Artificial Intelligence Based Precision Agriculture for Enhanced Productivity

Nilesh Jain[1*] and Smita Lenka[2]

[2] *ICAR – National Bureau of Plant Genetic Resources, Pusa, New Delhi – 110012, India*

***Abstract*- Agriculture contributes to about 29% of Gross Domestic Product (GDP) of developing nations and 18.2% of India's GDP accounting for about 65% of the developing countries' population and 42.3% of India's population. Agricultural development is one of the most important and powerful tool for any country's economic development including poverty alleviation and providing food and nutritional security. For this, we need to improve land-use by using healthy, sustainable and inclusive food systems with strong technological interventions including prominent use of Artificial Intelligence (AI) in precision agriculture, especially with global food production requirement to increase by 60-70%.**

Developing nations have been experiencing a slowdown in agricultural output rates in the developing countries where Total Factor Productivity (TFP) has grown by 1.06% in the 2010s as contrasted to 2.20% in the 2000s, whereas, it has increased from 0.83% in 2000s to 1.27% in the 2010s in the developed countries.

Precision agriculture using AI and data-driven approaches help drastically improve productivity and environmental sustainability while using technologies like sensors, drones, IoT, image recognition, etc., to precisely target optimum utilization of resources like water, fertilizers and pesticides through site-specific management, Variable Rate Application (VRA), AI sensor-based real-time monitoring leading to increased productivity and reduce loss by automatic fertigation system and image recognition based plant health monitoring and disease diagnosis/pest control coupled with automated drone/aerial based pesticide/insecticide application system is proposed to revolutionize traditional agriculture by reducing biotic and abiotic stress on one hand and the farmer reaping enhanced economic returns on the other. For this, institutional credit and government funding will essentially be required for capital investment in this paradigm-changing revolutionary concept.

***Keywords*- Precision Agriculture, Artificial Intelligence, Technology, Productivity, Disease Control, Fertigation**

I. INTRODUCTION

Agriculture contributes a substantial proportion of the developing countries' economies as also provides employment to a large section of their population. In the year 2018, agriculture employed more than 50% of the Indian workforce and accounted for 18% of its Gross Domestic Product (GDP). However, it is observed that the yield of the major cultivated crops including wheat, rice, pulses, cotton, fruits and vegetables is quite less as compared to the developed nations. Hence, with burgeoning population and reduction in arable land area due to increased urbanization, there is an urgent need for providing food security coupled with nutritional security to the citizens. Developing countries like India have, among others, a serious problem of dependence on the *monsoons* and the limited availability of scientific support in its villages to diagnose and control crop diseases to minimize crop loss.

Traditional farming is also one of the major causes of lower per capita productivity and consequent farmer incomes (Shakeel 2018). Traditional agriculture needs to be reinforced with modern approach in order to increase productivity and production (Reddy and Reddy, 1967). Modern agriculture practices are essentially required to make agriculture a profitable enterprise in India (Rao and Gulati, 1994). Introduction to new technologies and technological factors in fertilizers, biotechnology, seeds, etc. need to be accelerated for a better yield and output in the Indian agricultural sector and make it to become one of the leading agricultural countries. To do this, Artificial Intelligence (AI) can exceedingly and provenly be applied to agriculture. As observed (Zha, 2020), application of AI in agriculture has been considered to be one of the most viable solutions for addressing issues relating to the needs of food and nutritional security for a growing population.

Artificial Intelligence (AI):

Artificial Intelligence (AI) integrating the essential concept of adaptability, rapid performance, precision and cost-effectiveness creates machines that have the inherent capability of learning, reasoning and subsequently behaving like humans, and is exceedingly and quite successfully being applied to the field of agriculture, among others, be that in crop and soil monitoring, disease detection, monitoring and control, precision fertigation through predictive analysis based on the usage of machine vision, machine learning, deep learning and robotics, resulting in improved productivity and concurrently reduced crop loss with reduced human interference and drudgery (Subeesh and Mehta, 2021). John McCarthy coined the term in 1956 as branch of computer science concerned with making computers behave like humans when he and his colleagues sent the proposal for the now-iconic Dartmouth Conference on Artificial Intelligence. The central principles of AI include, such as reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects (Saini, 2023). There are several components of AI which can be applied in order to create a fully functional automated and integrated system for effective and efficient precision agriculture including smart fertigation and disease control mechanism.

Category	Component	Description
Machine Learning (ML)	Supervised Learning	Training models on labeled data
	Unsupervised Learning	Finding patterns in unlabeled data
	Reinforcement Learning	Training agents using rewards/punishments
	Deep Learning	Using neural networks with multiple layers
Neural Networks	Convolutional Neural Network (CNN)	Used for image recognition and processing
	Recurrent Neural Network (RNN)	Used for sequential data like speech and text
	Long Short-Term Memory (LSTM)	A type of RNN that handles long-term dependencies
	Transformer Models	Advanced deep learning architectures like GPT and BERT
Computer Vision	Image Processing	Techniques to analyze and process images
	Object Detection	Identifying objects in images/videos
	Semantic Segmentation	Classifying each pixel in an image
Natural Language Processing (NLP)	Text Classification	Categorizing text into predefined labels
	Sentiment Analysis	Understanding emotions in text
	Named Entity Recognition (NER)	Identifying names, places, etc., in text
	Machine Translation	Translating text between languages
AI Planning & Reasoning	Search Algorithms	Algorithms like A* and DFS for problem-solving
	Knowledge Representation	Storing information for reasoning
	Expert Systems	AI that mimics human decision-making
Robotics	Path Planning	Finding optimal routes for movement
	Sensor Fusion	Combining multiple sensor inputs
	Reinforcement Learning in Robotics	Training robots through trial and error
AI Ethics & Fairness	Bias Detection	Identifying and reducing AI bias
	Explainable AI (XAI)	Making AI decisions interpretable
	Fairness in AI	Ensuring AI models are unbiased

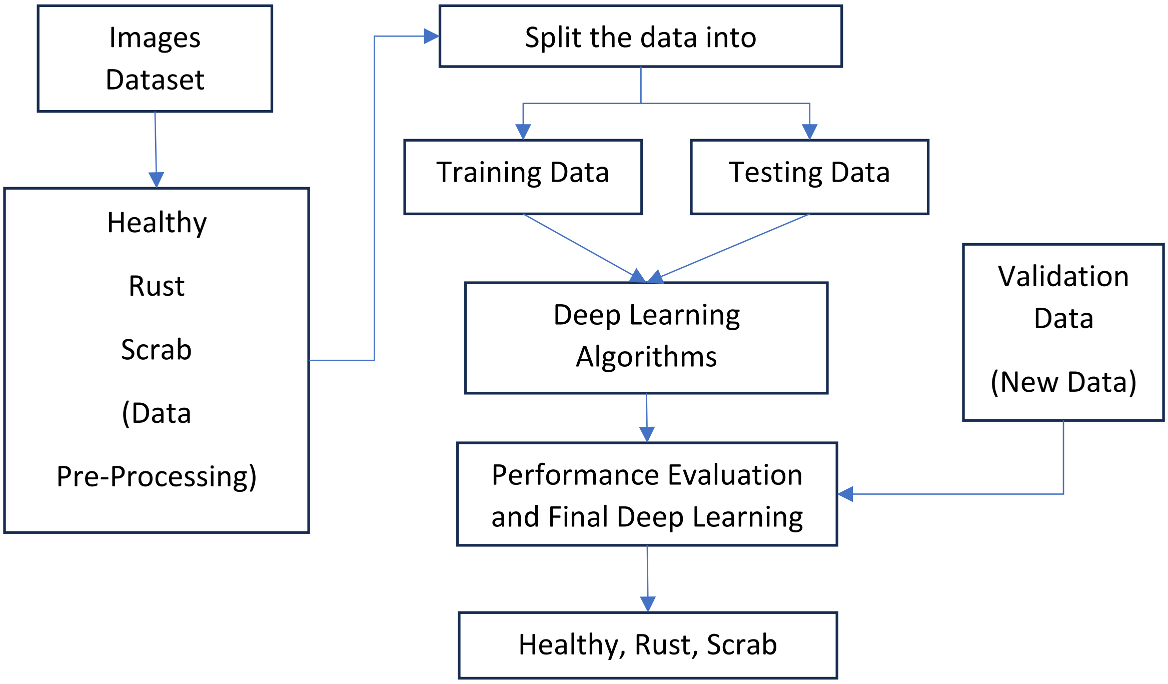
Machine Learning (ML) in Agriculture:

ML is one of the subsets of AI wherein machines are trained to learn for themselves through iterations and improve in tasks through experiential learning to make decisions by feeding them with data. ML algorithms include Supervised Learning, Unsupervised Learning, and Reinforcement Learning. In Supervised Learning, the model is developed and trained based on both known input objects and desired output/target/labeled value data for predictions. In Unsupervised Learning, the model identifies the hidden patterns autonomously and groups and interprets the data based only on the input object data/information. Reinforcement learning is used by machines to take suitable actions to increase the reward to find the best possibility which should be taken in to account.

Some of the use cases of ML in agriculture are optimizing cultivation, management, decision making and automation to enhance resource allocation, boost yield, and manage risks effectively. ML algorithms analyze images captured through satellites, drones, hand-held smartphones, Internet of Things (IoT) data captured through sensors to monitor crop health, detect disease, assess yield potential and crop growth. Insights of crop rotation, pest control strategies, optimal harvesting times are the thrust areas of ML application in agriculture.

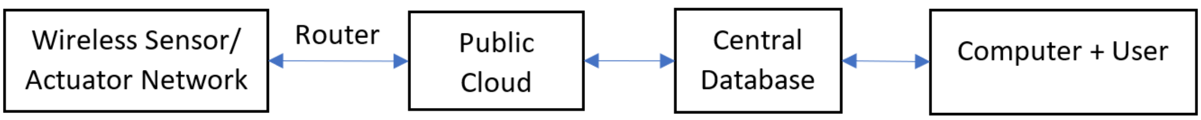
Deep Learning (DL) in Agriculture:

DL is a subset of ML that uses multilayer neural networks exposed to vast amounts of data, training machines to solve problems which require thought for predictive analysis. DL and ML differ from each other in certain ways. In ML, feature engineering is manually crafted while in DL, it autonomously learns complex features from raw data through hierarchical abstraction, ideal for unstructured data processing like images and texts. Some of the top DL algorithms are multilayer perceptrons, radial basis function networks, convolutional neural networks (CNNs), recurrent neural networks, long short – term memory networks, restricted Boltzmann machines, self-organizing maps, generative adversarial networks, autoencoders and deep belief networks.



Internet of Things (IoT) in Agriculture:

IoT establishes through the mechanism of enabling connection between devices and systems like sensors for real-time monitoring of parameters including soil moisture, temperature, humidity, crop health, actuator-controlled fertigation dispensing systems, cameras mounted in farms for scanning leaf structure, pigmentation, color and recognize changes for helping enhanced decision-making, resource optimization and predictive analysis. These are also important for scaling resources up or down based on demand, accommodating seasonal variations (scalability), allowing collaboration and data sharing among farmers, researchers and experts, and ensuring data privacy and integrity.



IoT System

IoT based precision agriculture system has two main layers, these are the Application Layer which is used for application development and deployment, set up configuration tools, remote sensing applications, big data analytics platform along with user interaction with AI; Communication Layer which includes various protocols for capturing data and connecting it to devices and platforms (animal, plant and computing resources like sensors, gateways and servers) such as JSON/XML, COAP/HTTP, UDP/TCP, IEEE, REST APIs, etc. Smart farming based on AI and IoT applications help farmers conduct effective real-time monitoring for optimal utilization of the resources including soil, water, fertilizer, manpower leading to sustainable, profitable and environment friendly agricultural practice (Zhao et al., 2010; Madakam et al., 2015; Verdouw et al., 2019).

Cloud Computing:
Cloud computing involves a network of servers connecting computers or IT infrastructure over the Internet. This essentially involves sharing of resources, software, applications and services over the internet to meet the varied demand of the users entailing least effort or interaction with the service provider. Cloud computing has three types of services:

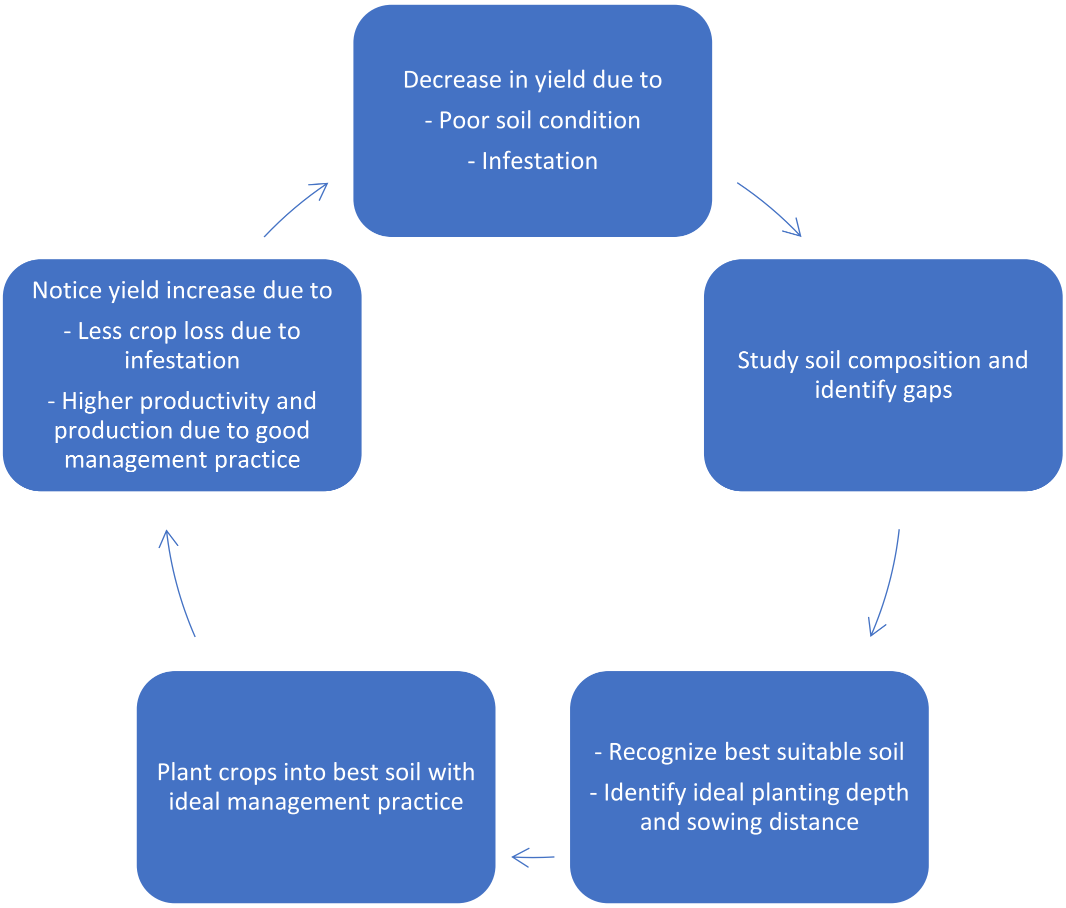
Platform as a Service (PaaS) is used to build software applications and engines to support relevant infrastructure and backbone for applications; Software as a Service (SaaS) helps in anytime–anywhere access to data and applications; Infrastructure as a Service (IaaS) provides computing power the storage needs for cloud.

The advantage of cloud computing is mainly based on the fact that data stored in cloud has vast amounts of agricultural data, sensor readings, satellite imagery, historical records, etc. Data processing helps in high performance computing for data analytics, modeling, creating predictive algorithms, etc.

Google Cloud and AI in Farming:
Offers precision agriculture platform, AI based solution for targeting large scale data, pictures of crops for disease and pest infestation early-stage diagnosis, and prediction for timely Phyto pathological intervention to avoid crop loss, thereby, producing healthier plants, leading to increased yields with lesser efforts. Timely detection of infestation by pathogens with the help of imaging sensors and image analysis has extensively been used in recent times for disease detection in cotton, banana, cassava, maize, rice, grapes, potato, wheat, tomato, peas, cucumber, peach, mango, apple, tea, etc., thereby enabling timely and appropriate intervention for eliminating such deterrents to healthy crops. Smart drones with high-definition cameras and image recognition systems on board have helped in early disease detection and monitoring and consequently, through autonomous and self-guided systems, applied the appropriate pesticides in accurately applicable quantities and frequency on the affected crop, removing human intervention. Also, several studies have established strong correlation between pest infestation and yield loss in various crops in India (Nair, 1975; Dhaliwal and Arora, 1994; Muralidharan *et al*, 2003; Rajeswari *et al*, 2004; Muralidharan and Pasalu, 2006; Rajeswari and Muralidharan, 2006), which is estimated to be about 37.4% in rice, 28.2% in wheat, 31.2% in maize and 26.3% in soybean worldwide (Oerke, 2007). Similarly, it amounts to 25% in rice and maize, 5% in wheat, 15% in pulses and 50% in cotton (Dhaliwal *et al*, 2010). Such precision pre-symptomatic disease detection from biotic and abiotic data analysis can traverse a long way in mitigating crop loss and ensuring higher productivity, production and increased profitability. It also helps in providing precise data and, consequently prediction of sowing date, planting depth, spacing based on soil mineralogy, fertilizer recommendations and weather forecast.

India’s largest precision farm includes soil-less cultivation (uses cocopeat instead), has temperature-controlled germination rooms, climate sensors and high-pressure fogging system.
Soilless agriculture has been highly appreciated by the world over primarily due to its ability for maximizing crop production in an intensive environment. It utilizes enclosed growing structures and systems enabling the management of reusable effluents, thereby minimizing water and nutrient losses, resulting in reduced water and environmental pollution. With the integration of IoT sensors, continuous monitoring of crop growth is done for immediate and real-time restoration of normalcy. Hydroponics, aeroponics, and aquaponics which are widely used in soilless cultivation techniques, involve nutrient solutions and inert media for supporting plant growth. Such technological advancements offer promising prospects for profitable and sustainable agriculture. (Satpute et al., 2024).

Smart Farming Cycle:



Challenges:

However, with a multitude of advantages which harbinger tangible results and benefits, AI based technologies have their inherent challenges, primarily with regard to data privacy and security, connectivity issues in rural and remote areas where internet access is limited, especially in developing and underdeveloped countries coupled with adoption barriers, technology literacy, and resistance to change. Another major constraint in effective and real-life application of AI based precision agriculture is the huge amount of investment required for an integrated system farm which needs to be addressed at governmental levels since such large-scale investments seem to be a distant reality for individual farmers, especially medium and small farmers having access to limited financial resources.

Prospects of AI in Agriculture:

AI and ML will be used for advanced analytics, predictive modelling, and decision making. Edge computing will bring computing resources closer to the source of data for faster processing and reduced latency. Combining IoT and Cloud computing will enhance the capabilities of emerging technologies. Automated drones can be used for precise fertilization, keep track of soil and crop health and progress which will be very beneficial to understand the crop cycle process. Satellites use AI to provide accurate and detailed weather reports. This can also help in increasing the productivity and reducing operator exposure. This method has been a priority in China and Thailand. The Covid-19 pandemic affected everyone globally which was challenging to farmers and the economy of the countries. Despite of the stay-at-home order, farmers continued to go out and work in farms to keep the crop productivity alive for food production. (Narain, 2020, pp. 2-6). India has diversity in its climatic and soil conditions. Areas which are densely vegetated receive heavy rainfall throughout the year. But certain areas don't receive rainfall for years and are highly dependent on monsoon. This affects the food production and the nation's economy (Saha et al., 1979, pp. 177). Monsoon season in India (June-September) majorly affects the crop productivity for the two main crops which are Kharif (summer) and Rabi (winter) and the economy of India. Almost 65% of India's population consists of rural areas which are dependent on agricultural practices (Prasanna, 2014, pp. 1129).

Majority of Indian farmers are not well equipped with technology for having strategies for manual water system and this brings up and down in their economic status (Karnawat et al., 2020, pp. 1019-1021). Plant disease has massive impact on the quality and production of fiber, crops, food, etc. Pests and insects often damage the crops and farmers cannot do much about it. Billions of dollars are spent on crop disease management without any technical support which cause pollution, result in poor disease control, and other harmful biological effects. This might also degrade the land on which the crops are being produced (Guest, 2006).

A comprehensive AI based fertigation system for improved productivity and production together with intelligent disease diagnostic and control system to address some of the major issues presently being faced by Indian agriculture is the necessity of the hour. There is a huge gap in the present availability of scientific agricultural practice systems developed in the laboratory and research field conditions and the actual implementation in the farmers' fields. The question, therefore, is how to make use of the available technology for improving the farmers' economic condition as also reduce dependence on agricultural produce imports together with increased agricultural produce exports by such developing countries.

AI based sensors for moisture and micronutrients like Nitrate (N), Phosphate (P) and Potassium (K) will be placed in the farmers field which will be divided into cells of appropriate size forming a matrix. These sensors will be calibrated with pre-filled data relating to optimum moisture and NPK levels for the standing crop. These sensors will also continuously transmit real time data which will be received at a receiving station near the field which will subsequently feed this data into a computer. The field will have a network of servo motor-based irrigation system which will double up as water mixed fertilizer supply lines also.

Based on the real time information being received from the sensors and comparing them with pre-fed desired data levels, the automatic water and/or fertilizer (N or P or K) will be supplied to specific cells of the matrix which will trigger such distress signals. Thus, there will not be any abiotic stress faced by the growing crop thereby increasing productivity and consequently production. High yield variety seeds will be used to further optimize yield. No human interference will be required leading to available manpower getting engaged in other productive sectors.

Additionally, pest and control are another important area to achieve higher productivity and production levels. For this, low flying camera equipped drones will regularly fly over the cropped area and transmit real time visual data of the canopy leaves to the control center system. The transmitted image will be matched with pre-fed healthy leaves images and immediately trigger distress signals in case of unhealthy (diseased) leaves being spotted for remedial action including spraying of insecticide/pesticide. This would concurrently be remotely monitored by experts for effective diagnosis of infestation by experts. This real time identification and diagnostic mechanism will drastically reduce the biotic stress on crops and reduce the otherwise possible crop loss leading to unimaginable economic losses.

II. CONCLUSION

This AI based farming model is highly cost effective requiring very less manpower and is bound to deliver high quality yield of the crops due to optimum and timely provisioning of water and micronutrients reinforced with least abiotic and biotic stress. This, however, required initial capital for establishment of the farmland which seems to be a detriment in the developing countries' perspective. Hence, institutional credit finance would be required to bridge this gap. The remote diagnosis of disease is one of the best features of this model, especially where we do not have locally available expertise. This model if implemented can transform agricultural practices in countries leading to exponential increase in their GDP.

REFERENCES

[1] Chennareddy, V., (1967). Production efficiency in South Indian agriculture. Journal of Farm Economics, 49(4), 816. https://doi.org/10.2307/1236938.

[2] Davis, M. R. (n.d.). Agriculture. Agriculture | Special Issue : The Impact of Plant Disease on Food Security. Retrieved November 19, 2021, https://www.mdpi.com/journal/agriculture/special_issues/plant_disease.

[3] Indian agriculture: Emerging perspectives. (n.d.). Retrieved November 19, 2021, from https://www.jstor.org/stable/4402192.

[4] Karnawat, M., Trivedi, S. K., Nagar, R., & Nagar, D. (n.d.). Role of monsoon in Indian agriculture. Biotica Research Today. Retrieved November 19, 2021, https://bioticainternational.com/ojs/index.php/biorestoday/article/view/488.

[5] Madakam, S., Ramaswamy, R. and Tripathi, S. (2015) Internet of Things (IoT): A Literature Review. Journal of Computer and Communications, 3, 164-173.https://doi.org/10.4236/jcc.2015.35021.

[6] Narain, D. (n.d.). Transforming Indian agriculture: A policy framework to guide Us-India Partnership. Atlantic Council.

[7] Prasanna, V. (2014). Impact of monsoon rainfall on the total foodgrain yield over India. Journal of Earth System Science, 123(5), 1129–1145. https://doi.org/10.1007/s12040-014-0444-x.

[8] Saha, K. R., Mooley, D. A., & Saha, S. (1979). The Indian monsoon and its economic impact. GeoJournal, 3(2). https://doi.org/10.1007/bf00257706.

[9] Saini, N., Artificial Intelligence and Its Applications, International Journal of Science & Engineering Development Research (www.ijrti.org), ISSN:2455-2631, Vol.8, Issue 4, page no.356 - 360, April-2023, http://www.ijrti.org/papers/IJRTI2304061.pdf

[10] Satpute, Ajay & Gavhane, Kishor & Kaur, Simranpreet & Jha, Ayushi & Pradhan, Nrusingh & Chowdhury, Manojit. (2024). Integration of AI and IoT in Soilless Cultivation to Power Sustainable Agricultural Revolution. 10.1007/978-981-97-0341-8_19.

[11] Shakeel, A., (2018) Traditional Agriculture and its impact on the environ-ment. Jaran Josh 3–5. https://www.jagranjosh.com/general-knowledge/traditional-agriculture-and-its-impact-on-the-environment-1518096259-1.

[12] Subeesh, A., Mehta, C.R., Automation and digitization of agriculture using artificial intelligence and internet of things, Artificial Intelligence in Agriculture, Volume 5, 2021, Pages 278-291, ISSN 2589-7217, https://doi.org/10.1016/j.aiia.2021.11.004.

[13] Verdouw, C., Sundmaeker, H., Tekinerdogan, B., Conzon, D. and Montanaro, T.(2019) Architecture Framework of IoT-Based Food and Farm Systems: A Multiple Case Study. Computers and Electronics in Agriculture, 165, Article ID: 104939.https://doi.org/10.1016/j.compag.2019.104939.

[14] Zha, Jiali, Artificial Intelligence in Agriculture, 2020 J. Phys.: Conf. Ser. 1693 012058.

[15] Zhao, J., Zhang, J., Feng, Y. and Guo, J.X. (2010) The Study and Application of the IOT Technology in Agriculture. 2010 3rd International Conference on Computer Science and Information Technology, Chengdu, 9-11 July 2010, 462-465.