of glycine betaine in alleviating drought was demonstrated in maize. In this experiment, 10 and 15% concentration of *Kappaphycus* biostimulant along with equivalent amount of glycine betaine were applied thrice to maize plants that were well watered (WW), moderately drought stressed (MS) and severely stressed (SS) maize plants along with a suitable control. It was evident from the results that 10% KSWE effectively enhanced the seed yield under WW and MS conditions while 15% was optimal under SS condition. The improvement in seed yield in WW, MS and SS conditions at the optimal KSWE concentrations was 13.5, 21.7 and 36.4%, respectively in relation to control indicating higher yield response to KSWE treatments at higher stress levels (Trivedi et al. 2018a). The yield advantage under stress was attributed due to minimal damage of photosystem in KSWE treated plants as evidenced by higher pigment content, photosynthetic rate, reduced photoinhibition and lipid peroxidation by enhanced protection against reactive oxygen species (Trivedi et al. 2018a). Similar drought alleviatory benefits of KSWE was also observed even with its single application in maize plants subjected to drought at grain filling stage (Trivedi et al. 2018b). Although other constituents of the biostimulants have been implicated in the drought response, most of them were hypothetical and no direct empirical evidence has been provided. The benefits of KSWE in overcoming biotic stress was demonstrated in its efficacy against *Macrophomina phaseolina* causing charcoal rot in tomato plants (Agarwal et al. 2016). The application of the biostimulant not only resulted in increase in the concentration of plant growth regulators like abscissic acid, indole acetic acid, salicylic acid and zeatin but also enhanced the transcript levels of pathogenesis related genes PR-1b1, PR-3 and PR-5.

Conclusion

Thus from the above reports it is evident that seaweed based biostimulants not only promote growth and enhance productivity of crops growing in semi-arid regions but do so in an environmentally friendly manner and help in mitigating both biotic and abiotic stress. Thus, a paradigm shift in policy is needed to encourage use of biostimulants in the context of mitigating adverse effects of global climate change and expecting better returns.

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Risk Coping in Drylands

Risk Management in Rainfed Agriculture in India

C. A. Rama Rao, B. M. K. Raju, Josily Samuel, and G. Ravindra Chary

Abstract Sustainable growth in rainfed agriculture is key to achieve various development objectives related to poverty, equity and nutrition in Indian economy. Rainfed agriculture is synonymous with risky agriculture as its very basic features predispose it to climate risk. The climate risk is further compounded by poor resource base and other biotic sources of risk resulting in considerable yield and production risk. Policy and institutional focus on irrigated agriculture has only aggravated the risk further. It should be noted that agricultural risk is more covariate than it is idiosyncratic while considering the insurance as a means of risk management. A comprehensive and strategically chosen combination of technological, institutional and management options that help reduce vulnerability and thus risk in the short and long term is required.

Keywords Rainfed agriculture · Risk · Risk management · Technologies · Management · India

Introduction

India is now one of the fastest growing economies of the world. The growth in economy is now being driven by the secondary and tertiary sectors while the primary sector, i.e., agriculture contributed to the growth during the past. The contribution of agriculture to the country's Gross Value Added (GVA) fell to 16.1% during 2018–19 (GoI 2019) with secondary and tertiary sectors playing a key role. However, agriculture continues to be major source of livelihood to more than half of the workforce. This is reflected in the widening disparities between sectors in terms of income and standard of living. Accelerating and sustaining growth in agriculture is essential in order to fulfil the country's development objectives of inclusive growth and to meet the Sustainable Development Goals that the world nations have agreed to meet by 2030.

C. A. Rama Rao (✉) · B. M. K. Raju · J. Samuel · G. Ravindra Chary
ICAR—Central Research Institute for Dryland Agriculture, Hyderabad 500059, India
e-mail: car.rao@icar.gov.in

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Indian agriculture witnessed remarkable growth and contributed significantly to the country's development. However, such growth was more conspicuous in irrigated regions and irrigated crops leaving behind the larger rainfed agriculture. India ranks first in terms of area under rainfed agriculture in the world (Sathyan et al. 2018). Sustainable growth in rainfed agriculture is a key to achieving more inclusive, broad based economic growth and other poverty- and nutrition-related development objectives of the country.

Rainfed agriculture is practiced in two distinct environments: (i) relatively warmer—arid, semi-arid and dry-sub-humid- regions of the country. In these regions, the annual precipitation falls short of the potential evapo-transpiration demand. This together with lack of access to irrigation results in agriculture that is dependent on monsoon rains. Not only is the course of the monsoon during a season unpredictable, but also the inter-annual variation in the rainfall is high in these regions. (ii) Moist sub-humid, humid and per-humid regions in the eastern, north-eastern and some south-western parts of the country where the problems are different. Though agriculture is rainfed in these regions, rainfall is high in relation to crop water requirements. Thus, rainfed agriculture includes agriculture in the drier and wetter regions (Rama Rao et al. 2020) (Fig. 1).

Rainfed Agriculture is Risky

Rainfed agriculture is synonymous with risky agriculture as production is dependent on monsoon rains and recurrent occurrence of droughts is a common phenomenon. The incidence of drought, measured in terms of severe droughts, is high in districts of Rajasthan, Tamil Nadu, Maharashtra, etc. (Fig. 2).

The productivity levels are not only low but are also highly variable which act as an impediment to investment by the resource-poor small holder farmers who dominate rainfed agriculture. Climatic risk is manifested in terms of incidence of droughts, floods and high intra-season variability in rainfall. Hence, risk—climatic and other forms of risk—remains a key challenge to the researchers and policy makers. A dissection of risk, points out some basic factors—poor capacity of soils in terms of nutrients, organic matter, water holding capacity and low availability of water. The generic nature of these problems is more or less adequately understood and recognized. However, how to address these issues in varied situations is an important challenge that deserves the attention of all concerned. Monsoon aberrations in terms of late onset, early withdrawal, incidence of pests and diseases, untimely rains etc. are principal causes of yield and production risk in rainfed agriculture (Suresh et al. 2017).

In addition to production risk, rainfed farmers also face price risk as price and food policies of the Government favoured irrigated crops more compared to rainfed crops. The policies on procurement, input pricing (subsidies) and credit also acted in a manner that discouraged investments in rainfed agriculture. The rainfed crops such as coarse cereals, pulses and oilseeds face higher price risk compared to the irrigated

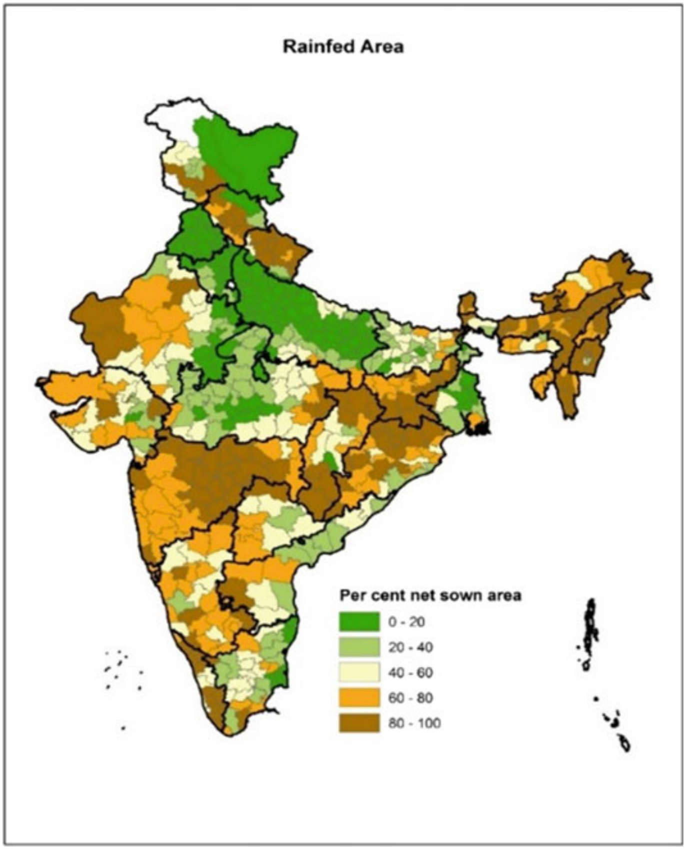

Fig. 1 Distribution of rainfed agriculture in India (*Source* NRAA 2020)

crops viz., rice, wheat and sugarcane. Higher risk of crop failure also discourages lenders to provide credit to rainfed agriculture and thus risk also affects investments even when it is not realized.

Climatic risk is more dominant as far as rainfed agriculture is concerned as crops depend more on rainfall than on 'controlled' irrigation. Rainfall in India is more driven by south-west monsoon and by north-east monsoon in some regions on the south-eastern parts of the country. Droughts characterized by rainfall deficits on a seasonal or annual scale and dry spells, the rainless periods, during the crop growing period are the two major sources of yield risk in rainfed agriculture. Multiple nutrient deficiencies, low soil organic carbon and other land and soil related constraints further amplify the ill-effects of rainfall deficits as evident in the wide fluctuations in yields of major crops. The yields of rainfed crops are being impacted due to increasing high intensity rainfall events, rising temperature, increasing incidence of flood and also by due to changing pest dynamics. Thus, rainfed agriculture suffers from a variety of risks caused by both biotic and abiotic factors. A distinguishing feature of risk

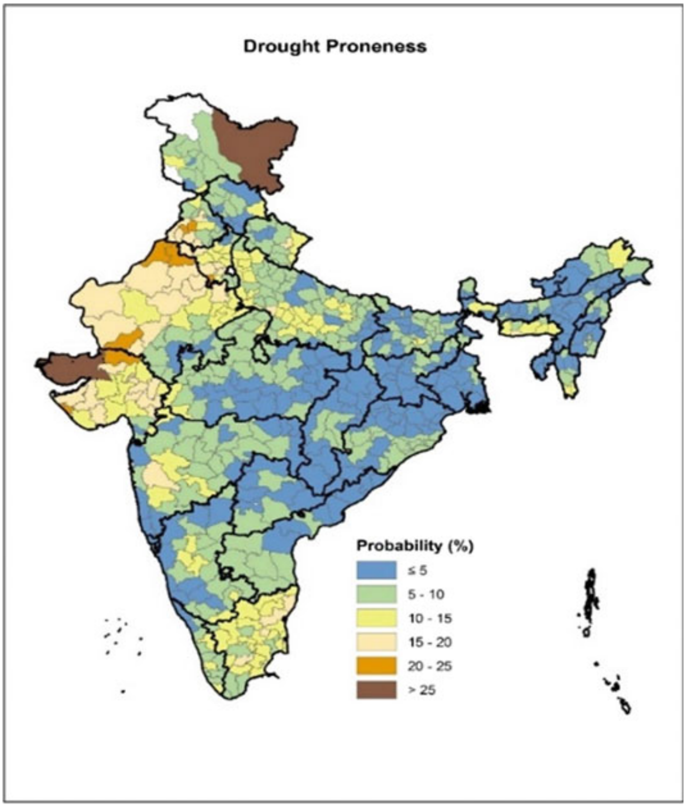

Fig. 2 Incidence of drought in districts of India (*Source* Rama Rao et al. 2019b)

in agriculture as opposed to that in other sectors is its being 'spatial' or 'covariate' in nature which has implications to the effectiveness of various risk management options. Integration of crop and animal production to more closely-knit value chains also exposes farmers and crop production to other sources of risk. For example, climatic or policy shocks at a particular point on the value chain can transmit the risks to other players along the value chain.

Climate Change Risk

Climate change has now emerged as a potent threat to sustainable agriculture, food security and livelihoods of farmers in developing countries like India. In the context of climate change, risk is defined as "the potential for *consequences* where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur". (Oppenheimer et al.

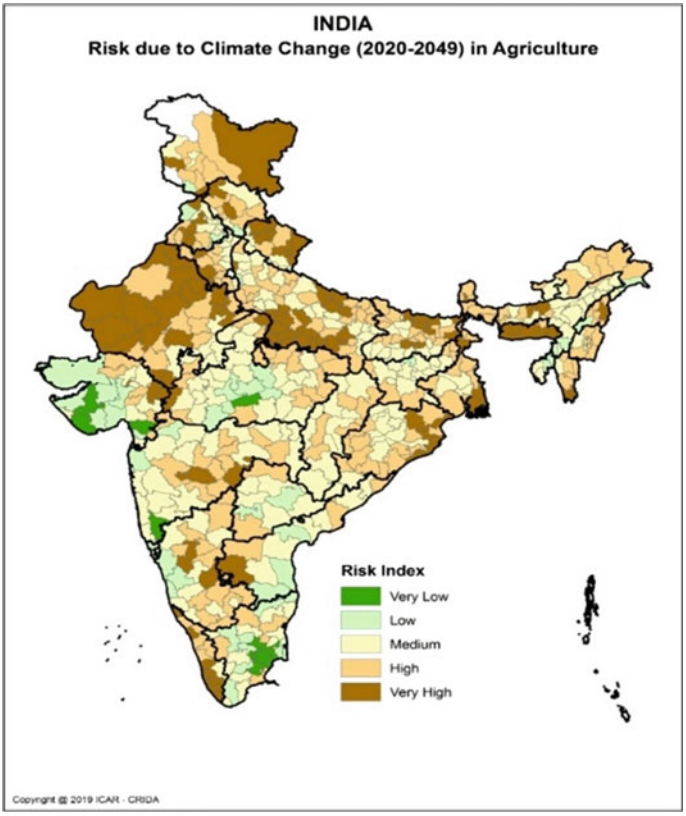

Fig. 3 Climate change risk in India (*Source* Rama Rao et al. (2019a, b)

2014). Risk is viewed as a consequence of interaction among the three components viz., vulnerability, exposure and hazard. Vulnerability represents predisposition of those systems or people that are exposed to the hazard of climate change and is viewed as a function of capital and resource endowments, technology, etc. Regions dominated by rainfed agriculture are relatively more vulnerable to climate change risks (Rama Rao et al. 2016, 2019b) (Fig. 3).

Risk Management

Managing risks is an important strategy towards more sustainable rainfed agriculture in the country. Availability and selection of various risk management options will depend on both supply and demand related factors as well as on the nature of risk. As mentioned, management of climate risk is more important and challenging in rainfed agriculture though a holistic strategy for dealing with other sources of risk will be more rewarding. Conceptually, risk management can be through adopting *ex ante* options or *ex post* options. These options can be also categorized into formal or informal based on whether they require support or involvement of specific institutions (Planning Commission 2008). The options can also be classified into technological, infrastructure and policy related measures. An ideal strategy is to evolve a particular combination of these measures that would help minimize risk with a minimum cost to the farmer and to the society.

Technological options: A number of technological interventions are developed and transferred to farmers for adopting to reduce yield risk emanating from climate or weather variability. For example, adoption of drought tolerant crop varieties is shown to reduce yield risk (Palanisami et al. 2015; Rama Rao et al. 2018a; Ward and Makhija 2018). The Technological interventions and yield resilience in sorghum in Pune district of Maharashtra is shown in Fig. 4. Such yield stabilizing effects can further be enhanced if complemented by soil and water conservation measures in rainfed regions. Some other examples of technological options for yield risk management are spraying of urea on receipt of rains after a dry spell, contingency measures such as reducing plant population, in situ moisture conservation measures, adoption of short duration crop varieties, etc. Rainwater harvesting through farm ponds is also an important resource management technology for saving crop yields during a sub-normal rainfall seasons (Srinivasa Rao et al. 2017; Rama Rao et al. 2019a). Changing planting dates, adoption of micro-irrigation, use of improved varieties were also found to be useful and adopted by farmers to manage yield risk (Suresh et al. 2017).

Management options: Income risk from farming can be better managed by choosing a diverse portfolio of crops and livestock commodities. A more diverse cropping pattern will help smoothen income fluctuations, especially when the portfolio includes crops that respond differently to climate variability or varying resource requirements (Table 1). In rainfed agriculture, inter-cropping and mixed cropping have been traditional ways of reducing risk. Such cropping systems are more acceptable to small holders with limited scope for spatial diversification. An extension of

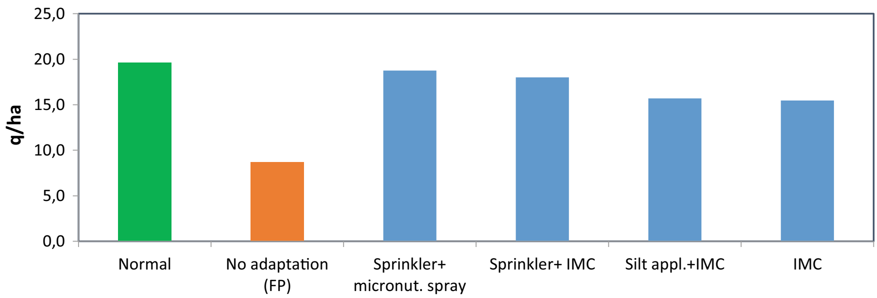

Fig. 4 Technological interventions and yield resilience in sorghum, Pune, Maharashtra (FP: farmers' Practice; micronut. spary: micronutrient application; IMC: In situ Moisture Conservation; Silt appl.: Silt application) (*Source* Rama Rao et al. 2018a)

Table 1 Crop diversity and income resilience, Pune, Maharashtra, India

Simpson's Index (n)	Income during a normal year (thousand INR /Household)	Income during a drought year (thousand INR /Household)	Income resilience
0–0.25 (2)	68	26	0.38
0.25–0.50 (11)	70	33	0.46
>0.50 (32)	93	55	0.59

Figures in parentheses are number of farmers
Source Rama Rao et al. (2018a)

cropping system to include livestock in the form of mixed farming systems or integrated farming systems has also been popular in India as a means for more stable incomes. It is also evident that farm households diversify their economic activities into non-farm sectors such as participation in labour market for wage earnings to augment and stabilize household incomes. However, in relatively better endowed regions, diversified production portfolio may give lower incomes during a 'normal' year compared to more specialized portfolio of commodities (Table 2) which can be an impediment to farm level diversification (Rama Rao et al. 2017). Migration is also one of the prominent measures of income stabilization in rural India, especially in rainfed regions.

Contingency crop planning is an essential component of risk management in agriculture. These plans comprise of measures that the farmers can take for such situations as late onset of monsoon, early withdrawal, long dry spells during the crop season, untimely excessive rains, floods, etc. The measures suggested include sowing date adjustments, saving the crop from any weather aberration or pest risk, alternative crop and variety choices, etc. Such information on contingency planning for various districts of India is available at http://www.icar-crida.res.in.

Institutional options: These options, such as seed banks, fodder banks, community nurseries, enabling access to improved farm implements through custom hiring centres play a vital role in dealing with yield risk (Srinivas et al. 2017; Srinivasa Rao et al. 2016). Contract farming, share cropping, labour pooling, collectivization of

Table 2 Crop diversity and income resilience, West Godavari, Andhra Pradesh, India

Simpson's Index (n)	Income during a normal year (thousand INR /Household)	Income during a flood year (thousand INR /Household)	Income resilience
0 (9)	156	30	0.19
0–0.25 (15)	223	89	0.38
0.25–0.50 (7)	190	64	0.35
>0.50 (31)	116	71	0.61

Figures in parentheses are number of farmers
Source Rama Rao et al. (2017)

farming and marketing activities also have a considerable role to play in managing various forms of risk. Strengthening social capital as means of accessing other forms of capital lies at the core of such initiatives.

Another institutional arrangement that brings together institutional players, knowledge and technologies is delivery of weather based agro-advisories. A number of efforts are underway involving public, private and civil society agencies that are trying to enable farmers to take tactical decisions based on the weather forecasts. The decisions taken by farmers following such advisories were found to be useful in reducing costs and increasing returns (Dupdal et al. 2020).

Financial measures: Financial products such as credit, insurance and hedging are also useful in dealing with price and income risk. However, the penetration of these products is rather limited in India for a number of reasons. Linking credit to collateral security, yield and income risk, high transaction costs are some of the supply side constraints to institutional credit. On the demand side, low financial literacy, procedural difficulties, low and variable profitability, smaller farm size, cultural and habitual rigidities are hindering the demand for various financial options for risk management. Formal agricultural insurance has evolved considerably learning from the experiences over years since 1965.

There is a renewed emphasis on promoting crop insurance in the form of *Pradhan Mantri Fasal Bima Yojana* (Prime Minister's Crop Insurance Programme) and weather-based insurance programme through participation of private sector players. The programme is now emphasizing on harnessing the information and communication technologies, remote sensing and geographical information systems capabilities and other institutional arrangements to quicken processing of claims. However, existence of relatively high basis risk (Ward and Makhija 2018), information asymmetries, high transaction costs, adverse selection (Jensen et al. 2018) and moral hazards continue to limit the progress on wider scale adoption of insurance as a risk management option. Direct payments in the form of cash transfers, relief payments, and input subsidies are also gaining prominence in managing risk. Some traditional forms of risk management such as labor pooling or sharing, community-based initiatives in management of common pool resources, contingent crop growing, have almost disappeared over time.

Farmers' Perceptions on Managing Drought Risk

In order to mainstream policies for better risk management, it is important to understand what the farmers in the drought and flood prone regions would like the government to do to address the issues related better. This is considered important for two reasons: First, incidence of extreme events is expected to rise in frequency and intensity with climate change. Secondly, the ability to deal with current climate variability will only strengthen the capacity to deal with future climate change too. The farmers in the west zone opined that the governments and others should be investing in technologies for land development, rain water harvesting and development of drought resistant crop varieties and should be complemented with such policy measures as improved access to credit, ensuring remunerative prices, capacity building and knowledge dissemination among different stakeholders and support to community-based organizations such as self-help groups. Improved irrigation methods such as micro-irrigation, better infrastructure for irrigation, access to input markets, provision of insurance, enhanced investments in research and development, improved drought forecasting and a better coordinated administrative support are among the measures that the farmers thought were important in managing drought situation in the country. In case of flood, protection measures like strengthening river and farm bunds, early warning systems, crop varieties tolerant to inundation are the important areas where farmers desire the government should invest. Farmers believed that ensuring remunerative prices, softening input prices, improvement in the supply of electricity for irrigation were also important to enhance their capacity to deal with climate change' (Rama Rao et al. 2018b) (Tables 3 and 4).

Some of the government programmes seem to match the perceptions of farmers. The efforts to expand irrigation and increase water use efficiency through *Pradhan Mantri Krishi Sinchayee Yojana*, emphasis on soil health management, weather forecasting and investments in renewable energy are steps in right direction. There are also multi-institutional collaborative efforts for enabling farmers to take tactical decisions based on weather forecasts, crop condition which are proving to be useful. This is an area where the advances in ICT are being harnessed better. There are also efforts to institutionalize the drought management better through more cohesive functioning of departments and ministries concerned for improving preparedness, mitigation and relief measures related to drought. Programmes such as MGNREGS (Mahatma Gandhi National Rural Employment Scheme), Public Distribution System (agricoop.nic.in) will also help smoothening income and consumption during climatic shocks and thus help the recovery and resilience.

Some of the general interventions viz., ensuring remunerative prices for farm produce, increased spending on research and development and better infrastructure also strengthen farmers' ability to deal with risk by bridging development deficits and by making available more resources necessary to deal with risk. In terms of risk management, it is important to devise bundles of various options to manage risk in a given location or for specific farm typologies for better acceptance and adoption by the stakeholders. Research and development efforts in this direction are more likely to be successful rather than relying on a specific risk management option such as insurance.

Risk Management Through Vulnerability Reduction and Resilience Building

Since rainfed agriculture experiences risk in many forms and from various sources, it is important to effect systemic changes that help reduce vulnerability and strengthen

Table 3 Farmers' preferences on government's support in dealing with drought

Zone	East	West	North	South
States	Bihar, Orissa, Jharkhand, Chhattisgarh, West Bengal	Gujarat, Rajasthan, Maharashtra, Madhya Pradesh	Punjab, Haryana, Uttar Pradesh	Andhra Pradesh, Karnataka, Kerala, Tamil Nadu
Technology related	Improved irrigation methods; Development of drought resistant variety; Change in cropping pattern; Introduction of alternate crops Improved soil management practices; Crop diversification and cropping systems;	Land development; Rainwater harvesting; Improved irrigation methods; Promotion of organic manures; Development of drought resistant varieties; Better crop management; Better soil management (bunding, terracing, strip farming; fallowing etc.); Improvement of Common Property Resources for grazing	Rainwater harvesting and better groundwater management; Improved irrigation methods; Development of heat and drought resistant variety; Better crop/soil management; Change in cropping pattern;	Rainwater harvesting and better groundwater management; Improved irrigation methods; Development of drought and disease resistant varieties; Better crop/soil management; Mechanization;
Infrastructure related	Construction of dams; Electricity supply; Enabling life saving irrigation; Bore wells; Restoration of vegetation cover and replant trees for soil protection;	Creation of irrigation facilities (bore wells);	Canal development;	Creation of irrigation facilities; Better power supply;

(continued)

Table 3 (continued)

Zone	East	West	North	South
Policy related	Creating a coordinated decision structure; Improved drought forecasting and early warning system; Training and capacity building; Policy for equitable distribution of water;	Timely and easy access to input markets; Capacity building and information sharing among stakeholders; Support to Self Help Groups; Credit facility; Insurance; Investment in research and development; Awareness about organic farming; Promotion of animal husbandry;	Credit facility; Insurance; Investment in research and development; Capacity building and information sharing among stakeholders; Policies for Income diversification; Water accounting/budgeting; Improved drought forecasting and early warning system;	Timely supply of inputs; Capacity building and information sharing among stakeholders; Remunerative prices; Market access; Credit facility (micro-finance); Insurance; Investment in research and development; Income diversification;

Source Rama Rao et al. (2018b)

resilience. Expanding irrigation facilities should be complemented by enhancing water use efficiency which calls for a combination of technological and social engineering. Many of the natural resource management technologies warrant collective community action in the form of watershed management. Such interventions should be supported by appropriate policy and institutional changes that facilitate adoption of locally appropriate measures for reducing risk. Apart from various technological and management options, efforts should also be made to improve weather forecasting and early warning for strengthening preparedness of farmers and other stakeholders, skill strengthening for farmers and agricultural labour to seek productive employment outside agriculture, to build more robust infrastructure and provide relief in the event of any disaster. Households should not be compelled to resort to erosive coping measures such as selling household and farm assets, discontinuing children education, reduced food consumption which will only further aggravate the risk and make the recovery to normal livelihoods longer and harder.

It is equally important to understand and factor in the risk orientation, whether they are risk averse, risk taking or risk neutral, of the farmers while devising the strategies for risk management for better acceptance by farmers.

Conclusion

Rainfed agriculture in India is synonymous with risky agriculture as production is dependent on monsoon rains and recurrent occurrence of droughts. The productivity levels are not only low but are also highly variable which act as an impediment to investment by the resource-poor small holder farmers who dominate rainfed agriculture. Climatic risk is manifested in terms of incidence of droughts, floods and high intra-season variability in rainfall. Hence, risk—climatic and other forms of risk—remains a key challenge to the researchers and policy makers. Poor soil quality, inadequate and unreliable access to water, low investment capacity of farmers predispose rainfed agriculture to risk incidence. The generic nature of these problems is more or less adequately understood and recognized. However, how to address these issues in varied situations is an important challenge that deserves the attention of all concerned.

Risk is to be addressed in terms of building resilience to crops, to soils that support these crops and to farmers whose livelihoods are dependent on the crop and animal production. Rainfed agroecology-specific land, soil, cropping systems, alternate land

Table 4 Farmers' preferences on government's support in dealing with facing flood

Zone	East	West	North	South
States	Bihar, Orissa, Chhattisgarh, West Bengal	Rajasthan	Uttar Pradesh	Andhra Pradesh, Kerala, Tamil Nadu
Technology related	Development of flood resistant variety; Crop diversification; Removal of sand from the fields; Change in cropping systems (e.g., intercropping); Improved soil management practices;	Reduce high salinity; Improved Drainage system;	Better crop management practices (improved varieties);	Lining the field with bunds; Improved Drainage; Intercropping system; Mechanization;
Infrastructure related	Construction of dam; Electricity supply; Restoration of vegetation cover and replant trees for soil protection; Improved Drainage system;		Construction and strengthening of river banks; Improved transportation in flood prone zones;	Enhanced water storage capacity; Flood protection walls; Ensuring timely supply of inputs (e.g. seeds, fertilizers);

(continued)

Table 4 (continued)

Zone	East	West	North	South
Policy related	Improve flood forecasting and early warning system; Training support; Inputs at subsidized prices; Capacity building and information sharing; Crop insurance and loans waiving; Ensure remunerative prices; Income diversification (non- farm income sources); Credit facilities; De-silting of the river so that water flows to sea;	Ensure remunerative prices;	Creating a coordinated decision structure for better response; Improved flood forecasting; Comprehensive insurance; Credit facilities; Capacity building and information sharing;	Remunerative prices, market access; Improve flood forecasting and early warning system; Ensure labor availability through NREGA; Investment in research and development (e.g. flood tolerant crops and varieties); Formation of community-based water management groups; Credit facilities; Capacity building and information sharing; Ensure crop insurance; Reduce input prices; Restoration of vegetation cover and replant trees for soil protection; More priority to agriculture in policy making;

Source Rama Rao et al. (2018b)

use systems and crop-tree-fodder-livestock based integrated farming systems need to be developed. Emphasis also needs to be given to biological approaches to nutrient and pest management.

Rainfed agriculture is highly diverse and presents numerous challenges with climate change further aggravating all those challenges. However, it is imperative to address the challenges through concerted and coordinated efforts in technology generation, extension and policy spheres. For this to happen, actors and agencies engaged in such relevant spheres must develop appropriate institutional arrangements to provide the required support to rainfed agriculture. Only then will it be possible to realize the goal of more sustainable and equitable growth in agriculture and in the economy in a larger context. All measures to reduce risk should be strategically combined to reduce risk in the short and long term through vulnerability reduction and resilience building. A comprehensive strategy consisting of technological, institutional and management interventions is needed for effective risk management in rainfed agriculture.

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