Rukhsana
Asraful Alam *Editors*

Agriculture, Environment and Sustainable Development

Experiences and Case Studies

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Preface

Agriculture is one of the economic sectors most vulnerable to climate change. Climatic characteristics that have the most direct effect on agricultural productivity include frequency and intensity of rainfall change, augmented temperatures, and extreme weather events. This includes whether impending climate change due to an increase in greenhouse gases will have a direct impact on agricultural productivity and production and, consequently, on farmers' incomes. Climate change is happening very rapidly; the temperature has been 5.0 °C lower than it is now as compared to the gradual change in temperature during the last ice age. Therefore, due to the current climate change predictions, there is a need for urgent action to reduce the impact of climate change as well as adopt climate change mitigation for agriculture system.

According to a recent assessment of the impact of climate change on agricultural productivity, global food production is not susceptible by projected climate change, different previous forecasts. However, the regional agricultural productivity gap due to climate change will augment the percentage of the population which may become more vulnerable to hunger. Recent estimates as per the IPCC projected that climate change will have both positive and negative impacts on the productivity of agriculture, depending on the type of farming. Increasing atmospheric CO_2 concentration will certainly affect agricultural productivity.

Agricultural sustainability does not mean rejecting any technology or practices on ideological grounds. If a technology supports to advance productivity for farmers and doesn't cause excessive harm to the environment, it is likely to have some sustainability profits. Agricultural systems focusing these principles are also multifunctional within economies and landscapes. Sustainable agriculture aims to make the best use of technologies, goods of nature, services, and practices must be applied and adapted which are most probable to emerge from new formations of social capital, new horizontal and vertical partnerships between institutions, and human capital that contains inventiveness, leadership, the ability to innovate and management. It is advised that there are many ways towards sustainable agricultural, and is suggested that no one conformation of technologies, inputs, and ecological management is more widely applied than the other. Sustainable agriculture reflects the need to fit these factors into the specific conditions of different farming systems. Availability, accessibility, and adequacy of food are frequent anxieties while developing policies to attain zero hunger. Climate change and land borders are also emerging as significant factors that are snow balling the problem of food insecurity worldwide.

This volume discusses emerging contexts of climate change, agriculture, environment, and sustainable development from local and global perspectives as well as contemporary technological advances. By the 1980s, global growth in food production surpassed the concomitant growth of the human population, yet progressively agriculture is becoming increasingly unable to meet per-capita demands for food. It is expected that the global human population will exceed 14 billion by 2050, while adequate food, fuel, and space for such an increased population will unreachable. These problems are heightened by factors such as worldwide reduction in soil fertility, rapid erosion of land suitable for food production through soil degradation, migration of human population from rural populations to cities, and extremely rapid rates of global deforestation. This volume is divided into three parts: (i) Land Use Changes and Agriculture Development, (ii) Water, Environment *(iii)* Agriculture Sustainability and Sustainable Development and Environmental Management. It deals with past trends, patterns, and emerging challenges associated with agricultural production, water and environmental management, and local and international development. This book provides a broad exposition of the trends and current practices of basic principles on sustainable agriculture and strengthens the understanding for its use to develop environmentally sustainable and profitable food production systems. The various chapters contain conceptual and empirical material from research conducted in various states of India and other countries. They describe the ecological sustainability of agricultural systems, current innovations to improve efficiency in the use of resources for sustainable agriculture, and the proposal for technological options and new areas of research in this very significant field of agriculture. Some of the topics covered in this book include food demand, transformation of agricultural landscape, climate change, environmental impact assessment, sustainable livelihoods, social and environmental impacts on agricultural development, urban agriculture, soil science, and remote sensing for agricultural land suitability. Potential solutions to global sustainability in agriculture and natural resources should include the integration of ecological, cultural, sociopolitical, and economic considerations, and national and international policies.

Arshad Bhat, Abid Sultan, Iqra Qureshi, and Abid Qadir (Srinagar, Kashmir; and Uttar Pradesh, India) looked into the *economic evaluation and assessment of modern apple varieties in the Kashmir valley (ex-post) though propensity score-matching methods* in Chapter "Economic Evaluation and Assessment of Modern Apple Varieties in Kashmir Valley (Ex-Post) Though Propensity Score Matching Methods". Propensity score methods used in this chapter for making dependability of the ex-post examination and results uncovered that efficiency of apple expanded which assistant yield significant yields to the growers up to Rs. 1,200,000/ha^{-1}. The chapter further uncovers that in spite of high establishment costs, modern cultivars profited apple growers through early organic product bearing, higher efficiency, and through employment generation.

Chapter, entitled "**The Intensification of Shifting Cultivation in Tanzania: Effects on Soil and Vegetation**," by Charles Joseph Kilawe, Salim Mohamed Maliondo, Thilde Bech Bruun, Torben Birch-Thomsen, Dos Santos Aristaricky Silayo, and Ole Mertz (Denmark and Tanzania) is another important contribution of this book. This chapter investigates the effect of intensification of shifting cultivation on the recovery of soil properties and vegetation in East Central Tanzania. The study is based on soil sampling conducted in 40 (5 m × 5 m) plots from adjacent sites under fallows of 1, 2, 3, 4, 5, and 7 years, a reserved forest that has never been cultivated, and a field under a ridge and flat continuous cultivation. Vegetation sampling was also conducted in sites under fallows and the reserved forest. Shortening of fallow length deteriorates soil quality due to a decline in total N, plant-available P, and exchangeable K. Furthermore, shortening of fallow length negatively affects the recovery of plant species composition and diversity. Young fallows harbored more diverse vegetation, mostly shrubs, while older fallows were less diverse but dominated by trees. Soils under the ridge and flat continuous cultivation had significantly higher plant-available P than soils under fallow or reserved forest. Moreover, the soil under the ridge and flat cultivation contained levels of soil pH, plant-available P, exchangeable K, and Ca that have been described as sufficient for sustainable crop production.

The chapter by Thanga Suja Srinivasan, Sugitha Thankappan, Madhumitha, and Vijaya Bhaskar (Tamilnadu, India), "Impact of**Plant Hea**lth on**Global Food Secu**rity: A**Holistic**view" (Chapter), is an effort to provide information relevant to the impact of plant health on crop productivity, challenges associated with plant health, advancement in diagnostic techniques, and the role of integrated plant health system to achieve the goals of food security.

The fifth chapter, "Crop Diversification as a Measure of Sustainable Agriculture and Production Growth," contributed by Md. Faiyaz Afzal and Shamsul Haque Siddiqui (Aligarh, India), studies the pattern of crop diversification and growth in agricultural production during the period 2000–01 and 2014–15. The variation in crop diversification is a response to the fast-changing physical and socio-cultural conditions which helps in attaining agricultural sustainability. The index of crop diversification has been employed by using Gibbs-Martin Index of Crop Diversification (1962). The study highlights that there has been a shift in cropping behavior from cereals towards non-foodgrain crops, and the production of major crops has also increased manifolds in both the districts.

Part II of the book compiles the description and analysis of water, environment, and agriculture sustainability through five chapters (Chapters "Spatio-Temporal Analysis of Built-Up Area Expansion on Agricultural Land in Mousuni Island of Indian Sundarban Region", "Levels of Agriculture Development and Crop Diversification: A District-Wise Panel Data Analysis in West Bengal", "Engineering Interventions to Mitigate the Agricultural Waste in India", "The Study of Red Onion (Allium cepa) on Growth and Yield Parameters in Response to Plant Spacing in Jaffna District, Sri Lanka", and "Soil Potential Erosion Risk Calculation Assessment Using Geospatial Technique in Keonjhar District, Odisha, India"). Sabir Hossain Molla and Rukhsana work on **spatiotemporal analysis of built-up area expansion**

on agricultural land in Mousuni Island of the Indian Sundarbans, and this study was conducted to quantify the nexus between built-up growth and agricultural land conversion for the period 2000–2020. Geographic information system and random forest (RF) classification technique were used to classify Landsat TM of 2000 and Landsat OLI of 2020 images of the Island and produced land-use/ land cover (LULC) classes. The analysis revealed that during the past 20 years, the built-up land increased by 168.43% from the early (223.20 ha) built-up area in 2000. The newly formed built-up area exhibited 13.15% (375.93 ha) of the total Island of which 10.91% (312 ha) came from expanses of agricultural land and 3% (64 ha) came from other categories. It is concluded that the built-up expansions were predominantly on agricultural lands where 15.6 ha/year of agricultural lands were eliminated. These abrupt rates of losing agricultural lands are alarming and require adopting appropriate strategies for sustainable land use in this area.

"**Levels of Agriculture Development and Crop Diversification:A District-Wise Panel Data Analysis in West Bengal** (Chapter), by Rukhsana and Asraful Alam (Serampore and Kolkata, India), examines agricultural development and its indicators in the context of crop diversification in West Bengal, a state in the eastern region of India. The areas of agricultural development (used composite z-score) and crop diversification (used Herfindahl index) have been developed to detect diverse agricultural impacts in West Bengal. Crop diversification has been found to be low in some districts of West Bengal due to traditional farming practices, and other major factors like total irrigated land, percentage of HYVs area as gross cropped area, average land holding size, and per capita income as determinants of crop diversification can be identified. The expansion of crop diversification depends on improvement in production risk through technical assistance, quality input supply, insurance cover, and the existence of modern storage-processing centers in the region.

Chapter, entitled "**Engineering Interventions to Mitigate the Agricultural Waste in India,**" by Prabhakar Shukla, Anjali Sudhakar, Prem Veer Gautam, and Shekh Mukhtar Mansuri (Jodhpur and Bhopal, India), elaborates that India produces more than 620 million tons of agricultural waste annually. Out of that, only 25–30% is utilized as livestock fodder and for energy production, and the remaining goes as waste. For next crop sowing, most of the farmers are practicing incineration to clean the field in the rice-wheat crop system as well as other crops. This practice releases harmful gases like CO_2, CH_4, N_2O, H_2S, O_3, and smog which cause air pollution. It also affects public life and disturbs soil's physical, biological, and chemical properties by destroying beneficial soil microorganisms. Along with crop production, other enterprises like dairy, fishery, poultry, agro-forestry, goat, and sheep rearing produce huge agricultural waste likes crop residues and cow dung. Therefore, engineering interventions to mitigate the agricultural waste in India can be an option to solve the above problems and also provide better inputs to crop productivity.

The empirical study in Chapter, "**The Study of Red Onion (Allium cepa) on Growth and Yield Parameters in Response to Plant Spacing in Jaffna District, Sri Lanka,**" was carried out in randomized complete block design with four replicates. There were three different plant spacing measures taken as treatments, namely T1: 5 cm × 5 cm; T2: 7.5 cm × 7.5 cm; and T3: 10 cm × 10 cm. Parameters on growth characters such as plant height and number of leaves per plant were measured at 3-weeks interval from planting. Further, the bulb length, diameter, average weight, and total bulb yield were recorded at the time of harvesting. The analysis revealed that plant spacing had significant ($P < 0.05$) effect on the growth and yield parameters of red onion with varying levels of plant spacing. It could be concluded that the widest spacing (10 cm × 10 cm) in T3 produced significantly ($P < 0.05$) higher values in plant height, number of leaves, bulb length, diameter, and average weight. It was found that the narrow plant spacing (5 cm × 5 cm) in T1 character value was recorded to be decreased. On the other hand, the highest total yield was recorded in T1 with higher plant density compared to the yield produced with lesser plant density in T3. In T3 (10 cm × 10 cm), quality of the bulb is better than T1 (5 cm × 5 cm). As a result, the marketability is high for the bulbs. Meanwhile, higher yield was generated in T1 when compared to T3 due to high volume of bulbs produced. However, the marketability is lesser than T3 with the low quality of bulbs. Therefore, the study recommends wider spacing for red onion cultivation in Jaffna district as it is the ideal choice for farmers based on consumer behavior.

"Soil Potential Erosion Risk Calculation Assessment Using Geospatial Technique in Keonjhar District, Odisha, India" (Chapter) is authored by Raghib Raza, Suraj Kumar Singh, Shruti Kanga, S.C. Moharana, and Srinivas Rao (Jaipur, Ahmedabad, and Bhubaneshwar, India). Revised Universal Soil Loss Equation (RUSLE) model was used to estimate the soil loss of Keonjhar District, Odisha. Various analyses are done in the district with addition of land use and land cover, slope variation, types of soil, rainfall, flow accumulation, and various inner calculations. In the study area, 0–10 t ha^{-1} Y^{-1} having 36.31% area comes under weak severe zone; 10–20 t ha^{-1} Y^{-1} is moderate severe, having 27.69% area covered; 20–30 t ha^{-1} Y^{-1} is strongly severe, having 16.57% area covered; 30–40 t ha^{-1} Y^{-1} is very strong, having 11.82% area covered; and lastly, extremely strong severe zone for soil loss is 40 t ha^{-1} Y^{-1} and above, covering 7.61% area of the annual potential soil loss.

Part III of this book focuses on agriculture sustainability, sustainable development, and environmental management, and it includes Chapters "Organic Farming Sector of India: A Statistical Review and Recommendations", "The Agrarian Vision: Sustainability and Environmental Ethics Via, Good Agricultural Practices (Gap)", "Soil Community Composition and Ecosystem Processes", "Household Access to Actual Food Intake and Fertility Level of Muslim Population: A Study from Rural West Bengal", and "Livelihood, Food Security, and Sustainability in Murshidabad District". In Chapter, "**Organic Farming Sector of India: A Statistical Review and Recommendations**," a statistical review has been carried out by Manavalan (Bangalore, India). This chapter mainly intends to bring out the year-wise progress details of the organic farming sector in India in a chronological order by which its growth scenario and major achievements are analyzed. Authenticated data pertaining to the key indicators of the organic farming sector of India from year 2003 till date has been collected and analyzed. Data related to key indicators for the land assessment, such as areal extent of Organic Land, areal extent of Wild collection, number of Organic Producers, Processors, Exporters of India as well as organic market related factors such as Production quantity, Export Volume, Export Value were analyzed in detail. Wherever required, both the source data as well as outcome of the analyzed results were cross validated with the help of multiple reference articles as well as through Web content mining. At the end, the importance of developing and deploying a geographic information system–based decision support system (GIS-DSS) under the banner of National Organic Farming Atlas of India is insisted, which will certainly enhance the growth status of the organic farming sector in India right from taluk to district as well as at state level.

"**The Agrarian Vision: Sustainability and Environmental Ethics**via**Good Agricultural Practices (GAP)**" (Chapter), authored by M.S. Sadiq, I. P. Singh, M.M. Ahmad, and N. Karunakaran (Nigeria and India), is another important contribution of this book. The authors explain that agricultural sustainability is predicated on the idea that we must meet current needs without jeopardizing future generations' ability to meet their own. As a result, long-term control of both natural and human capital is equally important for short-term economic gain. A sustainable agricultural method tries to utilize natural resources in such a way that they can regenerate their productive capacity while also minimizing negative ecosystem consequences beyond the field's edge. One must recall Mahatma Gandhi's famous saying, "There is enough on this earth for the needs of everyone, but not for anyone's greed." The "green" revolution has also been called a "greed" revolution. One must be careful not to attempt to get the maximum yield beyond the soil's carrying ability and the resource's sustaining potential. Let's start with good agricultural practices that will lead us in the future to sustainable/organic farming.

The work by Arjita Punetha, Shailaja Punetha, and Amir Khan (Uttarakhand, India) on "**Soil Community Composition and Ecosystem Processes**" in Chapter attempts to analyze the soil community composition and ecosystem processes and explain that soil is a major hub of nutrients and water supply that directly govern the growth, nutrient status, and productivity of crops, thereby indirectly influencing human health. Therefore, in order to maintain the proper functioning of soil and its community, soil restoration is the need of the hour. This requires reducing the use massive machinery for agricultural and other purposes, shifting to organic farming, syncing nutrient release and water availability with requirement of plants, and monitoring the biological activity.

The study by M Soleman Khan and AKM Anwaruzzaman (India) in Chapter, "Household Access to Actual Food Intake and Fertility Level of Muslim Population: A Study from Rural West Bengal**,**" based on both secondary and primary data covering 600 households, intends to examine food access of the households classified by their socio-economic condition among married Muslim population. The present study is conducted on select community development (CD) blocks of West Bengal using a multi-stage random sampling technique. After detailed study, it has been found that there is a negative relation between actual food intake of married Muslim women and fertility level of Muslims in rural West Bengal. It is further observed that Muslim women are deprived in terms of the consumption of food compared to

Muslim men due to male supremacy and low access to food mainly because of their poor socio-economic conditions.

Chapter is entitled "Livelihood, Food Security and Sustainability in Murshidabad District," authored by Bulbul Nargis Sultana and Nasrin Banu (India). They discuss the issues of livelihood sustainability, and this is measured adopting the formula of Livelihood Vulnerability Index developed by Intergovernmental Panel on Climate Change (IPCC). In addition to this, livelihood sustainability has been categorized into four stages on the livelihood ladder adopting the concept of Oxfam, that is, Accumulating, Adapting, Coping, and Surviving. In accumulating stage of sustainability, there are eight villages where life is going well and households are able to cope with most of the external shocks. Food security status of the accumulating stage is also better than the other stages. Households of adapting-stage villages have higher hold on assets, but it is slightly lower than the households of accumulating stage. The villages which are under adapting stage have sustainable food security. In coping stage, things are good enough but not at the satisfactory level. There are six villages in these stages where food security status is below the sustainability level. Seven villages came under the surviving stage where livelihood is most vulnerable, and households of this stage are unable to cope with even small shocks, having limited asset possession.

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Kolkata, India

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Rukhsana is currently serving as an assistant professor in Department of Geography at Aliah University, Kolkata. She obtained her doctoral degree in geography from Aligarh Muslim University. She has published more than 40 research papers in reputed journals and 4 books at national and international levels. Dr. Rukhsana has presented a number of research papers, and she was also conferred with the International Young Geographer Award. She has attended XXV FIG International Congress 2014, Malaysia, and ICGGS-2018, Bangkok, Thailand. Dr. Rukhsana has supervised four PhD students. Her research interests include agriculture, urban population, environment, and development in geography. She has supervised four scholars and led them to achieving PhD degrees in geography. Dr. Rukhsana has successfully completed a major research project sponsored by ICSSR, New Delhi. She has been the head of the Department of Geography at Aliah University.

Asraful Alam is an assistant professor and head of the Department of Geography, Serampore Girls' College, University of Calcutta, West Bengal, India. He received his MA and PhD degrees in geography from Aligarh Muslim University, Aligarh, and Aliah University, Kolkata, India, respectively, and also completed PG diploma in remote sensing and GIS. Dr. Alam completed his postdoctoral fellowship (PDF) in the Department of Geography, University of Calcutta, Kolkata, India. Earlier, he was an assistant coordinator of postgraduate studies in the Department of Geography, Calcutta Women's College, University of Calcutta, Kolkata, India. His research interests include population geography, agricultural geography, climatology, remote sensing and GIS, and developmental studies. He has published 2 books (three by Springer) and more than 32 papers in peer-reviewed journals. Dr. Alam has served as reviewer for many international journals.

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Part I
Global Warming and Climate Change: Vulnerability in Agricultural Sectors

Agriculture, Environment and Sustainable Development: An Overview

Rukhsana and Asraful Alam

Abstract In an age of frequent climate change, the most important challenge in the world is to produce enough food for a growing population. Therefore, using advanced technology, high-yielding varieties, including irrigation water and fertilizers have helped the world to develop a food surplus. The destruction of natural potential, the destruction of the agricultural sector and the pollution of the environment have threatened the very existence of mankind as a result of the increase in man-made environmental change manifested in the form of climate change. Achieving food and nutrition security is a priority in developing countries, which requires the restructuring of relevant policies as one of the key ways to achieve sustainable agriculture in order to have a resilient global food system and control and maintain the environment. This brief provides some basic insights into the current understanding of agriculture, the environment and sustainable development in the agricultural sector. This chapter presents the concepts, relationships and current situation of agriculture, sustainable development in climate change and summarizes the wisdom part of this book. It focuses on global agricultural challenges, associations, climate change and sustainability. This summary emphasizes the interdisciplinary nature of agricultural and environmental concerns, which are addressed through an effective cross-sectoral approach.

Keywords Agriculture and climate change · Environment and agriculture sustainability

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1 Introduction

Sustainable agriculture is key to achieving the world's development goals, one of the most effective strategies for eradicating extreme poverty and feeding 9.7 billion people by 2050. Agricultural growth is four times more effective in increasing income among the poor than in other sectors. In 2016, it was reported that 65% of poor working people depend on adult agriculture (World Bank, 2012). The majority of farmers worldwide are found in middle- and low-income countries, where agricultural sector generates a major part of employment and national income.

People face a variety of challenges, most of them related to the food security of an explosive population, which could exceed 9 billion by 2050. Agriculture is the livelihood of more than 2.6 billion people in the world, while the share of agricultural production in the total domestic agriculture is declining. In low-income countries the potential for non-farm employment is limited, inequality is increasing and the viability of small-holding agriculture is under stress (Rukhsana & Alam, 2013). Along with the extraordinary progress in food production over the past half century, unsustainable levels of consumption in some countries and hunger and malnutrition in others, mainly in South Asia and Africa, have led to poor health, low earning capacity and environmental degradation. The rapidly evolving phenomenon of climate change is putting more pressure on the natural resources on which we depend, and the planetary limits of Earth's resource system are shrinking. Therefore, it results in a rethink about the food that is grown, processed, shared and consumed (UN, 1996).

If we want to feed today's 925 million hungry people, of whom 230 million live in India, we need to make a profound change in the global food system. If corrective measures are not implemented, about 2 billion people are expected to join the sector by 2050, especially in developing countries (UN, 2012). Significant augmenting in global food production over the past four decades have been a major achievement, but they have also created serious environmental problems. These contain the cumulative effects of salinization on land productivity and soil erosion, pesticide hazards and chemical fertilizers, desertification and the accelerated conversion of crops to non-agricultural uses. Large-scale industrial agriculture has also caused genetic degradation, species loss and wildlife habitat degradation, with more than 4000 plant and animal species being threatened by agricultural intensification (FAO, 2010). Improvements in productivity and technological advances have contributed to efficient use of many resources and improved food security, but major concerns remain that 795 million people are still hungry and more than 2 billion people are suffering from micronutrient deficiencies. Agricultural production is extremely vulnerable to climate change, which threatens the sustainability of large-scale food systems.

Despite various developments around the world, improvements in food production, sustainability and levels of global hunger have remained astonishing, with more than 820 million people still suffering from daily hunger, a gradual increase over the past three years. Around 2 billion people face food insecurity and lack of safe and nutritious food, especially women, children and indigenous groups, especially those suffering from hunger. The political, economic and social implications of this silent state of emergency are enormous as the world struggles to achieve such advanced development results in the face of climate disaster. Hunger and food insecurity are the products of many complex factors, including climate-related triggers (such as droughts, floods, cyclones), often exacerbated by economic hardship and conflict (FAO, 2019).

In recent decades, with global food production increasing in the early 1960s, agricultural production has increased significantly. Since then, the total world food production has increased by 145%. It increased by 140% in Africa, about 200% in Latin America and 280% in Asia. The highest growth was in China, where more roses were grown in the 1980s and 1990s. In industrialized countries, production starts from a higher base; yet it has doubled in 40 years in the United States and 68% in Western Europe (FAO, 2006).

At the same time, the world's population has grown from 3 billion to over 6 billion, resulting in an increase in the impact of human footprints on the earth as the type of spending changes. Today there is 25% more food per person than in 1960. However, these aggregate statistics obscure significant regional differences. In Asia and Latin America, per capita food production increased by 7% and 26%, respectively. Africa, however, is doing poorly today with a 10% lower per capita food production than in the 1960s. China, again, achieved best with a triple of food production per capita in same period. These agricultural production profits have lifted millions out of poverty and provided a platform for rural and urban economic development in worldwide. However, these advancements in overall productivity have not reduced the hunger for all. At the beginning of the twenty-first century, more than 800 million people are still hungry and do not have adequate access to food (Conway, G., & Toenniessen, G. 1999).

First growing nature of world population, at least until the middle of the twenty-first century, the demand for food will also increase, increase in income will also mean more purchasing power of the people and it will increase the demand for food. But with the change in diet, the demand for different types of food will also change drastically. A large number of people are going through nutritional changes. In particular, increasing urbanization has meant that people are more likely to adopt new diets, specifically consuming more meat, fat and refined grains, and less traditional grains, vegetables and fruits (Munir & Rukhsana 2008).

Agriculture is one of the riskiest economic sectors for climate change. Climate characteristics have the most direct impact on agricultural productivity, including the frequency and intensity of rainfall changes, temperature rise and extreme weather events (Mendelsohn & Dinar, 2009). This includes whether impending climate change due to an increase in greenhouse gases will have a direct impact on agricultural productivity and production and, consequently, on farmers' incomes. Climate change is happening very rapidly; it has been 5.0 °C lower than today's temperature compared to the gradual change in temperature during the last ice age (Duncan, 2009; Rukhsana & Alam 2021). Therefore, due to the current climate change forecast, urgent steps are needed to mitigate the effects of climate change as well as mitigate climate change in the agricultural system.

The gap in regional agricultural productivity due to climate change will increase the percentage of the population which may be more at risk for hunger. According to the IPCC, recent estimates suggest that climate change will have both positive and negative effects on agricultural productivity, depending on the type of cultivation (IPCC, 2007; Rukhsana et al., 2021). Increasing atmospheric CO_2 concentration will certainly affect agricultural productivity (Taub, 2010).

The food crisis marked a dramatic turning point in the previous era of highly volatile food supply in 1972–1974, and world market prices divided countries with food abundance. As a result, in the 1970s, food security insurance schemes were established, which ensured international access to physical food supplies. Better food security assurances need to be achieved through good management among supporting organizations, agencies and monitoring of food availability in the address countries. In the 1980s, after the success of the Green Revolution, which helped boost food production, it was documented that the food crisis and even famine did not cause catastrophic declines in food production because of the sharp decline in purchasing power. Therefore, food security was extended, and role of women in poverty mitigation and development was promoted. Then actual plans were designed to minimize hunger and malnutrition in 1990. In the 2000s, the decrease of hunger and malnutrition was seen in terms of overall development, poverty lessening and attainment of the Millennium Development Goals (UN SCN, 2004; Rukhsana & Alam, 2021).

Since the 1960s, there have been green revolutions around the world, significantly increasing the production of some crops, but also bringing about regional disparities in production and income generation. Growing poverty and unequal distribution apply for equal access to food (Alam et al., 2021). Poor people showed strange behaviour, for example, poverty forced people to starve to save food for the future (Maxwell, 1995). The situation was further strengthened when Amartya Sen in his book "Poverty and Famines", 1981 (Alam et al., 2021) emphasized the right to food against starvation caused by poverty and unequal access to food.

As an effect, in 1983 the concept was changed to provide access to food for all. The new definition, formulated by the FAO, was "to ensure that all people always have access, both physically and economically, to the basic food they need". (FAO, 2006). Agriculture is involved with many environmental changes, including loss of biodiversity and degradation of water and land, which are also highly dependent on climatic conditions and ecosystem services. In addition to adapting to climate change, the impact of biofuels on agricultural biodiversity is an important factor for sustainable development. Biofuels are capable of boosting national energy security as well as economic growth.

Technology and gradual harvesting practices should be practiced to help meet the world's food needs. Also, a reliable crop can be very beneficial in improving and maintaining soil fertility and increasing the income of farmers. (Sheha et al., 2014). Both solutions will occur when land is limited, so that the labor and water obtained from intensive harvesting can be used adequately. (Gallaher, 2009). Farmers can grow multiple crops on the same land at the same time to achieve maximum water use efficiency and maintain soil fertility (Joseph & Avika, 2011; Rukhsana & Alam, 2021).

Agricultural sustainability does not mean rejecting any technology or practice on an ideological basis. If a technology helps farmers increase productivity and does not harm the environment too much, it has the potential to have some lasting benefits. To make the best use of sustainable agricultural technology, nature's products, services and practices must be applied and adapted to new forms of social capital, the potential for new horizontal and vertical partnerships within the organization and human capital, which includes innovation, leadership, innovation and management skills (Chambers, 1989; Molla & Alam, 2020). It suggests that there are many ways toward sustainable agriculture and suggests that one form of technology, input and environmental management is not more widely applied than the other. Sustainable agriculture reflects the need to fit these factors into the specific conditions of different agricultural systems. Food availability, accessibility and adequacy are frequent concerns when formulating policies to achieve zero hunger. Climate change and land borders are also emerging as significant factors contributing to the global food insecurity (Rukhsana & Alam, 2021).

Environmental concerns in the 1950s and 1960s can be traced to agricultural sustainability and food security. Today, agricultural sustainable organizations warn of the need to establish agricultural technologies and practices that will not adversely affect the environment, improve food productivity and have a positive impact on environmental products and services. Sustainability in the agricultural system integrates the concepts of both resilience and sustainability and addresses a number of macroeconomic, social and environmental consequences (Alam & Satpati, 2021). The impact of agricultural practices on environmental sustainability is consistent with current and future needs due to the impact of climate change (FAO, 2008; Kuhlman & Farrington, 2010). Existing literature acknowledges that changes in land use pose a significant threat to achieving the goal of environmental sustainability (Kuhlman & Farrington, 2010; Ayivor & Gordon, 2012).

2 Conclusion

Based on the review, this infer that some agricultural practices such as deforestation, land clearing for agricultural use, irrigation, use of agro-chemicals, livestock slash-burn-agriculture, soil nutrients mining, soil and water management, poultry production, animal health, use of growth hormones in animal production and agricultural biotechnology pose serious risks and have negative effects on the human society as well our environment which hamper environmental sustainability. Different facility loss influence on the environmental resources, increase biodiversity loss, deforestation, promoting carbon emissions, ozone-depleting substances, reduce fish stocks, increase used water resources, effect on endangered species and also reduce sustainable access to safe drinking water. In this case, the agricultural production system, economic livelihood and environmental well-being of both present and future generations are at risk and therefore all stakeholders have to play their respective roles to counteract the trend of environmental degradation and improve the conservation of basic environmental resources. However, sustainable agricultural technology has a positive impact on agro-environmental and human health, which one accepted by the world community through research, advocacy and policy proposals, which also meet the current needs without compromising the ability to meet the needs of future generations (Goodland, 1995; Leiserowitz et al., 2005). There is a bright future for the present and future generations on the environmental sustainability of sustainable agricultural practices practiced through both adaptive / resilient technologies and low-carbon economy technologies to address the adverse effects of sustainable agricultural practices. (Pretty & Ball, 2001; Wall & Smit, 2005; Chel & Kaushik, 2011).

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Economic Evaluation and Assessment of Modern Apple Varieties in Kashmir Valley (Ex-Post) Though Propensity Score Matching Methods

Arshad Bhat, Abid Sultan, Iqra Qureshi, and Abid Qadir

Abstract Modern apple cultivars have been introduced in the Union Territory (UT) of Jammu and Kashmir to make ideal usage of accessible land assets to expand creation and efficiency of apples, particularly grade A. The modern cultivars bore fruit within just 3–4 years of their planting. The old varieties, with a long bearing time of 8–9 years, yielded too little per unit of land, and hectic and clumsy management practices were followed. Logically, modern cultivars are unique in relation to old varieties in plant thickness, usefulness, plant density, productivity, gestation lag, management practices, and so on. The chapter utilizes propensity score methods to assess dependability of the ex-post examination, and results revealed that efficiency of apple farming increased, providing significant yields to the growers of up to Rs. 1,200,000/ha^{-1}. The chapter further shows that despite high establishment costs, modern cultivars benefited apple growers through early organic product bearing, higher efficiency and employment generation.

Keywords Propensity score · Ex-post · Cultivars · Productivity · Fruit bearing

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1 Introduction

Kashmir is home to organic products such as apples, pears, peaches, plums and so on, because of its soil, environment and climate. Developed on a space of 3.31 lakh hectares (2018–2019), production of 20 lakh metric huge loads of apples with normal output of 11–13 tons/ha (Directorate of Horticulture, 2020) has continued despite the dangerous apple scab (Venturia inaequalis) and other lethal illnesses such as alternaria leaf spot, fine mold, marsonina leaf smudge, root and collar decay and so forth, which are expensive ti control. Moreover, heavy rains and haze affect natural product quality and shading improvement. Likewise, those regions experience high winds, which hinder apple development (Shubhi, 2013, 2021; Amin, 2004). The territories of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Arunachal Pradesh and Nagaland are pioneers in apple development in the country.

Scientifically developed apple varieties ordinarily developed across the landmass are M 9, M 26, M7, MM 106, MM 11 (clonal rootstocks) Hazratbali, Razakwari, Gala Mast, Kesari, Red Delicious, Royal Delicious, American Apirouge, Golden Deloicious, Maharaji, Coxs Orange Pippin, Chamura (commercial varieties), Red Velox, Starkrimson, Cooper 4, Gala Redlum, Oregon Spike, Silver Prod, Wells Spike, Fuji Zehn Aztec, Coe Red Fuji, Gala Brookfield, Mitch Gala, Elstar, Elrosa, Wiltons Star, Red Braeburn, Jona Gold, Golden Clone B, Golden Reinders (newly presented varieties), Prima, Priscilla, Sir Prize, Jonafree, Florina, Macfree, Nova Easy Grow, Coop 12, Coop 13 (Redfree), Nova Mac, Liberty, Freedom, Firdous, Shireen (Scab safe), Red Delicious x Ambri, Ambri x Golden Delicious, Early Shanburry x Red Delicious, Red Delicious x Ambri, Richared x Ambri, Starking Delicious x Ambri (Hybrids), Michal, Schlomit, Anna, Tamma, Vered, Neomi, Tropical Beauty, Parlin's Beauty (low chilling assortments) and Tydeman's Early, Red Gold, Golden Delicious, McIntosh, Lord Lambourne, Winter Banana, Granny Smith, Starkspur Golden and Golden Spur (pollinizers).

Logically, modern apple cultivars maintain high tree density in excess of 1500 trees for each section of land, and they bear fruit within 2–3 years after planting (Aashiq, 2014; Jahangeer, 2019; Rafiya, 2019; Mishra, 2013; Bakhtaver et al., 2020). Intelligent overshadowing rootstock is utilized to accomplish early development, which needs a high thickness plantation and changed and progressive pruning to amplify its growth (Masoodi, 2004). A lasting exorbitant iron design utilized in its development expands the underlying foundation cost. The predominant rootstocks have better returns in the third year, keeping a division of 0.8 × 3.2 m and plant thickness of 3906 for every hectare, which has been seen to be most productive (Rebecca, 2007; Robinson, 2012; Michael and Eric 2016). M9, with a weak root framework, requires a solid supportive network (currently a four-wire lattice framework for a tall axle preparing framework is utilized), is the most favored rootstock worldwide. Poles of concrete, packed wood or steel are utilized in the framework to maintain balance and dispersing between the shafts. Additionally, if hail is predicted, a hail net with retractable capacity is utilized to forestall harm (Robinson, 2012). The compensation period has been assessed at 5 years; in any case, it requires roughly 35.00 lakhs per hectare for its foundation in the first year (Rebecca, 2007), which is remunerated through higher usefulness and quality. The development of modern cultivars of apples has changed the situation for apple production worldwide and is additionally in the associated region of Jammu and Kashmir. The selection of modern apple cultivars (Red Gala) expanded the yield of apples more than twofold compared to the old apple cultivars. With this background, an ex-post investigation utilizing propensity score matching was attempted to determine the economic potential of this variety.

2 Methodology

The information was gathered from 185 respondents across Kashmir Valley, involving 78 adopters and 107 non-adopters. Propensity score matching (PSM) was utilized on the information to arrive at a sound and obvious end result. The model for determining the propensity score for the i^{th} respondent might be emblematically addressed as:

$$\boldsymbol{e}_i = \Pr\left(\boldsymbol{Z}_i = \mathbf{1} | \boldsymbol{X}_i\right)$$

where Z_i is the marker variable for application or non-use of treatment (0 or 1, respectively). Propensity scores are by and large assessed utilizing a calculated relapse model and include framing coordinated with sets of treated and untreated respondents who have a comparative worth of the propensity score (Dehejia & Wahba, 2002; Chen & Ravallion, 2003; Rosenbaum & Rubin, 2013; Morgan, 2017). PSM carried out here is a separate approach, which includes defining respondents into fundamentally unrelated subsets dependent on their assessed inclination score.

There were two pre-conditions for PSM: (1) being free of the treatment task on potential results contingent on the noticed benchmark covariates and (2) having non-zero likelihood of every respondent getting both of the two medicines; for this situation, there was appropriation of logically progressed cultivars and their non-selection. If the conditions are fulfilled, the average impact of the treatment on treated (ATT) can be assessed, which is characterized as the normal impact of treatment on those respondents who eventually got the treatment.

$$\boldsymbol{ATT} = \boldsymbol{E}\left(\mathbf{Y1} - \mathbf{Y0} | \mathbf{Z} = \mathbf{1}\right)$$

ATT was assessed utilizing four calculations, specifically nearest neighbor matching (NNM), kernel matching, stratified matching and radius matching. NNM coordinates with every adopter with the non-adopter having the nearest propensity score inside the area, while, kernel matching utilizes a weighted normal of all farmers in the adopter gathering to build a counterfactual (Westreich et al., 2010; Sahu & Das, 2015). A significant benefit of kernel matching is that it produces ATT impacts with more modest lower change, as it uses more prominent data than the NNM. Essentially, stratified and radius matching methods coordinate with an adopter with a non-adopter inside indicated layers and inside a predefined span to help discover similarly likely counterfactual.

3 Results and Discussion

Table 1 presents the ex-ante and ex-post financial assessment of modern apple cultivars.The table shows that there is a difference of Rs. 210,056/ha^{-1} in only two kinds of assessments, which implies the two assessments are standard and can be the basis for further assessment.

Table 2 shows that for propensity score coordinating with investigation, 107 non-adopters of deductively progressed apple cultivars with a level of 57.84 and 78 adopters with a level of 42.16 were considered.

4 Propensity Score of Adopters and Non-adopters of SKUAST-K Spray Schedule

The examination was done across Kashmir Valley with 78 adopters and 107 non-adopters of deductively progressed apple cultivars. The propensity score of the adopters in the dispersion is given in Table 3. The scope of inclination and quantity of adopters and non-adopters goes from 0.14 to 0.6. The most noteworthy number of non-adopters falls in the inclination score of 0.2 as against the most noteworthy

Table 1 Ex-ante and ex-post average cost and income of scientifically advanced apple cultivars in Kashmir Valley *(Rs. Ha^{-1})*

Economic evaluation	Average gross income	Average total income	Average total cost
Ex-ante	1,414,140	1,229,140	185,000
Ex-post	1,201,097.57	1,019,084.04	182,013.5

Table 2 Frequency of the adopters and non-adopters of scientifically advanced apple cultivars in Kashmir Valley

Trt	Freq.	Percent	Cum.
0 (non-adopters)	107	57.84	57.84
1 (adopters)	78	42.16	100.00
Total	**185**	**100.00**	

Table 3 The inferior bound, the number of treated and the number of control group for each block

Inferior of block of pscore	Trt		Total
	0	1	
0.14	8	2	10
0.2	49	21	70
0.4	32	38	70
0.6	11	17	28
Total	**100**	**78**	**178**

adopters, which fall in the penchant scope of 0.4, while the least number of adopters and non-adopters falls in the propensity score of 0.14.

Table 4 shows the absolute number of adopters and non-adopters of modern apple cultivars in Kashmir valley in the entire circulation. The determined normal treatment impact on the treated (ATT) comes out to be 1.55 with a standard error of 43275.44 and t-value of 27.72.

Table 3 shows the normal treatment impact on treated (ATT) determined from various perspectives coordinating with strategies utilized to the arrangement of perceptions. The ATT assessed from the closest neighbor strategy by doing a bootstrap of 100 replications to the informational collection comes out to be Rs. 1,194,808/— with a predisposition of 6793.131 and standard error of 652027.926 at 5% degree of importance. Likewise, the normal treatment impact of treated (ATT) assessed through pieces coordinating with strategy, span coordinating with technique and separation coordinating with strategy by doing 100 bootstrap replications, each is Rs. 1,190,246/−, Rs. 1,197,571/, −Rs. 1,187,487/—with a predisposition of 7188.708, − 5465.155, − 9891.374 and a standard error of 43838.58, 50248.262, 46830.729 at 5% degree of importance individually meaning subsequently that adopters of experimentally progressed apple cultivars are profiting as far as high return and pay.

5 Propensity Score Graph (Ps Graph)

The propensity score graph is used to show the quantity of adopters and non-adopters who got backing and who did not discover their help in the circulation. Ps diagram shows the adopters in green on top and the non-adopters in red on the base. Figure 1 looks encouraging because practically every one of the recipients and non-recipients have a penchant score going from 0.15 to 0.8; correspondingly, a portion of the cases doesn't discover any help in the conveyance and in like manner a few cases are there in the treated group, which do not in any way have any help in the non-treated group.

Table 4 Matching methods and estimated value of the propensity score

Matching method	Replications	n. trt.	n. contr.	Bias	Observed value	ATT	Std. err.	T	[95% Conf. interval]
Nearest neighbor method (attnd)	100	78	53	−6793.131	1,194,808	1.19e+06	52027.926	22.965	1,085,869 1,303,747 (N) 1,087,220 1,291,463 (P) 1,087,989 1,301,880 (BC)
Kernal matching method (attk)	100	78	100	−7188.704	1,190,246	1.19e+06	43838.58	21.763	1,103,261 1,277,231 (N) 1,092,899 1,276,155 (P) 1,106,000 1,277,662 (BC)
Radius matching method (attr)	100	78	100	−5465.155	1,197,571	1.20e+06	50248.262	23.833	1,104,649 1,290,493 (N) 1,109,919 1,307,905 (P) 1,126,203 1,337,372 (BC)
Stratified matching method (atts)	100	78	100	−9891.374	1,187,487	1.20e+06	46830.729	25.572	1,087,596 1,287,378 (N) 1,090,929 1,297,150 (P) 1,107,150 1,305,035 (BC)

Note: *N* normal, *P* percentile, *BC* bias corrected

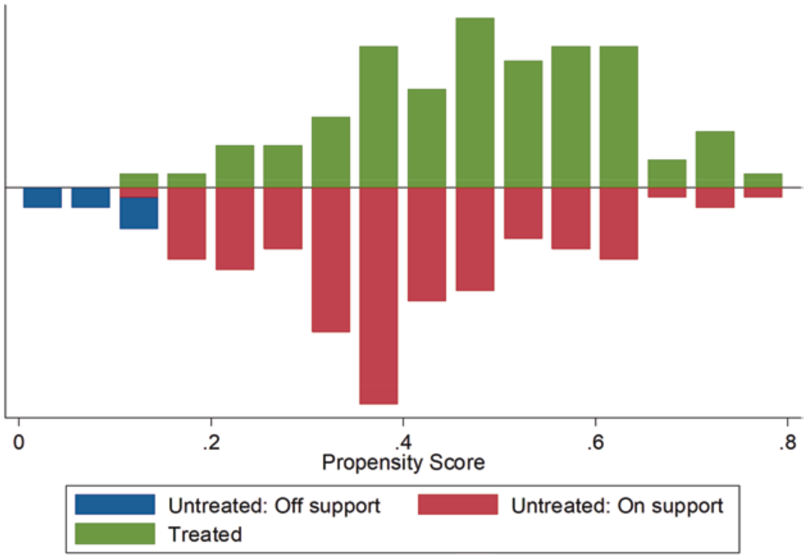

Fig. 1 Propensity score matching of the adopters and non-adopters of modern apple cultivars in Kashmir Valley

6 Kernel Density

To get a smoother picture, a partial thickness strategy is utilized. For piece thickness, the information is partitioned into non-covering stretches, and checks of the region are made of the quantity of information focused inside every span. To be explicit about bit thickness, the reach is isolated into stretches, and gauges of the thickness at the focal point of spans are created. From Fig. 2, it very well may be seen that the thickness goes from 0 to 4 as it appeared along the y-hub, and the size of affinity appeared along the x-axis. For the region under the red line (non-adopters), the inclination goes from 0.2 to 0.8 and most of the adopters (blue line) additionally fall in the 0.1 to 0.8 territory, which implies very nearly 70 to 80% of the adopters are falling inside the reach and tracks down their basic help in the informational index. Not many the perceptions do snot discover their help in the dispersion.

7 Conclusion

The examination found that evaluations of potential and acknowledged monetary advantages from plantation of modern apple cultivars have expanded. The ex-post evaluation of modern apples shows that not just creation of unrivaled evaluation of

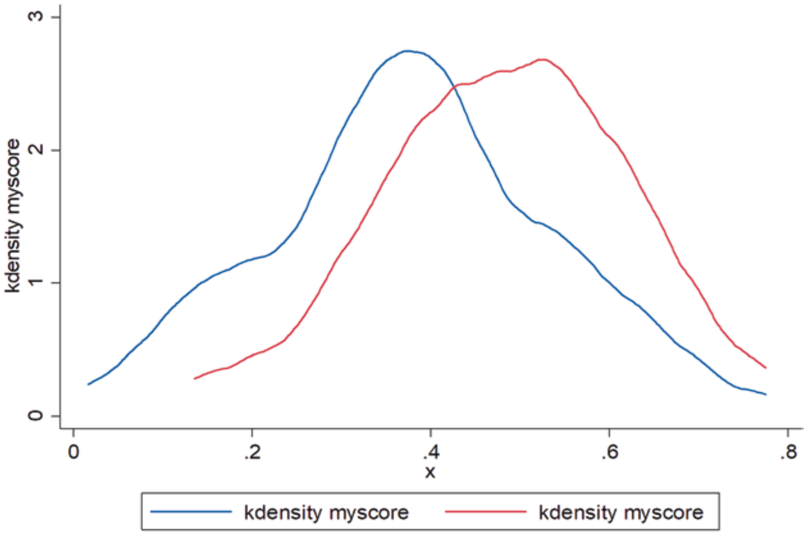

Fig. 2 Kernel density of adopters and non-adopters of modern apple cultivars

apples has expanded; however, it has greatly expanded efficiency. PSM has assessed that roughly Rs. 1,200,000/ha^{-1} have been procured by the growers after plantation of modern apple cultivars contrasted with the old apple cultivars. Although modern apple cultivars significantly increase expenses, they remunerate with early organic product bearing and high efficiency. The modern apple cultivars have expanded per human-day for educated and illiterate masses of the area and have improved the expectation for everyday comforts in regions of the country specifically in Kashmir valley. The coordination with techniques affirmed that around Rs. 1,100,000/ha^{-1} have been earned by the farmers in the Kashmir Valley.

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The Intensification of Shifting Cultivation in Tanzania: Effects on Soil and Vegetation

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Abstract This study investigated the effect of intensification of shifting cultivation on the recovery of soil properties and vegetation in East Central, Tanzania. The study is based on soil sampling conducted in 40 (5 m × 5 m) plots from adjacent sites under fallows of 1, 2, 3, 4, 5, 7 years, a secondary forest that has never been cultivated, and a field under a ridge and flat continuous cultivation-an innovative farming practices adopted in continuous annual cropping. Vegetation sampling was conducted in sites under fallows and the secondary forest. Intensification of shifting cultivation through shortening of fallow length deteriorates soil quality due to a decline in total N, plant-available P, and exchangeable K. Furthermore, shortening of fallow length negatively affects the recovery of plant species composition and diversity. The dominant plant species in young fallows (1 -4-years) was different from older fallows (5-and 7-years) and the secondary forest. Young fallows harbored more diverse vegetation but mostly shrubs (multiple stems, ≤5 m tall) while

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older fallows and secondary forest were less diverse but dominated by trees (single stem, > 10 m tall). Soils under the ridge and flat continuous cultivation had significantly higher plant-available P than in soils under fallow or secondary forest. Moreover, the soil under the ridge and flat cultivation contained levels of soil pH, plant-available P, exchangeable K, and Ca that have been described as sufficient for crop production.

Keywords Plant diversity · Miombo woodland · Land use change · Soil properties · Slash-and-burn

1 Introduction

Over the past few years, increasing evidence shows that shifting cultivation has been transformed into more intensive farming practices (Chidumayo, 1987; Grogan et al., 2013; Ickowitz, 2006; Kilawe et al., 2018; Mertz et al., 2009; Schmidt-Vogt et al., 2009; van Vliet et al., 2012). The intensification involves shortening of fallow length or conversion of shifting cultivation areas to permanent cultivation of annual crops or tree crop plantations (Chidumayo, 1987; Cramb, 2007; Grogan et al., 2013; McDonagh et al., 2001; Padoch et al., 2007; Schmidt-Vogt et al., 2009; Stromgaard, 1989; van Vliet et al., 2012). Studies conducted in Zimbabwe, Zambia, and Tanzania revealed further that intensification of shifting cultivation is often accompanied by the adoption of intensive farming practices which allow the farmers to continue cultivation without relying on external inputs such as organic fertilizer or pesticides (Grogan et al., 2013; Kilawe et al., 2018; Stromgaard, 1989).

There have been many studies on the effects of this intensification of shifting cultivation on the environment, particularly on soils. Studies have documented an increase in soil erosion, carbon losses, nutrients leaching and vitalization, negative nutrients balance, and change in species composition with the intensification of shifting cultivation (Bruun et al., 2009, 2013; Kilawe et al., 2019; Klanderud et al., 2010; Lawrence, 2004; Lawrence & Schlesinger, 2001; Murty et al., 2002; Nye & Greenland, 1960; Palm et al., 2005; Stromgaard, 1989; Styger et al., 2009). In contrast, other studies found no effect of intensification on soils or a mixed effect where some nutrients decline but others increased (Bruun et al., 2006; Lawrence & Schlesinger, 2001; Ramakrishnan & Toky, 1981; Roder et al., 1995; Szott et al., 1999; Szott & Palm, 1996). A comprehensive review of 80 studies on the effect of shifting cultivation on tropical soils revealed a remarkable disagreement among researchers with some suggesting negative effects but most showing either positive or no effects on soils (Ribeiro Filho et al., 2013). The disagreement among researchers is not surprising as the effects depend on factors such as the previous land-use practices, land-use intensity, inherent soil properties, and climatic conditions (Hughes et al., 1999; Lawrence et al., 2005; Swanson et al., 2010). Most of these factors do vary considerably in space and time.

Despite the large body of literature on the effect of intensification of shifting cultivation on soil properties, emphasis in these studies was placed on change in soil properties or yields after clearing fallows of given ages. Few studies show the effect of intensification on recovery of soil properties during fallow (Juo & Manu, 1996), and these are based in Central America (Aguilera et al., 2013; Arnason et al., 1982; Brubacher et al., 1989), Southeast Asia (Lawrence & Schlesinger, 2001), and West Africa (Are et al., 2009; Aweto, 1981; Juo & Kang, 1989; Juo & Lal, 1977; Juo & Manu, 1996; Masse et al., 2004). East and Central Africa have been inadequately studied apart from the earlier work by Stromgaard (1989) on the recovery of soils and vegetation on *Chitemene* shifting cultivation in Zambia. Knowledge on soil dynamics during fallow is essential since nutrients build-up in the vegetation during this phase determines the productivity and sustainability of shifting cultivation system (Aweto, 1981; Juo & Manu, 1996; Kleinman et al., 1995). It is even more important now that the fallow length has been shortened and nutrients accumulation in the biomass may not be sufficient. The literature search revealed few studies that have evaluated the sustainability of continuous cropping of annual crops as an alternative to shifting cultivation systems (Terefe & Kim, 2020). It is concluded from these few studies that transformation of shifting cultivation to continuous cropping increases losses of mineral nutrients through runoff, erosion, and leaching, thus the sustainability of annual cropping must rely on external inputs such as inorganic fertilizers and lime (Aweto, 1981; Juo & Kang, 1989; Juo & Manu, 1996). However, the role of innovative farming practices and technologies such as conservation tillage, intercropping, ridge and flat cultivation, and mulching have not been sufficiently investigated. Indeed, more case studies showing the effects of intensification of shifting cultivation on soils are required in Africa. The knowledge generated will aid in development of sustainable land use policies, strategies, and plans that stimulate benefits and reduce negative environmental and social consequences associated with transformation processes of shifting cultivation.

The present study aims to widen our knowledge on the effects of intensification of shifting cultivation on the recovery of soils and vegetation in Africa. The study was conducted in Kilosa District, East Central Tanzania, and it compared the soil properties of sites under fallow with sites under continuous cropping of annual crops and a reserved forest. The sites were evaluated based on soil attributes that integrate physical, chemical, and biological attributes of the soil. This approach has been described as appropriate in evaluating soil quality change due to land-use change (Aboim et al., 2008; Are et al., 2009; Arshad & Martin, 2002; Ayoubi et al., 2011; Bruun et al., 2009; Carter et al., 1997; Doran & Parkin, 1994; Gregorich et al., 1997; Karlen et al., 2003; MacEwan, 1997; Sinha et al., 2014; Veum et al., 2014; Weil et al., 2003). Intensification of shifting cultivation was defined as the conversion of fields under shifting cultivation to continuous annual cropping or shortening of fallow length. Thus specifically we asked two questions: (1) to what extent does shortening of fallow length affect soil physical and chemical properties, plant species composition, and diversity? (2) To what extent do innovative farming practices adopted in continuous annual cropping affect soil physical and chemical properties? We assumed that the soils and vegetation of the sites currently under fallows and continuous cultivation were once similar to the adjacent forest reserve, thus the differences in soil quality between the sites was due to the land-use change at *cetris peribus.*

2 Materials and Methods

2.1 Study Area

This study was conducted in Ulaya Mbuyuni village in Kilosa District. The village is situated 30 km along the road from Kilosa to Mikumi Township and is bounded by latitude 7°01′29″ and 7°01′55″ South and longitudes 36°57′07″ and 36°58′01″ East (see Fig. 1). Ulaya Mbuyuni has a total village area of 57.22 km^2 but more than half of this area (35.4 km^2) is a village forest reserve. The total adult population is 2691 people (excluding children under 18 years) living in six sub-villages and 354 households (KDC, 2012). The traditional ethnic group in the village is *Wasagala*, but many other ethnic groups such as *Wagogo, Wasukuma*, *Waha, Wanyamwezi, Wangoni, Wahehe,* and *Wakwiva* have moved in overtime. Most of the immigrants were laborers in the failed sisal plantations in the district. The mean annual rainfall

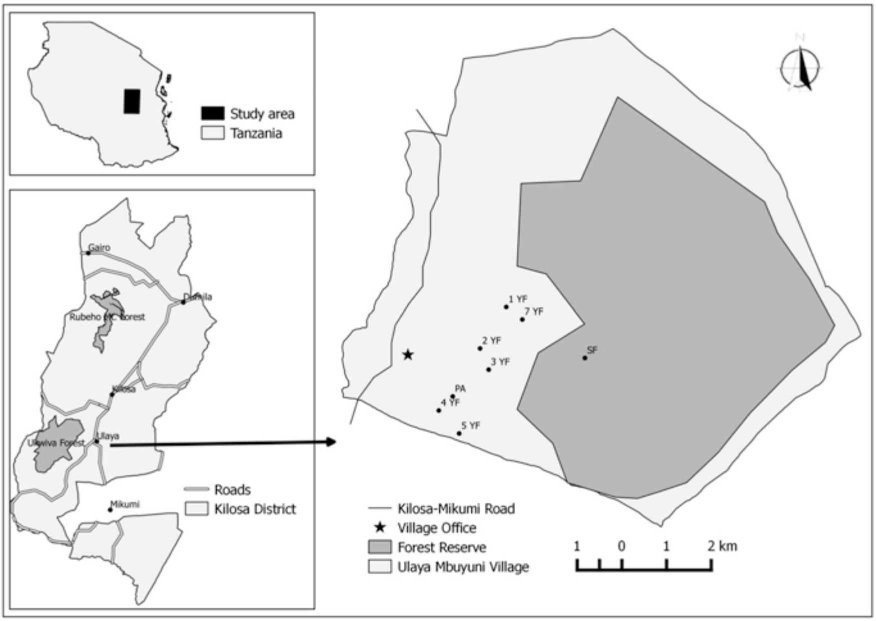

Fig. 1 Map of the study sites, Ulaya Mbuyuni village, and its location in Tanzania. Where: 1 YF, 2 YF, 3 YF, 4 YF, 5 YF, 7 YF, PA, and SF represent 1-7- year-old fallows, ridge and flat continuous cultivation, and secondary forest respectively

ranges between 1000 and 1400 mm falling in two seasons ("long" rains between March and May and "short" rains between October and December). The mean annual temperature ranges between 25 and 27 °C. The natural vegetation is Miombo woodland dominated by *Brachystegia microphylla, Brachystegia boehmii, Diplorhynchus condylocarpon,* and *Combretum collinum.* The landform of the village is dominantly a peneplain (altitude 400–600 masl) comprising gently undulating to undulating plains to low-lying ridges (slope gradient 2–8%) with broad summits but in places, there are some valley bottoms.

The soils of Ulaya Mbuyuni village are typically an association of very deep, well-drained, dark gray, very friable, clays with thick reddish-brown clay topsoils on ridge summits (*Rhodi-Ferric Ferralsols*) and very deep, well-drained, dark brown to strong brown, sandy clay loams with thin brown sandy loam topsoils on ridge slopes (*Ferri-Profondic Luvisols* and *Acrisols*). On the valley bottoms the soils are very deep, moderately well and imperfectly drained, sand loams to sandy clay loams (*Hapli-Eutric Gleysols*). The soil temperature and moisture regimes in the peneplain soils are respectively *isohyperthermic* and *ustic,* while in the valley bottoms they are *isohyperthermic* and *aquic* respectively (Kimaro et al., 2008). The underlying geology from which the main soils of the study area have formed is composed of metasedimentary rocks mainly acid and biotite gneisses (Kimaro et al., 2001, 2008).

According to Village Environmental Committee, shifting cultivation in Ulaya Mbuyuni is practiced by about 25% of the households. The practice involves the following five steps: (1) Land clearing is performed between July and September and involves clearing of vegetation and collecting into several small heaps. (2) Burning of the plant residue (collected in heaps) is done between late September and early October. (3) Post-fire land preparation is performed between October and November. It involves deep plowing to loosen the soil and bury undecomposed vegetation (*Kukwatua*) or scratching of the soil surface and spreading the undecomposed vegetation on the soil surface (*Kuberega*) (4) Planting is performed between late November and early January. The crops planted are mostly sesame and pigeon pea if the farms are located far from the settlement but otherwise include a mix of different crops such as cowpea, maize, sunflower, millet, sorghum, cassava, beans, and groundnuts. (5) Fallowing and shifting to another field. Cropping continues until the increase in weed and pest infestation becomes too high or yields decline, usually 3 years for the field under sesame or sorghum and 5 years for the field under pigeon pea, maize, or mixture of both. Then farmers shift to another field and leave the current farm to rest as fallow. Generally, the fallow length varies a lot depending on factors such as land availability, land tenure, clearing costs, and labor. However, a by-law in this village (enacted in 2012) restricts the fallow length to a maximum of three years (KDC, 2012).

2.2 Study Sites

We selected eight sites representing the following land-use systems: Ridge and flat continuous cultivation, fields under fallow for 1, 2, 3, 4, 5, and 7 years, and a secondary forest that has never been cultivated (Fig. 1). Interviews were conducted with site owners to obtain the fallow length. Recall of the fallow length was estimated to be very good due to consistent answers provided to repeated questions on the length of the fallow. Further, the farmers were able to relate fallow length with the age of their household members. The sites under the ridge and flat cultivation were selected purposively to represent adoptive farming practices in the continuous cropping and cultivation system. Reserved forest was purposively selected based on a short distance to other sites and a low level of disturbance. The forest is reserved and there has only been little disturbance from illegal logging and grazing. All sites were situated in one location, originally covered by Miombo woodland species. The furthest distance between the sites was 10 km and the climate, altitude and surrounding vegetation, and shifting cultivation practices were comparable (Table 1). The inherent soil properties of the sites currently under fallow and continuous cropping of annual crops were assumed to be similar to those of reserved forest, thus any difference was assumed to be due to management or land-use change. This assumption was based on the proximity of the sites; similar slope, altitude, and soil texture (Fig. 1, Tables 1 and 2).

2.3 Soil and Vegetation Sampling

Soil sampling was undertaken on all eight sites in June 2015. At each site, five plots (5 m × 5 m) were marked, one located at the center of the site and four others located randomly in the four corners of the site. On each plot, five soil cores were taken from the surface (0-10 cm) using a 10 cm diameter core sampler; one from the center and four were taken from four points located 2 m away in the cardinal directions from the center (Stromgaard, 1984, 1989, 1992). On each plot, a composite soil sample was made by mixing all five cores and a 500 cm^3 subsample collected, making a total of five subsamples collected from each site. In each center plot for each site, a 2 m × 2 m subplot was marked out. A 1 m × 0.5 m × 0.5 m pit was excavated to expose the soil profile and an undisturbed soil sample was collected by using a steel core cylinder (5 cm × 5 cm). In the field, all undisturbed soil samples were weighed by using a scale as soon as the samples were collected. The disturbed loose samples were evenly spread on a black tray and air-dried for 15 min (Weil et al., 2003). The samples were then packed in polythene bags, labeled, and transferred to Sokoine University of Agriculture Soil Science laboratory for further processing and analysis.

Vegetation sampling was undertaken at the same time as soil sampling in all sites except the site under ridge and flat continuous cultivation by using transects. In each

Table 1 Characteristics and histories of management on sites under the ridge and flat cultivation (PA), fallows for 1–7 years, and a secondary forest (SF)

Site and plot characteristics	Sites							
	PA	1-y-f	2-y-f	3-y-f	4-y-f	5-y-f	7-y-f	SF
Area (ha)	4	6	2	3	13.5	5.5	7	3520
Elevation (m.a.s.l)	551	573	569	581	538	544	571	556
Slope (%)	4	12	4	4	8	5	8	5
Vegetation cover (%)	–	70	60	50	70	65	40	75
Vegetation height (m)	–	2	3	5	6	5	6	15
No. of cropping since the area was first cleared (seasons)	>18	2	3	1	15	3	4	–
No. of fallowing since the area was first cleared	0	1	1	1	4	1	2	–
Crops	Sunflower, maize, sesame, cowpeas, green gram, pigeon pea, bean, cassava, vegetables	Sesame	Sesame, cowpeas	Sesame	Sesame, cowpeas, cassava	Sesame, green gram	Sesame	–
Fertilizer/pesticide	Pesticides-applied on sesame	0	0	0	0	0	0	–
Land preparation practice	*Kukwatua* + ridges +flat cultivation	Slash-burn+ *kukwatua*	Slash-burn+ *kukwatua*	Slash-burn+ *kuberega*	Slash-burn+ *kukwatua*	Slash-burn+ *kukwatua*	Slash-burn+ *kuberega*	–
Other activities	–	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing, selective harvesting	Grazing

Table 2 Soil physical properties at 0–10 cm depth

Soil attribute	Sites							
	PA	1-y-f	2 -y-f	3 -y-f	4-y-f	5 -y-f	7 -y-f	SF
Soil color	Dark gray	Reddish black	Very dark gray	Brown	Dark gray	Dark gray	Reddish black	Brown
Clay (%)	8	10	12	12	8	8	14	8
Silt (%)	10	8	12	10	14	12	14	10
Sand (%)	82	82	76	78	78	80	72	82
Total porosity (%)	46.9	40.8	42.8	39.7	39.7	33.6	45.9	43.8
Gravimetric water content at field condition (gg-1)	0.5 v tvg040	0.027	0.028	0.037	0.028	0.030	0.090	0.029
Gravimetric water content at saturation (gg-1)	0.371	0.268	0.298	0.289	0.269	0.199	0.313	0.312
Bulk density (gcm^{-3})	1.26	1.52	1.44	1.38	1.48	1.43	1.47	1.45

site, three transects were marked. One at the center and the remaining marked parallel but on each side of the center transects. The transect length covered the extent of the site but was at least 5 m away from the boundary to avoid edge effects (Klanderud et al., 2010). In each transect, all plants were identified, plant species abundance recorded, and classified into life forms as either shrubs (≤5 m tall), small trees (>5 ≤ 10 m), or trees (> 10 m).

2.4 Laboratory Analysis

The disturbed soil samples were analyzed for pH, plant-available phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), soil organic carbon (SOC), total nitrogen (TN), and soil texture, while the undisturbed soil samples were analyzed for water content (WCED, 1987), bulk density (BD), and total porosity. Before laboratory analysis, all loose samples for chemical analysis were further dried at 80 °C for 24 h (Bruun et al., 2013).

Soil pH was measured in a 1:2.5 soil: water ratio (Greenland et al., 1994; Thomas, 1996). Exchangeable cations (Mg^{2+}, K^{+}, Na^{+}, and Ca^{2+}) were extracted by ammonium acetate and determined by flame emission photometry (Na and K) and atomic absorption spectrophotometry (Ca and Mg) (Okalebo et al., 1993). Effective Cation Exchange Capacity (ECEC) was determined through summation of all base cations (Mg^{2+}, K^{+}, Na^{+}, and Ca^{2+}) using unbuffered solutions. Available P was determined by using the Olsen method using NaHCO3 at pH 8.5 (Okalebo et al., 1993), total nitrogen by the Kjeldahl method (Bremner, 1996), and SOC by Walkley-Black wet oxidation method (Nelson & Sommers, 1996). Soil texture was analyzed by the Bouyoucos hydrometer method (Gee & Bauder, 1986). Soil bulk density, porosity, and gravimetric and volumetric water content were measured as follows: (1) the soil cores were placed on a wet mat overnight to saturate and thereafter weighed; (2) the soil cores were then oven-dried at 105 °C for 24 h; (3) gravimetric water content was calculated as the ratio of the mass of water to mass of dry soil and volumetric water content as the ratio of volume of water to volume of the soil sample; bulk density as the ratio of oven dry mass of the soil to the volume of the soils and total porosity as the ratio of volume of the pores to volume of the soil sample (Hillel, 1998).

2.5 Statistical Analysis

Changes in soil chemical properties between sites was compared by using one-way ANOVA followed by Tukey's HSD multiple comparison procedure. The association between fallow lengths and soil chemical properties was assessed using Pearson's correlation. Sites under flat and ridge cultivation and reserved forest were not included in the correlations as these do not represent land use under shifting cultivation. All analyses were performed in SAS JMP (SAS Institute Inc., Cary, NC, 1989–2021).

3 Results and Discussion

3.1 Effects of Intensification of Shifting Cultivation on Soil Physical and Chemical Properties

Table 2 summarizes the soil‘s physical properties among study sites. Soil color and texture were comparable among sites, supporting the assumption of similar inherent soil properties among the sites. Bulk density was lower but water content and porosity were higher in soils under the ridge and flat cultivation than soils under fallows and secondary forest, contradicting other studies that documented higher bulk density in fields under continuous cropping than fields under fallow and reserved forest (Murty et al., 2002; Ribeiro Filho et al., 2013). Murty et al. (2002) suggested that continuous cropping breaks and compacts soil aggregates, thus increasing bulk density. In the present study, higher bulk densities observed in fallows and reserved forests are most likely due to grazing activities done in these sites, while there was no grazing activity in the field under the ridge and flat continuous cultivation. Cattle remove the grass cover and tramp on the soil, leading to soil compaction and exposing the soil to drying and erosion. The same explanation applies to the higher water content and porosity observed in the site under the ridge and flat continuous cultivation when compared to fields under fallow and the reserve forest. Lack of change in textural classes between land uses categories was not surprising and was also reported in studies conducted in Nigeria. It has been argued that this particular

Table 3 Chemical soil properties at 0–10 cm soil depth

Sites	pH (H_20)	SOC (%)	TN (%)	Avl.P (mg/kg)	Exchangeable bases (cmol(+)/kg) Ca	Mg	K	Na	ECEC (cmol(+)/kg)
PA	$7.2^{a} \pm 0.2$	$1.11^{bc} \pm 0.08$	$0.11^{bc} \pm 0.0$	$30.9^{a} \pm 5.9$	$6.4^{ab} \pm 0.8$	$0.76^{b} \pm 0.13$	$0.29^{ab} \pm 0.02$	$0.034^{a} \pm 0.001$	$7.6^{ab} \pm 1.2$
1-y-f	$6.7^{abc} \pm 0.0$	$1.10^{bc} \pm 0.07$	$0.09^{c} \pm 0.0$	$9.5^{b} \pm 1.7$	$3.8^{b} \pm 0.4$	$0.76^{b} \pm 0.13$	$0.14^{c} \pm 0.02$	$0.016^{a} \pm 0.004$	$4.7^{b} \pm 0.5$
2 -y-f	$7.0^{ab} \pm 0.2$	$1.17^{b} \pm 0.12$	$0.12^{bc} \pm 0.0$	$8.1^{b} \pm 1.0$	$6.3^{ab} \pm 1.2$	$1.87^{a} \pm 0.26$	$0.20^{b} \pm 0.02$	$0.028^{a} \pm 0.003$	$8.4^{ab} \pm 1.4$
3 -y-f	$6.4^{c} \pm 0.2$	$1.35^{bc} \pm 0.04$	$0.11^{bc} \pm 0.01$	$8.4^{b} \pm 2.5$	$3.4^{b} \pm 0.4$	$1.32^{ab} \pm 0.21$	$0.22^{abc} \pm 0.01$	$0.011^{a} \pm 0.001$	$5.0^{b} \pm 0.6$
4 -y-f	$6.4^{c} \pm 0.1$	$1.02^{c} \pm 0.06$	$0.12^{bc} \pm 0.01$	$13.0^{b} \pm 5.7$	$5.0^{ab} \pm 0.5$	$0.86^{ab} \pm 0.24$	$0.15^{c} \pm 0.03$	$0.037^{a} \pm 0.001$	$6.0^{ab} \pm 0.6$
5 -y-f	$6.4^{c} \pm 0.1$	$1.45^{b} \pm 0.10$	$0.13^{b} \pm 0.01$	$8.7^{b} \pm 0.9$	$4.4^{ab} \pm 1.4$	$1.43^{ab} \pm 0.39$	$0.25^{abc} \pm 0.05$	$0.034^{a} \pm 0.015$	$6.3^{ab} \pm 1.3$
7 -y-f	$6.8^{abc} \pm 0.1$	$2.38^{a} \pm 0.10$	$0.17^{a} \pm 0.0$	$17.3^{ab} \pm 5.7$	$8.0^{a} \pm 0.9$	$1.42^{ab} \pm 0.16$	$0.32^{a} \pm 0.02$	$0.022^{a} \pm 0.005$	$9.7^{a} \pm 1.0$
SF	$6.7^{abc} \pm 0.0$	$1.44^{b} \pm 0.08$	$0.13^{b} \pm 0.01$	$10.0^{b} \pm 1.1$	$4.1^{ab} \pm 0.6$	$0.84^{ab} \pm 0.16$	$0.15^{c} \pm 0.03$	$0.026^{a} \pm 0.005$	$5.2^{ab} \pm 0.7$

*Values in the columns connected by different letters ‘a-b’ or ‘b-c’ indicate a slight significant differences ($p < 0.05$), and ‘a-c’ indicate the most significant difference ($p< 0.01$). Values with the same letters are not statistically significant different.

characteristic may not change even when the management changes and is an inherent soil property (Are et al., 2009; Aweto, 1981).

The soil chemical properties are summarized in Table 3. The table shows that the soils under the ridge and flat continuous cultivation (PA) had significantly ($p < 0.05$) higher pH levels than soils under 3-, 4-, and 5-y-f. Furthermore, the soils under the ridge and flat continuous cultivation had significantly higher contents of plant-available P than soils under 1-, 2-, 3-, 4-, 5-y-f, and SF and higher contents of exchangeable K than soils under 1-, 4-y-f, and SF. However, soils under the ridge and flat continuous cultivation had significantly lower contents of SOC and TN than soils under 7-y-f and significantly lower contents of exchangeable Mg than soils under 2-y-f. The results confirm previous studies which found higher pH levels in soils under continuous cultivation than in soils under fallow and forest (Aboim et al., 2008; Ribeiro Filho et al., 2013; Stromgaard, 1992) and higher contents of plant-available P in soils under flat and ridge continuous cropping than in soils under fallow and forest (Arnason et al., 1982; Harris, 1971; Jordan, 1989). Higher soil pH and plant available P contents in soils under flat and ridge continuous cropping could be due to intercropping with legumes and the practice of ridge and flat cultivation which involves burying of grasses and herbs into the soil. The grasses and herbs buried in the soil and intercropped legumes could be gradually releasing nutrients to the soil and reducing losses of K, Ca, and Mg through erosion and leaching which in turn raise the soil pH to alkaline conditions (Aweto, 1981; Juo et al., 1995; Juo & Lal, 1977). The slightly alkaline soils under continuous cropping usually increase the content of plant-available P since at soil pH 7.2 and above, all forms of plant-available P ($H_2PO_4^-$ and HPO_4^{2-}) are equally available in the soil solution (Foth, 1990). By contrast, in young fallows and secondary forests the exchangeable cations are taken up and stored in growing vegetation leaving the soil slightly acidic (Aboim et al., 2008; Stromgaard, 1992). Under slightly acidic condition (6.5–7.0) there is only one form of plant-available P (HPO_4^{2-}) (Foth, 1990) and when pH declines below 6.5, P is immobilized by aluminum and iron oxides (Harcombe, 1980). Soils under 7-y-f had significantly higher SOC and TN than soils under the ridge and flat continuous cultivation probably due to the longer fallow length. The accumulation of SOC and TN has been found to increase with time in fields under fallow. Another reason could be that the 7-y-f showed the highest species richness and this could affect the recovery of soil nutrients (Brubacher et al., 1989). Further, at site 7-y-f, there was a selective clearing of trees and vegetation (after every 3 years) whereby most of the cleared vegetation decomposed at the site and this could have enriched the site with SOC, TN, and other nutrients.

The content of TN and SOC in soils under the ridge and flat cultivation could have been confounded by the timing of soil sampling which was conducted while crops were still growing and some of the nutrients could be bound in the biomass of growing crops. Researches have shown that pigeon pea takes about 42% of available N in their biomass, and N is potentially returned if it is retained as mulch after grain harvest (Peoples et al., 1995). The content of SOC found could also be confounded with the growing crop biomass. Juo and Lal (1977) showed that maize crops add 36% of SOC when retained in the farm. Nevertheless, other studies have found lower SOC and TN in fields under continuous cropping than in fallows (Bruun et al., 2006, 2009; Terefe & Kim, 2020). It is argued that higher microbial decomposition rates and soil erosions brought by continuous tillage reduce SOC and TN (Bruun et al., 2009; Feller & Beare, 1997; Juo et al., 1995).

Generally, the ridge and flat continuous cultivation showed high potential of improving soil quality because the contents of plant-available P of 30.9 mg/kg, exchangeable K^+ of 0.29 cmol(+)/kg, exchangeable Ca^{2+} of 6.4 cmol(+)/kg, and exchangeable Mg^{2+} of 0.76 cmol(+)/kg are well above the contents of plant-available P of 10mg/kg, exchangeable K^+ of 0.13 cmol(+)/kg, exchangeable Ca^{2+} of 4.9 cmol(+)/kg, and exchangeable Mg^{2+} of 0.376[1] that are described as sufficient for crop production in East Africa (Okalebo et al., 1993).

The content of TN of 0.11% is below recommended moderate levels of 0.12–0.25% TN. However, the difference is not small and improvement can be naturally made through the integration of leguminous crop or tree species. The already established legume crops such as bean, cowpea, pigeon pea, and green gram are good nitrogen fixers, and farmers can be advised to increase the intensity of these. Further, nitrogen-fixing tree species such as *Croton* spp. have been introduced and accepted by farmers in the Kilosa District (it can be seen planted around the homestead and roadsides in many places in the district). This tree species has high foliar N and is a good source of nitrogen and can be promoted and integrated with continuous farming systems.

3.2 Effect of Intensification of Shifting Cultivation on Soil Chemical Properties

Pearson's correlations revealed a strong positive association between fallow length and TN, SOC, and exchangeable K^+, and a weak association between ECEC, plant-available P, and exchangeable Ca^{2+} (Fig. 2). Similar findings have been documented on a positive relationship between fallow length and SOC (Aweto, 1981; Brubacher et al., 1989; Kleinman et al., 1996; Nye & Greenland, 1960; Ramakrishnan & Toky, 1981) and between fallow length and TN, avl. P, and K^+ (Aguilera et al., 2013; Brubacher et al., 1989; Juo & Lal, 1977; Ramakrishnan & Toky, 1981). It is argued that with time, the organic matter and nutrients build up slowly from the decomposition of litter and absorption from the subsoil or unavailable forms in the topsoil (Aweto, 1981; Harcombe, 1980). Further, it has been observed that the amount of nutrients recovered in the soils and vegetation under the fallow period depends on the inherent soil properties and the diversity of fallow vegetation (Brubacher et al., 1989). Young fallows are often dominated by pioneer species which contains higher levels of nutrients than successional tree species, thus it is likely that soils under older fallow and secondary forest accumulate more nutrients than young fallows (Brubacher et al., 1989; Juo & Manu, 1996).

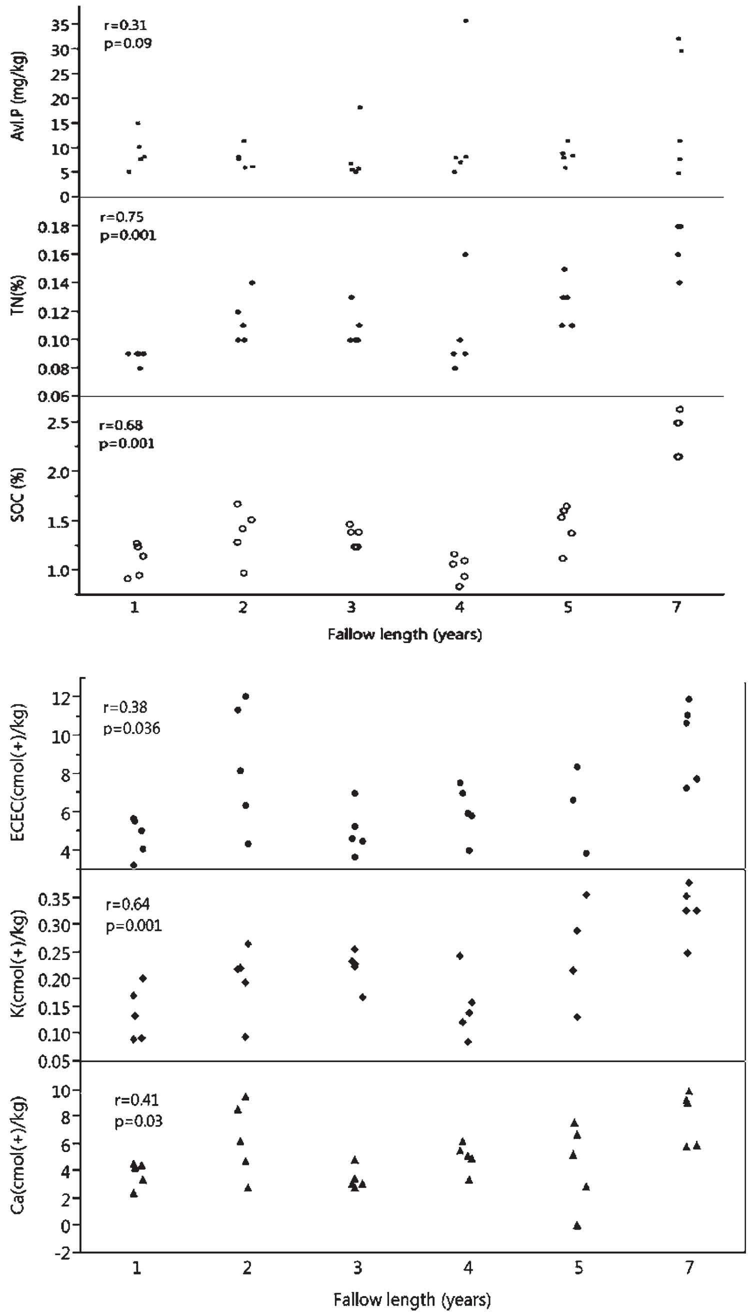

Fig. 2 Pearson's correlations between fallow length and soil chemical properties. Only attributes significant at less than 10% are included

Table 4 Summary of dominant tree species, richness, and diversity

Sites	Dominant tree species	Abundance (%)	Richness (R)	Diversity (H′)
1-y-f	*Diplorhynchus condylocarpon*	13.9	33	3.1
2 -y-f	*Allophylus rubifolius*	24.9	29	2.6
3 -y-f	*Allophylus rubifolius*	28.6	22	2.6
4 -y-f	*Markhamia platycalyx*	33.9	19	2.3
5 -y-f	*Markhamia platycalyx*	47.6	12	1.8
7 -y-f	*Combretum melchiorianum*	17.2	34	3.2
SF	*Brachystegia microphylla*	19.2	32	2.8

3.3 Effect of Intensification of Shifting Cultivation on Plant Species Composition and Diversity

The summary of the vegetation is indicated in Table 4 and the complete list of all tree species for each vegetation types in Appendix. Table 4 shows that the composition of the dominant tree species in young fallows (1 -3-y-f) was different from older fallows (4-, 5-and 7-y-f) and the composition of dominant tree species in all fallows was different from the reserved forest. *Diplorhynchus condylocarpon* was dominant in 1-y-f and SF*; Allophylus rubifolius* was dominant in 2-y-f and 3-y-f, *Markhamia platycalyx* in 4- and 5-y-f, and *Combretum melchiorianum* in 7-y-f, and *Brachystegia microphylla* and *Diplorhynchus condylocarpon* were the species dominant in secondary forest. The difference in dominant tree species composition could be a response of individual plant species to soil nutrients and water availability. In the current study, we have shown that exchangeable K and Ca, plant available P, ECEC, SOC, and TN were positively correlated with fallow length. Lawrence (2003), in a review of 87 studies on the response of plants to nutrient, found that species composition was positively associated with TN and available P. Another study conducted in Australia revealed that forest species composition was determined by the amount of P, N, K, and Ca (Harcombe, 1980). In Miombo woodlands, species composition was associated more with water content (Backeus et al., 2006).

Another reason for the observed difference in species composition between fallows and secondary forest could be the distance from the nearby site or forest. In the present study, we found that nearby site, e.g., 2- and 3-y-f; 4-and 5-y-f; and 1-y-f and secondary forest were composed of similar dominant tree species (Table 3, Fig. 1). Lawrence (2004) showed that species composition and diversity of neighboring sites influence the species composition and diversity in recovering fallows. Table 3 shows further that, as fallow length increased, the abundance of the dominant tree species also increased but the diversity and richness decreased, except in 7-y-f. In other words, as fallow length increased, the dominant tree species expanded more, hence reducing tree species richness and diversity. The increase in abundance of the dominant tree species with fallow length support the tolerance and competition theory (Connell & Slatyer, 1977). It is argued that due to strong traits of the dominant species, greater seed production ability, excellent dispersal mechanisms,

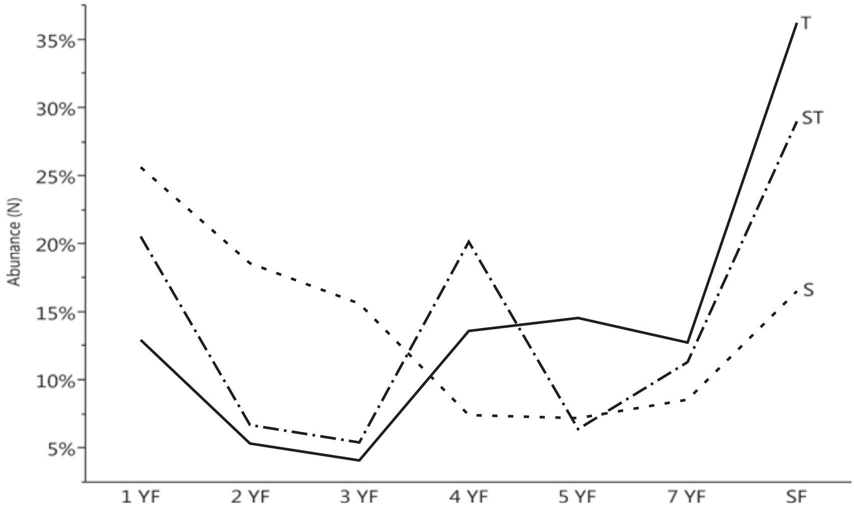

Fig. 3 Abundance of trees (T), small trees (ST), and shrubs (S) in each site

higher nutrients accumulation, and tolerance to limited resources, the abundance of dominant tree species increases with time, affecting negatively the abundance of rare species and ecosystem diversity (Bengtsson et al., 1994; Lawrence, 2003; Lawrence et al., 2005; Sasaki & Lauenroth, 2011; Tilman et al., 2006).

Furthermore, results show that, young fallows harbored a substantial abundance of shrubs and small trees, and these declined as fallow length is increased (Fig. 3). The dominance of shrubs in young fallows and trees in older fallows and secondary forest followed the Initial Floristic Composition model which suggest that shrub species will dominate early fallows and declines with time where trees dominate (Egler, 1954). Similar pattern of recovery has been found in studies on recovery in Africa (Klanderud et al., 2010; Mullah et al., 2012; Kilawe et al., 2019) and Central America (Brubacher et al., 1989). The recovery of forest species has been associated with farming frequency and intensity (Brubacher et al., 1989; Klanderud et al., 2010; Lawrence, 2003). However, in the present study, there was no correlation found between cropping frequency and the abundance of recovered tree species. The most plausible explanation for the poor recovery could be the competition for limited resources whereby the shrubs are able to establish in nutrient poor sites but with time the forest species establish and competitively exclude the shrubs (Bengtsson et al., 1994; Finegan, 1984; Gehring et al., 2005; Lawrence, 2003).

4 Conclusions and Perspectives

The present study suggests that intensification of shifting cultivation through shortening of fallow length would deteriorate soil quality due to decline in total N, plant-available P, and exchangeable K. Furthermore, we show that shortening of fallow negatively affects the recovery of plant species composition and increase the abundance of shrubs and small trees. We show further that the already adopted practice of ridge and flat continuous cultivation has the potential of improving soil quality since soil physical and chemical properties under this land use practice were at levels sufficient for sustainable crop production. The soils could have been improved through intercropping with leguminous crops and the introduction of farming practices that involve the subsoiling of grasses and herbs. These practices could have improved nutrients contained in the soil and reduced nutrient loss through leaching, erosion, and run-off in fields under continuous cropping. This conclusion, however, is based on findings from only one field. We recommend more studies on this farming practice as it presents a huge potential for soil improvement under intensified shifting cultivation systems.

Appendix: List of All Tree Species Found in Each Site in Ulaya Mbuyuni Fallow and Forest Reserves

S/N	Species name	Life form	1 YF	2 YF	3 YF	4 YF	5 YF	7 YF	FR
1	*Acacia mellifera*	Small tree	0	0	4	15	22	0	22
2	*Acacia nigrescens*	Tree	0	0	2	0	0	0	0
3	*Acacia nillotica*	Small tree	0	1	0	0	12	3	0
4	*Acacia polyacantha*	Tree	0	0	0	0	0	7	0
5	*Acacia robusta*	Tree	0	0	0	0	0	1	0
6	*Acacia albida*	Tree	23	0	0	0	0	4	0
7	*Acacia Senegal*	Small tree	0	0	0	0	0	6	0
8	*Albizia anthelmintica*	Tree	4	0	0	0	0	0	0
9	*Allophylus rubifolius*	Shrub	20	53	53	0	0	5	1
10	*Annona senegalensis*	Small tree	8	0	0	22	0	10	0
11	*Balanites aegyptiaca*	Small tree	0	0	0	0	20	0	0
12	*Borusus palm*	Tree	0	0	0	0	0	1	0
13	*Boscia salicifolia*	Small tree	2	0	0	0	0	1	1
14	*Brachystegia boehmii*	Tree	12	10	12	46	26	13	97
15	*Brachystegia bussei*	Tree	10	0	0	0	0	0	5
16	*Brachystegia microphylla*	Tree	16	0	12	0	0	11	154
17	*Brachystegia speciformis*	Tree	0	0	0	0	0	0	5
18	*Burkea africana*	Tree	1	0	0	0	0	0	1
19	*Cassia abbreviata*	Shrub	0	0	0	0	0	0	0
20	*Cassia burtii*	Shrub	0	0	0	2	0	0	0

S/N	Species name	Life form	1 YF	2 YF	3 YF	4 YF	5 YF	7 YF	FR
21	*Combretum collinum*	Small tree	9	0	0	0	0	3	55
22	*Combretum melchiorianum*	Small tree	35	0	0	0	0	52	6
23	*Combretum molle*	Small tree	23	0	2	12	8	0	10
24	*Combretum zeyheri*	Small tree	35	27	8	17	3	5	22
25	*Commiphora africana*	Shrub	3	2	0	2	7	4	3
26	*Cordia africana*	Tree	0	0	0	0	0	7	0
27	*Cordyla africana*	Tree	5	0	0	7	0	0	5
28	*Crossopteryx febrifuga*	Tree	9	0	3	5	0	8	8
29	*Dalbergia boehmii*	Small tree	0	7	0	0	0	0	0
30	*Dalbergia melanoxylon*	Small tree	0	0	4	32	0	13	20
31	*Dichrostachys cinerea*	Shrub	36	17	7	19	25	9	35
32	*Diospyros fischeri*	Tree	8	3	0	0	7	8	14
33	*Diplorhynchus condylocarpon*	Small tree	64	14	23	44	0	17	153
34	*Flacourtia indica*	Shrub	0	1	0	0	0	0	0
35	*Flueggea virosa*	Shrub	38	8	9	0	0	11	0
36	*Grewia bicolor*	Small tree	0	0	0	1	0	0	0
37	*Grewia goetzeana*	Tree	5	0	0	0	0	18	0
38	*Julbernardia globiflora*	Tree	0	0	0	0	0	0	5
39	*Kiggelaria africana*	Tree	0	3	2	0	0	0	0
40	*Lannea schimperi*	Small tree	0	3	0	0	0	0	0
41	*Lannea schweinfurthii*	Shrub	0	0	0	0	0	0	2
42	*Lonchocarpus bussei*	Tree	0	0	0	0	0	2	14
43	*Malacantha alnifolia*	Tree	0	0	0	0	0	13	0
44	*Markhamia acuminat*	Small tree	12	0	0	0	0	0	0
45	*Markhamia platycalyx*	Tree	25	14	3	130	120	1	0
46	*Maytenus undata*	Shrub	0	0	0	3	0	0	0
47	*Papea capensis*	Shrub	0	0	0	1	0	0	0
48	*Pericopsis angolensis*	Tree	0	0	0	0	0	0	2
49	*Piliostigma thonningii*	Shrub	0	0	0	5	0	0	0
50	*Pseudolachnostylis maprouneifolia*	Tree	11	0	4	0	0	19	32
51	*Pseudolachnostylis stapfiana*	Tree	11	16	0	0	0	0	0
52	*Psidium cattleianum*	Small tree	0	0	1	8	0	0	0
53	*Pterocarpus angolensis*	Tree	2	0	3	0	0	4	6
54	*Pterocarpus mildbraedii*	Tree	0	0	0	0	0	1	0
55	*Salvadorapersica*	Small tree	0	0	0	0	0	0	1
56	*Sclerocarya birrea*	Tree	0	2	0	0	1	7	1
57	*Sclerochiton boivini*	Tree	0	4	0	0	0	0	0
58	*Sorindeia obtusifoli*	Small tree	4	0	5	0	0	2	0
59	*Steganotaenia araliacea*	Small tree	0	0	2	6	0	4	0
60	*Sterculia quinqueloba*	Tree	0	0	0	0	0	9	3
61	*Strychnos potatorum*	Tree	0	0	3	0	0	0	0
62	*Strychnos spinosa*	Shrub	11	1	0	0	0	0	0
63	*Tabernaemontana* sp.	Small tree	1	9	0	0	0	0	0

S/N	Species name	Life form	1 YF	2 YF	3 YF	4 YF	5 YF	7 YF	FR
64	*Tarenna nigrescens*	Small tree	5	0	0	0	0	1	2
65	*Turraea stuhlmannii*	Tree	1	0	0	0	0	0	23
66	*Uapaca kirkiana*	Small tree	0	0	1	0	0	0	0
67	*Vangueria madagascariensis*	Tree	1	0	0	0	0	0	8
68	*Xeroderris stuhlmannii*	Small tree	3	0	0	0	1	0	4
69	*Ximenia caffra*	Shrub	0	0	0	0	0	0	0
70	*Zanthoxylum chalybeum*	Small tree	0	0	1	0	0	0	0

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Impact of Plant Health on Global Food Security: A Holistic View

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Abstract Plant pests and diseases are responsible for 20–40% of losses in the global food sector (FAO, http://www.fao.org/news/story/en/item/1187738/icode/, 2019). Pests and diseases possess a major threat to plant health affecting crop growth, productivity and increase in production cost. They also indirectly affect the quality and nutritional status of foods in the form of post-harvest losses. Insect pests and diseases are able to rapidly adapt to changing climatic conditions, host plants and pesticides and pose a major risk to the current pest management approaches. In recent years, plant health is often considered as a single disease term with a one step solution, but it has to be addressed in a more integrated-holistic way for a sustainable healthy environment. Plant health includes yield-related components, food quantity and biodiversity, and it integrates plant protection with plant hygiene, trade, food quality and ecology. The changing climatic conditions and global trading are thwarting the goals of plant health, thereby threatening the global food security agenda. Integrated Plant Health Management (IPHM) approach aims to grow healthy plants with a most appropriate monitoring and evaluation system. The advancement in agricultural research including technological innovations, molecular biology tools, bio-control agents, and nano-based sensors has a great potential to contribute to the significance of plant health management in developing more specific and targeted products with minimal reliance on chemical pesticides. The present chapter is an effort to provide information relevant to the impact of plant health on crop productivity, challenges associated with plant health, advancement in

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diagnostic techniques and the role of integrated plant health system to achieve the goals of food security.

Keywords Food security · Plant health · Integrated · Crop productivity · Sustainable · Detection · Monitoring

Plant and plant-based products form a major part of human diet and are the primary source for livestock nutrition. Global yield loss of staple food crops leads to loss of food production and shortage of foods leading to millions of people in hunger. Plant pests and diseases are major threat to plant health and are responsible for 20–40% of losses in global food production sector (FAO, 2019). They have a direct impact on plant health affecting crop growth, productivity and increases production cost. They also negatively affect palatability and nutritional status of foods in the form of post-harvest losses. Plant health is a key component for sustainable human and animal health and has a vital role in mediating complex interactions between the environment, humans and animals (Rizzo et al., 2021). The United Nations has declared the year 2020 as the International Year of Plant Health (IYPH) to increase awareness, research and outreach activities on plant health and its effects on society). Plant health is an important constituent for achieving food security and improved nutrition, and the United Nations Sustainable Development Goal 2(SDG 2) highlights the complex inter-relationship between food security, nutrition, rural transformation, and sustainable agriculture. Effective plant health management is essential for improved productivity and sustainable and resilient food systems (CGIAR). Most of the low- and middle-economic zones of the world are affected by pest and disease incidence every year due to poor advisory and extension services resulting in hunger, malnutrition and food insecurity. The highest losses due to pests and diseases are mainly reported in under-developed countries with malnutrition and fast-growing populations (CGIAR).

Plant health and food security are directly proportionate, where food security can be achieved only under safe healthy plant growing conditions. The committee on World Food Security in 2021 insisted that protecting plant health from pest and disease outbreaks as an integral part in achieving food security and right to nutritious food for all during the crisis time. Nearly 70% of the food produced around the world is by small-scale farmers. Ensuring food security relies on the growth and development of agricultural sector by small-scale farmers especially in developing countries. Better small hold farm productivity starts from quality inputs, technological interventions, wide extension and advisory services and knowledge mobilization across regions and countries. The chapter reviews the importance of plant health in achieving food security and a sustainable environment along with a case study on rice ecosystem highlighting IPHM approach. Further, the chapter comprehensively reviews the next-generation technologies in agriculture that can detect and monitor plant health efficiently at a larger scale.

1 Plant Health for Agriculture Productivity and Food Security

Agriculture sector plays a strategic role in food production and productivity and thereby reducing hunger and poverty and achieving food security. Farming and farming-related activities are the major contributors of Gross Domestic Product (GDP) in many developing and developed nations including India. However, the world population is expected to steadily rise in the next few decades and to meet the demands of the growing population, agriculture production has to nearly double (Chakraborty & Newton, 2011) and improved plant health alone can contribute to 30% increase in production (CGIAR, 2021). During the past decades, importance has been given mainly for human and animal health compared to plant health in developing vaccines, medical aids like implants, drugs and instruments. However, plants always have major impact on the livelihood of humans. The world history has marked pests and disease outbreaks causing major food shortage and famine. Few examples included from the past, 1942 outbreak of rice fungal brown spot disease (*Helminthosporium oryzae*) in India causing Great Bengal Famine; 1845 Irish famine by potato late blight disease (*Phytophthora infestans*) killing millions of people. In recent years, wheat black stem rust (*Puccinia graminis tritici*) in South Asia and coffee wilt disease (*Fusarium xylarioides*) in Central and Eastern Africa are reported to cause major yield losses. The virulence of plant pathogens are continuing to spread and evolve and will affect the livelihood of millions of marginal farmers in these regions (Flood, 2010).

Agriculture productivity is the ratio of output produced by a farmland to the total amount given as input or resources. It is a complex factor associated with many plant traits and environmental and socio-economic factors, and of all the one major factor that contributes to loss of productivity is plant health (Flood, 2010). According to FAO estimates annually around 20–40% of global crop production is lost due to pests and diseases with diseases contributing around $220 billion, and invasive insects around US$70 billion loss of global economy (FAO, 2019). The global trade market and travel along with weak phytosanitary measures has further increased the chance of pest movement from their native environment to more vulnerable and favourable environment. The ability of plant pests to adapt to varying climatic conditions and host plants can lead to significant disruption of global food chain and security leading to global economy loss. In China, Colorado potato beetle was first reported in 1993 from several provinces seriously damaging potato and other *Solanaceous* plants and the current estimated crop loss is around 3.2 million USD (Liu et al., 2012).

. In India, the total land area under agriculture has started to decline or is in steady state after 1985 (Fig. 1c) with an increase in population every year. Better food capacity and affordability can only be assured by increasing the agriculture farm production and productivity. This increase in production and productivity can be made possible by technological interventions, high yielding varieties and integrated plant health management approaches. However, in the past decades Indian

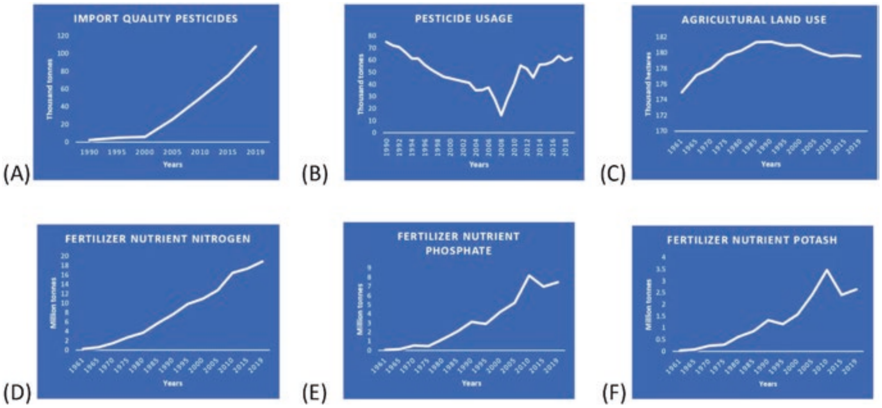

Fig. 1 Trends of total land area and agriculture inputs in India from 1961 to 2019. Graphs indicate trends in (**a**) pesticide import, (**b**) pesticide usage, (**c**) total land area under agriculture, (**d**) fertilizer- nitrogen utilization and (**e**) fertilizer- phosphorous utilization (**f**) fertilizer- total potash utilization. All graphs were drawn using open access data from

agriculture has relied heavily on fertilizers and pesticides (Fig. 1) that are degrading the ecosystem and plants, including human health. In developing countries, more investments on agriculture sector must be concentrated with new policies to increase farm income and productivity without environmental degradation. National government agencies must focus on adopting integrated policy framework facilitating security to small hold farmers through technological interventions, improved farm inputs, quality seeds, irrigation management, crop surveillance for pest and diseases and farm loans at lower interest rate to increase production and total area under cultivation (Upadhyay & Palanivel, 2011). Further, transfer of knowledge and technologies from developed to developing countries, improving diagnostic capacity, global surveillance systems, crop estimate models, risk forecasting for major pests and diseases, alongside rapid response and management systems can ensure farm productivity in food deficit regions of the world (Pawlak & Kołodziejczak, 2020).

2 Post-Harvest Losses on Food Security

Post-harvest loss refers to a series of interconnected activities from harvest, processing, marketing, food preparation and finally the decision by the customer to eat or discard (Kiaya, 2014). Massive amount of food loss occurs due to poor storage facility, infrastructure and transport resulting in spoilage or wastage. According to the United Nations 2016 report, nearly one-third of the food produced is wasted due to poor transportation and other post-harvest losses. In developed countries, food wastage occurs at the final consumer table while in low- and middle-income countries, it usually happens during the early and middle stages of the value chain (FAO, 2011). As per the estimates of the Committee on Doubling Farms Income 2019 from India nearly 40% of agriculture and horticulture products are not being sold in the market for which investments have been made by the small hold farmer. If the post harvest losses can be managed, it can significantly address food nutrition and security. In post-harvest losses, poor storage facility is one factor contributing the farmer to sell the produce at a lower price soon after harvest. Lack of proper storage, poor market information, improper handling reducing the quality and quantity of the produce and inadequate access to market lead to significant post-harvest losses (Kasso & Bekele, 2016). Small holding farmers are not able to adopt sophisticated storage and infrastructure facilities. They use the locally available source materials like straw, mud, wood, bamboo and cow dung to design their own storage structures, which are mostly inadequate to inhibit pest infestation or mould growth leading to post-harvest losses (Boss & Pradhan, 2020). In these cases, technology interventions and improved storage structures using locally sourced materials will reduce post-harvest losses and improve farmer's income.

On an average, 20% of the stored products are lost during storage worldwide. The physiological factors at the time and place of storage are also critical, since high temperature and moisture favour fungal and insect problems (Mesterházy et al., 2020). It is important to determine the moisture content and temperature of the storage facility at frequent intervals and setting of insect traps to monitor the presence of any storage pest. Furthermore, mycotoxins are toxic chemicals present in harvested products, which are unsuitable for human consumption and animal feed. Mycotoxins are produced by fungi and are detectable at harvesting stage and can be properly treated, but improper storage can lead to significant increase in mycotoxin contamination. Post-harvest management can minimize losses and bring value generation and value distribution to the produce at the post-harvest level. Crop-based and area based needs and challenges are to be identified followed by innovative skilla and training to minimize losses in perishable agricultural products. Similarly, private sector involvement in farm mechanization, storage infrastructure at reasonable prices, bridging the market gap between farmers and consumers by educating and training the farmers using skill development, extension services, providing on-farm trials and stores etc. are required to reduce post-harvest losses and increase food supply.

3 Challenges Associated with Achieving Plant Health and Food Security

The challenges associated with achieving plant health and food security are all interconnected with one affecting the other and vice versa. Food and agricultural products continue to increase in demand with decline of natural resources like land area and water resources. Climate change and scarcity of natural resources will result in over-exploitation of resources and decline in food production, hunger, poverty, and food insecurity. This urges the concept of producing more food for the increasing population with limited natural resources. In addition, the increasing production cost due to higher input costs, labour, land degradation and other socio-economic factors constrains agricultural production.

The climate prediction models indicate an increase in sea water level and global temperature with increased frequency of drought, heat, erratic rainfall, cold waves and sea water intrusion (IPCC, 2020). The change in climatic conditions along with increase in world population poses a major threat to global food security. The farming system is at a high risk due to the climate variability affecting multiple levels of cropping patterns, livestock, farm production and income. The change in climatic conditions with intense and frequent drought, flooding and temperature has a tremendous impact on crop growth and reproduction affecting farm production and productivity. The change in climatic conditions like increase in temperature and Co_2 concentration also influence insect behaviour and physiology with a change in their population trend, adaptation and migratory responses. A study by Horgan et al. (2020) has observed change in climatic conditions linked to increase in abundance of planthopper populations in rice. This increased fitness of insect herbivores to climatic factors presents even more challenges to the present-day pest management approaches.

Another major challenge in sustainable agriculture and food security is the greenhouse gas (GHG) emission from agriculture and allied sectors. In India, agriculture sector contributes a major share in GHG (directly 17% and indirectly 7–14%) of which rice cultivation has a major share (MoEFC, GOI). The Indian government has launched the National Mission for Sustainable Agriculture (NMSA) under National Action Plan on Climate Change (NAPCC) to address issues regarding sustainable agriculture in the context of climate change by adapting strategies for food security, availability, nutrition, enhancing livelihood and economic stability of the nation (Sustainability framework for realizing SDG2). Achieving farm productivity with reduced carbon footprints and implementing climate resilient agriculture practices is the main agenda of the framework.

Water scarcity is a growing constrain with the total area under irrigated cultivation at a decline phase. Agriculture sector is the greatest user of freshwater resources with the major portion of water drawn up from the earth for producing food. Most of the agriculture land in developing countries are rainfed contributing to 50% of global food production. Future demand for water supply largely depends on the availability of nearby water resources, change in precipitation and climate change-driven factors. With limited freshwater resources, climate change and increased demand for food production, there is an alarming need for an effective and sustainable water management system.

Another challenge in farming systems is the dependence on few major food crops like rice and wheat for cultivation. This leads to excess production and low produce price for farmer, food stocks, over-exploitation of water and other resources by few crops, and shortage of other farm commodities. Also, Indian agriculture system is largely dependent on fertilizers and pesticides thereby degrading the land and water resources and making the land unfit for cultivation for the future India.

Fig. 2 The challenges and strategies associated with achieving plant health and food security

The drinking water sources of India are highly contaminated with toxic pesticides like organochloride, organophosphate due to run-off (Agarwal et al., 2015). The challenges reported so far can be tackled by innovative systems like climate resilient agriculture and conservation agriculture that protect and enhance natural resources with increase in crop productivity. Similarly, technological innovations to reduce fossil fuel usage will help in addressing climate change-related issues (Fig. 2).

4 Integrated Plant Health Management Approach

Integrated Plant Health Management (IPHM) approach is an integrated and innovative approach that involves several methods to grow healthy plants with minimum disturbance to agro-ecosystem and mainly allows natural enemies and plant immunity to induce plant resistance. IPHM ensures sustainable agriculture and food security and addresses the United Nations Sustainable Development Goal 2- Zero Hunger. IPHM involves decision-making by farmers that are economic, knowledge-based, and with minimum impact on ecosystem. The integrated approach includes several components like host resistance and cultural, physical, biological, chemical and regulatory measures. Of which the chemical component forms the smallest part, which is used as the last option. Host plant resistance is one of the important components where the innate immune system of plants is employed in developing resistance against pest and diseases. The advancement in molecular biology tools and marker-assisted selection has resulted in the identification of numerous resistant genes and quantitative trait loci (QTL) in plants. These resistant R genes/QTLS have been successfully introgressed into high-yielding varieties deploying resistant high-yielding cultivars (e.g. *Xa1* gene against rice blight disease (*Xanthamonas oryzae*); *Bph1* gene against brown planthopper (BPH) (*Nilaparvata lugens*) of rice). Further, pyramiding of one or more resistant genes into a single genotype results in broad spectrum, durable and stable resistance in plants (Srinivasan et al., 2015). This technique minimizes the need for chemical-based pesticides and encourages plant innate system and natural enemies for defence.

Another important attribute in IPHM is crop monitoring and surveillance for pest and disease incidence and damage. This includes comparison with the threshold level and any range/level above the threshold affects farm production and requires immediate attention (Horgan, 2017). IPM techniques like trap plants, biologically antagonistic organisms that can kill or restrict phyto-pathogenic organisms are considered eco-safe and alternate to commercial pesticides. Similarly, strict government plant quarantine and eradication programs can minimize the spread of pest and diseases to less prevalent area. All the different components of the approach are employed in “mix and match” based on agroecological zone, cropping system, pattern, pest and disease incidence, previous experiences, availability of effective tools in each component etc. for a sustainable solution (Ellis & Boehm, 2008). The case study on rice ecosystem highlights how integration of different components can be beneficial to each other.

5 Case Study: 1 Rice Ecosystem and Pest Management

Rice ecosystem is a highly diversified system with many different components interacting at different levels like herbivores insects, diseases, parasitic nematodes, snails in direct contact and other components like weeds, predators, rodents, birds, decomposers and other diversified organisms at the next level (Horgan, 2017). The Green Revolution era has doubled the rice production with increased agro inputs like fertilizers and pesticides affecting the ecosystem (Fig. 1). High levels of nitrogenous fertilizer and heavy doses of pesticides have resulted in increase in planthopper populations in rice. Recent outbreaks of rice planthoppers have been reported in China (2005–2006), Indonesia (2009), Vietnam (2010) (Horgan, 2018) and Northern India (2013–2015) (Directorate of Rice Research, 2015; Srinivasan et al., 2015). BPH is a serious pest under low land irrigated rice cultivation system with excessive nitrogenous fertilizer and pesticide usage (Bottrell & Schoenly, 2012). White backed planthopper (WBPH) incidence in China has been linked to hybrid rice with cytoplasmically inherited susceptibility (Horgan et al., 2016a, b). The increase in temperature has been flavourful for pest populations of rice especially planthoppers (Horgan et al., 2020). There has been a phenomenal increase in adaptation of BPH to resistant rice (Srinivasan et al., 2015, 2016). Unfortunately, the current farming practices of extensive monocultures, high N fertilizers and pesticides increase planthopper incidence in rice.

Maintaining rice ecosystem by regulating the interaction modes of rice with other components of the ecosystem can reduce pesticide usage and increase rice yield. Natural enemies like predators and parasitoids maintain the rice ecosystem by regulating pest populations. It is a strictly advised to avoid spraying of insecticides during the first 40 days of transplanting in rice. This is mainly to maintain the populations of generalist predators during initial days which later regulates rice pests. Establishment of bird porches to encourage bird vist can help to maintain insect pest below threshold levels. Further strategies include growing bund flower crops/vegetable crops to provide a habitat source for natural enemies. Integrating fish and other economic sources like duck will be an additional income source for the farm and can increase the ecosystem function. This agro intensification with increase in natural biodiversity increases unit production of food and income by farmers (Horgan et al., 2016b). This also provides diversified food source for the farmer increasing his nutritional status. This approach can increase rice yield with reduced pest damage, minimum inputs of pesticides, biodiversity establishment and increase in activity of beneficial insects including bees and birds and increase farm income. Agro-intensification along with employment of high yielding cultivars, bio amendments, bio-control agents can further have a tremendous potential in achieving food targets and security (Horgan, 2017).

6 Plant Health Detection and Monitoring Tools

Plant health is constantly dealing with a wide range of organisms that can be harmful to plants, such as other plants, fungi, bacteria, viruses, insects, mites, nematodes and members of many other groups of organisms, all of which have a significant impact on crop production and productivity. In the prevention of diseases caused by harmful microorganisms, monitoring is the most important control point. In plant health monitoring, early detection of plant diseases is critical. It provides ease in management of disease infection in greenhouses and in the field at various phases of plant disease development, as well as minimizing the hazard of disease infection spread and preventing the introduction of novel plant diseases, particularly quarantine pathogens at country borders (Anderson et al., 2004; Strange & Scott, 2005; Brassier, 2008; Vincelli & Tisserat, 2008; Miller et al., 2009). The early detection of plant pathogens could be perceived through a process called diagnosis that refers to the process of detecting a particular cause to the symptoms observed and determining its nature and name. This is necessary before appropriate measures can be applied to eradicate or control a disease or infestation. The process begins with the discovery of an organism, followed by its identification, which entails assigning it to a certain taxon in a classification system. There are many different methods available for detection, testing and indexing, depending on the material and the primary purpose of the exercise. Classically, detection depended heavily on morphological appearance, but in recent years it has been increasingly possible to place more emphasis on different approaches i.e., microscopic techniques, nucleic acid analysis, spectroscopic studies, profiling techniques, artificial intelligence through machine learning systems, remote sensing and biosensors. The choice of methods used will be influenced by the symptoms observed, the type of material and knowledge of the organism likely to be present. Ideally, the method should be accurate, sensitive, reproducible, rapid, cheap and quantifiable.

7 Morphological Detection Methods

Detection methods frequently incorporate a way of identification. The initial standard procedure used in the previous 80 years was symptom observation, which comprised field inspections to identify disease symptoms as well as laboratory testing such as pathogen growth on selective medium followed by biochemical, physiological and pathogenicity assays (Martinelli et al., 2015). On the other hand, these approaches are far too independent. Hence, new technologies allow for a more objective assessment of diseases with reliability, precision and accuracy.

8 Molecular Detection Techniques

Plant health detection molecular techniques have become well established in recent years. The sensitivity of molecular methods refers to the smallest amount of microorganisms that can be detected in a test sample. ELISA and PCR are two frequently used molecular methods for detection of diseases. Fluorescence in situ hydridization (FISH), immunofluorescence (IF), flow cytometry and DNA microarrays are examples of other molecular methods (Sankaran et al., 2010).

9 Nucleic Acid-Based Detection

Ever since the 1980s, all plant pathogenic organisms have been identified using polymerase chain reaction (PCR), a nucleic acid amplification technique. PCR detection is reliant on nucleic acid either DNA or RNA. Fluorescence in situ hybridization (FISH) and several PCR variations (PCR, nested PCR (nPCR), cooperative PCR (Co-PCR), multiplex PCR (M-PCR), real-time PCR (RT-PCR) and DNA fingerprinting are examples of DNA-based pathogen detection technologies. Other RNA-based amplification methods include reverse transcriptase PCR and nucleic acid sequence-based amplification (NASBA). All of these techniques may overcome ambiguous pathogen taxonomy or diagnosis, allowing for quick and accurate pathogen detection and quantification (López et al., 2009). The specificity of PCR is ultimately determined by the design of proper PCR primers that are unique to the target organism (classical or real time). Because of their great sensitivity, sophisticated PCR technologies such as reverse-transcription PCR (RT-PCR) have been utilized for plant pathogen detection in addition to basic PCR technology (López et al., 2003). Multiplex PCR was proposed to identify several DNA or RNA sequences in a single reaction (James, 1999, Nassuth et al., 2000). It consents the synchronized detection of quite a lot of organisms through the introduction of diverse primers to amplify DNA regions encrypting for specific genes (Radhika et al., 2014). On-site, fast detection of plant diseases based on nucleic acids of fungi, bacteria and virus has also been done using real-time PCR systems. Real-time PCR allows for quicker results without the need to manipulate the recognition steps. The measurement of fluorescence emission by a particular dye that binds to the targeted amplicon yields real-time PCR data. Because the intensity of the fluorescence is related to the amount of amplified product, this reaction may be monitored in real time, bypassing time-consuming post-amplification techniques like gel electrophoresis (Stephane Swillens et al., 2004; Rodrigo et al., 2015). Despite its high sensitivity and specificity, the time and laborious identification of the amplified product, fidelity of DNA amplification and lack of operational robustness are the main reasons why classical PCR has not been adopted by most plant disease regulatory and diagnostic laboratories (Van der Wolf et al., 2001).

To overcome this, several isothermal DNA amplification techniques for on-site diagnosis of plant infections have recently been developed. Recombinase polymerase amplification (RPA) (Rojas et al. 2017), helicase-dependent amplification (HDA) (Schwenkbier et al., 2015), and loop-mediated isothermal amplification (LAMP) are examples of these methods (Feng et al., 2018). Because of its speed, simplicity, and practicality, the LAMP technique invented by Notomi et al. (2000) has become a popular alternative to PCR. The reaction, unlike PCR, has a high specificity and may be performed at a constant temperature. To visually monitor or measure amplification, colour indicators or the turbidity of the reaction mixture (Mori et al., 2001, 2004) might be utilized (Goto et al., 2009; Iwamoto et al., 2003). Furthermore, the LAMP reaction is effective even with poor template DNA extractions (Feng et al., 2015; Kitamura et al., 2016; Miyake et al., 2017; Shen et al., 2017). As a result, LAMP is ideally suited for field diagnostics simply requiring a water bath or a heat block. The LAMP assay has been used to detect a wide range of plant pathogens including viruses, viroids, fungi, bacteria, and oomycetes (Boubourakas et al., 2009; Fukuta et al., 2012; Hodgetts et al., 2015; Miyake et al., 2017; Rigano et al., 2010; Tomlinson et al., 2010). Similarly, Helicase-dependent amplification (HDA) is also another isothermal technique developed by New England Biolabs in 2004 (Vincent et al., 2004). This isothermal method is like traditional PCR in that it does not need heat denaturation to split the double stranded DNA and permits primers to anneal to their corresponding target sequences. Because of its simple reaction steps, helicase-dependent amplification has become a common isothermal method. Although it uses the same idea as PCR to amplify the target sequences using a pair of primers, the processes are significantly easier because there are no numerous temperature cycling phases (Lau & Botella, 2017). The recombinase polymerase amplification (RPA), a new isothermal DNA amplification and detection technology that can be operated at a single constant low temperature circa 37 °C (Piepenburg et al., 2006), it plays an effective role in on-site testing programmes for the undesired plant disease in farms, nurseries and biosecurity, assisting with prompt eradication efforts. It exploits an enzymatic mixture of polymerase and DNA recombination protein to achieve exponential amplification of the target viruses in under 30 min (S.C. West, 2003, Piepenburg et al., 2006, Krejci et al., 2012, Piepenburg et al., 2011). RPA's usage in plant health detection is growing because of its appealing instrument simplicity, mobility and cost-effectiveness as nucleic acid extraction may be avoided.

10 Genetic Engineering Approaches

10.1 Synthetic Biology

Plants contain inducible defensive systems that protect them from infections, poisons and nutrient deficits. In vivo phytosensors that report various plant pathogens, toxins, or nutrient deficiencies were reported using synthetic biology approach (Liu & Stewart, 2015). The reporter genes like fluorescent proteins are fused to induce plant defense promoters and the plants perceive pathogens on a molecular level. This results in a quick read that can be seen with the naked eye, allowing for disease identification to happen quickly. Nevertheless, the time frame for detection often ranges from several days to few weeks from infection to expression of disease symptoms. Phytosensors are feasible for on-the-ground, in-field detection or on a larger scale to monitor fields using satellite images. The elements were the promoter regions of pathogen-inducible genes and genes encoding plant defence signal chemicals like salicylic acid, jasmonic acid and ethylene. The pathogen-inducible synthetic promoters fused with GUS (reporter genes) were transformed in model host plants such as Arabidopsis and tobacco (Mazarei et al., 2008). Plant elicitor and phytohormones-treated plants exhibited an increase in GUS expression when infected with alfalfa mosaic virus. Besides, Fethe et al. demonstrated the probability of phytosensors in live plants and in-field locations where the model host plants transformed with four pathogen-inducible promoter elements fused to orange fluorescent protein exhibited fluorescence signals 48 h post infection of bacterial pathogens (Fethe et al., 2014). Many innate plant responses could be used in phyto-sensor designing, whereas the sensitivity and specificity varies with promoter.

11 Imaging Techniques

Imaging is one of the rapid disease diagnostics techniques for crop health monitoring. The imaging techniques including RGB imaging, thermography, fluorescent imaging and hyperspectral imaging are employed for plant disease assessment.

RGB Imaging The changes in transmittance are measured and captured using digital cameras in a field. Plants with biotic stress could be detected using RGB colour images containing red, blue and green channels (Bock et al., 2010). RGB can be used for single plants, with a smartphone sensor, drones or unmanned aerial vehicles (UAV) to monitor huge fields. Machine learning procedures are designed to sense different patterns corresponding to specific ailments (Mahlein, 2016). Since, RGB is an indirect method that relates to colour changes, specificity is the major lacuna. RGB imaging cannot provide specific insights into factors affecting the plant.

11.1 Thermography

This imaging technique detects the heat emitted by the targets objects, and it is often used for disease surveillance in large areas of land. Infra-red thermography (IRT) measures the plant temperature and relates it with water status of plant, microclimate (Lenthe et al., 2007) and changes in transpiration. The plant temperature changes can be attributed to pathogen response, such as stomatal closing. Also, it is useful to detect the spatial colonization of pathogens where the conidia and hyphae are microscopic (Oerke et al., 2011). Thermography is for monitoring large fields and is non-invasive; it is an indirect and non-specific detection method.

11.2 Fluorescent Imaging

Fluorescent imaging uses the principle of fluorescent excitation using a laser beam, in addition to a camera. Chlorophyll pigment naturally fluoresces when excited by certain light and the fluorescence can be related to photosynthetic efficiency. A leaf or plant's chlorophyll fluorescence imaging is compared to nearby plants or to a baseline value. Different ambient air pollution and various agro-chemicals influence the chlorophyll fluorescence, indicating interruptions in photosynthetic activity (Bolhar-Nordenkampf et al., 1989). Several portable in-field devices also use the chlorophyll imaging principle as the chlorophyll is luminous under bright sun; a simple fluorimeter is being used to assess the photosynthesis and thereby monitors crop health. It is a highly non-invasive, non-destructive technique, easily adaptable to in vivo purpose; however, it is non-specific. Due to the lack of specificity, it is unable to diagnose specific abiotic or biotic stressors. The major drawback of fluorescence imaging is that the leaf fluorescence fluctuates often in response to multiple biotic and abiotic factors (Mohammed et al., 2019).

11.3 Hyperspectral Imaging

Hyperspectral imaging examines changes in the electromagnetic spectrum that are not evident with traditional RGB imaging. Despite the fact that hyperspectral imaging can detect more changes than visual or fluorescent images, it can also be utilized to identify changes in plant surfaces. Hyperspectral patterns, on the other hand, can be linked to specific situations. The hyperspectral features of yellow rust disease were identified, and yellow rust was distinguished from nutritional inadequacies using proper statistical analysis (Zhang et al., 2012).

11.4 Nano-sensors

Before imaging, leaves were coated with polydiacetylene (PDA) polymer or DNA-functionalized single-walled carbon nanotubes (SWCNTs). Both strategies have the potential to be useful in the field. Seo and his colleagues created a PDA-based brush-on sensor that monitors the quantity of water loss from individual stomata (Seo et al., 2016). Diacetylene monomers brushed on the abaxial side of the leaves were photopolymerized in PDA sensors. Fluorescence microscopy detects a blue-to-red shift in the polymer in response to variations in moisture from individual stomata. Open stomata can be recognized using this technique, which can be used to visualize putative environmental influences on stomatal activity (temperature, wind or humidity).

Wu et al. created a hydrogen peroxide sensor using functionalized SWCNTs and near-infrared fluorescence imaging more recently (Wu et al., 2020). When plants are stressed, hydrogen peroxide is produced. The sensor was used to assess the impacts of UV-B, wounding and pathogen-related stressors, as well as the application of hydrogen peroxide. In the sensors, SWCNTs were combined with an aptamer sequence that binds to hemin, that catalyses the conversion of hydrogen peroxide to free hydroxyl radicals. The near-infrared fluorescence of SWCNTs was then suppressed by reactive hydroxyl radicals (Fig. 3). Fluorescent emissions were significantly reduced with direct hydrogen peroxide application and under stress conditions.

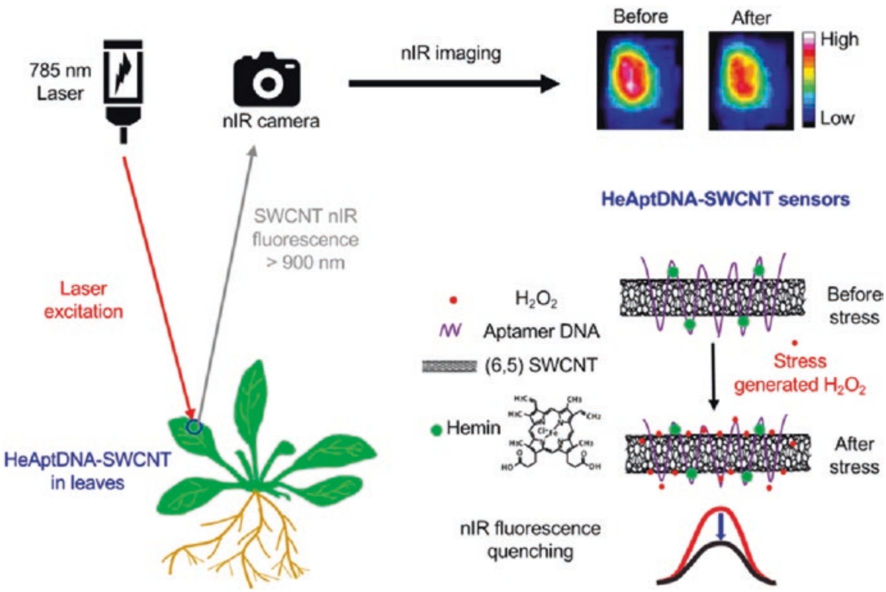

Fig. 3 Plant health monitoring by SWCNT sensors for H_2O_2. SWCNTs functionalized with a DNA aptamer that binds to hemin (HeAptDNA-SWCNT) quench their nIR fluorescence upon interaction with H_2O_2 generated by the plant stress. Thespatial and temporal changes in nIR fluorescence intensity in leaves embedded with HeAptDNA-SWCNT sensors are remotely recorded by an nIR camera to assess plant health. (Adapted from Wu et al., 2020; Copyright 2020 American Chemical Society)

12 Spectroscopic Techniques

Spectroscopic techniques include Raman spectroscopy, X-ray spectroscopy and mass spectrometry.

12.1 Raman Spectroscopy

Raman spectroscopy senses vibration frequencies of particles. This principle can be used to identify molecules by determining the chemical footage of a structure. When a monochromatic laser illuminates a sample, the light interacts with the sample, causing energy elements to move (Fig. 4). This provides information about the molecules present in a sample. Raman spectroscopy is a biochemically safe and non-destructive approach for detecting molecules in very complex samples. Altangerel et al. (2017) built a portable Raman spectroscopy apparatus for coleus lime as the model host based on this principle. The Raman spectroscopy was used to study the photosynthetic system's anthocyanins and carotenoids. Anthocyanins can block harmful irradiations, and carotenoids are the first line of defence against

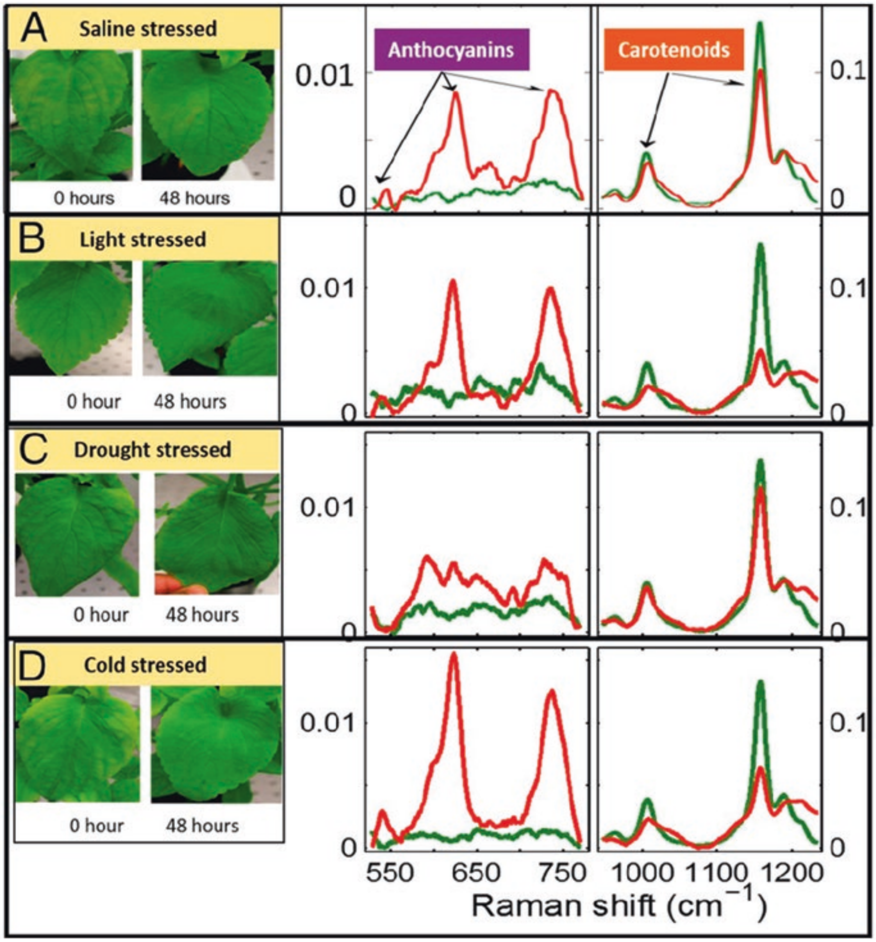

Fig. 4 Raman spectra of unstressed plants (green curves) and stressed plants at 48 h after stress (red curves) of (**a**) saline, (**b**) light, (**c**) drought and (**d**) cold in coleus leaves. (Adapted Altangeral et al., 2017; Copyright 2017 National Academy of Sciences)

reactive oxygen species (ROS). The relative concentrations of carotenoids and anthocyanins, which indicate abiotic stress, were measured 2 days after exposure to light, cold, drought or saline stress. The carotenoid and anthocyanin concentrations indicate the presence of stress in the plant before expression of physical symptoms. During abiotic stress, Raman spectroscopy reliably analyzes these compounds and reveals a functional link between the chemicals and ROS. The portable Raman instrument, on the other hand, was unable to identify anthocyanins, necessitating further refinement. Recently, a portable Raman leaf clip sensor was created that can discriminate between nitrogen-rich and nitrogen-deficient plants (Farber et al., 2019; Gupta et al., 2020). Raman spectroscopy has also been used to detect infections and pests living within host seeds, as well as pesticide residues (Pang et al., 2016).

12.2 X-Ray Fluorescence (XRF) Spectrometry

It is a non-destructive way to figure out the chemical composition. It works on the principle that an X-ray beam interacts with the sample, resulting in fluorescent X-rays that may be used to identify the elements in the sample. The uptake dynamics of aqueous Zn and Mn in soybean leaves and stems were studied for 48 h using XRF and an infrared gas analyzer (Montanha et al., 2020). The distribution patterns of elements in plants provide information about the effects of localized X-ray exposure on live plant tissue.

12.3 Mass Spectrometry

Mass spectrometry determines the mass-to-charge ratio of ions. Ambient ion mass spectrometry allows for mass spectrometry analysis using a high vacuum environment. Low-temperature plasma (LTP) is a relative method of ionizing and can be used to ionize samples at ambient air. Martinez-Jarquín et al. (2018) demonstrated that LTP mass spectroscopy can be used to examine nicotine biosynthesis in tobacco.

13 Combination Approaches

For more accurate diagnostics and more sensitive detection, combination of two or more imaging or spectroscopy techniques can be used. A recent influx method by Crawford et al. (2019) allows for in vivo monitoring of genomic targets by integrating plasmonicnano-probes along with other imaging and sensing techniques (surface-enhanced Raman scattering (SERS), XRF and plasmonic-enhanced two-photon luminescence (TPL). In the combined approach, plasmonic-active silver-coated gold nano-sensors functionalized with double-stranded DNA was used. The nano-sensors sense the changes and conform to the presence of a specific bio-target. To verify imaging modalities, this approach was tested in Arabidopsis to detect miR156 using SERS tags. When the probe connects to its target, Raman imaging detects the disease. As a result, the combinatorial technique enables disease detection and quantification, which is critical in bio-sensing. This method can also be used to follow changes in a target over time and for plant pathogen detection (Wang et al., 2019).

14 Artificial Intelligence (AI) in Agriculture

Drones equipped with AI tools can be used to identify crops, pests, diseases, deficiency symptom and for application of fertilizers and herbicides. The photographs taken by the drone are compared with the field-level inputs to decide on the efficacy. The drone can capture about 2000 aerial shots of the fields covering an area of 500 acres during one sortie. The pictures captured by the drone are analyzed by AI tools and the data are cross-checked with the data obtained by the agriculture department officials for the accuracy. By viewing an image of symptomatic tissue, farmers and qualified plant scientists can often diagnose disease and deficiency signs with high confidence. However, such visual diagnosis does not scale well, and even if each plant could be clearly documented, one person cannot quickly analyze every plant in a broad area. Robust computer vision models that recognize or classify items in images can be beneficial when using aerial data for disease surveillance and related applications (Fig. 5). Wu et al. (2019) developed a technique for identifying maize (*Zea mays L.*) northern leaf blight (NLB), which results in considerable yield losses. It takes a long time to score visual diseases over a vast area, and human evaluations are subjective and prone to inaccuracy. Researchers demonstrated an automated, high-throughput technique for detecting NLB in field pictures of maize plants in this work. They took high-resolution photographs with an unmanned aerial vehicle (UAV). They used lower resolution sub-images to train a convolutional neural network (CNN) model, which obtained 95.1% accuracy on a different test set of sub-images. The CNN model was utilized to generate understandable heat maps of the source images, identifying the locations of suspected lesions. The ability to detect lesions at a fine spatial scale opens up the possibility of high-resolution disease detection for plant breeding and crop protection.

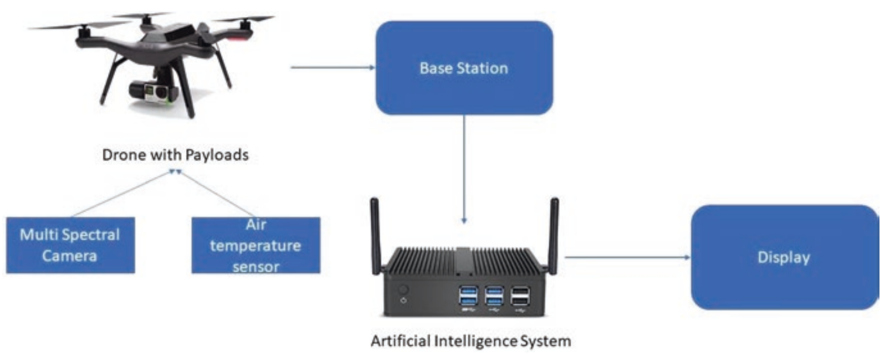

Fig. 5 Aerial imaginary system employing drones for pest and disease surveillance and detection

15 Electronic Nose (e-Nose) in Agriculture

The electronic nose (e-nose) is a non-destructive intelligent electronic sensing equipment that works in the same way as the human olfactory system to detect, distinguish, and classify odours and aromas. The electronic nose is made up of a set of partial-specificity electronic chemical sensors and a pattern recognition system that can recognize simple or complicated aroma. Due to the advancement in AI algorithm the grading and classification of odours/volatiles can be achieved with high degree of accuracy. With the introduction of e-nose, new instruments for grading fruits and other perishable items using more consistent qualitative and quantitative evaluations of aroma qualities, rather than the high variable subjective judgements of human graders, have become available. These instruments offer new ways to characterize fruit aromas for a variety of applications, from geneticists or fruit breeders developing new fruit varieties to the time of harvest, transportation, storage and final grading by traders and retailers in market.

16 Conclusion

Agriculture sector needs huge investments in the next few decades to meet the growing needs of food and the challenges in achieving food security, nutrition and a sustainable environment. Avoiding post-harvest losses through proper preventive and educative measures can increase food supply and nutrition security. Current technologies for assessing plant health or diagnosing disease is expensive and mostly invasive. The sensors-based approach should become a component of precision agriculture, for maximizing crop yield and post-harvest disease management. Moreover, research and government schemes should promote these technologies making them affordable and accessible to small-scale marginal farmers especially in developing and under-developed countries. Also, transformative changes in agri-food systems like developing and implementing sustainable and climate resilient agriculture can ensure the livelihoods of millions of small hold farmers with a safer planet.

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Crop Diversification as a Measure of Sustainable Agriculture and Production Growth

Md. Faiyaz Afzal and Shamsul Haque Siddiqui

Abstract The agriculture in West Bengal is mainly of intensive subsistence nature. There is a predominance of single cropping of rice from the distant past. The rural, as well as urban people of West Bengal, are totally dependent on agriculture and allied industries for their livelihood. Thus, it is very interesting to know the degree of crop diversification so far achieved in the rural areas of West Bengal, as the sustainable income and employment of people are largely dependent on the nature and degree of diversification of crops. Crop diversification generally means, raising varieties of crops in a given area in one cropping season. Thus, the sustainability of agriculture in any area mainly depends on the degree of crop diversification in that area. Therefore, to acquire knowledge about the crop diversification and production growth in rural West Bengal two typically agricultural districts have been taken into account for the present study, namely, Uttar Dinajpur and Dakshin Dinajpur. About 80–90% population of both the districts are directly or indirectly engaged in agricultural activities. The present chapter tries to study the pattern of crop diversification and growth in agricultural production during the period 2000–2001 and 2014–2015. The variation in crop diversification is a response to the fast-changing physical and socio-cultural conditions which helps in attaining agricultural sustainability. The index of crop diversification has been employed by using the Gibbs-Martin Index of Crop Diversification (1962). The study highlights that there has been a shift in the cropping behaviour from cereals towards non-foodgrain crops, and the production of major crops has also increased manifolds in both districts.

Keywords Crop diversification · Crop diversification index · Cropping pattern · Gibbs-Martin · Sustainable agriculture

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1 Introduction

The agriculture in West Bengal is mainly of intensive subsistence nature. There has been a predominance of single cropping of rice from the distant past. The rural, as well as urban people of West Bengal, are totally dependent on agriculture and allied industries for their livelihood. Thus, it is very interesting to know the degree of crop diversification so far achieved in the rural areas of West Bengal as the sustainable income and employment of people is largely dependent on the nature and degree of diversification of crops. Crop diversification generally means the raising of varieties of crops in a given area in one cropping season. It is actually the idea of competition among the parallel crops cultivated in a region. If there is high competition among the crops in the region, there will be a higher magnitude of crop diversification and if there is less competition among the crops in the region, there will be a trend towards crop specialization or monoculture (Bhatia, 1965). Essentially, it is an indicator of the multiplication of agricultural activities which involves intense competition among various activities for space (Singh & Dhillion, 1997).

In India, crop diversification is generally considered as shifting from traditionally grown less remunerative crops to more remunerative crops (Husain 1996; Wanjari et al., 2006). The level of crop diversification is largely dependent on the geo-climatic set-up, socio-economic conditions and technological know-how in a region. The regions with a higher level of agricultural mechanization and endowed with rich farmers experience a lesser degree of diversification, while the regions with poor farmers and comparatively less mechanization generally experience a higher degree of crop diversification (Ranade, 1980; Goyal & Kumar, 2013; Dabai, 1979; Vaishampayan et al., 2019). Basically, it is a kind of farming system where a variety of alternative crops are being cultivated by the farmers in the same field, which itself has great relevance in the agricultural land use scenario and is considered as a vital component of the cropping behaviour of a region (Shafi,1981; Vyas, 1996); Ratnaparkhi, 2012). It also has great relevance in agricultural land use planning of a region, as the farmer instead of growing only one crop over the entire cultivated area grows a variety of crops like rice, wheat, maskalai (urd), musur, jute and potato. Consequently, a diversified cropping pattern can enhance the nitrogen intake of soil and makes the soil more fertile, arable and increase the sustainability of the soil. Besides this, farmers remain engaged in agricultural activities like sowing, weeding, harvesting and marketing of produced crops throughout the year which ultimately leads to employment generation. It can also bring down the risk of crop failure as different crops respond differently with the geo-climatic conditions of an area, wherein the production of a certain crop may get affected by extremely hot weather but it may be beneficial for some other alternative crops.

The main advantages of crop diversification lie in the fact that it is very helpful for planning and developing agricultural practices of an area (Bisai et al., 2016). It has been observed that the nature of crop diversification of a geographical unit is basically influenced by the existing social and economic status, educational attainment, infrastructural facilities and physical conditions of that region (Todkari, 2012). In West Bengal, the first incidence of diversified cropping took place soon after the Green Revolution period (1960s). Whereas, the initial period was favourable for the wheat but later on a gradual shift towards mustard-potato (rabi crops) has been noticed (Pal, 2008). There exists a small peasant-based farm economy in India with nearly 35% cultivated land and about 80% holding below 2 hectares on an average (Ghosh, 2011; GOI, 1997). The small size of holdings does not allow the farmers to increase their earnings by simply boosting the yield of cereals crops. However, in due course of time with the advancement of science, the water seed-fertilizer technique has enabled the farmers to change their cropping behaviour towards certain high-value cash crops by practising horticulture (Joshi et al., 2003). The results are also visible in West Bengal, as the small farmers of the state are now opting for high-value crops like tea, maize, potato, summer paddy and mustard (De, 2000).

It is a scientific solution to numerous problems experienced by the nations with high population, highest share of marginal farmers, low level of agricultural mechanization and acute physio-climatic conditions. The agricultural output of a region can be enhanced after moving from low-value to high-value crops by adopting crop diversification (Dutta, 2012). Thus, the sustainability of agriculture in any area mainly depends on the degree of crop diversification in that area. Therefore, to acquire knowledge about the crop diversification in rural West Bengal, two typically agricultural districts have been taken for the present study, namely, Uttar (North) Dinajpur and Dakshin (South) Dinajpur. These two districts are mainly agrarian as almost 85% population are dependent on agricultural activities, but due to lack of institutional and infrastructural facilities, agricultural sustainability is hindered (Government of West Bengal, 2000–2001).

2 Study Areas

Uttar and Dakshin Dinajpur districts of West Bengal have been selected as the study areas because these districts are very backwards in every aspect of socio-economic parameters and no such research has been conducted till now in these two districts. Also, a study of the cropping behaviour of two adjacent districts may give us a better understanding of crop diversification and its dynamic role in influencing the growth of production in a different way in each district. In other words, by this comparative study, we can see two sides of a single coin i.e. crop diversification.

On 1 April 1992, the West Dinajpur division of West Bengal bifurcated into two separate districts namely Uttar Dinajpur and Dakshin Dinajpur for the upliftment of socio-economic conditions and better administration. The district of Uttar Dinajpur stretches from 25°11′ N to 26°49′ N latitude and 87°49′ E to 90°00′ E longitude. This district is spread over 3140 sq. k.m. area. The district is bounded by Darjeeling and Jalpaiguri districts on the north, Kishanganj district of Bihar on the west and Malda district on its south. On the eastern side there lies the international border between India and Bangladesh (Fig. 1). According to census 2011, the total

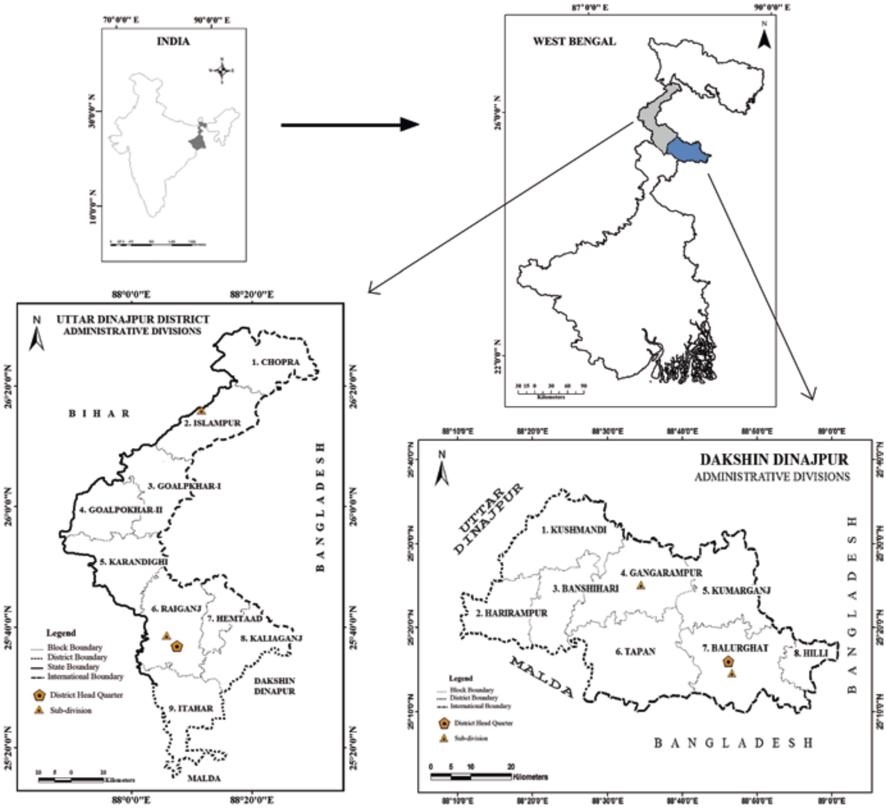


Fig. 1 Locational map of the study areas

population of the district is 30 lakhs, out of which more than 85% of people were living in villages and dependent on agricultural activities for their livelihood. The average literacy rate of the district was 60.1% (Census, 2011). The net sown area of the district is 275.6 thousand hectares (88.2%) and the cropping intensity of the district is altogether 210.07%. The district is dominated by marginal farmers with <1 hectare (only 0.88 hectares) of land on average. Rice, wheat, jute, mustard, potato, sugarcane and potato are the major crops grown in the district (Comprehensive District Agricultural Plan (C-DAP)).

On the other hand, the district of Dakshin Dinajpur stretches from 26° 35′ N to 25° 10′ N latitudes and 89° 00′ E to 87° 48′ E longitudes. This district is located in the north-eastern part of the state of West Bengal and surrounded by Uttar Dinajpur on its north and west, Malda district on the south-west and Bangladesh border lie on its east and south. According to census 2011, the total population of the district is 16 lakhs out of which almost 80% of people are engaged in agricultural activities and living in rural areas. The average literacy of the district is 72.8% (Census, 2011).

The rich alluvium soil has enabled double as well as multiple cropping in the district (Siddiqui et al., 2017). Major crops grown in the district are rice, jute, potato, wheat, mustard and maskalai. Out of the total reporting area of the district about 84% is sown and the average cropping intensity of the district is altogether 182%.

The general topography of both the districts is almost flat having a gentle slope from north to south. The old and new alluvium soil of Uttar Dinajpur is rich in organic compound and phosphate, while the old alluvium soil of Dakshin Dinajpur is rich in potassium content, besides certain parts of the district have lateritic soil near the Tapan block. The climate of Uttar Dinajpur is muggy (annual rainfall 1500–2400 mm), while Dakshin Dinajpur has a scorching climate (annual rainfall 1000–1500 mm). Apart from this, both the districts are well connected through roadways and railways with the entire state.

3 Why Crop Diversification?

Crop diversification simply means an addition of a new crop or adoption of a new cropping system on a particular farm taking into consideration the increase in production and output return from value-added crops along with the use of HYV seeds. It is an important tool for the growth of farm output which ultimately leads to the economic growth of the farming community. Crop diversification can lead to an increase in the productivity of land, provides the opportunity to raise several crops in the same land at a time, which makes farmers self-dependent and the income of small farm holders withstands the price fluctuations. It can also mitigate the effect of increasing climatic uncertainty. A diversified cropping system could balance the increasing food demand, thus sustaining food security. It reduces the dependency on off-farm inputs and minimises the risk of environmental pollution. Through the techniques of crop rotation, a check on the weed problems can be imposed which could ultimately lead to a decrease in insects and pests in the farms. Thus, the overall resilience of agricultural sustenance can better be governed by crop diversification.

4 Objectives

Hence, keeping in mind the significance of crop diversification the following objectives have been formed for the present study:

1. To outline the extent of crop diversification at the block level in both districts.
2. To analyse the relation between crop diversification and crop production in the study areas.

5 Database and Methodology

This study is entirely based on secondary sources of data collected from the Statistical Handbooks of Uttar and Dakshin Dinajpur districts for the years 2000–2001 and 2014–2015. The data has been obtained from the Bureau of Applied Economics & Statistics, Government of West Bengal. Simple statistical techniques and tools have been used for the analysis of data. Besides, the author has purposively used Gibbs-Martin's (1962) technique for the delineation of crop diversification regions of both districts. The formula for the index of crop diversification is as follows:

X is the percentage of total cropped area under an individual crop. The magnitude of the crop diversification obtained by applying this formula ranges from 0.1 to 1.0. Whereas, the index value is positively related to the magnitude of crop diversification i.e., higher the index means higher the magnitude of diversification and vice-versa.

The calculated index value of crop diversification of different blocks (2000–2001 and 2014–2015) has been categorised into three classes, viz. high, medium and low crop diversification regions. The results are being represented graphically with the help of colourful choropleth maps prepared on QGIS 2.14 software. Apart from this, the production of major crops has also been obtained from the District Statistical Handbooks of both the districts for the two time periods. The production of crops for each block of both districts is measured in tonnes. The change in production is represented by bar diagrams to have a better understanding of the growth of each crop in comparison.

6 Extent of Crop Diversification (2000–2001 and 2014–2015)

A spatio-temporal change of crop diversification indicates changes in the cropped area with respect to different crops (Bisai et al., 2016). Here an attempt is made to identify the changes in crop diversification regions during the period 2000–2001 and 2014–2015. The investigation reveals that there are some blocks where change is significant, while in some other blocks of the districts the change is insignificant or negligible. In some blocks, the physio-climatic conditions have put the limit on the diversification of crops and thus influencing agricultural productivity. Rice is the principal crop in all the blocks, besides numerous other crops are also being cultivated by the farmers including wheat, jute, potato and maize.

It is evident from Table 1 that both the districts have witnessed blooming diversification across the blocks during the study period. However, it is worth mentioning here that the blocks that are nearer to the sub-divisional towns have exerted rapid change in the diversification pattern, which can be visible in Figs. 2 and 3. The crop diversification index of Uttar and Dakshin Dinajpur districts has increased from 0.55 and 0.36 in 2000–2001 to 0.62 and 0.43 in 2014–2015 respectively. The Gibbs-Martin index of crop diversification has come out with three classifications of crop diversification regions in the study areas, as follows;

Table 1 Production of Major crops in Uttar Dinajpur and Dakshin Dinajpur districts, 2000–2001 to 2014–2015. (Production in Thousand tonnes)

Crops	Symbol	Uttar Dinajpur			Dakshin Dinajpur		
		2000–2001	2014–2015	Change	2000–2001	2014–2015	Change
Rice	R	628.6	599.9	−28.7	467.3	520.8	53.5
Wheat	W	86.2	89.6	3.4	25.2	41.4	16.2
Maize	M	0.1	333.1	333	0.05	7.5	7.45
Masur & gram	MG	0.8	0.1	−0.7	0.1	0.05	−0.05
Rapeseed & Mustard	RM	27	43.9	16.9	20.8	26.4	5.6
Jute	J	457.5	827.2	369.7	146.1	280.1	134
Sugarcane	S	28.7	45.5	16.8	NA	NA	00
Potato	P	133.4	222.2	88.8	87.8	123.3	35.5
Tea	T	0.01	1	0.99	NA	NA	00
Chillies (dry)	C	2.3	7.9	−5.6	1.3	3.3	−2

Source: Statistical Handbook of Uttar Dinajpur and Dakshin Dinajpur districts (2000–2001 and 2014–2015)

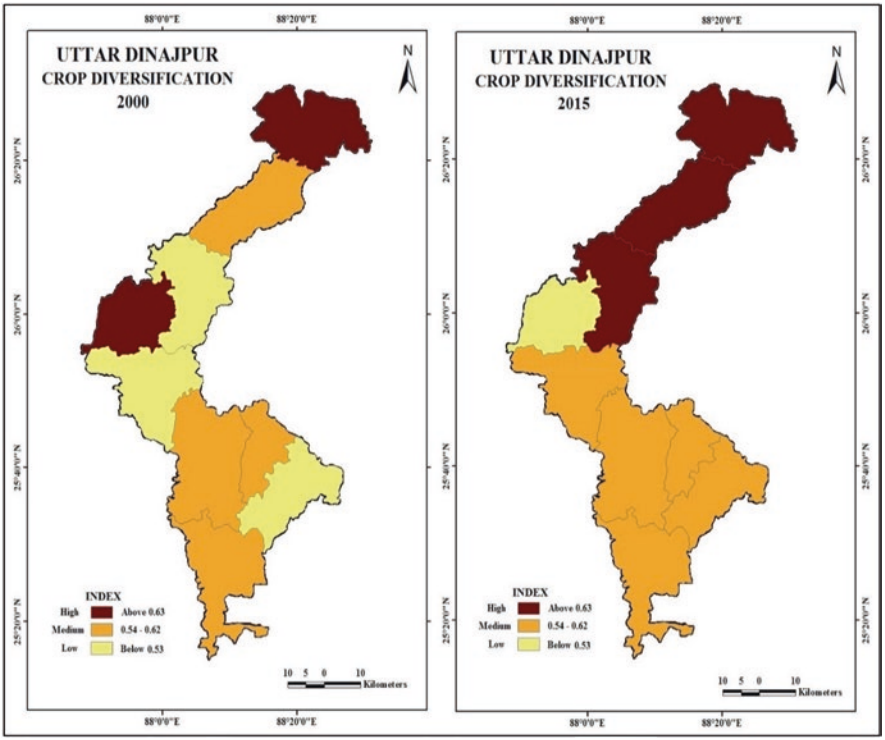


Fig. 2 Crop diversification during 2002–2015 in Uttar Dinajpur

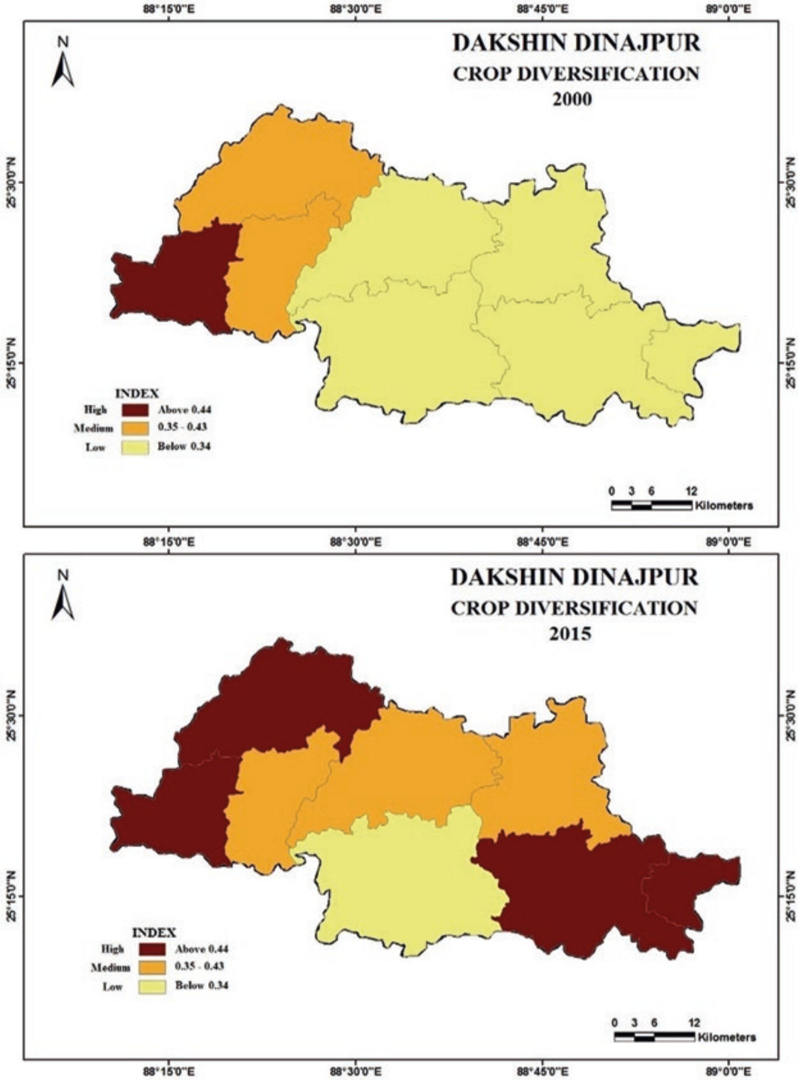


Fig. 3 Crop diversification during 2002–2015 in Dakshin Dinajpur

6.1 *High Crop Diversification Region*

Out of the total nine blocks of Uttar Dinajpur district, two blocks came under the category of high crop diversification in the year 2000–2001. Chopra block with a crop diversification index (ICD) of 0.67 had a significant region of 5 to 6 crops such as rice, jute, wheat, till, potato and linseed. The other block i.e., Goalpokhar-II recorded 0.63 ICD and also cultivated crops like rice, jute, wheat, mustard, potato, maskalai and linseed. In 2015, as many as 8–9 crops are being cultivated in high crop diversification regions. Presently, out of the nine blocks, three come under the high category namely, Islampur, Goalpokhar-I and Chopra. Islampur block with ICD 0.70 and Goalpokhar-I block with ICD 0.68, has a significant region of rice, jute, mustard, potato, wheat, maize, till, and maskalai. While in Chopra block (ICD 0.64), the cultivation of various crops like rice, wheat, jute and potato is being done as before, but the area for these crops has decreased and the area of few cash crops such as maize, tea and pineapple has increased significantly.

On the other hand, in Dakshin Dinajpur district, out of the total eight blocks, only one block came under high crop diversification region in the year 2000–2001 i.e., Harirampur (ICD 0.59), which has a significant region of rice, mustard, wheat, jute, potato and masur. In 2014–2015, the number of blocks under high crop diversification has increased to four blocks i.e.; Kushmandi (0.54), Harirampur (0.51), Balurghat (0.47) and Hili (0.45) with significant crops like rice, mustard, jute, wheat, potato and maskalai.

The sub-divisional towns in both the districts are exerting diversified cropping patterns due to accessibility of modern amenities, irrigation facilities and increasing demand of varying ranges of food products in the market.

6.2 Medium Crop Diversification Region

In 2000–2001, four out of nine blocks of Uttar Dinajpur came under medium crop diversity region namely, Islampur (0.61), Itahar (0.59), Raiganj (0.57) and Hemtabad (0.55). In these blocks, moderate crop diversification prevailed with 4–5 major crops being cultivated such as rice, wheat, jute, mustard, gram and potato. While in the year 2014–2015, the number of blocks under this category has increased to six blocks, namely Hemtabad (0.62), Kaliaganj (0.62), Itahar (0.60), Raiganj (0.58), Goalpokhar-II (0.56) and Karandighi (0.57). It is a sign that the district is moving gradually towards crop diversification by opting for more than 6 to 8 crops being cultivated instead of the traditional single- or double-crop dominance.

On the other hand, in Dakshin Dinajpur district the number of blocks under medium crop diversification region has increased from two blocks i.e., Banshihari (0.42) and Kushmandi (0.40) in 2000–2001 to three blocks out of eight in 2014–2015 i.e., Gangarampur (0.44), Kumarganj (0.38) and Banshihari (0.35). All these blocks are moving steadily towards diversification with cultivating crops like rice, mustard, jute, wheat, potato, maskalai and masur. Thus, the trend of diversification is visible too in Dakshin Dinajpur district.

6.3 Low Crop Diversification Region

There were three blocks of Uttar Dinajpur district that came under low crop diversification region in the year 2000–2001 namely, Goalpokhar-I (0.51), Karandighi (0.28) and Kaliaganj (0.39). Among them Kaliaganj has the lowest ICD, thus it can be said that this block has practised a single or double cropping system of traditional crops like rice, jute and wheat. But in 2014–2015, there is no such block that comes under this category, which means that the district is completely devoid of a mono-cropping system and it is a positive sign for crop diversification.

In Dakshin Dinajpur district, earlier there were five blocks under low crop diversification region namely, Kumarganj (0.34), Tapan (0.33), Balurghat (0.31), Hili (0.27) and Gangarampur (0.23). In all these blocks there was a dominance of mono-cropping or double cropping in 2000–2001. But in 2014–2015, only one block i.e., Tapan (0.25) came under the low crop diversification region with the cultivation of 2 to 3 crops like rice, mustard and jute only. In this block, rice occupies as much as 74.8% of the gross cropped area. It means there is a single cropping system in the block and it seems that this block is moving towards crop specialization rather than diversification.

7 Spatial Analysis of Crop Diversification (2000–2001 to 2014–2015)

From the foregoing discussion, we came to know that there exists a trend of gradual shifting towards diversification in both districts. More precisely speaking, the nature of crop cultivation in both the districts is quite similar, but the only difference is that while in Uttar Dinajpur farmers are opting for food crops such as maize and cash crops like sugarcane, tea, potato and chillies, in Dakshin Dinajpur pulses such as masur, maskalai and gram and oilseeds are preferred by the farmers. Moreover, in both the districts high crop diversification regions include the cultivation of more than six to seven crops. In Uttar Dinajpur district the pace of moving towards diversification is comparatively slower than Dakshin Dinajpur as evident from Figs. 2 and 3 i.e., in the last 14 years the number of blocks under the high crop diversification category increased from two to three in Uttar Dinajpur, while in Dakshin Dinajpur the number of blocks under high crop diversification category has increased from one to four. Overall, the degree of diversification in Uttar Dinajpur district is comparatively high as all the blocks of the district fall under the high and medium category and there is no block under the low crop diversification category.

8 Status of Crop Production (2000–2001 to 2014–2015)

There has been a significant change in the agrarian situation of West Bengal during the last 50 years, especially on account of the land reform programme, popularly known as ‘operation barga’, which was successfully implemented around the 1970s under the communist regime. Owing to this policy, the surplus agricultural lands of the *Jamindars* (big land-lords), were reconsolidated among the land-less labourers by the Government. Since then, the production and productivity of major crops were increased significantly in the state. In general, the agricultural population of the state is generally dominated by marginal and small farmers, which constitutes about 85–90% of the total farmers. These small and marginal farmers have no choice except to raise a variety of crops from the same land, so as to minimise the risk of crop failure. The study on the behaviour of farmers to choose a certain crop suggests that the farmers are taking up agriculture alternatively. They are choosing diversification of crops, integrated farming system and modern hybrid seeds to have more remuneration, better input use efficiency and less risk involvement.

The cropping pattern of the state, as well as the individual districts, is dominated by foodgrain crops. Thus, for estimating the agricultural production in Uttar and Dakshin Dinajpur districts, the major food crops such as rice, wheat, pulses and other cash crops such as jute, maize, sugarcane, potato and tea have been taken into account. The crop-wise data reveals that except rice and masur, the production of almost all the other crops has increased significantly from 2000–2001 to 2014–2015 in Uttar Dinajpur districts (Figs. 4 and Fig. 5). In Dakshin Dinajpur district, the production of rice has increased from 467.3 thousand tonnes to 520.8 thousand tonnes in the last 14 years (Fig. 4). The production of maize has drastically increased manifolds in Uttar Dinajpur from 0.1 to 333.1 thousand tonnes with a rate of 78.4%, while in Dakshin Dinajpur the rate of maize production was quite lower i.e., 43%. The production of mustard has increased from 27 thousand tonnes and 20.8 thousand tonnes in 2000–2001 to 43.9 thousand tonnes and 26.4 thousand tonnes in 2014–2015 in Uttar and Dakshin Dinajpur respectively (Table 1 and Fig. 6). The production of jute and dry chillies has also increased positively in subsequent years in both districts.

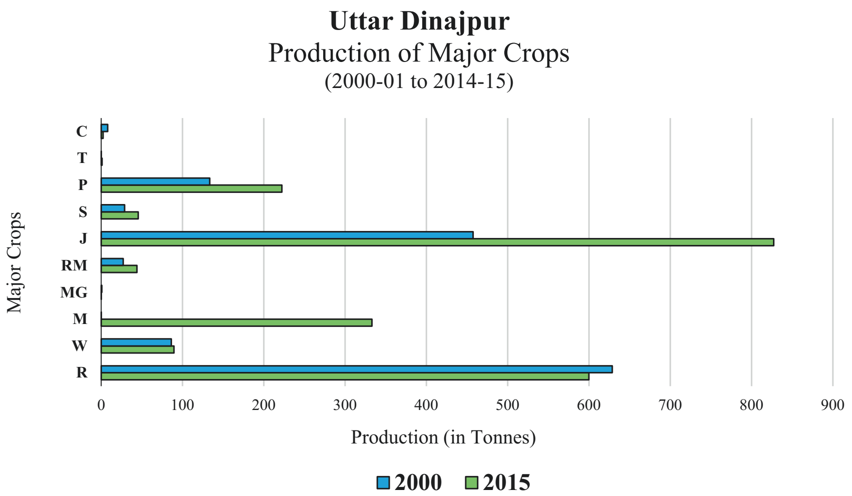


Fig. 4 Production of major crops in Uttar Dinajpur

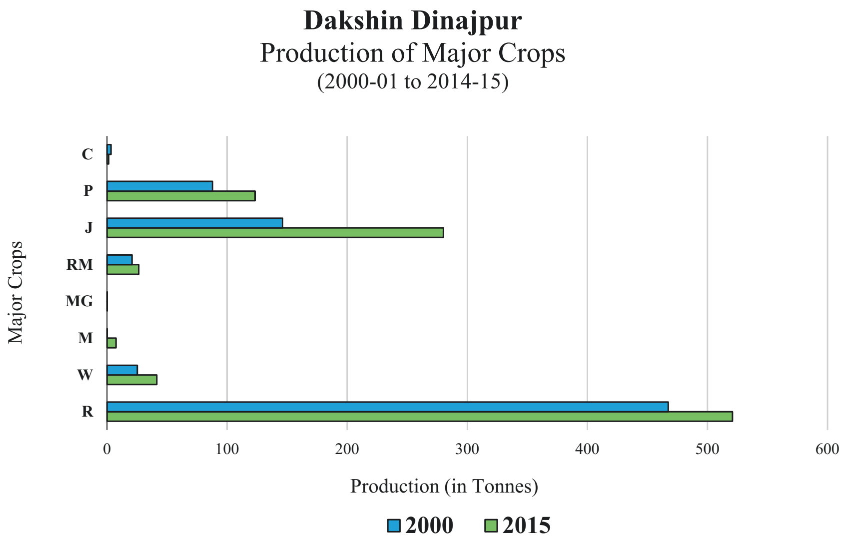
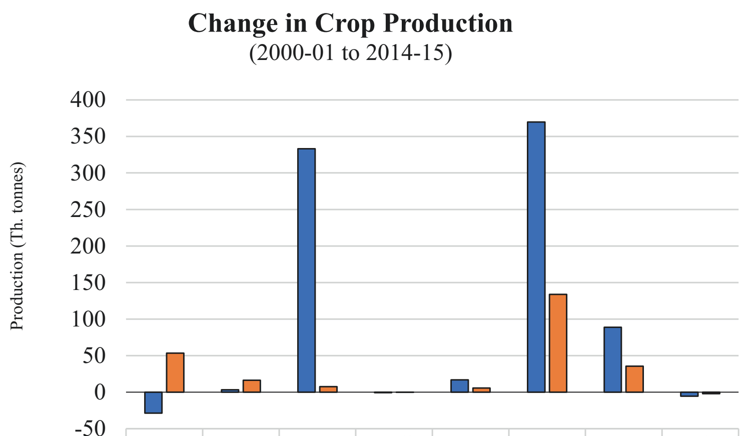


Fig. 5 Production of major crops in Dakshin Dinajpur



	R	W	M	MG	RM	J	P	C
Uttar Dinajpur	-28.7	3.4	333	-0.7	16.9	369.7	88.8	-5.6
Dakshin Dinajpur	53.5	16.2	7.45	-0.05	5.6	134	35.5	-2

Major Crops

Fig. 6 Changes in crop production in both selected study area

The major difference that can be sought from the comparative analysis is that Uttar Dinajpur districts are moving towards more remunerative cash crops and therefore the production of cash crops in the district has boosted tremendously, while the production of cereals or food crops has experienced sluggish growth. On the other hand, the district of Dakshin Dinajpur has opted for growing the traditional crops to fulfil the local demand of food crops and oilseeds by using modern hybrid seeds and therefore the production of cereals as well as food crops like potato has increased significantly in the district.

9 Crop Diversification and Production Growth

A keen observation of the block-wise data of crop diversification and crop production, reveals that the blocks in which the Index of Crop Diversification (ICD) has increased during 2000–2001 and 2014–2015, the production of crops has also increased and vice-versa. For example, in Uttar Dinajpur district the ICD value of seven blocks (Islampur, Goalpokhar-I, Karandighi, Raiganj, Kaliaganj and Itahar) has increased during the study period, except Chopra block. As a result, the production of crops in almost all the seven blocks has increased for the majority of the crops. For instance, in Goalpokhar-I block the ICD has increased from 0.51 in 2000–2001 to 0.68 in 2014–2015, simultaneously the production has increased for rice (from 57.7 thousand tonnes to 105.9 thousand tonnes), wheat (from 8.3 thousand tonnes to 9.9 thousand tonnes), potato (from 12.9 thousand tonnes to 32.7 thousand tonnes), masur (from 5 tonnes to 18 tonnes), maskalai (from 60 tonnes to 322 tonnes), mustard (from 2.8 thousand tonnes to 3 thousand tonnes) and jute (from 42.5 thousand tonnes to 79.4 thousand tonnes). While in Chopra block the ICD has decreased from 0.67 in 2000–2001 to 0.64 in 2014–2015, simultaneously the production has decreased for rice (from 45.9 thousand tonnes to 44 thousand tonnes), wheat (from 9.2 thousand tonnes to 7.7 thousand tonnes), potato (from 31.8 thousand tonnes to 24.7 thousand tonnes) and jute (from 66.1 thousand tonnes to 50.8 thousand tonnes) during the period from 2000–2001 to 2014–2015 (Figs. 7 and 8). However, it is worth mentioning here that the Chopra block of Uttar Dinajpur has rapidly moved towards the specialised cultivation of tea and pineapple, which can be seen as the main cause of this fall in the production of food crops.

Similarly, in the Dakshin Dinajpur district, the ICD value of five blocks (Kushmandi, Gangarampur, Kumarganj, Balurghat and Hili) has increased from 2000–2001 to 2014–2015. While the ICD of Harirampur, Banshihari and Tapan has decreased during the study period. Here also, the production of major crops has increased in those blocks whose ICD has increased, while the production of most of the crops like rice, masur, maskalai, gram and jute has decreased in those blocks whose ICD has decreased. Banshihari block, the ICD has been found to be decreased from 0.42 in 2000–2001 to 0.35 in 2014–2015, simultaneously the production has also decreased for rice (from 45.7 thousand tonnes to 37.9 thousand tonnes), potato (from 6.8 thousand tonnes to 6.5 thousand tonnes), masur, maskali and gram became

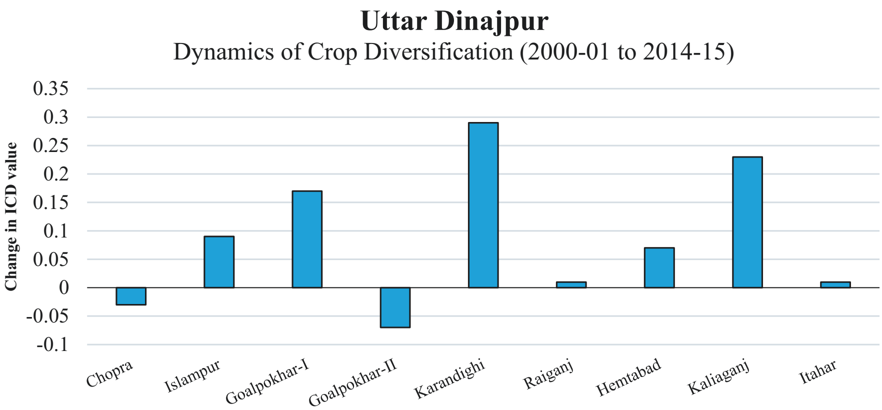
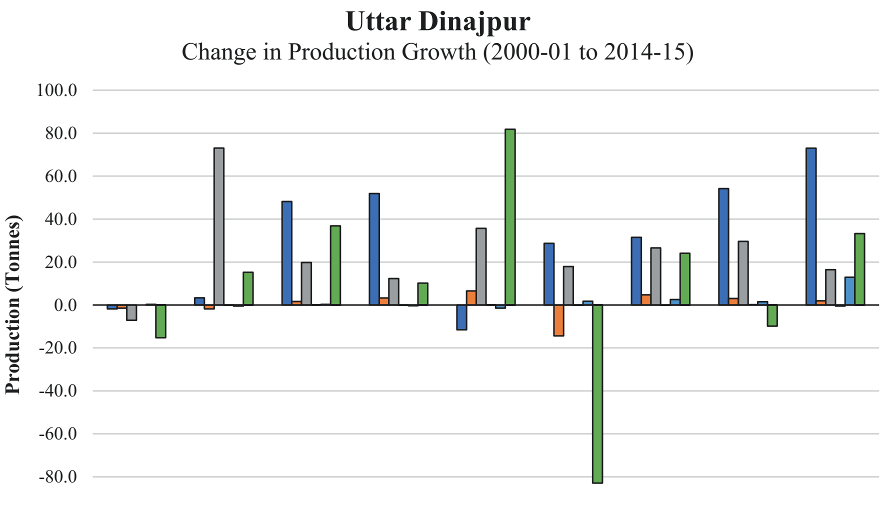


Fig. 7 Dynamics of crop diversification during 2002–2015 in Uttar Dinajpur



	Chopra	Islampur	Goalpokhar-I	Goalpokhar-II	Karandighi	Raiganj	Hemtabad	Kaliaganj	Itahar
Rice	-1.86	3.30	48.20	51.88	-11.52	28.69	31.49	54.20	73.04
Wheat	-1.46	-1.82	1.64	3.23	6.53	-14.40	4.74	3.00	1.93
Potato	-7.11	73.06	19.81	12.35	35.67	17.94	26.57	29.62	16.44
Masur	0.00	-0.01	0.01	-0.01	0.04	-0.05	-0.01	0.15	-0.51
Mustard	0.25	-0.50	0.25	-0.36	-1.49	1.77	2.54	1.54	12.89
Jute	-15.25	15.22	36.83	10.22	81.83	-82.94	24.12	-9.82	33.21

Fig. 8 Changes in crop production growth in in Uttar Dinajpur

nil and jute (from 18.6 thousand tonnes to 16 thousand tonnes). While the ICD value of Gangarampur has increased from 0.23 in 2000–2001 to 2014–2015, simultaneously the production has increased for rice (from 50.7 thousand tonnes to 83 thousand tonnes), wheat (from 2.7 thousand tonnes to 3.2 thousand tonnes), potato (from 2.2 thousand tonnes to 40.1 thousand tonnes), masur (from 5 tonnes to 160 tonnes), maskalai (from 10 tonnes to 137 tonnes) and jute (from 23.2 thousand tonnes to 45 thousand tonnes) (Figs. 9 and 10).

Hence, among the different strategies and technologies, crop diversification and inclusion of new hybrid varieties of seeds are the prioritised technologies to increase production, stabilise the farm income and maximise profitability. Introducing a greater variety of crops in a particular agro-system may provide better agricultural

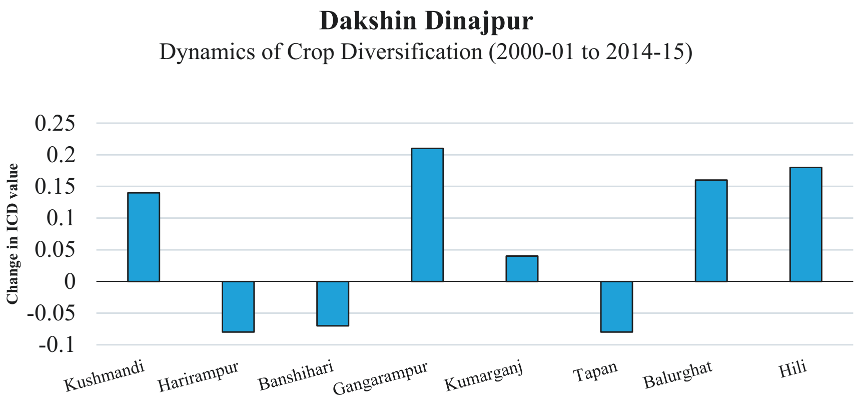
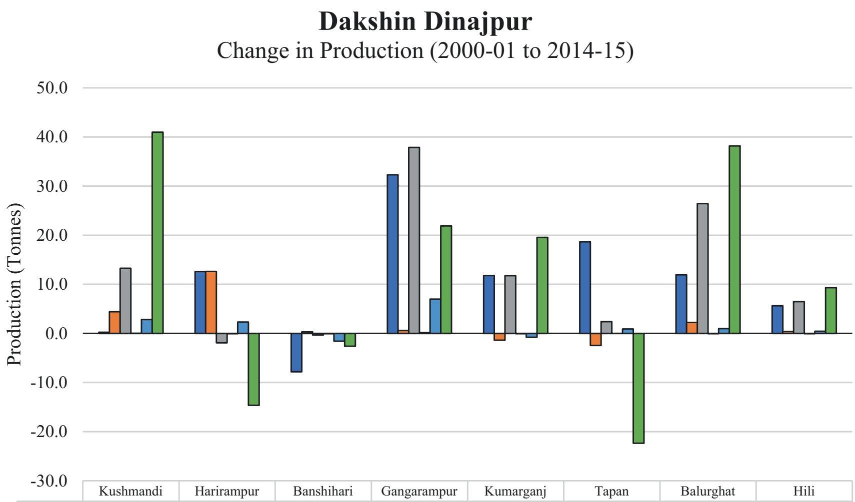


Fig. 9 Dynamics of crop diversification during 2002–2015 in Dakshin Dinajpur



	Kushmandi	Harirampur	Banshihari	Gangarampur	Kumarganj	Tapan	Balurghat	Hili
Rice	0.228	12.614	-7.818	32.305	11.802	18.649	11.935	5.62
Wheat	4.423	12.626	0.313	0.586	-1.382	-2.436	2.238	0.411
Potato	13.255	-1.91	-0.322	37.873	11.757	2.386	26.428	6.449
Masur	0.038	-0.005	-0.005	0.155	-0.005	0.001	-0.005	-0.005
Mustard	2.841	2.298	-1.573	6.996	-0.79	0.914	0.976	0.451
Jute	40.959	-14.637	-2.608	21.873	19.567	-22.368	38.182	9.317

Fig. 10 Changes in crop production growth in in Dakshin Dinajpur

output that can lead to a balanced natural bio-diversity, equilibrium in the ecosystem and ability to tackle the underlying stress (Khanam et al., 2018).

10 Conclusion

About 64% area of Uttar Dinajpur was under high and moderate crop diversification in 2000–2001, which has increased to 82.4% in 2014–2015 and about 33% area was under specialised traditional mono-cropping in 2000–2001 which is now completely absent. It means this district is now completely under a diversified cropping pattern. On the other hand, in Dakshin Dinajpur district about 44.5% area was under high and moderate crop diversification in 2000–2001, which has now increased to about 73.7% in 2014–2015. However, the traditional mono-cropping area has drastically decreased from 66.8% in 2000–2001 to 20% in 2014–2015. The change under high diversification area for Uttar Dinajpur was 10.5%, while the change for Dakshin Dinajpur was 27.5%. In both cases, the blocks which are nearer to the sub-divisional towns or urban areas are experiencing diversified cropping pattern due to the accessibility and availability of irrigation and infrastructural facilities entertaining multiple cropping systems (District Statistical Handbook, 2000).

Diversification of crops from traditional cereals to cash crops can improve the economic condition of the farmers in both the districts and they may become self-reliant in terms of food production. It can also manage price risk, on the assumption that not all products will suffer low market prices at the same time and increase the profitability of the farming community. Special attention should be given to the least diversified block of Tapan in Dakshin Dinajpur district for improvement of soil characteristics as the block has lateritic soil which is not favourable for crop cultivation, from the above analysis it has been reported that both the said districts are doing well in terms of agriculture practising a more diverse cropping system with due course of time and the production of several crops grown at a faster rate which can be seen as a major influencing factor for sustainable agriculture and the future of these two districts is bright concerning to minimising the regional disparities in agriculture and the overall agricultural growth.

Appendixes

Appendix A: Block-Wise Index of Crop Diversification (ICD) and Production of Major Crops in Uttar Dinajpur District, 2000–2001

Blocks	ICD	Rice		Wheat	Potato	Masur	Maskalai	Khesari	Till	Mustard	Linseed	Gram	Jute
Chopra	0.67	A	24,760	4730	1750	NA	100	NA	3840	390	1570	NA	12,780
		P	44,090	9250	31,820	NA	40	NA	1850	320	350	NA	66,100
Islampur	0.61	A	23,965	3120	950	5	130	5	2080	2580	240	20	8230
		P	48,365	5740	23,390	5	60	5	1260	2230	60	10	53,710
Goalpokhar-I	0.51	A	30,095	4290	570	5	150	NA	1020	3510	5	NA	4700
		P	57,705	8300	12,950	5	60	NA	720	2840	5	NA	42,580
Goalpokhar-II	0.63	A	19,945	3730	1020	30	820	NA	80	3310	350	70	5770
		P	48,625	7990	22,990	10	340	NA	30	2430	110	30	47,920
Karandighi	0.28	A	49,445	1940	110	50	NA	NA	NA	5140	80	NA	2030
		P	128,235	5050	2090	40	NA	NA	NA	4530	20	NA	19,910
Raiganj	0.57	A	45,210	6880	280	210	70	90	NA	8860	520	240	10,100
		P	123,470	21,160	6990	210	40	100	NA	6460	270	110	97,600
Hemtabad	0.55	A	17,965	4420	480	130	280	5	NA	2100	170	70	2430
		P	42,135	9640	7570	60	340	5	NA	1580	70	30	21,620
Kaliaganj	0.39	A	34,520	2700	350	50	20	5	NA	2940	150	50	3950
		P	53,700	4580	5930	20	10	5	NA	1740	40	20	25,860
Itahar	0.59	A	37,340	5700	1230	1190	60	5	NA	5500	5	1240	9010
		P	82,290	14,530	19,640	530	20	5	NA	4890	5	570	82,170

A Area (in Hectare), *P* Production (in Tonnes)

Source: ICD Calculated by the researcher on the basis of Gibbs-Martin Index from Statistical Handbook of Uttar Dinajpur, 2000–2001

Appendix B: Block-Wise Index of Crop Diversification (ICD) and Production of Major Crops in Uttar Dinajpur District, 2014–2015

Blocks	ICD	Rice		Wheat	Potato	Masur	Maskalai	Till	Mustard	Gram	Jute	Maize	Sugarcane
Chopra	0.64	A	11,891	3067	684	NA	24	341	916	NA	3806	682	NA
		P	45,946	7788	24,709	NA	17	245	574	NA	50,848	1193	NA
Islampur	0.70	A	15,935	2260	2730	NA	45	338	4177	20	4885	1603	NA
		P	51,669	3921	96,453	NA	33	193	1728	19	68,927	4077	NA
Goalpokhar-I	0.68	A	25,667	5380	1480	24	446	412	6296	NA	5351	4456	2
		P	105,901	9938	32,756	18	322	236	3089	NA	79,409	11,334	214
Goalpokhar-II	0.56	A	21,618	5109	859	NA	NA	NA	3612	NA	3126	NA	NA
		P	100,505	11,216	35,335	NA	NA	NA	2072	NA	58,144	NA	NA
Karandighi	0.57	A	32,709	5999	1564	105	47	24	4004	NA	6530	955	183
		P	116,715	11,580	37,755	81	34	15	3043	NA	101,737	2429	19,584
Raiganj	0.58	A	34,025	3413	1076	240	64	NA	7771	NA	7614	896	240
		P	152,157	6761	24,926	164	46	NA	8228	NA	14,657	2279	25,683
Hemtabad	0.62	A	15,766	4585	1001	57	183	72	3296	32	2606	NA	NA
		P	73,623	14,382	34,143	55	190	44	4121	30	45,735	NA	NA
Kaliaganj	0.62	A	25,317	2970	1442	203	439	NA	4169	NA	9897	682	NA
		P	107,899	7576	35,552	169	267	NA	3276	NA	16,043	1735	NA
Itahar	0.60	A	35,487	5729	857	37	15	NA	13,031	NA	6511	NA	NA
		P	155,330	16,462	36,083	25	7	NA	17,779	NA	115,375	NA	NA

A Area (in Hectare), *P* Production (in Tonnes)
Source: ICD calculated by the researcher on the basis of Gibbs-Martin Index from Statistical Handbook of Uttar Dinajpur, 2014–2015

Appendix C: Block-Wise Index of Crop Diversification (ICD) and Production of Major Crops in Dakshin Dinajpur District, 2000–2001

Blocks	ICD	Rice		Wheat	Potato	Masur	Maskalai	Mustard	Linseed	Gram	Jute
Kushmandi	0.40	A	34,450	2240	990	60	760	4460	60	30	2170
		P	67,990	4850	17,150	20	460	2570	10	10	16,950
Harirampur	0.59	A	9300	1250	590	5	5	2440	NA	5	1940
		P	26,240	3290	8710	5	5	1500	NA	5	23,220
Banshihari	0.42	A	21,700	940	500	5	40	3570	NA	NA	2250
		P	45,780	2290	6850	5	20	2530	NA	NA	18,650
Gangarampur	0.23	A	28,620	1040	160	5	10	1140	5	5	1800
		P	50,790	2700	2240	5	10	870	5	5	23,220
Kumarganj	0.34	A	28,060	1290	470	10	5	2390	10	5	2690
		P	51,570	3720	7610	5	5	1960	5	5	28,880
Tapan	0.33	A	44,320	1410	430	5	10	5810	NA	5	2850
		P	94,460	4000	6280	5	10	5260	NA	5	38,400
Balurghat	0.31	A	36,370	1080	1320	10	100	2210	5	NA	2930
		P	71,330	2770	15,170	5	60	1990	5	NA	28,010
Hili	0.27	A	8260	280	230	5	5	360	5	NA	530
		P	17,230	620	3110	5	5	390	5	NA	5200

A Area (in Hectare), *P* Production (in Tonnes)
Source: ICD calculated by the researcher on the basis of Gibbs-Martin Index from Statistical Handbook of Dakshin Dinajpur, 2000–2001

Appendix D: Block-Wise Index of Crop Diversification (ICD) and Production of Major Crops in Dakshin Dinajpur District, 2014–2015

Blocks	ICD	Rice		Wheat	Potato	Masur	Maskalai	Mustard	Gram	Jute	Maize
Kushmandi	0.54	A	23,738	2398	905	75	NA	5181	NA	3980	42
		P	68,218	9273	30,405	58	NA	5411	NA	57,909	102
Harirampur	0.51	A	16,241	4215	220	NA	NA	2939	NA	632	NA
		P	38,854	15,916	6800	NA	NA	3798	NA	8583	NA
Banshihari	0.35	A	15,885	988	190	NA	NA	1685	NA	1165	NA
		P	37,962	2603	6528	NA	NA	957	NA	16,042	NA
Gangarampur	0.44	A	28,025	1081	1392	187	306	4893	NA	2479	NA
		P	83,095	3286	40,113	160	137	7866	NA	45,093	NA
Kumarganj	0.38	A	23,497	825	550	NA	157	1975	11	3150	130
		P	63,372	2338	19,367	NA	62	1170	15	48,447	317

Blocks	ICD	Rice		Wheat	Potato	Masur	Maskalai	Mustard	Gram	Jute	Maize
Tapan	0.25	A	37,835	542	271	12	NA	4363	NA	956	NA
		P	113,109	1564	8666	6	NA	6174	NA	16,032	NA
Balurghat	0.47	A	28,627	1849	1662	NA	250	2910	NA	4762	NA
		P	83,265	5008	41,598	NA	143	2966	NA	66,192	NA
Hili	0.45	A	7528	394	411	NA	NA	865	NA	1144	NA
		P	22,850	1031	9559	NA	NA	841	NA	14,517	NA

A Area (in Hectare), *P* Production (in Tonnes)
Source: ICD calculated by the researcher on the basis of Gibbs-Martin Index from Statistical Handbook of Dakshin Dinajpur, 2014–2015

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Part II
Water, Environment and Agriculture Sustainability

Spatio-Temporal Analysis of Built-Up Area Expansion on Agricultural Land in Mousuni Island of Indian Sundarban Region

Sabir Hossain Molla and Rukhsana

Abstract Mousuni Island is experiencing rapid population growth with the encroachment of agricultural land, which threatens the dominant agricultural activities that are the main sources of livelihood of the islanders. Therefore, the study was conducted to quantify the nexus between built-up growth and agricultural land conversion for the period 2000–2020. Geographic Information System and Random Forest (RF) classification technique were used to classify Landsat TM of 2000 and Landsat OLI of 2020 images of the island and produced land use/land cover (LULC) classes. The analysis revealed that during the past 20 years the built-up land increased by 168.43% from the early (223.20 ha) built-up area in 2000. The newly formed built-up area exhibited 13.15% (375.93 ha) of the total island of which 10.91% (312 ha) came from expanses of agricultural land and 3% (64 ha) came from other categories. It is concluded that the built-up expansions were predominantly on agricultural lands where 15.6 ha/year of agricultural lands were eliminated. These abrupt rates of losing agricultural lands are alarming and require adopting appropriate strategies for sustainable land use in this area.

Keywords Land use/land cover · Geospatial · Agricultural land loss · Built-up expansion · Mousuni Island

1 Introduction

Land cover is rapidly changing worldwide (Pechanec et al., 2018) and has become an important topic in environmental change assessments and sustainable development planning (Theobald & Hobbs, 2002; Maestas et al., 2003; Roy et al., 2014; Romano et al., 2018). Rapid land use/land cover changes (LUCCs) have had strong effects on natural and human environments (Xian et al., 2007). On a global scale, population growth is cited as one of the reasons for LUCCs (Muñoz-Rojas et al.,

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2011). Despite geophysical difficulties and the fact that 56% of the population is landless, agriculture is basis of the Sundarbans' economy. According to West Bengal Land Reforms Act of 1971 the average landholding size of a marginal and small farmer in West Bengal is only 0.41 ha and 1.49 ha, respectively, and even if all of the land on Mousuni Island were distributed equally, each family would own only 0.72 ha (Agriculture Department of West Bengal, 2006). The island has registered 16% land loss during the 1968/69–2012 period (Samanta et al., 2017) whereas over nearly the same time frame the population of this Island has increased by almost 265% (Danda, 2007). As the population grows, so does the demand for housing, infrastructure, roadways, and other business needs (Al-Kofahi et al., 2018), and such requirements will result in the loss of arable land. (Yar & Huafu, 2019). Once converted, agricultural land is lost permanently (Yar & Huafu, 2019), and it not only has a detrimental influence on agricultural output but also has massive environmental, ecological, and social ramifications (Haregeweyn et al., 2012). Furthermore, the high degree of impermeable surfaces can be attributed to the rising trend of developed environment at the expense of food basket land (Turok & Mykhnenko, 2007; Prokop et al., 2011). As a result, there is a growing need for local planning authorities to improve land conversion monitoring and agricultural land protection. (Li & Yeh, 2001; Gravert & Wiechmann, 2016).

This study uses remotely sensed data and a GIS environment to examine the spatiotemporal built-up expansion and its impact on agricultural land on Mousuni Island in the Indian Sundarban region. Remote sensing (RS) and Geographic Information Systems (GIS) are reliable, practical, and effective techniques for assessing the temporal and geographical dynamics of land use/land cover (LULC) change, analyzing and mapping these dynamics, and providing historical data for environmental monitoring (Lambin et al., 2001; Wu et al., 2015; Bakr et al., 2010). Additionally, remotely sensed data such as Landsat imagery are publicly available online and cover nearly the whole globe, allowing for continuous land cover change monitoring since 1972 (USGS, 2013). On the other hand, GIS are particularly well suited for computer-based study of geometric forms of a specific land use, such as compactness and contiguity. Both disciplines can benefit from each other when they are combined (Abdel Rahman et al., 2016).

Many academics have tackled the issue of accurately monitoring land cover and land use change in a number of contexts (Singh, 1989; Muchoney & Haack, 1994; El Bastawesy et al., 2008; Almutairi & Warner, 2010). Using multi-temporal satellite imageries, Yar and Huafu (2019) outline the urban land use pattern in and around Peshawar City, which is rapidly developing with important consequences for peri-urban agricultural land. Al-Kofahi et al. (2018) investigate the spatio-temporal urban expansion on the agricultural lands in Irbid and Amman cities during the period 2003–2015 using GIS and supervised classification technique in ENVI software. Therefore, the objectives of this study were to detect and analyze the spatio-temporal built-up area expansion and determine the agricultural land losses in Mousuni Island during the period 2000–2020 using geospatial techniques. Finally, the findings of this study are critical for planners and decision-makers seeking to prevent future conversion or fragmentation of agricultural land.

2 Study Area and Database

The Mousuni is a homestead island in the Indian Sundarban region located towards the lower part of West Bengal. It is a Gram Panchayat of Namkhana Block in Kakdwip subdivision of South 24 Parganas District, which is divided into four revenue mouzas: as Mousuni, Bagdanga, Kusumtala and Baliara. It ranges from 21°36′28″ N to 21°43′ 09″ N latitude and 88° 11′ 21″ E to 88° 13′ 43″ E longitude and covers an area of about 28.59 km^2 (Fig. 1). Physical boundary of the area is demarcated by the Muriganga or Bartala River in the west and northwest, Pitt's Creek in the east and Bay of Bengal in the south (WWF, 2010; Mukherjee & Siddique, 2018). The area is home to 22,073 people and 3340 families (Census, 2011), and the population has risen by about 265% (Danda, 2007). The land use pattern has changed with time as it has been severely subjected to human activities and thier negative effect on mainly agricultural land. The average maximum temperature of the study area is 29.29 °C, and the average minimum temperature is 22.31 °C. The mean monthly precipitation is 151.05 mm while average annual rainfall is 1812.66 mm (IMD, 2018).

This study used materials satellite and ancillary data. Ancillary data included (1) a topographic map (79 C/4) from Survey of India (SOI) at a scale of 1:50,000 for geo-referencing purposes and (2) ground truth data collected using the Global Positioning System (GPS) for image classification and overall accuracy assessment. Landsat satellite images (Landsat 5 TM, path/row 138/045, from year 2000; Landsat 8 OLI, path/row 138/045, from year 2020) were used to analyze the dynamics of

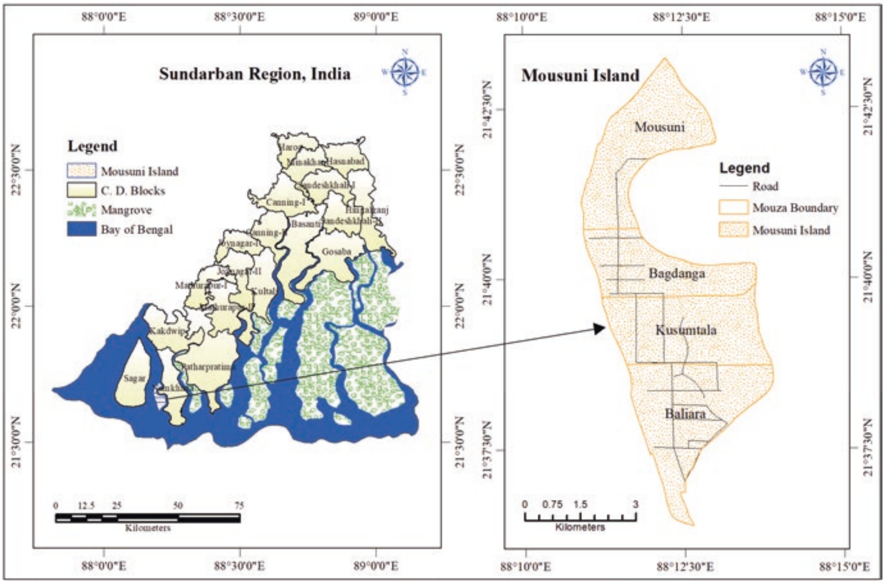

Fig. 1. Geographical location of the study area

land use change over the last 20 years in Mousuni Island, Indian Sundarban region (Table 1). Satellite data were downloaded from the website of USGS Earth Explorer (https://earthexplorer.usgs.gov).

3 Methods

3.1 Pre-processing of Images

Landsat image pre-processing was performed to establish a direct association of biophysical phenomena and the acquired data (Coppin et al., 2004). Preprocessing was implemented with the open-source Quantum Geographic Information System (QGIS) version 3.2.0 and the Semi-Automatic Classification Plugin (SCP) (Congedo, 2016). A total of six bandsets (excluding thermal band) for Landsat 5 TM and 8 bandsets (excluding thermal bands and band 1) for Landsat 8 OLI were combined by merging in the QGIS platform and clipped using the shapefile of Mousuni Island on ArcGIS Environment.

3.2 Image Classification

After successful pre-processing, a training set for image classification was developed using Google Earth historical data, field observation and local knowledge of the study area. Random Forest (RF) technique was used for image classification of all the Landsat images. Random Forest, developed by Breiman (Breiman, 2001), is one of the widely applied powerful ensemble supervised algorithms. The image classification workflow was performed in ArcGIS 10.5 software. For each image classification, a minimum of 240 training samples was selected by drawing polygons around representative classes. Primarily land use/land Cover maps were generated from the Landsat images in six classes including Mangrove, Vegetation, Water body, Mudflats, Agricultural land and Built-up and then finalized to Agricultural land, Built-up and Others categories (Table 2) to fulfill the purpose of the study using Reclassification technique in ArcGIS 10.5.

Table 1 Summary of main metadata of the selected Landsat datasets used in land use classification

Year	Scene ID	Platform sensor	Acquisition date	Path/row	Spatial resolution (m)
2000	LT51380452000314BKT00	Landsat 5 TM	9 November 2000	138/045	30
2020	LC81380452020321LGN00	Landsat 8 OLI	16 November 2020	138/045	30

Table 2 Name of the land use classes with explanations

LULC class	Description
Agricultural land	All cultivated and uncultivated agricultural lands areas in particular farmlands, croplands involving current fallow and horticultural lands.
Built-up	Human habitat, industrial, commercial, transportation, roads and land areas of exposed soil resulting from natural and human activities.
Others	Mangrove (forest/ dense vegetation), vegetation (land with sparse or open trees, scrub, bushes), water body (rivers, lakes, reservoirs, ponds, artificial water bodies) and mudflats (tidal flats or coastal wetlands).

3.3 Accuracy Assessment

The accuracy assessment of land use classes is a critical component in understanding categorization errors and their consequences for further analysis. To assess the accuracy, statistical parameters such as overall accuracy (O_A), kappa coefficient (k), user (U_A) and producer accuracies (P_A) were computed using 120 equalized stratified random sampled ground truth points (40 points per class) for both years (Brennan & Prediger, 1981; Fitzpatrick-Lins, 1981; Congalton & Green, 2002) (Eqs. 1 and 2).

$$\textbf{Kappa Statistics}\left(k\right)=\frac{N\sum_{i=1}^{n}m_{ii}-\sum_{i=1}^{n}G_iC_i}{N^2-\sum_{i=1}^{n}G_iC_i} \tag{1}$$

$$\textbf{Overall Accuracy}\left(\textbf{OA}\right)=\frac{\sum_{i=1}^{n}m_{ii}}{N} \tag{2}$$

where m_{ii} represents the number of samples classified into clusters I ($i = 1, 2,\ldots, n$); G_i signifies overall classification in category I; C_i denotes the overall reference data and N signifies the total number of samples for all categories.

3.4 Spatial Dynamics, Trends and Rates of Built-Up Expansions

The spatio-temporal changes of built-up area and their spatial trend of changes were carried out using Land Change Modeler (LCM) within TerrSet software based on land use maps obtained by classifying Landsat TM and Landsat OLI images of

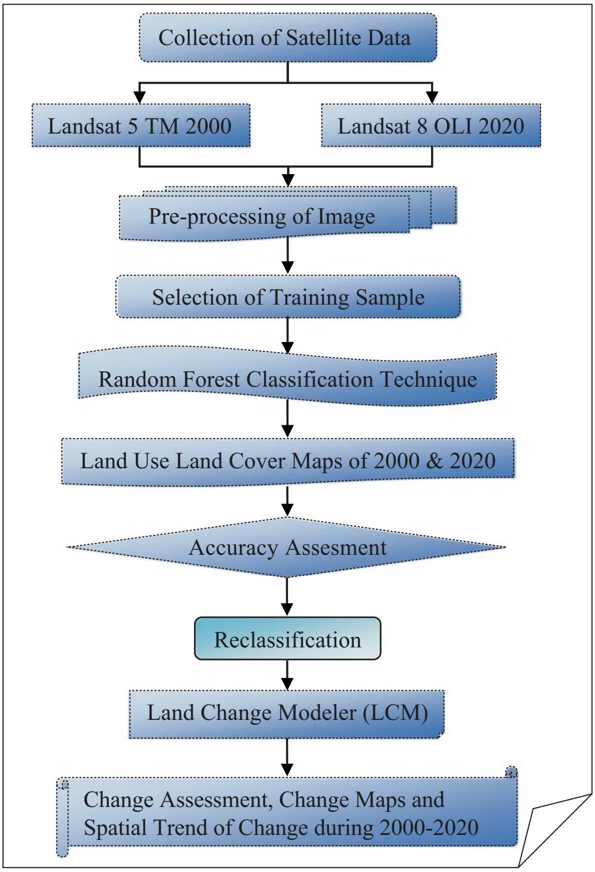

Fig. 2 Stepwise method of overall methodology

years 2000 and 2020, respectively. The LCM is a set of tools for LULC change analysis and modeling which was originally developed by Eastman (2006). The LCM uses two historical land use images to model the transition or change of land cover from one category to another (Sardar & Samadder, 2021). The flow chart of the methodology for this research is shown in Fig. 2.

4 Results and Discussion

The land use/ land cover change dynamics, specifically the expansion of built-up environment to agricultural land, remained the focus in this study. The growth in population has been primarily attributed to both natural increase and migration from neighboring localities (mainly Purba Medinipur district) and the demand for new housing units, communication, education, health facilities and employment opportunities, the major reasons behind dramatic land use changes.

4.1 Accuracy Assessment of LULC Maps

The class value was extracted and validated at each random point of the classified images using the Google Earth application and field visits for its original class. For the Landsat 5 TM images (2000) and Landsat 8 OLI images (2020), the overall accuracies were 85.83% and 88.33% with a kappa coefficient of 78.75% and 82.50%, respectively (Table 3). According to Landis and Koch (1977) and Congalton and Green (2002), kappa values > 0.8 indicate strong agreement, whereas values between 0.6 and 0.8 show substantial agreement between the reference data and classified maps. As a result, the confusion matrix report for all research periods that provided classified maps met the accuracy requirements and was ready for analysis of built-up area expansion on agricultural land.

Table 3 Confusion matrix and accuracy assessment of land use classification of 2000 and 2020

LULC category	Agricultural land	Built-up	Others	Total	PA (%)	UA (%)	EoO (%)	EoC (%)
Accuracy report of LULC for 2000								
Agricultural land	35	2	3	40	89.74	87.50	10.26	12.50
Built-up	1	34	5	40	87.18	85.00	12.82	15.00
Others	3	3	34	40	80.95	85.00	19.05	15.00
Total	39	39	42	120				
OA (%)	85.83							
Kappa (%)	78.75							
Accuracy report of LULC for 2020								
Agricultural land	35	2	3	40	87.50	87.50	12.5	12.50
Built-up	2	36	2	40	90.00	90.00	10.00	10.00
Others	3	2	35	40	87.50	87.50	12.50	12.5
Total	40	40	40	120				
OA (%)	88.33							
Kappa (%)	82.50							

Note: *PA* producer's accuracy, *UA* user's accuracy, *EoO* errors of omission, *EoC* errors of commission, *OA* overall accuracy

4.2 Detecting Changes

Change detection refers to the process of identifying and determining the type and extent of changes in LULC over a period of time using remote sensing images (Meng et al., 2017). The image classification results disclosed that intense LULC change occurred from 2000 to 2020 through the analysis of Landsat images. Figure 3 presents the land use/ land cover maps of the study area for the years 2000 and 2020. The results revealed that in the year of 2001, Mousuni Island were roughly covering by about 63.00% (1800.99 ha) agricultural land, 7.81% (223.20 ha) built-up areas and 29.19% (834.57 ha) others categories, respectively (Table 3). In the year of 2020, agricultural lands has reduced to 42.53% (1215.81 ha) while the built-up areas and others categories has jumped to over 20.96% (599.13 ha) and 36.51% (1043.82 ha), respectively (Table 3). The net change area during the period 2000–2020 explicit that agricultural land has net declined by 20.47% (585.18 ha) while the built-up areas and others categories exhibited a net positive change of 13.15% (375.93 ha) and 7.32% (209.25 ha), respectively (Table 3). During the study period 2000–2020, the total Sundarban region along with Mousuni Island was subjected to several development-related works like forest land reclamation for settlement and agriculture, demands for the construction of new housing, building roads for connectivity and increasing tourism, embankments to stop erosion and ingress of sea water, all of which have influenced alternations in LULC (Ghosh et al., 2015) (Table 4).

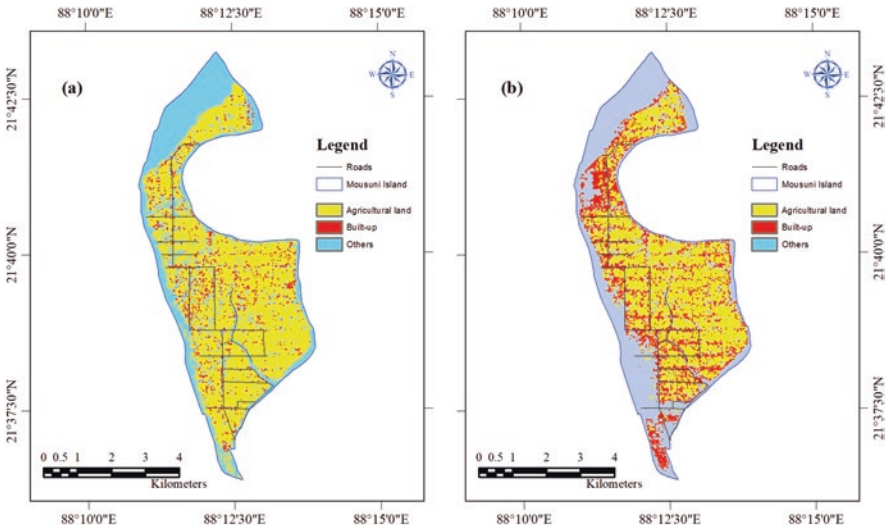

Fig. 3. The spatial distribution of different land use categories for years (**a**) 2000 and (**b**) 2020

Table 4 Area Coverages of the land use categories

Land use	2000		2020		2000–2020	
	Area (ha)	% of total area	Area (ha)	% of total area	Net change (area)	% Change
Agriculture land	1800.99	63.00	1215.81	42.53	−585.18	−20.47
Built-up	223.20	7.81	599.13	20.96	375.93	13.15
Others	834.57	29.19	1043.82	36.51	209.25	7.32
Total	2858.76	100.00	2858.76	100.00		

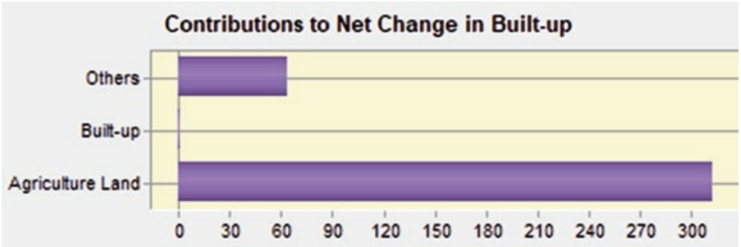

Fig. 4. Contributions to net change in built-up area (in ha) during 2000–2020

4.3 *Submergence of Agricultural Lands into Built-Up Area*

The analysis exposed that during the study period 2000–2020 the built-up areas increased almost three time, i.e., from 223.20 ha to 599.13 ha (total Mousuni Island area is 2858.76 ha) (Table 3). The built-up area of Mousuni Island during the past 20 years was increased by 168.43% from the early built-up area in 2000. This change is equivalent to 13.15% or 375.93 ha (Fig. 4) of the total study area turned into built-up land. On average, the percentage of study area that had been converted to built-up land in the past 20 years (2000–2020) was 0.66% (18.80 ha) annually. The built-up area of Mousuni Island spatially expanded towards the southern-central (Baliara mouza) and northeastern part (Mousuni mouza) where major roads are located and connect the surrounding areas (Fig. 5). During this time, the population density changed from 714 to 1071 persons/km^2, which represents a 50% increase in population density for that time. The advancement in built-up areas was attributed to rapid increase in population and the demand for new housing units and improvement in transport infrastructure, which started without proper land use planning and management.

The newly formed built-up area is 13.15% (375.93 ha), of which 10.91% (312 ha) came from expanses of agricultural land and 3% (64 ha) from other categories (Fig. 4). The agricultural land showed a steady decline from 63.00% (1800.99 ha) to 42.53% (1215.81 ha) (Table 3). The results demonstrated that 585.18 ha of the original (1800.99 ha) agricultural land was lost (1.02% or 29.26 ha/year). The main reason behind the conversion of agricultural land into built-up areas is expansion of

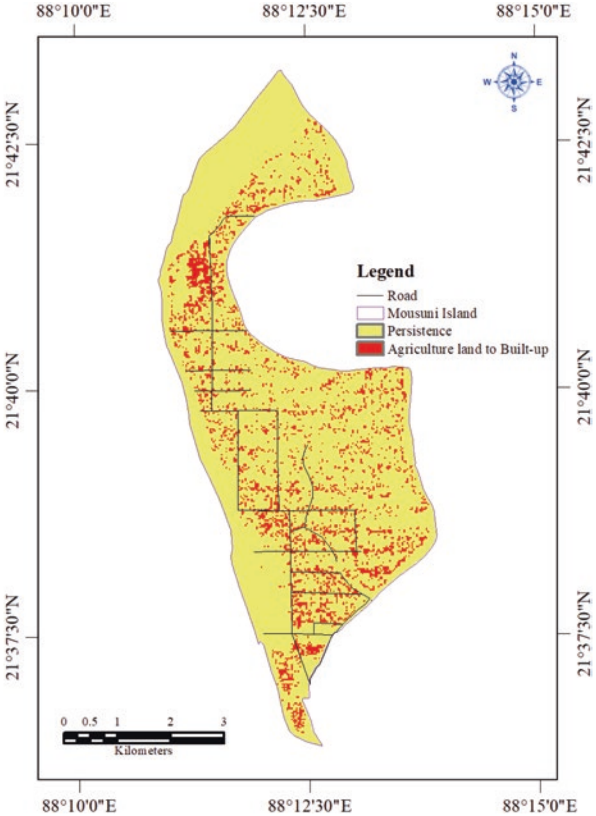

Fig. 5. Built-up expansions on agricultural land during 2000–2020

settlement and improvement of transports system. Such reduction in the agricultural and farmlands will impact the country's food security and water resources. Additionally, the ecological value of the lands will be reduced (Long et al., 2014).

4.4 Spatial Trends of Change of Built-Up Areas

Considering the spatial trend of change is an effective way to visualize and provide the generalized pattern of changes based on two observed LULC maps (Mishra & Rai, 2016). The spatial trend analysis was used to map the trends of transitions from all LULC to built-up environment during 2000–2020 (Fig. 6). In this study, the default third-order polynomial (best fit to the pattern of change) was used to generatea trend map. The spatial trend map showed that the agricultural land was mostly consumed by built-up land toward the southern-central part of the study area, as seen in Fig. 6.

Photo Plate 1 presents the morphological changes of built-up environment during the study period 2000–2020. The results showed that most of the built-up growth

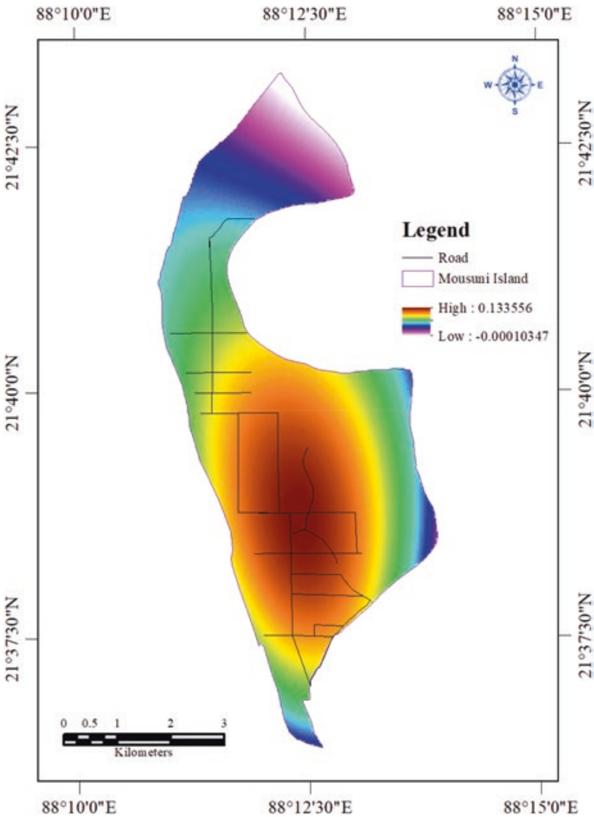

Fig. 6. Spatial trend of change of built-up land during 2000–2020

occurred in a relatively linear pattern particularly more visible along or near roads and the canal edge over the study area as shown in Photo Plate 1. This is possibly due to allowing the settlement to utilize transport routes or roads that are designed to provide farmers access to their farms and orchards.

5 Conclusion

The study concludes that Mousuni Island has experienced severe reductions in agricultural land due to steady growth of built-up areas over the past two decades (2000–2020). which has created multiple issues, like social, cultural, environmental and economic instability. During the 20-year study period, 312 ha (10.91%) of agricultural lands was converted into built-up environment. The built-up lands in Mousuni Island were expanded by 168.43% from the original (223.20 ha) built-up area in 2000. Most of the built-up areas were built predominantly along with road junctions, canal margins and arable land at an accelerated rate. The rate of losing agricultural lands because of built-up lands is increasing at an alarming rate because

Photo Plate 1 Conversion of agricultural lands into built-up areas during the study period 2000–2020

of the rapid natural growth of the population and migration from the neighboring district and individuals demand such as housing, transportation, schools, hospitals and other basic amenities of life. The enormous conversion of farmland into built-up land represents a significant threat to environmental sustainability and food security of the island. As a result, to conserve agricultural land, the government should grade the lands in terms of better usage and place a priority on farmland preservation. In addition, the government should also teach the general public about the harmful effects of rapid conversion of farmland into built-up areas. The results of this study can be useful for government officials, planners and decision-makers to control such irregular development patterns. Finally, additional research on the built-up expansion on agricultural land needs to be carried out using modern scientific approaches and very high-resolution imageries; these will be vital to appease the demand for swift built-up expansions on rural farmland.

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Levels of Agriculture Development and Crop Diversification: A District-Wise Panel Data Analysis in West Bengal

Rukhsana and Asraful Alam

Abstract Crop diversification is an important management to augment agriculture development sustainability in India, including income-enhancing strategies for farmers and employment generation, poverty eradication, judicious use of natural resources and promoting ecological management. This study analyzed the nature, extent and association between levels of agricultural development and crop diversification across districts of West Bengal using secondary data. The Herfindahl index has been used to calculate agricultural diversification, and the level of agricultural development was developed based on a composite z-score through selected parameters of agriculture. The result shows that the diversity of crops is diversifying at a faster rate than the all-India level. However, this has happened only in a few selected areas and not in the entire state. The level of crop diversification and agriculture development found varies among districts of West Bengal. It has been found that crop diversification has a positive correlation with all selected indicators of agriculture such as irrigation, cultivators, gross sown area and levels of agricultural development as a whole, showing a strongly positive correlation with crop diversification, indicating that crop diversification has increased with an increase in the level of agricultural development. Major constraints for low crop diversification in some districts of West Bengal are lack of irrigation facilities, frequent droughts, erratic rainfall, poor asset base, lack of awareness and training, lack of credit facilities, traditional farming practices, average land holding size and per capita income. Thus, the growth of crop diversification can be improved through technical support, supply of quality input, insurance coverage and the existence of modern storage-processing centers in the low agriculture diversified regions.

Keywords Levels of agriculture development · Crop diversification · Herfindahl index · Composite z-score

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1 Introduction

In the twenty-first century, there is a need to double global food and feed production on existing agricultural lands, which is essential to achieving food and nutritional security and improving agricultural resource use efficiency; protecting biodiversity in ecosystems is needed to restore the health of the ecosystem. These are some of the major challenges facing agriculture across the world. To attain this, there must be a substantial increase in food production, while at the same time, the environmental footprint of agriculture must be significantly reduced. This can be achieved by slowing agricultural expansion, augmenting crop efficiency, closing the yield gap, changing diet and reducing waste, and together these approaches can double food production while reducing the environmental influences of agriculture (Foley et al., 2011). Presently, the agriculture sector is facing many challenges, including climate change and associated variability effects, leads to more extreme events like drought and heat stress or flood, degrading land and water, loss of agrobiodiversity and declining food quality, all adversely effecting ecosystem health and food and nutritional security. Crop yields are either stagnant or declining (Ray et al., 2012), whereas we often have observed large yield gaps between potential yields and agricultural yields, especially in the developing world (Meng et al., 2013; Edreira et al., 2017).

Diversifying crops in agriculture can improve resilience and health of ecosystems in a variety of ways (for example, pest outbreaks and pathogen transmission that are likely to worsen due to global warming). Economic inducements that encourage the production of a select few crops, campaigns to grow transgenic crops and the idea of monocultures being more productive than diverse farming systems are major barriers to promoting this diversified approach. Crop diversification can be applied at different scales in a variety of forms and allowing farmers to decide on a policy which can leads to augmented resilience and uplift to economic of farmers (Lin, 2011). Crop diversification is considered a significant way to increase agricultural income, poverty alleviation, employment generation, soil conservation and water resources, and it is an important strategy to overcome many of the emergencies faced by developing countries (Joshi et al., 2004). Mandal and Bezbaruah (2013) observed that as a food risk-coping mechanism, crop diversification has a strong positive effect on small farmers' incomes in India. Von Braun (1995) found that agricultural diversity in export vegetable production augmented rural employment by 45% in Guatemala. Similarly, Ali and Abedullah (2002) showed that diversification of crops toward high-value commodities produced significant employment in food and feeding production. Recently, Birthal et al. (2004) found that household agricultural diversity of small farmers toward high-value crops is likely to be poor in developing regions at the household level.

The Indian agriculture sector is mostly dominated by marginal and small farmers who are facing the problems of low income, low productivity and low availability of food grains (Desai et al., 2011). Over the decades, farmers have been advised to diversify their agriculture to meet the basic needs of their families through increased income and to reduce environment challenges also (Sinha & Ahmad Nasim, 2016). Various benefits such as poverty alleviation, income generation, employment supply, food security, environmental development and agricultural sustainability can be achieved by crop diversification. Diversified cropping or new cropping systems were found to increase the value of natural resources. It has also been found that the pattern of diversification improves the agricultural income at higher levels, such as increasingly accommodating more profitable crops (Saleth & Maria, 1995; Dutta, 2012; Rukhsana, 2020). The physical and socioeconomic conditions of the area with a high level of agricultural technology and low degree of diversification should be controlled to lead to crop diversification (Raju, 2012). The purpose of this study is to determine the regional variation of crop diversification or specialization at the district level and levels of agriculture development in West Bengal and the association between crops.

The Study Area West Bengal state has been selected for the study; it lies between 21°31′ and 27°13′14″ north latitude and 85° 45′20″ and 89°53′ east longitude. It has 19 districts and 341 development blocks and is organized into 66 subdivisions. West Bengal lies in the eastern region of India with a great physical diversity and shares international borders with Bangladesh and Nepal (Fig. 1). Crop diversification is considered to be a way to increase the contribution to the production ratio of non-rice crops to achieve higher agricultural growth rates in the future. Apart from boosting development, diversification can also contribute to higher nutrition levels, poverty alleviation, employment generation and sustainable natural resource management.

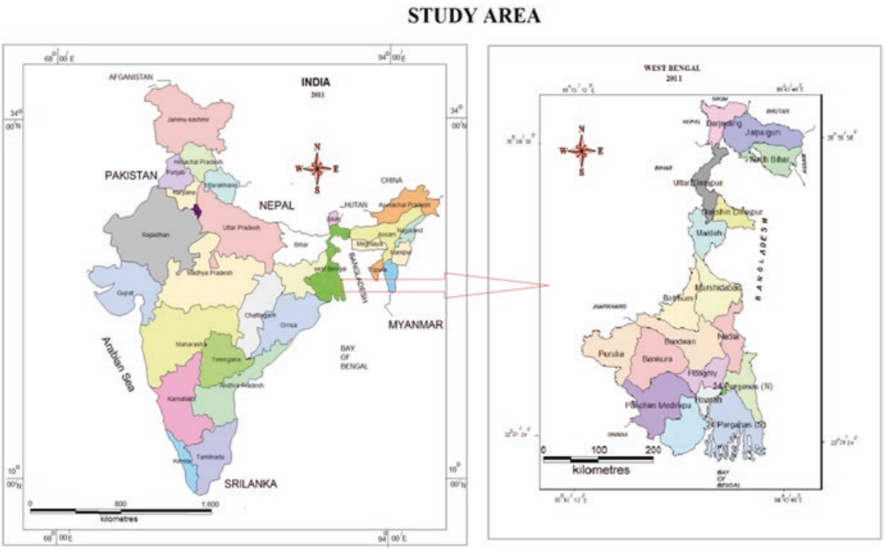

Fig. 1 Location map of West Bengal

Methodology Crop diversification involves adding more crops to the existing agriculture system (Makate et al., 2016). The main concept of crop diversity is the addition of more crops to the existing crops, denoted horizontal crop diversity (Joshi et al., 2004). However, this type of diversification means expanding the system base, adding more crops to the existing cropping system, using techniques like multiple cropping techniques combined with other efficient management practices. It can also describe crop diversity, for instance, crop additios and adjustments, which is related to the primary concept of crop diversification, but they are only a way to optimize profit and manage the land (FAO, 2015).

Various statistical methods have been found to estimate the diversity of agriculture or crop diversification from existing literature, including maximum ratios, augive index, entropy index, modified entropy index, composite entropy index, Simpson index, and so on. Kumar et al. (2012), Benin et al. (2004), Chand (1996) and Pandey and Sharma (1996) applied said indexes in their work. Each of these tools has its own merits and limitations of data requirements, ease of estimation and interpretation. Additionally, results attained through these indexes or methods are more or less the same.

In this study the crop diversification (CDI) index has been examined to define crop diversification for particular crops of interest. This was achieved by subtracting the Herfindahl index (HI) from one which is an index of concentration and has a direct relationship with diversification of crops, where a zero value signifies specialization and greater than zero indicates crop diversification. This index formula has been used to find the crop diversification area in the selected study area. The Herfindahl index given below is computed by taking the sum of squares of acreage proportion of each crop in the total cropped area. The formula of the Herfindahl index is as follows:

$$\text{Herfindalh index}\left(\text{HI}\right) = \sum_{i-1}^{N} P_i^2$$

where N denotes the total number of crops and Pi is area proportion of the i-th crop in total cropped area. With augmented diversification, the Herfindahl index would decrease. This index takes a value of one when there is complete concentration and approaches zero when diversification is perfect. Thus, the Herfindahl index is bounded by zero and one.

The correlation coefficient has been used for the dependent variable (crop diversity) and independent variables (selected agricultural development variables of the factors affecting crop diversity), and Student's t-test technique has been applied to find the determinants which are significant at 1% and 5% levels. The correlation coefficient has been calculated based on the Karl Pearson's correlation co-efficient (r) technique, as follows:

$$r = \frac{\sum xy - \sum x \sum y / n}{\sqrt{\sum x^2 - \frac{\left(\sum x\right)^2}{N}}\sqrt{\sum y^2 - \frac{\left(\sum y\right)^2}{N}}}$$

where *r* is the coefficient of correlation, X, *y* are the two given variables, and *n* is the number of observations. To find the computed '*t*' value, Student's t-test technique is used, which is given below: where *t* is the calculated value of '*t*' in the test of significance, *r* is the computed value of the coefficient of correlation, and *n* is the number of observations.

$$\text{Index of Cropping Intensity} = \frac{\text{Index of area under crops}}{\text{Index of net area sown}} \times 100$$

Levels of agricultural development have been scrutinized using composite z-score technique, expressed as follows:

$$Z = \frac{X - \bar{X}}{SD} \quad (1)$$

where Z = standard score, X = original values of the score, $\bar{X}$ = mean of variables and SD = standard deviation of variables; the obtained Z = score of each indicator is added district wise to be known as composite Z = score(s) for each spatial unit of the study area.

$$\text{Cs} = \sum Z_{ij} \quad (2)$$

where Cs denotes composite Z-scores, and Z_{ij} indicates the sum of Z-scores of indicators j in district i.

2 Result and Discussions

Regions of Agricultural Development Sustainable development of any country depends on food. It is necessary to check the levels of agricultural development to know the facts. The districts are organized into five categories of agriculture development: high = > 1.5, medium =0.5–1.5, low = −0.5 to 0.5 and very low = −1.5 to −0.5 in terms of the combined z-score (− < 1.5) in composite z-score. Agricultural development includes eight indicators including net sown area, gross sown area, total irrigated area, intensity of crop, percentage of land by size groups and fertilizer consumption in kilograms per hectare. The analysis shows that the lowest overall Z score of −2.08 has been obtained by Darjeeling, while the highest of 1.50 by Burdwan (Table 1). Figure 2 shows that a notable area of very high concentration of agricultural development comprises two districts, Burdwan and Nadia, while a high concentration of agricultural development is founs in five districts, including Murshidabad, Birbhum, Hooghly, Pashim Medinipur and Puraba Medinipur. It is clear from this figure that the development of agriculture is found more in the southern and central part of the study area. But these districts are counted as medium and low in crop diversification except for Murshidabad and Birbhum, which contribute to higher diversification because of the higher density of population and more industrialization with cash crops. A very low concentration of agricultural development is founs in five districts: Uttar Dinajpur, Dakhin Dinajpur, Purulia, Howrah and Norton 24 Parganas; these districts are high in crop diversification except for Purulia. Actually, those districts with the highest concentration of agricultural development have low crop diversification due to industrialization and commercialization of cash crops.

The analysis reveals that the lowest composite z-score of −2.08 is achieved by Darjeeling while the highest at 1.50 is attained by the Bardhaman (Table 1).

Regions of Crops Diversification Changing agricultural patterns and practices is the result of successful implementation of the "Green Revolution Program (GRP)" and policies. In addition, the Indian agricultural sector has seen significant changes

Table 1 District-wise distribution of agricultural development (in Composite Standardized Z-Scores) in West Bengal (2011–2012)

Name of the district	GCA	NSA	CI	TIA	FC	LH	CZS	RECZS
Bardhaman	1.24	1.554	−0.277	1.534	0.768	−0.218	4.82	1.50
Cooch Behar	−0.01	−0.330	0.627	−0.422	−1.346	−9.025	−1.48	−0.45
North24 Parganas	−0.25	−0.559	0.627	−1.498	−1.036	−7.733	−2.71	−0.84
South24 Parganas	−0.25	0.672	−0.890	1.239	0.130	−2.873	0.90	0.28
Bankura	−0.05	0.386	−0.802	−1.118	0.854	0.140	−0.74	−0.22
Uttar Dinajpur	−0.21	−0.117	−0.306	0.000	0.528	−1.216	−0.11	−0.03
Dakshin Dinajpur	−1.01	−0.914	−0.656	−0.573	−0.259	−4.495	−3.42	−1.05
Darjeeling	−1.56	−1.468	−1.094	−1.177	−1.424	−9.348	−6.72	−2.08
Howrah	−1.73	−1.962	0.248	−0.368	−0.067	−3.695	−3.88	−1.20
Malda	−0.37	−0.550	0.277	0.826	0.648	−0.717	0.83	0.26
Hooghly	0.03	−0.738	1.911	−0.717	1.765	3.939	2.25	0.70
Jalpaiguri	0.14	0.440	−0.511	0.569	0.569	−1.047	1.21	0.38
Murshidabad	1.82	1.014	1.327	−1.288	−0.043	−3.596	2.83	0.88
Nadia	0.95	0.040	1.823	2.137	−0.323	−4.762	4.63	1.44
Purba Medinipur	0.02	0.002	−0.015	0.484	1.314	2.057	1.80	0.56
Paschim Medinipur	1.92	2.120	−0.073	−0.431	−1.238	−8.576	2.30	0.71
Purulia	−0.86	0.063	−1.940	−0.377	−1.609	−10.121	−4.73	−1.46
Birbhum	0.20	0.349	−0.277	0.916	0.769	−0.211	1.95	0.61
AVERAGE	0.00	0.00	0.00	−0.01	0.00	−3.42	−0.01	0.00
SD	1.00	1.00	1.00	1.04	1.00	4.17	3.23	1.00

Note: *GCA* Gross sown area, *NSA* Gross sown area, *CI* Cropping intensity, *TIA* Total irrigated area, *FC* Fertilizer consumption, *LH* land holding

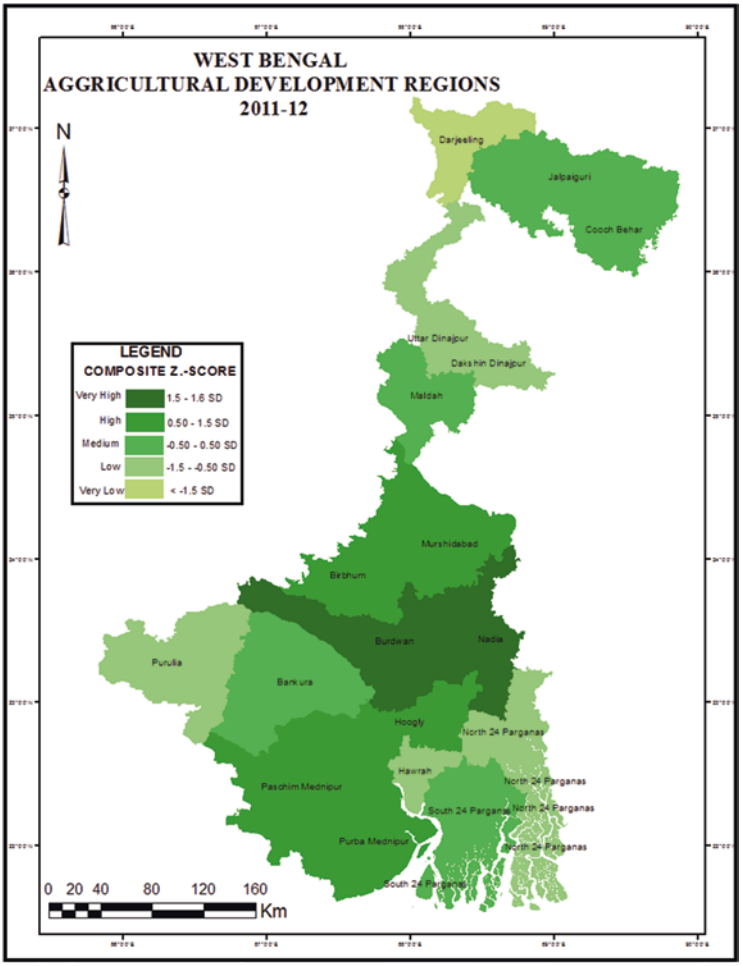

Fig. 2 Agricultural development regions

from traditional food grain farming to diversification and cultivation of commercial horticultural crops since the 1990s (Rukhsana, 2020). Furthermore, similar results have been observed in the state of West Bengal in relation to agricultural practices. Study area was graded into five categories (very high, high, medium, low and very low crop diversified regions) of crop diversification based on the Herfendahl index.

Table 2 and Fig. 3 present the scenario of crop diversification in west Bengal during 2012–13. The sample mean of the Herfindahl index is 0.057, which is found to be the highest Herfindahl index (Table 2). Crop diversification is mainly observed in the northern regions of West Bengal. Figure 2 shows that the Howrah district is the most highly diversified district followed by Dakshin Dinajpur (0.01), Birbhum (0.01) and Cooch Behar (0.01), while districts like Birbhum along with Uttar

Table 2 Crops diversity in West Bengal at district level

Sl. No.	Name of the district	2012–2013
1	Burdwan	0.06
2	Koch Behar	0.01
3	South 24 Parganas	0.03
4	North 24 Parganas	0.02
5	Bankura	0.02
6	Dakshin Dinajpur	0.01
7	Darjeeling	0.04
8	Hawrah	0.001
9	Maldah	0.03
10	Hoogly	0.08
11	Jalpaiguri	0.03
12	Murshidabad	0.03
13	Nadia	0.25
14	Paschim Mednipur	0.17
15	Purba Mednipur	0.08
16	Uttar Dinajpur	0.02
17	Purulia	0.13
18	Birbhum	0.01
Total average	0.057	

Source: Compiled by author. Calculation is based on data from Statistical Handbook West Bengal (2012) published by Bureau of Applied Economics & Statistics Department, Kolkata, W.B Office of the Directorate of Agriculture, Government Of West Bengal

Dinajpur have made tremendous improvement in crop diversification in West Bengal. Moderate diversification has been recorded in the districts of Hoogly (0.08), Burdwan (0.08) and Purba Mednipur (0.08), which made important advancements in crops diversification during 2012–2013 due to improvement of irrigation facilities and changes in institutional holding size and accessibility to markets.

Crop diversification is influenced by many factors including development of infrastructure, consumption of fertilizer and adoption of technology like irrigation facilities, relative income, cost of resources and population size and per capita income as well as climate change. This section examines the factors influencing diversification in favor of agriculture practice or high-value crops. Several regression analyses have been performed using data for the period 2012–2013 to identify important factors affecting crop diversification. To find the relation between crop diversification and its determinants, the co-efficient of correlation (r) has been calculated, which is shown in the mentioned figures of the respective determinants. After going through crop diversification and agricultural fields, it would be valuable to study the factors affecting crop diversification in the study area. Crop diversification and the relationship between agricultural development and population are discussed in this section.

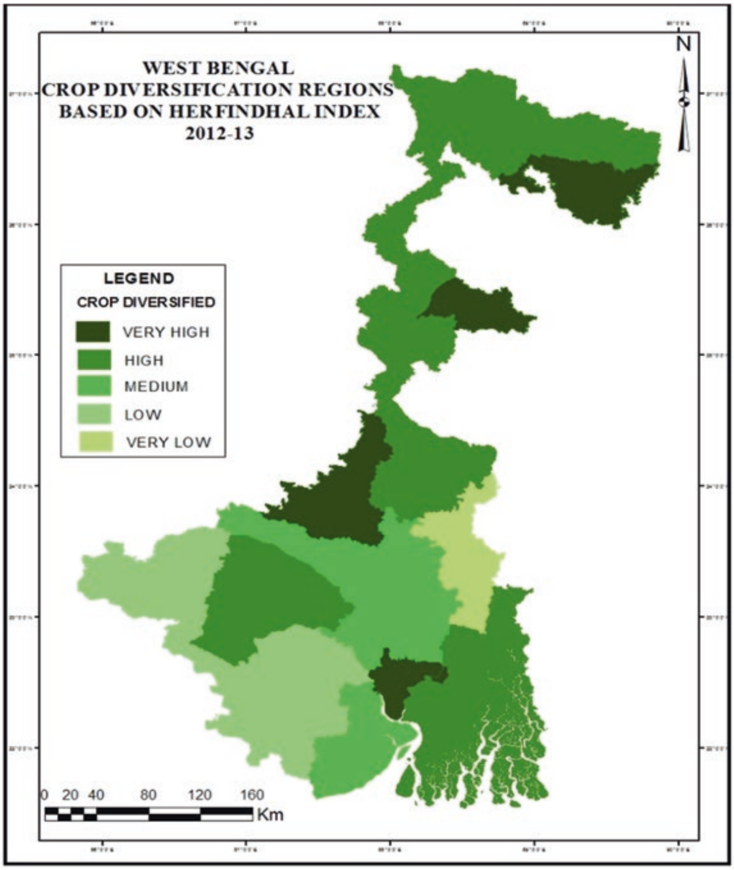

Fig. 3 Crop diversification region

Population density is the most important indicator for measuring crop diversity. The rural population, both skilled and unskilled, is pushed into agricultural land to pay for highland crop production. Population density, therefore, increases with continuous natural development in villages as the demand for food crops also increases. A high inverse relationship has been found between the two said variables. Figure 4a shows that negative correlation (r = −0.158) is indicated between population density and crop diversification. It also sheds light on the fact that as the population density increases as a result of crop diversification, it continuously decreases. It is clearly seen that there is a high positive correlation (r = 0.515) between crop diversification and work force participation (Fig. 4b). Crop diversification has increased almost equally with the increase in work force participation (Rukhsana & Alam, 2021). It is also further mentioned that with the increase of population the demand for human beings also increases and the demand for food crops for this situation also increases, as workforce participation increases for maximum production from a single filed.

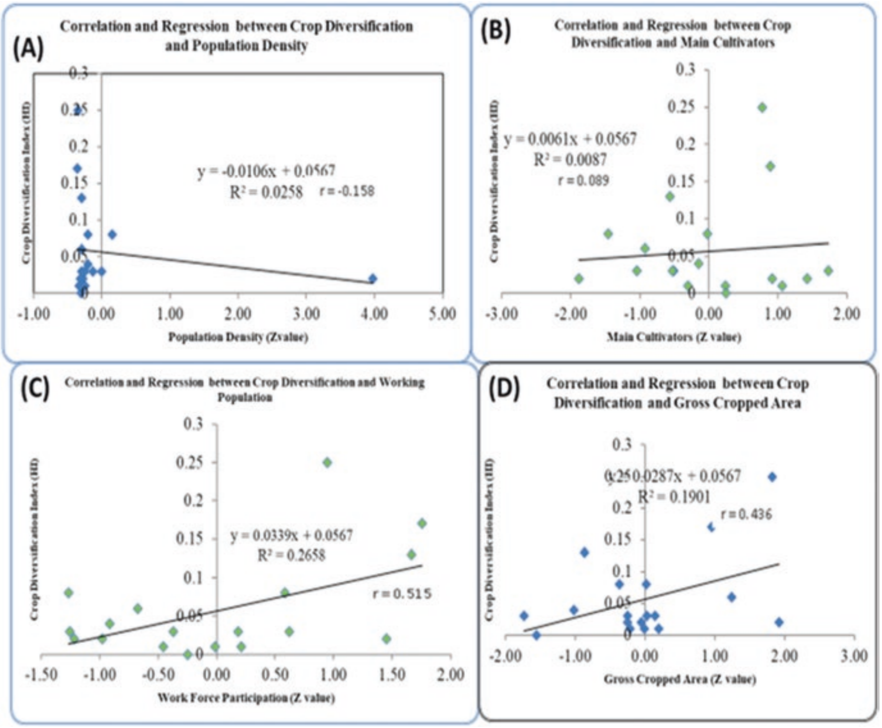

Fig. 4 Correction between crop diversification and agriculture selected determinants

Figure 4c expresses that a positive correlation (r = 0.089) has been found between crop diversification and main cultivators. It also shows that with an increasing number of main cultivators, crop diversification also increases day by day. As we know that farmers are one of the important elements for the development of the production of crops, no agricultural activities are possible without farmers. However, the growth rate of crop diversification is better than for the main farmers. In Fig. 4d, a positive correlation (r = 0.436) has been reported between ‘crop diversification and gross cropped area,’ indicating that crop diversification increases as well as gross crop area growth. The gross cropped area increases day by day because of the demand of the population for their daily lives. The maximum crop area results in an increase in maximum production as the result of crop diversification also increases. Most districts of West Bengal have a high density of population like Malda, Nadia and Burdwan.

Figure 5e shows the positive relationship between the variables plotted by simple linear regression (r = 0.230), which shows the corresponding increase of crop diversification with increasing net sown area. This can be attributed to the fact that land conversion in villages is a faster rate of occupational transfer as a result of the use of large-scale agricultural land for crop production in villages. The work force was previously engaged in agriculture and other forms of primary activities, but now the

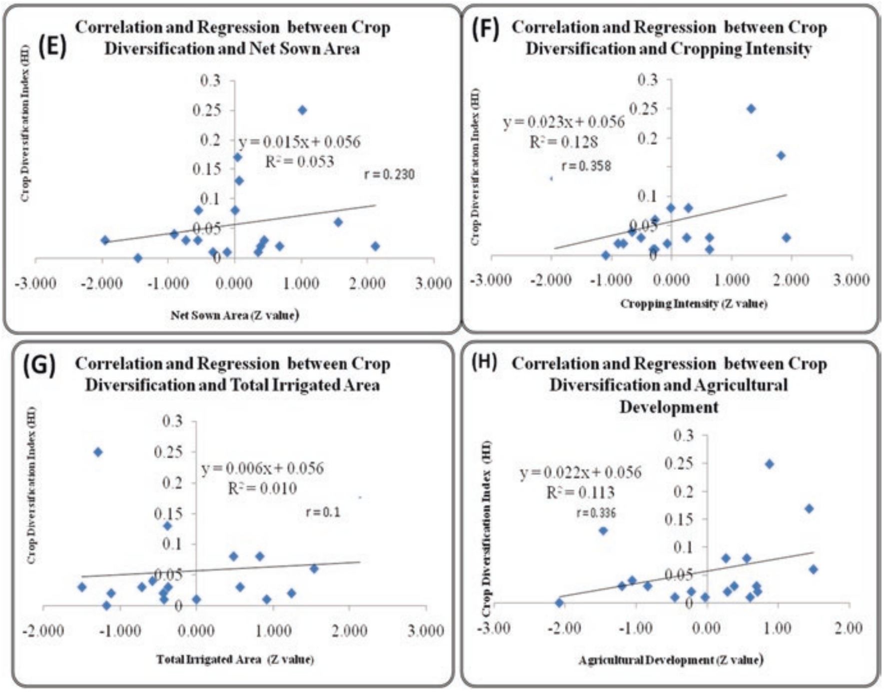

Fig. 5 Correction between crop diversification and agriculture selected determinants

farmer is focusing on single crop production like jute and paddy. Some districts, including Burdwan, Medinipur, Bankura, Purulia and Birbhum, are heavily cropped. Figure 5f displays strong positive correlation (r = 0.358) between 'crop diversification and crop intensity,' indicating that crop intensity increased with an increase in crop diversity in the districts of Nadia, Hooghly, Murshidabad, and so on, because gross and net sown areas also increase. Figure 5g exhibits strong positive correlation (r = 0.1) between 'crop diversification and total irrigated area,' which showed that crop diversification increased with the increase of total irrigated area. This indicates that there is a strong correlation between similar variables, with an 85.5% confidence level with 0.25% significance. Figure 5h shows strong positive correlation (r = 0.336) between crop diversification and agricultural development, which shows an increase in crop diversification with the development of agricultural development. The relationship between crop diversification and agricultural development indicates that there is a strong correlation between the same variables, with a 90% confidence level with 0.25% significance.

Conclusion Crop diversification is an important tool for increasing income and employment generation for small and marginal farmers, especially in an agrarian state like West Bengal. This study analyzed the nature, extent and association between levels of agricultural development and crop diversification in West Bengal district-wise. The result shows that crops are diversifying at a faster rate than the all-India level. However, this has happened only in a few selected areas and not in the entire state. The level of crop diversification and agricultural development found varies among districts of West Bengal.

The strong progress of diversity of crops has been reported for the northern portion of West Bengal including districts of Darjeeling, Cooch Behar, Jalpaiguri, Uttar Dinajpur, Dakhin Dinajpur, Burdwan and Malda. Crop diversification has been rated highest in Cooch Behar district because 80–90% of the population is engaged in the agricultural sector and dominated only by agribusiness. Major constraints on low crop diversification in some districts of West Bengal are lack of irrigation facilities, frequent droughts, erratic rainfall, poor asset base, lack of awareness and training, lack of credit facilities, traditional farming practices, average land holding size and per capita income. It has been found that crop diversification has a positive correlation with all selected indicators of agriculture such as irrigation, cultivators, gross sown area and levels of agricultural development as a whole, showing a strongly positive correlation with crop diversification, indicating that crop diversification grew with an increase in the level of agricultural development. This means using all agricultural facilities for the development of diversification in a proper way, and planning of crop diversification can be augmented and income level may be increased for small farmers.

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Engineering Interventions to Mitigate the Agricultural Waste in India

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Abstract India produces more than 620 million tons of agricultural waste annually. Out of that only 25–30% is utilized as livestock fodder and energy production and the remainder is waste. For next crop sowing, most of the farmers practice incineration to clean the fields in the rice-wheat crop system and others. This practice releases harmful gases like CO_2, CH_4, N_2O, H_2S, O_3, and smog, which cause air pollution. It also affects public life and disturbs soil physical, biological, and chemical properties by destroying beneficial soil microorganisms. Along with crop production, other enterprises like dairy, fishery, poultry, agro-forestry, goat, and sheep rearing produces huge agricultural waste like crop residues, cow dung, and so on. Therefore, engineering interventions to mitigate the agricultural waste in India can be an option to solve the above problems and also provide better inputs to crop productivity.

Keywords Agricultural waste · Incineration · Pollution · Soil microorganism · Interventions

1 Introduction

Waste is unavoidably produced in all human activities including crop production, dairy, fishery, poultry, agro-forestry, and goat and sheep rearing. The quantity of waste is directly proportional to the consumption of resources with time. Waste is very often dumped in wasteland, since it is considered non-useful. Our societies' growing consumerism lifestyle has exacerbated the waste problem as it increases

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the usage of disposable items. Processed food wastes now make up one of the most significant components of municipal garbage. Manufacturing operations are subject to stringent quality control, resulting in enormous amounts of food and packaging waste (Brennan & Grandison, 2011). An integrated agricultural waste management system follows the principle of resource management to minimize the input cost of production. Here, two or more enterprises are combined judiciously as the waste of one enterprise is utilized by another as input. For example, weeds and residue of crop production are used as livestock feed, dung from livestock is input for biogas production, and biogas slurry is an input of vermicomposting, which ultimately goes to crop production (Anon., 2011).

A large amount of biological yield in agriculture. i.e., crop and livestock by-products, weeds, crop residues, leaf litter, undesired plant parts, bedding materials of animals which generate during intercultural operations, harvesting, and other managerial practices is neglected in the form of waste. As per an estimate, 620 million tons of agricultural residues is generated every year in India but half of it has remained unutilized. The unutilized residue is burned in the fields by the farmers, which creates a negative impact on soil biological, chemical, and physical properties along with environmental pollution (Singh & Prabha, 2017). Other than the agricultural waste biodegradable waste, viz., flower cutting, hedge trimming, vegetables, and fruit market waste, domestic and commercial food waste, kitchen and household waste, and so on, generated from urban areas are left unutilized, which worsens the sanitary and hygiene conditions of cities in developing world. Vermicomposting can convert these biodegradable wastes into high-quality manures in an eco-friendly manner. The major crops producing waste are coconut (fronds, husk, shell), coffee (hull, husk, grounds), corn (cob, Stover, stalks, leaves), cotton (stalks), nuts (hulls), peanuts (shells), rice (hull/husk, straw, stalks), sugarcane (bagasse) and mixed types of agriculture crops and waste including non-organic wastes (Anon., 2009).

India produces > 620 million tons of agricultural waste annually, of which only 25–30% is utilized as livestock fodder and energy production. Most of the Indian farmers are practicing residue burning to clear the field in the rice-wheat cropping system for timely sowing of the next crop. The reason is low nutritive value and high cost of labor to clear the field. Crop residue burning causes air pollution by releasing harmful gases like CO_2, CH_4, N_2O, and smog. It largely affects public life and disturbs soil physical, biological, and chemical properties by destroying beneficial soil microorganisms. Implementation of effective agricultural waste management can not only solve the air pollution problem but also provide better inputs to the crops. In India, the production of 284.83 million tons of food grains utilizes 25.94 million tons of chemical fertilizers (NPK) per annum. Agricultural waste contains 0.5% nitrogen, 0.2% phosphorus, and 1.5% potassium as a source of plant nutrient. This can replace 6.5 million tons of chemical fertilizer equivalent to 25% of the total NPK requirement (Choudhary, 2018).

Availability of high-quality, safe, nutritious food is a fundamental need for the good health and general well-being of human beings. The continuous supply of these foods has been a major concern of civilizations all through the ages of human development. With rising urbanization and limited natural resources like agricultural land, water and energy, producing good quality and nutritious food for all is a challenge. The food supply chain starts from the field and ends with the consumer. It consists of different stages and stakeholders starting from farmers, intermediate handler/traders, processing industry, suppliers, transport, retailers, consumers and waste managers. All these players in the supply chain need to devise ways and means to fully utilize agricultural produce while keeping the wastage (losses) to a minimum. The food manufacturing industry needs to transform agricultural resources, in addition to producing food for humans, into different components so that each of them can be used, for example in animal feed, fertilizers, cosmetics, pharmaceuticals, bio-plastics, and biofuels. India increased the food grain output from 52.0 million tons in 1951–52 to 234 million tons in 2005. Inedible phytomers contribute to more than half of the dry matter produced yearly by cereals, legumes, roots and tuber crops. Calculated residue output from the major food crops produced on nearly 50% of the country's cultivable land is about 306.6 million tons, or about 58% of the annual aggregate crop yield of the major food crops (Bahl & Aulakh, 2002) (Table 1).

Considering the coming energy scarcity and environmental pollution problems, the Indian Council of Agricultural Research (ICAR), New Delhi, launched an All India Coordinated Research Project on Renewable Sources Energy for Agriculture and Agro-based Industries (AICRP on RES) in 1983. Several fields worthy of renewable energy devices/technologies have been developed and perfected under this project. The attempt has been made in this chapter to present a brief account of field-worthy technological development, undertaken under the ICAR-AICRP on Energy in Agriculture & Agro-based Industries (EAAI) and different universities suitable for curbing environmental pollution with special reference to Agricultural Waste Management & Renewable Energy Sources – National Scenario and Relevant Technologies.

Table 1 Annual harvests of major food crops and crop residue (1999–2000)

Sl. no.	Crop	Crop production (MT)	Major waste	Crop residue produced (MT)
1	Wheat	74.3	Straw, bran, husk	111.4
2	Rice	88.3	Straw, stalk, bran, hull/husk	114.7
3	Maize	11.6	Cob, bran	17.2
4	Total pulses	13.1	Pod, husk	14.4
5	Total oilseeds	21.2	Oil cake	42.4
6	Sugarcane	325	Bagasse	6.5
	Total	**533.4**		**306.6**

Source: Bahl & Aulakh, 2002

2 Technologies Developed for Agro-Waste Management

There are different conversion technologies for energy utilization like commercial level (household energy, briquetting, carbonization, combustion) and research level (bio-chemicals, bio-oil applications, gasification, pyrolysis). The most often utilized household energy technologies are for cooking, heating, and drying. For example, biomass cook-stoves are available in hundreds of variations across the world (Anon., 2009). Several renewable energy technologies (RETS) have been developed and perfected under the bio-conversion technology component of the project, and the summary of the developments is presented below.

2.1 Paddy Straw-Based Biogas Plant

The Punjab Agricultural University (PAU), Ludhiana, developed the paddy straw-based biogas plant. The plant has a capacity of 10 kilowatts, and its performance in fields has been evaluated (Fig. 1). Based on the results from the 124-l biogas digester, a biogas plant with a digester volume of 10 m^3 was constructed and

Fig. 1 Different phases of a paddy straw-based biogas plant

Fig. 2 View of the (**a**) installed prefab balloon digester; (**b**) installed digester

adjusted. This plant is made up of brick masonry construction, and its performance is under evaluation (Anon., 2012b).

2.2 Kitchen Waste-Based Prefab Balloon Digester

At Sainik School in Chittaurgarh, MPUA&T designed a kitchen waste-based prefabricated balloon digester in P-P-P mode to handle around 200 to 250 kg of kitchen waste per day, as presented in Fig. 2. The plant's overall performance has been improved by the installation of stirring and crushing technologies. A total of 15 m^3 of gas is generated, which is used to cook children's meals. In only 2 days, it may save the equivalent of one LPG cylinder. The plant's organic manure is used to fertilize the crops grown on the farm (Anon., 2012b).

They further designed and installed a 6-m^3 capacity "flexible balloon stirring digester" based on non-edible oil cake at Gopal Pura, Udaipur (Fig. 2b). The plant was constructed under Public-Private-Project for Green Oil Energy Sciences (Pvt) Ltd., New Delhi. Average gas production was 229.30 l/kg with average methane content of 65.75% and is being used for thermal and power generation applications. The biogas spent slurry from the plant had much more nutrient content than cattle dung and other forms of manure especially in terms of nitrogen and phosphorus.

2.3 Modified Janata Biogas Plant

The modified Janata biogas plant was constructed by UAS, Dharwad, and evaluation of a large-capacity plant for solid-state fermentation of cattle dung for power generation and cooking purposes and installed and commissioned a 45 m^3/day-capacity modified Janata biogas plant (Fig. 3) at Aihole Matha (Ashram), Airani, Haveri. The biogas generated is being used for cooking purposes (Anon., 2012b).

Fig. 3 View of installation of 45-m^3 solid-state biogas plant at Airani Ashram

Fig. 4 TNAU developed (**a**) pyrolysis unit, (**b**) biomass, coal, and binder material pelletizer, and (**c**) manufactured pellets

2.4 Non-electric Pyrolysis Unit

A pilot scale non-electric pyrolysis unit was designed and developed by TNAU, Coimbatore (Fig. 4a). The developed unit has a 2-kg capacity for charcoal production consisting of a pyrolysis chamber, combustion chamber, air inlet provision, chimney, protruding cylinder and pyrolysis gas outlet. Experiments conducted at different operating temperatures (250–500 °C) indicated that the charcoal production increases initially till 300 °C and decreases with further increase of temperature. At a temperature higher than 300 °C, the charcoal yield decreases, indicating excessive energy supply leads to complete exhaustion of the volatiles. Based on the studies conducted, a commercial-scale pyrolysis unit of 100-kg capacity was designed. The Centre further studied the various methods of feedstock preparation with coal and biomass (sawdust, cotton stalk, casuarina, and paper, etc.) for energy generation (Fig. 4b, c). The pellets/briquettes produced without binders were less dense, fragile, and easily broken. Pellet making was tried in a pelletizer with the combination of 40% coal, 40% biomass, and 20% cow dung as the binder. The pellets made are very wet and require more time to dry. Reducing the coal (20%) and increasing the percentage of biomass (60%) make the pellets stable. The pellets

Fig. 5 View of efficient combustion system

were evaluated with woodstoves. The performance of this pellet is better than the pellets made with 100 percent biomass (Anon., 2012b).

2.5 *Efficient Combustion System*

The TNAU, Coimbatore, further worked on the adoption and development of 18 kg/h-capacity efficient combustion system (Fig. 5) for agro-processing industries. The efficiency of the combustion system was found to be 18.25%, which is nearly double the time compared with the conventional method (10%), and the thermal output of the combustion system was worked out to be 26154.77 kcal/h and the power rating of the combustion system is about 30 kW. The overall system (steam generator cum combustion furnace) and the mass closure efficiencies were found to be 61 and 91%, respectively (Anon., 2012b).

2.6 *Pyrolysis Reactor*

The TNAU, Coimbatore Centre further worked on design of a 10-kg capacity fast pyrolysis reactor for bio-oil production (Fig. 6a) and optimization of process parameters for maximum bio-oil recovery. A laboratory-scale bio-oil producing setup was fabricated to assess the potential of bio-oil production (tar content) from biomass at various process conditions. This unit facilitates the condensation of vapor and also the collection of generated bio-oil. A pyrolysis unit consisting of a reactor chamber, cyclone separator, and condenser unit was used to carry out the pilot scale study on bio-oil production from selected biomaterials. The Centre reported that highly

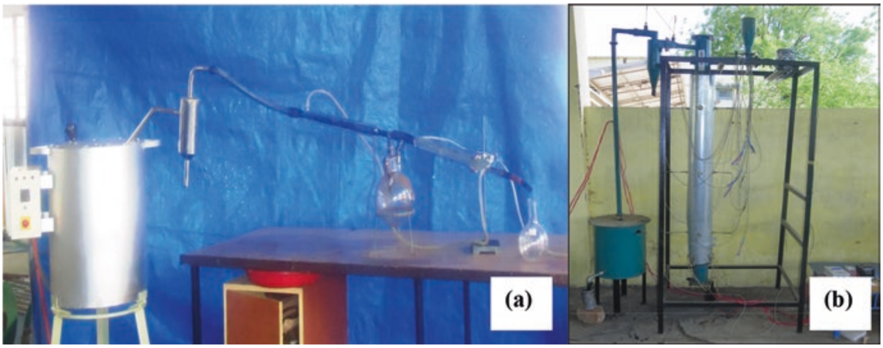

Fig. 6 (**a**) View of developed reactor for bio-oil production. (**b**) Developed fast pyrolysis setup

dense biomass such as casuarina and coconut shell (460, 370 kg.m^3, respectively) had higher heating values of 19.54 and 19.21 MJ kg^{-1} respectively, and high-density biomass species had higher potential for bio-oil production (Anon., 2012b).

2.7 Fast Pyrolysis Setup

The CIAE, Bhopal center, has designed and developed a 1-l/h capacity fast pyrolyzer as shown in Fig. 6b for agro-residues consisting of a 1-m-long vertical reactor with 10-kW heating element mounted on its periphery for obtaining the different temperatures for fast pyrolysis. The yield of different fractions, namely bio-oil, bio char, and other evolved gases, were in the range of 10–15%, 30–40%, and 50–60%, respectively.

2.8 Modified Fixed Dome Large-Capacity Biogas Plant

A high-scale biogas plant (with a capacity ranging from 25 to 500 m^3/day) was built by the Project's PAU, Ludhiana, to tackle the concerns of large dairy owners. Essentially, this is a higher capacity of the "Janata" design. The gas holder is hemispherical, structurally sound, and crack-resistant. Such a plant is simple to build and does not differ much from the Deenbandhu biogas plant technique. Compared to other conventional floating drum-type (KVIC) biogas plants, this plant may be built for around half the price. This design has been approved by the MNRE and the Punjab government for massive implementation by end-users for biogas and cogeneration production. The building construction materials like bricks, cement, sand, bajri, etc., are required for the construction of the plant (Anon., 2012b).

2.9 Biodegradation Technology for College Campus Waste

The SPCW, Courtallam, developed technology for biodegradation of college campus waste. One ton of paper waste collected from classrooms and the examination center was spread in alternate layers with 10% biogas slurry and fungal cultures (*Pleurotus sajor caju* and *Phanerochete crysosporium*). To accelerate the microbial growth, 0.2% urea was also added. The same process was carried out with dry leaves (2 tons) collected within the campus (Anon., 2012b). The entire load was sealed with cow dung smear and left as such for composting. The water was sprinkled on every alternate day to maintain 60% moisture. Turning was done once a month. After 3 months, the composting process was over. The samples were taken for the analysis of constituents present in both paper waste and dry leaf compost. Composting bulky organic wastes (paper, paper cups, paper covers) and dry leaves into nutrient-rich manure keeps the environment clean and improves public health (Parr et al., 1986), and the NPK contents of the paper waste compost (N2-1.29%, P-0.424%, and K-0.256%) and dry leaf compost (N_2-1.12%, P-0.436%, and K-0.398%) indicate that both the composts can support plant growth with adequate macronutrients. Moreover, the carbon supplied through the manure is utilized as food by soil microorganisms.

2.10 Bio-Methanation System for Fruits and Vegetable Waste

The biphasic technology for bio-methanation of green/moist agro-residues and for the Anand Municipal Corporation developed by SPRERI, VV Nagar, a prototype for biphasic bio-methanation of vegetable market waste with a capacity of 3 tons per day was established (Fig. 7). Following that, an odorless bio-methanation method for waste fruits and vegetables was developed. The technique included

Fig. 7 Odorless bio-methanation system at Mother Dairy, FVU, New Delhi

bio-methanation of fruit and vegetable leachate, with the solids remaining after leachate extraction being composted or dried and pelletized for burning. A pilot plant has been constructed at Mother Dairy's Fruits and Vegetable Unit in Mangolpuri, New Delhi, based on this technology. Every day around 3 tons of waste fruits and vegetables was fed into this system, which generates 85–90 m^3 biogas/day with a methane content of 68–72% (Anon., 2012b). The cost of a single unit is now about Rs.7–8 lakh per ton of fruit and vegetable waste handling capacity.

2.11 NRRI Chaff and Husk Stove

The low-cost technology of chaff and husk stoves was designed and developed by the NRRI, Cuttack (Fig. 8). The stove uses rice husk and chaff to provide heat energy for cooking. It works on the principle of gasification and induced natural air draft. It burns the husk or chaff without producing smoke. The technology has a high level of sustainability since it makes use of commonly accessible rice husk. It is made up of MS sheet, rod, flat, and so on. Its weight is 2.6 kg, and its fuel holding capacity is 1.2 kg rice husk. The unit cost of the developed technology is about Rs. 700/kg (Anon., 2012b). For water heating, rice cooking, and other tasks, this technology benefitted the rural population. The technology is simple to use and emits less smoke. These units are created to demand and can be produced by small businesses.

Fig. 8 NRRI chaff and husk stove

2.12 Organic Farming Using Beedi Leaf Waste

The SPCW, Courtallam, prepared organic manure using beedi leaf waste collected from the nearby village. One ton of beedi leaf waste was spread in ten alternate layers (100 kg in each layer) with 10% biogas slurry in a cement tank of size 150 × 75 × 50 cm. For each ton of the substrate 1 kg of lignite-based fungal cultures (*Pleurotus sajor caju* and *Phanerochete crysosporium*), 100 g of phosphate solubilizing bacterial cultures (*Bacillus megaterium, Serratia marcescens* and *Bacillus polymyxa*), 2% rock phosphate, and 0.2% urea were added to obtain nutrient-rich organic manure. After applying the microbial cultures, the entire load was completely sealed with a cow dung smear. Water was sprinkled on alternate days to maintain 60% moisture. Turning was done once a month. After 3 months, the organic manure was ready. The specialty of the process is that it does not use toxic chemicals, pesticides, or fertilizers. The process provides biological diversity, maintenance, and replenishment of soil fertility. It provides healthy soil and a good farm production environment. It supplies healthy crops/food with better palatability, taste, and nutritive value.

3 Innovative Technologies Trends Towards Agro-Waste Utilization

3.1 Agricultural Waste or Farm Waste Shredder

Shredder is used to shred waste material and produce small pieces of materials. The shredder has a high horsepower electrical motor with sharp edge cutting blades on the rotating shaft to perform the shredding operation (Fig. 9). Shredders are known for their ability to crush and treat agricultural crop wastes (Anon., 2009). The reduced small pieces of waste are suitable for compression or mulch. This prevents

Fig. 9 Shredder

Fig. 10 Rice straw chopper-cum-spreader. (Anon., 2014)

moisture loss and weed regrowth and improves the crop production capability of agriculture fields.

3.2 Straw Chopper-Cum-Spreader

Although several uses of paddy straw are possible, like cattle feed, packaging material for horticultural crops, bedding for ruminants, and thermal power generation, still all these uses account for up to 20% of paddy straw, and the rest is considered waste and burned in the fields. This practice needs to be discouraged because the burning of paddy residue is not only a source of atmospheric pollution but also leads to the loss of rich organic matter. The only solution to resolve this problem of paddy straw management is the incorporation of paddy straw in soil. If the straw is to be incorporated into the soil, then a straw chopper and spreader may be used. The chopper chops the straw and the spreader spreads the same. The chopped and spread stubbles can be buried easily in the soil with minimum tillage efforts using traditional tillage implements such as disc harrows and rotavators. A tractor-drawn straw chopper cum spreader is used in a single operation to cut the residual straw left after combine harvesting and spread it on the field (Anon., 2008). PAU, Ludhiana, has developed a tractor-operated straw chopper-cum-spreader in collaboration with a manufacturer (Fig. 10).

3.3 Super Straw Management System (SMS)

The Super Straw Management System (SMS) on combine harvesters allows the machine to shred straw into small pieces and spread it behind the tail of the machine. Not only does the new attachment slow down the harvesters' speed, but it also increases fuel consumption. This new farm appliance could not manage the deadly 'paddy stubble burning menace' despite its extensive promotion by the Punjab government and even after an advisory being issued by the Punjab Pollution Control Board (PPCB) about its use (Anon., 2014). The Punjab government is promoting the 'new retrofitting' of Super SMS with Combine Harvesters to control stubble during harvesting so that farmers do not have to burn it. Field fires burn across the state at times both day and night, creating massive pollution not only in the state but also in New Delhi.

3.4 *Efficient Liquid Manure Application (EMA) Technologies*

The conventional application of manure by broadcasting onto the tillage surface or grassland uses a splash plate. Manure is scattered on both tillage and grassland. The method of manure application can significantly impact the nutrient losses in the soil. EMA technologies offer many advantages over broadcasting like reducing odor and ammonia emissions, the ability to directly place nutrients into the seedbed thus reducing loss of nutrients, and increasing the ability to offset fertilizer costs. Producers and custom applicators in British Columbia can currently choose from five EMA technologies, i.e., an aeration system, deep injection, shallow injection, trailing hose, and trailing shoe (Fig. 11). Soon, India will adopt these technologies as well. Manure is pumped from the tank to a trailing hose system through a chopper/distributor manifold. A band of manure is deposited slightly below the crop canopy by hoses. As a result, smell is reduced, ammonia loss is reduced, and manure dispersion is improved. The trailing shoe applicator has a succession of shoes and a boom at the back. From the tank or dragline, manure flows into hoses that travel to each shoe through the chopper/distributor manifold. The shoe separates the crop, and the hose applies a manure band underneath the crop canopy. After the unit passes, the grass will regrow and hide the manure band. To reduce odors and

Fig. 11 Efficient liquid manure application. (**a**) Trailing hose. (**b**) Aeration. (**c**) Deep injection. (**d**) Shallow injection. (**e**) Trailing shoe. (Source: Anon., 2012a)

improve air quality, the grass should be at least 8 cm in height. With an aerator, holes are punched into the soil, allowing for manure collection. Perforating the surface improves manure uptake and reduces runoff and ammonia losses. A separate pass might be made pre- or post-spreading of manure on the field. Aerators may be placed in front of or behind manure application units to aerate and apply manure in one pass. Slightly injecting manure into the soil exposes the manure band. The application unit opens vertical slots between 2–5 cm deep using a knife, disc coulter, or chisel. A hose pumps manure into the area. Less exposure to air reduces volatilization and surface runoff losses. Deep injection application methods inject manure at depths of 5–20 cm. To finalize the system, tines or shanks are pulled through the soil. Like banding and shallow injection systems, manure is transported to each tine through hoses and dumped at the end. Press wheels or rollers coupled to the tines may cover the slots. Deep injection is appropriate only for pre-seed tillage on corn-planted land because of mechanical soil disturbance and crop root impact (Anon., 2012a).

In terms of fertilizer savings, all economic manure applicator systems provide some financial advantage to the producer. Table 2 below shows different liquid manure applications at 6000 gallons/acre slurry volume capacity.

3.5 Agro-Waste for Sustainable Construction Materials

Agricultural industries' solid waste disposal is also a serious issue faced by most developing countries like India. Most of the world's agricultural phytomass is present in the form of crop residues, and such residues are usually left unused or burned in the fields. Recently, the use of agricultural waste has shifted to the production of heat or converting it into electricity by burning biomass to harness its stored energy. The produced ash and burnt residues of agricultural waste such as sugarcane bagasse and paddy straw are disposed of in the form of landfills without proper management. These ashes are the last stage of waste produced from the agro-industries with no chance to reduce them further. These wastes are a potential alternative

Table 2 Different efficient liquid manure applications (EMAs)

Application method	NH_3 loss reduction (% of TAN)	Available N from slurry (kg N/acre)	N from purchased fertilizer	Fertilizer saving ($/acre)
Broadcast	–	15.5	44.5	–
Broadcast/ incorporation	77	38.5	21.5	17.27
Trailing hose	36	26.3	33.7	8.13
Trailing shoe	64	34.8	25.2	14.45
Shallow injection	75	38.1	21.9	16.93
Deep injection	95	44.1	15.9	21.44

Source: Anon., 2012a

component for sustainable construction materials. The introduction of ‘sustainability’ in building construction material involves unconventional materials that are available naturally and are recyclable; some of them are available on the market, while others are in the early stages of development or research. Conventional sources like mineral wool and plastics widely used in building materials cause environmental issues. Many construction materials, such as thermally insulated walls, particle boards, solid boards/panels, ceiling panels, masonry composites, multilayers, slurry types, coil, cementations materials, and fiber reinforcement are developed using agricultural waste and by-products as a raw material (Liuzzi et al., 2017). Sugarcane bagasse and paddy straw ashes have good potential in the development of energy-efficient brick materials that also have good thermo-mechanical behavior. The products produced from agro-waste are comparatively cheaper, lightweight, durable, and environmentally friendly compared with the conventional ones (Liuzzi et al., 2017).

However, since fibers are a natural resource, their quality should be evaluated constantly. Moisture and free water may have undesirable effects (like mold production) in products. Hence, careful harvesting, processing, and manufacturing methods are essential. To avoid harmful impacts on air quality, fiber thermal insulation needs the use of regulated additives (Liuzzi et al., 2017).

3.6 Bioplastics from Agro-Wastes

Plastics, generally referred to as petroleum-based synthetic polymers, have continuously risen in popularity and have become one of the most attractive forms of material. Polyethylene, polypropylene, polyvinyl chloride, polystyrene, polyethylene terephthalate, and polyurethane are the most extensively used polymers. Due to the increasing manufacturing of plastic products and the pace of deposition throughout the last 2 decades of the twentieth century, they are now the most prevalent and permanent pollutants on a global scale. Under natural circumstances, the decomposition of synthetic plastics is relatively gradual, influenced by environmental elements and natural microorganisms. This has increased global interest in the production of biodegradable polymers, encouraging research activities to change existing goods, induce degradation, or create novel biodegradable alternatives (de Moura et al., 2017). These materials, when used in applications with a limited life span, such as food packaging, provide an environmentally friendly way to decrease solid-plastic waste (de Moura et al., 2017).

Environmentally sustainable polymers are a rare and costly subset of biodegradable polymers (biocompatible and biodegradable). The manufacturing method for such biopolymers can be categorized into four distinct stages, based on the targeted products and the accessible materials/precursors (Fig. 12). The four categories include bacterial synthesis methods, biopolymer blends, chemical synthesis techniques, and renewable sources of synthesis energy (Maraveas, 2020).

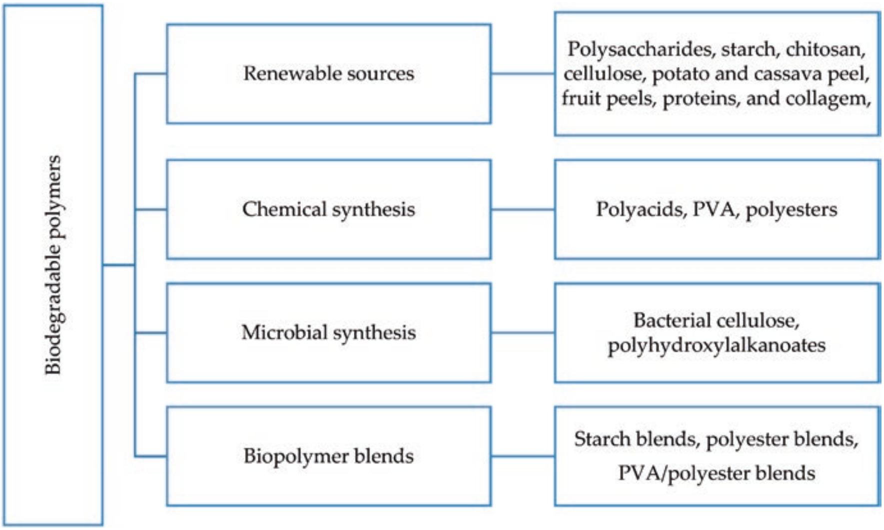

Fig. 12 Classification of biodegradable polymer-production processes. (Source: Satyanarayana et al., 2009)

The availability of starting materials/precursors has an impact on the production of agro-waste-based biopolymers (Maraveas, 2020); these resources should be economical and widely available. India and China have the potential to dominate the manufacturing of fruit and vegetable-based biopolymers because of their huge production capacity and share of global output. Bio-based polymers may come from a variety of non-conventional sources. Bio-based polymers have been created using plant-based precursors such as cellulose esters, lingo cellulose fibers, polylactic acid, and poly hydroxy alkanoates (PHA) (Kumar & Sharma, 2013). Lingo cellulosic fibers are found in plants such as curaua, pineapple, sisal, and jute. Organic components/precursors with high levels of cellulose and other fibers are selected because they improve the mechanical strength of the material. On the downside, although cellulose is a bio-based material, the precursor is not biodegradable because of a higher degree of replacement. Agricultural waste, unlike other renewable resources derived from plants, is made up of post-harvest trash and food processing by-products including fruits peels, shells, and/or seeds, which have generally been discarded as waste at agricultural field and processing centers (Maraveas, 2020).

Plasticizers and antioxidant additives derived from agricultural waste are key sources of raw materials. Polysaccharides are common in vegetable-based agricultural wastes and are precursors of natural plasticizers. Plasticizers help bio-based polymers retain their elasticity and mechanical strength (Maraveas, 2020). Acceptable agro-waste meets the following criteria: bioavailability and impact on agricultural supply networks and food security, synthetic complexity, and desired material qualities (Maraveas, 2020). The proportion of cellulose and starch in agricultural waste precursors is a limiting criterion in their selection.

4 Conclusion

The advancement in technologies and different research findings makes agricultural waste a good source of energy production rather than an environmental issue. The use of agro-waste in the development of usable material makes the environment sustainable and reduces the emission of greenhouse gases. The conversion of agro-waste into fertilizer improves soil health, fertility, and finally crop yield with the reduction in dependency on chemical fertilizer. Agricultural waste perception has moved from waste to wealth.

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The Study of Red Onion (*Allium cepa*) on Growth and Yield Parameters in Response to Plant Spacing in Jaffna District, Sri Lanka

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Abstract The control of plant spacing is an important agronomic practice which influences the growth, yield and quality of red onion bulbs. Accordingly, an experiment was conducted to investigate the best plant spacing measures for optimum growth and yield of selected red onion varieties in Jaffna district of Sri Lanka. The empirical study was carried out in a randomized complete block design with four replicates. Three different plant spacing measures were taken as treatments, namely T1: 5 cm × 5 cm, T2: 7.5 cm × 7.5 cm and T3: 10 cm × 10 cm. Parameters on growth characters such as plant height and number of leaves per plant were measured at 3-weeks intervals from planting. Furthermore, the bulb length, diameter, average weight and total bulb yield were recorded at the time of harvesting. The analysis revealed that plant spacing had a significant ($P < 0.05$) effect on the growth and yield parameters of red onions with varying levels of plant spacing. It could be concluded that the widest spacing (10 cm × 10 cm) in T3 produced significantly ($P < 0.05$) higher values in plant height, number of leaves, bulb length, diameter and average weight. The values of this character were found to be decreased with the narrow plant spacing (5 cm × 5 cm) in T1. On the other hand, the highest total yield was recorded in T1 with the higher plant density compared to the yield produced with lesser plant density in T3. In T3 (10 cm × 10 cm), the quality of the bulb is better than T1 (5 cm × 5 cm). As a result, the marketability is high for the bulbs. Meanwhile higher yield is generated in T1 when compared to T3 due to the high volume of bulbs produced. However, the marketability is less than for T3 with low-quality bulbs. Therefore, the study recommends wider spacing for red onion cultivation in Jaffna district as it is the ideal choice for the farmers based on consumer behavior.

Keywords Growth · Plant spacing · Red onion · Quality · Yield

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1 Introduction

Red onion is a common vegetable in the day-to-day life of humans, and demand for it is stable throughout the year. It is also a well-known cash crop predominantly cultivated in most parts of Sri Lanka. The bulb contains nutrients such as calcium, phosphorous and vitamin C (ascorbic acid). Because of increasing demand for red onions in the country, priority has been given to extending the existing cultivable land for red onion cultivation to increase the average production per unit of land area. At present, the production cost of red onion varies from Rs. 38 to Rs. 49 per kilogram. The price fluctuation prevails because of the crop management practices and crop cultivation area. In the Sri Lankan context, the average production range of red onion is 11.2–11.4 tons per hectare. To cater to the demand, it is important to increase the average production by encouraging the farmers through the efficient utilization of high-yielding varieties, irrigation, fertilization and integrated crop nutrient management practices. This will also reduce the cost of production.

Red onion is successfully cultivated in dry and intermediate zones on the island and is predominantly grown in Jaffna, Vavuniya, Puttalam, Killinochchi, Trincomalee and Monaragala (DOA, 2015). Jaffna is one of the districts where red onion is extensively cultivated because of its geographical advantages. Of the stated districts, the highest targeted and cultivated extents were in Jaffna (HARTI, 2019), and the cultivation comprises two thirds of the total red onion cultivation in the country (Pattie & Wickremasinghe, 1993). Dias (2016) reported large stocks of red onion supplies from Jaffna peninsula going to the Dambulla Economic Centre because of the bumper harvest in the area. There is a huge demand for the red onions produced in Jaffna district. the crop is mainly grown in Yala and Maha seasons in the area. Therefore, the number of farmers involved in red onion cultivation has increased in the vicinity.

At present, the government provides much assistance to local farmers to enrich their livelihood by providing land and irrigation facilities for red onion cultivation. As per the study conducted by Ishara Mudugamuwa (2010), an increasing trend was observed in the amount of cultivated land and number of farmers engaged in red onion cultivation. As a norm, the level of red onion production and price shows immense potential for increasing the income of local farmers. Furthermore, the related studies conducted by many scholars in the past have already proven that the yield and quality of any crop is greatly influenced by environmental factors, crop cultivars, plant spacing and other cultural measures.

Several factors influence the quality and yield of red onion, among which control of plant spacing is particularly important. The statement is supported by the findings of Nichols and Heydecker (1964). As proven in earlier studies, narrow spacing and higher plant density have a positive impact on marketable yield of red onion bulbs (Villgran & Escaff, 1982). Wider spacing, i.e., lower plant population, leads to high yield per plant (Decampose et al., 1968; Singh & Rathore, 1977; Nehra et al., 1988).

Therefore, the research study was organized under the climatic condition of Jaffna district to investigate the best plant spacing for optimum growth and yield of selected red onion varieties with the different plant spacing measures. Meanwhile, the selection of the appropriate variety relies on varying environmental conditions in the specified environment. The report published by HARTI (2019) stated that the cultivation progress of red onion is at a marginal level due to unfavorable weather conditions in Jaffna. Hence, it is prudent to select a suitable variety to cultivate in the district. The most successful and a tested variety, known as 'Vallarai,' was selected for this study. Vallarai is the most successful variety in the northern part of Sri Lanka. It generates relatively higher average production of 17 to 20 tons per hectare compared to other varieties. Hence, the present experiment was conducted and assessed in detail to study the performance and adaptability of 'Vallarai' under the climatic condition of a dry zone with varying plant spacings.

2 Materials and Methods

This experimental study was conducted from July to October 2020 at Point Pedro, in Jaffna district inSri Lanka, which belongs to the agro-ecological region of DL3. Geographically, it is located at 9°49′00″N latitude and 80°13′59″E longitude at an elevation of 12 m above sea level. The soil of the experimental site is calcic red-yellow latasol. The empirical study was laid out in randomized complete block design with four replicates consisting of 12 plots. The treatment of this experiment included three plant spacings: T1: 5 cm × 5 cm; T2: 7.5 cm × 7.5 cm; T3: 10 cm × 10 cm. The seedlings, which were 40 days old and 10–15 cm high, were planted in the field with the above-mentioned plant spacing for this experiment. All other management practices including fertilization and irrigation, and so on, were carried out as recommended by the Department of Agriculture. The outcome was measured based on growth parameters, namely the plant height and number of leaves per plant at 3-week intervals commencing from stage of planting. At the time of harvesting, the yield components of red onion such as bulb length, bulb diameter, average weight and total bulb yield were recorded. The mean values of the above response parameters were subjected to the analysis of variance (ANOVA) using SAS Studio advanced version. Whenever the treatment was significant, least significance differences (LSD) were used for mean separation at $P = 0.05$ probability level.

3 Results and Discussion

3.1 Effects of Different Spacing on the Growth Parameters of Red Onion

3.1.1 Plant Height

Plant height is a crucial agronomic trait and plays an important role in improving the crop yield. The analysis regarding the plant height of red onion showed a significant difference ($P < 0.05$) among the treatments from the day of planting to the sixth week (Table. 1). That the results differ among the treatments is based on the effect

Table 1 Mean plant height values (cm)

		Days after planting	
Treatments	2WAP	4WAP	6WAP
T1	23.5 ± 1.2	33.1 ± 0.8	41.3 ± 0.4
T2	24.4 ± 0.7	35.4 ± 0.8	42.9 ± 0.2
T3	26.2 ± 0.6	38.8 ± 0.6	44.8 ± 0.5
$LSD_{0.05}$	1.5	2.9	1.9

Values are means with ± standard error of the mean

of spacing, allowing the plant to grow freely with proper utilization of nutrients and water from the soil during the vegetative growth period. Thus, a gradual increase was observed throughout the cultivation period. Consequently, in the second WAP, the plant height recorded in T3 was the highest compared to T1 and T2. However, the average plant height ranged from 23.5 cm to 26.2 cm at the second WAP. Furthermore, T1 and T2 showed no significant difference (P > 0.05) during the second to fourth WAPs. But they all varied significantly ($P < 0.05$) from T3 (Figs. 1 and 2 and 3).

The summary of the above result was that T3 has wider spacing of 10 cm × 10 cm and showed high values due to less inter-plant competition for nutrients, moisture, light and space, and so on. T1 had narrow spacing of 5 cm × 5 cm, showing low values due to higher plant population per unit area, which resulted in high competition to obtain the required resources, inhibiting the growth of plants. This was in line with results obtained by Kumar et al. (1998), Khushk et al. (1990) and Rizk et al. (1991). In addition, similar results were found by Yemane kashay et al. (2014) showing superior plant height for intra-row spacing of 10 cm than 5 cm and 7.5 cm.

3.1.2 Number of Leaves

In crop production, canopy development influences the harvest by optimizing light interception, photosynthesis and dry matter accumulation. The crop canopy cover can be managed by modifying the row spacing and plant population. As the plant density increases, the number of leaves per plant will decrease. Hence, this phenomenon affects the photosynthesis efficiency of crops and leaf count.

The present investigation results (Table. 2) revealed that there was a significant difference ($P < 0.05$) among the treatments in the number of leaves per plant during the vegetative growth period. Number of leaves per plant at second WAP indicated high values in T3 compared to T1 and T2.

During the fourth and second WAP (Figs. 4 and 5), T1, T2 and T3 were significantly different ($P < 0.05$) among the treatments. Average number of leaves per plant at fourth WAP ranged from 23.5 to 30.8. During the sixth WAP (Fig. 6), T2 and T3 were not significantly different ($P > 0.05$). However, they all varied significantly ($P < 0.05$) from T1. Maximum number of leaves per plant was produced from 10 cm × 10 cm intra-row spacing, whereas the narrow plant spacing (5 cm × 5 cm) produced comparatively lower values for this parameter throughout the vegetative

Fig. 1 Plant height (cm) (2WAP)

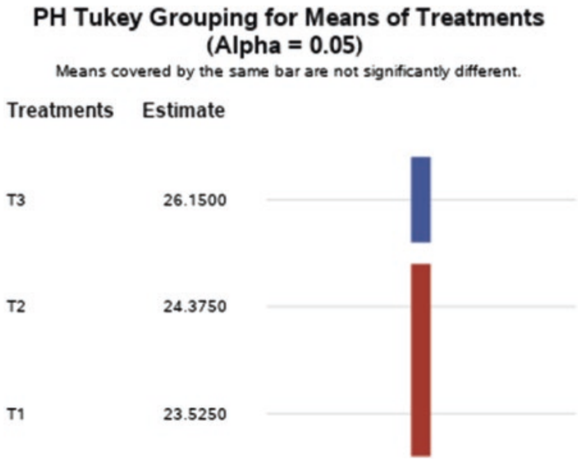


Fig. 2 Plant height (cm) (4WAP)

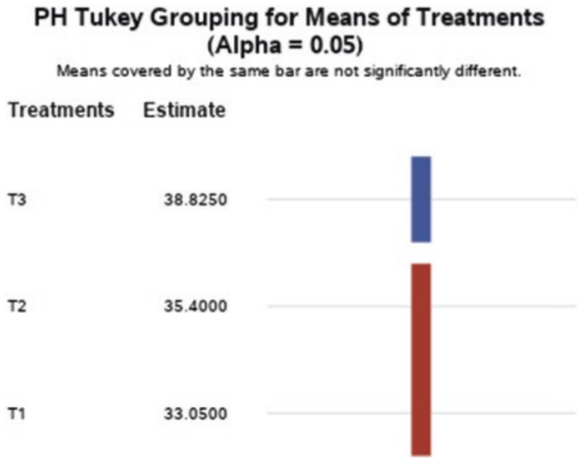


Fig. 3 Plant height (cm) (6WAP)
PH **Plant height. Means covered by the same bar are not significantly different by Tukey test at** $P < 0.05$.

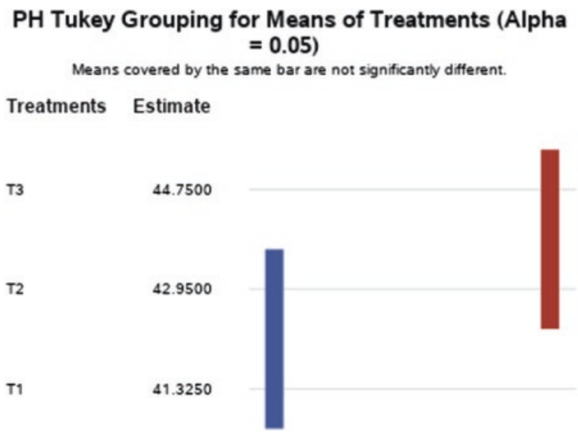


Table 2 Mean values of number of leaves per plant

		Days after planting	
Treatments	2WAP	4WAP	6WAP
T1	11.5 ± 0.6	23.5 ± 1.7	30.5 ± 0.6
T2	14.0 ± 0.4	27.0 ± 1.6	34.8 ± 1.3
T3	16.8 ± 0.9	30.8 ± 1.3	36.8 ± 1.3
$LSD_{0.05}$	3.1	2.9	2.5

Values are means with ± standard error of the mean

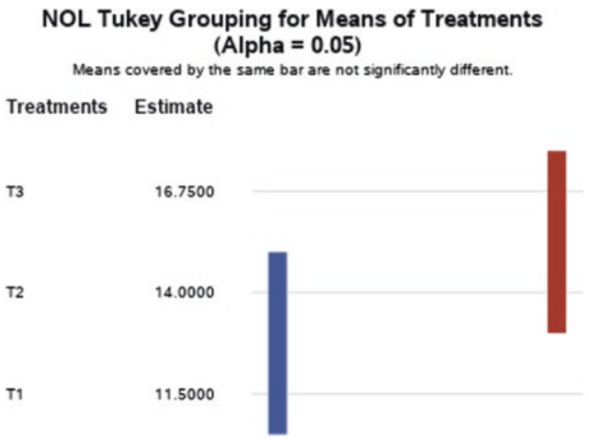


Fig. 4 Number of leaves (2WAP)

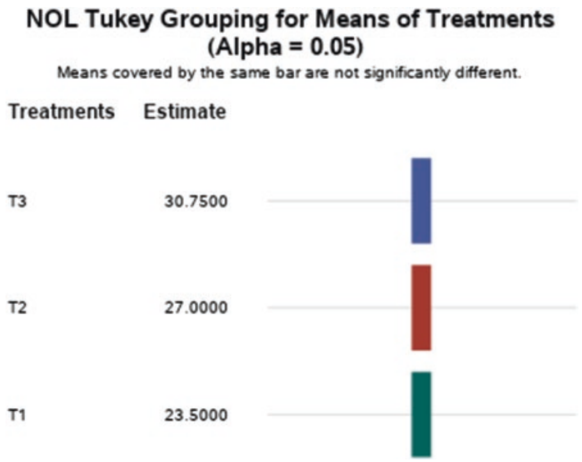


Fig. 5 Number of leaves (4WAP)

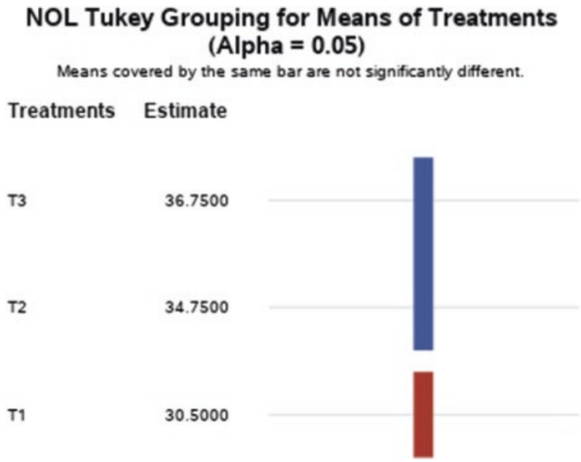


Fig. 6 Number of leaves (6WAP) **Means covered by the same bar are not significantly different by Tukey test at *P* < 0.05.**

growth phase. The results were similar to those of Abuga (2014), Ghoname et al. (2007) and Naik and Hosamani (2003), perhaps because plants with wider spacing have a tendency to receive more light than plants with narrow spacing. Plants that receive more light tend to produce more leaves than those which receive less light (Milthorpe & Mourby, 1979). In a nutshell, this could be interpreted as the plant getting more light has a successive rate of photosynthesis.

3.2 Effects of Different Spacing on the Yield Parameters of Red Onion

Figure 7 shows that the bulb diameters significantly varied ($P < 0.05$) among the treatments at the time of harvesting, and the values ranged from 1.8 cm to 2.4 cm (Table. 3). The length of bulb also showed a significant difference ($P < 0.05$) among the treatments (Fig. 8), ranging from 2.6 cm to 3.2 cm. In T3, the diameter and length of the bulb showed higher values compared to T1 and T2. This might be due to the accumulation of carbohydrates because of the successive rate of the photosynthetic process. In other words, it could be interpreted as a higher supply of food materials to the bulb where the plants grown at wider spacing had decreased competition for moisture, light and nutrients.

Data represented in Fig. 9 show that there was a significant difference ($P < 0.05$) in average weight of bulbs per plant among the treatments. The highest weight of bulbs per plant was obtained in T3 while T1 showed the lowest Increase in diameter and length of bulb contributed to increase in weight of bulbs per plant in T3. Average weight of bulbs per plant ranged from 28.9 g to 43.8 g.

Fig. 7 Bulb diameter (cm)

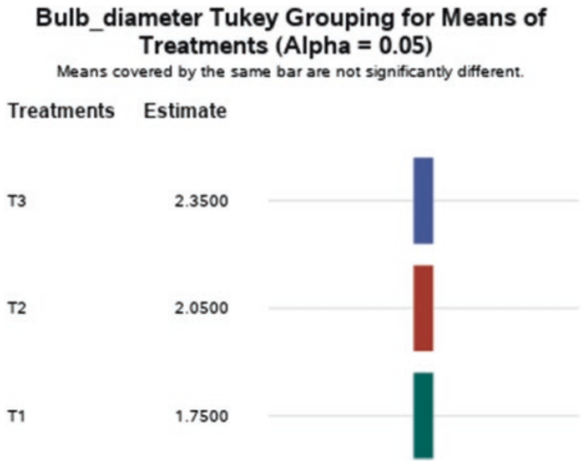
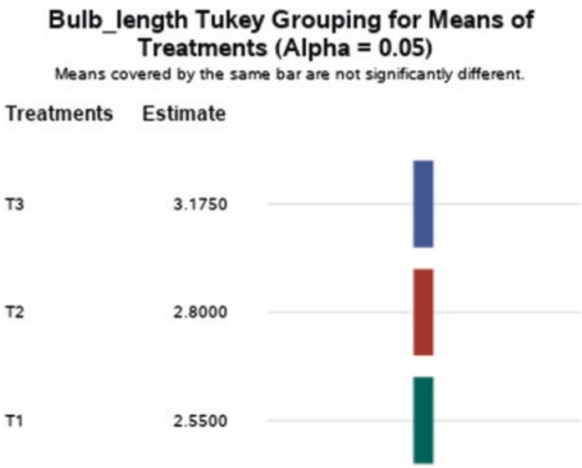


Table 3 Mean values for yield parameters

		Yield parameters	
Treatments	Bulb diameter (cm)	Bulb length (cm)	Weight of bulbs per plant (g)
T1	1.8 ± 1.2	2.6 ± 0.8	28.9 ± 0.5
T2	2.1 ± 0.7	2.8 ± 0.8	36.6 ± 0.2
T3	2.4 ± 0.6	3.2 ± 0.6	43.8 ± 0.2
$LSD_{0.05}$	0.1	0.1	0.8

Values are means ± standard error of the mean.

Fig. 8 Bulb length (cm) **Means covered by the same bar are not significantly different by Tukey test at *P* < 0.05.**



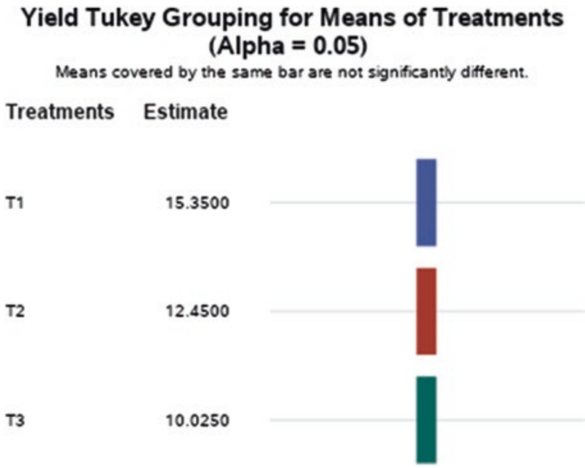


Fig. 9 Average weight of bulbs per plant (g)
Means covered by the same bar are not significantly different by Tukey test at *P* < 0.05.

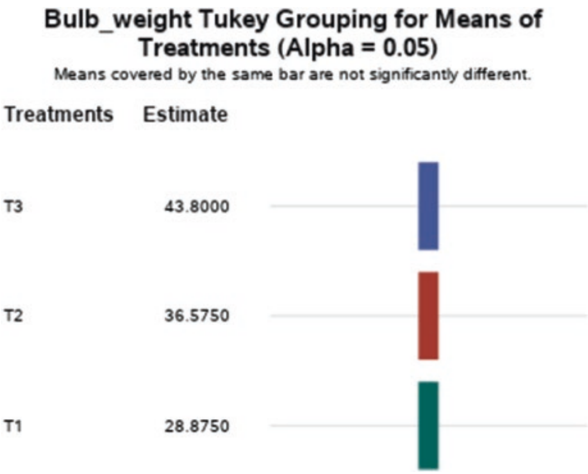


Fig. 10 Average total yield (t/ha)
Means covered by the same bar are not significantly different by Tukey test at *P* < 0.05.

In general, heavier bulbs were produced in wider spacing because of the lower competition of plants for limited resources compared to plants in narrower spacing. This may due to higher assimilation and accumulation ofmore dry matter in the bulbs. The results of the study revealed that the red onion variety "Vallarai" performed better in terms of yield parameters under wider spacing (10 cm × 10 cm) because of less plant population per unit area. Results was in conformity with Gupta (1991), who reported high fresh bulb weight with the wider spacing of 15 cm × 10 cm.

Furthermore, in the current study, the total bulb yield differed (Fig. 10) significantly ($P < 0.05$) in terms of different spacing. Average yield started at 15.35 t/ha to 10.02 t/ha. The highest average total yield or best performance was obtained in T1 (5 cm × 5 cm) where the red onion grew in higher plant density with the closest spacing compared to the yield of T3, which was produced with the widest spacing (10 cm × 10 cm). This was supported by the findings of Karsanbhai (2003) and

Misra et al. (2016) who showed high yield at less spacing. The maximum yield of onion in the closest spacing was due to more plants being grown in a unit area, which impacts the total average yield. However, the length and diameter of bulbs in the closest spacing were relatively small compared to T3. However, it may not be a suitable product for marketing as the customers do not prefer it because of the inferior quality of the product. On the other hand, lower yields were observed in the wider row spacing. This is because of the collective effect of slower canopy closure, lower leaf area index and greater in-row competition, resulting in reduced light interception and fewer bulbs per plant, which will affect the total yield.

4 Conclusions

The use of appropriate agronomic management undoubtedly contributes to increasing any crop yields. Control of plant spacing is one of the key agronomic practices in the context of crop production and plays a crucial role in managing growth and yield parameters of red onion, especially bulb size, shape, weight and yield. Hence, the study was conducted and assessed in detail the performance of *var.* 'Vallarai' under dry zone condition with varying levels of plant spacing and recommends the appropriate plant spacing for red onion cultivation in Jaffna district. Accordingly, it could be concluded that the wider spacing (10 cm × 10cm) in T3 produced significantly ($P < 0.05$) high values for parameters of plant height, number of leaves, bulb length and diameter. The values decreased with the less plant spacing or the closest spacing (5 cm × 5 cm) in T1. Thus, the increase in growth and yield parameters recorded at wider plant spacing was probably due to having more nutrients and space, moisture availability, which enlarged bulb size. Similarly, high plant density implies closer spacing and ultimate reduction in space availability between plants. Because of the smaller spacing, bulb expansion was restricted. Contrarily, the total yield showed higher values in T1 with the closest spacing compared to the yield produced in the widest spacing (T3). But the size of bulbs in the closest spacing was smaller, and they were not suitable for distribution as the customers prefer high-quality larger bulbs.

The summary of the study shows that red onion planted in wider spacing produced high-quality large bulbs, which are preferred by the customers for obvious reasons. Red onion planted in narrow spacing produced many bulbs, benefiting the farmers in terms of high yield and economic benefits. Even though the narrow spacing generates high yield for the farmers, it is noted that the customers prefer to buy the high-quality product in the market. Therefore, the marketability of the low-quality product will be at stake and will result in financial loss to the farmers. Considering this, it is suggested to choose wider plant spacing (10 cm × 10 cm) when planting *var.* "Vallarai" in Jaffna district.

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Soil Potential Erosion Risk Calculation Assessment Using Geospatial Technique in Keonjhar District, Odisha, India

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Abstract The greatest threat to our economic and environmental well being is soil erosion. GIS is used to estimate erosion rates over a number of terrains. Soil erosion has been investigated in mines and forest covered with drainage in Odisha. We used the newly developed Revised Universal Soil Equation (USLE), which integrates a Geographic Information System (GIS) to quantify soil loss. A high degree of slope mainly affects the topsoil and fertility in agricultural land in contour farming. In Keonjhar district, soil erosion estimation is necessary because the population in that region is increasing. Also, extraction of minerals has been started in many regions, which causes deforestation and also affects the loss of agricultural land. About 80% of the population is agriculture-dependent, and about 1,1976,000 Million tonnes. minerals have been extracted from the district in the mineral sector, which involves the rest of the population and much less of the population in the tertiary sector economy. Hence, soil erosion must be controlled with planning. This study, through a Revised Universal Soil Loss Equation (RUSLE) model, estimates the soil loss of Keonjhar District, Odisha. Various analyses are done in the district with addition of land use and land cover, slope variation, types of soil, rainfall, flow accumulation

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and various inner calculations. In the study area, 0–10 t ha^{-1} year^{-1} having 36.31% area is in the weakly severe zone, 10–20 t ha^{-1} year^{-1} is moderately severe, having 27.69% area covered, 20–30 t ha^{-1} year^{-1} is strongly severe, having 16.57% area covered, 30–40 t ha^{-1} year^{-1} is very strong, having 11.82% area covered, and the extremely strong severe zone for soil loss is 40 t ha^{-1} year^{-1} and above, covering 7.61% area of the annual potential soil loss.

Keywords RUSLE · Factors · Keonjhar · Soil Loss

1 Introduction

Sedimentation is an important issue in agricultural land use and is present in modern times all over the world (Lu & Liu 2003; Kim et al., 2005). Loss of soil nutrients is regarded as one of the greatest problems because it increases riverbed sedimentation and decreases the storage capacity and water retention in rivers and reservoirs (Devatha et al., 2015). Sea environments have a variety of human and natural interactions but face additional issues due to anthropogenic and naturally occurring flooding and seasonal erosion, river floods and natural disasters (Vinayaraj et al., 2011; Monalisha & Panda, 2018). During soil loss, topsoil nutrients and minerals essential for plant growth are also lost. Ultimately they are deposited in rivers as sedimentation and decreases the area of the storage capacity of river basins and plants will get less water than they did before from that river basin (Devatha et al., 2015). The erosion process due to water mostly in mining area and also in urban expansion regions is mainly caused by the kinetic energy of cutting soil through water pressure, transporting and depositing soil particles. Soil loss threatens sustainable development of humans and also the biophysical characteristics of the environment (Lal, 1998). Soil loss not only affects the phenomenon of agricultural land productivity but also many other fields like mining, mountains and hills, rivers, and so on (Parveen & Kumar, 2012). Degradation of soil caused by the water is estimated at about 110 Mha and due to wind is about 550 Mha (Saha, 2003).

Soil erosion results from the destruction of soil caused by human activity (Bai et al., 2008). Water flow leads to land quality problems, such as sheet erosion through creek formation, soil transport and accumulation in the catchment area (Tideman, 1996; Fernandez et al., 2003). The severity of soil erosion in India is among the many serious issues there (Narayana & Babu, 1983). Against the spatial, economic, environmental and agricultural background, a full assessment of the erosion problem is required (Ganasri & Ramesh, 2016). A soil erosion control measure would be reducing the loss of soil and water to the point that it won't cause further deterioration (Karthick et al., 2017). Higher rates of erosion are necessary for use in coastal India's land-use planning and soil conservation. The land assessment of soil erosion and soil degradation would be helpful in matching suitable soil protection and ecosystem management strategies (Shi et al., 2004). Mean soil depreciation per land area can be calculated using the Universal Soil Equation (USLE) (Wischmeier & Smith, 1978; vanRemortel et al., 2001; Lee & Lee, 2006).

Remote sensing and GIS techniques have better capacities for measuring the size and extent of erosion at larger spatial and temporal scales. They have been employed in a number of projects that demonstrate the effectiveness of remote sensing integration in soil mapping (Parveen & Kumar, 2012). Soil erosion is caused by many factors, such as rainfall intensity, susceptibility, soil erodibility and land use practices. To determine soil loss, its spatial distribution needs to be considered while evaluating erosion (Bera, 2017). Using both geographic and spatial knowledge to plan on soil erosion contributes to environmental protection and land management. Identifying erosion-prone locations and obtaining quantitative soil loss assessments are critical for development and implementation (Sharda et al., 2013). In view the above aspects, a case study was attempted in Keonjhar District, which covers the major mines and some forests in the river bed region to estimate the soil erosion.

2 Study Area

Keonjhar district is in Odisha state, India, as shown in Fig. 1. On January 1, 1948, Kendujhar district was established. Once the whole district was a princely state according to old Khijjinga territory history, in modern Khiching. During the first half of the twelfth century it became a separate state with Jyoti Bhanja as its ruler.

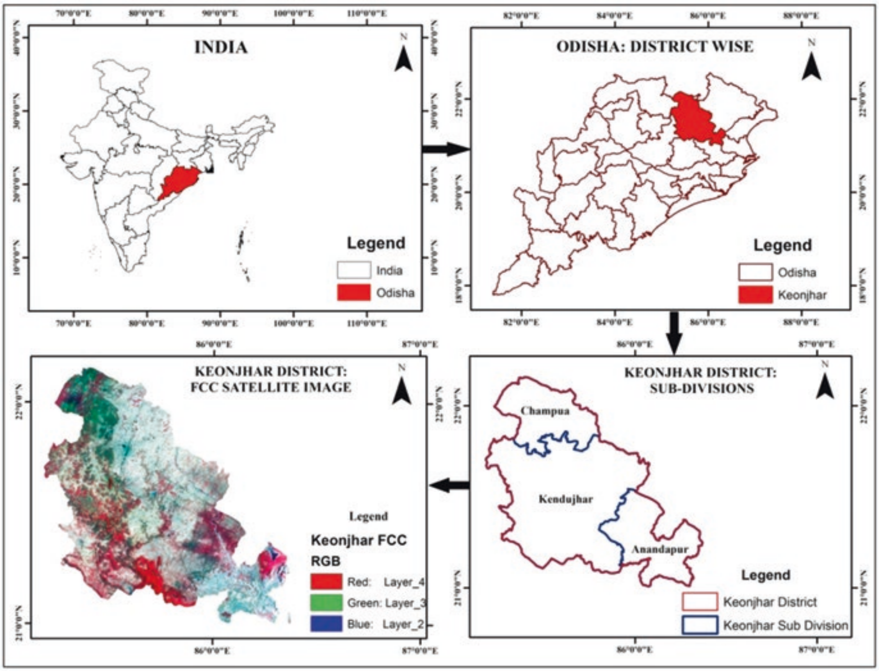

Fig. 1 Study area

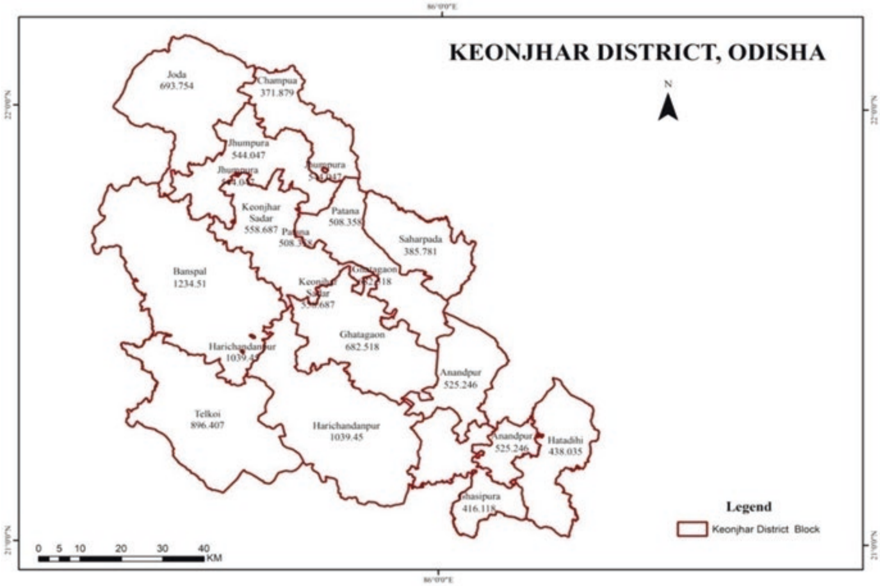

Fig. 2 Keonjhar District blocks

Now, the area covered by Keonjhar district is 8240 km^2. The population is 18.2 lakh; the number of subdivisions is three, with 13 total blocks: Anandpura, Banspal, Champua, Ghasipura, Ghatgaon, Harichandanpur, Hatadih, Jhumpura, Joda, Kendujhar, Patna, Saharapada and Telkoi, shown in Fig. 2.

The surrounding districts are Mayurbhanj and Bhadrak to the east, Jajpur district to the south, Dhenkanal and Sundargarh districts to the west, and West Singhbhum district of Jharkhand state to the north. The weather and climate of Keonjhar district is oppressively hot with high humidity and cold with low humidity and prolonged erratic rainfall; 75% of monsoons occur between the second week of June and up to September; the remaining 25% monsoons occur between October to December. Temperature in winter goes to 7° C (District census, 2011). Paddy, moong, groundnut, wheat, maize, mango, sugarcane, tomato, jute, mustard, potatoes and so on. About 80% of livelihoods is provided by traditional agriculture and vegetables during Rabi, Kharif and Zaid seasons (Keonjhar portal).

3 Different Mode and Parameters for RUSLE

Estimation of soil erosion can be considered in different ways; these methods can vary from simple to complicated. Each method for estimation also differs in their data collection, data input and ability to predict soil erosion risk in the study area. The soil degradation, sedimentation yield and erosion may extend in area, which

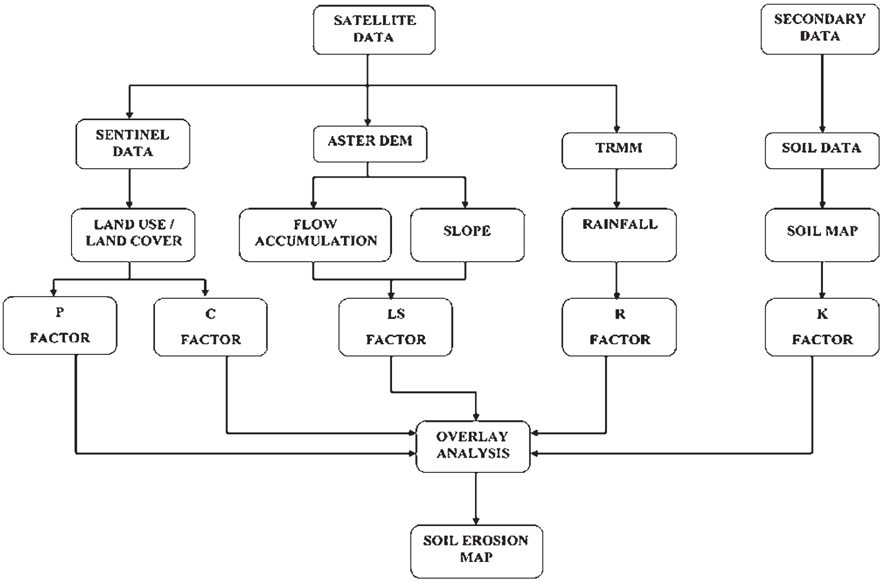

Fig. 3 RUSLE model flow chart

mainly comes from areas more prone to geological features, topography, land cover, human-made development, fallow land and loose soil categories. Through remote sensing and GIS, the RUSLE model is most widely used to predict long-term temporal estimation of soil degradation and soil erosion, which is carried by different agents like water or air and help in the management practices on farm land, which is mostly affected.

The Revised Universal Soil Loss Estimation (RUSLE) is developed based on many years of temporal data from about 10,000 small plots for testing throughout the United States by Wischmeier and Smith (1978), which has 22 m flow length. All are operated in the same manner, allowing the soil loss calculations to be combined into a predictive tool. Earlier in 1978, a new research USLE publication was developed to incorporate the RUSLE model (Wischmeier & Smith, 1978). Planning for agricultural conservation is guided by Agriculture Handbook 703 (Renard et al., 1997) with the RUSLE. The eroded minerals and particles are not source limited; capacity of flow is limited by erosions. Whenever the sediment loads exceed the carrying capacity of the flow, detachment can no longer occur. Figure 3 shows the flow chart of the RUSLE model.

Revised Universal Soil Loss Equation (RUSLE) remained the basic form, but some factors are changed. USLE and RUSLE are used in GIS, and remote sensing for the calculation of average annual soil erosion estimated on field of contour and slopes and the equation for RUSLE are shown in Eq. (1).

$$\mathbf{A} = \mathbf{L} \times \mathbf{S} \times \mathbf{P} \times \mathbf{R} \times \mathbf{K} \quad (1)$$

where:

A = A mainly denotes spatial and temporal average soil loss estimation per unit area; these are usually selected so that A is expressed in ton × acre^{-1} × year^{-1}, but other units can be selected (that is, ton × ha^{-1} × year^{-1});
R = R is denoted as runoff erosive calculated from annual or monthly rainfall (100 ft × tonf × acre^{-1} × year^{-1});
K = K shows the soil erodibility factor where the soil erosion at a rate of dismissal of soil loss index unit for a specified soil texture;
L = slope length factor, which is mainly shown from flow accumulation;
S = slope steepness factor, which shows the slope value in percent in all angles;
C = cover management factor shows the soil loss in specified land use and land cover;
P = support practice factor is mainly a support practice like contouring, strip cropping or terracing to soil loss with straight-row farming up and down the slope.

4 Slope Length (L) and Slope Steepness (S) Factor

Digital elevation model (DEM) has 30-m resolution from the cartosat 1. LS factor is slope length and slope gradient factor shown in Fig. 4. It mainly represents the ratio of soil erosion or soil loss under various applied conditions to that at field value

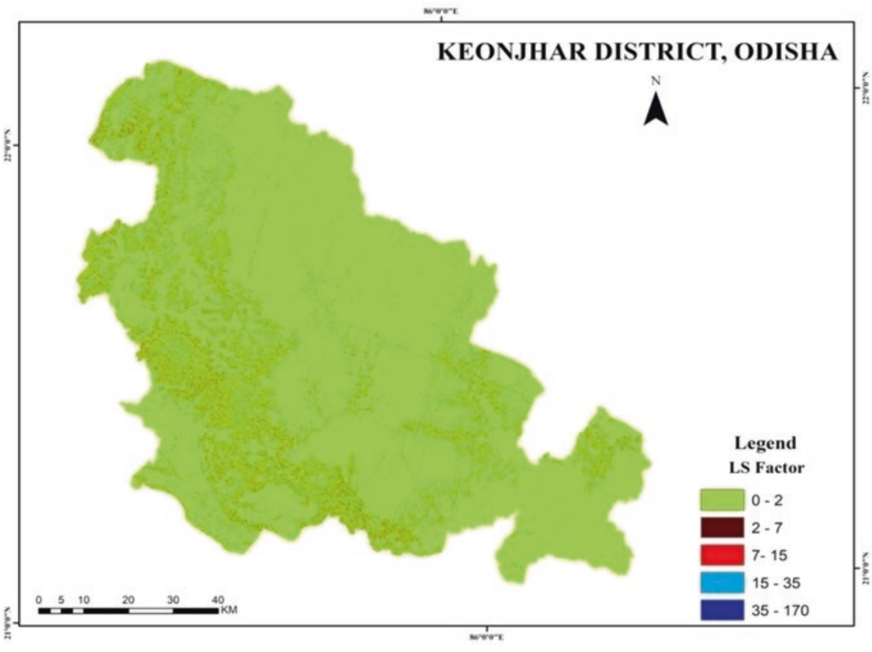

Fig. 4 LS factor map

with the standard slope steepness of 9% or more and the slope length of about 22.15 m or above. The higher the value of slope value, the higher the risk for soil erosion is (Stone & Hilborn, 2012). First DEM data go under preprocessing before LS factor calculation and spatialization. Flow accumulation first calculated from DEM data with fill sinks and flow direction and the slope calculation in degrees for each cell and slope percent wise for the LS factor calculations. The following Eqs. 2, 3, 4, 5, 6, and 7 (Vela Squez, 2013) are used to calculate the factors in ArcGIS 10.5, and Eq. 7 is used in a raster calculator for the Keonjhar district LS factor calculations:

$$\mathrm{F} = \frac{\sin(\text{slope} \times 0.01745 / 0.0896}{3 \times \text{Power}\left(\sin\left(\text{slope} \times 0.01745\right).0.8\right) + 0.56} \tag{2}$$

$$M = \text{“}F\text{”}\left(1 + \text{“}F\text{”}\right) \tag{3}$$

$$\mathrm{L} = \frac{\text{Power}\left(\left(\text{Flow accumulation} + 900\right), \left(M + 1\right)\right) - \text{Power}\left(\text{Flow accumulation}, \left(M + 1\right)\right)}{\text{Power}\left(30, \left(M + 2\right)\right) \times \text{Power}\left(22.13, M\right)} \tag{4}$$

$$\begin{aligned}\mathrm{S} = \text{con}[&\tan\left(\text{slope} \times 0.01745\right) < 0.09, \left(10.8 \times \sin\left(\text{slope} \times 0.01745\right) + 0.03\right)\\ &\left(16.8 \times \sin\left(\text{slope} \times 0.01745\right) - 0.5\right]\end{aligned} \tag{5}$$

$$\mathrm{LS} = \text{“}\mathrm{L}\text{”} \times \text{“}\mathrm{S}\text{”} \tag{6}$$

$$\begin{aligned}\mathbf{LS} = &\left(\left(\text{“Flow accumulation”} \times 30 / 22.13\right)\hat{}\, 0.5\right) * (0.065 + 0.045 \times \text{“Local slope gradient}\left(\text{percent wise}\right)\text{”}\\ &+ 0.0065 \times \text{“Llocals Slope gradient}\left(\text{percent wise}\right)\text{”} \times \text{“Llocals Slope gradient}\left(\text{percent wise}\right)\text{”))}\end{aligned} \tag{7}$$

LS is a factor which shows slope steepness and slope length factor with spatial resolution of 30-m resolution.

5 Soil Erodibility Factor (k factor)

The K factor is a soil erosivity factor which is defined as the rate at which different soil erosion occurs. K factor values show the rate of soil loss per rainfall erosivity (R) factor denoted in Fig. 5. This is not actual soil loss as it depends on the various other factors like rainfall, land use and land cover, slope and so on. The source of the soil texture shape file is prepared from the Odisha space application center report prepared by the National Bureau of Soil and Land Use Planning. Various categories of soil texture are found in the district, such as organic matter content, loamy and sandy texture, silt texture and many other related compounds of soil, which are critically used for the factor analysis.

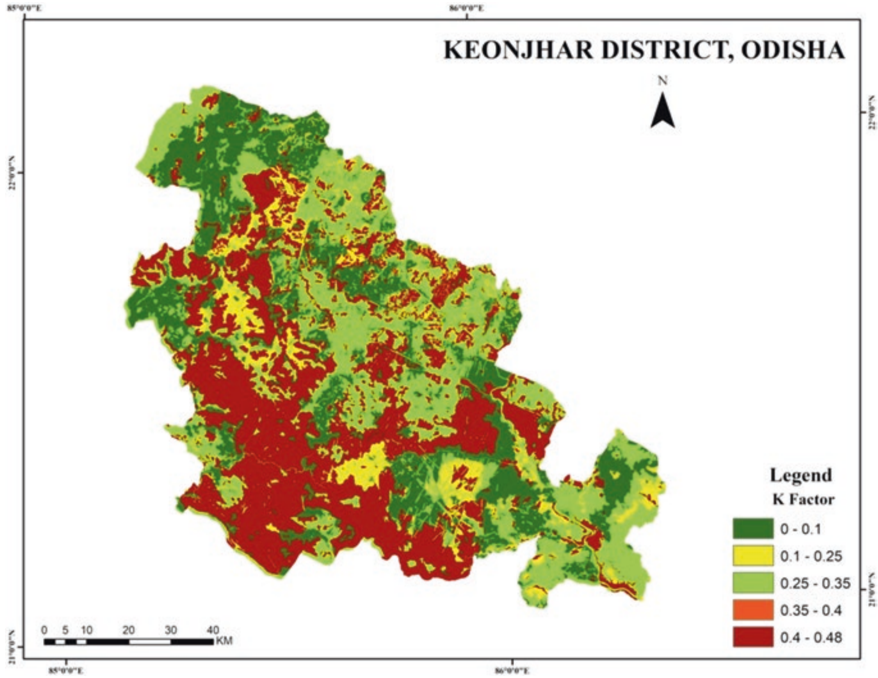

Fig. 5 K factor map

In present study of soil erodibility of Keonjhar district, the K factor is the relationship between organic matter content and soil texture forms proposed by (Schwab et al., 1981). With different soil classes, the soil erodibility factor (K) is presented in Table 1 (Schwab et al., 1981).

6 Land Cover and Crop Management Factor (C factor)

Protection of soil from erosion can be controlled mostly by various subcategories of vegetation cover. The ratio of soil erosion or soil loss from crop land or fallow land under some circumstances corresponds to erosion from slope steepness and continuous fallow land (Wischmeier & Smith, 1978). Presently, a remote sensing temporal data set is used for the various classifications of land use and land cover, and through GIS one can calculate the assessment of various factors including C Factor (Karydas et al., 2009). Land use and land cover have a close linkage with C factor (Prasannakumar et al., 2012). Sentinel 2A data of 10 m spatial resolution are used for classification with a supervised classification technique (Fadil et al., 2011). Land use and land cover types are: crop land (25.9%), fallow land (21.33%), dense forest (24.23%) and sparse forest (20.67%). The values assigned are shown in Table 2, and C factor evaluated map is shown in Fig. 6; 0.05 – 1 is the assigned value of C factor to dense forest to barren land, respectively.

Table 1 Values of soil erodibility factor

Soil texture	Amount of organic matter (%)		
	0.5	2.0	4.0
Silty clay	0.25	0.23	0.19
Fine sand	0.16	0.14	0.1
Silt clay loam	0.37	0.32	0.26
Very fine sand	0.42	0.36	0.28
Clay loam	0.28	0.25	0.21
Loamy sand	0.12	0.10	0.08
Silt loam	0.78	0.42	0.33
Loamy very fine sand	0.44	0.38	0.30
Loamy very fine sand	0.47	0.41	0.33
Sandy loam	0.27	0.24	0.19

Table 2 Cover management factor (C)

S.N.	Land cover type	Cover management factor (C)	Area covered (km^2)	Area (%)
1	Water body	0	100.09	1.21
2	Dense forest	0.05	2010.68	24.24
3	Spars forest	0.10	1714.42	20.66
4	Crop land	0.60	2150.64	25.93
5	Fallow land	0.50	1769.43	21.33
6	Barren land	1	48.99	0.59
7	Settlement	0	218.41	2.63
8	Shrub land	0.2	128.58	1.55
9	Mining	1	154.54	1.86

7 The Support Practice Factor (P factor)

P stands as a support practice factor in RUSLE. Mostly three types of activity are calculated through p facto: strip-cropping, contouring and terracing by RUSLE. It is unit-less. Figure 7 shows the P factor, which is defined as the ratio of soil erosion with a specific P factor value mentioned in Table 3 to high slope and down slope steepness (Shin, 1999).

8 The Runoff Erosivity Factor (R factor)

Erosivity response due to explicit rainfall is defined as rainfall erosivity (R factor). R factor is computed as a multi- or single storm nature as it has different functions like volume intensity, duration and acidic content (Prasannakumar et al., 2012). For calculating the R factor values, the original form of the USLE and RUSLE in their original equations requires rainfall amount (mm), intensity (mm h^{-1}) and the maximum 30 min intensity (mm h^{-1}). In most of the cases rainfall intensity data are not

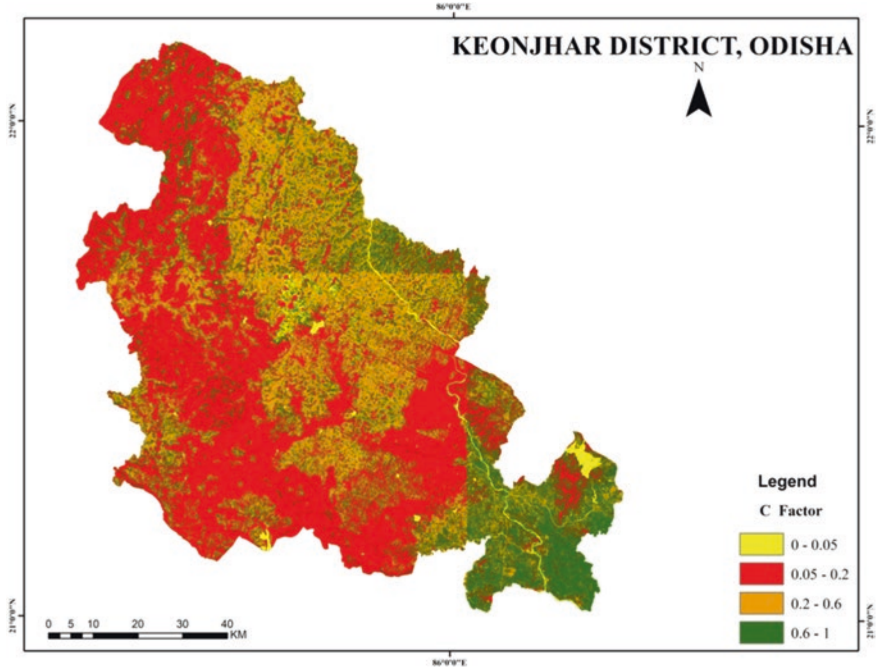

Fig. 6 C factor map

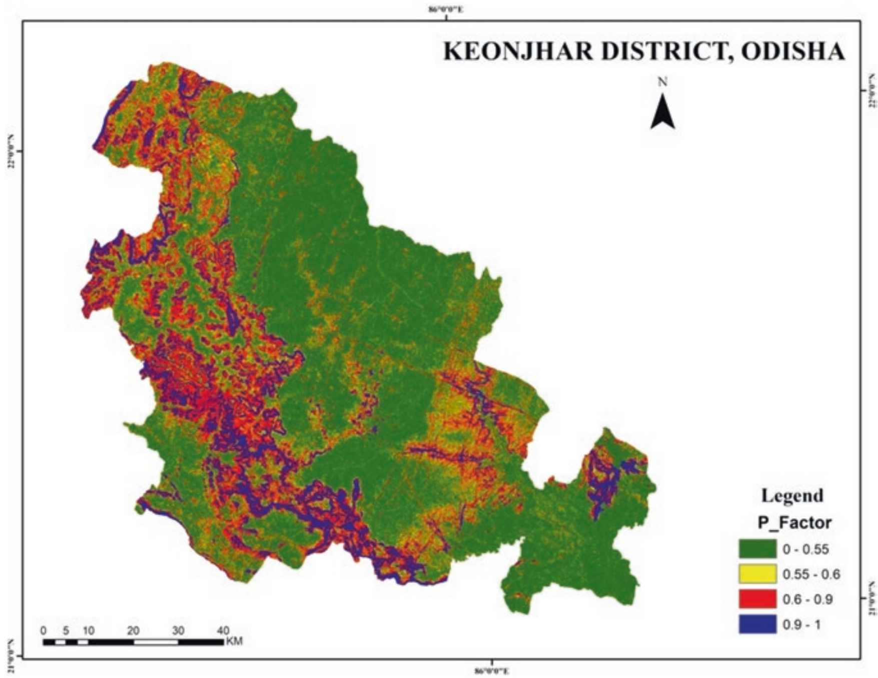

Fig. 7 P factor map

Table 3 Support practice factor (P)

S.N.	Slope %	Contouring	Strip cropping	Terracing
1	0.0–7.0	0.55	0.27	0.10
2	7.0–11.3	0.60	0.30	0.12
3	11.3–17.6	0.80	0.40	0.16
4	17.6–26.8	0.90	0.45	0.18
5	26.8 >	1.00	0.50	0.20

Table 4 Equations for *R* factor calculation

Sr. No	Equation	Source
1	$R = 79 + 0.363 \times AAP$	Singh et al. (1981)
2	$R = 50 + 0.389 \times ASP$	Singh et al. (1981)
3	$R = 0.1059abc + 53$	Singh & Phadke, (2006)
4	$R = 22.8 + 0.6400 \times AAP$	Ram Babu et al., (1979)
5	$R = 81.5 + 0.375 \times AAP$	Ram Babu et al., (2004)

AAP Average annual precipitation (mm), *ASP* Average seasonal precipitation (mm)

available for the correlation of rainfall erosivity, and hence many researchers calculate the soil erosivity factor. Different types of equations are developed for the calculations of R factor mentioned below in Table 4.

In Keonjhar district, R factor is calculated with the equation given by (Singh et al., 1981) for India. This equation is used in several other research papers for the calculation of soil erosivity factor and mentioned in Eq. 8 (Ban et al., 2016; Karthick et al., 2017; Dewangan & Ahmad, 2019). Monthly rainfall data are used to calculate R factor, and source of data is the Odisha Rainfall monitoring system, year 2020.

$$R = 79 + 0.363 \times AAP \tag{8}$$

Arc GIS 10.5 is used for the calculation of the R factor map of Keonjhar district using IDW interpolation tool of spatial analyst extension shown in Fig. 8.

9 Results

Rainfall Erosivity Factor (R)

Many studies have shown that the rate at which soil erodes more or less depends on the rainfall factor (Jain et al., 2001; Dabral et al., 2008). Annual rainfall is used to calculate the R factor; it is available, computation is easy, and it has rigidity of data according to the region in the exponent (Shinde et al., 2010). Using the IDW interpolation technique in Arc GIS 10.5, calculation has been done in the Keonjhar district. R factor value ranges from 523.68 to 776.27 (MJ mm ha^{-1} $hr^{-1}year^{-1}$). The R factor analysis showed that Telkoi and Harichandanpur block received low rainfall, and Ghasipura, Hatadih, Anandpur and Ghatagaon received high rainfall and were priority zones for soil erosion.

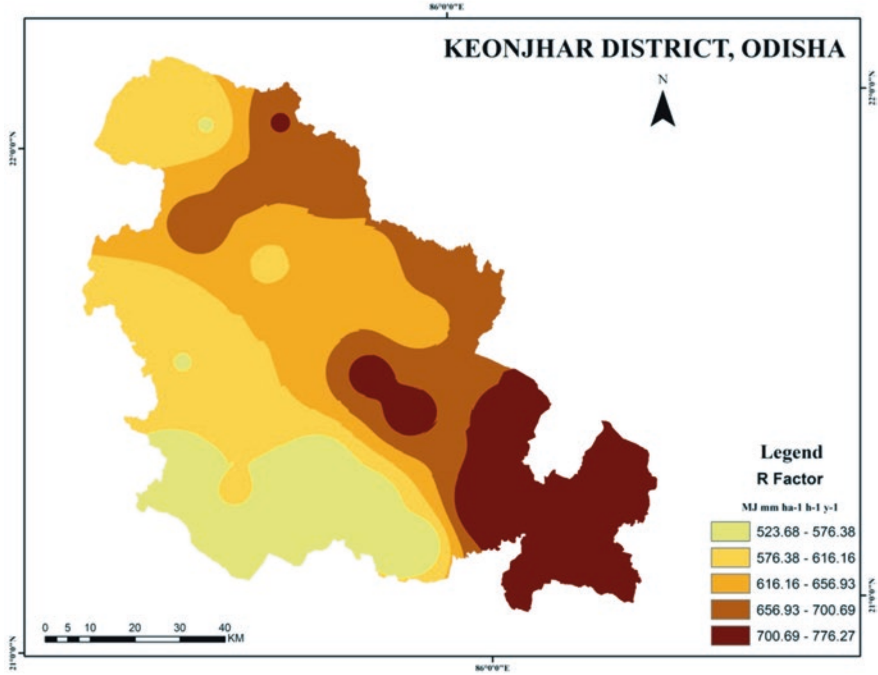

Fig. 8 R factor map

Soil Erodibility Factor (K)
Soil erodibility factor (K) values are assigned according to Table 1 on the soil texture of Keonjhar district to generate a soil erodibility map in Fig. 5. The values of K factor range from 0 to 0.48, as mentioned in Table 5 for Keonjhar district. A high value is assigned to high permeable soil and high moisture content.

Topographic Factor (LS)
LS factor is calculated with Eq. 7 in the raster calculator of Arc GIS, using Cartosat 1 DEM data with 30-m spatial resolution collected from the Bhuvan portal. Hence, the topographic factor is showing the slope length and slope steepness on the soil erosion process. The value is calculated with the layer of flow accumulation and slope in percentage as an input in the equation. The final LS factor map shows the value ranges from 0 – 170. The value of the factor increases as the flow accumulation and slope increases.

Crop management Factor (C)
Table 2 shows the C factor values assigned to the Keonjhar district features. Land use and land cover are used for proper analysis of zones that can be eroded and affect the development planning for the control of erosion in that area. Sentinel 2 data of 10 m spatial resolution are used for preparing the thematic layer of land use and land cover. Using land use-land cover maps and C factor values shown in Fig. 6, the C factor map was prepared. High value is given to the mining and crop land as these lands are directly eroded by human activity and water and air.

Table 5 K factor value assigned to Keonjhar district soil type

S. no.	Soil types	Area covered (km^2)	K factor
1.	Clayey skeletal, mixed hyperthermic, Fluventic Ustochrepts	2.02	0.25
2.	Coarse loamy, mixed hyperthermic, Fluventic Ustochrepts	1407.35	0.44
3.	Fine loamy, mixed hyperthermic, Fluventic Ustochrepts	787.48	0.27
4.	Fine, mixed hyperthermic, Typic Ustochrepts	1111.62	0.28
5.	Fine, mixed hyperthermic, Udifluventic Ustochrepts	544.25	0.23
6.	Habitation	206.39	0.28
7.	Loamy, mixed hyperthermic, Lithic Haplustalfs	158.29	0.26
8.	Loamy skeletal, mixed hyperthermic, Fluventic Ustochrepts	233.58	0.26
9.	Mixed hyperthermic, Typic Ustipamments	0.24	0.28
10.	Sand skeletal, mixed hyperthermic, Lithic Ustorthents	13.54	0.42
11.	Sandy, silicious hyperthermic, Lithic Ustorthents	1.47	0.48
12.	Unidentified	2032.91	0
13.	Water body	194.39	0.28
14.	Fragmental, mixed hyperthermic, Lithic Haplustalfs	1621.17	0.42

The Support Practice Factor (P Factor)

In Keonjhar district, values assigned to the P factor are according to Table 3 for contour farming. Slope steepness depends on the support practice factor. When the percent of slope increases, the soil-holding capacity is decreased, raising chances for soil erosion. Figure 7 shows the P factor; most hilly areas have high P factor values.

Soil Loss Estimation (A)

The estimation of potential annual soil loss is done using the RUSLE model equation by the product of factor P, LS, K, C, and P in the equation using geospatial technology. In Arc GIS 10.5, the raster calculator from the map algebra tool of spatial analyst toolset is used for the calculation of soil loss annually. Table 6 shows the soil erosion severity zone with the area covered by each zone. The means annual soil erosion rate in Keonjhar district is 0 to 36997 t ha^{-1} $year^{-1}$. For soil conservation, implementation can be done according to the prioritization of the study area, and severity prioritizations are also given in Table 6. In the final soil loss map shown in Fig. 9, Block Banspal, Telkoi and Harichandanpur are in the southwest, extreme North side of Joda block, and Anandpur block in the southeast zone has strong to extremely strong zones for soil loss. Most of the zone comprises hilly areas and mining areas. Crop land is mostly in the middle of the district and eastern side where there is only a strong zone for the soil loss severity. In the study area, 0–10 t ha^{-1} $year^{-1}$ having 36.31% area is a weakly severe zone, 10–20 t ha^{-1} $year^{-1}$is moderately severe having 27.69% area covered, 20–30 t ha^{-1} $year^{-1}$ is strongly severe having 16.57% area covered, 30–40 t ha^{-1} $year^{-1}$ is very strong having 11.82% area covered, and lastly the extremely strong severe zone for soil loss is 40 t ha^{-1} $year^{-1}$ and above and covers 7.61% area of the annual potential soil loss. The results reveal

Table 6 Annual soil loss rates and severity classes with their conservation priority in the study area

Soil loss (t ha^{-1}year^{-1})	Severity zones	Priority classes	Area (km^2)	Percent of total area
0–10	Weak	V	3011.84	36.31
10–20	Moderate	IV	2296.83	27.69
20–30	Strong	III	1374.45	16.57
30–40	Very strong	II	980.44	11.82
40 >	Extremely strong	I	631.23	7.61
Total			8294.79	100%

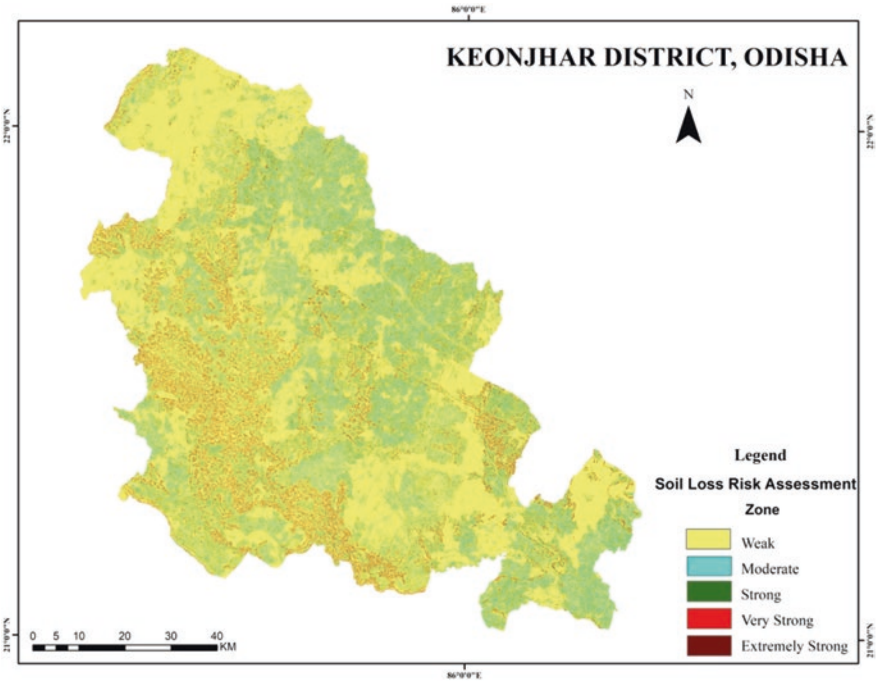

Fig. 9 Map showing soil erosion risk zone

that crop land, mining, sparse forest and a hilly zone which covers about 72.69% of the total Keonjhar district areas have strong to extremely strong severe soil loss; the remaining 27.31% area is land use and land cover of weak to moderate soil loss.

10 Conclusions

Revised Universal Soil Loss Estimation (RUSLE) is used for the prediction or estimation of spatial distribution of various soil erosion severities in land use and land cover and can help in adoption of the appropriate soil conservation planning and techniques according to the severity and area covered. Through remote sensing and GIS study, one can easily demonstrate the planning and technique for soil conservation and development in the entire three sectors of the Indian economy. Socioeconomic problems can be resolved easily with RUSLE-3D model with GIS various tools for identifying spatial features of severe soil loss prone zones. The result of the calculation of RUSLE gives information of annual average soil loss in spatial distribution land classification for the adoption of proper and suitable conservation techniques for protecting soils from further erosion. RUSLE method is often used by researchers for the conservation of soil resources. Therefore, the study of RUSLE in Keonjhar district has the following policy implications:

- For accelerated land degradation, there should be a sustainable and suitable method for soil conservation strategies in the strong zones.
- The vegetation cover of the land should be improved to reduce the removal of soil organic matter.
- The water-holding capacity and nutrient availability of the soil should be increased by applying biological and agronomic conservation schemes to increase agricultural productivity and minimize biodiversity loss in the area.
- The farmers should be included in all such schemes as active participants.

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Part III
Agriculture Sustainability and Sustainable Development and Environmental Management

Organic Farming Sector of India – A Statistical Review and Recommendations

Manavalan

Abstract During the year 2019–2020 India devoted 2.3 million hectares of land to the organic farming sector and became the world's biggest producer of organic farming products. In relation to this, this article reports the yearly progress details of India's organic farming sector in chronological order, analyzing the growth of the organic farming sector in India and its major milestones. Authenticated data pertaining to the key indicators of India's organic farming sector from 2003 to date have been collected and analyzed. Data pertaining to land-related key indicators such as areal extent of organic land, areal extent of wild collections, number of organic producers, processors, and exporters in India as well as organic market-related factors such as production quantity, export volume, and export value are analyzed in detail. Wherever required, both the source data and outcome of the analyzed results were cross validated using multiple reference articles and web content mining. At the end, the importance of developing and deploying a Geographic Information System-based Decision Support System (GIS-DSS) under the banner of the National Organic Farming Atlas of India is recommended, which will certainly enhance the growth status of the organic farming sector of India right from the taluk, district, and state level.

Keywords Organic farming · Key indicators · National Organic Farming Atlas of India

1 Introduction

Health hazards associated with the continuous use of chemical fertilizers in agricultural farms have been well analyzed by worldwide researchers, and their adverse effects on the environment as well as humans have been proved beyond doubt. Due

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to the large scale of health issues associated with the consumption agricultural products grown using synthetic chemical fertilizers, health experts and agricultural scientists are keen to gradually downsize and shift the existing chemical-based agricultural practices to a completely organic-based approach. In this regard, enough awareness has been raised among worldwide citizens and many nationals from developed and developing countries, who are looking for branded, certified organic products for their daily consumption. Such awareness leads to the exponential growth of worldwide organic farming industry, and its impact can be seen in the export sector of organic farming industry products, which is growing every year.

In India, a similar competitive growth trend is already observed as the key indicators of the organic farming sector of India have exhibited exponential growth since 2003, and respective details have been analyzed andreported in the rest of this article. A major gap exists worldwide in knowledge about developing and deploying domain-specific Information Technology (IT)-based tools that can be integrated into the operational and monitoring environment of the organic farming sector of any country. To be specific, a customized geo-analytical tool that can map, monitor and forecast the growth status of organic farming commodities of a specific region can be developed. When such a geographical information system (GIS) is integrated with data from district, state and national levels, voluminous geospatial information pertaining to the organic farming sector of a region as well as overall nation is provided. Effective analyses of such voluminous data also need the support of analytical algorithms which help to bring out many insights and foresights of organic farming sectors from the local to district, state and national levels. During the year 2019–2020, Sri Lanka, an island country in South Asia, implemented complete organic farming practices by banning the import of chemical fertilizers. However, due to poor estimation of demand-yield agricultural-analytical studies, which hindered by Covid-19-related issues, the country went into a severe economic crisis in 2021. This might have been avoided if an IT-based geo-analytical system had been developed and implemented in the organic farming sector. Even in the case of India, any such IT-based geo-analytical system developed for the organic farming sector, which can integrates information from local to regional scale, has yet to be developed. Any such integrated analytical system will certainly enhance the growth of the organic farming sector of any country as well as be useful in monitoring the growth status of organic farming commodities from the local farm to national level.

2 Objectives

The objectives of this article include:

(i) Study of the organic farming sector of India (including chronologically listing the Government of India's key initiatives and major milestones)
(ii) Analyzing the current role and usage details of IT and ITES (Information Technology Enabled Services) of the organic farming sector and identifying

the digital gaps of the IT and ITES sector that can enhance the profitability of organic farming sector of India

(iii) Data analytics of major key indicators of the organic farming sector of India

(iv) Describing the need and significance of developing and deploying local to regional scale geo-spatial analytical solutions that can enhance the growth of the organic farming sector of India

(v) Describing the need and significance of developing advanced data analytics solutions which can address the nation level challenges of the organic farming sector of India

This chapter is arranged as follows: Section 3 gives the details about the materials used and method of approach. Section 4 gives a short overview of the international scenario of the organic farming sector. The first objective of this article is discussed in detail in Sect. 5. The second objective is discussed in Sects. 6 and 7. Sections from 8, 9, 10, 11, 12, and 13 form the core theme of this article as well as address the third objective of this article. Sections 14 and 15 respectively discuss the details related to the fourth and fifth objectives. Section 16 concludes the article with details of overall observations and recommendations.

3 Materials Used and Method of Approach

This article is primarily based on the in-depth study of listed references from where much required critical as well as authenticated information is extracted through text mining techniques. To be specific, FiBL & IFOAM Organic International reports from 2005 to 2021 (listed as references Willer & Yussefi, 2005, 2007; Willer et al., 2008, 2013, 2020, 2021; Willer & Kilcher, 2009, 2010, 2011, 2012; Willer & Lernoud, 2014, 2015, 2016, 2017, 2018, 2019) provide information about land and human groups related to key factors of organic farming sector in India but these reports alone are not sufficient to meet all the objectives of this article. Hence, information from other listed references were also extracted through a text mining approach as well as cross validated with the information published under Agriculture & Processed Food Products Export Development Authority (APEDA) web portal of Government of India (listed under online database/Web References 1 to 6). In addition, articles focused on the Indian context by Deshmukh, 2015; Makadia & Patel, 2015; Manaloor et al., 2016; Baisakhi Mukherjee, 2017a, b; Mukherjee et al., 2017; Bisoyi & Das, 2017; Ummyiah et al., 2017; Sathiya & Banumathy, 2017; Mamgain, 2019, and Raghuveer Singh et al., 2019 and the PhD thesis of PriyaSoni, 2017 were also considered. The available information was not sufficient to describe the two-decade-old trends of organic farming key indicators of India. To overcome the limitation as well as to fill in the missing details, the authenticated information submitted to the Parliament of India (Lok Sabha) against specific organic farming-related queries was used (Government of India, Lok Sabha (2020)). Moreover, huge efforts were made to check the authenticity and accuracy of extracted information by cross validating it between and across the references. Reports from a few banking and private sectors who have specifically studied the organic farming sector of India also were used to cross check the extracted data (Narayanan, 2005; Prahalathan et al., 2015; Charyulu & Biswas, 2010, 2016 and Dutta et al., 2017).

4 Overview of International Scenario of Organic Farming Sector

Worldwide, over 150 countries produce certified organic products in commercial quantities. In the context of business potential, it is estimated that by 2022 the global market for organic food will reach $327,600 million (Ref. 7). Based on regional geography, the organic food and beverage market sector has been segmented into North America, Europe, Asia Pacific, and LAMEA (Latin America, Middle East and Africa). As of 2020, North America holds largest market share and is expected to continue the market dominance till 2022. At the same time, the Asia-Pacific organic industry has the fastest growing market share roughly estimated with a Compound Annual Growth Rate (CAGR) of 22.9% (Ref. 8). Based on this, it can be confidently said that the demand for organic food products is steadily increasing in both developed and developing countries with an estimated annual average growth rate of 20–25%, which varies from region to region and at the country level (Refs. 7 and 8).

With reference to adopting standards in the organic farming sector, the first act was evolved by the European Union in 1991 and required moving towards eco-friendly sustainable agricultural practices (Ifadis et al., 2004). Australia is the first country to obtain organic farming under industry status and later the same was recognized in many European countries (Yussefi, 2006). Worldwide organic production farms adopt specific formulated standards and aim at achieving agro-ecosystems balance that is socially and ecologically sustainable. To expand the market, respective details are declared as part of their product label and detailed information is disseminated through the web. To date, the USA and other developed European counties are major market importers of organic products, and due to this many other developing nations will benefit (Amarender, 2017). In South Asian countries, a considerable part of the high-altitude regions of Northern India, Sri Lanka, Bhutan, Pakistan and Afghanistan have naturally adopted organic farming practices.

When it comes to research, related to potentials of farm yield, Seufert et al. (2012) was the first who to carry out comprehensive analysis by examining the relative yield performance of organic and conventional farming systems (Seufert et al., 2012). Seufert et al.'s (2012) study reveals that general organic yields are typically lower than conventional yields. Any yield differences are highly contextual, depending on system followed and site characteristics and can range from 5% to 34%. Seufert et al. reveals that under certain conditions and through systematic temporal organic good management practices, organic systems can thus nearly match conventional yields. Seufert et al. (2012) study also cautions that, due to low yield of organic farming fields against the fastest growing population demands, there are chances of expanding the organic farming fields over forest lands, which would affect the balance of ecology and its associated biodiversity, in turn undermining the environmental benefits of adopting widespread organic practices. In general, organic yield is assumed to be at a lower level due to use of natural manures and maintaining the ecological balance of farmland.

With reference to analytical studies, Rathnayake et al. (2019) from Sri Lanka proposed a system for an organic cultivation management and prediction system (OCMPS). OCMPS analyses the historical data gathered from Central Province of Sri Lanka and decisions related to crop selection, harvest prediction, price prediction and verification of organic farmers. In addition to following machine learning and optimization techniques, Rathnayake et al., 2019 proposed adopting block chain technology mainly to help customers find genuine organic products. However, details pertaining to on-field implementation and volume of temporal data analyzed in OCMPS are not observed in Rathnayake's studies.

5 Organic Farming: National Scenario

Most of the plain regions of India, in the last 50 years, used huge amounts of fertilizers and pesticides. Due to such prolonged continuous use of synthetic fertilizers, the yield across the country has reached its plateau and diminishing returns have been observed (Venkateswarlu et al., 2008). This practice of farmers annually increasing the quantity of fertilizers is mainly targeted at small increases in production quantity, which in turn causes hazardous second-generation health-related problems, about which many on-field farmers are still not aware. These examples show why some regions of Punjab are the cancer belt of our country; farmers in the cashew plantation regions of Kerala extensively used chemical fertilizers, which contaminated the ground water resources and affected the health of many members of the respective local farming communities. Such indiscriminate use of synthetic chemicals threatened both human life and the ecosystem's health (Aktar et al., 2009). Moreover, due to prolonged use of synthetic fertilizers, the organic content of farming soil is adversely affected, which in turn leads to multinutrient deficiency, affecting the quality of major food crops across the farm fields (Singh et al., 2017). All such adverse effects associated with the modern fertilizer-based agriculture practices have currently forced scientists to reexamine the nation's agricultural practices (Balachandran, 2004).

As a result, many members of the Indian agricultural research community realize that fine-tuning and bringing back ancient agriculture practices through systemic approaches is the only efficient way our nation can achieve sustainable development in both the agriculture and health sectors. One such natural, recyclable, sustainable approach is organic farming, which is an effective and cost-efficient way to achieve sustainable development in the agriculture farming sector. Concerning the Indian terrain and soil conditions, it has great potential to produce all varieties of organic products because of its various agro-climatic regions. In several parts of the country, the inherited tradition of following organic farming practices is an added advantage. For example, the vast stretches of arable land, in the North and Northeastern hilly region, which is mainly rain-fed, negligible amounts of fertilizers and pesticides have been used over many decades; it was already identified by the Government of India as a potential region for organic farming industry. Currently, the natural organic farming practice is also adopted in many hilly regions of the southern states of India because of the growing demand for organic products.

Ramesh et al. (2005) were the first from India to review the prospects of following organic farming practices in India. Their study reports certain pertinent aspects of organic farming which are often debated by respective domain experts particularly with reference to its adoption among Indian farming communities. Later, Ramesh et al. (2010) published a survey article on feasibility of organic farming in terms of the production potential, economics, and soil health in comparison to the conventional farms (Ramesh et al., 2010). As per Ramesh et al. (2010)'s studies, there is a certain reduction in crop productivity from organic farming fields but the farming community can get higher profit mainly by selling the organic products with premium price labels as they have more demand than synthetic fertilizer-based products. The Ramesh et al., 2005, 2010 reviews can be used as a base to understand the practices followed in organic farming but these articles did not provide any details about the role of information technology-based solutions that can be used or developed specifically for the organic farming sector of India. However, both these reviews delineated significant inputs for the analytical challenges of the nationwide organic farming industry of India, and the same has been detailed in Section 15. With reference to organic products of India, Salvador & Katke, 2003 first listed the major products produced by India in the organic farming sector, shown in Table 1 (Salvador & Katke, 2003).

5.1 Organic Farming: Key Initiatives and Major Milestones of Government of India

Table 2 lists the major milestones of the organic farming sector of India in year-wise chronological order

Table 1 Organic products of India

Type	Products
Spices	Cardamom, black pepper, white pepper, ginger, turmeric, vanilla, mustard, tamarind, clove, cinnamon, nutmeg, mace, chili
Pulses	Red gram, black gram, cashew nut, walnut
Commodity	Tea, coffee, rice, wheat
Pulses	Red gram, black gram, cashew nut, walnut
Oil seeds	Sesame, castor sunflower
Fruits	Mango, banana, pineapple, passion fruit, sugarcane, orange
Vegetables	Okra, brinjal, garlic, onion, tomato, potato
Others	Cotton, herbal extracts

Table 2 Major milestones of organic farming sector of India

Year	Year-wise key initiatives and milestones of government of India
1984	First Conference on Organic Farming by the Association for Propagation of Indigenous Genetic Resources (APIGR) held at Wardha, Maharashtra*[1]
1985	An parliament ACT on 'Agricultural and Processed Food Products Export Development Authority (APEDA)' was passed by Indian Parliament during December, 1985 to establish APEDA under Ministry of Commerce and Industries (MOCI)
1986	The APEDA Act came into effect from 13 February 1986 through a notification issued in the Gazette of India
1994	Sevagram Declaration for promotion of organic farming in India*[1]
2000	MOCI-APEDA reported the 'National Programme of Organic Products' (NPOP)
2002	MOCI-APEDA under NPOP releases India Organic logo
2001	On October, 2001 INDOCERT (Indian Organic Certification agency) become India's first indigenous certification body of organic farming sector (https://indocert.org/)
2002	First record of organic cultivated land area of India was reported. India recorded 42,000 hectares of land as organic cultivated land area of India*[2]
2004	Establishment of 'National Project on Organic Farming' (NPOF)
	Establishment of 'National Centre of Organic Farming (NCOF)' at Ghaziabad, UP to implement NPOF initiatives*[1]
	Under NCOF, Regional Centre for Organic Farming was established across India
	India develops its own National Standards for Organic Production (NSOP), similar to the IFOAM and other world standards
2005	National Horticulture Mission (NHM) and Horticulture Mission for North East and Himalayan State launched during the financial year 2005–2006:*[3]
	Provides assistance for organic certification of Rs. 5 lakh for a group of farmers covering an area of 50 hectares.
	Provides Rs. 30,000 per beneficiary for adopting organic farming
	Provides subsidy of 50% for establishing vermi-compost units and HDPE vermi-beds.
	First 'India Organic Trade Fair' organized by ICCOA in Bangalore. Since then it has become an annual event*[2]
2006	India's NSOP acquires the status of equivalence with the European Union (EU) and Swiss Standards. India's accreditation system attains equivalence with the US National Organic Program*[2]
2007	Rashtriya Krishi Vikas Yojana (RKVY)—scheme was initiated in 2007 as an umbrella scheme for ensuring holistic development of agriculture*[1]
	Provides assistance to the projects formulated and approved by the state for decentralized production and marketing of organic fertilizers*[3].
	Nagaland State declared intention to go organic and defined Organic Pathway and policy*[1]
2007	India Organic Trade Fair was organized in New Delhi by ICCOA in partnership with the NCOF and APEDA*[2]
2008	National Project on Management of Soil Health and Fertility (NPMSF)*[3]:
	To promote the judicious and balanced use of fertilizers and organic manure based on soil test results.
	Provides financial assistance of Rs. 500/hectare for promoting the use of organic manure
2010	Launching of Sikkim Organic Mission*[1]

(continued)

Table 2 (continued)

Year	Year-wise key initiatives and milestones of government of India
2012	The Rashtriya Krishi Vikas Yojana (RKVY) scheme of year 2007 is renamed as Remunerative Approach for Agriculture and Allied sector Rejuvenation (RAFTAAR) and continued by including 'Sericulture and Allied activities' as well as 'National Mission on Saffron'
2013	Network Project on Organic Farming in Horticulture Crops*[1]
2015	In June-2015, Ministry of Agriculture had constituted a Seven-member Task Force Committee on Organic and Non-Chemical Farming to come up with expert views and recommendations after conducting research and consultations with all stakeholders. A few key recommendations of the Task Force include
	Conversion of 10% of cultivated area into organic by 2025
	Setting up Central Organic Farming Research Institute
	Setting up research stations and farms across states with model organic farms and demo farms, one per block
	Separate departments for Organic Farming in all agricultural universities
	Incorporation of organic farming as a subject in school curricula
	Allocation of 30% of agricultural research budget to organic farming
	Tax waivers for organic input product units
	Dedicated organic market yards and marketing outlets
2015	Paramparagat Krishi Vikas Yojana (PKVY)*[1]; *[3]; *[4], *[5]
	Provides Rs. 20,000 to farmers for continuous 3 years to undertake organic farming.
	Total financial assistance available for a 20 ha or 50 acre cluster shall be a maximum of Rs. 10 lakhs for farmer members and Rs. 4.95 lakh for mobilization and PGS Certification (Participatory Guarantee System of India) with a subsidy ceiling of one hectare per farmer.
	To motivate and support marketing facilities, financial assistance of Rs. 36,330/ cluster is provided to organize an organic fair
2016	Mission Organic Value Chain Development for North Eastern Region (MOVCD-NER)*[1]
	Sikkim becomes first Organic State in India
	Launch of Participatory Guarantee System (PGS) of Certification
2017	In June 2017, the Food Safety and Standards Authority of India (FSSAI), under the Ministry of Health and Family Welfare, came out with a regulation called the 'Draft Food Safety and Standards (Organic Foods) Regulations, 2017' to ensure the safety and authenticity of organic food products and to provide a regulatory framework whereby consumers will be assured about the authenticity of organic products they consume.
	In November 2017, FSSAI launched a common logo for organic foods, called the 'Jaivik Bharat' logo. The logo will act as a symbol to identify organic products from conventional ones, and the tagline of 'Jaivik Bharat' will identify the product as an organic product of India (https://jaivikbharat.fssai.gov.in/index.php)
	FSSAI in association with APEDA and PGS-India, launched a regulatory portal the 'Indian Organic Integrity Database Portal,' through which consumers and other stakeholders in the organic business can access information about individual companies, producers, their certification system and the availability of certified organic products. The portal also classifies the products based on the states (https://jaivikbharat.fssai.gov.in/)
	India hosted the 19th Organic World Congress (OWC) during 9–11 November 2017 at New Delhi. Every three years, the organic sector comes together at OWC, which is the world's largest and most significant organic gathering share the experiences, innovations and knowledge about organic sector of each country. Subsequent 20th OWC was held in France from 6-10 September 2021.

Note for Table 2 Information cross reference details (*Aulakh & Ravisankar, 2017; *[2]PriyaSoni., 2017; *[3] Aniketa & Jagruti, 2019; *[4] Yadav, 2017; *[5]Das et al., 2020)

5.2 Organic Farming: Government of India Accreditation Boards

Ministry of Commerce has identified six organizations for the National Accreditation Board (NAB) of organic products of India, including Agricultural and Processed Food Products Export Development Authority (APEDA), Tea Board, Spices Board, Coconut Development Board and Directorate of Cashew and Cocoa and Coffee Board. Initially APEDA was assigned to regulate the sale of organic produce by ensuring each item is certified by a reputed agency. Later, the other five accreditation boards were included as part of organic farming certification. These accreditation boards give permission to many other certifying agencies to inspect, evaluate and certify organic products based on a set of well-defined prescribed norms. Over a period of time across the nation, many institutions were identified as authenticated certification bodies of organic farming sector of India. Certification through these boards and agencies has been made compulsory particularly for export market as Government of India has issued a public notice according to which no organic products may be exported unless it is certified by an inspection and certifying agency duly accredited by any one of the accreditation boards designated by the Government of India. Currently, 28 renowned Organic Farming Certification bodies are identified by six accreditation boards of organic products of India. Many of these 28 certification agencies also inspect and run seeds certifications as part of their official functions.

6 Status of Using Information Technology (IT) and Information Technology Enabled Services (ITES) in Organic Farming Sector of India

In the context of using IT-based solutions specific to the Organic Farming sector, Mishra et al. (2015) proposed a GIS-based analytical methodology to identify suitable lands for organic farming in the Uttarakhand state of India (Mishra et al., 2015). Mishra et al. (2015) suggested Analytical Hierarchy Process (AHP)-based geospatial modelling approach mainly to boost the Uttarakhand state rural economies through self-sustainable villages. In this article, multi-criteria site suitability analysis is followed mainly to narrow down appropriate locations for organic farming fields based on a group of defined criteria and constraints derived with the help of soil, drainage, slope and availability of roads/networks in the study area. However, the Mishra et al. (2015) model follows the complete footprints of AHP techniques of (Saaty, 1980, 1988, 1990)'s AHP model, one of the promising methods widely used for agricultural land suitability analysis, which is mostly based on individual criteria of farm land covering soil, drainage, slope, road networks and related quantitative analysis (Chen et al., 2010; Akinci et al., 2013; Gomathi et al., 2019). Moreover, Mishra et al. (2015)'s study did not report any information about on-field implementation; hence, the respective articles can be observed as research publications. Overall, dedicated national level efforts on developing domain-specific IT tools or ITES for the organic farming sector is a field yet to be addressed and has wide scope for further enhancing the profitability of the organic farming sector of India.

7 Research Gaps in Information Technology in Organic Farming Sector of India

This section mainly describes the probable challenges and open research gaps of organic farming sector of India that could be addressed through geo-spatial analytics, big data technologies and further development of suitable IT and ITES tools or environments. It is well known that any information technology tools or e-commerce solutions developed for the common agricultural sector are mostly suitable for organic farming sector after undergoing a customization process done specifically on the defined norms of the organic farming sector as well as with reference to specific standards followed in organic farming industry. However, to date, dedicated software tools or e-commerce or other IT-based analytical platforms focused on the specific requirements of organic farming sector are yet to be developed. Any such attempt is certainly missing on a national level and international level as well. In India, if any such domain-specific tool or system is developed, it has to be in sync with the analytical-related objectives of 'National Projects on Organic Farming' (NPOF) as not all the objectives of NPOF are related to IT or analytics. Complete list of NPOF objectives can be seen at (Ref. 9) and (Ref. 10). In-depth study of objectives of NPOF is out of the scope of this article. However, it can be firmly said that the analytical-related objectives of NPOF certainly need to be supported by IT or ITES tools or environments as any such objectives need to analyze the integrated information of nationwide organic farming resources, projects and other related initiatives. This is viable only when a dedicated GIS-based Decision Support System (DSS) is developed specific to organic farming industry. When any such tool integrates nationwide data, the need for Big Data Technologies and ML/DL algorithms is unavoidable mainly to provide insights and foresights of meaningful analytics for the organic farming sector.

8 Analytics in Organic Farming Industry

The role of using various machine learning algorithms in the agriculture sector is well reviewed by Liakos et al. (2018) but similar studies focused on the organic farming domain are missing so far (Liakos et al., 2018). As shown in Fig. 1, in the current practical situation, the Analytics in Organic Farming sector mostly starts with text or web mining techniques, which in general becomes the initiation point and afterwards proceeds towards developing a ML/DL based model. For example, in the organic farming sector data mining technique is followed to extract specific required information from voluminous unstructured data, which are mostly available in the form of government annual reports, publications, expert committee reports, research articles, authenticated government web portals, and so on. When such data mining techniques or models are related to the thematic spatial layers of a region or terrain, the Geospatial Analytical model can be used for organic farming. When the first one is integrated with the latter, a complete assessment of the organic farming sector of a specific region is developed. For example, when the database pertaining to the organic farming sector of a particular taluk or district or state is extracted through text or data mining techniques and further integrated with the respective geospatial layers, the performance status of the respective administrative unit and its impact at the national level can be very well studied. However, as to date in India no such domain-specific analytical system has been developed that can integrate the data from local regions and scale up to the state or at national level. Even states which have declared fully adopting organic farming practices do not have any such domain-specific geo-analytical system, which is helpful to manage and monitor the trend and outcome results of organic farming practices of respective state.

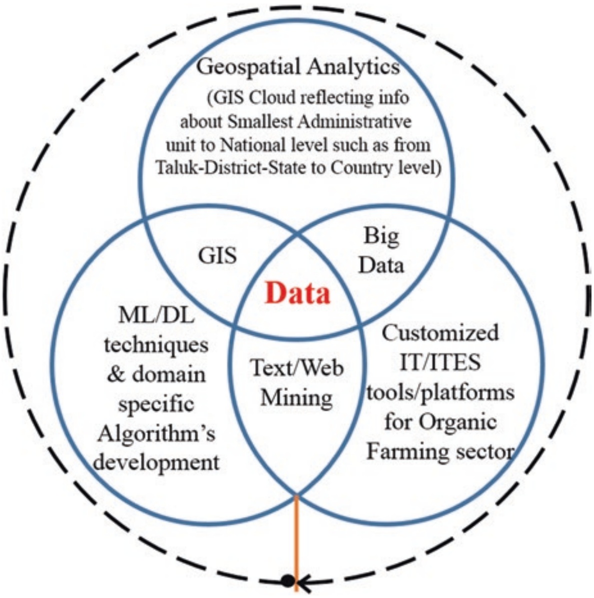

Fig. 1 Organic farming and data analytics: research and development perspectives

9 Key Data Mining of Organic Farming Sector of India

Data mining techniques mainly bring insights and foresight information of unstructured and semi-structured reports, research articles, publications, web achieves, documents, and so on. For the organic farming sector, the availability of structured data is feasible only when an authenticated database pertaining to the organic farming sector is released by the individual Government Institutions, which is hard to find in many countries. In general, information content of any such available structured data is not enough to meet ML/DL-based Big Data models, which are more focused on reporting he finer sub-parameter level details of insights and foresight factors of the farming sector of a particular region or state or nation. Hence, in addition to available structured data, any Big Data studies need to use all sorts of available information from unstructured and semi-structure database sources. In India, to date there are no single window interface or authenticated web archives or systems that can make available the complete past temporal data of organic farming sector details of a particular district or state. For example, past data pertaining to the organic farming sector of a particular district or state covering over a period of the last 10 years and more are not available even for the states which only adopt organic farming practices. Temporal data of this sort must provide insights and foresight for the growth status of the respective industry as well as decide on a suitable growth plan. To date, decision-making institutions, committees, policy-makers and domain researchers have made enormous efforts to collect such authenticated past data pertaining to the organic Farming sector of a specific region or state or nation. This certainly hampers both the decision-makers and researchers in identifying and planning a data-driven solution, which is a fundamental need for any future growth plan of any industry.

To be more specific, this article is interested in knowing the status of growth details of the organic farming sector of India in the past two decades. In this regard, data pertaining to the key indicators such as land used for organic agricultural practices, land used for wild collections, total organic land of India, total volume of organic production, number of organic producers, number of organic processors, number of organic exporters, number of authenticated certification agencies, total volume of organic products exported and revenue generated were extracted from the authenticated references, and analytics of the extracted key indicators are discussed in the following sections.

10 Analysis of Land-Related Key Indicators of Organic Farming Sector of India

India for the first time surpassed China with a total organic agricultural area of 2.3 million hectares (FiBL-IFOAM Report of year 2021, Ref. (Willer et al., 2021). The growth status of the areal extent of organic farming land of India fromr 2002 to 2020 is shown in Fig. 2. India initiated organic farming practices well before 2000 but the progress details are available from 2003. From a mere 42,000 hectares of

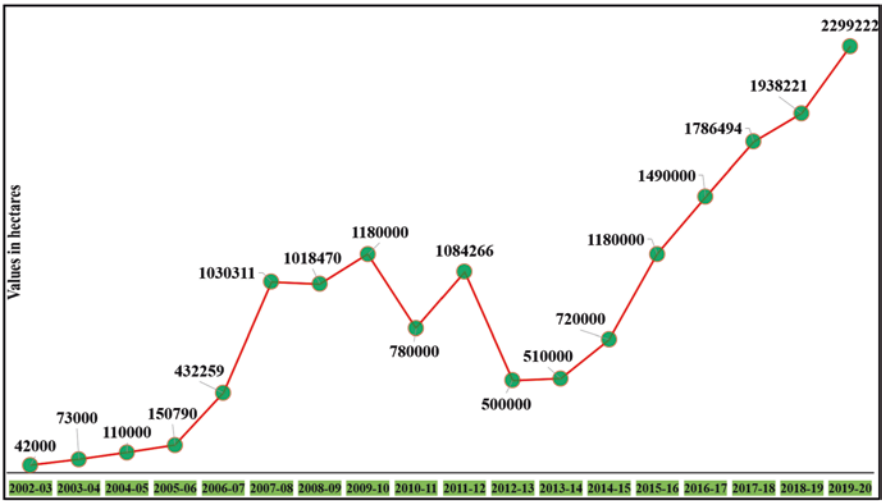

Fig. 2 Growth status of organic farming land of India from 2002 to 2020 (excluding wild collection, apiculture, organic aquaculture regions).

organically certified land in March 2003, the figure reached to 2,299,222 hectares of land under organic crop management by March, 2020 (Fig. 2). On 31 March 2020, total area under organic certification process registered under the National Programme for Organic Production was 3.67 million hectares (2019–2020). This includes 2.299 million hectares of cultivable organic area and another 1.37 million hectares of wild harvest collection area. Among all the states, Madhya Pradesh has covered the largest area under organic certification followed by Rajasthan, Maharashtra and Uttar Pradesh (Ref. 2). The Government of India plans such as PKVY and MOVCDNER respectively introduced during the year 2015 and 2016 led to the increase of the areal extent of organic farming of India in each following year. Due to these government schemes in 2016, Sikkim state was able to bring its entire cultivable land (> 76000 hectares) under the organic certification process and declared the first organic farming state of India. Figure 3 reflects the comparative growth status of key indicators of organic farming land of India, which includes organic agriculture land, wild collection land as well as total organic land of India during the period 2007 to 2019 as the required common authenticated data pertaining to organic agricultural land and organic wild collection land area details are available only during this period.

Input data references:

- Year 2002–2003 and 2003–2004 (Amarender, 2017)
- Text mining information for the year 2004–2005 to 2016–2019 are from References Willer & Yussefi, 2005, 2007; Willer et al., 2008, 2013; Willer & Kilcher, 2009, 2010, 2011, 2012; Willer & Lernoud, 2014, 2015, 2016, 2017, 2018, 2019; RaghuveerSingh et al., 2019.
- Year 2006–2007 information is as per the corrections shared by APEDA in FiBL & IFOAM 2009 Report i.e in Reference Willer & Kilcher, 2009.

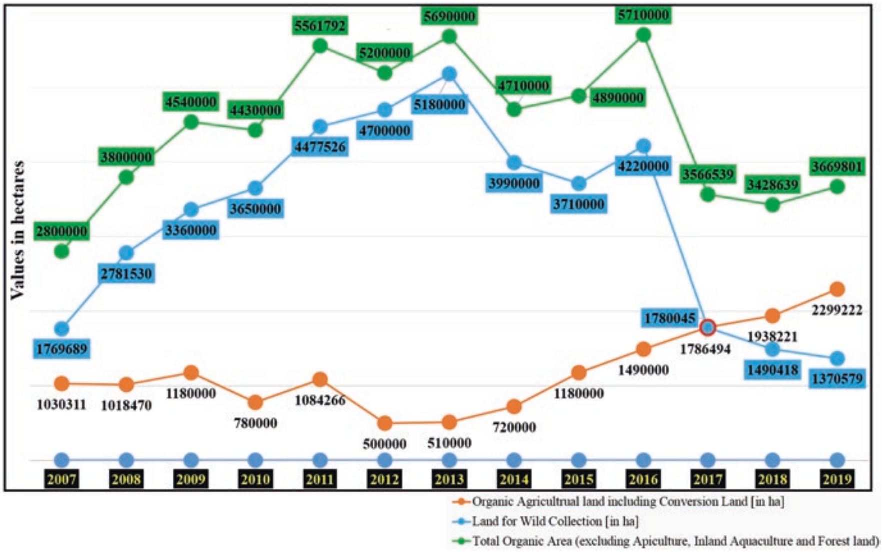

Fig. 3 Land-related key indicators of organic farming status of India (from 2007 to 2019) covering organic agricultural, wild collection and total organic area. References: From (Willer & Yussefi, 2005, 2007; Willer et al., 2008, 2013, 2020, 2021; Willer & Kilcher, 2009, 2010, 2011, 2012; Willer & Lernoud, 2014, 2015, 2016, 2017, 2018, 2019) as well as financial year end details from APEDA (listed under Web References from 1 to 6)

- Information during the year 2017–2020 is from References Willer & Lernoud, 2018, 2019; Willer et al., 2020, 2021 as well as financial year end details from APEDA (listed under Web References from 1 to 6)

11 Analysis of Key Indicators Related to Human Groups of Organic Farming Sector of India

In organic farming industry, working level groups mainly include those such as producers, processors, exporters and certifying agencies who plays vital roles in the success of the respective sector. Table 3 gives the available details of a number of working level group members of the Indian organic farming sector from 2007 to 2019. Data pertaining to year 2020 are yet to be published.

12 Status of Major Market-Related Key Indicators of Organic Farming Sector of India

Major key indicators of organic farming market-related factor include production quantity, export volume, export value, retail sales, and so on. Data pertaining to such factors also have to be analyzed for each organic commodity, which is out of the

Table 3 Number of organic producers, processors and exporters of India

Year	No. of producers	No. of processors	No. of exporters	No. of certification bodies
2007	195,741	*	*	12
2008	340,000	*	*	13
2009	677,257	299	233	16
2010	400,551	299	*	17
2011	547,591	71	*	22
2012	600,000	699	669	24
2013	650,000	*	*	*
2014	650,000	699	669	*
2015	585,200	699	669	*
2016	835,000	699	669	*
2017	*	*	*	*
2018	1,149,371	1452	*	*
2019	1,366,226	1667	*	*

Note: Data Source FiBL & IFOM–Organic International publications from 2008 to 2021 (listed as Refs. Willer et al., 2008, 2013; Willer & Kilcher, 2009, 2010, 2011, 2012; Willer & Lernoud, 2014, 2015, 2016) *Data not available

scope of the present article as commodity-specific past market data covering 10 plus years are not available. Table 4 shows the major market-related key indicators of the Indian organic farming sector of India covering the past 10 plus years, which has been text mined from various published references. Respective details are also part of Fig. 4, which shows the status of production quantity of organic farming products of India. Similar to this status of export volume and export value achieved from 2002–03 can be seen in Figs. 5 and 6.

13 Analysis of Key Indicators of Organic Farming Sector of India

From Fig. 3, initially it has been observed that in 2017 the areal extents of organic agricultural land and wild collection land area are same, which is generally not feasible (highlighted in red circle). While verifying the respective references (Willer & Lernoud, 2019; Willer et al., 2020), which are FiBL & IFOM–Organic International publications from 2019 and 2020, from where the respective information was text mined, it has been found that the value of areal extents of organic agricultural land and wild collection land area were the same in 2017, in other words 1,780,000 hectares. Any such situation where both organic agricultural and wild collection areal land area are the same is technically and statistically rare and not possible. Further cross analyzing the respective factors through web content mining with reference to APEDA portal data [listed as Web Reference 6], a marginal difference of 6449.29 hectares is found between organic cultivated area (1,786,494.06 ha) and wild harvest collection area (1,780,044.77 ha). Subsequently, the actual values are updated in Fig. 3. At the same time, such close value between organic cultivated area and

Table 4 Major market related key indicators of organic farming sector of India

Year	Production quantity (in MT)	Export volume (in MT)	Export value (in Crores)	Primary reference used*
2002–2003	14,000	4161	619.6	7
2003–2004	Data Not Available	6288	726.6	7
2004–2005	Data Not Available	8344	953.3	7
2005–2006	Data Not Available	7953	1281.6	7
2006–2007	585,970	7528	987	5
2007–2008	976,646	37,533	498.22	7
2008–2009	1,811,111	44,476	537	7
2009–2010	1,700,000	58,408	526	7
2010–2011	3,900,000	69,837	699	7
2011–2012	700,000	147,800	1866.33	7
2012–2013	1,300,000	165,262.06	2106.81	7
2013–2014	1,240,000	194,088	2563.08	7
2014–2015	1,100,000	285,607.81	2099	54
2015–2016	1,350,000	263,687.011	1975	54
2016–2017	1,100,000	309,766.94	2478	54
2017–2018	1,700,000	458,339.084	3453	54
2018–2019	2,600,000	6,140,89.614	5150.99	54
2019–2020	2,750,000	638,900	4686	63–68

*Note for Table 4. In addition to above-mentioned primary references used, simple text mining technique is used to extract the missing data as well as to cross validate the extracted information from other Refs. (Saaty, 1988, 1990; Baisakhi Mukherjee, 2017a,b; Aulakh & Ravisankar, 2017; Bisoyi & Das, 2017; Kranthi & Stone, 2020; Das et al., 2020; Ummyiah et al., 2017; Niggli et al., 2010; Amarender, 2017; and Government of India, Lok Sabha, 2020)

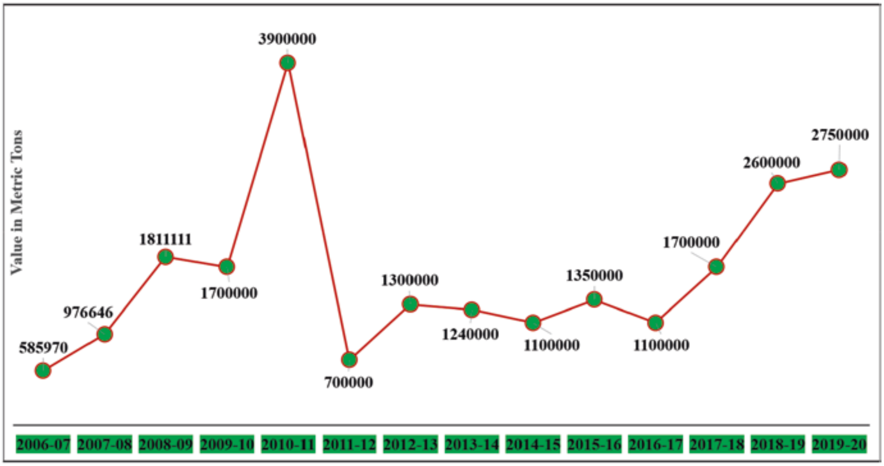

Fig. 4 Production quantity of organic products of India from 2006 to 2020 (values in MT)

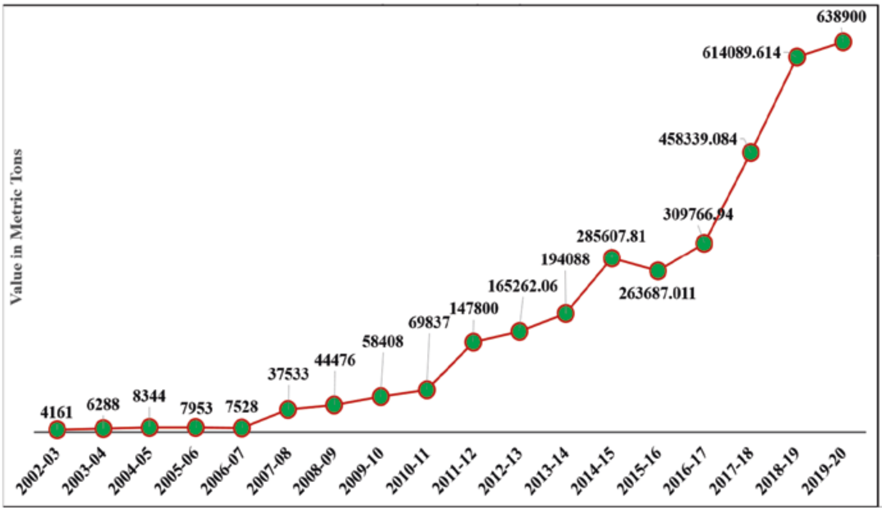

Fig. 5 Export volume of organic products of India from 2002 to 2020 (values in MT)

wild harvest collection area was never observed in preceding years. Hence, based on these analytical outcomes, it is advisable to cross verify the below highlighted concerns and related datasets

- In 2017, chances for data entry-related error may be possible while updating the details about the areal extent of land and wild collection area. If so this particular factor also leads to another error such as in estimating the total organic land of India during the year 2017 (Figs. 3 and 8).

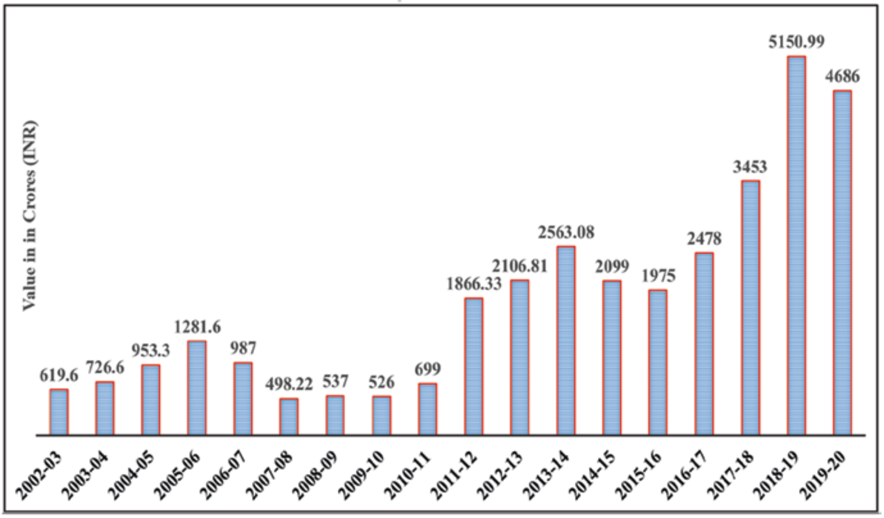

Fig. 6 Export value of organic products of India from 2002 to 2020 (values in Crore's INR)

- From 2017 onwards the wild collection land area exhibits a downward trend. That is while comparing the data from year 2007, the first time a steep decrease in the wild collection land area is observed in the year 2017 and the same is continued in subsequent years. There may be very little scope to judge that the Government of India in the year 2017 might have modified policy decisions about accounting for the wild Collection area of organic farming sector and if so respective details are not found in referred publications or in any other formal departmental announcement or in social media (Figs. 3 and 8).
- With reference to cultivable organic area 'average,' a gradual decline is observed in the areal extent of cultivated organic farming land from the year 2009 to 2013 (highlighted in red line in Fig. 8). This can be attributed to the issues associated with India's genetically modified *Bacillus thuringiensis* (Bt) cotton cultivation. Finer level discussion of Bt cotton issues is out of the scope of this article, and respective details can be seen in (Kranthi & Stone, 2020; Karihaloo & Kumar, 2009 and Web Reference (15 Years of Bt Cotton in India, Admission of failure official now, Article from Coalition for a Genetically Modified-Free India; 2017 http://indiagminfo.org/wp-content/uploads/2017/06/15-yrs-of-Bt-Cotton-in-India.pdf). Comparatively from year 2018 onwards, organic agriculture land area exhibits more upward growth than wild area land.
- Figure 7 shows the details on the number of organic producers in India from year 2007. In the year 2019, India had the largest number of organic producers worldwide with total number of producers of 1,366,226 (FiBL-IFOAM Report of year 2021, Ref. Willer et al., 2021). With reference to number of producers, other than an outlier (no data available for the year 2017), the average growth rate of number of organic producers exhibits a positive trend from year 2007.

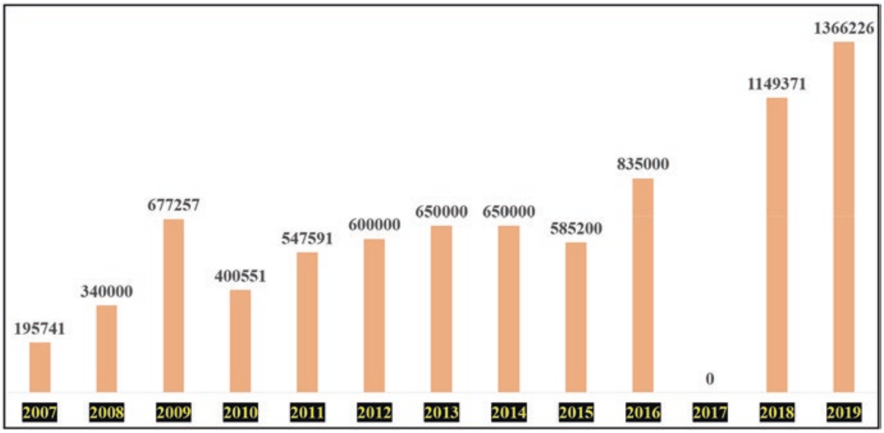

Fig. 7 Number of organic producers of India from year 2007. References: FiBL & IFOM–organic international publications from year 2008 to 2021 (From Refs. Willer & Yussefi, 2005, 2007; Willer et al., 2008, 2013, 2020, 2021; Willer & Kilcher, 2009, 2010, 2011, 2012; Willer & Lernoud, 2014, 2015, 2016, 2017, 2018, 2019); for the year 2017 data are not available

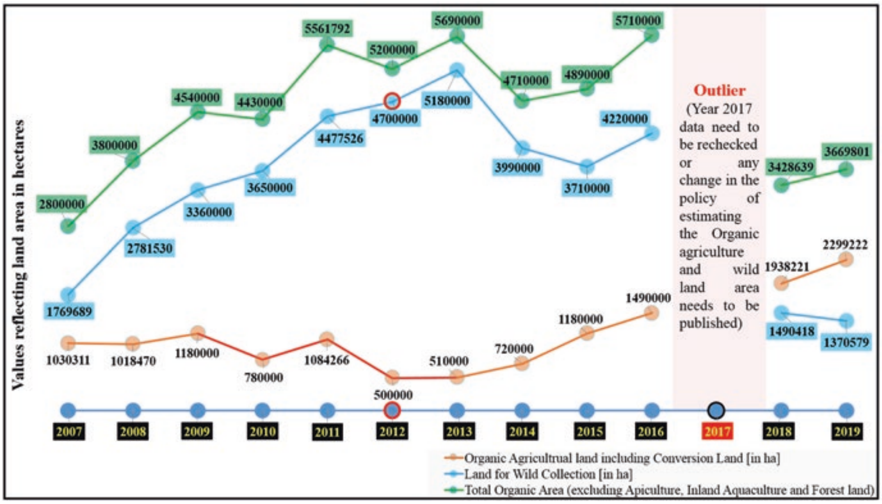

Fig. 8 Data analytics outcome of major key indicators of organic area of India. (From year 2007 to 2019)

- When comparing the number of organic producers of year 2011 and 2012, in the 2012 the number of organic producers increased (Fig. 7). However, in 2012 the areal extent of organic land decreased to the bottom line (of 500,000 ha) and at the same time the areal extent of wild area continued to increase (to 4,700,000). Respective details are highlighted in Fig. 8 using red circles. Statistical significance and growth details of such relationship can be understood only when an in-depth analysis of commodity-wise study is carried out including both organic agriculture and wild products.

- While comparing Table 3 and Fig. 7, it has been found for 2017 no data entry details are available for the number of producers, processors and exporters from of the references listed in this article. Moreover, while relating this particular observation with the earlier observations (observation made related to the areal extent of organic land and wild area in the year 2017), it can be said that all data pertaining to 2017 need to be rechecked to know the facts about the sudden fall of wild organic land during the 2017 as well as the downward trend of same since year. Hence, till 2017 data entry details are validated in the following Fig. 8, which is more suitable than Fig. 3.

The above-listed observations are the outcome of extensive data mining and subsequent analytics of major key indicators of organic farming sector of India starting from year 2003 to 2020. However, for most of the analytical study, the common data available during the period from 2007 to 2020 are considered. Overall, this study is useful in tracing the above highlighted concerns of organic farming sector of India, which may be possible to overcome with the help of respective functional organizations of the organic farming sector of India as well as by deeply analyzing the commodity-wise products of both organic agriculture and wild products, which is currently out of the scope of this article due to the non-availability of commodity-wise data from the year 2003 or 2007 onwards.

14 Need and Significance of Geo-Spatial Analytics in Organic Farming

The geoSpatial analytics of organic farming sector brings out the location-specific information pertaining to a taluk or district or state level, which can be integrated together mainly to project the status at national and international levels. Any such geo-analytical systems certainly make use of the spatial thematic layers of the corresponding region, which have to be digitally analyzed in a GIS environment mainly to derive and display the results of analytical outcomes or queries along with the spatially context-related details. In case of organic farming studies, with reference to region or scale of the study area (aerial extent of the study area), analytics in organic farming can be classified as local or regional. statistical analysis of individual organic farming fields performed through data analytics techniques, which can be called local analytics. Any such analytics which work on the defined dataset of local farms mostly make use of structured data. Past data pertaining to a minimum of three years of the plot area are needed for any meaningful statistical analysis. Any analytical model of such sort is useful for knowing the growth as well as yield status of the respective plot in subsequent years and mostly can forecast on the status of the respective organic farm from the fourth year onwards. The vegetation indices which are used to check the growth of the plants calculate the yields, monitor the health and progress details of the normal agriculture fields and also need to be fine-tuned to such organic farming plots.

The regional-scale analytics of organic farming support the integrated analysis of data collected from the smallest administrative unit level (taluk) to districts and states and finally tend to relate and consolidate the impact of a respective region at the state as well as at national level. In such scenarios, geo-analytical models play a vital role right from data collection, ETL process (extract, transform, load), pre- and post-processing of data and finally defining a suitable model which can develop future insights with the help of various ML/DL algorithms. All these certainly require developing as well as integrating respective analytical models over the GIS environment as this can only act as a meaningful decision support system (DSS). To date, both COTS and a few open-source GIS tools support Python-based ML/DL interpreters or plugins as part of their tool extension mainly to develop, test and deliver many such domain-specific ML/DL models. Hence, with reference to the National Organic Farming sector, a GIS-supported analytical DSS is the need of the hour as this helps in effectively monitoring and improving the organic farming sector's performance as well as during real-time decision-making process. Both the local and regional analytical models require a minimum of three plus year's temporal information of respective organic forming plot or region and such temporal data analytics are mandatory to project and derive a meaningful predictive forecasting model that suits the respective farm or region that has to be analyzed. Also, both the above-detailed local and regional geo-analytical models has to explore the complete advantages of various fields of data science as shown in Fig. 1. Integration of taluk, district and state level information will bring out the actual status of the organic farming sector of a country from the small administrative unit to national level. At global level, the outcomes of nationwide organic indices are consolidated to derive the status at continent level. Such an integrated mechanism can only be achieved through a GIS-DSS-based ML/DL model, which can only deliver answers for the following major challenges of organic farming sector of India or any other country.

15 Grand Analytical Challenges of Organic Farming Sector of India and Need of Developing Advanced Research Models

Ramesh et al. (2005) is the first study from India to identify the actual major analytical challenges of organic farming sector of India, and some of their views are captured in the first column of following Table 5 (Ramesh et al., 2005). Though Ramesh et al. (2005)'s article did not talk about any data analytics, these challenges can be very well answered by developing advanced analytical research models for which the above-detailed GIS-DSS based ML/DL approach forms the basic foundation. In line with this, the following table is an attempt to address Ramesh et al. (2005)'s observations using ML/DL-based analytical approach.

Table 5 Listing of the major analytical challenges of organic farming sector of India that need to be focused on by developing suitable advanced analytical models

Challenges of organic farming	Primary data required	Type of analytics	Probable approach of data analytics model	Outcome of model
Can organic farming produce enough food for everybody?	The following data from taluk to district to state level are required: i) Data pertaining to commodity-wise crop details from each taluk, district, state level are mandatory ii) Details related to total cultivable land used for organic farming, yield per acre produced at taluk, district level are mandatory. iii) To predict the yield of organic farms through ML/DL-based models the parameters such as soil native-natural carbon level, leaf biomass index, chemicals avoided during the phase change periods, weather conditions such as humidity, temperature and so on are needed. iv) Socio-economic details including population, consumption of food grains, and so on. Any such analysis requires temporal data covering over a period of three to four years of the region or farm	Predictive Analytics	Data capture -> storage -> preprocessing -> ETL-> analytics with suitable ML/DL techniques -> post-processing -> data integration on GIS-DSS environment-> Query-> visualization	Foresight information
Is it possible to meet the nutrient requirements of crops entirely from organic sources?	terrain specific factors such as soil type, water, pH details, no. of manure production units and its quantity, manure supply-demand details, and so on.	Diagnostic analytics & predictive analytics	Data capture -> storage -> preprocessing -> ETL-> analytics with suitable ML/DL techniques -> post-processing	Insight & foresight information
Are there any significant environmental benefits of organic farming?	Need land-specific information during the pre-organic farming period, during land conversion period and after the land conversion period, other terrain specific details, etc.	Descriptive analytics & predictive analytics	data capture -> storage -> preprocessing -> ETL-> analytics with suitable ML/DL techniques -> post-processing -> data integration on GIS-DSS environment-> Query-> visualization	Hindsight and insight information

Is the food produced by organic farming superior in quality?	Product inspection reports of farm and certification agencies	Descriptive analytics & predictive analytics	Data capture -> storage -> preprocessing -> ETL-> analytics with suitable ML/DL techniques -> post-processing	Hindsight and insight information. (The superiority details will become part of the label of the organic product)
Is organic agriculture economically feasible?	Population, consumption details, national annual demand and production details, total cultivable area, total area used for organic farming, commodity wise production details, etc.	Prescriptive analytics	data capture -> storage -> preprocessing -> ETL-> analytics with suitable ML/DL techniques -> post-processing data integration on GIS-DSS environment-> Query-> Visualization	foresight information
Is it possible to manage pests and diseases in organic farming?	Specific details related to disease happened during before and after land conversion stage	Descriptive analytics & predictive analytics	Data capture -> storage -> preprocessing -> ETL-> analytics with suitable ML/DL techniques -> post-processing -> data integration on GIS-DSS environment-> Query-> Visualization	Hindsight and insight information

To date, getting the much required input data from authenticated agencies for taluk, district and state level is the first major challenge which is not available for any meaningful analytical research. At the same time, India became the number one country in developing a total 2.3 million hectares of land under organic farming sector as well as becoming the world's highest producers of organic farming products. Hence, growing further the development and deployment of above-mentioned analytical techniques is unavoidable.

16 Recommendations and Conclusion

Worldwide, organic agriculture is gaining momentum as an alternative to synthetic fertilizer-based farming systems as it is able to maintain a win-win partnership with earth's natural ecosystem as well as with consumer's health (Kölling 2010). From year 2003 onwards, organic agriculture practices have evolved as a movement in India as organic food products offer profitable business opportunities in both domestic and export markets. In this context, this article mainly intended to show the need and importance of enhancing the organic farming sector of India by way of developing and deploying dedicated IT and ITES-based geo-analytical solutions. After an extensive in-depth analysis of major key indicators of organic farming sector of India, which has been discussed in detail and constitutes a major part of this article, it has been felt to further spread and enhance the profitability of the organic farming sector, and the following recommendations have to be considered by any government which aiming to further develop the organic farming sector:

- First, as per the defined scientific criteria of organic farming practices, a nationwide GIS-based digital mapping has to be undertaken mainly to map the existing organic farms as well as the terrain, which are suitable for organic farming
- In addition to collecting, integrating and analyzing voluminous data right form taluk, district and state level, any such domain-specific customized GIS also needs to be able to incorporate details related to temporal organic farming practices followed at respective local regions
- Such a data-centric GIS tool further needs to be fine-tuned as a real-time decision support system (DSS) with the support of various ML/DL-based geo-analytical models/algorithms, which needs to be developed through research and development and field validation process
- In addition to the above, a web-based information dissemination portal can be made available under the banner of '**National Digital Atlas of Organic Farming Sector of India,**' which can displays the information in 24/7 mode between and across the decision-maker locations.
- A GIS-based mobile interface has to be developed, which can deliver the selective services and advise the respective atlas directly to the mobile phones of farmers

- Today, world data-driven analytical models are changing the growth phase of many sectors when sufficient authenticated data archives are made available to the data scientists. However, with reference to organic farming sector based on the list of references studied, it can be observed that researchers are struggling to get the authenticated data which is needed to provide insights as well as forecast the future status of the organic farming sector of India. This article is the first to our knowledge to attempt to analyze the growth status of key indicators of Indian organic industry over a period of 15 plus years. However, in practical scenarios, any analytical system has to project the status of each commodity of organic farming rather than focusing only on key indicators. When past temporal data of an organic commodity covering a period of 10 years are made available to the researchers, there is certainly a possibility of identifying the growth trend and influence of respective commodities in overall organic farming industry. Hence, commodity-wise data analytics are the need of the hour but at the same time getting authenticated temporal data covering the past 10 plus years is a major challenge. For example, the commodity-wise analysis of basmati rice, honey, tea, coffee, dry fruits, sesame, spices, pulses, cereals, guar, gum, saffron, bee's wax, morels, arrowroot, oil and oleoresins, aromatic oils, fruits, medicinal and herbal plants, cotton, and so on, will bring insight and foresight information about influence of each commodity in the organic farming business. This study will also bring out the details about commodity-wise land utilization, commodity-wise production details, commodity-wise export volume and commodity-wise income earned, and so on.
- Overall, an integrated GIS+Analytics+DSS-based organic farming real-time system has to be developed that can deliver answers for any queries raised by both decision-makers and farmers of India

Any such integrated system will be able to provide many hidden data-centric facts about organic farming sectors of India from the taluk, district and state level. Practical use of such a data-centric system will certainly enhance the productivity of the organic farming sector of our country from the taluk, district and state level. To be more specific, when the existing organic farming institutional and policy frameworks (been currently monitored by APEDA and NPOP) are supported with the real-time statistical details of the proposed ML/DL-based GIS+Analytics+DSS system, much acceleration can be achieved by converting most of the agricultural regions under the organic farming scheme. Moreover, due to this integrated IT-based mapping, monitoring, analytical process, it will not be difficult for organic farming certification agencies to monitor the land conversion and related progress in near real-time mode. Due to involvement of the geo-analytical component, even the time duration required to convert new farmland into a complete organic farm can be estimated well in advance. Such practices helps the small farmers to take the advantage of the lucrative organic farming market, which could directly contribute to the improvement of their economic well-being.

In other heavy industry sectors, the technologies that have been developed at major metro cities of India are deployed in North Eastern states of India. However, in the organic farming sector North Eastern States have more advantages and rich experience than any other states in India. In this scenario, in the organic farming sector, North Eastern states can guide the restof India because of its advantage of having followed organic farming practices for a quite long period. Overall, the organic farming sector in India has great potential to flourish; however, it is yet to reach a complete well-established industry status. Government of India has already recognized organic farming as a potential export sector which is exhibiting exponential growth over the years. In this context, the proposed **'National Digital Atlas on Organic Farming Sector of India,'** which can reflect the status of Organic Farming at Taluk, district and state level, is the need of the hour and this need should be taken up by the Government on a priority basis.

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The Agrarian Vision: Sustainability and Environmental Ethics *Via*, Good Agricultural Practices (Gap)

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Abstract As food and fiber processing undermines the natural resource basis, future generations' potential to flourish and prosper falls. Over the last four decades, there has been a growing trend to question the significance of these high costs and to propose innovative alternatives. Agricultural sustainability is predicated on the idea that we must meet current needs without jeopardizing future generations' ability to meet their own. As a result, long-term control of both natural and human capital is equally important for short-term economic gain. A sustainable agricultural method tries to utilize natural resources in such a way that they can regenerate their productive capacity while also minimizing negative ecosystem consequences beyond the field's edge. One must recall Mahatma Gandhi's famous saying, "There is enough on this earth for the needs of everyone, but not for anyone's greed." The "green" revaluation has also been called a "greed" revaluation. One must be careful not to attempt to get the maximum yield beyond the soil's carrying ability and the resource's sustaining potential. Let us start with good agricultural practices that will lead us in the future to sustainable/organic farming.

Keywords Sustainable · Environment · Agriculture · GAP

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1 Introduction

Agriculture has changed dramatically since World War II ended. Food and fiber productivity has improved as a result of new technology, mechanization, increasing chemical use, specialization, and government policies that encourage optimizing production and lowering food prices. These innovations have enabled fewer farmers to produce more food and fiber at reduced rates. While these advances have had many positive effects and have minimized many agricultural threats, there are still considerable costs. Topsoil destruction, groundwater contamination, air pollution, greenhouse gas emissions, the decline of family farms, the neglect of farm employees' living and working circumstances, rising hazards to human health and safety due to the spread of developing illnesses, economic concentration in the food and agricultural sectors, and the dissolution of rural communities are all examples.

During the past four decades, a growing trend has arisen to challenge the importance of these high costs and to propose creative alternatives. Today, within our food production systems, this trend for sustainable agriculture is gaining momentum and acceptance. Three key priorities, environmental protection, economic prosperity, and social justice, are incorporated into sustainable agriculture. A number of theories, policies, and practices have contributed to these objectives, but most concepts of sustainable agriculture thread through a few basic themes and principles.

An understanding of sustainability requires an understanding of agro-ecosystems and food systems. Individual fields, farms, and eco-zones are all considered agro-ecosystems in the broadest sense. Food systems, which comprise agro-ecosystems as well as distribution and consumption components, vary from farmers to small communities to the entire world's population. A holistic understanding of our agricultural production and distribution endeavors, as well as their impact on human populations and the environment, can be gained by focusing on the system perspective. A structural perspective, on the other hand, allows us to examine the impact of human society and institutions on agriculture and its long-term environmental viability (Tiraieyari & Uli, 2011).

Studies of different natural and human systems have demonstrated that systems that persist over time are often highly robust, adaptive, and diverse. Because most agro-ecosystems face elements that are often highly turbulent and rarely stable over time, resilience is critical (including climate, pest populations, political contexts, and others). Adaptability is a critical component of resilience, as restoring an agro-ecosystem to its exact shape and function as before a disturbance may not always be possible or desired, but it may be able to alter and take on a new shape in the face of changing conditions. Because the more diversity within a food system exists, whether in terms of crop types or cultural understanding, the more tools and pathways a system would have to adjust to change; diversity tends to bestow adaptability.

A multipronged analysis, education, and action approach to the agro-ecosystem and food system is common. Producers, staff, retailers, customers, policymakers, and others interested in our agricultural and food systems, as well as academics from various fields, all have important roles to play in moving towards greater agricultural sustainability. Last but not least, there is no single, well-defined end goal for sustainable agriculture. In terms of environmental, social, and economic sustainability, scientific understanding is always evolving and is influenced by current concerns, opinions, and beliefs. For example, the ability of agriculture to adjust to climate change was not considered a crucial issue 20 years ago, but it is now gaining traction.

"Conversely, the specifics of what defines a sustainable system might differ from one set of circumstances (e.g., soil types, environment, labor expenses) to another, as well as from one cultural and ideological point of view to another, resulting in a contentious phrase "sustainable." It is also more useful and important to think about agricultural systems as ranging from unsustainable to very sustainable along a spectrum rather than as a black-and-white binary.

2 Sustainable Agricultural Development

Development has led to relatively restricted levels of growth for poor countries and even developing countries in the last few decades. Changes that lead to change or success are involved in growth. The concept of the notion of growth can therefore be described as an issue of norm or meaning, as well as economic development. Economic development is defined as an increase in society's overall wealth over time, while economic growth is defined as the process of growing the economy's ability to generate commodities and services. Sustainable development is defined as progress that improves the present generation's well-being without jeopardizing the well-being of future generations. This implies equality and promises between generations that welfare will never decline in time (Bélanger et al., 2012; Carvalho, 2017).

The growth of agriculture is a key factor leading to the contamination of the atmosphere. The challenge is that the demands for population growth, the expectations for continued production of agriculture and the need to protect the environment are reconciled. As a result, new agricultural development methods need to be established both for highly developed and developing countries, which will allow environmental tolerability capabilities to be preserved. Pollution reduction, produced by agricultural, zoo-technical and agro-industrial operations, is among the few means available (Blowers, 2013; Dicks et al., 2019).

Only when the security of the environment is guaranteed will agricultural production be maintained. Otherwise, erosion or progressive deterioration of the soil and, in general, of the ecosystem, will lead to economic development being unlikely. In this context, sustainable agricultural development refers to a new approach to agricultural development that allows agriculture to provide economic and social benefits to current generations without jeopardizing future generations' ability to meet adequate agricultural demands or jeopardizing the fundamental ecological process. This description underlines the fact that, thanks to agriculture, any deterioration or substantial contamination of the ecosystem and of ecological processes must not be sustainable in the long term, but the permanent conditioning of the nature of the soil and, in general, of the atmosphere must be permanently taken into account.

The following three conditions must be met for the achievement of sustainable agricultural production.

1. Eco-capacity security, which preserves the ability of ecosystems to function in the existence of pollution;
2. Efficient utilization of resources for renewable, human, material and energy utilization;
3. Ensuring an equal distribution of both the goods supplied by agricultural production and the loads generated by environmental degradation among populations.

2.1 Concepts of Sustainable Agriculture Development and the Environment Pollution

Sustainable agricultural production is mainly concerned with the conservation of the natural environment under conditions of consumer guarantee for the requirements of agricultural products and services for the entire population. This security must be done in an efficient way. Therefore, if alternatives exist to preserve the agricultural potential of the natural world, it is important to select a solution that minimizes the inputs (i.e. the inputs of energy and plant protection products) of the agricultural product unit or that maximizes the amount of agricultural products for the same inputs. As the economic history of a state attests, economic growth through the assistance of agriculture (agricultural production and services) has long since been the way in the face of high expectations of quality of life. For this purpose, agricultural policies must ensure that the most effective conversion of agricultural raw materials into agricultural products and services is achieved, subject to environmental quality and stability monitoring conditions (Adomako & Ampadu, 2015; Bachev & Terziev, 2017; Bélanger et al. 2012).

Future prediction is difficult; in return, it is possible to establish a scenario for achieving sustainable agricultural growth. "The idea of clean development and clean agricultural or industrial development is advanced from the earlier principles of clean technology and waste-free or waste-reduced technologies. There were three distinct and complementary goals for the old definition of clean technology:

1. Few environmental contaminants (water supplies, air, soil) are emitted;
2. Low waste (waste-free technologies or decreased waste production);
3. Reduced demand (water, electricity and raw materials) for natural resources.

Clean Agricultural Production It reflects a global approach to the conservation of the environment and agriculture, covering all the stages of the agricultural production process or the life cycle of agricultural production, with the main goal of avoiding and mitigating, in the short and long term, the threats to the environment and human health. From a scientific and practical point of view, it is not easy to describe the word "clean agricultural production" with regard to "cleanliness" or the quality of agricultural produce. Closing the agricultural production cycle would require agriculture to maintain the goods during their entire life cycle, starting with the production and use of agricultural materials, until the final storage period is complete. Clean agricultural production, because it decreases emissions, is profitable for the environment.

The guarantee of agricultural production and services under conditions of non-pollution and/or minor environmental pollution is taken into account in any problem relating to sustainable agricultural growth.

We found that the intensification and diversification of the environment took place in all of the components, along with the growth and modernization of socio-economic life and rising sources of pollution. Air, water, and soil contamination is becoming a threat to people's lives and health; has harmful impacts on agricultural production, flora, and fauna; and is making normal progress in agricultural production processes and services more difficult. The crops that adopt the form of pollution preventive approach have some direct income, such as:

1. Realization of cost savings by reducing waste of raw materials and energy;
2. Increasing the working performance of the farming units;
3. Achieving a higher quality of agricultural products due to the simpler functioning of the anticipatory unit;
4. The reuse of such discarded farm products.

Clean agricultural production needs a highly skilled study, improving agricultural production technology and shifting attitudes. The Environmental Protection Act No. 265/2006 is one of the general principles accepted as the basis for environmental management or ecological management of agricultural production operations and agricultural services, in accordance with the national environmental protection strategy.

a. ***The concept of pollution avoidance***: The prevention of pollution is simpler and less costly than the restoration of ecological equilibrium, respectively; it requires the introduction of less polluting agricultural technology, and also establishes a hierarchy of agricultural activities and services;
b. ***The concept of Best Agricultural Practices:*** Defines that any operation must take into account the current state of technical growth, environmental protection criteria, the selection and implementation of reliable economic and environmental steps, etc.;
c. ***The Concept for the protection of natural conditions for human health***: Imposes a guarantee of consumption of quality agricultural products and services;
d. ***The concept of vigilance in taking decisions*****:** Agricultural units must be vigilant of all the adjustments they make of terms of policies and production processes in order to keep their unpredictable impact on the environment under control;
e. ***The concept theory for the protection of biodiversity and unique bio-geographical ecosystems:*** Development of a national network of protected areas

for the preservation of the favorable conservation status of the natural environments of wild flora and fauna;

f. ***The concept of sustainable use of natural resources***: The preservation of future generation possibilities and living conditions, natural renewable resources at least at the current level for actual generation, as well as the improvement of environmental factors influenced by agricultural pollution;
g. ***The concept of "polluter pays" associated with the concept of manufacturer and user responsibility***: It creates the need for a clear legislative and economic structure in order to sustain the cost of emissions by producers (i.e. generators).

2.2 Eco-capacity Principle

Two essential aspects concerning the definition of eco-capacity are considered by experts in this area namely:

1. Agricultural system elasticity, i.e. the ability to sustain behavioral models against external disruptions;
2. Agricultural system stability, i.e. the ability to maintain balance, as a response to variations in the climate.

The preservation of the environment against agricultural pollution (the key source of food for the population) constitutes a fundamental requirement for sustainable growth. There are two primary security techniques due to the difficulty of environmental conservation problems:

a. Maintaining annual emissions and evacuations within the limits set by environmental standards of waste generated by various agricultural activities-minimization, treatment and valorization of agricultural waste. Usage of fertilizers, pesticides, plant protection products, and soil quality improvement (soil conditioning agents) can produce environmental emissions or evacuations (air, water supplies, soil, and subsoil) of hazardous or major hazardous (toxic) compounds having a polluting effect when the maximum allowable concentration is exceeded or accumulated. Substances used for crop protection will be used, while environmental regulations will be followed. Emissions requirements, design standards, and product standards are supplemented by environmental guidelines, all of which are included in the category of essential environmental conservation measures.
b. Stabilization and elimination of the overall load of local and regional contaminants. This policy has global and regional environmental issues in mind. Global and regional issues are associated with pollutions, such as the degradation of aquatic environments, particularly heavy metals and chlorinated carbon hydrides, soil and water pollutions with heavy metals, pesticides, nitrates, and various other hazardous substances.

The main objective of the development of standards for total pollutant loads is the reduction of environmental pollutant loads to a lower level than that imposed by environmental standards.
The constant reduction of pollutant emissions per unit of agricultural produce is necessary for sustainable agriculture development. Significant replacement of nonrenewable (conventional) raw materials and energy resources with renewable resources in the long term is possible, closing the cycle of agricultural materials and manufacturing them through optimal processes and goods.

2.3 Eco-equity Principle

Equity is described as the justice of what is distributed within society as wealth or prosperity. In this sense, equity may be managed between generations or within the same generation. Eco-equity is described by the fairness of the use and reproduction of natural resources (assets) within the same century.

1. ***The eco-equity into the same generation***: A constant or increased natural capital reserve will ensure the fairness of the distribution of income and wealth to the same generation, both within a state, but also between states. In the case of the same generation, examples of eco-equity include dependency on:

   a. Biomass as a fuel agent, such as wood burning, and farm and animal waste;
   b. Manure (organic materials) to protect the consistency of the soil; stocks of untreated water;
   c. Crops and forage;

Natural environmental conservation indirectly leads to the maintenance of this vulnerability and contributes to the health and well-being of the population. On the other hand, the protection of natural resources forces on the poor the burden of their responsibility to pay for the preservation of the required values. Natural resources may be replaced in this sense (Zaharia, 2010).

The environment has become a good market, and consumption goods with a decreased effect on the environment (i.e. agricultural products) tend to increase as revenue increases. As a result, wealthy people would be allowed to eat more, but this does not mean that poor people are prohibited to eat.

In developing countries, environmental conservation reforms are in line with the aim of achieving eco-equity in each generation. Decreasing material welfare (poverty) leads to environmental degradation in these states in order to acquire immediate stocks of food and raw materials for natural trade. When the world is damaged, the opportunities for future generations to survive are reduced. The proof of the beneficial position of eco-equity is not definitive for rich countries.

2. ***Eco-equity between generations***: The idea of sustainable growth implies equity between generations.

The principle of eco-equity, which implies sustainable agricultural production and sustainable agricultural consumption, includes sustainable agricultural growth. Real generations will produce and consume agricultural products in a sustainable manner and provide sustainable agricultural services in such a way that future generations will not be in danger of generating and consuming opportunities. In reality, this implies the justice of what consumes and reproduces the natural agricultural resources within a century.

Justice for future generations requires ensuring that welfare does not decline in time and that a simple overlap of initiatives is not capable of defining sustainable agricultural production or cost-benefit assessment policy. In this context, compensation between generations is needed and can be accomplished in two ways:

1. By establishing an intergenerational fund (conservation of such natural resources);
2. Ensuring nondiminishing natural capital (renewable natural resources) stocks.

The actual compensation process is right for the future generation, with the obligation that the natural resources transferred are not handled defectively by the future generation.

3 Good Agricultural Practices (Gap)

The action plan for achieving sustainable agriculture is built on the foundation of Good Agricultural Practices. They aid in the development of sustainable agriculture, as well as food security and natural resource management. The purpose of these practices is to encourage and enable producers, food processors, food merchants, customers, and governments to take full responsibility in the pursuit of socially viable, economically beneficial, and effective sustainable agricultural production systems that preserve human and animal health and welfare (Zeweld et al., 2017; Nicetic et al., 2016).

Food quality standards have been developed through the Codex Alimentarius, and approaches such as Integrated Pest Management and Conservation Agriculture have evolved to address specific production challenges. For the agricultural sector, there is no overarching structure to guide national debate and action on policies and practices for attaining sustainable agriculture. The Declaration of Specific Good Agricultural Practices Principles could serve as the foundation for coordinated worldwide and national action to develop long-term agricultural production systems (Lincoln & Ardoin, 2016; Nguyen, 2015).

The widespread worry about the biological, ecological, economic, and social sustainability of contemporary agricultural production systems demonstrates the need for action. Simultaneously, in developing countries, the quest for food security with limited inputs and technologies depletes the natural resource base while failing to meet the demand. Furthermore, worry for the protection of agricultural and livestock products are increasing in all parts of the world.

A rapid transition to sustainable production systems and natural resource management is required to ensure civilization's survival. These systems can better integrate biological and technical inputs, better capture production costs, maintain efficiency and environmental stability, and restore customer confidence in their products and manufacturing procedures (Wezel et al., 2014; World Health Organization & Światowa O.Z., 2003).

Benefits will accrue to:

- Small-, medium-, and large-scale farmers, who will get added value for their produce and improved access to markets;
- Consumers, who will be assured of higher-quality, safer food produced in environmentally friendly methods;
- Business and industry, which will benefit from improved products; and,
- Everyone who will benefit from a cleaner environment.

In order to attain these goals, all stakeholders and governments, notably farmers and consumers, must improve the understanding of what constitutes sustainable agriculture. Governments and commercial enterprises should create and enforce supportive policies. Farmers will respond to the incentives of improved market access and added value by using production practices that suit the demands of processors and consumers. Individual farmers will want detailed guidance on what is required and how it should be applied. Farmers must be successful and efficient, but they must also be paid a fair price for their products. To answer this need, it is proposed that a Good Agricultural Practices Guiding Principles structure be established, through which agriculture may better meet society's needs. They will serve as the foundation for the establishment of production system recommendations within specific agro-ecosystems.

As a result, the goals of these practices are to:

- Create a set of guiding principles for the public and private sectors to collaborate on in order to develop recommendations for good agricultural practices for production systems.
- Orient existing knowledge, options, and solutions toward risk management concepts that can be used as policy tools.
- Form the foundation for a public awareness campaign and SARD action to involve all segments of society in the conversation, action, and transition to sustainable agriculture.

Furthermore, the social and labor elements that should be developed for Sustainable Agriculture and Rural Development (SARD) and against which achievements should be measured will be discussed. The FAO has established a dialogue and consultation process to define possible responsibilities and benefits for governments and stakeholders, to seek understanding and consensus on the principles of Good Agricultural Practices, and to prepare a plan for moving forward with the creation of production system guidelines.

The next phase is to begin developing practical suggestions, which will include the participation of farmers and other specialists, as well as the integration of scientific and technological expertise to identify acceptable risk management strategies (such as H.A.C.C.P.). The food sector and/or farmers' organizations are expected to develop voluntary and market-driven local, national, and international quality assurance schemes or standards of practice. The FAO's role is to encourage these breakthroughs by providing vast, unbiased technical expertise and informing governments about their scientific validity and policy implications.

3.1 Framework for Good Agricultural Practices

The Good Agricultural Practices principle entails using existing information to ensure the sustainable use of the natural resource base for the production of effective, nutritious food and nonfood agricultural products in a humane way, while also ensuring economic viability and social stability. Knowing, understanding, preparing, evaluating, documenting and managing to attain established social , environmental and output goals is the underlying theme (Girardin et al., 2000; Gomiero et al., 2011).

The FAO's role is to encourage these breakthroughs by providing vast, unbiased technical expertise and informing governments about their scientific validity and policy implications. This comprises a good and detailed management plan as well as the ability to make delicate tactical modifications when situations change. Success is dependent on building the foundations of skills and competence, recording and analyzing performance on a continual basis, and seeking professional advice when necessary (Zeweld et al., 2020).

The framework illustrates the guiding principles of good agriculture through 11 components of resource demands, disciplines, and activities. The framework can be used to create detailed management guidelines for individual production systems within specific agro-ecosystems.

1. *Soil*

The physical and chemical structures of the soil, as well as its biological activity, are essential for agricultural production and, in their complexity, determine soil fertility. Soil management can conserve and promote soil fertility by reducing soil, nutrient, and agrochemical losses due to erosion, runoff, and leaching into surface or ground water. In addition to the potential for negative off-site impacts, such losses imply inefficient and unsustainable resource management. The goal of management is to promote the biological activity of the soil while simultaneously preserving the natural vegetation and wildlife that surrounds it. Agriculture will be benifite from sound practice:

- Farms should be managed in accordance with the soils' resources, distribution, and possible uses, with each land management unit's inputs and outputs being recorded.

- Maintain or enhance organic soil matter through the use of crop rotations and effective mechanical and conservation tillage procedures for soil building.
- Preserve soil cover to reduce erosion caused by wind and/or water.
- Apply agrochemicals and organic and inorganic fertilizers in appropriate quantities and timing, and using methods that meet agronomic and environmental requirements.

2. *Water*

In both quantitative and qualitative terms, agriculture bears a significant amount of responsibility for water resource management. Careful management of water resources and efficient use of water for the production of rainfed crops and pastures, irrigation where applicable, and animals are the criterion for successful agricultural practices. They include improving rainwater penetration on agricultural land and retaining soil cover to reduce surface run-off and water table leaching.

In order to accomplish this, it's crucial to maintain a significant amount of soil structure, particularly continuous macro-pores and soil organic matter. Effective irrigation methods and technologies would reduce losses during the supply and distribution of irrigation water by tailoring the quantity and timing to agronomic requirements to avoid needless leaching and salinization.

Water tables should be regulated to prevent excessive rise or fall. Good agricultural practice will:

- Water infiltration will be maximized, and unproductive watershed outflow from surface waters will be reduced.
- Management of soil and soil water through proper use or, if possible, prevention of drainage, as well as the development of soil structure and organic matter.
- Using methods that do not pollute water supplies, apply production inputs such as organic, inorganic, and synthetic waste or recycled items.
- Adopt procedures for tracking crop and soil water conditions, accurately planning irrigation, and avoiding soil salinization by using water-saving and recycling steps where practicable.
- Improve the water cycle's functionality by establishing permanent cover or, if necessary, protecting or restoring wetlands.
- To avoid unnecessary extraction or accumulation, monitor water tables.
- Provide sufficient, stable, clean livestock watering points.

3. *Crop and Fodder Production*

Individual annual and perennial crops, as well as their cultivars and varieties, are chosen to meet the demands of the local user and market based on their suitability for the site, their position in the crop cycle for managing soil fertility, pests, and diseases, and their response to available inputs. Perennial crops are grown to allow long-term development and intercropping possibilities. Annual crops, particularly those with pasture, are grown in sequence to maximize the biological benefits of interactions between species and to maintain productivity.

Rangelands are managed to maintain plant cover, productivity, and species diversity. Harvesting all crops and animal products removes the nutrient content from the site and must eventually be replaced in order to maintain long-term efficiency. On the basis of an understanding of their qualities, good agricultural practice will:

- Choose cultivars and varieties based on their response to sowing or planting time, efficiency, consistency, market acceptability, disease and stress tolerance, edaphic and climate adaptation, and responsiveness to fertilizers and agrochemicals.
- Design crop sequences to optimize the use of labor and equipment and to maximize the biological benefits of weed control through competition, mechanical, biological and herbicide choices, the provision of disease-minimizing nonhost crops, and, where appropriate, the inclusion of legumes to provide a biological nitrogen supply.
- Apply organic and inorganic fertilizers in a balanced way, with appropriate methods and equipment and at appropriate intervals to substitute nutrients derived by harvesting or lost during manufacturing.
- Maximize the benefits of crop and other organic residue recycling for soil and nutrient stability.
- Incorporate animals into crop rotations and use the nutrient cycling created by grazing or housed cattle to support the fertility of the entire farm.
- Rotate animals on pastures to allow for healthy pasture regeneration.
- Follow all safety standards and requirements when operating crop and fodder producing equipment and machinery.

4. *Crop Protection*

Crop health preservation is critical for both productivity and product quality in good farming. Long-term risk management measures for disease-resistant crops, crop and pasture rotation, disease breaks for susceptible crops, and limited use of agrochemicals to battle weeds, pests, and diseases in accordance with Integrated Pest Management principles are all included. Any crop protection procedure, especially those involving compounds that are toxic to humans or the environment, must be carried out only by professionals with extensive experience and the necessary equipment. A good agricultural practice will:

- Optimize pest and disease biological prevention by using resistant cultivars and varieties, crop sequences, partnerships, and cultural activities.
- Maintain a regular and quantitative examination of the balance of pests, diseases, and beneficial organisms in all crops.
- Adopt organic management approaches when and where possible.
- Whenever possible, use pest and disease forecasting methodologies.
- Decide on methods to limit pesticide use, particularly to support integrated pest management (IPM), taking into account all viable options as well as their short and long-term effects on farm productivity and environmental implications.
- Ensure that only specially trained and experienced individuals submit agrochemicals.
- Equipment used to handle and apply agrochemicals meets the defined safety and maintenance requirements. Keep accurate records of agrochemical usage.

5. *Animal Production*

Livestock require adequate space, food, and water for their welfare and productivity. Records of livestock acquisitions and breeding programs can ensure form and origin traceability. Supplements are given to grazing pasture or rangeland livestock as needed and stocking rates are adjusted. Chemical and biological contaminants in livestock feed are avoided to safeguard animal welfare and/or to prevent their entry into the food chain.

Manure treatment reduces nutrient loss and promotes positive environmental consequences. Acreage requirements are assessed in order to ensure adequate land for feed production and waste disposal. Good agricultural practice will:

- To avoid negative effects on the landscape, climate and animal health, position livestock units properly.
- Avoid biological, chemical, and physical pollution of pasture, feed, water, and the environment.
- Monitor inventory levels on a regular basis and adjust stocking, feeding, and water supply rates as needed.
- Plan, build, choose, utilize, and maintain equipment, structures, and handling facilities to avoid harm and damage.
- Prevent residues from veterinary medications and other chemicals in feed from entering the food chain.
- Reduce the use of antibiotics for nontherapeutic purposes.
- To avoid waste removal, nutrient depletion, and greenhouse gas emissions, integrates livestock and agriculture through efficient nutrient recycling.
- Maintain records of stock, breeding, losses, and sales acquisitions, as well as feeding plans, feed acquisitions, and sales.
- Follow the safety rules and specified safety criteria for the operation of animal production facilities, equipment, and machinery.

6. *Animal Health*

Animal health is protected through good management and shelter, as well as preventive therapies such as immunization, and regular examination, identification, and treatment of diseases, with veterinary assistance as needed.

Sound agricultural practice will:

- By effectively managing pasture, healthy feeding, adequate stocking rates, and good housing conditions,
- Minimize the danger of infection and disease.
- Maintain a clean environment for the animals, buildings, and feeding facilities, and offer enough, clean bedding in housing situations.
- Ensuring that employees are properly trained in animal care and treatment.
- Seek appropriate veterinary advice to avoid illness and health problems.
- Ensure that housing has a high level of sanitation by thoroughly cleaning and disinfecting it.
- Treat sick or injured animals as soon as possible, in collaboration with a veterinarian.

- Purchase, store, and use only approved veterinary products in accordance with regulations and directions, including withholding periods.
- Keep extensive records of all diseases, medical procedures, and mortality.

7. *Animal Welfare*

Farm animals are living beings whose well-being must be respected. Good animal welfare is defined as the absence of hunger and thirst, discomfort, pain, injury, or disease, the ability to express normal behavior, and the absence of fear and distress.

Agriculture best practices will:

- Provide safe and sufficient food as well as clean water.
- Stop nontherapeutic mutilations, such as tail docking and debeaking, and surgical or intrusive surgeries.
- Reduce the movement of live animals (by foot, train, or road) as well as the use of livestock markets.
- Handle animals with care and refrain from using equipment such as electric goads.
- Maintain animals in appropriate social groups wherever possible; animal separation (such as veal crates and sow stalls) should be avoided unless necessary for injury or disease.
- Observe the minimum space allowances and maximum stocking densities.

8. *Harvest and On-Farm Processing and Storage*

The execution of suitable harvesting, storage, and, when required, processing techniques for agricultural products also affects product quality. Harvesting must adhere to pesticide preharvest interval limits and veterinary medicine withholding periods. Food should be stored in a room that has been created specifically for that purpose and is kept at a temperature and humidity level that is suitable. Shearing and slaughtering are two examples of livestock operations that must adhere to animal health and welfare regulations. A good agricultural practice will:

- Harvest food commodities in accordance with specified preharvest cycles and withholding periods.
- Ensure that items are handled in a clean and hygienic manner for on-farm processing. For washing, use the specified detergents and clean water.
- Store food items in hygienic and suitable environmental conditions.
- Pack food items for shipment from the farm in clean and proper containers.
- Use humane and appropriate preslaughter handling and slaughter practices for each species, as well as necessary supervision, employee training, and equipment maintenance
- Maintain accurate records of harvest, storage, and processing.

9. *Waste and Energy Management*

Fuel is required by farms to power machinery used in cultural activities, processing, and transportation. The goal is to complete tasks on time, eliminate human labor drudgery, boost productivity, diversify energy sources, and reduce energy consumption. Farming produces by-products, some of which are possible pollutants in the land, water, or air. While some of these by-products are commodities that may be recycled, their output should be controlled. A good agricultural practice will:

- Develop input–output plans for farm energy, nutrients, and agrochemicals to guarantee effective usage and safe disposal.
- Adopt energy-saving methods in building construction, equipment sizing, repair, and use.
- Examine and implement alternative fossil fuel energy sources (wind, solar, and biofuels) where possible.
- Organic trash and inorganic materials should be recycled whenever possible.
- Reduce nonrecyclable garbage and dispose of it responsibly.
- Fertilizers and agrochemicals should be stored safely and in accordance with legislation.
- Establish emergency intervention measures to reduce the danger of unintentional emissions.
- Maintain accurate records of energy usage, storage, and disposal.

10. *Human Welfare, Health, and Safety*

Agriculture must be economically viable in order to be sustained. It is reliant on the social and economic well-being of farmers, agricultural workers, and the communities in which they live. Health and safety are frequently key concerns for anyone involved in farming activities. At all times, extreme caution and diligence are required. Agriculture best practices will:

- Guide all agricultural practices to achieve the best possible balance of economic, ecological, and social goals.
- Ensure appropriate household income and food security.
- Adhere to safe working practices, including reasonable working hours and rest periods.
- Pay fair compensation and do not abuse employees, especially women and children.
- Instruct employees on how to use technologies and machines safely and efficiently.
- Purchase inputs and other resources from local traders if at all possible.

11. *Wildlife and Landscape*

Agriculture provides habitat for a variety of mammals, birds, insects, and plants. Many people are concerned about the extinction of some of these species from the landscape as a result of habitat destruction caused by industrial agriculture. The aim is to preserve and develop wildlife ecosystems while keeping the farm company profitable. A good agricultural practice will:

- Identify and protect wildlife habitats and landscape features, such as lone trees, on the property.
- As much as feasible, create a variety cropping pattern on the field.
- Reduce the impact of operations like tillage and pesticide use on animals.

- Manage field margins to eradicate invasive weeds and encourage the growth of beneficial flora and fauna.
- Control water channels and wetlands to support wildlife and reduce pollutants.

4 Summary and Conclusion

Agro-ecosystems cannot be sustained in the long run without the experience, technological competency, and trained labor required to manage them properly. Given the constantly evolving and locality-specific character of agriculture, sustainability necessitates a varied and flexible knowledge base that incorporates both formal, experimental research and farmers' own local knowledge on the ground. Social institutions that facilitate farmers and scientists, inspire creativity, and support farmer–researcher cooperation can boost agricultural production and long-term sustainability. Social, economic, and environmental sustainability are all interconnected and necessary components of truly sustainable agriculture. Poverty-stricken farmers, for example, are frequently obliged to mine natural resources in order to achieve goals such as soil fertility, despite the fact that environmental degradation might harm their livelihoods over time. Developing policies that incorporate social, environmental, and economic objectives is the only way for societies to foster more productive agricultural systems.

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Soil Community Composition and Ecosystem Processes

Arjita Punetha, Shailaja Punetha, and Amir Khan

Abstract Soil is defined as weathered rock material consisting of organic substances, minerals, air and water. Soil being a dynamic and large habitat sustains the growth of numerous organisms and endows us with innumerable functions. Soil can therefore be considered as a multi-habitat ecosystem rather than just a component of any ecosystem. Owing to its enormously high physical and chemical heterogeneity, soil hosts a multifaceted and varied biological community which offers myriad services to us. Right from soil formation to its management, soil community helps in weathering, nutrient cycling, water cycling, supporting agriculture, regulating climate, maintaining fertility and remediating the contaminants present in soil. However, anthropogenic activities like intensive agriculture, use of excessive chemicals and deforestation have significantly affected the soils and associated communities. Soil is the major hub of nutrients and water supply that directly govern the growth, nutrient status and productivity of crops thereby indirectly influencing the human health. Therefore, in order to maintain the proper functioning of soil and its community, soil restoration is the need of the hour. This requires reducing the use massive machinery for agricultural and other purposes, shifting to organic farming, syncing nutrient release and water availability with requirement of plants and monitoring the biological activity.

Keywords Soil microbial community · Soil management · Nutrient cycling

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1 Introduction

Soils are a naturally produced intricate system made up of biotic and abiotic components that serve as the fundamental habitat for biological diversity and processes as well as a source of delivering a variety of ecosystem functions. The formation of soils takes place at the point of intersection of the lithosphere, biosphere, atmosphere and hydrosphere. The pedosphere (soil mantle of the Earth), which is made up of mineral, fluid, gaseous and biological elements, works as a facilitator of biogeochemical transformations and fluxes into and out of the contiguous spheres. Soils seem to be the most diverse natural material on the Earth and perhaps most crucial for human life because they impact food availability and its quality, purify and deposit water, detoxify pollutants and bring minerals and chemicals into human contact. Soils control most of the ecological processes in ecosystems and are home to a huge percentage of the world's biodiversity, and provide the structural foundation for a variety of human activities as well. Soils are a physically and chemically multifaceted ecosystem that supports a diverse microbiological and faunal taxonomic community. 10^9–10^{10} prokaryotic cells (bacteria and archaea), 10^4–10^7 protists, ~100 m of fungal hyphae and 10^8–10^9 viruses can be found in 1 g of surface soil (Srinivasiah et al., 2008, Bates et al., 2013; Bardgett & Van der Putten, 2014; Brady & Weil, 2014). In some soils, these values equate to prokaryotic biomass surpassing 5 tonnes per hectare, while fungal biomass ranges from 1 to 15 tonnes (Brady & Weil, 2014). These diverse communities of organisms perform vital roles in maintaining soil and ecosystem function, offering a slew of advantages to planetary cycles and human survival.

Numerous ecosystem activities are supported by the activities and dynamic interplay among soil organisms. Due to the several critical functions that soil performs, it is unquestionably one of the most important and strategic resources. Soil plays a pivotal role in (i) providing food, fibre and fuel; (ii) decay and decomposition of organic matter; (iii) recycling of vital nutrients; (iv) bioremediation of organic pollutants; (v) carbon capture and storage; (vi) regulation of water quality and its replenishment and (vii) habit formation for a wide range of organisms (Yang et al., 2020). Soil functions are dependent on soil features and interactions and are influenced by the use and management of soil. Various natural processes such as landslides and erosion diminish soil nutrients and biodiversity, eventually leading to soil degradation which poses a grave worldwide threat to food security and ecosystem sustainability (Godfray et al., 2010; Montgomery, 2010; Oldeman, 1998). Aside from this, anthropogenic activities such as the overuse of fertilizers and heavy equipment for agricultural purpose, livestock overgrazing and deforestation endanger the soil ecosystem's long-term sustainability. On a human life scale, soil is generally recognized as a non-renewable resource, since its recovery is an exceedingly sluggish process once it gets depleted (Camarsa et al., 2014; Lal, 2015). Considering the significance of soils for agriculture and livestock production, as well as delivering broader ecosystem services to local and global communities, retaining them in immaculate condition is crucial. In order to wisely manage the use of agricultural soils, decision-makers require science-based, convenient and cost-effective methods to analyze changes in soil quality and function.

2 Soil Organisms and Interlinkages Between Them

Soil harbors extremely rich and diversified biological community due to its exceptionally high physical and chemical variability at microscale and microclimatic properties that can support the establishment and maintenance of an enormously large number of niches (Tiedje et al., 2001; Ettema & Wardle, 2002). Based on their size, soil organisms are broadly classified as: microflora (1–100 μm, e.g. bacteria, fungi), microfauna (5–120 μm, e.g. protozoa, nematodes), mesofauna (80 μm–2 mm, e.g. collembola, acari) and macrofauna (500 μm–50 mm, e.g. earthworms, termites (Wall et al., 2001). The basic food web structure in soil is comparable to other food webs in that it also contains primary producers, consumers and detritivores, as in other food webs (Fig. 1). From the bottom to the top of the food chain, the number of soil organisms and their biomass per volume decreases by orders of magnitude. Soil food webs are perhaps more complex than other food webs, have longer food chains and greater cases of omnivory. Further, all fauna depend on primary producers (e.g. for litter). Debris of plants and other organic substances serves as habitat for soil organisms. Plants directly affect soil biota by producing organic matter above- and belowground and also indirectly influence soil organisms by providing them with shade, soil protection and source of water and nutrients. Energy and nutrients obtained by plants are ultimately integrated into detritus, which serves as the base of resources for a complicated soil food web.

Soil macrofauna disintegrate dead organic substance into smaller fragments, allowing soil bacteria and fungus to begin its degradation and convert it in the form of inorganic nutrients required for plant growth. This is followed by mineralization which is continued by organisms such as protozoa and nematodes that feed on bacteria and fungus, which are then eaten by first- and higher-order carnivores. Even in a distinct trophic classification, some species can be found “breaking the rules”. Collembolans, for example, which are widely thought to consume fungus, include few species that feed on nematodes instead (Chamberlain et al., 2005). Studies indicate that soil ecosystems can have long and stable food chains unlike the other ecosystems which can generally sustain very small food chains. Digel et al. (2014), for example, evaluated food webs in 48 different forest soils comprising 89–168 species and discovered 729–3344 various feeding linkages. Unfortunately, our existing knowledge of trophic interactions is insufficient, and we require a more precise picture of the abundance and characteristics of prospective consumers at various trophic levels. For instance, viruses and enchytraeids are frequently overlooked out of these food web studies, and only mites and nematodes can be divided in distinct groups while diverse ecological groups of earthworms and collembolans are normally left out. This is significant since the presence or absence of a particular food source may alter the overall understanding of the soil food webs. Our

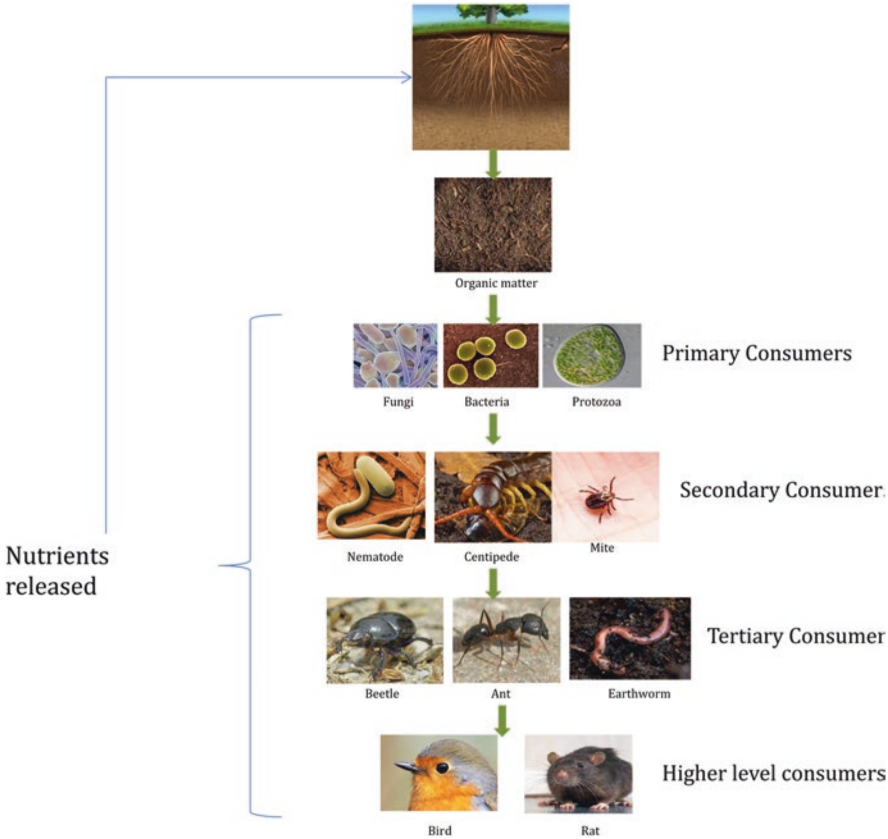

Fig. 1 Flow of energy between different trophic levels in soil ecosystem

understanding of nutrient cycles and flow of energy in the soil community and the linkage between dynamics of soil food chain and agro-ecosystem stability has been aided by soil food web analysis (Susilo et al., 2004; Van der Putten et al., 2004). Several obstacles are now inhibiting our ability to fully comprehend the performance of soil food webs, including (i) redundant nature of organisms (i.e. various organisms depending on same food source) and complement functional groups (Setala et al., 2005), (ii) the ability of certain soil organisms to keep changing their feeding sources or show diverse rate of feeding throughout their lifetime and (iii) density-dependent impacts on their feeding behavior (Kaneda & Kaneko, 2008). To offer a more realistic estimate of energy fluxes across the different trophic levels, they must all be included in food web analysis.

3 Ecosystem Services Provided by Soil and Soil Organisms

The organisms dwelling in the soil provide a number of functions to the other biota (Fig. 2). Services provided by soil organisms can broadly be classified into regulatory, supporting and provisional.

3.1 Regulating Services

Few of the regulatory services delivered by soil microorganisms chiefly involve the functions that ensure regulation of climate, water management and purification, disease and pest control and bioremediation of pollutants.

Fig. 2 Services provided by soil community

3.1.1 Climate Regulation

The biggest store of terrestrial carbon (C) reserves in the world is soil. Soils are a significant component of the global carbon cycle, containing both soil organic carbon (SOC) and soil inorganic carbon (SIC). Soil biodiversity is widely known for its function in limiting greenhouse gas emissions and regulating soil carbon storage (Jackson et al., 2017; de Graaff et al., 2015). The balance of C in soils is influenced by the interaction between climate, plant diversity and biodiversity of soil (Allison et al., 2010; Schimel & Schaeffer, 2012), and the short- and long-term fluxes and movements of carbon in and out of soils are ultimately controlled by the soil community.(Crowther et al., 2019). Litter breakdown and greenhouse gas emissions are also influenced by the soil community. Soil fauna enhance the surface area of litter by shredding leaves, which boosts the rate of its decomposition by microbes (Moore et al., 2004). The activity of earthworms can both stabilize soil C (Zhang et al., 2013) and augment greenhouse gas emissions (Lubbers et al., 2013) depending on the climate and conditions of local ecosystem.

3.1.2 Water Purification

Soil serves as a water purifier and reservoir, cleansing water as it flows through the soil and storing it for plant absorption. Better water infiltration also gives plants and soil organisms some additional opportunities to utilize dissolved and suspended nutrients like phosphates and nitrates, thereby lowering nutrient run-off into surface and groundwater. Phosphates and nitrates are recycled within terrestrial systems by the metabolic activity of soil microbes, which limits their export to aquatic systems (Elizabeth et al., 2020). Microorganisms play an important part in the filtration of water as it flows through soil because of their ability to breakdown a variety of pollutants. As an example, *Rhodococcus wratislaviensis*, a herbicide-degrading bacterium, has been found in soil as well as in groundwater samples that are contaminated with terbuthylazine indicating that it has the ability to detoxify contaminated soil and water systems. Additionally, soil microbes also have the ability to affect the quality and amount of soil organic matter, which can have an indirect effect on the rate of water infiltration (Turbé et al., 2010).

3.1.3 Disease and Pest Control

Biotic and abiotic components of soil can effectively inhibit plant diseases that are caused by soil-borne pathogens such as bacteria, filamentous fungus and oomycetes (Baker & Cook, 1974). Microbiota regulates the quality of soil organic matter (SOM) and availability of nutrients for plants growing in the respective soil, which is quite imperative for soil health maintenance (O'Donnell et al., 2005; Kibblewhite et al., 2008). Suppressive behavior is an inherent property of soil, which is widely recognized as a management technique for obtaining maximum agricultural output levels and ensuring low ecological footprints in systems that use intensive cropping techniques in presence of strong pathogen load (Kariuki et al., 2015). The biological activity of soil bacteria is thought to be the main mechanism driving this suppressive property of soil. Few examples of microorganisms that help in controlling of diseases include bacteria e.g. *Bacillus* and *Pseudomonas*, actinomycetes like *Streptomyces* and filamentous fungi such as *Trichoderma*, *Fusarium* and *Aspergillus*, which can elicit all mechanisms related to disease suppression and control.

3.1.4 Biodegradation of Organic Waste

One of the most serious risks to soil functions is pollution. Improper and unmanaged disposal of waste, industrial and mining activities, oil spills and agricultural practices are the main contributors of soil pollution. Microbial remediation of pollutants is recognized as a quick and cost-effective method that employs an extensive range of microbes to absorb organic contaminants as their carbon or nitrogen sources to support their growth (Chen et al., 2013; Mahmoud, 2016; Ortiz-Hernandez et al., 2018; Siles & Margesin, 2018; Zhan et al., 2018; Bhatt et al., 2020a). To support their growth and metabolic activity, microorganisms also use xenobiotic substances found in soil as their carbon or nitrogen sources (Mishra et al., 2021). Few examples of soil microorganisms involved in bioremediation of soil pollutants are bacteria like *Pseudomonas, Alcaligenes, Microbacterium, Methanospirillum, Bacillus, Sphingobium* and *Rhodococcus*, fungi such as *Aspergillus, Penecillium, Trichoderma* and *Fusarium* and yeasts like *Pichia, Candida, Aureobasidium* and *Exophiala* (Sathishkumar et al., 2008; Nzila, 2013; Sunita et al., 2013; Zhao et al., 2017; Bharadwaj, 2018; Yang et al., 2018a, b; Yu et al., 2019; Bhatt et al., 2020b). However, interaction between ecological parameters such as soil salinity, pH, temperature, carbon and nitrogen sources available and moisture content have significant impact on microbial biodegradation capacity (Megharaj & Naidu, 2010; Wu et al., 2014a, b; Bhatt et al., 2019).

3.2 Supporting Services

Supporting services are additional services which are not directly used by humans but are required for sustenance of ecosystem functioning. Soil microbial communities are involved in providing several supporting services such soil formation, nutrient and water cycling and primary production. In order to support and sustain plant growth, soil needs to be fertile and ensure sufficient supply of nutrients and adequate recycling of organic matter. Various species of bacteria and fungi are involved in the activities that lead to the breaking down and mineralization of nutrients and their cycling in the atmosphere. Soil microorganisms are identified as crucial drivers of plant diversity and primary production, and restoration of degraded terrestrial ecosystems can be done through manipulation of soil communities using microbes

(Wubs et al., 2016). A large portion of microbial diversity stimulates plant productivity through a variety of microbial methods. A variety of bacterial species including members of the *Actinobacteria, Proteobacteria* and *Firmicutes* genus have the ability to produce organic chemicals that affect plant root system proliferation (Haas & Defago, 2005; Doornbos et al., 2011). Soil microorganisms also help in nitrogen fixation. Symbiotic bacteria e.g. *Rhizobium* sp. and *Frankia* sp. and free-living bacteria such as *Azotobacter*, *Azospirillum*, *Bacillus* and *Klebsiella* spp. and some *Cyanobacteria* species notably add to atmospheric N fixation. Furthermore, numerous bacterial sp. like *Pseudomonas*, *Frankia* and *Streptomyces* and fungal sp. like *Aspergillus* have demonstrated the capability to create iron-chelating chemicals, hence boosting iron availability for plants. Siderophore-producing Streptomyces species have shown promise in biofertilization and microbial remediation of metal-contaminated soils (Dimkpa et al., 2008). Drought, excessive soil salinity, harsh temperatures, nutrient inadequacy and heavy metal toxicity can all be alleviated through plant–rhizobacteria interactions (Dimkpa et al., 2009). Identification of salt-and drought-tolerant microorganisms could be very useful in overcoming yield losses owing to water constraint around the world (Ali et al., 2014; Forni et al., 2017).

3.3 Provisioning Services

Provisioning services of soil refers to products formed by soil ecosystem services that can be brought to use by humans. Provisioning services encompass food, water, fibre, fuel, genetic resources, drugs and pharmaceuticals, all of which are derived from ecosystems. Soil bacteria are responsible for several of the benefits that soils offer to humans, including food production. This valuable soil service is produced by a healthy relationship between plants, microbes and soil, and humans rely on it for survival.

Many soil microbes assist the plants in obtaining inaccessible nutrients by transforming them into plant-available forms in exchange for energy from their host (Ango & Abdu, 2021). Several beneficial bacteria and fungi encourage plant growth by producing metabolites or by interacting physically with the host plant (Bender et al., 2016; Ragnarsdottir et al., 2015; Hayes & Krause, 2019). Antimicrobial agents and enzymes are also produced by soil microorganisms which are exploited in the field of biotechnology. Actinomycetes are one of the most abundant microbial groupings in the soil in nature. Species *Streptomyces* and *Micromonospora* are accountable for derivation of about 80% of the world's antibiotics (Sudha et al., 2011; Hassan et al., 2011; Brevik et al., 2020). Additionally, microbes can also be utilized to make bio-ethanol, biodiesel and bio-methane, which are all next-generation biofuels (Singh, 2015; Singh & Seneviratne, 2017; Peralta-Yahya & Keasling, 2010; Medipally et al., 2015).

4 Anthropogenic Activities Affecting Soil Community and Processes

4.1 Soil Pollutants

Maintenance of soil health and resilience to external conditions requires a healthy soil microbial community. Pollution has a significant impact on the growth and functioning of microorganisms, as well as the makeup and variety of the community in a soil ecosystem (Chen et al., 2014). Widespread incidence of organic pollution and its negative consequences have piqued popular interest. Many contaminants make their way to the soil, where they tend to accumulate over time, disrupting the soil ecosystem and processes.

4.1.1 Heavy Metals

Heavy metals, namely copper (Cu), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn) and manganese (Mn), garnered considerable attention due to their toxic and persistent nature and their tendency to bio-accumulate in ecosystems (Gan et al., 2017). While some of the heavy metals function as micronutrients for plants and are also required by microorganisms to maintain biological activities, copious amounts of heavy metals cause bio-toxicity, restrict microbial activity and disrupt the composition of soil community (Choppala et al., 2014; Khan et al., 2007). Heavy metals have the potential to alter the abundance and richness of microorganisms. (Tipayno et al., 2018; Zhang et al., 2019). Soil microorganisms can also interact with heavy metals and affect metal functional groups, resulting either in their mobilization (by dissolving, leaching or transforming them) or in their immobilization (by organic-metal binding and precipitation) (Gadd, 2004).

4.1.2 Antibiotics

Antibiotics are complex substances having different functional groups in their chemical structures and are categorized into several classes depending on their mode of action. Since most antibiotics are not entirely metabolized in the bodies of humans and animals, a significant amount of them is disposed into soil and water via municipal wastewater, livestock manure, sewage and organic wastes. (Bouki et al., 2013; Daghrir & Drogui, 2013; Wu et al., 2014a, b). Several studies have found that even low concentrations of antibiotics can alter a variety of soil processes facilitated by microbes. Soils containing sulfamethoxazole, sulfadiazine and trimethoprim demonstrated a significant reduction in soil respiration (SR) (Kotzerke et al., 2008; Liu et al., 2009) Antibiotic exposure is known to have an effect on nitrification and/or denitrification rates, and the effects are dependent on the type of antibiotic and the time of exposure. Antibiotics may also alter the rate of iron turnover in soil (Toth et al., 2011).

4.1.3 Agrochemicals

Agrochemical is a broad term used to define the chemical substances used for agricultural purposes, which comprise of pesticides, synthetic fertilizers, growth agents and raw manures. These agrochemicals may boost agricultural yields, but their widespread usage poses a significant harm to the environment, particularly soil biology. Some pesticides can disrupt association between plants and rhizobia, reducing the critical mechanism of biological nitrogen fixation. Pesticide-contaminated soils can also inactivate phosphorus-solublizing and nitrogen-fixing potential of bacteria (Hussain et al., 2009a, b). A substantial variation in microbial population has been detected between soils that were treated with pesticides and untreated ones, indicating that indiscriminate application of pesticides in the soil leads to reduction in microbial population and even their extinction (Ubuoh et al., 2012). Pesticides also affect microbial and enzymatic activities that underlie soil biochemical processes. (Demanou et al., 2004). In the literature, adverse effects of the use of agrochemicals on enzymatic activity of soil microbes have also been observed (Kalam et al., 2004; Menon et al., 2005; Gil-Sotres et al., 2005; Hussain et al., 2009a, b).

4.2 Intensive Agricultural Practices

One of the most prominent challenges of the twenty-first century is agricultural expansion. To keep up with the world's growing population, the total area under cultivation has been expanded by nearly 500% in the previous decades (FAO, 2018), with a 700% increase in fertilizer consumption and a several-fold increase in the use of agrochemicals (Tilman et al., 2002). Agricultural intensification has raised an extensive range of environmental concerns like chemical accumulation in soil and their leaching leading to groundwater eutrophication, increase in emissions of greenhouse gases, degradation of soil quality and soil erosion (Bender et al., 2016). Microbial communities play an indispensable role in ecosystems and render a wide range of services (Wall et al., 2001; Delgado-Baquerizo et al., 2016; Graham et al., 2016). Inadequate nutrient efficiency, increase in the amount of greenhouse gas emissions, groundwater eutrophication, loss of soil quality and soil erosion are all issues that have arisen as a result of agricultural intensification (Bender et al., 2016). Agricultural intensification, which involves high resource usage and limited crop diversification, can have an impact on soil- and plant-associated bacteria, as well as ecosystem services (de Vries et al., 2013). Current agricultural methods in many developing countries follow unsustainable practices, resulting in a massive volume of hazardous effluents being discharged directly or indirectly into the soil (Yanez et al., 2002). The introduction of nanotechnology and nanomaterials has complicated the picture of soil inputs and degradation even further (Mishra et al., 2017, 2018). Currently, numerous chemical fertilizers are used in an indiscriminate manner (Meena et al., 2016), causing harm to the soil biota. Furthermore, heavy machinery is a substantial contributor to soil compaction and change. Soil compaction reduces porosity, limiting oxygen and water delivery to soil microbes and plants, resulting in detrimental effects on soil ecology and forest productivity. Compaction has major repercussions in terms of runoff and erosion of the top soil, especially when restricted in ruts. In compacted soils, regeneration can be hampered or even blocked for lengthy periods of time, resulting in a significant reduction in microbial diversity in the soil and a negative impact on soil functioning.

4.3 Desertification

Desertification is a term used to describe the degradation of land in arid, semi-arid and sub-humid environments as a result of a variety of factors such as climatic changes and human activity. Desertification is mostly caused by overgrazing in many parts of the world. Other causes that contribute to desertification include urbanization, climate change, groundwater overdraft, deforestation, natural catastrophes and agricultural tillage practices. Desertification is one of the world's most serious social, economic and environmental problems. Total area impacted by desertification currently is 6–12 million km^2, and about 1–6% of residents live in these desertified areas (World Bank, 2009). The process of desertification introduces a significant alteration in the dominant species of the community, plant community structure and landscape pattern change. Desertification results in deficiency of several nutrients which also diminishes the carbon and nitrogen sources of microbes living in the soil, therefore hugely affecting their survival and decreasing their richness. As a result of which, the overall quality of soil deteriorates and soil functioning is severely affected.

5 Practices to Manage Soil and Achieve Optimum Functionality of Soil Community

Diverse, interacting forces shape soil microbial populations. Crop rotation, fertilizer and tillage practices all modify the physicochemical properties of soil, thereby influencing the variety and composition of soil bacterial and fungal communities (Francioli et al., 2016). Therefore, management of soil nutrients, promoting organic farming, practicing no tillage, using biological pest control methods etc. can hugely help in the maintenance of soil microbial community and ensuring soil sustainability.

5.1 Managing Soil Nutrients

Agricultural management influences microbial community composition and structure and their function of nutrient-cycling by establishing soil physicochemical features. Organic fertilizers improve soil microbial diversity and heterogeneity (Lupatini et al., 2017), and the bacterial and fungal community structure of organically managed soil systems is markedly different from that of conventional systems. (Francioli et al., 2016; Mader et al., 2002; Li et al., 2017; Wang et al., 2016). Organic fertilizers play a critical role in accumulation of soil organic matter and aggregate formation and hugely influence the composition of microbial community and their co-occurrence in microhabitats. Microbial communities provide nitrogen to plants in available forms through biological N fixation and mineralization of organic forms, and also limit N losses by immobilizing it in soil organic matter. The abundance, diversity and activity of soil microorganisms is hugely modified by the organic inputs such as compost and cover crop residues used for agriculture purpose (Li et al., 2017; Kong et al., 2010), while synthetic fertilizers mostly result in increased abundance of Acidobacteria (Francioli et al., 2016) and decrease the abundance of ammonia-oxidizing archaea (Muema et al., 2016). Synthetic fertilizers may affect microbial community structure by changing the soil pH and acidifying the soil, thereby indirectly increasing the abundance of acid-tolerant taxa. Modification in the structure and activity of microbial communities present in soil influences not only the rates but also the outcomes of agriculturally and environmentally important N-cycling processes like denitrification (Bhowmik et al., 2017).

5.2 Tillage Practices

No-tillage practices aid soil conservation by limiting the disturbance in soil and resulting negative carbon (C) mineralization, thereby acting as a C sink rather than being a source of carbon. In comparison to tillage systems, no tillage practice allows residue storage in soil itself, which provides additional benefits to the soil such as better soil fertility, minimized erosion and increased accessible moisture (West & Post, 2002; Lal, 2004; Franzluebbers, 2005). White and Rice (2007) concluded that in comparison to conventionally tilled soils, no-tillage soils showed higher microbial abundance. Crop rotation method and bio-covers can cause alterations in archaeal and bacterial composition and abundance (White & Rice, 2007). Agricultural conservation methods like crop rotations, animal manures and cover crops are said to preserve and enhance soil quality for long-term increase in agricultural output (DeBruyn et al., 2011). Cropping sequence diversity and crop rotations are also important factors in bacterial assemblages and species richness. Soybeans and legume cover crops with high protein content are said to create more fragile residues than cereals with a high C:N ratio, such as maize (Sarrantonio & Gallandt, 2003). In addition, increased diversity of cropping sequence and cover crops sustain more microbial biomass and encourage more fungal-based community structures, resulting in higher amounts of microbially derived organic matter (Six et al., 2006).

5.3 Biological Pest Management

Biopesticides are naturally occurring compounds that can be obtained from microorganisms, plants or other naturally occurring products to provide pest control (Lacey & Gerorgis, 2012). Biopesticides are important components of pest management strategies that aim to provide better and more environmentally friendly alternatives to conventional pesticides while avoiding soil pollution and contamination and preserving soil microbial ecosystems. While pathogenic microorganism-based biopesticides are particular to a target pest, biopesticides derived from beneficial interactors are a superior and more environmentally friendly option. Furthermore, unlike conventional chemical pesticides, biopesticides do not affect the ecosystem or soil bacteria (Gupta & Dikshit, 2010). Active substances released by several plants are also used as biocontrol agents. For example, strigolactones (a sesquiterpene) production promotes symbiotic associations by attracting *Glomeromycota* mycorrhizal fungi (Akiyama & Hayashi, 2006). The legumes produce flavonoids, which act as signalling molecules, attracting N-fixing bacteria to the rhizospheric zone and allowing rhizobial symbioses to form (Pathan et al., 2018). The release of organic acids by plant growth-promoting rhizobacteria (PGPR) benefits other soil microbes. For example, tomato roots emit citric and fumaric acids, which attract *Pseudomonas fluorescence* (Gupta, 2003). Another good example of a biopesticide is neem cake oil, which provides critical sustenance for soil microbes and enhances soil physicochemical qualities while also controlling a variety of pests (Gopal et al., 2007).

6 Conclusion

Soils support a diverse microbiological and faunal taxonomic community, which contributes to a wide range of ecosystem services that are critical for long-term viability of natural and agricultural ecosystems. These services have been classified as those related to the provision of products, the regulation of ecological processes and supporting services. The intricacy of demonstrating soil food webs under field conditions has been a major stumbling block to fully appreciating the contributions of soil microorganisms to soil processes and ecosystem services. As new analytical techniques and instruments become available, there is a continual need to identify, investigate and manage additional groupings of soil biota. For a better understanding of the links between soil biodiversity, their functioning and ecosystem services provided by them, multidimensional approaches that integrate new and existing information are required. However, there are also several natural and anthropogenic activities that pose serious threat to the survival of soil community, thereby hindering the ecosystem services provided by them. Therefore, there is also a pressing need to introduce and expand soil conservation methods in order to ensure appropriate soil functioning and long-term sustainability.

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Household Access to Actual Food Intake and Fertility Level of Muslim Population: A Study from Rural West Bengal

Soleman Khan and A. K. M. Anwaruzzaman

Abstract Access to food is determined by socioeconomic conditions, food prices, and the purchasing power of households to buy enough food or actual food intake. The phenomenon of hunger is very much region- or context-specific. India remains in the 'severe' category in the Global Hunger Index Severity Scale, 2017. Noticing the importance of food for surviving in this article, initiative has been taken to analyze the impacts of the access of food and actual food intake on the fertility level of Muslims in rural West Bengal. The study was based on both secondary and primary data covering 600 households, also intending to examine food access of the households classified by their socioeconomic condition among the married Muslim population. The present study is conducted on selected Community Development (CD) blocks of West Bengal using a multi-stage random sampling technique. After detailed study, a negative relation was found between actual food intake of married Muslim women and the fertility level of the Muslims in rural West Bengal. It was further observed that Muslim women are deprived in terms of the consumption of food compared to Muslim men because of male supremacy and low access to food mainly because of their poor socioeconomic conditions.

Keywords Fertility rate · Muslim · Food consumption · Protein consumption · Gender disparity

1 Introduction

Muslims are one of the socioeconomically backward groups in India as well as in West Bengal (Khan, 2020; Hussain, 2009; Hossain, 2013; Robinson, 2008). The *Census of India* (2011) data reflect that Muslims are behind in terms of various socioeconomic indicators such as educational attainment, occupational status, and so on. Many previous studies observed that there is a positive relationship between food consumption and the socioeconomic status of the people (Alkerwi et al., 2015; Pechey & Monsivais, 2016; Morgan, 1986). The concept of 'food access' is derived

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from the food security concept, which is one of the most important components and represents the ability of a family or individual to obtain food through production, purchase or food aid, and so on. As per the Global Hunger Index (GHI), 2017, India had a serious hunger and food security problem and ranked 100th of 119 countries, ranked based on four indicators including undernutrition, child mortality, child wasting and child stunting (United Nations, 1975; Rukhsana & Alam, 2021). Robert et al. (2013) demonstrated that food access is ensured when communities and households and all individuals within them have adequate resources, such as money, to obtain appropriate foods for a nutritious diet. The Food and Agriculture Organization in 1983 stated that food security means 'ensuring that all people at all times have both physical and economic access to the basic food they need' ((M. S Swaminathan Research Foundation and The World Food Programme, 2008). This food security concept is 'access by all people at all times to enough food for an active and healthy life' (World Bank, 1986). Food accessibility may be considered as the axis of food security around which all the economic activities revolve by either growing food directly under primary economic activity or earning money finally to buy food through secondary or tertiary economic activities (Sajjad & Iffat, 2014).

The overall fertility level of the Muslims in the country as well as in West Bengal is quite high compared with various other groups of people like Hindus (Haque & Patel, 2016; Bhat, 2005; Jeffery & Jeffery, 2000). The differential fertility rate of the two major religious groups (Hindu and Muslim) in India as well as in West Bengal creates strong disputes among common people and academic professionals. Earlier studies showed that a negative relationship prevails between socioeconomic conditions and fertility level; it is also true for the Muslims in West Bengal (Basu & Sajeda, 2000; Bhat & Zavier, 2005; Chatterjee & Mohanty, 2021; Roy et al., 1999; Hull & Hull, 1977). Most academic professionals consider various socioeconomic factors to be largely responsible for the high fertility level of Muslims. Nevertheless, some people and academic professionals (saffron demographers) try to relate the religious identity of Muslims to their high fertility level (Jeffery & Jeffery, 2005; Rao, 2010). This highlights that there is still confusion behind the reasons for the high fertility level of Muslims in India as well as in West Bengal. As the status of access to food and actual food intake is found to be linked with the socioeconomic conditions; therefore, there may be an association between food consumption and fertility level of the Muslims in rural areas of West Bengal. This issue is examined in this study.

2 Study Area

The state of West Bengal is one of the major states of the Eastern Indian region. It lies between 85° 50′ and 89° 50′ east longitudes and from 21° 38′ to 27° 10′ north latitudes (Fig. 1). The northern part of the state is characterized by the Himalayan mountain region whereas the southern part of the state is bounded by the world-famous mangrove forest (Sundarbans). The study was conducted in the rural areas (including statutory towns) of six selected CD blocks, such as Barasat-II, English Bazar, Suti-II, Nalhati-II, Mograhat-II and Kaliachak-III. These CD blocks where the primary survey was conducted are characterized by mainly a plain region (under the lower Gangetic plain) and fall under the monsoonal climatic characteristic zone. The study area is a part of the greater Bengal delta region; therefore, the

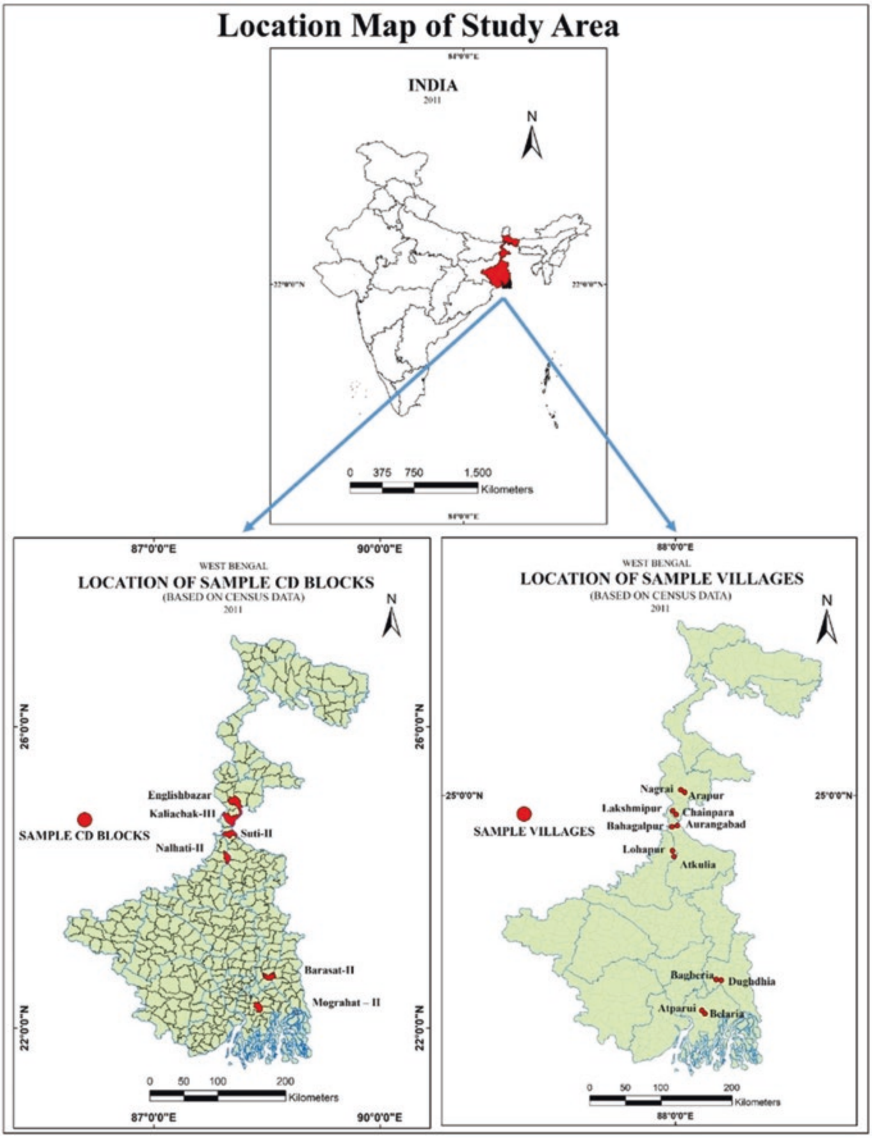


Fig. 1 Location map

fertility of the soil is quite good. The area is renowned for various agricultural activities; paddy is the principal cultivated crop. In terms of the geographical area, the state covers approximately 88,752 km^2 with a population of 9,12,76,115 persons (*Census of India*, 2011). The six CD blocks that are considered for the primary survey comprising 1.16% of the total area of the state account for 2.13% of the total population and also account for 3.86% of the total Muslims in the state. The state is divided into 19 districts and 341 Community Development (CD) blocks (*Census of India*, 2011) for administration. According to the data of the *Census of India*, 2011, Hinduism is the prime religious group of the state (70.54%), and Muslims are the second (27.01%).

The major objectives of this study are first to assess the relationship between access to food and actual food intake of Muslim married women and fertility level of Muslims in rural West Bengal and second to find out whether there is any difference between the food intake of married Muslim men and women.

3 Database and Methodology

The entire study was based on secondary and primary data. Agriculture-related data and population data were taken from the statistical abstract, published by the Bureau of Applied Economics and Statics, Government of West Bengal, as well as *Census of India*, 2011.

The primary survey was done for the purpose of the collection of data, and a field survey was conducted on the selected six CD blocks in 2018 by using a pre-designed survey schedule. The respondents were married Muslim women in the reproductive age group, i.e., between 15 and 49 years. The total number of respondents was 600 (100 from each sample CD block). The respondent married Muslim women were also asked about the consumption of protein-rich non-vegetarian (meat, fish and egg) food items by their husbands.

The selection of respondents as well as sample CD blocks is done by following the multi-stage random sampling technique. At the first stage, based on *Census of India* (2011) data (excluding the population of statutory towns), Muslim majority CD blocks with at least 50% Muslim population were identified. Considering the *Census of India* (2011) database on infrastructural indicators like amenities and services, such as the percentage of the residence houses in good condition (x_1), percentage of households with safe drinking water facilities (x_2), percentage of households using electricity as the main source of lighting (x_3), percentage of households with latrine facilities within the premises (x_4), the ratio of primary (x_5), middle (x_6), secondary (x_7), higher secondary (x_8) and higher education institutions (college and university) (x_9) to the total population, the ratio of medical institutions to the total population (x_{10}), the ratio of doctors and paramedical staff strength in medical institutions to the total population (x_{11}) and the ratio of medicine shops to the total population (x_{12}). Based on these indicator z scores of all the Muslim majority, CD blocks were calculated. The CD blocks were then arranged in descending order based on their respective z scores. Two CD blocks of Barasat-II and Englishbazar were selected from the top third z scoring CD blocks using simple random sampling techniques. Two CD blocks of Mograhat-II and Nalhati-II were selected from the middle third z scoring group of CD blocks, and the remaining two CD blocks of Kaliachak-III and Suti-II were selected from the bottom third z score ranking CD blocks. At the second stage of sampling, based on the same principle of the Muslim majority and availability of amenities and services, two villages were selected from each sample CD block for conducting the study. While selecting the sample villages from the z score list of villages of respective sample CD blocks, the first village was selected from the top of the z score list, and the second one was selected from the bottom of the list. At the third stage of sampling, the list of Muslim households with married women in the 15–49-year age group was collected from Integrated Child Development Scheme (ICDS) Centres and the Accredited Social Health Activist (ASHA) workers. The respondents were selected randomly using a simple random sampling technique with the help of a random table.

The databases on infrastructure, amenities and services were considered to access the socioeconomic backwardness of the households selected for the survey.

The formula by which Z scores have been calculated is as follows:

$$Z = \frac{x - \mu}{\sigma}$$

where Z = standard score, x = observed value, μ = mean of the sample and σ = standard deviation of the sample.

For the measurement of the status of actual food intake in this study, the focus is on the measurement of the consumption of various protein-rich non-vegetarian (meat, fish and eggs) food items that are consumed by married Muslim men and women. The study shows that the entire population under study falls under the non-vegetarian category; therefore, it may be considered as the base of the condition of food supply to the households. For convenience, the quantity of consumption of protein-rich non-vegetarian (meat, fish and eggs) food items are considered as the basis of estimation of access to food and actual food intake of married Muslim men and women. For the convenience of the study, a three-point scale was considered in studying the status of food supply, namely, 'high,' 'moderate' and 'low.' The categories of 'high,,' 'moderate' and 'low' indicate access to food and actual food intake, i.e., per head consumption of non-vegetarian food items (meat, fish and eggs) > 500 g, 250–500 g and < 250 g per week, respectively.

The statistical tests of ANOVA and Tukey HSD at 95% confidence level were applied to measure the statistical difference in the number of live births per married Muslim woman among various groups of women who consume different amounts of protein-rich non-vegetarian (meat, fish and eggs) food items. The ANOVA test is calculated by following the linear model:

$$X_{ij} = \mu_i + e_{ij}$$

where X_{ij} denotes the j-th observation in the i-th group; μ_i denotes the mean of the i-th population; e_{ij} denotes error due to many unspecified causes. The ANOVA test indicates only the overall statistically difference in the number of live births per married Muslim woman among various groups of women who consume different amounts of protein-rich non-vegetarian (meat, fish and eggs) food items. Besides, the Tukey HSD test is conducted for the calculation of the statistical difference in the mean of the number of live births among those groups of women having a difference in the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items with respect to each other. The formula used in the calculation of Tukey's test is very similar to that of the t-test. After ANOVA, the conduction of Tukey's test is essential in understanding whether the means of the number of live births of various groups of women statistically differ from each other or not. After calculating ANOVA, the formula that has been used in the calculation of Tukey's test is as follows:

$$q_s = \frac{Y_{\max} - Y_{\min}}{SE}$$

where $Y_{\max}$ is the larger of the two means being compared; $Y_{\min}$ is the smaller of the two means being compared, and SE is the standard error of the sum of the means. This q_s value can then be compared to a q value from the studentized range distribution. If the q_s value is larger than the critical value q_α obtained from the distribution, the two means are said to be statistically different at 95% confidence level.

Pearson's product moment correlation coefficient was conducted to identify the strength of linear correlation between the consumption amount of protein-rich non-vegetarian (meat, fish and eggs) food items of married Muslim women and the number of live births per woman.

An independent sample t-test is also conducted to identify whether there is a mean difference in the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items between married Muslim men and women. The formula used in the calculation of the Student t-test is as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where $\bar{X}_1$ and $\bar{X}_2$ are sample means; S_1 and S_2 are standard deviations of the samples, and n_1 and n_2 are the sizes of the samples.

Based on *Census of India* (2011) data, the fertility rate is calculated by following the total fertility rate (TFR) method. On the other hand, based on primary data, the fertility level of Muslims is calculated by measuring the number of live births per married Muslim woman. The formula of the calculation of TFR is as follows:

$$\textbf{Total fertility rate (TFR)} = \frac{\sum \textbf{Age} - \textbf{specific fertility rate}}{\textbf{1000}} \times \textbf{5.}$$

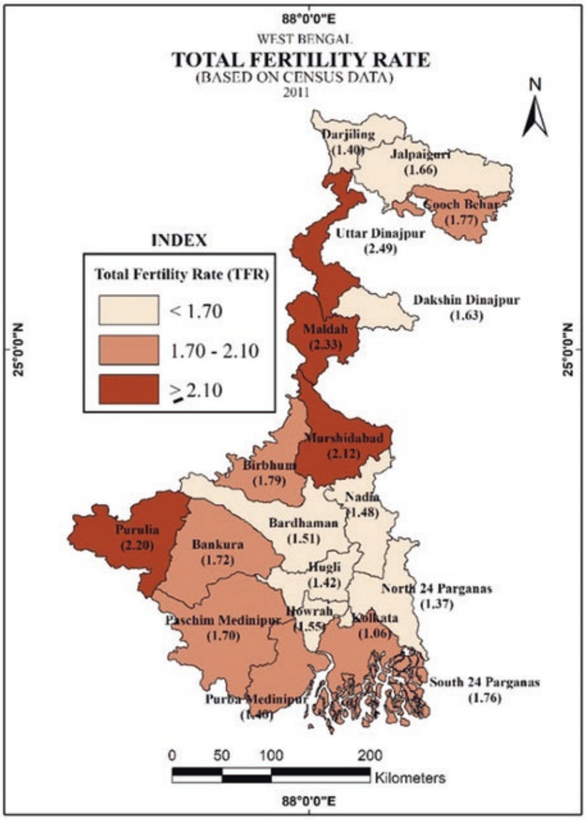
4 Results and Discussion

Food Consumption and Fertility Scenario in West Bengal Vnurumuku (2014) worked on the Food Consumption Score (FCS) and its endemic diversity in West Bengal. Their study showed that the percentage of people belonging to the 'poor' FCS category is significantly higher in various districts of West Bengal, in the drought-prone western part of West Bengal and in and around the flood-prone districts of Malda and Murshidabad. In Dooars and Sunderban regions crop productivity is low because of salt water and soil salinity. These regions are facing the problem of poor food consumption due to a weak public distribution system (PDS) and economic problems.

Figures 2 and 3 show the level of fertility of the overall population of the state as well as of Muslims in terms of total fertility rate (TFR). The analysis of fertility data shows that the districts that are characterized by poor food supply status have high fertility rates for both the overall population and backward community (in terms of socioeconomic development) Muslims in the state. For example, the districts of Cooch Behar, Maldah, Murshidabad, Purulia, South 24 Parganas, and so on, show high TFR for both the overall population and Muslims where the overall accessibility of food is quite low. Throughout the western part of the state, the fertility of Muslims is quite high in terms of TFR where the accessibility to food is also observed to be quite poor and also disappointing. Figures 2 and 3 show that there is a negative relationship between the accessibility of food and fertility.

Access to Actual Food Intake and Fertility Rate Status of Muslim Population at Household Level The condition of access to food and food intake is an important factor reflecting the overall economic condition of families (Shariff et al., 2015). Moreover, adequate food assures nutrition, which has a strong relation to mortality, particularly infant and child mortality, which has a great bearing on fertility (Asiseh et al., 2018; Campbell et al., 2009; Cassidy-Vu et al., 2022). Figure 4 exhibits the overall status of the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items by members of Muslim families (above 15 years old) in the sample CD blocks. Around 21.61% of Muslim households fall under the low intake category. This specifies that around 21.61% of Muslim households in the study area consume < 250 g per week of non-vegetarian (meat, fish and eggs) items . The food availability status of the highest share of households (59.13%) is moderate (250–500 g/week). The category 'high' (> 500 g) food availability has the lowest share in Muslim households (21.61%). The CD block-wise analysis of data on food availability shows a negative relationship between fertility level and food intake. The result of the analysis of field survey data further shows a comparatively better status of access to food and actual food intake of the Muslims in Barasat-II, Englishbazar and Nalhati-II CD blocks, where a low fertility level is also detected among Muslim families. On the other hand, CD blocks of Kaliachak-III, Suti-II and Mograhat-II have comparatively poor food availability and low intake of various

Fig. 2 Total fertility rate



non-vegetarian (meat, fish and eggs) food items for Muslims combined with high fertility.

The correlation analysis (Fig. 5) between the average level of the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items of Muslim women and total live births per woman also indicates a prevalence of a negative relationship between them. The calculated correlation coefficient (r) is $r = -0.55$, $p = <0.001$.

Based on the field survey data, a one-way analysis of variance (ANOVA) test between groups was conducted to determine whether there is a statistical difference in the fertility level of the Muslims across different levels ('high,,' 'moderate,' and 'low') in the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items among Muslim women (Table 1) in rural West Bengal. For this purpose, the consumption amount of protein-rich non-vegetarian (meat, fish and eggs) food items consumed by married Muslim women was divided into three groups, 'high,,' 'moderate,' and 'low.' The total number of live births per married Muslim woman was taken as the dependent variable in this analysis. The test was statistically significant, and Table 1 exhibits the statistically significant difference [F (2, 597) = 243.98, $p = < 0.001$ at the $p < 0.05$ level] in the total number of live births

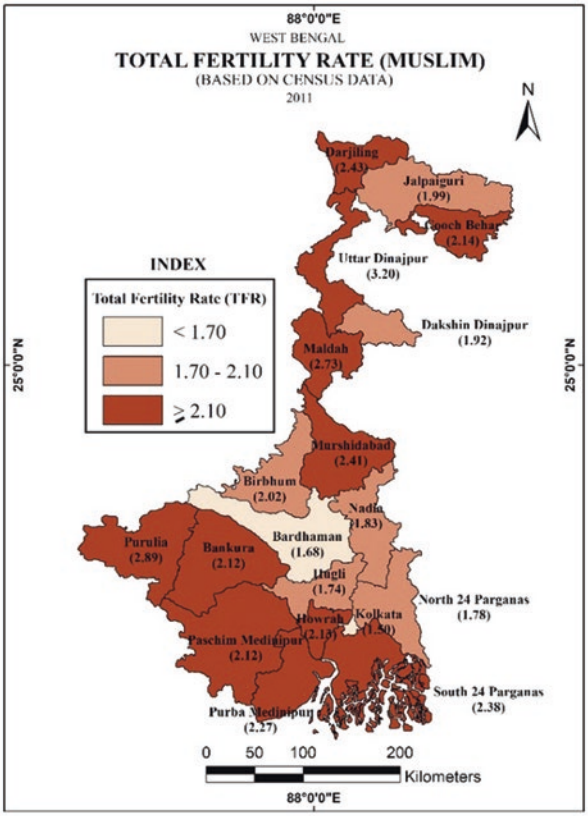


Fig. 3 Total fertility rate of Muslim population

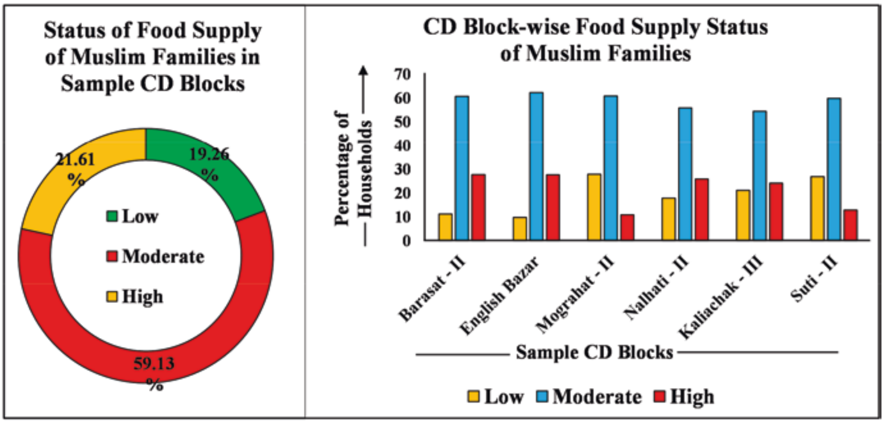


Fig. 4 Household food supply status of Muslim families

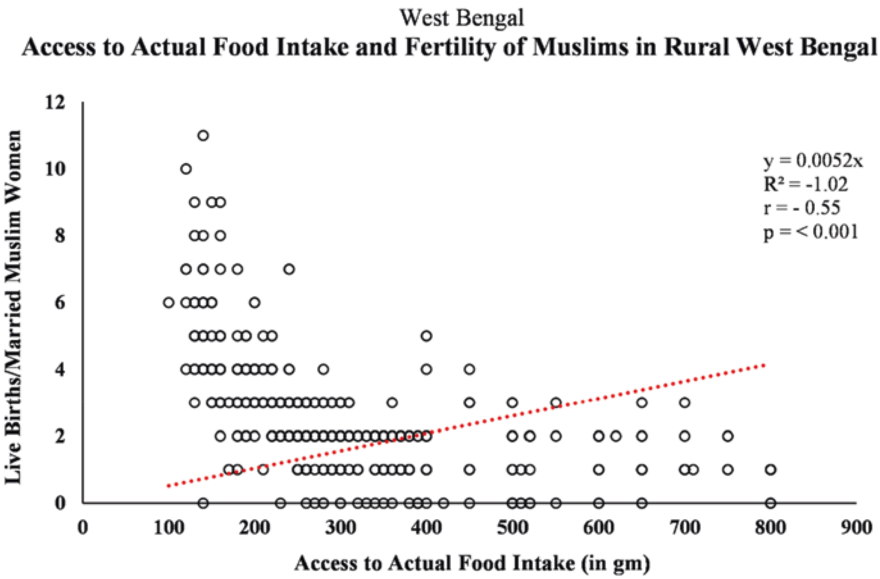


Fig. 5 Household access to actual food intake and fertility association

Table 1 West Bengal: relationship between access to actual food intake (protein-rich non-vegetarian food items like meat, fish and eggs) of married Muslim women and number of live births per married Muslim woman

	ANOVA			
Sum of squares	df	Mean square	F	Significance
743.91	2	371.96	243.98	< 0.01
910.16	597	1.53		

Source: Compiled by authors

per married Muslim woman among the groups of women consuming different levels of protein-rich non-vegetarian (meat, fish and eggs) food items.

Table 2 shows the statistical significance of the difference in live births per married Muslim woman among the three groups ('high,' 'Moderate' and 'Low') with respect to each other. Table 2 shows that there is a statistically significant mean difference in the number of live births per married Muslim woman among these three groups of Muslim women with different levels of consumption of protein-rich non-vegetarian (meat, fish and eggs) food items of 'high' ($\mu = 1.13$, $\sigma = 0.79$), 'moderate' ($\mu = 1.71$, $\sigma = 0.99$) and 'low' ($\mu = 3.90$, $\sigma = 1.69$). This indicates that the difference in the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items among various groups of Muslim women plays a significant role in creating the difference in the fertility level of the Muslims in rural West Bengal.

In this study, the data acquired from the field survey are also analyzed to understand whether there is any gender disparity in terms of the consumption of food between married Muslim men and Women. The result of the analysis directs that

Table 2 West Bengal: Post-hoc multiple comparisons test using the Tukey HSD analysis for access to actual food intake (protein-rich non-vegetarian food items, like meat, fish and eggs) of married Muslim women and number of live births

Food consumption level (I)	μ	σ	Food consumption level (J)	Mean difference in the no. of live births (I–J)	Significance
Low	3.90	1.69	Moderate	2.19[a]	< 0.01
			High	2.77[a]	< 0.01
Moderate	1.71	0.99	Low	−2.19[a]	< 0.01
			High	0.58[a]	< 0.01
High	1.13	0.79	Low	−2.77[a]	< 0.01
			Moderate	−0.58[a]	< 0.01

Source: Compiled by authors
[a]The mean difference is significant at the 0.05 level

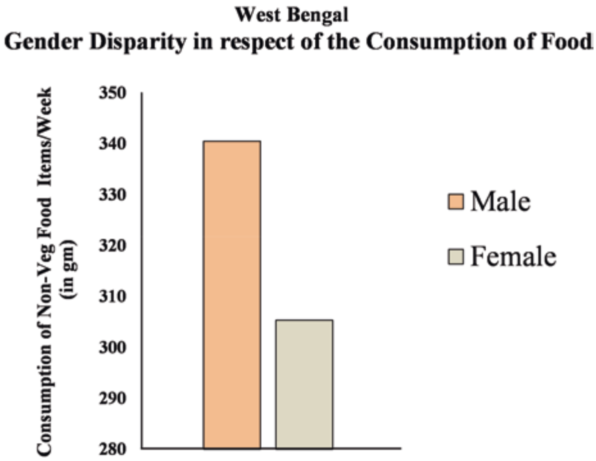


Fig. 6 Gender disparity in respect to food consumption

Muslim married women are deprived regarding the consumption of various protein-rich non-vegetarian (meat, fish and eggs) food items compared with Muslim men (Fig. 6). Gender disparity is considered a hindrance to women's empowerment (Bayeh, 2016; Kabeer, 2005). The earlier studies support that there is a negative relationship between women's empowerment and fertility (Phan, 2013; Samari, 2019; Behrman & Gonalons-Pons, 2020; Prata et al., 2017). Analyzing primary data showed that married Muslim women consume a low amount (305.38 g/week) of protein-rich non-vegetarian (meat, fish and eggs) food items compared with married Muslim men (340.43 g/week), which may have a positive association with their fertility level.

Based on the field survey data, an independent sample t-test is conducted to determine whether there is a statistically significant difference in the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items between the married Muslim men ($n = 600$) and women ($n = 600$) in the rural areas of West Bengal. The result shows (Table 3) that the t-test is statistically significant [t (1198) = 4.01, 95%

Table 3 West Bengal: mean difference in access to actual food intake (protein-rich non-vegetarian items like meat, fish and eggs) between married Muslim men and women

Gender	N	Mean	σ	t
Male	600	340.43	149.82	4.01[a]
Female	600	305.38	152.89	

Source: Compiled by authors
[a]$p < 0.001$

Cl, p = <0.001] ,which means that there is a statistically significant difference in terms of the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items between married Muslim men and women. Table 3 further exhibits that Muslim men ($\bar{x}$ = 340.43, σ = 149.82) consume more protein-rich non-vegetarian (meat, fish and eggs) food than Muslim women ($\bar{x}$ = 305.38, σ = 152.885), and the difference is statistically significant. The mean difference in the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items between married Muslim men and Women is also quite high (35.05).

5 Conclusion

The result of the study reveals that access to actual food intake of the Muslim married women in terms of consumption of protein-rich non-vegetarian (meat, fish and eggs) food items plays a significant role in creating the difference in the overall fertility level of the Muslims in rural West Bengal. The correlation between the intake of protein-rich non-vegetarian (meat, fish and eggs) food items of married Muslim women and the number of live births per married Muslim woman is observed to be significantly negative. The difference in the intake of protein-rich non-vegetarian (meat, fish and eggs) food items between married Muslim men and women is also statistically significant. The study shows that gender disparity regarding the consumption amount of non-vegetarian (meat, fish and eggs) food items among Muslim married men and women is quite high. This highlights that Muslim married women are deprived even in terms of access to food in the study area. The deprivation of married Muslim women in terms of access to actual food intake (protein-rich non-vegetarian items, like meat, fish and eggs) indicates the poor empowerment status of Muslim women in the study area, and this is associated with their high fertility rate. The low food consumption of married Muslim women also indicates their poor nutritional status. Thus, it can be concluded that to reduce the fertility level of the Muslims, it is crucial to increase the overall food consumption of Muslim women. especially protein-rich non-vegetarian (meat, fish and eggs) food items, and remove the gender gap regarding the consumption of protein-rich non-vegetarian (meat, fish and eggs) food items.

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Livelihood, Food Security, and Sustainability in Murshidabad District

Bulbul Nargis Sultana and Nasrin Banu

Abstract The present study is an attempt to elucidate the different stages of livelihood based on sustainability with special attention to food security status in Murshidabad district. The district comes under the 100 most backward districts of India due to its largest share in the poverty. The study is mainly based on primary data collected from sampled households of the villages through a well-structured schedule. Here, livelihood sustainability has been measured adopting the formula of Livelihood Vulnerability Index developed by Intergovernmental Panel on Climate Change (IPCC). In addition to this, livelihood sustainability has been categorised into four stages on the livelihood ladder adopting the concept of Oxfam i.e. Accumulating, Adapting, Coping and Surviving. In accumulating stage of sustainability, there are eight villages where life is going well and households are able to cope with most of the external shocks. Food security status of accumulating stage is also better than the other stages. Households of adapting stage villages have higher hold on assets but it is slightly lower than the households of accumulating stage. The villages which are under adapting stage have sustainable food security. In coping stage, things are good enough but not at the satisfaction level. There are six villages in this stages where food security status is below the sustainability level. Seven villages came under the surviving stage where livelihood is most vulnerable and households of this stage are unable to cope with even small shocks having limited asset possession.

Keywords Food security · Livelihood · Sustainability · Accumulating · Adapting · Coping · Surviving

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1 Introduction

In simple words, livelihood is the means for securing the necessities of life. Livelihood has been defined as adequate stocks and flows of food and cash to meet basic needs. Chambers in 1988 has explained that the term sustainable refers to the maintenance or enhancement of resource productivity on a long-term basis. The achievement of food security is one sub-set of objectives while food is one of a whole range of factors which control why the poor take decisions and spread risk, and how they outstandingly balance competing interests in order to subsist both in the short and longer term. There is general consensus that food security stands as a fundamental and basic need for all human beings in a civilized society.

Livelihood has largely been an imbedded theme in the concept of food security, which will be achieved when equitable growth ensures that the poor and vulnerable have sustainable livelihoods (Maxwell, 1988, 1991). Maxwell in 1990 again argues that poor people will modify their attitudes to food in order, for example, to preserve their asset base or in other ways protect their livelihoods. From these arguments it is to be said that livelihoods have must to be sustainable for achieving food security.

Generally, sustainability is defined as the ability to cope with and recover from stress and shock, while maintaining or enhancing capabilities and assets (Chambers & Conway, 1992; Scoones, 1998). Conway (1985) defines sustainability as the ability of a system to maintain productivity in spite of a major disturbance, such as caused by intensive stress or a large perturbation. Hansen (1996) further conceptualises sustainability as a system's capacity to continue through time. Households' livelihoods would be secure when they are in a position to acquire, protect, develop, utilize, exchange and benefit from assets and resources. In extended words, livelihoods are secure when households have secure ownership of resources as well as better access to resources (both tangible and intangible) and have income-earning activities including reserves and assets, to offset risks, ease shocks and meet contingencies (Chambers, 1988).

The present study is an attempt to elucidate the different stages of livelihood based on sustainability with special attention to food security status in Murshidabad district. A lot of work has been done on sustainable livelihood and food security separately at international, national and regional level. But a very few studies have been found which focused on amalgated issues of both sustainable livelihood and food security. The available studies are mostly based on secondary data collected at national and state level, and a few of them are at micro level. Till now no work has been done on sustainable livelihood and food security based on primary data in Murshidabad district. Following the IPCC's livelihood vulnerability index, an attempt has been made to identify the stages of livelihood sustainability.

The study has been organised into five sections. The first section highlights the background of the study. In the second section, the sources of data and applied methods have been discussed. The third section sheds light on the rationale about the study area. The results have been elucidated in the fourth section. Finally in the fifth section, on the basis of the whole study conclusions have been drawn.

2 Data and Methods

The present study is mainly based on primary data collected from sampled villages through a well-structured schedule. According to 2011 census, approximately 7.1 million people live in Murshidabad district, which has 26 community development blocks consisting of 2210 villages, out of which 1925 are inhabited. To fulfil the purpose of the study, one village from each CD block has been selected considering the population size, density and accessibility. In the present study, households were considered as the smallest social units for micro-level survey. From each sampled village, 30 households were surveyed using systematic random sampling. Thus a total of 780 households were surveyed. Data on food and nutritional security and occupational activities were collected at the individual level and finally 3374 individuals including children have been surveyed.

For data analysis, appropriate statistical techniques have been executed i.e. cross tabulation, descriptive statistics and simple percentage method using SPSS 16 version software. Technique of normalization has been used here for preparing score of Livelihood Asset Index, Vulnerability Index and Food Security Index as this approach has been used by UNDP for developing Human Development Index as well as it is widely accepted for preparing index specially in social sciences (UNDP 1990, 1992). Adopting LVI-IPCC method, the Livelihood Sustainability Index (LSI) was calculated.

Livelihood Sustainability Index (LSI) = (Livelihood Assets Index − Vulnerability Index)* Food Security Index ……………………………………………….(i)

3 Rationale of the Study Area

Murshidabad district is located in the central part of West Bengal, which is one of the eastern states of India. The latitudinal extent of the district lies between 23°43′30″ and 24°50′20″ North and longitudinal extent is from 87°49′17″ to 88° 46′00″ East. The area of the district is 5341 km^2. The district resembles an isosceles triangle which is situated on the left bank of the Ganga River (Fig. 1). Unfortunately, the district comes under the 100 most backward districts of India because of its higher share in the poverty. As a consequence, this district is the shelter of 1.47% of India's poor people. Again it is very striking that more than half of its population (56%) lives below poverty line. Nearly 80% of the population of this district are rural, and agriculture is the prime occupation for most of them. But nowadays agriculture is also suffering due to low yield resulting from small land holdings and poor irrigation facilities. The overall socio-economic situation of this district is not satisfactory at all; that is why this district has been selected as the study area.

The district is also in a vulnerable situation because of arsenic contamination, as the ground water of 19 blocks out of the total 26 blocks of the district is arsenic contaminated. In addition, floods are very frequent along with river erosion.

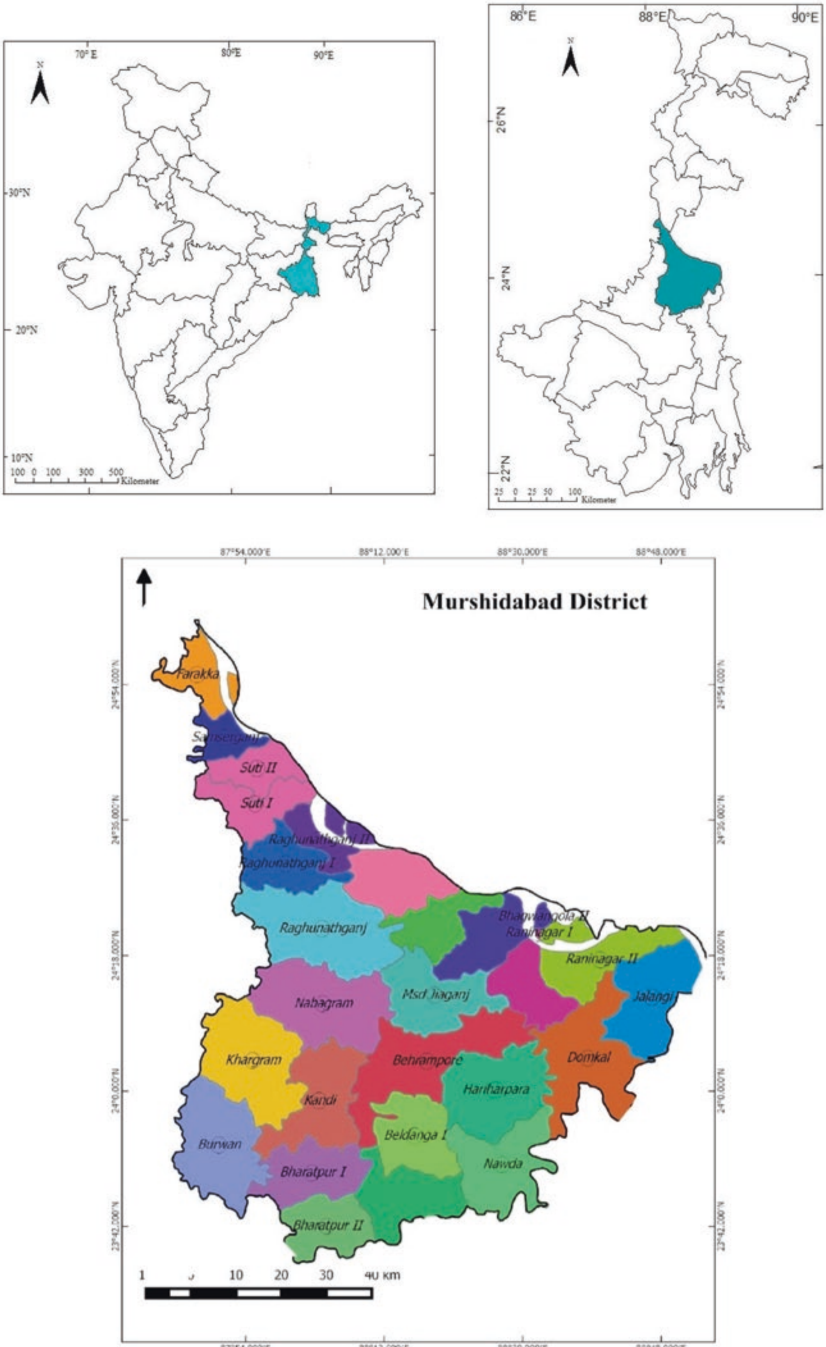

Fig. 1 Location map of Murshidabad District

Sometimes droughts are also faced by the people. Keeping all these problems prevailing in the study area in mind, it is the need of the hour for an integrated research on sustainable livelihood and food security.

4 Results and Discussion

4.1 Livelihood Sustainability and Food Security

For measuring livelihood security, considerable efforts have been made to identify suitable indicators for livelihood security. In this context, Morris at the Overseas Development Council developed the physical quality of life index (PQLI) to measure different social development indicators (Lindenberg, 2002). After that UNDP introduced human development index (HDI) for measuring economic and social development outcomes (UNDP, 1992). Intergovernmental Panel on Climate Change (IPCC) in 2007 has developed a technique for the assessment of Livelihood Vulnerability Index using adaptive capacity, exposure and sensitivity in the context of climate change (IPCC, 2007). Because of areal differentiation in biophysical and socio-economic conditions, indicators used in one country are not necessarily applicable to other countries. Thus, indicators always should be pertinent to specific location and that too within the context of the contemporary socioeconomic situation. Considering the biophysical and economic conditions of Murshidabad District, the Livelihood Sustainability Index (LSI) has been calculated, where vulnerability has been considered as exposure, five types of livelihood assets have been considered as adaptive capacity and sensitivity has been represented by food security. The formula used to calculate Livelihood Sustainability Index has been given below

Livelihood Sustainability Index (LSI) = (Adaptive capacity − Exposure) *Sensitivity……………………………………………………………….(i)

or

Livelihood Sustainability Index (LSI) = (Livelihood Asset Index-Vulnerability Index)*FoodSecurityIndex…………………………………………………(ii)

The LSI score varies from +1 to −1, where +1 refers to the most sustainable condition and _1 refers to the most vulnerable condition. The concept of livelihood ladder developed by Oxfam, has been excecuted in the present study. Following the concept of Oxfam, Livelihood Sustainability has been categorised into four stages on the livelihood ladder i.e. Accumulating stage, Adapting stage, Coping stage and Surviving stage. As people's livelihood assets increase, they move up the ladder and vice versa. The study reveals that values for sustainability ranged from a minimum of −0.79 in Hasanpur village to a maximum of 0.346 in Malihati. It means Malihati is the most sustainable and Hasanpur is the most vulnerable. A household's level of sustainability depends on its asset base and vulnerability context. As households' asset base increases, they are better protecting themselves from any kind of stress and shocks (Banu & Fazal, 2017).

4.2 Accumulating Stage of Livelihood Sustainability and Food Security

In the Livelihood Sustainability Ladder, Accumulating stage is the best one where livelihoods are sustainable due to higher asset possession. In this stage, life is going well and households are resilient to the external shocks. Occupational options are more flexible here. From the survey it has been found that villages in accumulating stages have high level of all the asset possession except social assets. Seven villages, namely, Malihati (0.34), Chhatrapur (0.26), Singara (0.18), Naopara (0.21), Talai (0.21), Gangapur (0.18) and Ahiron (0.19) fall under the accumulating stage of livelihood (Table 1 and Fig. 2). All these villages have scored very high for physical capital (0.83) which is followed by natural capital (0.67), financial capital (0.66) and human capital (0.51). Over all, livelihood asset index is also above the value of 0.45, which has been considered as sustainable. It is a well-known fact that food security is an important livelihood outcome. Level of food security is measured by the composite index of food availability, food accessibility, food utilization and food stability. In food security index, performance of food utilization is best because of their higher possession of assets and they are financially able to maintain their food utilization of sanitation, drinking water and housing condition. Food stability is at the second position having a higher score after food utilization index. Food stability presents constancy of the other three dimensions of food security.

Fortunately, majority of the households have high level of food stability, which helps the villages having higher score in composite food security index and that too is higher than the standard value of 0.45 fixed for measuring sustainability. Thus the food security status of the villages of accumulating stage was found as sustainable.

Villages of this stage are also exposed to vulnerability, particularly to economic vulnerability. The reason behind the fact is that most of the households of this stage had taken loan for education and business purposes. But, the severity of vulnerability is very low for accumulating stage on the one hand, and on the other hand, they are able to cope with higher hold on assets and food security. Finally, livelihood security index is higher for the households of the villages at the accumulating stage because these villages have very high level of infrastructural security (0.72), food security (0.64), health security (0.64) and economic security (0.63). Because of high food security as well as higher level of asset possession, villages of accumulating stage are able to recover and resilient even in any kind of shock and stress.

With the help of Pearson correlation coefficient, it is possible to reveal the relationship between level of asset possession and status of food security of the villages under accumulating stage. Human capital is the most important asset, and it is significantly correlated with four indices at 1% level of significance and with one index

Table 1 Sustainable livelihood index

Sampled Village	LAI	FSI	VI	LSI
Andhua	0.53	0.49	0.26	0.12
AntarDwipa	0.36	0.46	0.34	0.00
Ahiron	0.46	0.57	0.13	0.19
Amuha	0.42	0.49	0.29	0.06
Talai	0.53	0.64	0.19	0.21
Pirojpur	0.41	0.44	0.56	−0.07
Naopara	0.56	0.60	0.20	0.21
Malatipur	0.32	0.49	0.37	−0.02
Khosbag	0.47	0.57	0.27	0.11
Habaspur	0.47	0.52	0.31	0.09
Hasanpur	0.31	0.35	0.53	−0.08
Singara	0.61	0.60	0.30	0.18
Hijol	0.28	0.32	0.52	−0.08
Khargram	0.56	0.41	0.66	−0.04
Godapara	0.63	0.61	0.44	0.11
Chhatrapur	0.65	0.68	0.26	0.26
Malihati	0.69	0.70	0.20	0.34
Benidaspur	0.40	0.46	0.28	0.06
Gangapur	0.55	0.52	0.20	0.18
Maradighi	0.46	0.56	0.24	0.12
Kedartala	0.45	0.53	0.45	0.00
Muhammadpur	0.48	0.50	0.37	0.06
Madhurkul	0.48	0.53	0.22	0.14
Moktarpur	0.46	0.48	0.28	0.08
Majhardiar	0.44	0.47	0.31	0.06
Dayarampur	0.34	0.21	0.60	−0.06
	0.49	0.54	0.34	0.08

Sources: Household Survey (2013)

at 5% level of significance. Human capital has very strong positive association with financial capital, physical capital, livelihood asset index and also with livelihood sustainability index (Table 2).

Table 2 shows that higher human capital i.e. good health, education, capability to work in the households of accumulating stage, leads to higher financial capital i.e. saving, land and livestock as well as higher physical capital i.e. pucca houses, safe drinking water, sanitation and electricity. Finally it is to be found that human capital index is positively related with livelihood asset index and livelihood sustainability index too, while it is negatively associated with economic vulnerability (−0.96**). This result explains that their financial asset is based on human capital, and in a consequence human capital helps to decrease economic vulnerability.

In the first stage of livelihood sustainability, there is no significant relationship between natural capital and livelihood sustainability. This is a very remarkable fact found from the study that financial capital has strong positive association with

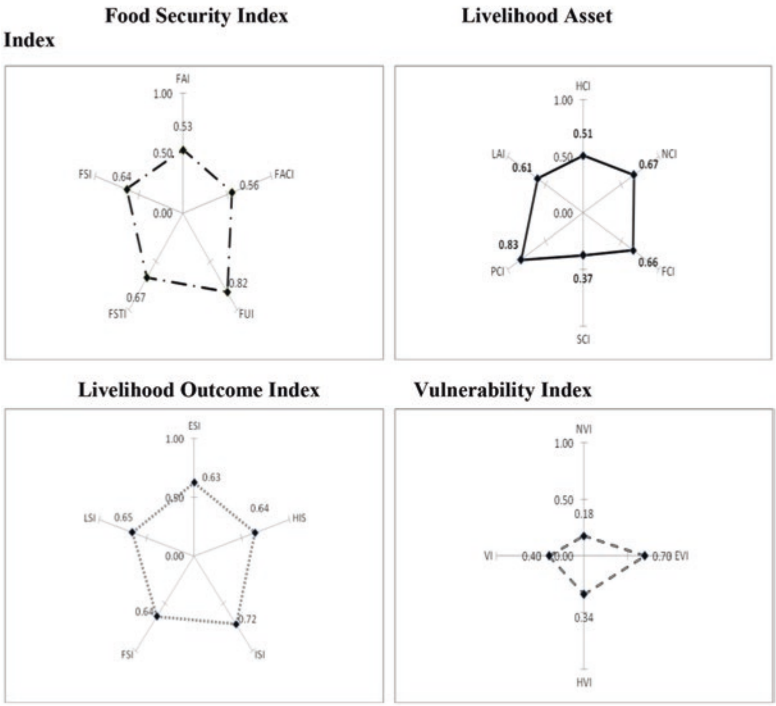

Fig. 2 Accumulating stage: sustainable Livelihood index. (Source: Based on Field Survey, 2013)

human capital (0.97**), physical capital (0.88*), livelihood asset index (0.99**) and livelihood sustainability index (0.99**). So, it is to be said that as financial capital increases, human capital, physical capital, livelihood assets and livelihood sustainability would be increased. Social capital is not playing an important role for maintaining livelihood status of households under accumulating stage because their performance at financial, physical and human capital is much enough for sustaining livelihood. It is very surprising that social capital is positively related with vulnerability and negatively related with livelihood assets and sustainability. This result indicates that when livelihood attains sustainability, its dependence on social capital decreases. Physical capital has positive relationship with human capital, financial capital, livelihood asset index and all the four components of food security. Increase in livelihood assets leads to increase in food availability, and food accessibility is negatively associated with economic vulnerability at 5% level of significance. Food utilisation is positively related with food security index and its fourth dimension i.e. food stability. It has been observed that economic vulnerability is negatively associated with human capital, financial capital, livelihood asset index and livelihood sustainability index at 5% level of significance. Economic vulnerability is positively related with social capital, because the lack of assets make the people dependent on social capital. Finally, there is strong positive relationship between livelihood

Table 2 Correlation matrix for accumulating stage

	HCI	NCI	FCI	SCI	PCI	FAI		FACI	FUI	FSTI	NVI	EVI	HVI	VI	FSI	LAI	LSI
HCI	1																
NCI	0.47	1															
FCI	0.97**	0.63	1														
SCI	−0.84	−0.67	−0.93*	1													
PCI	0.96**	0.28	0.89*	−0.76	1												
FAI	0.86	0.47	0.86	−0.85	0.91*	1											
FACI	0.78	0.39	0.84	−0.84	0.67	0.55		1									
FUI	0.78	0.24	0.68	−0.53	0.88*	0.88*		0.25	1								
FSTI	0.82	0.06	0.67	−0.43	0.91*	0.75		0.36	0.93*	1							
NVI	−0.62	−0.84	−0.79	0.88*	−0.43	−0.53		−0.79	−0.15	−0.07	1						
EVI	−0.96**	−0.49	−0.97**	0.89*	−0.88	−0.77		−0.92*	−0.59	−0.65	0.75	1					
HVI	0.12	−0.43	0.04	0.11	0.06	−0.32		0.44	−0.28	0.08	0.05	−0.27	1				
VI	−0.74	−0.85	−0.88	0.96**	−0.63	−0.78		−0.71	−0.46	−0.30	0.93*	0.78	0.29	1			
FSI	0.79	−0.004	0.629	−0.41	0.89*	0.75		0.31	0.94*	0.99**	−0.01	−0.61	0.05	−0.27	1		
LAI	0.97**	0.66	0.99**	−0.90*	0.89*	0.88*		0.76	0.75	0.72	−0.74	−0.94*	−0.04	−0.86	0.67	1	
LSI	0.92*	0.73	0.99**	−0.96**	0.82	0.86		0.81	0.63	0.57	−0.85	−0.93*	−0.08	−0.94*	0.53	0.98**	1

Sources: Based on Field Survey (2013)

sustainability and livelihood asset index and food security index too at 1% level of significance.

4.3 Adapting Stage of Livelihood Sustainability and Food Security

Adapting stage is the second stage of the livelihood ladder where life is going well and households are in a position to meet their basic needs and requirements. Out of 26 sampled villages, seven villages, namely, Modhurkol (0.13), Godapara (0.11), Khoshbag (0.11), Andhua (0.12), Maradighi (0.12), Moktarpur (0.08) and Habaspur (0.08), have a score that falls under the adapting stage, where households have higher level of assets possession but it is slightly lower than the households of accumulating stage. They have highest access of physical capital (0.55) which is followed by human capital (0.53), natural capital (0.52), financial capital (0.50) and social capital (0.37). The average score for all the asset possession under this stage is higher than 0.45 value except social capital. The reason behind the low level of social capital is similar to that of accumulating stage. Lastly, the overall livelihood asset index score (0.50) indicates the sustainability of the assets over a long run, which is satisfactory.

Human beings should always be food secure. Food security index is the composite score of food availability, accessibility, utilization and stability. From the field data, it has been found that in the adapting stage households have higher score food utilization (0.60), which is followed by the score of food stability (0.56), food availability (0.50) and food accessibility (0.49) (Fig. 3). The reason behind the better food utilization (sanitation, drinking water, electricity etc.) is their higher access to financial capital. As the score of food accessibility is slightly higher than the sustainability cut off, i.e. 0.45, it is pointing towards sustainable food security status of the villages under adapting stage.

Unfortunately, households of adapting stage face vulnerability at moderate scale. In addition to that overall vulnerability index score (0.45) is higher than that of accumulating stage (Fig. 3). In this stage, the score of natural vulnerability is higher than other kinds of vulnerability and that is because of frequent flood and drought. Majhardiar and Godapara are flood-prone villages. Khoshbagh, Maradighi and Gangapur face drought frequently. Natural calamities are responsible for loss of people's asset base.

But, this is a good indication that households of adapting stage are able to cope with majority of shocks, which has been observed from the livelihood outcome index. Life does not appear unbearable because households in this stage have high level of health security (0.56), followed by food security (0.55), economic security (0.53) and infrastructural security (0.51). They have better food security status than the asset possession. Although Godapara and Majhardiar are frequently affected by flood, instead of that they are able to cope with the vulnerable situation because of

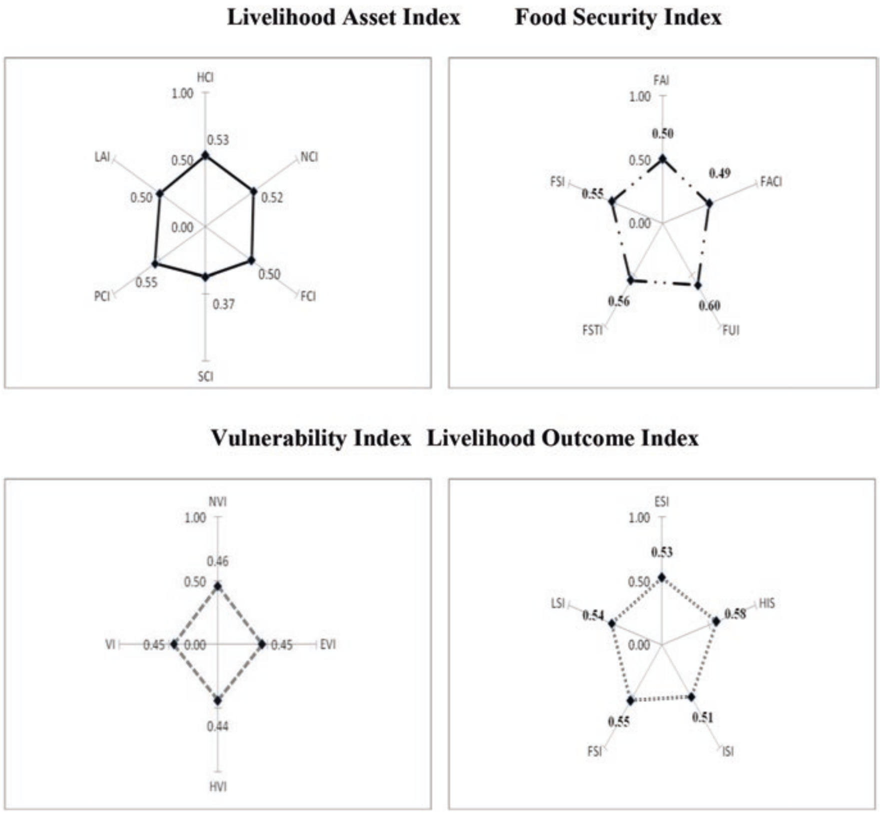

Fig. 3 Adapting stage: sustainable Livelihood index. (Sources: Based on Field Survey, 2013)

their higher accessibility of food security and better access to natural, human and social capital. In this stage, things gradually begin to improve and there is hope to reach the accumulating stage in the near future. Here, livelihood options are flexible but limited because of limited asset possession.

Here, Karl Pearson correlation coefficient technique has been executed to analyse the relationship between sustainability of livelihood in adapting stage and the index of assets, vulnerability and food security. It has been observed that human capital has significant positive correlation with seven indicators. So, the increase in human capital also leads to increase in physical capital, food accessibility, utilization and food stability increases. Thus human capital has strong positive relationship with food security and livelihood assets because of its dominant role in controlling the other capital. Populations with higher level of education and good health are able to earn higher income and become resilient to any kind of shocks and stresses (Table 3).

Table 3 Correlation matrix for adapting stage

	HCI	NCI	FCI	SCI	PCI	FAI	FACI	FUI	FSTI	NVI	EVI	HVI	VI	FSI	LAI	LSI
HCI	1															
NCI	0.56	1														
FCI	0.29	0.08	1													
SCI	−0.17	−0.27	−0.6	1												
PCI	0.89**	0.65	−0.09	−0.07	1											
FAI	0.42	0.18	−0.06	−0.09	0.55	1										
FACI	0.91**	0.53	0.42	−0.52	0.83*	0.48	1									
FUI	0.83*	0.35	−0.21	0.29	0.88**	0.40	0.64	1								
FSTI	−0.79*	−0.21	−0.04	0.22	0.79*	−0.54	0.84*	−0.72	1							
NVI	−0.49	−0.36	−0.42	0.56	−0.49	−0.21	−0.65	−0.35	0.31	1						
EVI	0.19	0.34	−0.46	0.36	0.4	0.74	0.07	0.30	−0.19	0.29	1					
HVI	0.35	0.35	−0.29	0.25	0.44	0.68	0.22	0.33	−0.39	0.40	0.92**	1				
VI	−0.08	0.03	−0.49	0.53	0.02	0.38	−0.26	0.03	−0.03	0.78*	0.82*	0.87*	1			
FSI	0.83*	0.46	0.36	−0.09	0.73	0.57	0.73	0.71	−0.47	−0.63	0.28	0.25	−0.15	1		
LAI	0.92**	0.79*	0.43	−0.37	0.81*	0.35	0.89**	0.62	−0.59	−0.57	0.17	0.29	−0.15	0.80*	1	
LSI	0.81*	0.23	0.64	−0.38	0.58	0.39	0.82*	−0.57	−0.58	−0.73	−0.12	−0.04	−0.45	0.87*	0.75	1

Sources: Based on Field Survey (2013)

Increase in physical capital also leads to increase in human capital, food accessibility, food utilization and food stability increases and viz-a-viz. Food accessibility and livelihood asset are positively correlated at greater strength. It means that the adaptive capacity of a households to access food is enhanced by the increase of livelihood assets enhanced. On the other hand, the assets and food security are also affected by vulnerability. Economic vulnerability has strong positive association with health vulnerability and overall vulnerability index.

It is also observed from the data that food security has strong positive correlation with livelihood asset and livelihood sustainability. The increase in asset base of a household, especially the human and physical capital of the households of adapting stage, also leads to increase in food security by which livelihood sustainability is to be achieved.

4.4 Coping Stage of Livelihood Sustainability and Food Security

The third stage of livelihood sustainability is known as the coping stage. In this stage livelihood is good enough but not at the satisfaction level. Six villages, namely, Amuha (0.06), Majhardiar (0.59), Benidaspur (0.06), Muhammadpur (0.06), Kedartala (0.001) and Antardwipa (0.01), came under the category of coping stage. They live with limited asset possession and always make struggle and adjustment for living. Although they have access to slightly high level of physical (0.55) and natural capital (0.54), they lack financial and human capital. As a result, their dependence on social capital has increased which is revealed in Fig. 4. Overall livelihood asset value indicates that asset possession of the coping stage is not sustainable and they are just able to cope with the minor shocks but not the major ones.

As far as vulnerability is concerned, it is very high (0.43) in this stage. Low saving, poor financial assets and large liabilities lead to high economic vulnerability. Economic vulnerability in turn affects health and natural vulnerability.

Low level of food security is observed among the households at the coping stage. It is clear from the overall food security status, which is below the sustainability level of 0.45, that households are food secure on a transitional basis. Figure 4 indicates that food stability has the lowest rank in the food security index. Households of this category have remarkably high access to sanitation facilities which in turn raises the food utilization index value above the sustainability level. They are aware of the negative impact of open defecation which makes them able to access to sanitation facilities.

As their assets are limited, households of coping stage are unable to cope with major shocks. Figure 4 reveals their limited livelihood outcomes; average livelihood security (0.46) is below the level of sustainability. The study found that only health security (0.51) is better and lies above the sustainability level. Although infrastructural security (0.48) and food security (0.46) are slightly lower than the

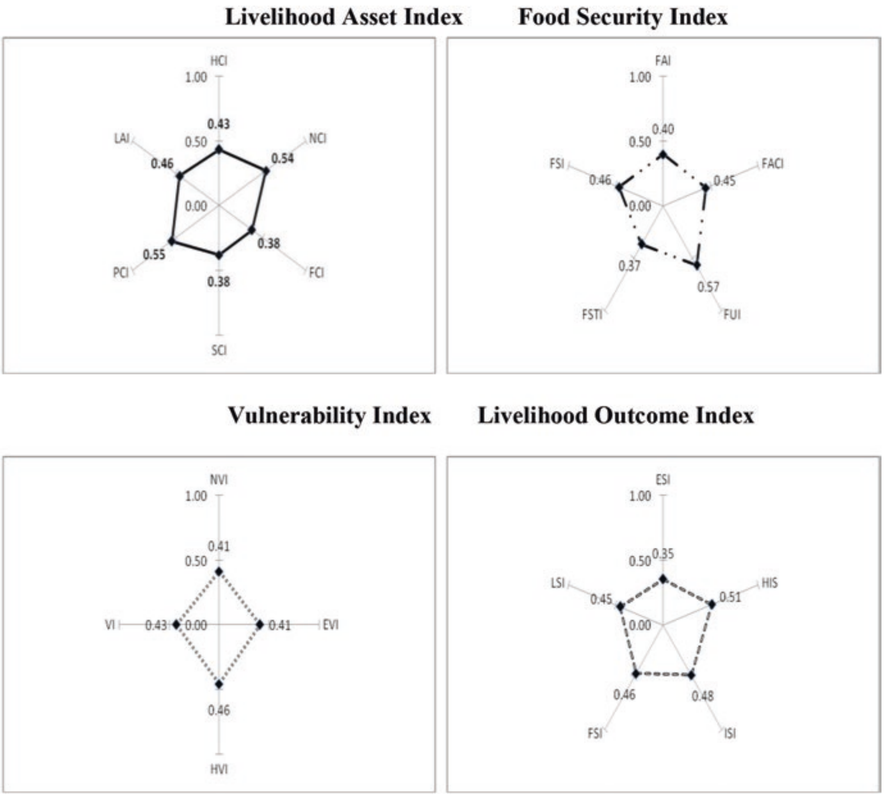

Fig. 4 Coping stage: sustainable livelihood index. (Sources: Based on Field Survey, 2013)

sustainability level, but economic security (0.35) is very low because of lower asset possession (Fig. 5).

Pearson correlation coefficient reveals that livelihood vulnerability index is affected by a strong relationship between natural vulnerability and health vulnerability Human capital and food accessibility are correlated at 5% level of significance. Because of their higher dependence on others, social capital has positive relation with livelihood security. Social asset plays an important role for protecting them to fall in Surviving stage (Table 4).

4.5 Surviving Stage of Livelihood Sustainability and Food Security

Surviving stage is the fourth stage of livelihood sustainability. Livelihoods are most vulnerable and unable to cope with even small shocks. Six villages fall under the category of surviving stage, namely, Dayarampur (−0.054), Pirojpur(−0.069),

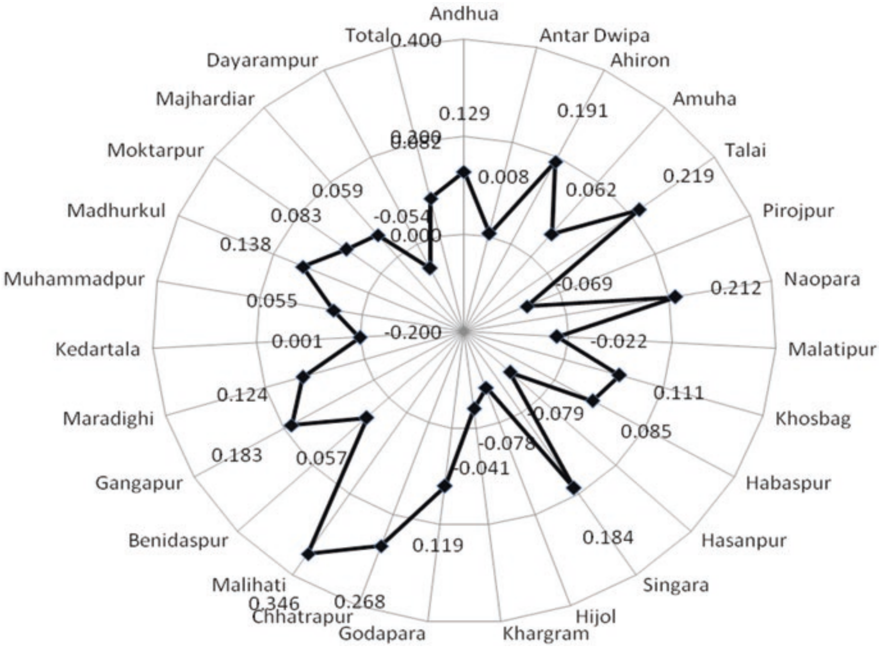

Fig. 5 Livelihood sustainability index. (Sources: Based on Field Survey, 2013)

Hasanpur (−0.079), Hijol (−0.078), Khargram (−0.049) and Malatipur (−0.022). Villagers have limited asset possession, except social assets (0.37), which is slightly higher as compared to other assets. But, their access to social assets is not at the level of sustainability (Fig. 6). This is due to the fact that their neighbours do not want to help them because they are poor. They have low access to natural assets (0.36). Low level of education, poor health and lack of knowledge and skills are the basic causes for their low human capital (0.36). As their access to per capita income is very low, the households of surviving stage are most poor in terms of financial assets (0.27) and physical assets (0.32). Although most of the houses have diversified their income earning activities for maintaining their livelihood, average livelihood asset index remains at only 0.34, which is far below the sustainability level.

Food Security status of the surviving stage is also very poor. Food availability index (0.39) is slightly higher than the other dimension of food security because of free food assistance from PDS. Lack of assets leads to poor accessibility, stability and utilization of food. Majority of the households are food insecure. And people of this stage prefer to go hungry to save assets for the time of adversity.

Severe vulnerability is faced by the households of this stage. Their poor coping capacity make them more vulnerable to natural disaster (0.51) which ultimately leads to high level of overall vulnerability (0.53). It is higher than the other stages of livelihood. Low wages and low level of asset possession make them economically more vulnerable. Lack of education, knowledge and money are the main

Table 4 Coping stage: correlation matrix

	HCI	NCI	FCI	SCI	PCI	FAI	FACI	FUI	FSTI	NVI	EVI	HVI	VI	FSI	LAI	LSI
HCI	1															
NCI	−0.14	1														
FCI	−0.64	0.57	1													
SCI	−0.04	0.57	0.75*	1												
PCI	−0.56	0.60	0.32	−0.04	1											
FAI	−0.38	−0.31	0.31	0.16	−0.04	1										
FACI	0.73*	−0.28	−0.84**	−0.49	−0.19	−0.49	1									
FUI	0.46	0.37	−0.53	−0.27	0.295	−0.61	0.558	1								
FSTI	0.53	0.28	0.001	0.55	−0.36	−0.44	0.15	0.32	1							
NVI	0.03	0.07	−0.39	−0.32	0.46	0.1	0.35	0.64	−0.12	1						
EVI	0.33	0.11	−0.41	−0.19	0.38	−0.34	0.64	0.49	0.11	0.43	1					
HVI	−0.06	0.19	−0.35	−0.47	0.65	−0.12	0.39	0.61	−0.41	0.80**	0.58	1				
VI	0.09	0.13	−0.45	−0.38	0.57	−0.10	0.51	0.68*	−0.16	0.91**	0.73*	0.93**	1			
FSI	0.25	0.36	0.27	0.64	−0.31	0.002	−0.37	0.15	0.74*	−0.12	−0.37	−0.46	−0.34	1		
LAI	−0.25	0.96**	0.72*	0.72*	0.61	−0.09	−0.41	0.15	0.25	0	0.09	0.08	0.06	0.35	1	
LSI	−0.19	0.52	0.31	0.32	0.56	0.25	−0.19	0.21	−0.12	0.49	0.35	0.61	0.56	0.05	0.57	1

Sources: Based on Field Survey (2013)

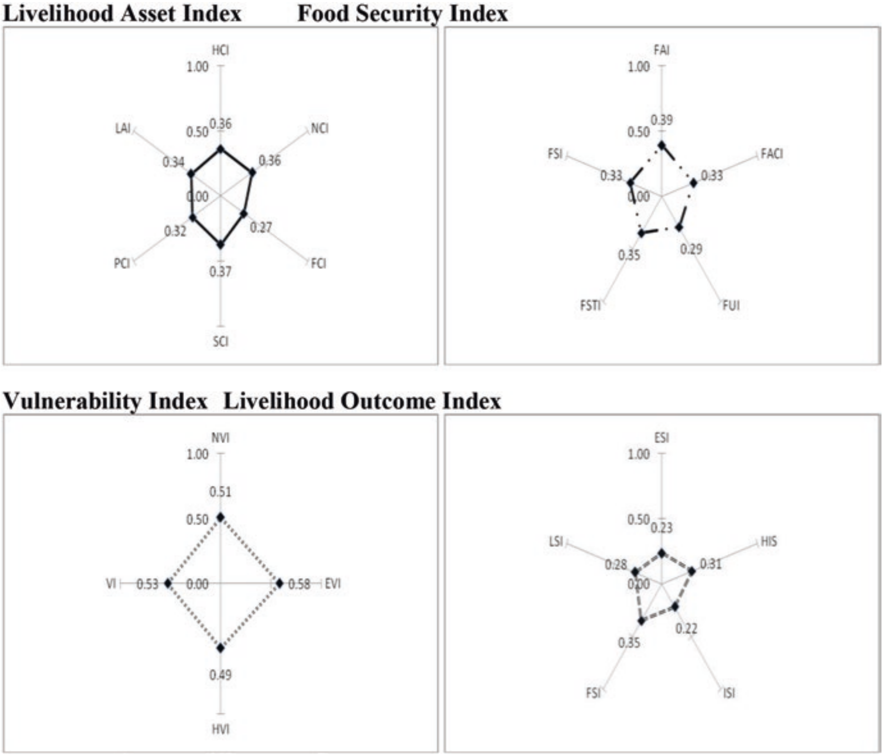

Fig. 6 Surviving stage: sustainable livelihood index. (Sources: Based on Field Survey, 2013)

causes behind the highest health vulnerability. Livelihood security index reveals that the household's livelihood security is very poor and not up to the level of sustainability. Their infrastructural security (0.22), economic security (0.23), health security (0.31) and food security (0.35) status are very poor. Overall livelihood security (0.28) is much below the level of sustainability. In the near future, there is a very little hope of sustainability for the surviving stage households.

It is clear from Pearson correlation that only physical capital has positive relationship with food utilization index and overall food security index at 5% level of significance. At 5% level of significance, economic vulnerability and food security are negatively related, which indicates that with the increase in economic vulnerability food security decreases (Table 5).

Households with vulnerable livelihood systems are unable to provide the basic needs to the family members because of their lower access to enough assets. As they are unable to create a surplus, they cannot cope with a crisis, and are often chronically in debt. Households of this stage are found to be burdened with liabilities, such as having unhealthy members or living in a degraded or hazardous environment, rather than having assets.

Table 5 Surviving stage: correlation matrix

	HCI	NCI	FCI	SCI	PCI	FAI	FACI	FUI	FSTI	NVI	EVI	HVI	VI	FSI	LAI	LSI
HCI	1															
NCI	−0.41	1														
FCI	0.29	−0.02	1													
SCI	0.82	−0.62	0.369	1												
PCI	0.14	−0.29	0	−0.23	1											
FAI	−0.29	−0.53	−0.14	−0.30	0.75											
FACI	0.84	−0.16	0.66	0.83	−0.23	−0.58	1									
FUI	0.16	−0.59	−0.12	−0.06	0.93*	0.86	−0.27	1								
FSTI	0.63	−0.31	0.59	0.32	0.71	0.27	0.49	0.59	1							
NVI	−0.07	0.79	−0.45	−0.39	−0.25	−0.61	−0.09	−0.45	−0.34	1						
EVI	0.82	0.18	0.425	0.502	0.004	−0.616	0.837	−0.173	0.564	0.341	1					
HVI	0.089	0.479	−0.35	0.12	−0.77	−0.87	0.21	−0.79	−0.61	0.74	0.30	1				
VI	0.34	0.62	−0.17	0.06	−0.36	−0.84	0.37	−0.54	−0.12	0.89*	0.69	0.82	1			
FSI	0.28	−0.54	0.29	0.06	0.91*	0.76	0.01	0.91*	0.83	−0.59	0.03	−.90*	−0.56	1		
LAI	0.38	0.29	0.60	−0.05	0.52	−0.06	0.41	0.22	0.82	0.12	0.67	−0.32	0.25	0.49	1	
LSI	0.86	0.03	0.48	0.53	0.19	−0.43	0.83	0.04	0.73	0.18	0.97**	0.09	0.54	0.26	0.75	1

Sources: Based on field Survey (2013)

5 Conclusions

Following the criteria opted by Oxfam, livelihood sustainability has been categorised into four stages on the livelihood ladder: accumulating, adapting, coping and surviving. Accumulating villages have high level of all the asset possessions except social assets. In this stage of sustainability, life is going well and households are able to cope with stress and shocks. More flexible are the occupational options. Even in a situation of crisis or stress, households of accumulating stage are able to recover and bounce back with the help of high asset possession, when a household's ability to accumulating resources increases, A household's ability to moves up the ladder is increased with the increasing ability to accumulate resources. On the other hand, with the loss of assets their risk of falling down the ladder increases. Sustainable food security has been observed among the households of accumulating stage. Households are able to meet most of their needs and life is going well. Households of adapting stage villages have low dependency on social capital and high hold on assets

The study reveals that things are good enough but not at the satisfaction level in coping stage. Assets possession is limited and is always adjusted by large family members. All the assets are below the level of sustainability in coping stage except natural and physical capital. Thus, overall livelihood asset value reveals that the asset possession of the coping stage is not sustainable and people are just able to cope with the minor shocks but not the major ones. Households are food secure on a transitional basis.

Livelihood in surviving stage is the most vulnerable. As the households of surviving stage villages have limited asset possession, they are unable to cope with even small shocks. Most of the houses have diversified their income earning activities due to their low capability to access human capital with the help of little or no education, poor health and lack of knowledge and skills. Majority of the households are food insecure and prefer to go hungry to save assets for the time of adversity.

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