
CHAPTER 04**Sowing the Future: Navigating Agricultural Production and Land Use**Sami Ullah¹, Wardah Naqvi², Iqra Batool³, Fatima Amjad², Raza Ullah^{2*}¹Pakistan Agricultural Research Council, Islamabad²Institute of Agricultural and Resource Economics University of Agriculture Faisalabad.³Faisalabad Institute of Science and Technology, COMSATS University Islamabad.**Corresponding authors' email: raza.khalil@uaf.edu.pk*

Abstract

Agricultural systems worldwide face increasing pressure from population growth, climate change, and declining natural resources. These pressures raise concerns regarding the sustainability of food production and land use systems, extending the food-system vulnerabilities described for Pakistan in Chapter 2 into the specific domain of land and demographic change. This chapter examines the interrelationship between agricultural production, land use dynamics, demographic change, and climate pressures, with particular emphasis on Pakistan. Drawing on global literature and policy reports, the chapter reviews technological innovations in agriculture, including precision farming and biotechnology, sustainable land-use approaches such as agroecology and permaculture, and governance challenges affecting agricultural productivity. The analysis highlights that improving food security requires integrating technological innovation with sustainable land management and effective policy frameworks, particularly as population growth and urban expansion continue to constrain arable land availability. The chapter also considers projected food-demand trends through 2050 and their implications for resource planning. The chapter concludes that resilient agricultural systems must combine productivity growth, environmental sustainability, and inclusive governance in order to meet future food demands without depleting the water, soil, and land resources that underpin long-term agricultural viability.

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4.1 Background

Agricultural production lies at the heart of global food security, yet it faces mounting pressure from two converging forces – rapid population growth and accelerating climate change. As the global population continues to expand, the demand for food, fiber, and bio-based resources is rising at an unprecedented rate, compelling farmers to produce more from increasingly constrained land and water resources. At the same time, shifting climatic patterns – manifested through erratic rainfall, rising temperatures, prolonged droughts, and extreme weather events – threaten the stability and productivity of agricultural systems worldwide. This dual challenge underscores the urgent need for adaptive strategies, innovative technologies, and sustainable practices to ensure that agricultural production can meet future demands without compromising environmental integrity or rural livelihoods.

The pressure of population growth on agricultural systems extends far beyond the need for higher yields alone. According to the latest OECD - Food and Agriculture Organization (FAO) outlook, the global population is projected to increase by about 729 million, reaching 8.8 billion by 2034, though the annual growth rate will slow to roughly 0.8% per year (OECD/FAO, 2025; Alexandratos & Bruinsma, 2012). This growth will be concentrated in regions such as Sub-Saharan Africa (~2.3% per year) and the Near East and North Africa (~1.6% per year). With more mouths to feed and dietary shifts (towards more meat, dairy and resource-intensive foods) expected as income rise, agricultural production must deliver more output from increasingly constrained natural resources – land, water, soil – even as cultivable area faces urban expansion and land-use change.

Climate change compounds these challenges by altering the very foundations of agricultural productivity: temperature, precipitation, soil health and water availability. A recent study found that global agricultural productivity is already about 21% lower than it could have been without climate change – effectively wiping out around seven years of productivity gains since the 1960s (Ortiz-Bobea et al., 2021). Agriculture accounts for nearly 23% of the total impact of disasters across all sectors during 2007-2022 (FAO, 2023) and droughts alone caused over 65% of losses in the agriculture sector during that period – translating into an estimated US \$3.8 trillion in lost crops and livestock production over 30 years (FAO 2023). In the case of Pakistan specifically (a major agriculture-based economy), productivity is expected to shrink by 8-10% by 2040 because of climate change impacts (Zulfiqar, 2023). These figures highlight not only the magnitude of the threat, but how urgent the pace of adaptation must be if agricultural production is to sustainably meet future demand.

These concerns necessitate the adoption of more strategic and sustainable land-management practices, particularly in regions experiencing rapid urbanization and environmental degradation. A primary problem is to balance between environmental conservation and food production. The political, technological, and environmental changes have shifted the land use research more towards ecosystem services and long-term sustainability (Schneider, 2014). In addition, the food policies are often incomplete in locations where high urban growth takes place, such as in China, and integrating the food security concerns into the urban development projects is difficult (Scott & Si, 2016). To solve these interrelated problems, innovative policies to help foster sustainable farming practices and satisfy the needs of urban populations as they increase are required.

This chapter aims to examine the interconnections between agricultural production, land use dynamics, demographic change, and climate pressures. Specifically, it analyzes global challenges affecting food systems, reviews technological innovations that may enhance agricultural productivity, and evaluates sustainable land-use approaches. Particular attention is given to Pakistan, where climate vulnerability, land governance issues, and demographic pressures pose significant challenges to agricultural sustainability. By integrating global evidence with Pakistan-specific insights, the chapter contributes to ongoing debates on how agricultural systems can become more productive, resilient, and environmentally sustainable.

4.2 Technological Innovations in Agriculture

The world is increasingly suffering the impacts of climate change, soil erosion and concerns about food security and technical solutions are the key to increasing the production and sustainability of agriculture. One of the most significant innovations is precision farming, which can bring maximum crop growth and the optimal use of resources through the use of satellite images, data analytics, and Internet of Things (IoT) technologies. Precision agriculture reduces wastage and promotes more sustainable use of land as it provides the farmers with more control of their crop. At the same time, organic agriculture has also attracted attention as an environmentally-friendly method of eco-intensification to improve performance without the need to harm the ecological environment (Cuoco et al., 2010). However, there exists a divergence on the way in which agricultural innovation is expected to proceed. Some emphasize the importance of indigenous knowledge and agro-ecological systems that can be used in addition to natural resource management, whereas others believe in the power of laboratory-based innovations like genetically modified crops (Levidow, 2012). It is an ongoing debate that states that there should be a comprehensive approach that encompasses various strategies that would ensure the long-term sustainability of agriculture.

4.2.1 Precision Farming and Biotechnology in Crop Yield Enhancement

Precision farming and biotechnology have revolutionized modern agriculture particularly in efforts to increase food production with less damage to the environment. Through precision farming, they use real time data, GPS and Internet of Things equipment to optimize farming techniques to maximize the use of herbicides, fertilizers and water. This is a narrow target to reduce negative environmental impacts and maximize production. During this period, more resistant crops to pests and unfavorable environmental

conditions are also products of biotechnology discoveries including the development of genetically modified organisms (GMOs). The use of such technologies still requires research and development investments to maximize their full potential especially in the rainfed agricultural regions where water can be managed effectively to produce higher yields (Rosegrant et al., 2002). Moreover, the concept of precision agriculture complies with the principles of agro-ecology and gives the small-scale farmers viable alternatives regarding the means of enhancing productivity without compromising environmental sustainability (Pinstrup-Andersen et al., 1999).

Although precision agriculture and biotechnology offer considerable potential for improving agricultural productivity, their adoption remains uneven across developing regions. In countries such as Pakistan, small farm sizes, limited digital infrastructure, and high initial investment costs constrain the widespread implementation of these technologies. Therefore, while technological innovation remains essential for future food systems, supportive policies, farmer training programs, and improved rural infrastructure are necessary to ensure that these technologies benefit smallholder farmers.

4.2.2 Sustainable Land Use Practices

The growing world food demand is an element that requires a transition to more sustainable land use policies that do not compromise the environment but promote food production. Crop rotation, conservation tillage techniques, and biodiversity promotion are some of the techniques that help in enhancing the health of the soil and alleviating the adverse effects on the surrounding ecosystems. Research also highlights that to develop resilience on a long-term basis, sustainable agriculture should incorporate the management of soil fertility, integrated pest control strategies, and ecological diversity (Khanal, 2024). Moreover, informists insist on the diversified agricultural landscapes that will promote ecological sustainability and food security, opposing the common knowledge that intensive farming is the answer to the increasing population (Bengtsson & Bommarco, 2023). Sustainable land use can help agricultural systems to resist climate risks and preserve some of the vital resources that need to be used by the future generation.

4.2.3 Permaculture and Agro ecology's Contribution to Environmental Sustainability

Agro ecology and permaculture are the keys to developing environmental sustainability because they are more inclined to the preservation of natural resources and reduce the dependence on industrial farming methods (Vaarst, 2010). The focus of these strategies is on regionally based approaches that enhance ecosystem resilience, biodiversity, and soils. Community-based initiatives such as the Organic Technology Extension and Promotion of Initiative Centre (OTEPIC) in Kenya can be used as an example of how agro-ecological principles can empower small-scale farmers and promote local food self-determination (Fabrin, 2015). These activities conserve natural ecosystems and create economic rewards through promoting self-sustaining agricultural systems. The incorporation of organic and agro ecology into mainstream agriculture offers a possible pathway to sustainable food production prioritizing the well-being of the people and the environment, particularly since the food demand of the world keeps increasing (Cox, 2017).

4.3 Literature Review

The general scientific consensus of scholars and policymakers is that food production should be enhanced to satisfy the growing demand on the planet, that food consumption should be altered to bring about more efficient use of food resources to stop undernourishment and obesity, that agricultural lands should not be extended, and that food production must be carried out in a sustainable manner to minimize environmental effects (Giller et al., 2021).

Amid these potential problems, one aspect of food production and consumption has garnered much scholarly and popular discussion regarding the future of food. More output can be achieved by improving yields on unproductive lands, improving crop production, encouraging changes in diet, and reducing food waste (Foley et al., 2011; Tilman et al., 2011). Additionally, the transformation of the food industry requires the coordination with more general changes, including: the replacement of fossil fuel use by bio-

based products, the introduction of climate-neutral economic models, the introduction of Industry 4.0 and digitalization into food logistics and using bioresources (Galanakis et al., 2021; Kamilaris et al., 2019; Galanakis, 2022).

The primary aim of governmental policies and strategic priorities should be to promote agro-ecological practices such as rooftop farming, vertical farming, and precision agriculture using IoT technologies. Moreover, the development of a blue bio economy should be encouraged with the help of such programs as multi-trophic systems and aquaculture (Galanakis et al., 2022) along with ensuring food safety through digital monitoring (Rizou et al., 2020) and ensuring that food is distributed in a just manner (Godfray et al., 2010).

Although these challenges are global in nature, their impacts are particularly pronounced in developing countries such as Pakistan. Pakistan's agricultural sector plays a central role in the national economy, contributing significantly to employment, rural livelihoods, and food production. However, the sector is highly vulnerable to climate change, water scarcity, and land-use pressures. Extreme weather events, including floods and droughts, increasingly affect crop productivity, particularly staple crops such as wheat and rice.

The climatic conditions and natural resources availability are the main factors affecting agricultural production. Pakistan is one of the most susceptible countries to climate change, which has major issues with its food security and the agriculture industry since there is a large population with a high rate of poverty (Abdullah et al., 2016). Extreme weather patterns have become more frequent and serious during the past years, as unpredictable weather e.g., monsoon patterns cause longer drought periods and common floods (Government of Pakistan, Ministry of Climate Change [NCCP], 2012). It has also affected the production of staple crops, particularly wheat and rice, through high temperatures, heat stress, and other climate-related stresses (Arshad et al., 2017; Shakeel et al., 2026). To deal with these complex problems and ensure long-term food security, a comprehensive strategy including climate resilience, policy interventions, and sustainable agriculture is needed. The effective implementation along with improved market conditions are pre-requisites and play an essential role in the food production systems (Pervaiz et al., 2019).

4.3.1 Who Will Produce Our Food in the Future?

Examples of production systems that are often discussed in the context of agricultural future include agro-ecological, organic, regenerative and conventional farming as opposed to the intricate relationships of the global food system or the connections between the various forms of agriculture. Whereas there is an increasing tendency to move away with the traditional methods of agriculture towards more sustainable environmental agriculture, such recommendations do not provide region-specific advice on how agriculture can be developed. The heterogeneity of conventional agriculture, and the range of environmental impacts, also makes it difficult to develop universal policies.

This is because the changes necessary to take place in large-scale, capital-intensive farming in the developed world cannot be applied as a blanket solution to smallholder agriculture in the Global South which utilizes less capital and has a relatively small environmental impact. However, changes in large scale farming activities also affect world markets and, therefore, determine the agricultural environment in the developing economies. Meanwhile, the profitability of farms is a significant issue on a global scale. It takes strong policy frameworks to achieve a sustainable transformation of the various farming systems and still be economically viable. Such structures should enhance an increase in productivity, promote an environmentally friendly production mode, and promote the co-existence of diverse farming models (Pervaiz et al., 2019).

Even though Pakistan is an agrarian economy, the food insecurity crisis is very high. Conventionally, food security has been improved by the rise in the cultivation of high yield crop varieties, use of mechanized cultivation methods and better input and output market. But little focus has been placed on the contribution of land use to food security, especially in developing countries.

The correlation between size of the farm and agricultural productivity is an issue of contention. Indicatively, a study carried out in India reported negative relationship between farm size and productivity, but Wang et al. (2015) indicated a positive relationship. Similarly, Heltberg (1998) found out that there was negative correlation between farm productivity and size of farm among Pakistani farmers. In addition, wealthier, politically influential farmers were often better placed to reclaim underutilized or marginal land to be used as agricultural land (Komarek et al., 2017).

The land use dynamics are affected by a variety of factors including land administration, governance, tenure security, valuation, development and many more. In rural economies such as Pakistan, land is a very important resource particularly to the subsistence farmers who are smallholder farmers. Their food security is indistinguishably linked to their access to arable land and their rights to land. Without the management and governance systems in place to effectively handle land, governmental food security programs will not work. Failure of farmers to secure agricultural loans through insecure tenure of the land stalls essential land development activities. The poor land administration worsens the ineffective land use by limiting farmers in their production of crops. Moreover, farmers are often not willing to invest in agricultural productivity on a long-term basis without secure land tenure (Malik et al., 2016).

4.3.2 Evolving Land Use Patterns and Future Challenges in Pakistan

The land use patterns in Pakistan have evolved over the ages because of a longitudinal effect of both human and natural forces. Natural characteristics such as landforms, soil structure, climatic changes and water supply, population increase, economic growth, market and cultural activities and practices have made a significant contribution. An agricultural growth analysis however demonstrates that Pakistan land use planning has not been significantly influenced by government initiatives and legislative activities. Moreover, the attempts to implement the public policy to conduct the crop-specific zoning or the specialized pattern of cropping have failed in most cases (Pervaiz et al., 2019).

Land and water are the basic resources of food production, which remains basic to the survival of human beings (Rosegrant et al., 2002). Soaring population, economic growth and environmental variations are exerting increasing pressure on these essential resources. Consequently, the primary objective of the future agricultural systems should be to increase yields with the help of fewer resources. In addition to meeting consumer demand, global food production is directly connected with many fundamental societal outcomes, including reducing poverty and malnutrition, increasing the availability of healthy food, enhancing freshwater management, increasing the utilization of renewable energy, and safeguarding ecosystems and biodiversity. Scientific analyses of food production in comprehensive, model-based formats are very important in guiding stakeholders and policymakers because of the complex interactions between food production and broader developmental goals (Schneider et al., 2011; Bouwman et al., 2006).

Decreasing agricultural land per capita has been a significant issue in the world in the long-term, and the United Nations Food and Agriculture Organization (FAO) estimates that by 2050, only one-third of the arable land will be available per capita than what existed in 1970 (FAO, 2016). This decrease is caused by climate change, the growth of drylands, the disappearance of freshwater resources, and the sudden increase in population (Fedoroff, 2015; FAO, 2016; USCB, 2016). Other threats to the future availability of arable land include climate variability, losing fisheries (that leads to dependence on land-based food production), urbanization, the rising price of agricultural inputs such as fertilizers and pesticides, soil erosion due to unsuitable agricultural activities, and excessive use of agricultural land (Benke & Tomkins, 2017).

The continuous extension of the metropolitan areas and the absorption of adjacent countryside landscape are one of the significant aspects contributing to the land use change. The necessity of housing, industrial development, creation of infrastructure, and the services connected with it are the primary factors that promote this process. As the rural areas become more urbanized, depending on infrastructure and available job opportunities, they may be suburban or in some cases, informal settlements. Concurrently, subsistence and semi-commercial agriculture are being replaced by more intensive and commercialized practices of agriculture. A shift toward consumable product agriculture rather than manufacturing staple

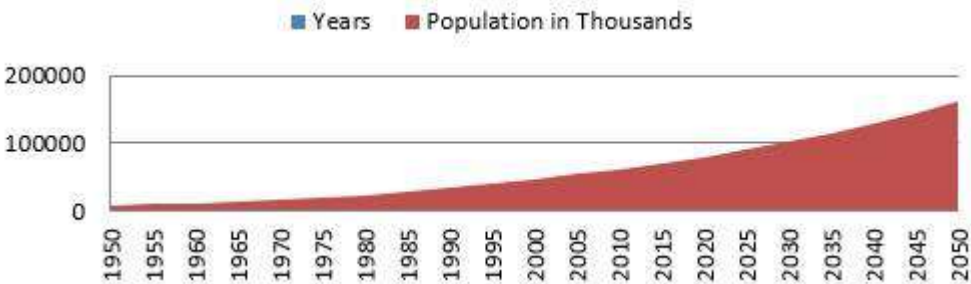
crops such as dairy and poultry farming is a typical aspect of this transition (Khan, 2021). Recent evidence from peri-urban Faisalabad further shows that agricultural land conversion associated with urban expansion can adversely affect food adequacy, dietary quality, and the sustainability of local agricultural and water systems (Wajid & Bashir, 2026).

These problems can only be addressed successfully through strategic planning and policies that are balanced in consideration of the urban growth and sustainability of agriculture. To secure the future of agriculture and food security in Pakistan, the land governance will be strengthened, the promotion of farming practices that are resilient to climate and ensuring the land and water resources are properly managed.

4.4 Demographic Trends and Their Implications for Sustainable Development

Four key demographic trends, namely urbanization, population growth, aging, and international migration, are defining the social and economic environment of the world. Both opportunities and challenges are related to the shifts in the size of the population, its age structure, and their spatial dynamics. By effectively addressing these problems and using opportunities, societies can accelerate inclusive and sustainable development. Besides environmental protection, strategic population management can be used to eliminate poverty, access to social safety, healthcare, and education, gender equality, and more sustainable production and consumption patterns.

The demographic trends in the future are usually predictable even soon and medium term compared to other revolutions in the world such as economic changes or technical advances which are not yet known but unpredictable. Population trends are a vital instrument to decision-makers due to their reliability. An understanding of these patterns, such as the 2030 Agenda to Sustainable Development and other intergovernmental frameworks, makes it possible to develop policies that are in line with international commitments (United Nations, 2015). Demographic information in policy planning can ensure that governments can ensure the resilience and long-term sustainability of economic and social systems.



Source: World Urbanization Prospects: The 2018 Revision.

Figure 4.1. Pakistan’s urban population

The figure illustrates the steady increase in Pakistan’s urban population since 1950. Urbanization accelerated significantly after the 1990s due to industrial expansion and rural-urban migration. The urban population is projected to reach approximately 170 million by 2050, which will increase pressure on surrounding agricultural land and natural resources.

4.4.1 Projected Trends in Food Production for the Short and Medium Term

It has been projected that in the future; the demand of different food products will keep growing despite the attempts to reduce population growth. The current population is contributing to this trend in the rising number of households that have the overall growth rates maintained. This therefore requires agricultural production to increase to address these changing needs.

Table 1 below provides the estimated rate of growth of the various food groups needed to have sufficient supply. It is worth noting that the growth rate of staple food grains will only need relatively low growth as opposed to horticultural products (fruits and vegetables) and animal-based products. This underscores the importance of diversification in crop-livestock production systems to support the changing dietary choice and nutritional requirements.

Table 4.1: Average growth rate in production needed to fulfill food supplies for rising population in Pak.

Period	Wheat	Rice	Other cereals	Pulses	Milk	Oils & fats	Meats	Fruits	Vegetables	Misc.	Total
2020 to 2025	1.68%	1.51%	2.12%	1.55%	2.37%	2.04%	3.83%	2.31%	1.97%	1.83%	2.05%
2025 to 2030	1.77%	1.58%	2.14%	1.58%	1.78%	2.07%	1.86%	2.32%	2.03%	1.88%	1.86%
2030 to 2035	1.53%	1.42%	2.07%	1.41%	2.21%	1.89%	3.51%	2.15%	1.79%	1.71%	1.91%
2035 to 2040	1.63%	1.46%	2.00%	1.45%	1.65%	1.93%	1.73%	2.18%	1.87%	1.76%	1.72%
2040 to 2045	1.50%	1.41%	1.90%	0.79%	2.15%	1.84%	3.31%	2.10%	1.79%	1.68%	1.86%
2045 to 2050	1.59%	1.46%	1.96%	1.60%	1.61%	1.89%	1.70%	2.14%	1.83%	1.74%	1.69%

Source: Growth rates estimation made from future food demand projection by Farooq, 2015.

Farooq (2015) estimated growth rates (in percent) of various food commodities between 2020 and 2050 expressed in 5-year interval. There is moderate increase in the overall food demand which averages about 1.7 -2.0 per year. Meat and milk are those commodities that have always demonstrated higher growth rates due to increasing incomes and dietary changes in favor of foods rich in protein, whereas wheat, rice, and pulses demonstrate the slower and less fluctuating growth rates, and are likely to indicate saturation in the intake of staple foods. Oils and fats, fruits and vegetables show constant moderate increase, which is a sign of diversifying the diets. It is interesting to note that growth of most of the category's changes slightly over the periods with small decreases in the latter ones (2040–2050) indicating a slow stabilization of the food demand with the decrease of the rates of population and income growth.

The analysis presented in this chapter highlights the complex interactions between demographic change, climate variability, technological innovation, and land governance. Addressing future food security challenges requires integrated approaches that combine productivity growth with environmental sustainability. In developing countries such as Pakistan, strengthening institutional capacity, improving agricultural policies, and investing in rural infrastructure are essential for promoting sustainable agricultural development.

4.5 Conclusion

Agricultural systems worldwide face mounting challenges from population growth, climate change, and declining natural resources. These pressures require a transformation in how agricultural production and land resources are managed. Technological innovations such as precision agriculture and improved crop varieties provide opportunities to increase productivity while reducing environmental impacts. At the same time, sustainable land-use practices—including agroecology, conservation agriculture, and biodiversity-based farming—play a critical role in maintaining ecosystem resilience.

In Pakistan, the interaction between climate vulnerability, land governance challenges, and demographic pressures makes sustainable agricultural transformation particularly urgent. Strengthening land administration systems, promoting climate-resilient farming practices, and investing in agricultural research and extension services are key policy priorities.

Ultimately, ensuring future food security requires integrating technological innovation with ecological sustainability and effective land governance. Such an integrated approach can help build resilient agricultural systems capable of meeting the needs of future generations while preserving environmental integrity.

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