Advances in Input Management for Food and Environmental Security

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Abstract

Achieving food security while protecting the environment in the context of future global climate changes is a great challenge to the sustainability of modern agricultural systems. Food production is likely to maintain priority over

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environmental protection. In modern agriculture, input management is very crucial for sustaining future food security and environmental protection which might be achieved by the integration of land, pest, disease, nutrient, and other resource management practices. This chapter focuses on the potential of next-generation input management techniques for safer food production and environmental protection. The possible impacts of next-generation input management techniques for safer and nutritious food production without environmental degradation as along with other vital dimensions of food security have been discussed. Additionally, next-generation input assessment studies, possible integration of

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different techniques, and approaches for food and environment security have been objectively described.

Keywords

Food · Environment · Agricultural input · Frontier technology · climate change

Abbreviations

FAO	Food and Agriculture Organization
FUE	Fertilizer use efficiency
GHGs	Greenhouse gases
CH_4	Methane
N	Nitrogen

6.1 Introduction

Globally, swiftly expanding human population, pollution (water, air, and soil), climate change, decreasing soil fertility, biotic and abiotic stresses, urbanization, and other socioeconomic issues are likely to pose serious challenges (Misselhorn et al. 2012; Poppy et al. 2014; Raza et al. 2019; Brevik et al. 2020; Iqbal 2020). Targeted efforts are needed to ensure food security which entails the provision of safe, sufficient, and nourishing foods all the time at affordable prices (FAO 1996; Bilali et al. 2018). Besides, environmental security is also equally important achieved through restoration, compliance, protection, prevention, and implementation of environmental security techniques (Thomas 1997; Iqbal and Iqbal 2015; UNEP 2019; Islam and Kieu 2020). However, interlinks between food security consequences and environment (ecosystem services) are complicated and multidimensional, because food security is dependent on agricultural inputs and a major driver for the loss of ecosystem services (Ericksen 2008; Kumar et al. 2018a, b). Quality seed, soil, fertilizer, insecticide, pesticides, and water are crucial inputs for crop production. Their excess and inefficient use in the recent past have led to environmental and ecosystem degradation. Therefore, researchers are focusing to develop eco-friendly, sustainable, and more efficient strategies to combat environmental degradation and boost production along with the quality of food (Scialabba and Hattam 2002; Gebbers and Adamchuk 2010; Clark and Tilman 2017; Debaeke et al. 2017; FAO 2017; Das et al. 2018). To achieve these objectives, next-generation input management techniques hold potential as a promising approach to ensure food and environmental security under changing climate scenarios (Ejeta 2009; Lal 2013; Jones et al. 2017; Pachapur et al. 2020).

Accessibility of super quality planting materials including seeds is a fundamental requirement for sustaining future food security under a fluctuating environment and can be achieved by the next-generation approaches (Ayieko and Tschirley 2006; Spielman and Kennedy 2016). In this context, advancement in genetic and molecular breeding approaches (marker-assisted selection, next-generation sequencing, and transgenes) have primed to the progress of boosting harvest (hybrids, transgenics), stress and disease-tolerant, and bio-fortified (rich in quality traits) varieties with higher potential even under different environmental conditions (Varshney et al. 2009; Chikara et al. 2014). Likewise, seed treatments with bio-stimulants, pesticides, insecticides, and the use of synthetic seeds not only protect the emerging seed from different diseases, insects, and soil-borne pathogens but also reduce the load of chemical fertilizers (Rouphael and Colla 2018; Kumar et al. 2020).

The second most important input in agriculture is soil, which provides support, essential nutrients, and water for crop growth. Intensive farming has caused land degradation, soil toxicity, loss of soil fertility, and productivity (Lal 2001; Kopittke et al. 2019, 2020). Therefore, next-generation strategies, such as smart soil, bio-concrete, organic chemicals, and nanoparticles might enhance soil fertility and reduce synthetic substances capacity of the soil (Iqbal et al. 2015a; Panpatte et al. 2016; Paustian et al. 2016; Seifan et al. 2016). Besides, quality planting material and soil characteristics, water is one of the most important inputs for crop production. Its accelerated anthropogenic and extensive use causes water pollution and water crisis for agriculture. For time being, next-generation technologies have focused on water management through digital metering technologies, land management, crop diversification, irrigation scheduling, and drip irrigation (Belder et al. 2007; Bautista-Capetillo et al. 2018; Nikolaou et al. 2020; Nguyen et al. 2020) leading to water conservation (de Vries et al. 2003; Bai et al. 2017; Hatfield and Dold 2019). Moreover, recent molecular and physiological advances for improving crops roots structure architecture, length, weight, density, and hydraulic conductivity for efficient water uptake and transport (Parry and Hawkesford 2010; Fang et al. 2019; Mohammed et al. 2019; Reddy et al. 2019; Falk et al. 2020; Klein et al. 2020).

The application of chemical fertilizer, such as insecticide, herbicide, and systemic poisonous insecticides are major problems of modern agriculture and adversely affect food quality and environmental sustainability (Umesha et al. 2018; Zhang et al. 2018; Elahi et al. 2019). However, in recent past, the application of biopesticide, insecticide, herbicide, and bio and nano-fertilizer mostly in developed countries has led to organic agriculture and improved food production without loss of ecosystem services (Scialabba and Hattam 2002; Iqbal et al. 2015b; Durán-Lara et al. 2020).

Considering the above facts, this chapter reviews the potential of next-generation input management techniques for food and environmental security. In addition, emphasis has been placed on the next-generation multidimensional input assessment studies and the possible integration of different techniques and approaches for food and environmental security.

6.2 Next-Generation Input Management Technologies: Concepts and Prospects

Green revolution entailing improved crop varieties and utilization of synthetic fertilizers and pesticides significantly bolstered crops yield (Iqbal 2018; Iqbal et al. 2019; Khaliq et al. 2019; Siddiqui et al. 2019; Faisal et al. 2020). The strong interconnection between farm inputs and crops improved the food and nutritional security, while modern next-generation methodologies aim to minimize the loss of farm inputs. However, for the last decade, the grain yield of most of the staple crops has become stagnant while decreasing land area under cultivation, and increasing human population are putting pressure on agricultural resources (Shamshiri et al. 2018; Kumar et al. 2021). Besides, substantial losses of nutrients and pesticides from agricultural fields have become major sources of environmental pollution, which are threatening the sustainability of cropping and other agroecological systems. This scenario demands another green revolution, especially with respect to environmental fluctuations globally. The handling of next-generation input methodologies holds a promising tool to boost agricultural productivity through the effective utilization of input resources. The concept of next-generation input management technology encompasses effective management of farm inputs through a combination of advanced mathematics for inputs (fertilizer, pesticides, seeds, irrigation, etc.), for per unit area, automation, sensor systems advancements, and next-generation plant breeding. These technologies integrate science and technology to work in cohesion for delivering a step change in crop yields and growing more produces from lesser inputs (Posadas 2012; Saiz-Rubio and Rovira-Más 2020; Talaviya et al. 2020).

These technologies are setting the stage for another green revolution, directing possible means of viable and guaranteed farming in future under the context of the world facing drastic environmental changes, along with paving the way for securing healthy dietary needs of masses across the globe. Closed ecological systems having no reliance on matter exchange from outside the system have the potential to clean atmospheric air by converting unwanted goods into oxygen, organic manures, and irrigation for ecosystems. Currently, the availability of particular arrangements is only in minor scales because of the limited technologies that hamper the scaling. Automated farm groups involving theoretical groups of agricultural automated systems with thousands of minute devices grow crop plants, supply inputs, monitor crop growth, and soil health predict crop yield, with practically no human intervention. Similarly, vertical farming, encompassing crops cultivation within enclosed or multipurpose towers reduce transportation costs of farm inputs along with the provision of quality food. Moreover, nano-based fertilizers and pesticides were introduced (DeRosa et al. 2010; Adisa et al. 2019; Shebl et al. 2019; Usman et al. 2020), having the possibility of penetrating plant roots more efficiently, and thus their loss to lower horizons as well to the environment as gaseous emissions decline significantly compared to bulk chemical fertilizers and pesticides (Zhang et al. 2006; Mikkelsen 2018; Iqbal 2019).

6.2.1 Perspective Mathematics Revolution for Input Management

For the effective management of agricultural farm input resources, advanced mathematical processes involving the latest generation of computing, software, and hardware hold promise for boosting farm productivity (Posadas 2012). For instance, simulation models utilizing historical data enable farmers to determine the optimal sowing time, fertilizer requirement, etc., based on reliable information. Effective crop input management can never be achieved without using high-yielding varieties, while advanced mathematics has enabled plant breeders to identify crop varieties having higher yields along with desirable traits, such as insect-pest resistance and inherent ability to tolerate environmental stresses including temperature extremes, water scarcity, salt stress, heavy metals toxicity, etc. Besides, the mathematical revolution can potentially assist in scheduling farming activities from the harvest to loading trucks in such a manner that ensures delivery of fresh crops to the market (Shamshiri et al. 2018; Meena et al. 2020). Last but not least, the mathematics revolution imparts power to the entire agricultural supply chain to make informed decisions about using input resources leading to higher utilization efficiency and multiplied grain yields. However, the perspective mathematics revolution has a limitation that high-quality data are needed to be fed to the simulation models, miscalculations might lead to reduced utilization efficacy of farm inputs.

6.2.2 Perspective Sensing Revolution for Input Management

Advanced sensor technologies enable a real-time estimation of input requirements on modern farms. The latest equipment utilizes smart sensor networks that actively monitor soil health along with the water and nitrogen needs of crop plants. In this way, precise data on soil fertility status and moisture content helps to apply irrigation and fertilizers optimally, leading to scarce resources conservation and yield maximization (Panchard et al. 2014; Paek et al. 2014; Stevanato et al. 2019; Burton et al. 2020; Erler et al. 2020; Ferrarezi et al. 2020). In addition, sensors help real-time traceability of applied nutrients and the diagnosis of crops along with determining the status of farm machines (Rai et al. 2012; Saiz-Rubio and Rovira-Más 2020). Thus, the perspective sensing revolution holds the promise to optimize the use of water and chemical fertilizers that are vital for leading to environmental protection. The promising use of nanotechnology and its products in next-generation agriculture and environmental sustainability is highlighted in Fig. 6.1. Besides, various high-resolution crop sensors, direct use of equipments (sprayers, seed, and fertilizer drills, water drips, etc.) to supply the needed amounts instead of prescribing fertilization before application (Wen et al. 2019; Yadav et al. 2020).

Optical sensors or drones can identify crop health using infrared light across the field. Along with the management of farm inputs, animal collars having integrated biometric sensors and Global Positioning System (GPS) furnishes real-time monitoring regarding the actual location of animals and thus enabling ranchers to respond quickly in case of any emergency. Precision agriculture, which is intra-field

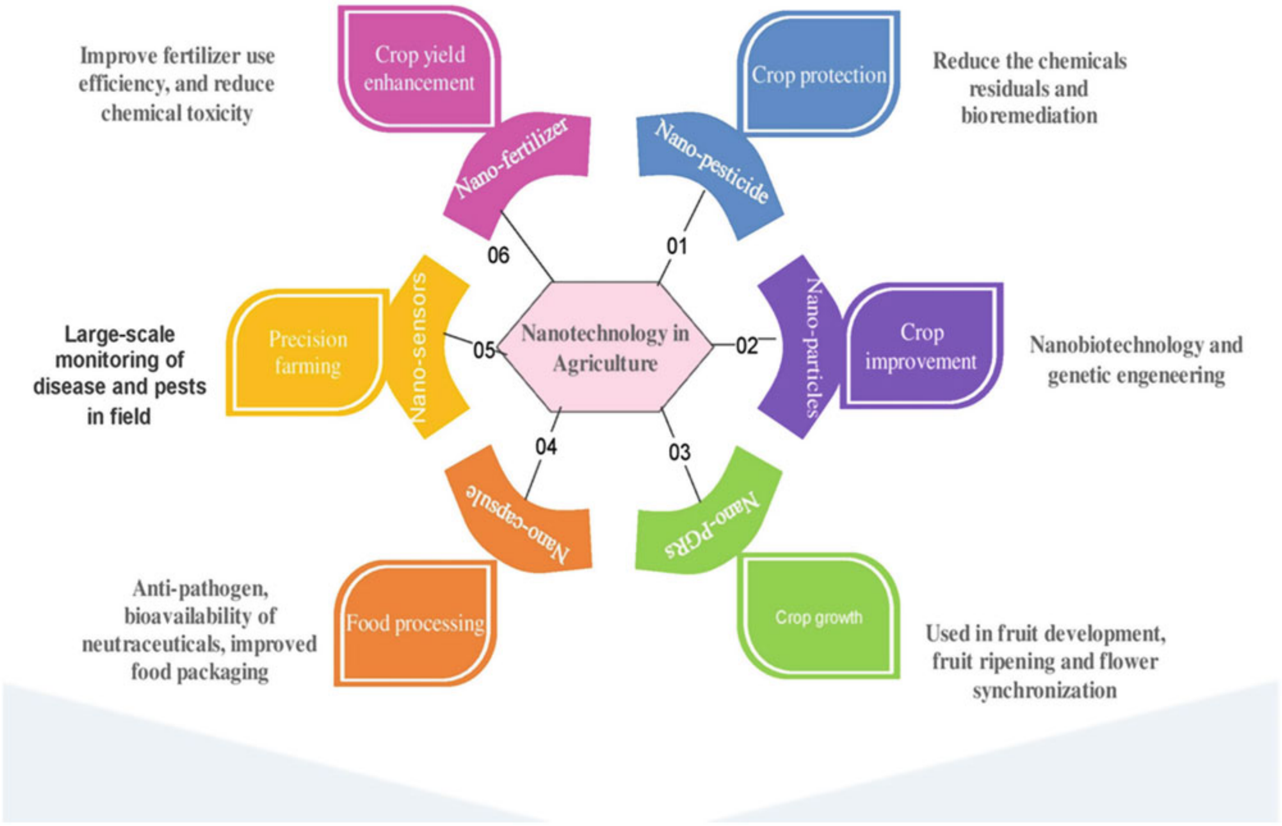

Fig. 6.1 Highlights the implication of nanotechnology and its products in next-generation agricultural improvements

variations observation-based farming management, can also be assisted by high-resolution sensors leading to sustainable farming (Barkunan et al. 2019; Müller et al. 2019; Kayad et al. 2019; Mulley et al. 2020). These technologies can multiply returns on inputs used by preserving scarce resources at ever-larger scales. Furthermore, the use of precise sensors with crop variability information and geolocated weather data allows accurate and improved inputs use (Shamshiri et al. 2018). Thus, the perspective sensing revolution not only has the potential not only to optimize nonfarm inputs but also monitoring choices for actual conditions of crops and animal location in grasslands.

6.3 Perspective Automation Technology for Input Management

Engineering encompasses cutting-edge technologies that boost the level of farm input management to new means (Tillett 1993). Of particular, interest will be the development of smart devices that have the potential to perform input supplying operations independently as per programmed data without human intervention. The use of artificial intelligence, such as robotics (for sowing, picking fruits, and chemical spraying), drone (handling agriculture operations at large scale), satellite (for prediction of weather), digital application (for giving timely information), and advanced molecular strategies in next-generation agriculture are highlighted in Fig. 6.2.

Automation integration with high-resolution sensing and advanced mathematics ensures optimization of planting time, irrigation needs along with other input applications with absolute precision. Agricultural robots (also known as agbots)

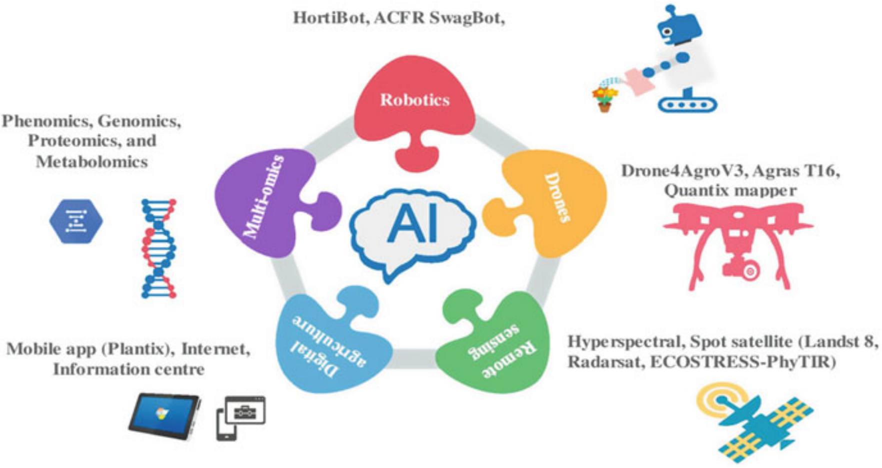

Fig. 6.2 Highlights of some of the automated machines (Artificial Intelligence (AI)) in the next-generation agriculture

have been designed and manufactured to perform numerous automated agricultural tasks that are quite tedious, such as weeding, spraying, fruit picking, etc. (Tarannum et al. 2015). The perspective is the utilization of energy-efficient robots which are designed to work in a network for monitoring actual conditions of agricultural fields and subsequently supply essential inputs without human intervention. Moreover, automation is bound to help sustainable farming via micro and large-scale robotics to check and thereafter maintain crops at the plant level. Thus, using robots for crop input management means fewer farm injuries and less environmental pollution owing to insignificant and negligible waste of synthetic fertilizers and pesticides, especially of higher shelf life. Moreover, variable-rate swath control is another critical advantage associated with the use of robotics in managing farm inputs. Future swath control technology using geolocation tools has the potential to substantially save seeds, minerals, fertilizers, and herbicides by avoiding overlapping of applied inputs. This technique involves precomputing the field shape and clearly understanding the relative productivity of different areas; equipment or robots can procedurally supply inputs at variable rates throughout the field, which leads to input saving along with higher utilization efficiency (Tillett 1993). However, the limitations are the expensiveness of robotic uses, the occurrence of technical glitches, and high-tech operation and maintenance, which necessitates further refinement of agricultural robotics technology for the effective management of farm inputs. Equipment telematics is another next-generation farm input management technology that allows mechanical devices, such as boom sprayers, seed-cum-fertilizer drills, and tractors to warn out about faulty operation.

6.4 Next-Generation Plant Breeding to Increase the Utilization Efficiency of Farm Inputs

Keeping in view the increasing population, boosting agricultural productivity with meager use of farm-applied resources has become a necessity. In the years ahead, the global population has been projected to increase by two billion, and their dietary accessibility can only be guaranteed through boosting crop yields via effective handling of farm inputs. Moreover, due attention needs to be given to environmental pollution and degrading biodiversity owing to excessive loss of farm inputs from agriculture fields. The overall efficiency of farm inputs needs to be much higher securing uncertainties that agriculture is facing during changing climate and global warming. The necessity of breeding cultivars having higher inherited potential to utilize inputs and produce higher biomass as well as economic yield has become the need of time (Barabaschi et al. 2016). Thus, to improve the utilization efficacy of farm inputs, one of the most exciting advances could be the development of crop hybrids having the potential to utilize higher amounts of applied inputs (by modified roots architecture, botanical superiority, and adaptability) and which thrive well in ultrahigh densities under environmental stresses including temperature extremes, water scarcity, salt stress, ion toxicity and water-logging. The next-generation selective breeding encompasses a quantitative analysis of end results while suggesting improvements algorithmically (Harfouche et al. 2019). Artificial intelligence assisted plant breeding for desired traits enabling crops to utilize inputs (fertilizers and water) with greater efficacy leading to boost crop yield, thus safeguarding food and nutritional safety of masses across the globe. Therefore, next-generation plant breeding holds a promising perspective to bolster water and fertilizer use efficiency leading to higher crop yield. The key next-generation approaches in environmental safety are summarized in Table 6.1.

6.5 Dietary and Ecological Safety Through Novel Technology: Filling the Gap Add a Flow Chart

By 2050, the global population will be nearly 10 billion which is bound to double the food insecure population (Poppy et al. 2014; Ranganathan et al. 2018; Islam et al. 2020; Hossain et al. 2020). Therefore, the global agricultural system needs to be drastically transformed to produce sufficient food for its increased population to ensure food security (FAO 2017).

Two major challenges of current and future agriculture are uplifting crop productivity with minimal inputs while implementing measures to minimize undesirable ecological events (Beddington 2009). Global ecological events affect negatively crop growth and predict more climatic events exacerbating crop growth triggering heat, precipitation, and weather events (FAO 2016a, b). The major agricultural resource, such as water and labor are diminishing, and besides, the fertility level of the cultivated land is also decreasing (FAO 2016a, b; Kanianska 2016). Cater to the global food requirement for the growing life on earth, intensification of crop growth, as well as the applying agrochemicals including chemical fertilizer and pesticide, are increasing tremendously, which negatively impacts the ecosystems and living beings (Kumar et al. 2019). Current farming practices that are more resource-intensive and responsible for major Greenhouse Gases (GHGs) emissions are no longer sustainable. Therefore, exploring novel concepts of research concurrently focusing on boosted crop production, while minimizing ecological consequences are a prime objective for catering future food demand (Godfray and Garnett 2014). The general term, “sustainable intensification” explains the enhancement of agricultural productivity in prevailing lands under agriculture by increasing the crop and livestock productivity and profitability, food security and health of human, social and gender equity, and environmental impact on biodiversity (Kehoe et al. 2017; Cassman and Grassini 2020). Sustainable intensification is likely to target-related than the other approaches, highlighting the significance of environmentally friendly agriculture production systems with minimal carbon footprints (Evans 2009; FAO 2011a).

Provisions of food and nutrition to all livelihoods on earth are defined as food security (Venugopal 1999). The interactions of agricultural production systems and external environment are quite complicated networking systems thus, efficient and smooth handling and integration of related activities are paramount for a better outcome (Ericksen 2008). Thus, boosting agricultural production system while balancing environmental impacts through minimal carbon footprint, giving

Table 6.1 Summary of key next generation approaches, strategies, and their application in the environment safety

S. No.	Next-generation approaches	Strategies	Application	References
1	Nanotechnology	Implementation of NPs-based smart input system (seed treatments with micronutrients; nano-fertilizers (nano N, P, K), nano-pesticides, nano-insecticides, and nano-capsules)	Plant disease, insect resistance, efficient nutrient utilization, improve fertilizer use efficiency, abiotic stress tolerance, and reduce the chemical load on soil	Panpatte et al. (2016), Duhan et al. (2017), Shang et al. (2019), Moulick et al. (2020)
2.	Artificial intelligence	Artificial intelligence (AI) makes it possible for machines to learn from experience, adjust to new inputs, and perform human-like tasks	It helps in yield healthier crops, control pests, and diseases, input resource managements, decision-making, and improve a wide range of agriculture-related tasks in the entire food supply chain	Nabavi-Pelesaraei et al. (2016), Sánchez et al. (2020), Talaviya et al. (2020)
3.	Advanced molecular breeding	Genome editing, transgenics, multi-omics (genomics, metabolomics), and next-generation sequencing	Introduction of desirable traits (biotic and abiotic stress tolerance, improve multiple input use efficiencies (water, light, and nutrient)	Reddy et al. (2020), Singhal et al. (2021), EL Sabagh et al. (2021), Kumari et al. (2021), Indu et al. (2021)
4.	Improved agronomical practices	Precision farming, automated irrigation, climate-smart agriculture, conservation agriculture and crop models, zero tillage, crop residual management, cropping pattern	Improve the input use efficiency, more production and productivity, and higher benefit/cost ratio	Branca et al. (2011), Nyagumbo et al. (2017)
5.	Improved soil and water management	Growing cover crop, organic manure, application of biochar, soil nutrient analysis, irrigation scheduling	Improve soil nutritional status, fertility, improve water holding and utilization efficiency, and reduces the	Hoorman (2009), Jatav et al. (2020)

(continued)

Table 6.1 (continued)

S. No.	Next-generation approaches	Strategies	Application	References
			chemical load on soil	
6.	Conservation and restoration of ecosystem	Zero tillage, less mechanization in the field, restricted human interference in the natural ecosystem, adopt green technology, grow more trees, and sustainable natural resource management	Improve environmental sustainability, reduce soil and environment pollutions, nullifying the effects of climate change, and maintain natural biodiversity	Young (2000)
7.	Reduce GHSs production	Modified rice cultivation practices, reduce fertilizer applications, and restricted the burning of agricultural bi-products	Reduce the global warming effect on crop production	Smith et al. (2007)
8.	Reducing pre and postharvest losses of food	Improved agricultural practices, timely harvesting, development of warehouse facilities, strengthen the market facilities	To fulfill the future global food security	Prusky (2011)

provisions to food for all, protecting natural ecosystems, improving crop yields by various breeding tools, utilizing species diversity, genetic improvements of crop and animal by modern techniques, and harnessing trade and e-commerce are required to achieve food and environment security (Beddington 2010; Tomlinson 2013; Godfray and Garnett 2014). To achieve food and environmental safety for the increasing population, the following approaches can be implemented are discussed followed and presented in Fig. 6.3.

6.5.1 Improved Crop Breeding Adapting to Environmental Changes

The drastic fluctuations in the environment are projected to adversely affect the whole agriculture production system with over 5% drop by 2050 if adaptive cultivars

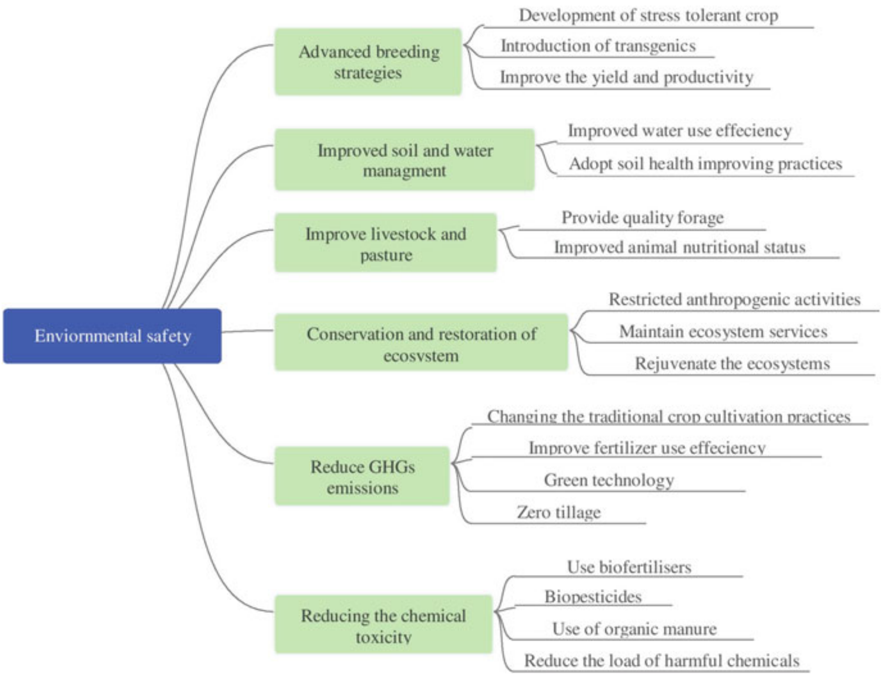

Fig. 6.3 Schematic representation of strategies used for future environmental sustainability

are not developed to boost yield (Ranganathan et al. 2018). Adaptation will require growing alternate crops as well as breeding crops that can cope with changing climate, stresses (biotic and abiotic), and require fewer resources. Advances in molecular breeding and biotechnology offer great potential to increase yield gains by deliberate manipulation of target genes for particular traits, and by editing or slicing genes. Although major crops have received due attention but more efforts are needed to breed minor crops (e.g., millet). The prime aim of new targeted breeding programmes jointly carried through public–private partnerships should be to develop cultivars having better adaptability to climate changes.

6.5.2 Increasing Cropping Intensity

Cultivating prevailing agricultural lands intensively introducing modern cropping techniques would be ideal for enhancing land-use efficiency within the existing land area. Therefore, appropriate cropping systems that will be highly suitable in a particular area and will increase the system productivity need to be identified. Increasing annual cropping intensity by 5% beyond 2050 is said to be reduced land requirement by 14% and the GHGs modification gap by 6% (Ranganathan et al. 2018). Future research needs to be directed toward designing such intensive cropping systems relevant to the availability of inputs and considering other limitations.

6.5.3 Improved Soil and Water Management

Using novel practices for soil and water management, cultivation of damaged lands especially the drylands having less organic matter can be augmented. Agroforestry (incorporating trees with crops) is a great option to recover the damaged lands thereby enhance land productivity. For water scare and salinity areas, rainwater harvest using an artificial pond is an excellent option to improve water management. In the intensive cropping area, green manuring crops (e.g., *Sesbania* spp.) can be cultivated for a short time and then incorporated with the soil, which will increase soil fertility and soil health. In rice cultivation, alternate wetting and drying practices can save a significant irrigation water requirement (Lampayan et al. 2015).

6.5.4 Increase Livestock and Pasture Productivity

In developed countries whereby crop yields have been maximized, there is little scope for further improvement. The potential yield can be easily achieved in animal husbandry by taking care of the wellbeing and health of farm animals (Ranganathan et al. 2018). Progress of knowledge on animal structure and functions, social behavior, etc. are the best indicators to evaluate resilient animal breeds. The demand for products from farm animals is increasing and is estimated to increase by 70% by 2050. Therefore, boosting pasture productivity is a feasible solution to increase food production for animals (Ranganathan et al. 2018). Improving animal nutrition status through the provision of quality forages and other feedstocks might lead to a significant increase in milk and meat productivity as suboptimal nutrition seriously decreases farm animal's productivity and economic returns (Iqbal et al. 2015c). The exploitation of alternate feed sources, such as crops leftovers, weeds, tree leaves, nutritionally improved forage species, etc. might bring another white revolution provided animals feeds are met as per their requirement. Based on the reliable data set, different nutrition models might be developed to determine the nutritional requirements of dairy animals to their physique, growth rate, production potential, and overall health condition.

6.5.5 Reduced Loss and Waste of Food

A huge percentage (33%) of global food produced is lost or wasted throughout the production chain from field to fork. The events and consequences of such losses and wastes are due to poor or inadequate harvesting techniques, storage, and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems, inefficient management, communication gaps among players in the supply chain (FAO 2011b). Thus, significant loss of resources is inevitable. Meantime the by-products such as GHG emissions create extra burden as environmental pollutants exacerbating the situation. In this context, the production chain from field to fork necessary to be reinforced by farmer empowerment through public and private partnerships. The policies related to food supply chains in developing countries need to be restructured while strengthening infrastructure.

6.5.6 Reduced Biofuel Production in Agricultural Lands

The bioenergy production in agricultural lands has negative impacts on global food security expanding the food, land, and GHGs mitigation gaps. Development of bioenergy production in many countries of the American continent and Europe currently facing the drastic rising prices of food and feed including grains, oilseeds, and vegetable oils (Babcock 2015). Therefore, it is urgent to avoid biofuel crop cultivation in food cropland.

6.5.7 Conservation and Restoration of Natural Ecosystems and Restricted Shifting Cultivation

The improvement of agronomic practices is key to protect global green biomes by limiting the transformation of natural habitats into agricultural lands. In certain situations, unfertile bare or marginal lands could be converted to natural forests through restoration (Ranganathan et al. 2018). In addition, agricultural practices need to be transformed into a more sustainable manner to avoid further damaging of an ecosystem, while restoration and conservation plans need to be developed on a priority basis. Furthermore, changing climate and global warming have negatively affected flora and fauna of terrestrial and marine ecosystems which must be assessed by utilizing the latest technologies including global positioning systems and remote sensing (Smartt et al. 2016).

6.5.8 Increase Fish Production

People who live in poverty have limited or less access to nutritionally high diets to safeguard their nutritional requirements and food security (FAO 2011b). The diet of poor people often depends on the cheaper starchy food, such as wheat, maize, or rice, and economically do not strong enough to purchase meat, fruit, and vegetables. Fish is cheaper than meat, and contains higher protein contents, enriched with essential minerals and vitamins, and can provide a more diverse diet for many poorer households. To improve fish productivity, more research and extension work is needed in both freshwater-and marine-based farms.

6.5.9 Reduce GHGs Emissions from Agricultural Production

Agricultural activities have a significant contribution to GHGs emissions, and it is said to be that roughly 26% of all GHGs emissions originate from agriculture production systems (Ritchie 2020). Among agricultural practices, which are mainly responsible for GHGs emissions are rice cultivation, application of nitrogen fertilizers, livestock farming, and energy use. Among agricultural emissions, only the rice sector contributed around 11% of total GHGs emissions (Smartt et al. 2016), in the form of methane. However, there has been a huge scope to reduce GHG emissions in rice production by changing its production practices. For example, in Asian countries, the common rice cultivation method is puddle transplanted rice, which is resource intensive. However, direct-seeded rice has emerged as an alternative rice production technology that has the potential to save water and labor resources as well as lessen methane (CH_4) gas emission by restricting the time period of field flooding (Pathak et al. 2013). Continuous standing water in the rice field is a common practice in Asian counties; however, alternate wetting and drying in the rice field showed lower CH_4 releases up to 90% additionally conserving water and in some cases, it also increases rice yields (Lampayan et al. 2015). Some rice varieties have the potential to generate less CH_4. Therefore, rice breeding programs need to be more emphasized on lower CH_4 rice varieties and less nitrogen (N) requirement, and those which can tolerate more water stress with boosting rice yields (Zhang et al. 2018). Globally, the use of N-fertilizers is tremendously increasing, however, the higher portion of applied fertilizer is lost as gas emissions and leaching. The Fertilizer Use Efficiency (FUE) can be enhanced by improving fertilizer management practices thereby enhancing the nitrogen absorption rate of the crop by genetic modification or crop varieties require less nitrogen or ability to fix nitrogen biologically is urgent (Zhang et al. 2015). Recent advances in the chemical application that avoids converting N into nitrous oxide, and cultivating pastures that regulate this activity naturally are also needed. The sequestering of carbon in soil is one of the mitigation strategies of GHG and therefore, activities to boost carbon retention in soil including zero-tillage farming (conservation agriculture), conversion of forests, and introducing novel approaches for making carbon where soil fertility is essential for food security can be very much useful (Jat et al. 2020).

6.5.10 Reducing Pesticide Risks to Farmers and the Environment

Pesticide use in agriculture has increased and continues to multiply tremendously for increasing food production in intensive commercial-oriented farming systems. Judicious and safe use of pesticides is urgent to minimize the health hazards to farmers and the environment. The use of highly hazardous pesticides needs to be reduced, and a stewardship guideline is required on pesticide use for each country, which will guide farmers to understand pesticide risk and its safe use.

6.5.11 Harnessing Trade and E-Commerce

We are very close to the digital world, and e-commerce has great potential to help bridge the gaps and promote agribusiness. More needed actions to be taken to improve the online marketing of agro-based products.

6.6 Next-Generation Modeling Tools for Sustainable Input Management and Crop Production

Crop modeling in agriculture is a key supportive factor for regulating sustainable agriculture. Different crop simulation models like APSIM (Agricultural Production Systems Simulator), DSSAT (Decision Support System for Agrotechnology Transfer), and DNDC (DeNitrification-DeComposition) (Keating et al. 2003; Holzworth et al. 2015; Jones et al. 2017; Rahman et al. 2018, 2019; Zhao et al. 2019) are working, and provide an estimation of resources to the researchers because of the natural resources become scares under climate change scenarios. To fulfill current and future needs, modification of crop models according to special cropping systems is direly needed. Currently, mostly crop models can work on a crop, but cropping rotations and intercropping schemes also require models for better estimation of resource use efficiencies (Wajid et al. 2014; Awais et al. 2017a, b; Ullah et al. 2019). So, the future crop model's languages, documentation, visualization, and framework should be easy for researchers (Holzworth et al. 2018) and should be included modern farming techniques and analysis features.

Decision-makers of both private and public sectors have engaged agricultural system models as important tools for the prediction and assessment of the capability of the growing systems. The valuation of the need for user-friendly knowledge tools that would help or facilitate the utilization of model outputs was considered a distinguishing feature of the next-generation study. Hence, cloud-based analytical tools and mobile application technology, and other such types of well-defined knowledge-based products can use models more efficiently under a diverse set of stakeholders in comparison to current possible situations. Moreover, there is a need to devise a positive approach that would help in upholding the group of people-related research agenda and agricultural systems modeling in the right direction of next-generation vision (Dokoohaki et al. 2016; Antle et al. 2017; Jones et al. 2017; Tariq et al. 2018; Siad et al. 2019).

6.6.1 Evaluation of Input Uncertainties

Most of the climatic models are considered deterministic unless having uncertain outputs in reality. However, different methods, such as computer-based models, emulation of the model, and sensitivity analysis, have been used for the estimation of uncertainty of deterministic models (Uusitalo et al. 2015). For the assessment of the variance of studied parameters and output of deterministic models, professional expert assessment can also be engaged. More uncertainties in the stakeholders' knowledge and input values' parameters can be quantified by stakeholder opinion, and probabilistic approaches (Van der Lippe et al. 2011). For example, uncertainty for a particular parameter can be estimated through information recorded from the range of variance or quartile of studied values of a particular parameter. Higher inputs of stakeholders might be required when there is higher uncertainty (Sahin et al. 2014). Moreover, higher uncertainty provides supportive extra evidence to enhance assurance in the projected insecurity. According to Morris et al. (2014), free web-based software tools are also available, which help in the elicitation of skilful experiences as probability distributions. Furthermore, the degree of agreement and modeling the disagreement as insecurity can be used for the enhancement of the elicited information (Krueger et al. 2012). The degree of uncertainty has been estimated by Van der Lippe et al. (2011) in the particular data of stakeholders by investigating the degree of gaps between them. Bayesian Decision Network (BDN) approach was used instead of limited system mechanistic models due to very high insecurity (Catenacci and Giupponi 2013). Some uncertainties lead to ambiguities, such as twisting of elicitation outputs owing to a lack of reliable data availability. For the good representation of ambiguities, imprecise probability theory has been proposed by Rinderknecht et al. (2012). Moreover, the bias in the stakeholder elicitation can be present. Similarly, a protocol for the integration of local data with expert knowledge and a Bayesian approach for the assessment of common cognitive biases were proposed by Scholten et al. (2013).

6.6.2 Model Design Criteria for Future Generation

Particular goals distinct from the GB-QUEST govern the plan of the AgFutures model. Therefore, to engage the stakeholders in a debate and to assemble realistic scenarios of the desirable futures, GB-QUEST looks for two potentially opposing goals (Carmichael et al. 2003). As compared to other traditional land-use models, GB-QUEST implies diverse plan criteria for that particular model. Hence, several criteria for the model plan which have been done in the model are given as under:

6.6.2.1 User-Friendly, Simple Interface

The most important object to make a model is to engage society in the context of sustainability. A broader array of problems should be shown and easily displayed in the interface to engage users to make the model more important to a broad person and group's variety. The development of an interface that is user-friendly and easy-to-understand is important for the easy understanding of main constraints, which are shown to the users as questions and their solution to the general public by preventing scientific terms through this interface. Therefore, under the preferred conditions, these answers to questions stated the model components, which ultimately produce future consequences.

6.6.2.2 Involvement of Stakeholders

The authentic issues and viable options that are endured by the society which are of serious concern to the society should be addressed by the models for policy support (Iqbal et al. 2015a). Therefore, the steps involved in the identification of issues that act as the precursor for the model development, engage stakeholders along with policymakers, while the typical approach of stakeholders involves the stakeholders in decision-making of policy that have been preferred and assessed by the model experts solely in the final phase of selection from a particular agreed guideline (Ejeta 2009). Therefore, both of these approaches are in contrast to each other in involving the stakeholders for policy development. In the process of demonstrating the fundamental issues of agriculture and outcomes, an imperative role is played by the stakeholders to make AgFutures more appropriate and satisfactory by the society for its use (Iqbal 2020). Furthermore, to tackle the issues related to the community helps the policymakers. Based on this approach, policies formulated were socially acceptable by the community.

6.6.2.3 Integrated Approach

Integration of both physical and social sciences can potentially evaluate complex land-use systems and related sustainability analysis. The integrated models provide less information regarding important issues but are easy to use and implement. Whereas, the disciplinary models provide more information about important issues, but their application is complex. However, the utilization of a systematic approach of integration of the disciplines, resolutions, styles, and degrees of certainty is the main objective of integrated modeling (CIESIN 1995). Models of land use with curative nature are presenting in different proportions, biotic or abiotic related to land-use change and presenting just one proportion of land-use change systems due to more complexity (Veldkamp 2001). At multiple scales, integration of human and natural proportions of land-use systems might evaluate their effects on economic, social, and environmental sustainability on well-defined sustainability indicators for the assessment of balanced perception, the integration of three components of sustainability variables is required to emphasize in comparison to those analyses that highlight just environmental or economic impacts of the particular system in AgFutures higher.

6.6.2.4 Complexity, Quick, and Invisible Back-End Model

When AgFutures is integrated with GB-QUEST, then there is a need for the assistance of a back-end model which is designed in such a way that the actual modeler rule implements with the experience to produce the anticipated consequences for users, while just the very last-related outputs are shown. Moreover, the underlying model provides issues and outputs widely, which is generally established on a complicated web of related connections that only describes the viable options and outputs. Furthermore, it utilizes the complicated technology for the production of ‘what-if’ scenarios concerning land-use changes and the estimation of associated impacts on community, economy, and ecological outputs. Larger time has been spent on designing a model, such as statistical formulae, assessments regarding significances used for appropriateness of land, and coefficient of models aimed at reducing the setting period for run-time calculations, which in turn help in permitting the rapid generation of future scenarios. Moreover, the choices of a user vary the value of main variables allowing the quick production of 'desired' scenarios.

6.6.2.5 Scenarios-Based Approach

Generally, predictive models emphasize forecasting the future based on past history. However, predictive models are unsuccessful in identifying particular future scenarios arising from actual and anticipated future choices. The application of that scenario associated with backcasting strategy should be used for decision and policy making rather than keeping the future predictable, and it presents that our community has substantial control over the future consequences (Sharma et al. 2006). Moreover, the model uses the scenarios-based strategy, which allows users to evaluate various assumptions regarding the values and behavior of humans and technology and institutions, but these assumptions are rarely applied in predictive models.

6.6.2.6 Tackle the Uncertainty

When climatic models are engaged for the estimation of unusual futures, then there is a need to evaluate the uncertainty adjacent to the system's behavior in a user-friendly way. Hence, the necessity of evaluating the risk factors is particularly related to situation of the generation of a model having uncertainties from several kinds of actions and that hope to think schedule distant into the particular future. Strategy based on the scenarios---applied consists of the unambiguous capability to observe how scenario changes under various presumptions concerning the particular aspects of uncertainty, comprising the values and behavior of humans and technology and institutions. The application of scenarios also gives resources to check the sensitivity of variables, i.e., prices (Sharma et al. 2006).

6.7 Next-Generation Input Management Technologies for Food and Environmental Security

Attaining food security in a seamless squall is a key contest for society. If by 2030, 50% of food, 50% of energy, and 30% of freshwater cannot be used, then the "perfect storm" will appear on a global scale at the same time, which will be a "storm" (Beddington 2009). When temperature change and a growing world population act along, this will become an even more "evil problem," which makes the challenge of achieving world food security a lot of advanced and severe. Food security "exists when all people have biophysical and economic access to adequate, safe and nourishing food at all times to feed their nutritional needs and dietetic partialities for an active and healthy life" (FAO 1996; Beddington 2009). This is dictated by four elements: (1) accessibility (from rural creation and land use or trade); (2) strength of gracefully (e.g., occasionally and from year to year); (3) access (relies upon monetary assets yet in addition on physical access and social elements);

and (4) organic utilization of food (for e.g., dietary assorted variety and sanitation issues) (Barret 2010). It has been assessed that about one billion individuals experience the harsh effects of hunger because of the absence of macronutrients (FAO 2010), and one billion individuals lack adequate micronutrients, which is unsafe for wellbeing or improvement. (Foresight 2011).

6.7.1 Food Security

Ensuring adequate, safe, and nutritious food for all people has been a major global challenge truly in the twenty-first century. Food security is typically characterized in four measurements: food accessibility, admittance to food, food use, and food strength (FAO 2016a, b). These aspects form a common basis for the definition established by the Food and Agriculture Organization of the United Nations (FAO): "Food security exists when all individuals, consistently, have physical, social and financial admittance to adequate amounts of sheltered and nutritious food, which meets their dietary needs and food inclinations for a functioning and solid life" (FAO 2016a, b). For every aspect, a progression of pointers has been characterized to survey progress in improving food security.

6.7.2 Input Management Technologies for Environmental Security

The concept of sustainable intensification covers a significant number of the subjects in this extraordinary issue from an overall perspective, yet, there is still no agreement on its viable application (Garnett et al. 2013). Given that numerous archives in this issue have communicated the need to consider crop needs while ensuring human wellbeing and nature, everybody approves those ideas like sustainable intensification can advance powerful arrangements and works on during the change of horticultural frameworks. Consequently, it is recognized as a worldwide need. The success of this concept needs to be wide enough to cover sophisticated intensive farming systems in developed countries as well as traditional or conventional small-scale farming, especially in developing countries. Even though the FAO of the UN has distinguished sustainable intensification as a suitable methodology for the improvement of smallholder horticulture (FAO 2011), the practices sketched out in "Protection and Growth" give small comprehension of the open doors offered by plant science, and they do not address the issues we face the scale or multifaceted nature of the creative challenge. Each of the four reports in some portion of the meeting is enormous scope extends that are as of now effectively associated with examination, training, and investigation of farming frameworks in underdeveloped countries. The three papers include authors from the United States and Africa, all of which show successful global participation that is basic to viable advancement.

6.7.3 Innovation for Sustainable Agriculture

Following the arrangement proclamation of the Royal Society and the report on the practical rural turn of events (Royal Society 2009), the papers in this area center around the improvement of farming by shielding crops from natural misfortune while limiting harvest misfortunes. Expanded insurance is fundamental with the goal that interest in land readiness, seeds, water, and supplements is not squandered. A definitive objective is to give improved assurance and lessen carbon impression through seeds while upgrading plant execution, atomic reproducing, and misusing species, assorted variety using friend plants, and hereditary adjustment (genetically modified; GM). The essential objective of this area is to underline the new sciences in this field, which will establish the framework for another worldwide rural framework.

The possibility to improve plant execution by utilizing plant enhancers or initiators as a medium, when applied to crops, will upgrade its essentialness, flexibility, and execution. From the proof of right now accessible mixes, (for e.g., the monetarily accessible compound benzothiazole-S-methyl and normal item laminarin), it tends to be seen that the arrival of increasingly more attractants can improve the parasite (that is, the parasite that slaughters its host). Protective organic control of herbivorous irritations (Sohby et al. 2014). Next is a portrayal of how to utilize hereditary screening techniques to recognize new ideal growth regulators.

6.7.4 Management of Agroecosystems Using the Framework of Ecosystem Services

The Millennium Ecosystem Services Report is a progressive distribution that has significantly affected science and strategy (MEA 2005). This technique has been exposed to a progression of public appraisals (Biggs et al. 2004; NEA 2011), and this system is broadly applied/considered for future land-use the executives' choices. Although there is banter about how best to clarify the "esteem" of assistance (Fisher et al. 2009; TEEB 2010), The idea of biological system administrations is increasing a significant political establishment, and even by lessening deforestation and woods corruption (REDD) and REDD emanations, assisting with forming thoughts identified with biodiversity balances (UK nature) and installments for environment administrations past carbon exchanging (Bond et al. 2009; Porras et al. 2013). It, without a doubt, gives a valuable structure to the improvement of ideas, for e.g., manageable farming turn of events and how to accomplish food security while nature is steady. It is identified with a few Millennium Development Goals.

Guaranteeing food security requires the concurrent arrangement of four fundamental difficulties. When searching for momentary arrangements, the flexibility/strength part is frequently neglected. This can prompt a "misfortune of the open area"and the loss of key administrations (Ostero Mu et al. 1999). This last arrangement of articles takes a gander at natural maintainability with regards to the food framework in the desire for attempting to “close the hole,” which is the fundamental focal point of the conversation meeting.

6.7.5 Agroforestry for the Provision of ESS and Sustainability of the Agriculture System

Agroforestry systems, have the potential to support climate-resilient production systems by considering both pillars of environmental fluctuations, i.e., strategies for adjustment and mitigation (FAO 2013). Agroforestry indicated the possibility of enhancing crop productivity in different regions, especially under tropical and temperate climatic conditions (Palma et al. 2007). It is successfully being used under different conditions and has the potential for adaptability and sustainable production (Bayala et al. 2015). Agroforestry is the innovative approach being sued to improve food security, mainly perennials contributed to soil fertility by increasing organic matter resulting in improved crop yields (Powlson et al. 2011). Different benefits are being received from trees under agroforestry system than mono-cropping as trees are the source of valuable timber, fodder, fruits, fuel and construction materials, and human nutrition (Lott et al. 2009; Jose 2012; Böhm et al. 2014; Burgess and Rosati 2018; Kay et al. 2019). Agroforestry has the possibility of contributing much better for sustainability as it can be used both for adjustments and alleviation of environmental fluctuations for the short and long term (Powlson et al. 2011; Luedeling et al. 2014; Abbas et al. 2017; Udawatta et al. 2019). Practices and strategies of agroforestry have shown an ability for the sustainability of resources and their management under different crop and land-use systems by promoting and conserving the ecosystem services (Dagar and Tewari 2018; Crous-Duran et al. 2019). Agroforestry has numerous advantages like to improve soil health and structure, better water infiltration and regulations, develop microclimate, promote ecosystem services, reduce soil erosion, improve the fertility and sustainability of soil, enhance carbon sequestration, effect the emission of GHGs, and source of finance for both short-and long-term growers (Jose 2009; Sistla et al. 2016; Beuschel et al. 2020). Contribution of agroforestry toward ESS provisions, sustainability, climate change mitigation, and adaptions depends on the components of an ecosystem, and site-specific response not only the positive impacts under each system in a short time, but it may also need a longer period (Torralba et al. 2016; Burgess and Rosati 2018).

6.8 Science and Technology for Food Security

Accomplishing food security by 2030 is said to be a significant test and will continue so all through the twenty-first century. The sustainability developmental targets including the rest of the other worldwide endeavors to accomplish food security utilize novel advancements as a fundamental device to terminate starvation. This part talks about how certain uses of science and innovation assume a job intending to different parts of food security. The key scientific scopes to adopt in food security includes accessibility, access, consumption, and sustainability. The application of science and technology in each step of the food production chain from farm to fork can enhance food production for the future (Asseng et al. 2014).

6.8.1 Improvement in Agricultural Productivity Through Science and Technology

FAO (2006) has diagnosed a gap of about 70% crop energy to be had in 2006 and predicted caloric necessities in 2050. To fill this gap, it's far essential to enhance genetics to enhance meal production, lessen meal loss, waste, and nutritional changes, and increase productiveness through the way of means of enhancing or keeping soil fertility, pasture productiveness, and re-establishing damaged land (Ranganathan et al. 2016). Thus, given the reduction of arable land, limited water resources, ecological and agronomic constraints, the food supply will have to narrow this food gap. Appraising the previous 40 years, approximately 33% of the cultivated area worldwide has been degraded due to contaminations or run-off.

6.8.2 Crop Production and Plant Varieties Improvement Through Conventional Cross-Breeding

Genetic amendment of plant sorts may be used for dietary fortification, drought resistance, herbicides, pests and diseases, and growth yield. In earlier styles the crop improvement concerned traditional breeding methods. In the mid-1800s, Gregor Mendel officially delivered a way that used nonstop generations of "relative crops" with the best breeding traits till the very last range fit the traits of the goal range. Though crop improvement is confined to the superior characteristics in the same crop family (Buluswar et al. 2014), this technique is still useful, especially for smallholder farmers in many areas.

6.8.3 Increase in Agricultural Production Through Genetically Engineered Crops

The genetic modification of crops through the insertion or deletion of genes from genetically distant organisms resulted in new crops with superior traits. Transgenic organisms have many benefits, inclusive of biotic stress resistance (pests, diseases), abiotic stress resistance (deficit water and salinity), progressed nourishment, flavor, texture, herbicide resistance, and decreased artificial fertilizer inputs. With current issues of water shortage and growing depletion of agriculture land, such technology doubtlessly improves productiveness in keeping with a unit of land or factory. Many countries, which include Bulgaria, are growing the abilities of those present-day agricultural biotechnologies through their Institute of Plant Physiology and Genetics to enhance crop resilience to environmental stress. Notable examples of present-day genetically changed vegetation include:

- Bt-cotton in India and China and Bt-Maize in Kenya1311
- Disease-tolerant as well as early maturing *Zea mays* cultivars that drove maize yield in Nigeria in the 1980s
- Nigerian cassava resistant to cassava mosaic virus that improved production in the 1990s
- New Rice for Africa (NERICA) rice genotypes that are hybrid mixtures of African and Asian rice species
- Banana *Xanthomonas* wilt
- Bt-Brinjal (*Solanum melongena*) in Bangladesh
- *Maruca vitrata* (developed by Nigerian scientists)
- African Orphan Crops Consortium that arranges African indigenous crop plants
- The NextGen Cassava Project uses genetic assortment to improve crop productivity (Buluswar et al. 2014; World Bank and FAO 2009).

6.8.4 Crop Yield Improvement Through Soil Management

For decades, artificial fertilizers had been used to improve agricultural production, however, their investment reliance on herbal fume (mainly with inside nitrogen), and big biological footprint of such sources lead them unsustainable. Excessive use of fertilizers and water can motive environmental harm and monetary waste to smallholder farmers. In addition, the Intergovernmental Soil Technology Group established soil as a nonrenewable resource by considering frequent soil mining (ITPS 2015). Many novel knowledges are assembling extra viable manure use possible. Novel techniques that keep away from using contemporary constant properties and energy-in depth techniques of nitrogen fixation and different fertilizer additives could make dietary supplements extra environmentally sustainable. A current observed that nitrogen-solving timber inside important water and temperature thresholds could boom yield through growing soil water-keeping capability and water permeability (Folberth et al. 2014; United Nations 2015a, b). For example, “N2Africa” is a large-scale, science-primarily-based development-to-studies mission committed to making use of nitrogen fixation generation to small-scale growers developing pulse vegetation in Africa (Giller et al. 2009).

6.8.5 Availability of Water for Food Production Through Irrigation Technologies

Light-weight drilling rigs for shallow groundwater and system for detecting groundwater can also additionally make it less complicated to achieve groundwater through irrigation. Solar irrigation pumps can also additionally grow the possibilities of irrigation. In this case, guide irrigation pumps that can be tough to apply are not enough, or pricey electric-powered pumps and gas charges are financially unaffordable (Buluswar et al. 2014). Inexpensive facilities for rainwater harvesting also are an ability generation to resolve irrigation problems (UNCTAD 2010). Where diesel or sun pumps cannot be used, hydraulic pumps (inclusive of the aQysta Barsha pump) could be adopted for watering with the availability of water streams. Greenhouses can alleviate water shortages as a result of inadequate precipitation allowing farmers to have a year-spherical developing season. For example, the modern greenhouse fuel line output (GRO) that the sector hopes will permit farmers to construct low-fee greenhouses in Sierra Leone and Mozambique in only days over a length of 5 years (UNCTAD 2011).

6.8.6 Increasing Regional and Global Stage Agricultural R&D Investments

Local and international agricultural research and development may have an actual effect on the productiveness and best of inputs. The ever-converting ecology, surroundings, and biodiversity surroundings call for nonstop studies and improvement to generate inputs and disseminate know-how to maximize agricultural manufacturing at the same time as protective of the surroundings. Government-funded R&D sports improved via way of means of 5.5% in line with years among 1995 and 2000, and improved via way of means of 15% in line with year after 2000, and are taken into consideration to be the important thing to negative farmers' adoption of superior technologies (UNCTAD 2015). Globally, FAO, IFAD (International Fund for Agricultural Development), and WFP (World Food Programme) estimate that casting off starvation via way of means of 2030 would require an extra US$267 billion in line with the year (United Nations 2015b; FAO 2015).

6.9 Challenges for Adaptation of Next-Generation Input Management Technologies

The yield of staple crops is reported to slow down, but in the next 33 years, more food is expected than in 10,000 years since the agricultural revolution started as it is influenced by population increase, dietary change, climate change, environmental degradation, etc. (Sustaining Food Availability 2020). Among these, climate change is a major constrain of transition for food security in the world, since it affects food development and its stability, as well as other facets of food systems, such as transportation, food distribution, and usage (Wheeler and Von Braun 2013). Furthermore, to adopt a holistic approach to the food production of welfare, the objectives of agricultural production, health, and nutrition security are summarized together (Fig. 6.4). Climate change's impacts intersect with other patterns of change from local to global fiscal, political, temporal, and biophysical aspects. These changes are distinguished by contradictions in the implementation of sequential and unilateral policies (Kriegler et al. 2012; Vervoort et al. 2014). Thus, the challenges to ensure sustainable food safety are structural, thereby decision-makers should take serious system-wide steps (Vermeulen et al. 2013).

In this context, an exceptional process reached its decision in 2015; with an agreement of eco-friendly sustainable development for the betterment of future manhood (i.e., 2030 Agenda for Sustainable Development). This agenda articulates a common and coordinated application action plan in all countries (both developed and emerging) through 17 sustainable development goals and 169 targets (UN 2015a). Thus, these need to combine all aspects of ecological growth across all to set viable development goals (Caron et al. 2018).

6.9.1 Major Challenges

The main challenges for the adaptation of next-generation input management technologies are discussed with complete details in Table 6.2.

Thus, the above provided the summary of above-mentioned major challenges for adaptation of next-generation input management technologies. All of them are directly and/or indirectly associated with each other. For example, poverty, food security, and nutrition narratives have become increasingly part of the food systems and are inherent in rural economic growth. Consequently, modernization of all upcoming farm activities could be predicted.

6.10 Conclusion

Under changing climate and rapidly expanding human population, crop yields need to be multiplied by intensive utilization of existing traditional farming. However, intensive farming systems utilizing imbalanced doses of synthetic fertilizers and pesticides have caused environmental pollution. Overexploitation of natural resources has posed serious threats to food security for future generations. Therefore,

Fig. 6.4 Schematic presentation of main factors of sustainable food generation (Modified from Pingali et al. 2019 with permission)

Table 6.2 Summary of key challenges aimed at adaptation of next-generation input management technologies

S. no	Main challenges	References
1.	*Increased food demand and sustainable agricultural production* To satisfy the expected dietary requirements according to global demand and the continuing change to wealthier foods, some estimates indicate that world food production needs to be doubled by 2050. It is now a critical challenge to fulfill global food requirements with the means of safe and nutritious for the rising population. The key priority of today's agriculture should, therefore, be to increase crop production by protecting the atmosphere and mitigating adverse consequences of climate change. Thus, sustainable intensification can be the preferred solution to global food security issues, increasing crop yields while reducing their environmental impact, thus ensuring future generations' ability to use the land. Because the use of improved cultivars, irrigation, the applications of chemical fertilizers and agrochemicals to increase yields, etc. are demarcated as traditional agricultural practices which are reported to be responsible for the overuse or abuse and degradation of the field and environmental contamination, as well as adverse effects on human, plant, animal, and aquatic ecosystems. therefore, the generation of nutritious and affordable food, restoration of soil fertility, and climate change mitigation are suggested as keys to sustainable food production	Davis et al. (2016), Kumari et al. (2018), Timsina (2018), Beltran-Peña et al. (2020)
2.	*Climate change and acceleration in natural hazard incidents* One of the challenges for the next adaptation of next-generation input management technologies is climate change and other aspects of environmental deterioration. Currently, humans are consuming 1.7 times more energy than the earth can regenerate and consume and creating more wastage. Thus, there is an exploitation of tomorrow's resources, knowingly or unknowingly. Furthermore, due to this imbalance, there was an increase recorded the incidences of natural hazards that are also affecting food production	Global Footprint Network 2017; Wheaton and Kulshreshtha (2017), Ritchie et al. (2018), Montt et al. (2018), del Pozo et al. (2019), Ruhullah et al. (2020)

(continued)

Table 6.2 (continued)

S. no	Main challenges	References
	For examples: (a) According to the study of Wheaton and Kulshreshtha (2017), a rising frequency of extreme climate, including drought, heat waves, and excess rainfall, are expected in the future (b) A study reported the impact of global dietary guidelines on the greenhouse gases emission and revealed that the existing recommendations at the national level are highly discordant with a target of 1.5 °C as well as also incompatible with a budget of 2 °C unless other sectors are completely decarbonization by 2050 (Ritchie et al. 2018) (c) The adaptation of agricultural products to environmental deviations in the five Mediterranean-climate regions of the world requires the synchronized strategies covering the various organizational levels, i.e., crops, cropping methods, and farming system (del Pozo et al., 2019) (d) In the study of Ruhullah et al. (2020), evidence showed that the Climate Change Assessment Initiatives in Bangladesh could be successful in partnership with the United Nations development programs	
3.	*Poverty and inequality* In international debates over the years, the double issues of environmental pollution and poverty have become a great deal of concern because of challenges pertaining to the viable growth in the world. A case study from Nigeria revealed that rural poverty and unstainable practices contributed to the instantaneous environmental effects and even adversely impacted resource management. Furthermore, according to sustainable development goal 1 (SDG 1), by 2030, extreme poverty should be eradicated from everywhere who are living less than 1.25$ per day	Imai (2017), Nwokoro and Chima (2017)
4.	*Hunger and all forms of malnutrition* Global hunger is persistent in over 800 million, while micronutrient deficiency is over 2 billion. The cause of malnutrition is physical and mental illnesses, a variety of infectious diseases, and premature deaths. Therefore, actions on multiple types of malnutrition are generally taken by	FAO (2019), Qaim (2020).

(continued)

Table 6.2 (continued)

S. no	Main challenges	References
	different laws, policies, initiatives, communities, governance, and funding sources, etc. the SDG two aims to stop all types of malnutrition as well as to end hunger along with doubling farm production and small-scale profits to ensure sustainable food production	
5.	*Making food systems more efficient*: According to scientific literature, there is evidence that food systems are important for sustainable development as they are linked to food protection, nutrition, and human health, ecosystem sustainability, climate change, and social justice. As per the observations of recent work, the new plant breeding technologies offer great possibilities to contribute toward stabilized crop production and dietary safety. Furthermore, the dietery systems comprise all the fundamentals and activities that are related to food production, distribution, food preparation, and use, consumer and institutional networks regulating these activities and their socioeconomic and environmental outcome	Caron et al. (2018), Ruben et al. (2018), Qaim (2020)
6.	*Improvement in earning opportunities:* Sustainable crop production sometimes could not provide enough economic benefits. This statement was found correct as per the finding of Zeweld et al. (2020), which stated that the livelihoods of farmers and rural households in mainly agricultural economies could be hard to boost without destroying natural resources. Moreover, climate change is reported as the key constrain that affecting the livelihood of farmers	Saina et al. (2013), Zeweld et al. (2020)
7.	*The requirement of logical and vigorous authority locally and globally*: The food protection and commerce law and regulation have grown with the maturation of food production processes and the extension of foreign trade. The legislation that was acting at national levels has traditionally been created and resulting in jurisdictional differences. Moreover, the global food trade has risen to over 520 billion dollars annually, thus adding new challenges to the regulation on global food safety for the coherence at local and worldwide	King et al. (2017)

next-generation input management in traditional farming is very crucial for sustaining future food and environmental security. This can be achieved by the integration of land, pest, disease, nutrient, and other resource management practices. Adoption of next-generation plant breeding approaches, judicious application of water and fertilizers in crop production systems, environment-friendly crop protection practices, eco-friendly soil and land management systems, and systematic integration of different disciplines hold great promise to avert nutritional food insecurity and environmental degradation.

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References

Abbas F, Hammad HM, Fahad S, Cerdà A, Rizwan M, Farhad W, Ehsan S, Bakhat HF (2017) Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios-a review. Environ Sci Pollut Res 24:11177–11191. https://doi.org/10.1007/s11356-017-8687-0

Adisa I, Pullagurala V, Peralta-videa J, Dimkpa C, Gardea-Torresdey J, White J (2019) Recent advances in nano-enabled fertilizers and pesticides: A critical review of mechanisms of action. Environ Sci Nano 5:6. https://doi.org/10.1039/C9EN00265K

Antle JM, Jones JW, Rosenzweig CE (2017) Next generation agricultural system data, models and knowledge products: introduction. Agril Syst 155:186–190

Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB, Cammarano D, Kimball BA, Ottman MJ, Wall GW, White JW, Reynolds MP (2014) Rising temperatures reduce global wheat production. Nat Clim Change 5(2):143–147

Awais M, Wajid A, Bashir MU, Habib-ur-Rahman M, Raza MA, Ahmad A, Saleem MF, Hammad HM, Mubeen M, Saeed U, Arshad MN (2017a) Nitrogen and plant population change radiation capture and utilization capacity of sunflower in semi-arid environment. Environ Sci Pollut Res 24:17511–17525. https://doi.org/10.1007/s11356-017-9308-7

Awais M, Wajid A, Nasim W, Ahmad A, Saleem MF, Raza MA, Bashir MU, Habib-ur-Rahman M, Saeed U, Hussain J, Arshad N (2017b) Modeling the water and nitrogen productivity of sunflower using OILCROP-SUN model in Pakistan. Field Crop Res 205:67–77. https://doi.org/10.1016/j.fcr.2017.01.013

Ayieko MW, Tschirley DL (2006) Enhancing access and utilization of quality seed for improved food security in Kenya (no. 680-2016-46721)

Babcock BA (2015) Breaking the link between food and biofuels. Lowa Agric Rev 14:3

Bai B, Bian HW, Zeng ZH, Hou N, Shi B, Wang JH, Zhu MY, Hanmi N (2017) R393-mediated auxin signaling regulation is involved in root elongation inhibition in response to toxic aluminum stress in barley. Plant Cell Physiol 58(3):426–439

Barabaschi D, Tondelli A, Desiderio F, Volante A, Vaccino P, Valè G, Cattivelli L (2016) Next generation breeding. Plant Sci 242:3–13

Barkunan SR, Bhanumathi V, Sethuram J (2019) Smart sensor for automatic drip irrigation system for paddy cultivation. Compu Elect Eng 73:180–193

Barrett CB (2010) Measuring food insecurity. Sci 327:825–828. https://doi.org/10.1126/science.1182768

Bautista-Capetillo C, Márquez-Villagrana H, Pacheco-Guerrero A, González-Trinidad J (2018) Cropping system diversification: water consumption against crop production. Sustain 10(7):2164. https://doi.org/10.3390/su10072164

Bayala J, Sanou J, Teklehaimanot Z, Ouédraogo SJ (2015) Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the west African Sahel: a review. Agric Ecosyst Environ 205:25–35. https://doi.org/10.1016/j.agee.2015.02.018

Beddington J (2009) Food, energy, water and the climate: a perfect storm of global events? Sustainable development UK annual conf., London, 19 March 2009. http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.Pdf. Accessed 20 Aug 2020

Beddington JR (2010) Global food and farming futures. Phil Trans Roy Soc B 365:20120272. https://doi.org/10.1098/rstb.2010.0181

Belder P, Rohrbach D, Twomlow S, Senzanje A (2007) Can Drip irrigation improve food security for vulnerable households in Zimbabwe? (Vol. 2). Briefing Note No.7, ICRISAT, Bulawayo, Zimbabwe

Beltran-Peña AA, Rosa L, D'Odorico P (2020) Global food self-sufficiency in the 21st century under sustainable intensification of agriculture. Environ Res Let 15:095004

Beuschel R, Piepho HP, Joergensen RG, Wachendorf C (2020) Effects of converting a temperate short-rotation coppice to a silvo-arable alley cropping agroforestry system on soil quality indicators. Agrofor Syst 94:389–400. https://doi.org/10.1007/s10457-019-00407-2

Biggs R, Bohensky E, Desanker PV, Fabricius C, Lynam T, Misselhorn AA, Musvoto C, Mutale M, Reyers B, Scholes RJ, Shikongo S, van Jaarsveld AA (2004) Nature supporting people: the southern African millennium ecosystem assessment. Council for Scientific and Industrial Research.Pretoria, Pretoria

Bilali HE, Callenius C, Strassner C, Probst L (2018) Food and nutrition security and sustainability transitions in food systems. Food Energy Secur 8:e00154. https://doi.org/10.1002/fes3.154

Böhm C, Kanzler M, Freese D (2014) Wind speed reductions as influenced by woody hedgerows grown for biomass in short rotation alley cropping systems in Germany. Agrofor Syst 88:579–591. https://doi.org/10.1007/s10457-014-9700-y

Bond I, Grieg-Gran M, Wertz-Kanounnikoff S, Hazlewood P, Wunder S, Angelsen A (2009) Incentives to sustain forest ecosystem services: a review and lessons for REDD. IIEED, London

Branca G, McCarthy N, Lipper L, Jolejole MC (2011) Climate-smart agriculture: a synthesis of empirical evidence of food security and mitigation benefits from improved cropland management. Mitig Clim Change Agric Ser 3:1–42

Brevik EC, Slaughter L, Singh BR, Steffan JJ (2020) Soil and human health: current status and future needs. Air Soil Water Res 13:117862212093444. https://doi.org/10.1177/1178622120934441

Buluswar S, Friedman Z, Mehta P, Mitra S, Sathre R (2014) Critical scientific and technological advances needed for sustainable global development. Food Security and Agricultural Development Report. Institute for Globally Transformative Technologies, Lawrence Berkeley National Lab, Berkeley, CA. https://ligtt.org/sites/all/files/page/50BTsFoodSecurityAndAgriculturalDevelopment_0.pdf. Accessed 7 Mar 2021

Burgess PJ, Rosati A (2018) Advances in European agroforestry: results from the AGFORWARD project. AgroforSyst 92:801–810. https://doi.org/10.1007/s10457-018-0261-3

Burton NO, Riccio C, Dallaire A et al (2020) Cysteine synthases CYSL-1 and CYSL-2 mediate *C. elegans* heritable adaptation to *P. vranovensis* infection. Nat Commun 11:1741. https://doi.org/10.1038/s41467-020-15555-8

Carmichael GR, Tang Y, Kurata G, UnoI, Streets DG, Thongboonchoo N et al (2003) Evaluating regional emission estimates using the TRACE-P observations. J Geophys Res. https://doi.org/10.1029/2002JD003116

Caron P, de Loma-Osorio GF, Nabarro D, Hainzelin E, Guillou M, Andersen I, Bwalya M (2018) Food systems for sustainable development: proposals for a profound four-part transformation. Agron Sustain Dev 38(4):41

Cassman KG, Grassini P (2020) A global perspective on sustainable intensification research. Nat Sustain 3:262–268. https://doi.org/10.1038/s41893-020-0507-8

Catenacci M, Giupponi C (2013) Integrated assessment of sea-level rise adaptation strategies using a Bayesian decision network approach. Environ Model Softw 44:87–100

Chikara SK, Pandey M, Pandey S, Vaidya K, Chaudhary S (2014) Next generation sequencing: a revolutionary tool for plant variety improvement. Am J Social Issues Human 5:37–154

CIESIN (Centre for International Earth Science Information Network) (1995) Thematic guide to integrated assessment modeling of climate change (online), University Centre, Mich, 1995. http://sedac.ciesin.org/mva/iamcc.tg/TGHP.html

Clark M, Tilman D (2017) Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environ Res Let 12(6):064016

Crous-Duran J, Graves AR, Garcia-De-Jalón S et al (2019) Assessing food sustainable intensification potential of agroforestry using a carbon balance method. iForest 12:85–91. https://doi.org/10.3832/ifor2578-011

Dagar JC, Tewari VP (2018) Agroforestry: anecdotal to modern science. Agrofor Anecdotal Mod Sci 5:1–879. https://doi.org/10.1007/978-981-10-7650-3

Das S, Ali MM, Rahman MH, Khan MR, Hossain A, EL Sabagh A, Barutcular C, Akdeniz H (2018) Soil test based with additional nutrients increased the fertility and productivity of wheat-mungbean-T. Aman rice cropping pattern in the high Ganges river floodplain soils of Bangladesh. Bulgarian J AgricSci 24(6):992–1003

Davis KF, Gephart JA, Emery KA, Leach AM, Galloway JN, D'Odorico P (2016) Meeting future food demand with current agricultural resources. Glob Environ Change 39:125–132

de Vries P, Frits WT, Acquay H, David M, Scherr SJ, Christian V, Olufunke C (2003) Integrated land and water management for food and environmental security. International Water Management Institute (IWMI), Colombo. https://doi.org/10.3910/2009.392

Debaeke P, Casadebaig P, Flenet F, Langlade N (2017) Sunflower and climate change in Europe: crop vulnerability, adaptation, and mitigation potential. Oilseeds Fats Crops Lipids 24:D102. https://doi.org/10.1051/ocl/2016052

delPozo A, Brunel-Saldias N, Engler A, Ortega-Farias S, Acevedo-Opazo C, Lobos GA, Molina-Montenegro MA (2019) Climate change impacts and adaptation strategies of agriculture in Mediterranean-climate regions (MCRs). Sustain 11(10):2769

DeRosa MR, Monreal C, Schnitzer M, Walsh R, Sultan Y (2010) Nanotechnology in fertilizers. Nat Nanotechnol J 5:91–97

Dokoohaki H, Gheysari M, Mousavi SF, Zand-Parsa S, Miguez FE, Archontoulis SV, Hoogenboom G (2016) Coupling and testing a new soil water module in DSSAT CERES-maize model for maize production under semi-arid condition. Agric Water Manag 163:90–99. https://doi.org/10.1016/j.agwat.2015.09.002

Duhan JS, Kumar R, Kumar N, Kaur P, Nehra K, Duhan S (2017) Nanotechnology: the new perspective in precision agriculture. Biotech Rep 15:11–23

Durán-Lara EF, Valderrama A, Marican A (2020) Natural organic compounds for application in organic farming. Agric (Switzerland) 10(2):1–22

Ejeta G (2009) Revitalizing agricultural research for global food security. Food Security 1(4):391–401

EL Sabagh A, Islam MS, Skalicky M, Raza MA, Singh K, Anwar Hossain M, Hossain A, Mahboob W, Iqbal MA, Ratnasekera DP, Singhal R (2021) Adaptation and management strategies of wheat (*Triticum aestivum* L.) against salinity stress to increase yield and quality. Front Agron 3:43

Elahi A, Ajaz M, Rehman A, Vuilleumier S, Khan Z, Syed Zajif Hussain SZ (2019) Isolation, characterization, and multiple heavy metal-resistant and hexavalent chromium-reducing Microbacterium testaceum B-HS2 from tannery effluent. J King Saud Univ Sci 31(4):1437–1444. https://doi.org/10.1016/j.jksus.2019.02.007

Ericksen PJ (2008) Conceptualizing food systems for global environmental change research. Glob Environ Change 18(1):234–245. https://doi.org/10.1016/j.gloenvcha.2007.09.002

Erler JT, Bennewith KL, Nicolau M et al (2020) Retraction note: lysyl oxidase is essential for hypoxia-induced metastasis. Nature 579:456. https://doi.org/10.1038/s41586-020-2112-4

Evans A (2009) The feeding of the nine billion: global food security. Chatham House, London

Faisal M, Iqbal MA, Aydemir SK, Hamid A, Rahim N, El Sabagh A, Khaliq A, Siddiqui MH (2020) Exogenously foliage applied micronutrients efficacious impact on achene yield of sunflower under temperate conditions. Pakistan J Bot 52(4):1215–1221

Falk E, Schlieper D, van Caster P, Lutterbeck MJ, Schwartz J, Cordes J, Grau I, Peter Kienbaum P, Neukirchen M (2020) A rapid positive influence of S-ketamine on the anxiety of patients in palliative care: a retrospective pilot study. BMC Palliat Care 19:1. https://doi.org/10.1186/s12904-019-0499-1

Fang EF, Hou Y, Palikaras K, Adriaanse BA, Kerr JS, Yang B, Lautrup S, Hasan-Olive MM, Caponio D, Dan X, Rocktäschel P (2019) Mitophagy inhibits amyloid- and tau pathology and reverses cognitive deficits in models of Alzheimer's disease. Nat Neurosci 22:401–412. https://doi.org/10.1038/s41593-018-0332-9

FAO (Food and Agriculture Organization) (1996) Rome declaration on world food security and world food summit plan of action. World Food Summit 13-17 November 1996, FAO, Rome

FAO (Food and Agriculture Organization) (2006) World agriculture: towards 2030/2050 interim report. FAO, Rome

FAO (Food and Agriculture Organization) (2010) Climate-smart agriculture. Policies, practices and finances for food security, adaptation and mitigation. FAO, Rome

FAO (Food and Agriculture Organization) (2011) Save and grow: a policy makers guide to the sustainable intensification of crop production. Food and Agriculture Organization, Rome, p 116

FAO (Food and Agriculture Organization) (2011a) Save and grow: a policymaker's guide to the sustainable intensification of smallholder crop production. FAO, Rome

FAO (Food and Agriculture Organization) (2011b) Global food losses and food waste - extent, causes and prevention. FAO, Rome

FAO (Food and Agriculture Organization) (2013) Climate-smart agriculture sourcebook, 1st edn. FAO, Italy

FAO (Food and Agriculture Organization) (2015) Mapping the vulnerability of mountain peoples to food insecurity. FAO, Rome

FAO (Food and Agriculture Organization) (2016a) The state of food and agriculture climate change, agriculture and food security. FAO, Rome

FAO (Food and Agriculture Organization) (2016b) The state of food and agriculture, climate change. Agriculture and Food Security. Food and Agriculture Organization of the United Nations, Rome

FAO (Food and Agriculture Organization) (2017) The future of food and agriculture-trends and challenges. FAO, Rome

FAO (Food and Agriculture Organization) (2019) The state of food security and nutrition in the world. FAO, Rome

Ferrarezi RS, Nogueira TAR, Zepeda SGC (2020) Performance of soil moisture sensors in Florida sandy soils. Water 12:358. https://doi.org/10.3390/w12020358

Fisher B, Turner RK, Morling P (2009) Defining and classifying ecosystem services for decision making. Ecol Econ 68:643–653

Folberth C, Yang H, Gaiser T, Liu J, Wang X, Williams J, Schulin R (2014) Effects of ecological and conventional agricultural intensification practices on maize yields in sub-Saharan Africa under potential climate change. Environ Res Let 9:044004

Foresight (2011) The future of food and farming: executive summary. Government Office for Science, London

Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer P, Burlingame B, Dawkins M, Dolan L (2013) Sustainable intensification in agriculture: premises and policies. Science 341:33–34

Gebbers R, Adamchuk VI (2010) Precision agriculture and food security. Science 327(5967):828–831

Giller KE, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crops Res 114(1):23–34

Global Footprint Network (2017) National footprint accounts: 2017 edition. Oakland, Global Footprint Network

Godfray HCJ, Garnett T (2014) Food security and sustainable intensification. Phil Trans Roy Soc B 369:20120273. https://doi.org/10.1098/rstb.2012.0273

Harfouche AL, Jacobson DA, Kainer D, Romero JC, Harfouche AH, Mugnozza GS, Moshelion M, Tuskan GA, Keurentjes JJB, Altman A (2019) Accelerating climate-resilient plant breeding by applying next-generation artificial intelligence. Trends Biotechnol 37(11):1217–1235

Hatfield JL, Dold C (2019) Water-use efficiency: advances and challenges in a changing climate. Front Plant Sci 10:23. https://doi.org/10.3389/fpls.2019.00103

Holzworth D, Huth NI, Fainges J, Brown H, Zurcher E, Cichota R, Verrall S, Herrmann NI, Zheng B, Snow V (2018) APSIM next generation: overcoming challenges in modernising a farming systems model. Environ Model Softw 103:43–51

Holzworth D, Huth NI, Fainges J, Herrmann NI, Zurcher E, Brown H, Snow V, Verrall S, Cichota R, Doherty A, De Voil P (2015) APSIM next generation: the final frontier? In: Proceedings - 21st international congress on modelling and simulation, MODSIM 2015 2020 Jan 1, pp. 347–353. Modelling and Simulation Society of Australia and New Zealand Inc. (MSSANZ)

Hoorman JJ (2009) Using cover crops to improve soil and water quality. The Ohio State University, Agriculture and Natural Resources

Hossain A, Sabagh AEL, Barutcular C, Bhatt R, Çig F, Seydoşoğlu S, Turan N, Konuskan O, Iqbal MA, Abdelhamid M, Soler CMT, Laing AM, Saneoka H (2020) Sustainable crop production to ensuring food security under climate change: a Mediterranean perspective. Aust J Crop Sci 14(03):439–446

Imai KS (2017) Roles of agricultural transformation in achieving sustainable development goals on poverty, hunger, productivity, and inequality (no. DP2017-26). Research Institute for Economics and Business Administration, , Kobe University, Nada, pp 1–60

Indu, Lal D, Dadrwal BK, Saha D, Chand S, Chauhan J, Dey P, Kumar V, Mishra UN, Hidangmayum A, Singh A, Singhal RK (2021) Molecular advances in plant root system architecture response and redesigning for improved performance under unfavourable environments. Academic Press, London

Iqbal MA (2018) Comparative performance of forage cluster bean accessions as companion crops with sorghum under varied harvesting times. Bragantia 77(3):476–484

Iqbal MA (2019) Nano-fertilizers for sustainable crop production under changing climate: a global perspective. In: Crop production. IntechOpen, London, pp 1–12

Iqbal MA (2020) Ensuring food security amid novel coronavirus (COVID-19) pandemic: global food supplies and Pakistan's perspectives. Acta Agric Slov 115(2):1–4

Iqbal MA, Hamid A, Ahmad T, Hussain I, Ali S, Ali A, Ahmad Z (2019) Forage sorghum-legumes intercropping: effect on growth, yields, nutritional quality and economic returns. Bragantia 78(1):82–95

Iqbal MA, Iqbal A (2015) A study on dwindling agricultural water availability in irrigated plains of Pakistan and drip irrigation as a future life line. Am-Eur J Agric Environ Sci 15(2):184–190

Iqbal MA, Iqbal A, Afzal S, Akbar N, Abbas RN, Khan HZ (2015a) In Pakistan, agricultural mechanization status and future prospects. Am-Eur J Agric Environ Sci 15(1):122–128

Iqbal MA, Iqbal A, Akbar N, Khan HZ, Abbas RN (2015c) A study on feed stuffs role in enhancing the productivity of milch animals in Pakistan-existing scenario and future prospect. Global Veterinaria 14(1):23–33

Iqbal MA, Maqsood Q, Ahmad Z, Saleem AM, Afzal S, Ahmad B (2015b) A preliminary study on plant nutrients production as combined fertilizers, consumption patterns and future prospects for Pakistan. Am-Eurasian J Agric Environ Sci 15(4):588–594

Islam MS, Hossain A, Timsina J, Saif H, Sarker MMR, Khan ASMMR, Hasan MK, Zahan T, EL Sabagh A, Akdeniz H, Barutçular C (2020) Feasibility and financial viability study of an intensive mustard –Mungbean–transplanted Aus Rice–transplanted Aman Rice cropping system in a non-saline coastal ecosystem of Bangladesh. Philipp Agric Scientist 103(1):73–83

Islam MS, Kieu E (2020) Tackling regional climate change impacts and food security issues: a critical analysis across ASEAN, PIE, and SAARC. Sustainability 12:883. https://doi.org/10.3390/su12072840

ITPS (2015) Status of the World's soil resources (SWSR). FAO intergovernmental technical panel on soils. ITPS, Rome

Jat ML, Chakraborty D, Ladha JK, Rana DS, Gathala MK, McDonald A, Gerard B (2020) Conservation agriculture for sustainable intensification in South Asia. Nat Sustain 3:336–343. https://doi.org/10.1038/s41893-020-0500-2

Jatav HS, Singh SK, Jatav SS, Rajput VD, Parihar M, Mahawer SK, Singhal RK (2020) Importance of biochar in agriculture and its consequence. In: Applications of biochar for environmental safety. IntechOpen, London, p 109

Jones JW, Antle JM, Basso B, Boote KJ, Conant RT, Foster I, Godfray HC, Herrero M, Howitt RE, Janssen S, Keating BA (2017) Brief history of agricultural systems modeling. Agric Syst 155: 240–254. https://doi.org/10.1016/j.agsy.2016.05.014

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. AgroforSyst 76:1–10. https://doi.org/10.1007/s10457-009-9229-7

Jose S (2012) Agroforestry for conserving and enhancing biodiversity. AgroforSyst 85:1–8. https://doi.org/10.1007/s10457-012-9517-5

Kanianska R (2016) Agriculture and its impact on land use. In: Environment, and ecosystem services, landscape ecology-the influences of land use and anthropogenic impacts of landscape creation. IntechOpen, London. https://doi.org/10.5772/63719

Kay S, Rega C, Moreno G, den Herder M, Palma JH, Borek R, Crous-Duran J, Freese D, Giannitsopoulos M, Graves A, Jäger M (2019) Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. Land Use Policy 83:581–593. https://doi.org/10.1016/j.landusepol.2019.02.025

Kayad A, Sozzi M, Gatto S, Marinello F, Pirotti F (2019) Monitoring within-field variability of corn yield using sentinel-2 and machine learning techniques. Remote Sens 2019:11. https://doi.org/10.3390/rs11232873

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JN, Meinke H, Hochman Z, McLean G (2003) An overview of APSIM, a model designed for farming systems simulation. European J Agron 18:267–288

Kehoe L, Romero-Muñoz A, Polaina E, Estes L, Kreft H, Kuemmerle T (2017) Biodiversity at risk under future cropland expansion and intensification. Nat EcolEvol 1:1129–1135. https://doi.org/10.1038/s41559-017-0234-3

Khaliq A, Iqbal M, Zafar M, Gulzar A (2019) Appraising economic dimension of maize production under coherent fertilization in Azad Kashmir, Pakistan. Custos e Agronegocio 15(2):243–253

King T, Cole M, Farber JM, Eisenbrand G, Zabaras D, Fox EM, Hill JP (2017) Food safety for food security: relationship between global megatrends and developments in food safety. Trends Food SciTechnol 68:160–175

Klein S, Cortese M, Winter SL, Wachsmuth-Melm M, Neufeldt CJ, Cerikan B, Stanifer ML, Boulant S, Bartenschlager R, Chlanda P (2020) SARS-CoV-2 structure and replication characterized by *in situ* cryo-electron tomography. https://doi.org/10.1101/2020.06.23.167064

Kopittke PM, Dalal RC, Hoeschen C, Li C, Menzies NW, Mueller CW (2020) Soil organic matter is stabilized by organo-mineral associations through two key processes: the role of the carbon to nitrogen ratio. Geoderma 357:113974. https://doi.org/10.1016/j.geoderma.2019.113974

Kopittke PM, Menzies NW, Wang P, McKenna BA, Lombi E (2019) Soil and the intensification of agriculture for global food security. Environ Int 132:105078. https://doi.org/10.1016/j.envint.2019.105078

Kriegler E, O'Neill BC, Hallegatte S, Kram T, Lempert RJ, Moss RH, Wilbanks T (2012) The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. Glob Environ Change 22(4):807–822

Krueger T, Page T, Hubacek K, Smith L, Hiscock K (2012) The role of expert opinion in environmental modelling. Environ Model Softw 36:4–18. https://doi.org/10.1016/j.envsoft.2012.01.011

Kumar S, Meena RS (2020) Impact of various sowing environment and nutrient sources on growth performance of Indian mustard (*Brassica juncea*). Indian J Agrono 65(4):465–470

Kumar S, Meena RS, Bohra JS (2018b) Interactive effect of sowing dates and nutrient sources on dry matter accumulation of Indian mustard (*Brassica juncea* L.). J Oilseed Brass 9(1):72–76

Kumar S, Meena RS, Lal R, Yadav GS, Mitran T, Meena BL, Dotaniya ML, ELSabagh A (2018a) Role of legumes in soil carbon sequestration. In: Meena R, Das A, Yadav G, Lal R (eds) Legumes for soil health and sustainable management. Springer, Singapore

Kumar S, Meena RS, Singh RK, Munir TM, Datta R, Danish S, Singh GS, Yadav KS (2021) Soil microbial and nutrient dynamics under different sowings environment of Indian mustard (*Brassica juncea* L.) in rice based cropping system. Sci Rep 11:5289. https://doi.org/10.1038/s41598-021-84742-4

Kumari A, Kaur R, Kaur R (2018) An insight into drought stress and signal transduction of abscisic acid. Plant Sci Today 5(2):72–80

Kumari A, Sharma B, Singh BN, Hidangmayum A, Jatav HS, Chandra K, Singhal RK, Sathyanarayana E, Patra A, Mohapatra KK (2021) Physiological mechanisms and adaptation strategies of plants under nutrient deficiency and toxicity conditions. In: Plant perspectives to global climate changes. Academic Press, London

Lal R (2001) Managing world soils for food security and environmental quality. AdvAgron 74: 155–192. https://doi.org/10.1016/S0065-2113(01)74033-3

Lal R (2013) Food security in a changing climate. Ecohydrol Hydrobiol 13(1):8–21

Lampayan RM, Rejesus RM, Singleton GR, Bouman BAM (2015) Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. Field Crops Res 170: 95–108

Lott JE, Ong CK, Black CR (2009) Understorey microclimate and crop performance in a Grevillea robusta-based agroforestry system in semi-arid Kenya. Agric For Meteorol 149:1140–1151. https://doi.org/10.1016/j.agrformet.2009.02.002

Luedeling E, Kindt R, Huth NI, Koenig K (2014) Agroforestry systems in a changing climate-challenges in projecting future performance. CurrOpin Environ Sustain 6:1–7. https://doi.org/10.1016/j.cosust.2013.07.013

MEA (Millennium Ecosystem Assessment) (2005) Ecosystems and human Well-being: synthesis. Island Press, Washington

Meena RS, Lal R, Yadav GS (2020) Long-term impact of topsoil depth and amendments on carbon and nitrogen budgets in the surface layer of an Alfisol in Central Ohio. Catena 194:104752. https://doi.org/10.1016/j.catena.2020.104752

Mikkelsen R (2018) Nanofertilizer and nanotechnology: a quick look better crops. Better Crops with Plant Food 102:3. https://doi.org/10.24047/BC102318

Misselhorn A, Aggarwal P, Ericksen P, Gregory P, Horn-Phathanothai L, Ingram J, Wiebe K (2012) A vision for attaining food security. Curr Opin Environ Sustain 4(1):7–17

Mohammed U, Caine RS, Atkinson JA, Harrison EL, Wells D, Chater CC, Gray JE, Swarup R, Murchie EH (2019) Rice plants overexpressing OsEPF1 show reduced stomatal density and increased root cortical aerenchyma formation. Sci Rep 9(1):5584. https://doi.org/10.1038/s41598-019-41922-7

Montt G, Fraga F, Harsdorff M (2018) The future of work in a changing natural environment: climate change, degradation and sustainability. International Labour Office, Geneva

Morris MR, Richard R, Leder EH, Barrett RD, Aubin Horth N, Rogers SM (2014) Gene expression plasticity evolves in response to colonization of freshwater lakes in threespine stickleback. Mol Ecol 23(13):3226–3240

Moulick RG, Das S, Debnath N, Bandyopadhyay K (2020) Potential use of nanotechnology in sustainable and ‘smart’agriculture: advancements made in the last decade. Plant Biotech Rep 26: 1–9

Müller RD, Zahirovic S, Williams SE, Cannon J, Seton M, Bower DJ, Tetley MG, Heine C, Le Breton E, Liu S, Russell SH (2019) A global plate model including lithospheric deformation along major rifts and orogens since the Triassic. Tectonics 2019:38. https://doi.org/10.1029/2018TC005462

Mulley C, Ho C, Balbontin C, Hensher DA (2020) Mobility as a service in community transport in Australia: can it provide a sustainable future? Transp Res 131:107–122. https://doi.org/10.1016/j.tra.2019.04.001

Nabavi-Pelesaraei A, Abdi R, Rafiee S, Shamshirband S, Yousefinejad-Ostadkelayeh M (2016) Resource management in cropping systems using artificial intelligence techniques: a case study of orange orchards in north of Iran. Stoch Env Res Risk A 1:413–427

NEA (Nuclear Energy Agency) (2011) Annual report for 2010–2011. National Academies Press, Washington, D.C

Nguyen TT, Carpanen D, Rankin IA, Ramasamy A, Breeze J, Proud WG, Clasper JC, Masouros SD (2020) Mapping the risk of fracture of the tibia from penetrating fragments. Front Bioeng Biotechnol 8:544214. https://doi.org/10.3389/fbioe.2020.544214

Nikolaou G, Neocleous D, Christophi C, Heracleous T (2020) Irrigation groundwater quality characteristics: a case study of Cyprus. Atmos 11(3):15. https://doi.org/10.3390/atmos11030302

Nwokoro CV, Chima FO (2017) Impact of environmental degradation on agricultural production and poverty in rural Nigeria. AmeInt J Contemp Res 2(7):6–14

Nyagumbo I, Mkuhlani S, Mupangwa W, Rodriguez D (2017) Planting date and yield benefits from conservation agriculture practices across southern Africa. Agric Sys 150:21–33

Ostero M, Joanna B, Christopher BF, Richard BN, David P (1999) Revisiting the commons: local lessons, global challenges. Science 284:278–282. https://doi.org/10.1126/science.284.5412.278

Pachapur PK, Pachapur VL, Brar SK, Galvez R, Le Bihan Y, Surampalli RY (2020) Food security and sustainability. In: Sustainability: fundamentals and applications. Wiley, Hoboken, pp 357–374

Paek J, Hicks J, Coe S, Govindan R (2014) Image-based environmental monitoring sensor application using an embedded wireless sensor network. Sensors (Basel) 14:15981–16002

Palma M, Goffeau A, Spencer-Martins I, Baret PV (2007) A phylogenetic analysis of the sugar porters in hemiascomycetous yeasts. J Mol Microbiol Biotechnol 12(3–4):241–248

Panchard J, Prabhakar TV, Hubaux JP (2014) Common sense net: a wireless sensor network for resource-poor agriculture in the semi-arid areas of developing countries. Inf Technol Int Dev 4:51–67

Panpatte DG, Jhala YK, Shelat HN, Vyas RV (2016) Nanoparticles: the next generation technology for sustainable agriculture. In: Microbial inoculants in sustainable agricultural productivity. Springer, New Delhi, pp 289–300

Parry MA, Hawkesford MJ (2010) Food security: increasing yield and improving resource use efficiency. Proceed Nutr Soc 69(4):592–600

Pathak H, Sankhyan S, Dubey DS, Bhatia A, Jain N (2013) Dry direct-seeding of rice for mitigating greenhouse gas emission: field experimentation and simulation. Paddy Water Environ 11:593–601

Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smith P (2016) Climate-smart soils. Nat 532(7597):49–57

Pingali P, Aiyar A, Abraham M, Rahman A (2019) Indian food systems towards 2050: challenges and opportunities. In: Transforming food systems for a rising India. Palgrave Macmillan, Cham, pp 1–14

Poppy GM, Jepson PC, Pickett JA, Birkett MA (2014) Achieving food and environmental security: new approaches to close the gap. Phil Trans Roy Soc B 369:20120272. https://doi.org/10.1098/rstb.2012.0272

Porras I, Barton DN, Miranda M, Chacón-Cascante A (2013) Learning from 20 years of payments for ecosystem services in Costa Rica. IIED, Washington

Posadas B (2012) Economic impacts of mechanization or automation on horticulture production firms sales, employment, and workers' earnings, safety, and retention. Hort Technol 22(3):388–401

Powlson DS, Gregory PJ, Whalley WR, Quinton JN, Hopkins DW, Whitmore AP, Hirsch PR, Goulding KW (2011) Soil management in relation to sustainable agriculture and ecosystem services. Food Policy 36(1):572–587. https://doi.org/10.1016/j.foodpol.2010.11.025

Prusky D (2011) Reduction of the incidence of postharvest quality losses, and future prospects. Food Security 3(4):463–474

Qaim M (2020) Role of new plant breeding Technologies for Food Security and Sustainable Agricultural Development. Appl Econ Perspec Poli 42(2):129–150

Rahman MHU, Ahmad A, Wajid A, Hussain M, Rasul F, Ishaque W, Islam MA, Shelia V, Awais M, Ullah A, Wahid A (2019) Application of CSM-CROPGRO-cotton model for cultivars and optimum planting dates: evaluation in changing semi-arid climate. Field Crop Res 238:139–152. https://doi.org/10.1016/j.fcr.2017.07.007

Rahman MHU, Ahmad A, Wang X, Wajid A, Nasim W, Hussain M, Ahmad B, Ahmad I, Ali Z, Ishaque W, Awais M (2018) Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agric For Meteorol 253-254: 94–113. https://doi.org/10.1016/j.agrformet.2018.02.008

Rai V, Acharya S, Dey N (2012) Implications of nanobiosensors in agriculture. J Biomater Nanobiotech 3:315–324

Ranganathan J, Vennard D, Waite R, Dumas P, Lipinski B, Searchinger T (2016) Shifting diets for a sustainable food future. Working paper, installment 11 of creating a sustainable food future. World Resources Institute, Washington, DC

Ranganathan J, Waite R, Searchinger T, Hanson C (2018) How to sustainably feed 10 billion people by 2050, in 21 charts? https://www.wri.org/blog/2018/12/how-sustainably-feed 10-billion-people-2050-21-charts

Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y, Xu J (2019) Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. Plan Theory 8(2):34. https://doi.org/10.3390/plants8020034

Reddy SH, Kambalimath SK, Singhal RK, Chikkakariyappa MK, Muthurajan R, Rajanna MP, Sreevathsa R, Sevanthi AM, Mohapatra T, Sarla N, Chinnusamy V (2019) Allele-specific analysis of single parent backcross population identifies HOX10 transcription factor as a candidate gene regulating rice root growth. Physiol Planta 166(2):596–611

Reddy SH, Singhal RK, DaCosta MV, Kambalimath SK, Rajanna MP, Muthurajan R, Sevanthi AM, Mohapatra T, Sarla N, Chinnusamy V, Singh AK (2020) Leaf mass area determines water use efficiency through its influence on carbon gain in rice mutants. Physiol Planta 169(2):194–213

Rinderknecht SL, Borsuk ME, Reichert P (2012) Bridging uncertain and ambiguous knowledge with imprecise probabilities. Environ Model Softw 36:122–130

Ritchie H (2020) Environmental impacts of food production. https://ourworldindata.org/environmental-impacts-of-food. Accessed 26 Aug 2020

Ritchie H, Reay DS, Higgins P (2018) The impact of global dietary guidelines on climate change. Glob Environ Change 49:46–55

Rouphael Y, Colla G (2018) Synergistic biostimulatory action: designing the next generation of plant biostimulants for sustainable agriculture. Front Plant Sci 9:1655

Royal Society (2009) Reaping the benefits: science and the sustainable intensification of global agriculture. Royal Soc, London

Ruben R, Verhagen J, Plaisier C (2018) The challenge of food systems research: what difference does it make? Towards Sustain Glob Food Syst 17:171. https://doi.org/10.3390/su11010171

Ruhullah ME, Purnomo EP, Malawani AD (2020) Sustainable development affecting by the climate change: a secondary study of cyclones (natural disasters: Sidr, Aila and Roanu in Bangladesh). Sumatra J Disas Geogr Edu 4(1):22–28

Sahin O, Siems RS, Stewart RA, Porter MG (2014) Paradigm shift to enhanced water supply planning through augmented grids, scarcity pricing and adaptive factory water: a system dynamics approach. Environ Model Softw 1:14. https://doi.org/10.1016/j.envsoft.2014.05.018

Saina CK, Murgor DK, Murgor FA (2013) Climate change and food security. Environ Change Sust 5:235–257

Saiz-Rubio V, Rovira-Más F (2020) From smart farming towards agriculture 5.0: a review on crop data. Manage Agron 10(2):207. https://doi.org/10.3390/agronomy10020207

Sánchez JM, Rodríguez JP, Espitia HE (2020) Review of artificial intelligence applied in decision-making processes in agricultural public policy. PRO 8(11):1374

Scholten L, Scheidegger A, Reichert P, Maurer M (2013) Combining expert knowledge and local data for improved service life modeling of water supply networks. Environ Model Softw 42:1–16

Scialabba N, Hattam C (2002) Organic agriculture, environment and food security. FAO, Rome, p 258

Seifan M, Samani AK, Berenjian A (2016) Bioconcrete: next generation of self-healing concrete. Appl Microbiol Biotechnol 100(6):2591–2602

Shamshiri RR, Weltzien C, Hameed IA, Yule I, Grift T, Balasundram SK, Pitonakova L, Ahmad D, Chowdhary G (2018) Research and development in agricultural robotics: a perspective of digital farming. Int J Agril Biol Eng 11(4):1–14

Shang Y, Hasan M, Ahammed GJ, Li M, Yin H, Zhou J (2019) Applications of nanotechnology in plant growth and crop protection: a review. Molecules 24(14):2558

Sharma T, Carmichael J, Klinkenberg B (2006) Integrated modeling for exploring sustainable agriculture futures. Futures 38(1):93–113

Shebl A, Hassan AA, Salama DM, Abd El-Aziz ME, AbdElwahed MSA (2019) Green synthesis of Nanofertilizers and their application as a foliar for *Cucurbita pepo* Ll. J Nanomater 2019: 3476347. https://doi.org/10.1155/2019/3476347

Siad SM, Iacobellis V, Zdruli P, Gioia A, Stavi I, Hoogenboom G (2019) A review of coupled hydrologic and crop growth models. Agric Water Manage 224:105746. https://doi.org/10.1016/j.agwat.2019.105746

Siddiqui MH, Iqbal MA, Naeem W, Hussain I, Khaliq A (2019) Bio-economic viability of rainfed wheat (*Triticum aestivum* L.) cultivars under integrated fertilization regimes in Pakistan. Custos e Agronegocio 15(3):81–96

Singhal RK, Saha D, Skalicky M, Mishra UN, Chauhan J, Behera LP, Lenka D, Chand S, Kumar V, Dey P, Indu I (2021) Crucial cell signaling compounds cross-talk and integrative multi-omics techniques for salinity stress tolerance in plants. Front Plant Sci 12:1227

Sistla SA, Roddy AB, Williams NE, Kramer DB, Stevens K, Allison SD (2016) Agroforestry practices promote biodiversity and natural resource diversity in Atlantic Nicaragua. PLoS One 11:1–20. https://doi.org/10.1371/journal.pone.0162529

Smartt AD, Brye KR, Norman RJ (2016) Methane emissions from rice production in the United States - a review of controlling factors and summary of research. In: Greenhouse gases. IntechOpen, London. https://doi.org/10.5772/62025

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B (2007) Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agric, Ecosys Environ 118(1–4):6–28

Sobhy IS, Erb M, Lou Y, Turlings TCJ (2014) The prospect of applying chemical elicitors and plant strengtheners to enhance the biological control of crop pests. Phil Trans Roy Soc B 369: 20120283. https://doi.org/10.1098/rstb.2012.0283

Spielman DJ, Kennedy A (2016) Towards better metrics and policymaking for seed system development: insights from Asia's seed industry. AgrilSyst 147:111–122

Stevanato N, BalderramaSubieta S, Quoilin S, Colombo E (2019) Two-stage stochastic sizeing of a rural micro-grid based on stochastic load generation. Proceedings of the 13th IEEE PES power tech conference 2019

Sustaining Food Availability (2020). https://www.cgiar.org/research/research-theme/food-security/. Accessed Sept 2020

Talaviya T, Shah D, Patel N, Yagnik H, Shah M (2020) Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides. Artif Intell Agric 4(1):58–73. https://doi.org/10.1016/j.aiia.2020.04.002

Tarannum N, Rhaman MK, Khan SA, Shakil SR (2015) A brief overview and systematic approach for using agricultural robot in developing countries. J Mod Sci Technol 3:88–101

Tariq M, Ahmad S, Fahad S, Abbas G, Hussain S, Fatima Z, Nasim W, Mubeen M, urRehman MH, Khan MA, Adnan M (2018) The impact of climate warming and crop management on phenology of sunflower-based cropping systems in Punjab, Pakistan. Agric For Meteorol 256-257:270–282. https://doi.org/10.1016/j.agrformet.2018.03.015

TEEB (2010) The economics of ecosystems and biodiversity. Mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB. UNEP, Nairobi

Thomas GB (1997) US environmental security policy: broad concern or narrow interests. The J Environ Dev 6(4):397–425

Tillett ND (1993) Robotic manipulators in horticulture: a review. J Agri Eng Res 55(2):89–105

Timsina J (2018) Can organic sources of nutrients increase crop yields to meet global food demand? Agron 8(10):214

Tomlinson I (2013) Doubling food production to feed the 9 billion: a critical perspective on a key discourse of food security in the UK. J Rural Stud 29:81–90

Torralba M, Fagerholm N, Burgess PJ, Moreno G, Plieninger T (2016) Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agric Ecosyst Environ 230:150–161. https://doi.org/10.1016/j.agee.2016.06.002

Udawatta RP, Rankoth LM, Jose S (2019) Agroforestry and biodiversity. Sustain 11:5. https://doi.org/10.3390/su11102879

Ullah A, Ahmad I, Ahmad A, Khaliq T, Saeed U, Habib-ur-Rahman M, Hussain J, Ullah S, Hoogenboom G (2019) Assessing climate change impacts on pearl millet under arid and semi-arid environments using CSM-CERES-millet model. Environ Sci Pollut Res 26:6745–6757. https://doi.org/10.1007/s11356-018-3925-7

Umesha S, Manukumar HM, Chandrasekhar B (2018) Sustainable agriculture and food security. In biotechnology for sustainable agriculture. Woodhead Publishing, New York, pp 67–92

UN (United Nations) (2015a) Transforming our world: the 2030 agenda for sustainable development (a/RES/70/1). United Nations General Assembly, New York

UN (United Nations) (2015b) Agricultural technology for development. report of the secretary-general. United Nations, New York

UNCTAD (2010) Technology and innovation report 2010: enhancing food security in Africa through science, technology and innovation. United Nations, New York and Geneva

UNCTAD (2011) Applying a gender lens to science, technology and innovation. United Nations, New York and Geneva

UNCTAD (2015) Commodities and development report. United Nations, New York and Geneva

UNEP (United Nations Environment Programme) (2019) Emissions gap report 2019. https://www.unep.org

Usman M, Farooq M, Wakeel A, Nawaz A, Cheema SA, ur Rehman H, Ashraf I, Sanaullah M (2020) Nanotechnology in agriculture: Current status, challenges and future opportunities. Sci Total Environ 721:137778. https://doi.org/10.1016/j.scitotenv.2020.137778

Uusitalo L, Lehikoinen A, Helle I, Myrberg K (2015) An overview of methods to evaluate uncertainty of deterministic models in decision support. Environ Model Softw 63:24–31

Van der Lippe T, De Ruijter J, De Ruijter E, Raub W (2011) Persistent inequalities in time use between men and women: a detailed look at the influence of economic circumstances, policies, and culture. European Soc Rev 27(2):164–179

Varshney RK, Nayak SN, May GD, Jackson SA (2009) Next-generation sequencing technologies and their implications for crop genetics and breeding. Trends Biotechnol 27(9):522–530

Veldkamp EF (2001) Lambin, editorial: predicting land-use change. In: Agriculture, Ecosystems and Environment, vol 85, pp 1–6

Venugopal KR (1999) Food security vs. nutrition security. Health Millions 25(2):18–19

Vermeulen SJ, Challinor AJ, Thornton PK, Campbell BM, Eriyagama N, Vervoort JM, Nicklin KJ (2013) Addressing uncertainty in adaptation planning for agriculture. Proc Nat Acad Sci 110(21):8357–8362

Vervoort JM, Thornton PK, Kristjanson P, Förch W, Ericksen PJ, Kok K et al (2014) Challenges to scenario-guided adaptive action on food security under climate change. Glob Environ Change 28:383–394

Wajid A, Ahmad A, Hussain M, ur Rahman MH, Khaliq T, Mubeen M, Rasul F, Bashir U, Awais M, Iqbal J, Sultana SR (2014) Modeling growth, development and seed-cotton yield for varying nitrogen increments and planting dates using DSSAT. Pak J Agric Sci 51(3):639–647

Wen Y, He Z, Xu T, Jiao Y, Liu X, Wang YF, Yu XQ (2019) Ingestion of killed bacteria activates antimicrobial peptide genes in Drosophila melanogaster and protects flies from septic infection. Dev Comp Immunol 95:10–18

Wheaton E, Kulshreshtha S (2017) Environmental sustainability of agriculture stressed by changing extremes of drought and excess moisture: a conceptual review. Sustainability 9(6):970

Wheeler T, Von Braun J (2013) Climate change impacts on global food security. Science 341(6145):508–513

World Bank and FAO (2009) Awakening Africa's sleeping Giant. World Bank, Washington DC

Yadav GS, Lal R, Meena RS (2020) Vehicular traffic effects on hydraulic properties of a Crosby silt loam under a long-term no-till farming in Central Ohio, USA. Soil Till Res 202:104654. https://doi.org/10.1016/j.still.2020.104654

Young TP (2000) Restoration ecology and conservation biology. Biol Conserv 92(1):73–83

Zeweld W, Van Huylenbroeck G, Tesfay G, Azadi H, Speelman S (2020) Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: empirical evidence from northern Ethiopia. Land Use Policy 95:103799

Zhang F, Wang R, Xiao Q, Wang Y, Zhang J (2006) Effects of slow/controlled-release fertilizer cemented and coated by nano-materials on biology. Nanoscience 11:18–26

Zhang H, Li Y, Zhu J (2018) Developing naturally stress-resistant crops for a sustainable agriculture. Nat Plants 4:989–996. https://doi.org/10.1038/s41477-018-0309-4

Zhang X, Davidson EA, Mauzerall DL, Searchinger TD, Dumas P, Shen Y (2015) Managing nitrogen for sustainable development. Nature 528:51–59. https://doi.org/10.1038/nature15743

Zhao C, Liu B, Xiao L, Hoogenboom G, Boote KJ, Kassie BT, Pavan W, Shelia V, Kim KS, Hernandez-Ochoa IM, Wallach D (2019) A simple crop model. Eur J Agron 104:97–106. https://doi.org/10.1016/j.eja.2019.01.009