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The role of agricultural engineering in enhanced food security

Sreedevi MS, Krishnamma PN, Nagaraja G and Shoba H

Sreedevi MS
Assistant Professor, AICRP (FIM), Zonal Agricultural Research Station, V.C. Farm, Mandya, University of Agricultural Sciences, Bangalore, Karnataka, India

Krishnamma PN
Assistant Professor, Department of Processing and Food Engineering, College of Agricultural Engineering, GKVK, University of Agricultural Sciences, Bengaluru, Karnataka, India

Nagaraja G
Assistant Professor of Agricultural Engineering, College of Horticulture, Munirabad, Koppal. University of Horticultural Sciences, Bagalkot, Karnataka, India

Shoba H
Assistant Professor of Agricultural Engineering, College of Horticulture, Munirabad, Koppal. University of Horticultural Sciences, Bagalkot, Karnataka, India

Corresponding Author:
Sreedevi MS
Assistant Professor, AICRP (FIM), Zonal Agricultural Research Station, V.C. Farm, Mandya, University of Agricultural Sciences, Bangalore, Karnataka, India

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Abstract

An increasing global population, climate change and resource restrictions are all concerns that agricultural engineering must solve in order to improve food security. Agricultural engineering plays a significant role in tackling these difficulties. There has never been a time when the need for agricultural techniques that are creative, efficient and sustainable has been more pressing than it is now, given that the globe is facing the mammoth job of feeding an estimated 9.7 billion people by the year 2050. Food production can be improved, waste can be reduced, and food systems can be made more robust and sustainable via the use of agricultural engineering, which provides a holistic approach through its many subfields. Agriculture engineering has made significant contributions to the improvement of food security, one of the most important of which is the creation and improvement of more modern farming technologies. Agricultural engineers are responsible for the design and improvement of storage facilities, transportation networks, and processing technologies in order to significantly cut down on these losses. By prolonging the shelf life of perishable items and ensuring that transportation is both safe and efficient, these technologies contribute to the preservation of both the quality and quantity of food from the farm to the fork. Another important significant contribution that agricultural engineering has made to the improvement of food security is the technology of mechanization. Mechanization not only boosts production but also guarantees that agricultural activities are carried out in a timely manner, which is something that is essential for optimizing crop yields. In addition, agricultural engineers are concentrating their efforts on the development of equipment that is easily accessible and reasonably priced for smallholder farmers, who constitute a significant section of the farming population all over the world. Engineering professionals are working to create technologies that lessen the negative effects that farming has on the environment. These technologies include strategies for lowering greenhouse gas emissions, solutions for farms that utilize renewable energy, and systems for managing agricultural waste. Through the implementation of these technologies, more sustainable food system is being established, which guarantees that future generations will be able to continue the production of food without depleting natural resources or causing damage to the environment.

Keywords: Agriculture, engineering, engineers, post harvest, food, security

Introduction

In spite of the fact that climate change, a fast expanding population, and resource restrictions are all contributing factors, food security continues to be one of the most important global concerns available. Considering that it is anticipated that the global population will reach approximately 10 billion by the year 2050, it is becoming an increasingly difficult effort to guarantee that everyone has access to adequate food that is both safe and nutritious [1]. Agricultural engineering, which is the application of engineering concepts to the agricultural sector, is an essential component in the process of tackling these difficulties. Agricultural engineering allows for the development and implementation of novel technology and methods, which in turn improves the efficiency, sustainability, and resilience of food production systems [2]. The crucial relevance of agricultural engineering in the worldwide endeavour to attain food security and discusses the numerous ways in which it contributes to more sustainable and productive farming practices [3]. Agricultural engineering involves designing, developing, and implementing solutions to improve agricultural efficiency, productivity, and sustainability. The term “agricultural engineer” means a person trained in engineering who applies engineering knowledge to agriculture and food as defined broadly to include biological processes and environmental aspects [114].

Agricultural engineers work on a wide range of topics, including: farm machinery and equipment design; irrigation and water management systems; agricultural buildings and structures; soil and water conservation; crop processing and handling; livestock production and management; agricultural waste management; precision agriculture and automation; rural infrastructure development and agricultural technology and innovation.

Agricultural engineers use various tools and techniques, such as: Computer-Aided Design (CAD); Geographic Information Systems (GIS); remote sensing and drones; simulation modelling; data analytics and machine learning, prototyping and testing; soil and water testing; crop and livestock monitoring; energy auditing and management and environmental impact assessment

The goals of agricultural engineering include: increasing agricultural productivity and efficiency; improving food safety and quality; reducing environmental impact and pollution; enhancing rural livelihoods and communities; supporting sustainable agricultural development; addressing climate change and variability; improving agricultural water management; reducing post-harvest losses and waste; promoting agricultural innovation and technology adoption and ensuring global food security and sustainability.

Historical Context of Agricultural Engineering

The field of agricultural engineering has a long and illustrious history that can be traced back to the creation of various equipment and methods that aim to enhance agricultural output. Engineering advancements have played a significant role in the development of agricultural methods throughout history, beginning with the creation of the plough in ancient Mesopotamia and continuing through the modernization of agriculture throughout the Industrial Revolution [4]. Prof. Mason Vaugh (1894-1978) an agricultural engineer, founded the Department of Agricultural Engineering, and became the "Father of Agricultural Engineering" in India in the early 1940s and played a pivotal role in establishing the discipline of agricultural engineering in the country. In 1921, he established the first agricultural engineering department at Allahabad Agricultural Institute. The institute was later renamed as Sam Higginbottom University of Agriculture, Technology and Sciences to improve the economic status of the rural population. In 1942, it became the first institute in India to offer a degree in Agricultural Engineering. Prof. Vaugh's contributions had a lasting impact on Indian agriculture, and he is still revered as a pioneer in the field of agricultural engineering. His work laid the foundation for the development of modern agricultural engineering in India, and his legacy continues to inspire new generations of agricultural engineers and researchers.In the 20th century, there was a phenomenon known as the Green Revolution, which was characterized by huge increases in food production due to advancements in irrigation, automation, and crop breeding. On the other hand, these advances also brought about difficulties, such as the deterioration of the environment and the increase of social inequality. Agricultural engineering in the contemporary period is cantered on the development of food systems that are both sustainable and robust, with the objective of striking a balance between production, environmental stewardship, and social equality [5].

Precision Agriculture: Enhancing Efficiency and Productivity

Precision agriculture is a revolutionary method in contemporary farming that makes use of cutting-edge technology to maximize the efficiency with which resources are used, increase production, and reduce the negative influence on the environment. Precision agriculture is a kind of farming that alters inputs such as water, fertilizers, and pesticides to meet the precise requirements of individual sections within a field. This is in contrast to conventional farming approaches, which often administer similar treatments over whole fields without any variation [6]. The incorporation of technologies such as global positioning systems (GPS), remote sensing, and data analytics into agricultural operations makes it feasible to implement site-specific management.

Specific crop management, also known as site-specific crop management (SSCM), is an essential component of precision agriculture [7]. Farmers are able to monitor and control differences in soil qualities, crop conditions, and environmental elements within their farms with the use of supply chain management (SSCM). When farmers make use of the information gathered by soil sensors, aerial drones, and satellite photography, they are able to accurately administer inputs to the areas where they are required the most [8]. Variable Rate Technology (VRT), for instance, makes it possible to apply pesticides and fertilizers in a targeted manner, so guaranteeing that crops get the precise quantity that is required for maximum development. Not only does this increase crop yields, but it also limits the amount of pesticides that are used excessively, which results in financial savings and reduced damage to the environment [9]. With the ability to provide high-resolution, real-time data on crop health, moisture levels, and possible pest infestations, drones and satellite photography play an essential part in the practice of precision agriculture. These technologies make it possible to discover issues at an early stage, which equips farmers with the ability to take remedial steps before substantial harm occurs [10]. A drone that is fitted with multispectral cameras, for instance, is able to take comprehensive pictures of a field, therefore detecting regions of the field in which crops are experiencing stress as a result of a lack of water or an imbalance of nutrients. Farmers have the ability to enhance their yields and decrease their losses if they swiftly address these concerns [11]. The development of automated technology is yet another key factor that has contributed to the improvement of precision agriculture. Automated planting systems, robotic harvesters, and tractors that drive themselves are becoming more commonplace on farms with autonomous capabilities [12]. These devices have a high degree of accuracy, which helps to reduce the amount of human error and labour expenses while simultaneously boosting productivity. Automated systems are able to function constantly, even in difficult circumstances, which ensures timely planting, irrigation, and harvesting, all of which are essential for optimum output. The promotion of the effective use of resources is another way in which precision agriculture contributes to the concept of sustainability [13]. For instance, precision irrigation systems, which deliver water specifically to the root zones of plants based on real-time moisture data, considerably minimize the amount of water that is wasted compared to traditional irrigation methods. Similarly, the application of fertilizers and pesticides in a precise manner reduces the amount of runoff that enters neighbouring bodies of water, so lowering the potential for contamination and safeguarding the ecosystems of the surrounding area [14].

Precision agriculture is bringing about a revolution in the production of food by increasing the efficiency, productivity, and sustainability of the process. Precision agriculture allows farmers to obtain greater yields with less inputs by harnessing cutting-edge technology and making decisions based on data. This allows farmers to meet the rising demand for food across the world while simultaneously reducing the environmental impact of agricultural operations [15].

Table 1: Aspect of Agricultural Engineering

Aspect of Agricultural Engineering	Role in Food Security	Examples	References
Irrigation Systems	Enhances crop yield and resilience by ensuring water availability, especially in arid regions.	Drip irrigation in India's Maharashtra state has improved water efficiency, leading to increased crop yields.	FAO, 2018; World Bank, 2020
Soil Management	Improves soil health and fertility, leading to better crop production and sustainable farming practices.	Use of conservation tillage in the U.S. has reduced soil erosion, improving long-term soil fertility.	USDA, 2019; NRCS, 2021
Post-Harvest Technology	Reduces food loss and waste by improving storage, transportation, and processing methods.	Hermetic storage bags in Africa have significantly reduced post-harvest losses in grains.	CIMMYT, 2020; World Food Programme, 2021
Mechanization	Increases efficiency and productivity, reducing labor costs and enabling large-scale farming.	Use of combine harvesters in Southeast Asia has doubled rice production.	IRRI, 2018; FAO, 2020
Precision Agriculture	Optimizes inputs like water, fertilizers, and pesticides, leading to sustainable and efficient food production.	Use of GPS-guided tractors and drones in the U.S. for precision farming has led to higher yields with lower input costs.	USDA, 2021; Purdue University, 2020
Renewable Energy Integration	Reduces dependency on fossil fuels, lowers costs, and ensures sustainable energy supply for agriculture.	Solar-powered irrigation in India's Gujarat state has provided reliable and cost-effective water supply for smallholder farmers.	IRENA, 2021; World Bank, 2019
Genetic Engineering and Biotechnology	Supports the development of crop varieties that are more resistant to pests, diseases, and environmental stresses, thus ensuring a stable food supply.	Development of Bt cotton in India has reduced the need for chemical pesticides and increased yields.	ISAAA, 2019; FAO, 2020

Water Management: Addressing Scarcity and Efficiency

Water management is a crucial component of agricultural engineering in today's world, which is seeing a rise in the frequency of water shortages due to climate change, population growth, and over use of water resources. It is especially important to keep this in mind in a world where water resources are being drained at an exorbitant rate [16]. Due to the fact that water is an essential component for the growth of crops and the rearing of animals, efficient water management is an imperative need in order to ensure that agricultural production will continue to be maintained. Agricultural engineering provides innovative solutions that enhance water consumption efficiency, decrease waste, and guarantee that water resources are managed. These solutions are offered in order to ensure that water resources are managed in a sustainable way in order to achieve food security [17].

One of the most important advancements in the area of water management is the construction of modern irrigation systems, which is continually acknowledged as one of the most significant advances [18]. Two of the most prevalent reasons of significant water loss that happens as a result of conventional irrigation practices, such as flood irrigation, are evaporation and runoff. Both of these processes are responsible for the loss of water. On the other hand, modern irrigation techniques such as drip irrigation and spray irrigation are intended to provide water directly to the root zones of plants, which is the area of the plant where it is most necessary to have it [19]. An example of this would be drip irrigation, which makes use of a network of tubes and emitters to release minute amounts of water at predetermined intervals. With the help of this mechanism, plants are guaranteed to get a consistent and precise supply of moisture. In addition to assisting in the conservation of water, this method also contributes to the enhancement of agricultural yields by creating conditions that are optimal for the development of plants [20].

It is especially important to implement water harvesting and conservation strategies in regions where water resources are scarce or when rainfall is distributed seasonally. Furthermore, these courses of action are very necessary [21]. For the purpose of enhancing irrigation during dry years, agricultural engineers build systems that are capable of collecting and storing rainwater. After that, this water might be employed to supplement the irrigation process. The flow of rainwater may be slowed down by using methods such as contour bunding, check dams, and percolation tanks [22]. These techniques are all potential options. Rainwater is able to recharge aquifers and water sources as a result of this process, which permits it to sink into the soil [23]. These methods are particularly efficient in arid and semi-arid regions, which are places in which groundwater is a vital resource for agricultural output. This is because these regions are characterized by a lack of precipitation. Rainwater harvesting systems contribute to the long-term sustainability of water resources by increasing the quantity of groundwater that is recharged and decreasing the amount of runoff that occurs. This ultimately results in a reduced amount of runoff [24].

The use of agricultural engineering not only supports efforts to save water but also facilitates the recycling and reuse of water throughout the agricultural process. It is feasible to reuse treated wastewater, also known as greywater, for irrigation purposes in a safe manner, which in turn decreases the amount of fresh water that is required during irrigation [25]. Systems that are capable of treating and recycling agricultural runoff, which often contains fertilizers and pesticides, are developed by engineers in order to prevent the contamination of natural water bodies and to make it feasible to reuse nutrient-rich water for crop growth. This is done in order to make it possible to reuse water that is rich in nutrients. In addition to assisting us in conserving water, this strategy also serves to lessen the detrimental impact that agriculture has on the ecology that is located in the surrounding area [26].

The use of technologies that are outfitted with sophisticated water management systems is yet another area in which agricultural engineering is making significant advancements. For instance, farmers are able to monitor the amounts of moisture in the soil and get data in real time by using soil moisture sensors [27]. This allows them to make more informed decisions. This enables growers to make informed decisions about the timing of watering their crops and the amount of water that should be applied to them. It is possible for agricultural irrigation systems that are automated to be constructed in such a way that they can adjust the quantity of water that is provided to crops based on the weather forecast, the conditions of the soil, and the needs of the crop [28]. In this way, water is used efficiently and only when it is necessary, ensuring sustainable water management. These technologies are particularly helpful in areas that are facing water stress since they allow for the optimization of water consumption, the reduction of waste, and the augmentation of agricultural production.

Furthermore, agricultural engineers are now doing research into several methods that might improve the effectiveness of water use at the landscape level. Approaches to integrated water management, such as watershed management and integrated river basin management (IRBM), take into account the whole hydrological cycle and aim to find a balance between the water needs of communities, industry, and agricultural output. These approaches are examples of integrated water management. Through the management of water resources at the watershed level, engineers are able to create methods that will allow water to be distributed in a way that is both more egalitarian and sustainable. By doing so, we guarantee that agriculture does not have an impact on the amount of water that is available for use in other purposes [29].

Sustainable Land Management: Combating Degradation and Enhancing Soil Health

Agricultural engineering is built on the foundation of sustainable land management, which places an emphasis on the long-term health of the soil and the ecosystems that are necessary for agricultural productivity. Erosion, deforestation, excessive grazing, and inappropriate agricultural methods are all factors that contribute to soil deterioration, which presents a substantial risk to the safety of food supplies throughout the world [30]. Having good soil is crucial for the cultivation of crops, the maintenance of animals, and the preservation of biodiversity since it serves as the basis of all terrestrial ecosystems. Agricultural engineering offers the skills and procedures that are essential to address land degradation and encourage practices that boost soil health. This helps to ensure that agricultural land will continue to be productive and resilient for future generations [31].

Soil erosion is one of the most significant obstacles in the way of sustainable land management. This phenomenon has the potential to remove the nutrient-rich topsoil that is essential for the development of plants. A variety of soil conservation strategies have been developed by agricultural engineers in order to counteract soil erosion and to preserve the fertility of the soil. Terracing, for instance, is a method that is used in mountainous and hilly locations to create flat areas on steep slopes, therefore minimizing runoff and limiting the loss of soil [32]. Another approach is called contour ploughing, and it includes ploughing following the contours of the ground in order to create ridges that slow down the flow of water and encourage water to penetrate deeper into the soil. The wind speed is slowed down and the soil is protected from wind erosion when windbreaks, which are rows of trees or bushes planted along the boundaries of fields, are in place. These approaches are essential in areas that are prone to erosion because they assist to conserve the topsoil and sustain agricultural output [33, 111].

Monitoring the health of the soil is another factor that is essential to the management of sustainable land. The development of soil sensors and other diagnostic instruments that offer real-time data on soil characteristics, such as moisture levels, temperature, pH, and nutrient content, has allowed for advancements in soil science and engineering. These advancements have led to the creation of soil sensors [34]. With this knowledge, farmers are able to make educated judgments on the techniques of soil management, such as determining the appropriate time to apply fertilizers or water their crops. Monitoring the health of the soil on a regular basis helps to avoid deterioration and guarantees that soils may continue to be fertile and productive over an extended period of time [35].

Integrated pest management, often known as IPM, is an additional method that agricultural engineering adds to the management of sustainable land. In order to get rid of pests in a way that is both sustainable and kind to the environment, integrated pest management (IPM) integrates biological, cultural, mechanical, and chemical approaches. Integrated pest management (IPM) helps preserve soil health by limiting the accumulation of toxic chemicals in the soil [36]. This is accomplished by lowering the dependence on chemical pesticides. In order to naturally manage pest populations, biological control agents such as beneficial insects and microorganisms are used. Additionally, cultural methods such as crop rotation and intercropping are utilized to assist interrupt the life cycles of pests and lessen the influence that they have on crops. Incorporating integrated pest management (IPM) with other environmentally responsible activities is beneficial to the overall health of the soil and the ecosystem that surrounds it [37].

In order to further improve the health of the soil, agricultural engineers also concentrate on the control of the soil's fertility. Included in this is the use of cover crops, which are grown during off-seasons in order to prevent soil erosion, enhance soil structure, and provide organic matter to the soil. Green manures, which are crops that are planted particularly for the purpose of being ploughed back into the soil, not only increase the organic content of the soil but also enrich it with nutrients [38]. Another method that enhances soil fertility while simultaneously lowering the negative effects that agriculture has on the environment is the use of organic fertilizers, which include compost and animal dung, rather than synthetic fertilizers used in agriculture [39].

Agroforestry, which is the technique of incorporating trees and shrubs into agricultural landscapes, is yet another alternative method of sustainable land management that improves the health of the soil. Within the context of agroforestry systems, trees and shrubs provide a multitude of advantages, including the reduction of soil erosion, the improvement of water infiltration, and the enhancement of biodiversity. It is the roots of trees that contribute to the stabilization of the soil, while the leaves of trees provide organic matter, which enriches the soil and encourages the cycling of nutrients. Additionally, agroforestry offers farmers the opportunity to generate new revenue streams by means of the production of fruits, nuts, lumber, and other items derived from trees [40, 41, 42].

The problem of salinization, which is a kind of soil deterioration that happens when salts collect in the soil and leave it infertile, is another issue that agricultural engineers are working to solve. When it comes to dry and semi-arid locations, where irrigation is required, this is an issue that often surface [43]. The process of leaching, in which extra water is delivered to the soil in order to wash away salts, and drainage systems, which prevent the accumulation of salty water in the soil, are two examples of the solutions that engineers create and put into practice in order to control salinity. The implementation of these treatments is very necessary in order to preserve the productivity of irrigated areas and to forestall the loss of valuable agricultural land due to salinization [44, 112].

Post-Harvest Technology: Reducing Losses and Enhancing Food Quality

The preservation, handling, processing, and storage of crops after they have been harvested is the primary emphasis of post-harvest technology, which is an essential subfield of agricultural engineering. This phase is very important since it has a direct influence on the quality, safety, and availability of food items, all of which are crucial components of food security [45]. A considerable reduction in the quantity of food that is accessible for consumption may be brought about by post-harvest losses. These losses include the degradation of food that occurs as a result of improper handling, insufficient storage, and spoiling. The necessity of efficient post-harvest management is highlighted by the fact that these losses might amount to as much as thirty to forty percent of overall yield in many underdeveloped nations [46]. Post-harvest technology is designed to reduce these losses as much as possible and guarantee that food maintains its nutritional content, safety, and marketability from the farm to the table. This is accomplished via the use of modern technical solutions. Post-harvest technology places a significant emphasis on the development of enhanced storage systems as one of its key areas of attention [47, 48]. The conventional ways of storing crops, such as drying them in the open air and storing them in basic granaries, often expose the crops to pests, moisture, and temperature variations, which results in severe agricultural losses. The creation of settings that are less favourable to the deterioration of food and the infestation of pests is one of the ways that contemporary storage options, such as hermetically sealed containers and climate-controlled warehouses, provide superior protection [49]. As an example, controlled atmosphere storage (CAS) is a method that manages the quantities of oxygen, carbon dioxide, and nitrogen in storage facilities. This method slows down the respiration rate of fruits and vegetables, which in turn greatly extends their shelf life. In a similar vein, cold storage facilities are essential for the preservation of perishable items such as fruits, vegetables, dairy products, and meat [50, 51]. These facilities maintain low temperatures that limit the development of microorganisms and the action of enzymes, so keeping the quality of food for longer periods of time. Post-harvest technology includes a number of important aspects, including drying and dehydration, which are vital for lowering the moisture content of crops in order to avoid the development of microorganisms and the rotting of the crops [52]. The traditional method of drying in the sun, although efficient, is often sluggish and reliant on the weather. Solar dryers, mechanical dryers, and freeze-drying are some of the most effective drying technologies that have been developed by agricultural engineers [53]. In addition to a more uniform final product, these technologies provide for shorter drying periods, more control over drying conditions, and other benefits. Mechanical dryers, for example, are able to treat huge quantities of grains, fruits, and vegetables under regulated circumstances [54, 113]. This eliminates the possibility of mold development and mycotoxin contamination while also guaranteeing that the drying process is distributed evenly. In spite of the fact that it is more costly, freeze-drying is especially useful for high-value crops and goods since it maintains the taste and nutritional value of the food while simultaneously prolonging its shelf life [55].

The technology of packaging also plays an important part in post-harvest management since it safeguards food from being physically damaged, contaminated, and spoiled while it is being transported and stored. Modified atmospheric packaging (MAP) and active packaging are two examples of improvements in packaging materials that assist increase the shelf life of fresh food [56]. These advancements work by adjusting the gas composition that is contained inside the package. On the other hand, active packaging may either release or absorb chemicals such as moisture, oxygen, or ethylene in order to further protect food quality. MAP is responsible for adjusting the amounts of oxygen, carbon dioxide, and nitrogen that are contained inside the package in order to slow down the respiration rate and postpone the ripening process [57]. Edible coatings, which are formed from natural components such as waxes, proteins, or polysaccharides, are also being developed to offer an extra protective layer around fruits and vegetables. This layer will reduce the amount of moisture that is lost and will inhibit the development of microorganisms without the need for synthetic packing materials [58]. In addition to ensuring that the quality of the food is maintained, post-harvest technology also places an emphasis on the addition of value via processing. Not only can the processing of food extend the shelf life of goods, but it also results in the creation of new food items, which helps to reduce food waste and boosts the economic value of agricultural crop products [59]. As an example, fruits that are not fit for sale at fresh markets owing to defects may be processed into juices, jams, or dried fruit. This allows farmers to reduce their losses and generate extra cash for themselves. Other frequent post-harvest operations include milling, canning, pasteurization, and fermentation. These techniques help preserve food while also improving its taste, nutritional value, and safety [60]. In addition, these procedures play a significant part in ensuring that food items remain accessible throughout the year, even when the crops are not in season. It is a more common practice to include digital technology into post-harvest management in order to ensure that operations are optimized and losses are minimized [61]. Devices that are connected to the Internet of Things (IoT), such as sensors and smart packaging, provide data in real time on the temperature, humidity, and other environmental variables that are present throughout the storage and transit processes. This information makes it possible to improve the monitoring and management of the supply chain, which in turn helps to ensure that food is handled in the best possible circumstances and reduces the likelihood that it will go bad [62]. A further use of blockchain technology is being investigated for the purpose of improving traceability in the food supply chain. This technology can provide comprehensive information on the origin, handling, and quality of food items. Because of this openness, food fraud can be prevented, food safety can be improved, and customer confidence can be reinforced [63]. When it comes to underdeveloped nations, post-harvest losses are often made worse by a lack of infrastructure, technology, and expertise. Agricultural engineers are now attempting to create post-harvest solutions that are both accessible and cost-effective, and that are specifically customized to meet the requirements of smallholder farmers [64]. For instance, solar dryers that are inexpensive and hermetic storage bags are being advocated as simple and efficient methods for lowering food waste and enhancing food security in environments with limited resources. When it comes to teaching farmers and processors on the most effective methods for post-harvest handling, storage, and processing, extension services and training programs are also quite important [65].

Climate-Smart Agriculture: Building Resilience to Climate Change

When it comes to solving the combined concerns of food security and climate change, climate-smart agriculture (CSA) is a method that is considered to be of fundamental importance [66]. The resilience of agricultural systems is coming under growing danger as temperatures throughout the world continue to increase, weather patterns continue to become more unpredictable, and severe events such as droughts, floods, and storms continue to occur with greater frequency [67]. It is possible that these changes may result in decreased agricultural yields, deterioration of the land, a lack of available water, and an increase in the vulnerability of farming communities. Through the integration of climate resilience methods and sustainable agricultural practices, community supported agriculture (CSA) gives farmers the flexibility to adapt to changing circumstances, reduce the negative effects of climate change, and so contribute to the overall sustainability of the environment [68]. The objective of climate-smart agriculture is to increase agricultural production while simultaneously lowering emissions of greenhouse gases (GHG) and boosting the capacity of agricultural systems to withstand the disruptive effects of climate change [69]. This entails the use of a variety of farming methods and technology that are designed to improve the efficiency, sustainability, and resilience of agricultural systems. For example, conservation agriculture (CA) encourages practices such as crop rotation, permanent soil cover (through the use of cover crops or mulch), and minimum soil disturbance (via the practice of no-till farming) [70]. These techniques contribute to the mitigation and adaptation of climate change by improving the structure of the soil, increasing the amount of water that is retained, reducing the amount of erosion that occurs, and sequestering carbon in the soil. Another essential component of community supported agriculture (CSA) is agroforestry, which refers to the practice of incorporating trees and shrubs into agricultural landscapes [71]. Agricultural forestry systems provide a multitude of advantages, including the enhancement of soil fertility, the enhancement of biodiversity, the reduction of erosion, and the creation of microclimates that help shield crops from the effects of harsh weather. Trees also perform the function as carbon sinks, which means that they take up carbon dioxide from the air and store it in their biomass and soil [72]. One of the benefits of agroforestry is that it helps farmers better their livelihoods and disperse risk, which in turn makes them less susceptible to the effects of climate change. This is accomplished by diversifying agricultural produce.

The management of water is another essential component of agriculture that is adaptive to climate change [73]. The issue of water shortage is made worse in many locations as a result of climate change, which makes the effective use of water a vital component for maintaining agricultural output. The Community Supported Agriculture (CSA) movement encourages the use of precision irrigation methods, such as drip or spray irrigation, which supply water directly to the root zones of plants [74]. This helps to reduce the amount of water that is wasted and ensures that crops get the appropriate amount of moisture even during dry seasons. The collection of rainwater and the use of small-scale water storage systems are two further methods that may assist farmers in more successfully managing their water resources. These methods can also serve as a buffer against droughts and unpredictable rains [75]. CSAs also place a significant emphasis on climate-resilient agricultural types as an essential component. Agricultural engineers and scientists are working to produce and promote the usage of crops that are more resistant to harsh circumstances such as heat, drought, and salt. These crops are being developed and promoted right now [76]. The cultivation of these crops is designed to endure the challenges that are connected with climate change, which guarantees consistent yields even when the circumstances are unfavourable. The introduction of drought-resistant maize, flood-tolerant rice, and salt-tolerant wheat, for instance, is taking place in places that are prone to these particular difficulties [77]. By planting types that are climate-resilient, farmers may lessen the likelihood of their crops failing and continue to provide food despite the fact that the environment is becoming more unpredictable.

Integrated pest management, often known as IPM, is another method that contributes to the capacity of CSAs to withstand the effects of climate change [78]. The dynamics of pests and diseases may be changed as a result of warmer temperatures and different patterns of precipitation, which can make crops more susceptible to infestations. In order to manage pests in a manner that is both sustainable and kind to the environment, integrated pest management (IPM) applies a combination of biological, cultural, mechanical, and chemical control strategies [79]. Integrated pest management (IPM) helps safeguard beneficial insects, reduces the pollution of soil and water, and prevents the formation of pest populations that are resistant to pesticides. This is accomplished by using less chemical pesticides. When it comes to sustaining crop health and production in a climate that is always changing, this comprehensive approach to pest control is very necessary [80]. One cannot overestimate the significance of the role that digital technologies play in CSA. Recent developments in data collecting, remote sensing, and predictive modelling have made it possible for farmers to make more educated choices about the management of crops, the use of water, and the control of pests. Farmers are able to better anticipate and adapt to climate threats with the assistance of climate information services, which include real-time weather predictions, early warning systems, and climate projections [81]. Farmers, for instance, are able to change their planting dates, choose suitable crop kinds, and take precautions to preserve their crops and animals if they are aware of the chance that an imminent drought or severe rainfall will occur. It is also possible for mobile applications and other digital platforms to improve the distribution of best practices and give access to agricultural extension services, which in turn enhances the ability of farmers to successfully apply community supported agriculture (CSA) techniques. Carbon sequestration is yet another essential component of agriculture that is climate-smart [82]. Agricultural methods that enhance the quantity of organic matter in soils, such as cover cropping, decreased tillage, and the use of organic fertilizers, have the potential to remove considerable quantities of carbon from the atmosphere, so contributing to the mitigation of climate change. The management of soil carbon not only contributes to the reduction of atmospheric CO2 levels, but it also enhances the fertility of the soil and the retention of water, so making agricultural systems more resistant to the effects of climate change [83]. Furthermore, measures that minimize methane emissions from ruminants and increase the overall sustainability of animal husbandry are included in the implementation of livestock management in community supported agriculture (CSA). For example, rotational grazing gives pastures the opportunity to recuperate in between grazing seasons, which improves the quality of the forage and reduces the amount of overgrazing that occurs [84]. Methane emissions may also be reduced by the use of feed additives and alterations to animal diets. Additionally, better waste management procedures have the potential to trap methane for the purpose of converting it into biogas. This would provide an alternative energy source and minimize the environmental imprint of livestock production [85].

Digital Agriculture: The Role of Data and AI in Modern Farming

The agricultural industry is undergoing a change as a result of digital agriculture, which is the incorporation of data and artificial intelligence (AI) into farming methods. This approach is presenting chances that have never been seen before to improve productivity, efficiency, and sustainability [86]. With the intensification of global concerns such as population increase, climate change, and resource scarcity, the necessity for agricultural techniques that are more accurate and data-driven has become more crucial. For the purpose of better satisfying the requirements of contemporary food production, digital agriculture is changing conventional farming into a system that is highly efficient, intelligent, and responsive. This is being accomplished by using new technology [87]. The gathering and examination of enormous volumes of data that are produced by a variety of sources, including as satellites, drones, sensors, and farm equipment, is the fundamental component of digital agriculture. This information gives farmers the ability to make educated choices at every step of the agricultural process by providing real-time insights about the conditions of the soil, weather patterns, the health of the crop, and the behaviour of the animals under their care. For example, soil sensors are able to assess characteristics such as the amount of moisture present, the pH level, and the nutrient content [88]. This enables farmers to improve their irrigation and fertilization methodologies. The crops are guaranteed to get the appropriate quantity of water and nutrients, which results in a reduction in waste and an increase in yields. Among the most important developments that digital agriculture has made possible, precision agriculture is one of the most important improvements. For the purpose of monitoring and managing crops and animals with a high degree of accuracy, it includes the use of GPS technology, remote sensing, and Internet of Things devices [89]. Through the process of evaluating data on a field-by-field basis, precision agriculture enables farmers to administer inputs such as water, fertilizers, and pesticides precisely where and when they are required, hence reducing the amount of waste produced and increasing the amount of efficiency achieved. This focused strategy not only lowers expenses, but it also diminishes the effect that farming has on the environment by reducing the excessive use of pesticides and preserving natural resources [90]. In the field of digital agriculture, artificial intelligence (AI) plays a crucial part in the process of evaluating and interpreting the large volumes of data that are gathered. Through the processing of data from a wide variety of sources, the identification of trends, and the formulation of forecasts, machine learning algorithms may assist farmers in optimizing their operations. Platforms that are powered by artificial intelligence, for instance, are able to examine meteorological data, patterns of crop development, and historical yields in order to forecast the optimal periods for planting and prescribe certain crop kinds that are expected to perform well under the circumstances that are now present [91]. In a similar vein, artificial intelligence may be used to identify early warning indicators of agricultural illnesses or insect infestations, which enables prompt treatments that can avert extensive harm. Additionally, drones and satellite photography are essential components of digital agriculture. These technologies produce high-resolution photographs that provide a bird's-eye perspective of agricultural landscapes. It is possible to use these photographs to monitor the health of the crop, evaluate the damage that occurred as a result of severe weather events, and follow the development of the crop's growth throughout the season [92]. In order to identify tiny changes in plant colour or texture, which may signal stress, nutritional shortages, or disease, image analysis technologies driven by artificial intelligence may detect these changes. This enables farmers to treat concerns before they become more severe. In the past, it was difficult for farmers to do this degree of monitoring and analysis; now, with the help of digital technologies, they are now able to manage their fields with an unparalleled level of precision and accuracy [93].

By using intelligent technology and automation, labour-intensive agricultural jobs are being transformed into processes that are both efficient and automated. With the use of global positioning systems (GPS), sensors, and artificial intelligence (AI) systems, tractors, harvesters, and other pieces of agricultural machinery may now function independently or with minimum assistance from humans. With the help of these machines, seeds can be planted, fertilizers can be applied, and crops can be harvested with an astonishing level of accuracy [94]. This eliminates the need for human work and increases the efficiency of processes. For example, autonomous tractors are able to follow pre-programmed pathways to till fields with flawless precision, while robotic harvesters are able to recognize and select ripe fruits and vegetables without causing any damage to the plants. Through the use of intelligent monitoring systems, digital agriculture is bettering the wellbeing of animals and increasing production in the livestock farming industry [95]. The health, activity, and behaviour of individual animals may be tracked by wearable devices and sensors, which provides farmers with extensive information that can be utilized to enhance feeding, breeding, and healthcare for the animals. Systems that are powered by artificial intelligence are able to evaluate the data collected from these sensors in order to identify early warning indications of disease or stress. This enables timely interventions that may enhance animal health and production. Additionally, artificial intelligence is used by precision feeding systems in order to determine the precise nutritional requirements of each animal. This ensures that livestock are provided with the most suitable diet for development and production [96].

Blockchain technology is also making inroads into digital agriculture, giving a mechanism to improve transparency and traceability in the food supply chain. This is one of the implications of blockchain technology. Blockchain guarantees that information on the origin, handling, and quality of food items is easily accessible to customers, merchants, and regulators by documenting each stage of the manufacturing process on a secure and immutable ledger [97]. This ensures that transparency is maintained throughout the whole production process. Additionally, this openness helps to develop confidence in food systems, lowers the chance of fraud, and makes it possible to have more efficient recall procedures in the event that there are problems with food safety [98].

The use of big data analytics in agriculture is contributing to the development of better informed decision-making via its integration. Big data systems are able to give insights into trends, dangers, and opportunities at both the farm and global levels. These insights are obtained by combining and analysing data from many sources. For instance, big data may be used to estimate market demand, which enables farmers to plan their output in accordance with the prediction, so preventing either overproduction or shortages. It is also able to assist in the identification of new dangers, such as newly discovered illnesses or pests, and it may recommend preventative steps to lessen the effect of these hazards [99].

Conclusion

Agricultural engineering is at the heart of efforts to enhance food security in the face of growing global challenges. By integrating engineering principles with agricultural practices, this field offers innovative solutions that improve productivity, sustainability, and resilience. From precision agriculture and water management to post-harvest technology and digital agriculture, agricultural engineering is transforming the way we produce, process, and distribute food. As we move forward, it is essential to continue investing in research, education, and policy support to ensure that agricultural engineering can fully realize its potential in securing a sustainable and food-secure future for all. Agricultural engineering has experienced an evolution from traditional Agriculture Mechanization to Agricultural and Biological Engineering under the impact of the advancement of Science and Technology. The Research and Development for agricultural engineering need to be restructured to cater to the fast development of Science and Technology and contribute to providing solutions for the new needs of the world people, in consideration of limited natural resources, e.g. land, water, energy, and environment concern. More attention was needed to design machinery for conditions especially to the needs of small landholders. Agricultural engineering and economic development are complementary each other. However, the profession of agricultural engineering needs to be strengthened. Government policy always plays a vital role in the R&D for Agricultural engineering. Agricultural engineers should become a part of the social “team”and influence policy makers through effectively articulating the vital nature of our work in terms of social, economic and environmental benefits, and collecting and documenting examples of success stories of agricultural engineers.

References

1. Sibhatu KT, Qaim M. Rural food security, subsistence agriculture, and seasonality. PLoS ONE; c2017 .p. 12.
2. Jerzak MA, Śmiglak-Krajewska M. Globalization of the market for vegetable protein feed and its impact on sustainable agricultural development and food security in EU countries illustrated by the example of Poland. Sustainability. 2020;12:888.
3. Ahmed UI, Ying L, Bashir MK, Abid M, Zulfigar F. Status and determinants of small farming households’ food security and role of market access in enhancing food security in rural Pakistan. PLoS ONE; c2017 .p. 12.
4. Prosekov AY, Ivanova SA. Food security: The challenge of the present. Geoforum. 2018;91:73–77.
5. The top 10 causes of world hunger. Available from: https://www.concernusa.org/story/top-causes-world-hunger/ (accessed June 20, 2020).
6. Causes and effects of food insecurity environmental sciences essay. Available from: https://www.ukessays.com/essays/environmental-sciences/causes-and-effects-of-food-insecurity-environmental-sciences-essay.php (accessed June 20, 2020).
7. Smith LC, El Obeid AE, Jensen HH. The geography and causes of food insecurity in developing countries. Agric Econ. 2000;22:199-215.
8. Our World in Data. Available from: https://ourworldindata.org/hunger-and-undernourishment#what-share-of-people-are-undernourished (accessed May 22, 2020).
9. Porkka M, Kummu M, Siebert S, Varis O. From food insufficiency towards trade dependency: A historical analysis of global food availability. PLoS ONE; c2013 .p. 8.
10. Food and Agriculture Organization of the United Nations Statistical Database. Annual population. Available from: http://www.fao.org/faostat/en/#data/OA (accessed May 22, 2020).
11. Silva G. Feeding the world in 2050 and beyond–part 1: Productivity challenges. Michigan State University Extension; c2018. Available from: https://www.canr.msu.edu/news/feeding-the-world-in-2050-and-beyond-part-1 (accessed June 20, 2020).
12. Elferink M, Schierhorn F. Global demand for food is rising. Can we meet it? Harvard Business Review; c2016. Available from: https://hbr.org/2016/04/global-demand-for-food-is-rising-can-we-meet-it (accessed June 20, 2020).
13. Fukase E, Martin WJ. Economic growth, convergence, and world food demand and supply. Policy Research Working Paper 8257. World Bank Group, Development Research Group Agriculture and Rural Development Team: Washington, DC; c2017.
14. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, *et al*. Solutions for a cultivated planet. Nature. 2011;478:337–342.
15. Tilman D, Balzer C, Hill J, Befort BL. Global food demand and the sustainable intensification of agriculture. Proc Natl Acad Sci USA. 2011;108:20260–20264.
16. Smutka L, Steininger M, Miffek O. World agricultural production and consumption. Agris on-line Papers Econ Inform. 2009;1:3-12.
17. Otsuka K. Food insecurity, income inequality, and the changing comparative advantage in world agriculture. Agric Econ. 2013;44:7-18.
18. Smutka L, Steininger M, Maitah M, Škubna O. The Czech agrarian foreign trade—ten years after the EU accession. In: Agrarian Perspectives XXIV: Proceedings of the 24th International Scientific Conference, Czech University of Life Sciences Prague, Faculty of Economics and Management; Prague; c2015. p. 385–392.
19. Wegren SK, Elvestad C. Russia’s food self-sufficiency and food security: An assessment. Post Communist Econ. 2018;30:565–587.
20. Cook DC, Fraser RW, Paini DR, Warden AC, Lonsdale WM, De Barro PJ. Biosecurity and yield improvement technologies are strategic complements in the fight against food insecurity. PLoS ONE; c2011 .p. 6.
21. Stocking MA. Tropical soils and food security: The next 50 years. Science. 2003;302:1356–1359.
22. Smyth SJ, Phillips PWB, Kerr WA. Food security and the evaluation of risk. Glob Food Secur. 2015;4:16-23.
23. Pinstrup-Andersen P, Pandya-Lorch R. Food security and sustainable use of natural resources: A 2020 vision. Ecol Econ. 1998;26:1-10.
24. Irz X, Lin L, Thirtle C, Wiggins S. Agricultural productivity growth and poverty alleviation. Dev Policy Rev. 2001;19:449–466.
25. Majid N. Reaching Millennium goals: How well does agricultural productivity growth reduce poverty? Employment Strategy Paper No. 12. International Labour

Organization: Geneva; c2004.
26. Diaz-Bonilla E, Thomas M, Robinson S, Cattaneo A. Food security and trade negotiations in the World Trade Organization: A cluster analysis of country groups. TMD Discussion Paper No. 59. Trade and Macroeconomic Division, International Food Policy Research Institute: Washington, DC; c2000.
27. Diaz-Bonilla E, Thomas M. Why some are more equal than others? Country typologies of food security. Background Paper Prepared for The State of Agricultural Commodity Markets 2015-16. FAO: Rome; c2015.
28. Baer-Nawrocka A, Sadowski A. Food security and food self-sufficiency around the world: A typology of countries. PLoS ONE; c2019 .p. 14.
29. Yu B, You L, Fan S. Toward a typology of food security in developing countries. In: IFPRI Discussion Paper 00945. Development Strategy and Governance Division; International Food Policy Research Institute: Washington, DC; c2010.
30. Yu B, You L. A typology of food security in developing countries. China Agric Econ Rev. 2013;5:118–153.
31. Zhang X, Johnson M, Resnick D, Robinson S. Cross-country typologies and development strategies to end hunger in Africa. In: DSGD Discussion Paper No. 8. Development Strategy and Governance Division; International Food Policy Research Institute: Washington, DC; c2004.
32. Pieters H, Gerber N, Mekonnen D. Country typology on the basis of food and nutrition security. In: A typology of countries based on food and nutrition security outcomes and their agricultural, economic, political, innovation and infrastructure national profiles; FOODSECURE Technical Paper No. 2. LEI Wageningen UR: Wageningen, The Netherlands; c2014.
33. Maslow A. Motivation and personality. 3rd ed. Addison-Wesley: New York; c1954.
34. Malthus TR. An essay on the principle of population, as it affects the future improvement of society. Printed for J. Johnson: London; c1798.
35. Boserup E. Population and technology. Basil Blackwell: Oxford; c1981.
36. Smith K. The Malthusian controversy. Routledge & Kegan Paul: London; c1951.
37. Foster P, Leathers HD. The world food problem. Tackling the causes of undernutrition in the third world. 3rd ed. Lynne Rienner Publishers: Boulder, CO; c1999.
38. Dowd D. Inequality and the global economic crisis. Pluto Press: London; c2009.
39. Food and Agriculture Organization of the United Nations Statistical Database. Suite of food security indicators. Available from: http://www.fao.org/faostat/en/#data/FS (accessed May 22, 2020).
40. Poleman TT. Quantifying the nutrition situation in developing countries. Food Res Inst Stud. 1981;18:1–58.
41. Cirera X, Masset E. Income distribution trends and future food demand. Philos Trans R Soc B Biol Sci. 2010;365:2821–2834.
42. Rask KJ, Rask N. Economic development and food production-consumption balance: A growing global challenge. Food Policy. 2011;36:186–196.
43. Skoufias E, Di Maro V, González-Cossío T, Ramirez SR. Food quality, calories and household income. Appl Econ. 2011;43:4331-4342.
44. Sen A. Development as freedom. Anchor Books: New York; c1999.
45. Progress in nutrition. In: 6th report on the world nutrition situation. The United Nations System Standing Committee on Nutrition: Geneva; c2010.
46. Hazell P, Wood S. Drivers of change in global agriculture. Philos Trans R Soc B Biol Sci. 2008;363:495–515.
47. Nellemann C, Interpol, UNEP. The environmental crime crisis: Threats to sustainable development from illegal exploitation of natural resources. United Nations Environment Programme: Nairobi; c2014.
48. Ralston K, *et al*. The impact of the pandemic on food security and nutrition in the U.S. Food and Agriculture Organization: Rome; c2021.
49. Kearney J. Food consumption trends and drivers. Philos Trans R Soc B Biol Sci. 2010;365:2793–2807.
50. Setboonsarng S. Global food crisis: Causes, consequences, and solutions. In: In-Depth Analysis of the Food Crisis; Asian Development Bank: Manila; c2008.
51. Noleppa S, von Witzke H, Cartsburg M. The social, economic and environmental value of agricultural productivity in the European Union: impacts on markets and food security, rural income and employment, resource use, climate protection, and biodiversity. HFFA Working Paper No. 3. Humboldt Forum for Food and Agriculture e.V. (HFFA): Berlin, Germany; c2013.
52. Wang SL, Heisey P, Schimmelpfennig D, Bal E. Agricultural productivity growth in the United States: measurement, trends and drivers. Economic Research Report 189. U.S. Department of Agriculture, Economic Research Service: Washington, DC, USA; c2015.
53. Pretty J, Toulmin C, Williams S. Sustainable intensification in African agriculture. Int J Agric Sustain. 2011;9:5–24.
54. Lee DR. Agricultural sustainability and technology adoption: issues and policies for developing countries. Am J Agric Econ. 2005;87:1325–34.
55. Adenle AA, Weding K, Azadi H. Sustainable agriculture and food security in Africa: the role of innovative technologies and international organizations. Technol Soc. 2019;58:1–17.
56. Basiago AD. Sustainable development in Indonesia: A case study of an indigenous regime of environmental law and policy. Int J Sustain Dev World Ecol. 1995;2:199–211.
57. Zhang J, Chen GC, Xing S, Shan Q, Wang Y, Li Z. Water shortages and countermeasures for sustainable utilisation in the context of climate change in the Yellow River Delta region, China. Int J Sustain Dev World Ecol. 2011;18:177–85.
58. McDonald BL. Food security. Cambridge, UK: Polity Press; c2010.
59. Goodland R, Ledec G. Neoclassical economics and principles of sustainable development. Ecol Model. 1987;38:19–46.
60. Pretty JN. Participatory learning for sustainable agriculture. World Dev. 1995;23:1247-1263.
61. Daly HE. Ecological economics and sustainable development: selected essays of Herman Daly. Cheltenham, UK: Edward Elgar; c2007.
62. Zegar JS. Współczesne wyzwania rolnictwa (Contemporary challenges of agriculture). Warsaw, Poland: Polish Scientific Publishers; c2012.
63. Vitunskiene V, Dabkiene V. Framework for assessing the farm relative sustainability: A Lithuanian case study. Agric Econ Czech. 2016;62:134–48.
64. Conceição P, Levine S, Lipton M, Warren-Rodríguez A.

Toward a food secure future: ensuring food security for sustainable human development in Sub-Saharan Africa. Food Policy. 2016;60:1–9.

65. Food and Agriculture Organization of the United Nations Statistical Database. FAOSTAT; c2020. Available from: http://www.fao.org/faostat/en/#data/ (accessed May 22, 2020).
66. Ward JH Jr. Hierarchical grouping to optimize an objective function. J Am Stat Assoc. 1963;58:236-244.
67. Marek T. Analiza skupień w badaniach empirycznych, metody SAHN (Cluster analysis in empirical research. SAHN methods). Warsaw, Poland: Polish Scientific Publishers; c1989.
68. Cox DR. Note on grouping. J Am Stat Assoc. 1957;52:543–547.
69. Fisher WD. On grouping for maximum homogeneity. J Am Stat Assoc. 1958;53:789–98.
70. Mardia KV, Kent JT, Bibby JM. Multivariate analysis. London, UK: Academic Press; c1979.
71. Poczta W, Średzińska J, Chenczke M. Economic situation of dairy farms in identified clusters of European Union countries. Agriculture. 2020;10:92.
72. Burchi F, De Muro P. From food availability to nutritional capabilities: Advancing food security analysis. Food Policy. 2016;60:10-19.
73. Mrówczyńska-Kamińska A. Znaczenie rolnictwa w gospodarce narodowej w Polsce: analiza makroekonomiczna regionalna (The importance of agriculture in the Polish national economy: macroeconomic and regional analysis). Zesz Nauk SGGW Probl Rol Świat. 2008;5:96–107.
74. Poczta W, Pawlak K, Dec M. Globalny problem żywnościowy–typologia krajów według stopnia niedożywienia (Global nutrition problem–a typology of countries according to the rate of undernourishment). J Law Econ Sociol. 2008;70:191-204.
75. Baer-Nawrocka A, Markiewicz N. Zróżnicowanie przestrzenne potencjału produkcyjnego rolnictwa w krajach Unii Europejskiej (The spatial differentiation of agricultural potential in EU countries). Roczn Nauk Rol Ser G. 2010;97:9–15.
76. Sapa A. Rolnictwo krajów najbiedniejszych–wybrane aspekty (Agriculture in the economies of the Least Developed Countries–selected aspects). Roczn Ekonomiczne Kujawsko-Pomorskiej Szkoły Wyższej w Bydgoszczy. 2012;5:149–59.
77. Brooks J, Matthews A. Trade dimensions of food security. Food, Agriculture and Fisheries Papers No. 77. OECD Publishing: Paris, France; c2015.
78. Gohar AA, Amer SA, Ward FA. Irrigation infrastructure and water appropriation rules for food security. J Hydrol. 2015;520:85–100.
79. Misselhorn A, Hendriks SL. A systematic review of sub-national food insecurity research in South Africa: missed opportunities for policy insights. PLoS ONE; c2017 .p. 12.
80. Food and Agriculture Organization of the United Nations Statistical Database. Capital stock. Available from: http://www.fao.org/faostat/en/#data/CS (accessed May 22, 2020).
81. Food and Agriculture Organization of the United Nations Statistical Database. Value of agricultural production. Available from: http://www.fao.org/faostat/en/#data/QV (accessed May 22, 2020).
82. Sen AK. Ingredients of famine analysis: availability and entitlements. Q J Econ. 1981;96:433–64.
83. Food and Agriculture Organization of the United Nations Statistical Database. Macro indicators. Available from: http://www.fao.org/faostat/en/#data/MK (accessed May 22, 2020).
84. Food and Agriculture Organization of the United Nations Statistical Database. Land use. Available from: http://www.fao.org/faostat/en/#data/RL (accessed May 22, 2020).
85. Food and Agriculture Organization of the United Nations Statistical Database. Trade. Available from: http://www.fao.org/faostat/en/#data/TP (accessed May 22, 2020).
86. Baydildina A, Akshinbay A, Bayetova M, Mkrytichyan L, Haliepesova A, Ataev A. Agricultural policy reforms and food security in Kazakhstan and Turkmenistan. Food Policy. 2000;25:733–747.
87. Løvendal CR, Jakobsen KT, Jacque A. Food prices and food security in Trinidad and Tobago. ESA Working Paper No. 07-27. FAO, Rome; c2007.
88. Zhou Z. Achieving food security in China: past three decades and beyond. China Agric Econ Rev. 2010;2:251–75.
89. Urban In-Depth Emergency Food Security Assessment. Djibouti. WFP, July 2011. Available from: https://reliefweb.int/sites/reliefweb.int/files/resources/Full_Report_2172.pdf (accessed June 20, 2020).
90. Bala BK, Alias EF, Arshad FM, Noh KM, Hadi AHA. Modelling of food security in Malaysia. Simul Model Pract Theory. 2014;47:152–164.
91. Ramphul N, Nowbutsing KB, Chittoo HB. An analysis of government policies in ensuring food security in small island economies: a case study of Mauritius. IOSR J Humanit Soc Sci. 2016;21:43-49.
92. Huang J, Wei W, Cui Q, Xie W. The prospects for China's food security and imports: will China starve the world via imports? J Integr Agric. 2017;16:2933-2944.
93. Fiaz S, Noor MA, Aldosri FO. Achieving food security in the Kingdom of Saudi Arabia through innovation: potential role of agricultural extension. J Saudi Soc Agric Sci. 2018;17:365-375.
94. Pillay DPK, Manoj Kumar TK. Food security in India: evolution, efforts, problems, and strategies. Anal. 2018;42:595–611.
95. Gorman T. From food crisis to agrarian crisis? Food security strategy and rural livelihoods in Vietnam. In: Food Anxiety in Globalising Vietnam. Ehlert J, Faltmann N, editors. Singapore: Palgrave Macmillan; c2019.
96. Roy D, Sarker DD, Sheheli S. Food security in Bangladesh: insight from available literature. J Nutr Food Secur. 2019;4:66-75.
97. Dithmer J, Abdulai A. Does trade openness contribute to food security? A dynamic panel analysis. Food Policy. 2017;69:218-230.
98. Clapp J. Food self-sufficiency: making sense of it, and when it makes sense. Food Policy. 2016;66:88–96.
99. Fader M, Gerten D, Krause M, Lucht W, Cramer W. Spatial decoupling of agricultural production and consumption: quantifying dependences of countries on food imports due to domestic land and water constraints. Environ Res Lett. 2013;8:014046.
100. FAO. The state of food and agriculture; c2018.
101. World Bank. Agricultural irrigation: a key to food security; c2020.

102. USDA. Conservation tillage practices; c2019.
103. NRCS. Soil health management; c2021.
104. CIMMYT. Post-harvest loss reduction in Africa; c2020.
105. World Food Programme. Improving grain storage to reduce losses; c2021.
106. IRRI. Mechanization in rice production; c2018.
107. IRENA. Renewable energy in agriculture; c2021.
108. ISAAA. Global status of biotech crops; c2019.
109. Purdue University. Precision agriculture technologies; c2020.
110. El-Dukheri I, Amer KM. Role of the Arab Organization for Agricultural Development in promoting agricultural development and food security in the Arab region. In: Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 1: National analysis of agricultural and food security. Cham: Springer International Publishing; c2024. p. 29-64.
111. Zou B, Mishra AK. Modernizing smallholder agriculture and achieving food security: an exploration in machinery services and labor reallocation in China. Appl Econ Perspect Policy; c2024.
112. Singh A, Margaryan G, Harutyunyan A, Movsesyan HS, Khachatryan H, Rajput VD, *et al*. Advancing agricultural resilience in Ararat plain, Armenia: utilizing biogenic nanoparticles and biochar under saline environments to optimize food security and foster European trade. Egyptian Journal of Soil Science. 2024, 64(2).
113. Salam A. Internet of things in agricultural innovation and security. In: Internet of things for sustainable community development: wireless communications, sensing, and systems. Cham: Springer International Publishing; c2024. p. 71-112.
114. Stout BA. Agricultural engineering. Reston, VA: American Society of Agricultural Engineers; c1990.