Chapter 19
Toward Smart Agriculture for Climate Change Adaptation

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Abstract Agriculture plays a significant role in food security and forms the backbone of the economic system of a country. The increase in population has led to an urgent need to balance demand and supply, threatening sustainability and putting pressure on agricultural systems. Furthermore, climate change challenges like extreme weather conditions, climatic changes, and environmental impact have adversely impacted agriculture and linked resources. Besides this, about 85% of Indian farmers are marginal and small landholders. About 60% of the net sown area is under rainfed agriculture, and this makes India vulnerable to climate change considerably affecting the cropping system, livestock, and soil and increasing pests and diseases. Climate change would have a serious impact on Indian agriculture in the coming years which would negatively impact some important crops leading to food insecurity. The present trend and scenario are evident that without an efficient measure, it would be very difficult to meet agro-demand of the country. Therefore, there is an urgent need of efficient measures of adaption and mitigation. Therefore, smart agriculture using IoT (Internet of Things) technology has opened up extremely productive ways for farmers, helps in managing agricultural systems, and deals with weather uncertainties and challenges improving resource management. It enables farmers to collect real-time data related to weather updates, irrigation, production, yield quality, and soil moisture and predict pest, diseases, and market information and strengthen good agricultural practices in farms. Additionally, IoT solutions along with smart practices in agriculture offer opportunities for innovation in climate adaptation reducing the ecological footprints and enhancing the livelihoods of farmers. Thus, the present paper aims to review the current and future trends of IoT in the Indian agriculture system, highlighting potential challenges and also its role in combating climate change. Additionally, the study recommends adoption of good agricultural practices, capacity building, and switching from traditional to precise farming with IoT-based technology. For future scope, institutional innovations, networking of farmers, regulatory authorities, clear policies supporting the necessary

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legal and market architecture for smart farming, and transparent data management system will be required.

Keywords Smart agriculture · Internet of Things · Climate change · Livelihood · Adaptation

Introduction

Climate change is a global concern impacting the Earth's ecosystem and humankind. A recent report by IPCC (Intergovernmental Panel on Climate Change) (2021) provides new estimates of the chances of crossing the global warming level of 1.5 °C in the next decades and is unequivocal (IPCC 2021). There will be intensification of extreme events globally, and weather uncertainties will be natural resources including agriculture sector. Most importantly, water scarcity is also one of the greatest challenges of the twenty-first century (FAO 2011), and agriculture accounts for an estimated 70% of global water withdrawals (WWAP 2015). Therefore, it is also important to address water scarcity as well as water use efficiency (Hatfield and Dold 2019; Pande et al. 2022a). In the Indian context, agriculture is the main backbone of Indian economy and accounts for around 20% of India's gross domestic product (GDP) (Economic Survey 2020–2021). Climate change impacts will be more visible in developing countries like India as compared to developed countries as millions of populations are dependent on agriculture and natural resources for their livelihood (IPCC 2014). Additionally, the rise in population increases the demand for food security putting pressure on natural resources (Adamides et al. 2020; Pande et al. 2021a; Rajesh et al. 2021). Furthermore, developing countries are more vulnerable due to low adaptation measures, lack of financial resources, and technological constraints. Thus, these impacts in turn have significant economic, social, and environmental consequences, so a better understanding of all the changes that might arise in view of climate change and variability is essential. To meet the needs and to overcome these challenges, one has to adopt new technologies to gain a much-needed edge. New agricultural application in smart farming is precise through IoT which enables crop farmers to collect real-time data related to irrigation and plant protection processes, aiming to increase production volume, improve product quality, and predict diseases, while optimizing resources and farming processes (Adamides et al. 2020). It improves the livelihoods of farmers and helps them in tackling climate change challenges. Thus, this chapter reviews the potential of current and future trends of smart agriculture using IoT-based tools in India and challenges and role in combating climate change. The study recommends the use of good agricultural practices along with adoption of IoT-based smart agriculture in combating climate change.

Smart Farming Approach

Smart agriculture with IoT-based solution is "a group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate" (Dorsemaine et al. 2015). By utilizing data like temperature, rainfall, soil moisture, humidity, wind, pH, etc. from IoT devices in the field and using cloud computing and analytics, farmers are timely notified to proceed with such targeted activities, and proper planning is done for farming based on the real-time database (Ayaz et al. 2019; Adamides et al. 2020).

The schematic diagram below shows the use of IoT-based techniques where different sensors, microcontrollers, power supply, and cloud computing and its application in the agricultural system (Fig. 19.1).

The application of IoT in agriculture aims at empowering farmers, enhancing livelihoods of farmers, and providing decision tools and automation technologies that integrate products, knowledge, and services for increased productivity, quality improvement, and profit (Elijah et al. 2018). It utilizes advance information and communication technology (ICT) and deploys smart sensors in the field, scanning the field with drones and enhancing the use of spatial and real-time events (Walter et al. 2017). This approach improves farm productivity, quality yield, increased production, profitability, efficient irrigation, identification of pests/diseases, and precise use of pesticides. Good practice approach enhances the use of organic manure, less use of pesticides, selection of crops, timings, crop rotation, maintaining soil health, and efficient use of water in agriculture which in turn also reduces environmental footprint. Thus, for an economically and environmentally sustainable production system, there is a need to develop techniques that can increase crop

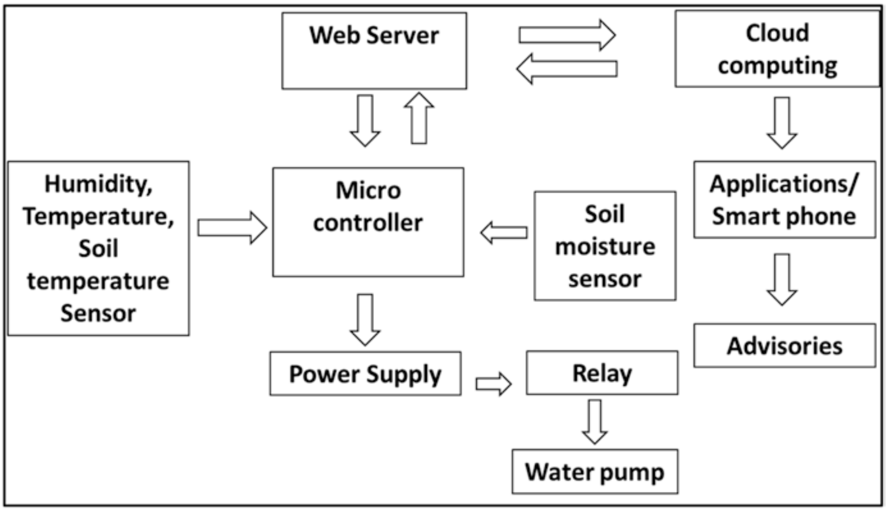

Fig. 19.1 Schematic diagram of IoT and its application

production through increased efficiency of input use and reduced environmental losses, and smart agriculture using IoT solutions is the key component of sustainable agriculture in the twenty-first century (Delgado et al. 2019; Sishodia et al. 2020). Smart agriculture is based on three important pillars: (i) better resource management, (ii) improved conservation of ecosystem and landscape, and (iii) smart farming technologies with more adequate services for farmers (Adamides et al. 2020). It is estimated that the smart agriculture market will grow by 12.7%, annually (Chen et al. 2019). In the next several years, the use of smart solutions powered by IoT will increase in agricultural operations. In fact, a few of the recent reports depicted that the IoT device installation will see a compound annual growth rate of 20% in the agriculture industry and a number of connected devices (agricultural) will grow from 13 million in 2014 to 225 million by 2024 (Machina 2017; Elijah et al. 2018). Thus, most countries are switching from traditional farming to technology-based farming in the long run.

From Data Collection to Farming Advisories

Different emerging technologies like the Internet of Things (IoT), Big Data analysis, artificial intelligence (AI), remote sensing, geographic information systems (GIS), and global positioning systems (GPS) are very important tools in agricultural operations which aimed to enhance production and reduce inputs and yield losses (Elijah et al. 2018; Delgado et al. 2019; Jha et al. 2019; Pande et al. 2021b, 2022a, b). Furthermore, IoT technology systems utilizing cloud computing, wireless sensor networks, and big data analysis have been developed for smart farming operations such as automated wireless-controlled irrigation systems and intelligent disease and pest monitoring and forecasting systems (Elijah et al. 2018; Jha et al. 2019; Shisodia et al. 2020). AI techniques, including machine learning, have been used to estimate different parameters like evapotranspiration (ET), soil moisture, soil pH, and crop predictions for automated and precise application of water, fertilizer, herbicides, and insecticides (Boursianis et al. 2020). These technologies and tools enable farmers to characterize the important crop growth parameters enabling the management of good growth and yield and avoiding losses (Koch et al. 2004).

The ecosystem of smart agricultures includes the following as mentioned below:

Internet of Things (IoT)

IoT is a technology aimed at connecting all intelligent objects within a single network, that is, the Internet. It involves all kinds of computer technologies, both (a) hardware (intelligent boards and sensors) and (b) software (advanced operating systems and AI algorithms). Its primary target is the establishment of applications for devices, in order to enable the monitoring and control of a specific domain primarily used in agriculture for the management of agricultural products within gathered real-time data, alongside: (1) searching, (2) tracking, (3) monitoring, (4) controlling, (5) managing, (6) evaluating, and (7) operations within a supply chain.

Big Data Analytics (BDA)

It refers to the large volume of data gathered from different dataset sources over a long period of time, that is, sensor, the Internet, and business data. Thus, BDA involved the utilization of (a) tools, classification and clustering; (b) techniques, data mining, machine learning, and statistical analysis; and (c) technologies (Alreshidi 2019). The use of BDA in agriculture focusses on the management of the supply chain of agricultural products, in order to enhance decision-making and minimize the cost of production cost. It is also employed for the analysis of the properties of different types of soil for classification and further enhancement. Furthermore, it is useful for improved prediction and crop production.

Cloud Computing

It is "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Alreshidi 2019). The cloud computing can be seen as a high virtualization method for datacenter infrastructure distributed over a wide geographical area, linked by means of high bandwidth network cables providing a variety of virtualized services. All these advanced data acquisitions and processing techniques aid the decision-making process for field crops, horticulture, pasture, and livestock (Shisodia et al. 2020).

Mobile Computing

It refers to infrastructure in which data processing and data storage take place externally to the mobile device. Systems collect and send daily data to farmers, informing them of both the production status and weather conditions.

Artificial Intelligence (AI)

AI covers many areas, including computer vision, data mining, deep learning, image processing, and neural networks (Kale and Patil 2019; Elbeltagi et al. 2022a, b). It includes robots, monitoring crops and soils, and predictive analytics, as the following:

(a) *Robots:* These are developed and programmed to handle fundamental agricultural tasks/human force.
(b) *Monitoring crop and soil:* It employs computer vision and deep learning algorithms for processing captured data by sensors monitoring crop and soil health.
(c) *Predictive analytics:* This analysis captures data, based on machine learning models capable of tracking and predicting various environmental impacts on crop harvest, that is, changes in weather. IoT/AI technologies (such as drone and satellite) that generate a large amount of data on a daily basis have the potential to enable agricultural production to forecast changes and detect opportunities (Alreshidi 2019).

Applications

Smart agriculture also includes Farm Management Systems (FMS) that assist farmers with a variety of collected information, by managing and controlling various tracking devices and sensors (Alreshidi 2019). The devices are attached to solar panel for power supply, and good network connectivity is the outmost need. Remote sensing and GIS tools can be also used for monitoring farms, crop yields, water management, nutrient management, disease management, and production spatially and temporally. Remote sensing uses sensor-based technology, and these sensors differ based on spatial, spectral, radiometric, and temporal resolution. Numerous vegetation indices like NDVI (normalized difference vegetation index), EVI (enhanced vegetation index), and statistical/machine learning approaches, such as deep convolutional neural network and random forest, have been applied to reduce the dimensionality of hyperspectral data to extract useful information on crop conditions (Zarco-Tejada et al. 2016; Chlingaryan et al. 2018; Chang et al. 2020; Elbeltagi et al. 2022a). More recently, quantification of solar-induced chlorophyll fluorescence (SIF) from hyperspectral images has increasingly been applied to estimate photosynthesis, plant nutrients, and biotic and abiotic stresses such as disease and water stress (Zarco-Tejada et al. 2016; Mohammed et al. 2019).

Additionally, special devices like automated weather stations collect weather-related data like rainfall, temperature, humidity, wind, etc. Disease models and sensor-based cameras provide accurate information on pest−/insect-related diseases in crops and help in predicting the trends. Precise information on crop pests/insects provides alerts when there is rise in pest attacks and saves the crops from further damage. Additionally, it provides guidance in the use of appropriate pesticides/insecticides in farms. The utilization process of IoT/AI technologies aids in establishment, monitoring, management, processing, and analysis of data generated from various agricultural resources, such as field, crops, livestock, etc. and further enriches decision-making of stakeholders (Kumar et al. 2012).

Decision-Making in Farmers

The large data obtained from sensor offers learning opportunities to improve decision-making in constantly changing environmental conditions; such decision-making can be over a short, medium, or long term (Adamides et al. 2020). It allows various farms to be connected and managed on a single platform, where information on scientific advances, production, marketing, farm management, recommendations, and other related topics are disseminated to maximize productivity, yield, and revenue. Automated decisions can be made from the IoT system when certain conditions are reached, therefore requiring less or no human interventions. Such automated decision could range from regulating the temperatures to the control of water supply from an irrigation system.

Insurance

Farmers are usually exposed to extreme weather conditions which could lead to poor harvest and yield loss due to unpredictable rain and lack of storage system. However, with the implementation of IoT technology, farmers can be insured with their crops and livestock. A network of sensors can be deployed, and monitoring can be achieved by remote unmanned stations (Alreshidi 2019). The data can be sent to the cloud and analyzed. The insurance policy can be embedded with a warning system, where extreme weather conditions are predicted and the insured farmers are alerted by text messages. This can enable the farmers to take precautionary approach to protect their farms.

Advisories

With the help of various applications and interfaces in smartphones, farmers can receive advisories at regular intervals at their doorsteps. They can plan agricultural practices as per the precise information reducing the risks. Additionally, with connectivity through online interface, they get platform to connect to markets for buying and selling their produce with the right price (Fig. 19.2).

Fig. 19.2 Mobile application

Climate Change and Agriculture

India is the third highest greenhouse gas (GHG) emitter after China, and the United States accounts for 18% of gross national emissions from agriculture and livestock. The agriculture sector is the main source of CH_4 and N_2O emissions (BUR 2021). In the year 2016, the agriculture sector emitted 407,821 Gg of CO2e. Within agriculture, in 2016, 54.6% of GHG emissions were due to enteric fermentation, followed by 17.5% from rice cultivation, 19.1% from fertilizer applied to agricultural soils, and 6.7% from manure management, and 2.2% due to field burning of agricultural residues (BUR 2018). Climate change is threatening India's food security with frequent dry spells, heat waves, and erratic monsoonal rainfall, adding to farmers' woes. As the global population continues to surge, developing countries will need to double food production by 2050. Consequently, scientists and policymakers are faced with the challenge of meeting the growing demand for food while also reining in on GHG emissions. Creating sustainable and climate-resilient agricultural systems has been highlighted as part of India's plan to meet its ambitious pledge to the United Nations Framework Convention on Climate Change international treaty to reduce the emission intensity of its GDP by up to 35% by 2030, compared to 2005 levels (INDC 2015). Moreover, frequent dry spells, heat waves, and erratic monsoonal rainfall add to farmers' woes. It is very much evident that climate change has a severe impact on global food production influencing both demand and supply of food grains, globally (Srinivasarao et al. 2018); under such conditions, the program of sustainable development goals will continuously slow down, affecting the communities immensely. Besides this, about 85% of Indian farmers and marginal and small landholders (Agricultural census 2011) and about 60% of the net sown area are under rainfed agriculture. This makes India vulnerable to climate change, considerably affecting the cropping system, livestock, fisheries, poultry, soil, pest, and diseases. Climate change would have a serious impact on Indian agriculture in the coming years which would negatively impact some important crops that would lead the country to food insecurity. The present trend and scenario are evident that without an efficient measure, it would be very difficult to meet agro-demand of the country. Thus, efficient measures of adaption and mitigation are required.

Advantages of Smart Agriculture Based on IoT and Good Agricultural Practices (GAPs)

IoT system has wide applications in the agricultural system. It can manage water content efficiency and soil health and also maintain crop growth. It has more advantages in multi-cropping agricultural system with diverse crops and huge yields. It saves time and minimizes manpower. It reduces the agriculture issues due to uncertainties in weather- or environment-related issues. It minimizes the manual works and makes a very effective farming system which promotes efficient use of water and soil management approach. It is a fast technology; increases crop production; improves crop quality, large production, and regular advisories; minimizes loss; and increases profits. To enable farm, produce to be internationally competitive innovative farming practices incorporating the concept of globally accepted good agricultural practices (GAP) within the framework of commercial agricultural production for long-term improvement and sustainability is essential. Good agricultural practices are "practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products" (Hobbs 2003). The four "pillars" of GAP are economic viability, environmental sustainability, social acceptability, and food safety and quality. GAP in addition to improving the yield and quality of the products also has environmental and social dimensions. Implementation of GAP would promote optimum utilization of water resources such as pesticides, fertilizers, water, and eco-friendly agriculture. Efficient use of fertilizer not only lowers emissions at the field but also reduces the need for fertilizer and the emissions associated with production and transportation. It also represents savings for the farmer. Mitigation options would include applying fertilizer at the right time and the right place for plant uptake or using slow-release fertilizer forms or nitrification inhibitors. Adoption of zero tillage farming and residue management-maintaining crop residues on the soil surface to protect the ground from erosion in rice, wheat, maize, cotton, and sugarcane was shown to reduce emissions. The use of sprinkler or micro-sprinkler irrigation and fertigation together reduces greenhouse gas emissions. Other good practices include the use of organic manure vermicompost, farm yard manures, integrated pest management, irrigation management, neem use of drip farming, zero tillage, no crop burning after harvest, timely sowing, harvesting, storage, transportation, and knowledge of markets. The implementation of GAPs contributes to sustainable agriculture and rural development.

Key Problems Faced in Indian Agriculture System

There are numerous factors which restrain India's agricultural output. Some of them are systemic or historical in nature, while others are related to environmental or technological factors. The technological factors have emerged primarily due to lack of advancement of agricultural techniques and affordability of machinery and equipment (Dixon et al. 2004). Systemic factors include cropping pattern monocropping; application of obsolete cropping patterns inhibits agricultural productivity and leads to soil degradation. Small/fragmented landholdings of farmers and land tenure make it difficult to achieve economies of scale and introduce new technologies and machinery. Further, due to lack of systematic agriculture financing provision, it is unaffordable for farmers to take load at high interest, thereby making finance unaffordable for farmers. Similarly, environmental factors like unpredictable behavior of monsoons influence agricultural productivity, overuse of fertilizers, increase in tillage, abandonment of traditional organic soil revival techniques, and insufficient rotation of crops resulted in soil degradation and loss of fertility (World Bank 2012). Furthermore, the diverse topography of India's land makes it essential to identify the right crops for the various soil variants and climatic conditions. Other factors include technological factors like lack of farm equipment, new farming techniques, lack of efficient ways of water supply for irrigation, groundwater, lack of storage facilities, awareness and illiteracy among farmers, market connectivity, and the use of traditional farming system (FAO 2017). An important aspect in rural India is the dependence of all household members on single source of livelihood which makes even more necessary to tackle the problems with a comprehensive strategy. While addressing most of these factors needs policy interventions, tackling some of them can be easier through the adoption of analytics and smart farming. Some of the drawbacks of IoT comprises requirement of continuous Internet connectivity, costlier, several kinds of security issues to maintain these types of networks, and a need of equipment maintenance done regularly.

Conclusion and Recommendations

Climate change is a global challenge affecting the natural ecosystem and humankind. It has detrimental effects on natural resources by altering their natural properties. Due to altering of soil and water properties, it not only impacts agriculture but also faulty farming practices have detrimental effects on the climate. Therefore, there is a need of smarter, better, and more efficient crop growing technology which meets the growing food demand of the increasing population, promotes sustainable agriculture, and reduces emissions. Thus, the use of AI and IoT techniques can help to practice sustainable agriculture and also contribute in climate mitigation by reducing the carbon footprint. Thus, this review paper highlights the role of IoT-based technology in agriculture in order to make agriculture smarter and more efficient to meet future expectations. Moreover, the high efficiency of integrated agriculture production systems delivers socioeconomic and ecological benefits that profit farmers as well as the whole society. There are many ways in which integrated agriculture production systems can help producers to adapt to climate change and provide important mitigation co-benefits. However, several factors hamper the effective adaptation of integrated production systems, such as lack of data on the impacts of climate change and high requirements in terms of knowledge and labor and initial investments that may pay off only over long time periods. Besides, a key area to be worked upon is the strategy to ensure economic feasibility and ease of adoption. Emphasis must be given to pilots, and after learnings from implantations, it can be further scaled up and framework could be developed. Furthermore, opportunities for entrepreneurs will arise in future in this sector. They can further help in capacity building of farmers and encourage for more adoption of such technology in their farms. Thus, the sustainable intensification of integrated agriculture production systems requires a better understanding of the impacts of changes in climate and climate variability on these systems; the generation and sharing of local and global knowledge, experiences, and practices; capacity development through research and development, dialogue, and dissemination of information; and the support and coordination of policies, particularly policies that can provide incentives and create enabling institutions. Climate-smart policies will emphasize incentives and capabilities to encourage improved decision-making at the farm level. This includes the adoption of best feasible technologies, improved input use, and post-harvest practices. Establishment of extension and improved supply chains may go a long way to meet this objective. Governments may also consider introducing insurance schemes with low transaction costs and moral hazard potential to reduce the cost of risk and risk aversion. Further, governments may provide input subsidies in short-term situations in which learning by doing is needed, as well as insured and subsidized credit. These activities should be designed to induce transition to sustainable and economically viable practices.

Thus, adopting smart agriculture IoT and practicing good agricultural practices in farms would be a boon in agriculture. It is a platform for development of new methods of improving crop yield and handling, technology, and innovation; tracking the crop growth, profit, safety, and nutrition labeling, and partnerships between growers, suppliers, and retailers and buyers. Additionally, IoT solution has bridged the gap between production and quality and quantity yield and increases profits. Real-time data provides precise information in the form of advisories related to weather updates, irrigation, production, yield quality, and soil moisture; predicts pest, diseases, and market information; and minimizes loss. The livelihoods of smallholder farmers will improve by adopting technology-based agriculture and play major role in managing food security in long run. Additionally, it acts as a viable climate change mitigation and adaptation approach to tackle climate change targets. Thus, it can be concluded that every inch of farmland is vital to maximize crop production and using of sustainable IoT-based sensors and communication technologies is not optional – it is necessary. This will further help in achieving our sustainable development goals and development of management practices, contribute in climate adaptation, and have implications in policy aspects.

In the way forward, it can be concluded that institutional innovations would be possible, leading to networks of farmers who are more self-organized and flexible than today. Joint use of machinery and applications can promote private exchange of sowing, maintenance, and harvesting operations. Yet, because regulatory authorities need to have access to some aspects of the data gathered, clear policies and a transparent data management system will be required. ICT and data management can provide novel ways into a profitable, socially accepted agriculture that benefits the environment (e.g., soil, water, climate), species diversity, and farmers in developing and developed countries. But this can only happen with the proactive development of policies supporting the necessary legal and market architecture for smart farming, with a dialogue among farming technology supporters and skeptics, and with careful consideration of emerging ethical questions.

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