JURNAL ONLINE
PERTANIAN TROPIK

Smart Agriculture Application in Rice Cultivation

Gürkan A. K. Gürdil [*1], Benny Hidayat [2], Bahadır Demirel [3], Elçin Yeşiloğlu Cevher [1]

[1] *Ondokuz Mayis University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering. Samsun, Türkiye*
[2] *Faculty of Agriculture, Universitas Sumatera Utara (USU), Medan, Indonesia*
[3] *Department of Biosystems Engineering, Faculty of Agriculture, Erciyes University, Kayseri, Türkiye*
[*]Corresponding Author:ggurdil@omu.edu.tr

ARTICLE INFO

Article history:
Received : July 2024
Revised : July 2024
Accepted : Augustus 2024
Available online:
https://talenta.usu.ac.id/jpt

E-ISSN: 2356-4725
P-ISSN: 2655-7576

How to cite:
Gurdil, G.A.K.,et al. (2024). Smart Agriculture Application in Rice Cultivation. Jurnal Pertanian Tropik. 11(2), 009-021

ABSTRACT

Rice is a staple food crop that feeds a significant portion of the world's population. Ensuring sustainable and efficient rice production is crucial for global food security. In recent years, the integration of smart agriculture technologies has shown promise in improving various aspects of rice cultivation. This paper provides an overview of the key smart agriculture applications that can enhance rice cultivation practices. The review discusses the use of precision farming techniques, such as GPS-guided tractors and drones for site-specific management of inputs like fertilizers and pesticides. It also examines how sensor networks and Internet of Things (IoT) devices can monitor environmental conditions, soil fertility, and plant health to enable data-driven decision-making. Smart irrigation systems leveraging soil moisture sensors and weather forecasts are highlighted as a means to optimize water usage. Furthermore, the paper explores the role of automation and robotics in automating labor-intensive tasks like transplanting, weeding, and harvesting. It also discusses the potential of machine learning and predictive analytics to improve crop yield forecasting, pest and disease management, and supply chain logistics. The adoption of these smart agriculture technologies in rice farming has demonstrated improvements in productivity, resource efficiency, and environmental sustainability. However, challenges remain in scaling up these solutions and ensuring their accessibility to smallholder farmers. The paper concludes by outlining future research directions and policy considerations to further advance smart agriculture in the rice cultivation sector.

Keyword: smart agriculture, land management, policy consideration, environmental condition

ABSTRAK

Beras merupakan tanaman pangan pokok yang memiliki porsi yg besar pada kehidupan penduduk dunia. Memastikan produksi beras yang berkelanjutan dan efisien sangat penting bagi ketahanan pangan global. Dalam beberapa tahun terakhir, integrasi teknologi pertanian cerdas telah menunjukkan hasil yang menjanjikan dalam meningkatkan berbagai aspek budidaya padi. Makalah ini memberikan gambaran umum tentang aplikasi pertanian cerdas yang dapat meningkatkan praktik budidaya padi. Tinjauan tersebut membahas penggunaan teknik pertanian presisi, seperti traktor dan drone yang dipandu GPS untuk pengelolaan input spesifik lokasi seperti pupuk dan pestisida. tulisan ini juga mengkaji bagaimana jaringan sensor dan perangkat Internet of Things (IoT) dapat memantau kondisi lingkungan, kesuburan tanah, dan kesehatan tanaman untuk memungkinkan pengambilan keputusan berdasarkan data. Sistem irigasi cerdas yang memanfaatkan sensor kelembaban tanah dan prakiraan cuaca disorot sebagai cara untuk mengoptimalkan penggunaan air. Lebih lanjut, artikel ini mengeksplorasi peran otomatisasi dan robotika dalam mengotomatisasi tugas-tugas padat karya seperti penanaman bibit, penyiangan, dan pemanenan. Hal ini juga membahas potensi pembelajaran mesin dan analisis prediktif untuk meningkatkan perkiraan hasil panen, pengelolaan hama dan penyakit, dan logistik rantai pasokan. Penerapan teknologi pertanian cerdas dalam pertanian padi telah

https://doi.org/10.32734/jopt.v11i2.17832

menunjukkan peningkatan produktivitas, efisiensi sumber daya, dan kelestarian lingkungan. Namun, masih terdapat tantangan dalam meningkatkan solusi-solusi ini dan memastikan aksesibilitasnya bagi petani kecil. Makalah ini diakhiri dengan menguraikan arah penelitian di masa depan dan pertimbangan kebijakan untuk lebih memajukan pertanian cerdas di sektor budidaya padi
Kata kunci*:* pertanian cerdas, mengelolaan lahan, kebijakan pertanian, lingkungan

1. Introduction to Smart Agriculture

Rice is an important cereal plant. The development of smart agriculture is also an important issue in the cultivation of rice. In this chapter, we will discuss some practical experience of smart rice cultivation. We use FPGA to collect image and crop information and provide a basis for farm and agricultural research. In terms of environmental management, we will also discuss the research results on water information collection and irrigation management. The remaining of this chapter is organized as follows: Section II introduces the smart agriculture application. In Section III, we provide information about practical methods for smart agriculture in rice cultivation. In Section IV, we summarize the chapter with the indicated smart agriculture applications and future directions.

The issues of food safety and energy and environment sustainability are important priorities in the smart agriculture industry. The high demand for food necessitates the development of new technologies in the agriculture industry. Smart agriculture refers to the practices that will make farming more productive and efficient using smart agriculture systems that integrate multiple devices and platforms such as sensors, IoT devices, mobile operation platforms, and intelligent devices connected via the network. Smart agriculture is applicable to domestic and industrial farming environments. The aim is to help farmers achieve sustainable and innovative farming that requires lower human intervention and helps them make informed decisions by providing valuable remote monitoring and management possibilities. These tools make smart agriculture a growing industry nowadays, and they have been employed in different industries to create value, such as those related to food and environment monitoring, tourism, public supply management, and public security. (Quy et al.2022) (Gagliardi et al.2021) (Dhanaraju et al.2022) (Boursianis et al.2022) (Javaid et al.2022) (Ouafiq et al., 2022)

2. Definition and Scope of Smart Agriculture

The rice grain quality, rice growth phase and classification, rice field weed control, rice field pest management, rice field disease and source of disease management, rice tillage, the rice field irrigation, rice field interplanting/nitrogen-fertilization assessment, rice field growth drought degree assessment, rice field organic MIN content, and cadmium accumulation characteristics will be connected to the entire processes, facts, and ideas described in this smart agriculture for a general view of smart agriculture in rice cultivation. This chapter answers what smart agriculture is in rice cultivation. It is beneficial to researchers, growers in the surrounding sites, educators, students, and others to understand what smart agriculture is in rice cultivation.

Smart agriculture is a coalescence of multiple technologies providing an automated agricultural platform, IoT (Internet of Things), AI (Artificial Intelligence), and big data, deeply rooted in the digital age for sustainable and high-yielding agriculture. The application of information technologies, such as IoT, AI, robotics, and big data platforms in agriculture, promises a substantial increase in farm productivity and ensures food security. By connected systems, data generation and collection capacities in the agricultural sector increase incredibly, allowing for the application of knowledge from already existing real-time decisions in rural production systems. This can modify time-consuming tasks, costly mistakes, and reduce environmental issues. (Kalogiannidis et al.2022)(Erickson & Fausti, 2021)(Ayim et al.2022)(Shankarnarayan & Ramakrishna, 2020)

3. Importance of Rice Cultivation

Rice is a versatile staple food consumed by a large section of the world population. According to the United States Rice Federation, rice cultivation is one of the most important activities on Earth, with the personnel of many nations—Asia in particular—farming rice three times a year. Rice is increasingly under threat due to the extensive pressure to increase its supply. Recent research and data have found that the supply of rice is threatened as the market faces challenges in generating the required supply levels. This is contributed to by several factors, including available farmland, climate change, water usage, and the decreasing interest of farmers in rice cultivation. With increasing mortality rates and ever-growing populations, the world needs to reassess the situation, potentially collaborating with other global agricultural systems to share resources and avoid conflicts in the future. (Bin Rahman & Zhang, 2023)

Rice is an important cereal and a staple food in many countries. It is produced in 115 countries throughout the world. There are various smart agriculture applications developed specifically for paddy/rice field. It includes applications for management and maintenance of paddy fields, precision agriculture, business management, and weather forecast. Due to the nature of the cultivation of the crop, layering of data through smart agriculture can be carried out at different altitudes, including land, canopy, and aerial devices. There is a high demand to involve smart agriculture techniques in paddy fields to increase the productivity of the crop and promote ease in managing the crop and the farm itself. The intervention of artificial intelligence in agriculture has been proven to yield faster, better, and cheaper responses. The aim of this paper is to introduce the different smart agricultural applications that can be utilized to monitor, maintain, and manage rice cultivation. (Mohidem et al., 2022)(Śliwińska-Bartel et al.2021)

4. Role of Rice in Global Food Security

Agricultural producers face unique challenges such as floods, a large number of grains in the water, transplanted rice crop at regular intervals, labor shortage, ecological changes in the rain-fed area, pests, diseases, and pests of golden rice and symbiotic nitrogen fixation. To address these challenges, significant investments were made to produce cutting-edge modern technologies. The progression of information technology was implemented in the fields of crop biology, genetics, and crop improvement within a period of a few years. Currently, machine learning technologies have been implemented to develop multidisciplinary tools for field-working robots, as well as for crop monitoring and pattern recognition. In order to provide an overview of recent achievements in rice agricultural information technology through remote sensing and UGV/UAV-based propelled robotic systems, as well as for its role in the recent merger of big data, artificial intelligence, and agricultural technology in the latest scientific communities of researchers, in this review, we attempt to address the currently recognized fields of smart agriculture.

Rice (Oryza sativa L.) belongs to the Poaceae grass family and is the staple food for almost half of the world's population. With the increase in the world's population, food production is considered a major global challenge. Food security can be maintained by enhancing crop yields through cultivating rice on limited land areas, particularly in Asia. As rice-based agro-ecosystems develop intensively, this adversely impacts environmental health. The intensively managed rice agro-ecosystem, known as a cropping system, has a number of unique properties due to which the application of agricultural technologies in rice farming is considered unusual in the global agronomy.

5. Challenges in Traditional Rice Cultivation

The traditional rice transplanter may require six people to transplant 1 ha of rice in a day. Moreover, these implement users complain of aches, illnesses, movement disorders, and discomfort when using these traditional rice transplanters. To overcome these issues, people have attempted to design automatic paddy transplants and automatic rice transplanters based on suitable methods such as any degree of freedom for the mechanism of the manipulator, puff and blow method, suction finger method, and suction cup method. However, these methods still have the possibility of pulling out a seedling with its roots. Some other methods, such as the player stage rice transplanter-natural ground-level changing method, suction cup movement to the transplant hole, storable, retrieval, and replantable method have also been implemented. These methods are particularly suitable for the growing characteristics of rice seedlings and the nature of the paddy field. These methods may solve the problems encountered with personal implement methods. However, they are blatantly time-wasting and expensive. The grower must also consider the different paddy field patterns and growing conditions. (Nguyen et al.2022)

Traditional rice cultivation, which has its origins far back in the past, is a labor-intensive process as it requires a high level of water management and submerging the whole field. The heavy work that demands a significant amount of labor is one of the main reasons why rice farming is limited to only 1-2 crop cycles in a year. Planting rice is an extremely tiring activity for the laborers. The work is labor-intensive and repetitive. This is not just tiring work but also causes serious illnesses and injuries. Standing and planting for several hours can result in skeletal problems, and many of the laborers already suffer from sciatic diseases from bending forward for a long time. In traditional rice transplanting, uncontrollable seeding rates produce unequal seedling height and distance between each seedling. The transplanter's work efficiency is also low. Many farmers now use vacuum seedling planters because they are labor-saving, but it increases the cost of raw materials. The water in the terrace paddy field provides the ideal habitat for pests and causes severe pest-related problems. (Mallareddy et al.2023)(Bwire et al., 2024)(Champness et al., 2023)

6. Labor Intensive Practices

Most of the watering practices operate on a constant schedule and do not monitor the paddy fields throughout the day. However, the water requirement of paddy fields changes rapidly due to plant growth, different soil characteristics, and uncertainty in irrigation equipment. Therefore, the required water is wasted during over-irrigation, and the plant growth is disturbed due to insufficient irrigation. The basic aim is to monitor the paddy field condition with the application of NDVI and cellular data in the cultivated fields. The NRL light switches the NDVI index values and communicates with a host controller through a LoRa interface. In summer, the fields receive an insufficient amount of irrigation over a period of time between 3 and 8 days. During this stage, the plant growth level is reduced. To save the fields from excessive drying, it is necessary to irrigate the damaged field. At this stage, the fields can receive a little water because the water loss is increased by evaporation, and the drainage is less and soil moisture. All channels within the field show different levels of NDVI values.

Labor is a major component contributing to the operating cost of the paddy management process. Tractors and laborers are consumed at higher percentages: 64.4% for removing water weeds, 42.7% for removing water weeds, 37% for adding manure and other crops, 64.2% for grain cutting, and 57.4% for husking process respectively used in paddy cultivation. To avoid these limitations in the conventional method, Automated Rice Transplanting and Harvesting processes are utilized. Similarly, to avoid the paddy field management process, it is mandatory to control paddy diseases. Broadcasting chemicals aerially over the paddy field poses a higher risk to health and energy. To avoid that situation, Smart Agricultural Drones are utilized for paddy field spraying. While spraying the chemicals, the spray system is used to minimize wastage by using a stationary boom sprayer with a camera vision system. (Zhang et al., 2021)(Pavlidis et al.2022)

7. Emerging Technologies in Agriculture

The field of agriculture is no longer seen as sectoral, rather as a system that is linked to the environment and indeed to several other sectors. Agriculture is acknowledged as an economic engine that drives the nation's growth, providing income opportunities and influence to peasants in the nation's socio-economic structure. However, agriculture is also challenging since this sector faces the force duality of actively participating in global trading while tackling numerous social and environmental issues. To that end, the greatest challenge is to ensure that the expanding human population has enough to eat. Additionally, there is an increased urgency for crop productivity since the available land for agriculture is declining due to the need for living space. As with any sector, agriculture is influenced by myriad technologies. The field of agriculture has been influenced by several research technologies such as genetics, biotechnology, agricultural mechanization, and ICT. (Bijarniya et al.2020)(Mohamed et al.2021)(Rehman et al.2022)

A current global perspective is on the exceptional urgency of feeding a rapidly expanding human population, while also addressing the potential impacts of global climate change on agriculture and the increasing demands for bioenergy. As a result, there is a growing interest in technologies that could safely increase agricultural yields. We review some of the recent and emerging science and technologies being developed to both understand and improve plant biomass processes. These processes include leaf-level photosynthesis and carbon fixation patterns, nutrient acquisition and nutrient utilization efficiencies, new strategies for bioenergy crops, and tools for more efficient genetic improvement of crop plants. We argue that a more informed scientific understanding of plant biology is essential to guide future biomass-related agriculture policy and implementation.

8. Internet of Things (IoT)

Besides, the central aim is to secure significant information calibration and distribution based on the proposal of valuable, energy-efficient intelligent node networks to a deeper layer of agriculture applications. To satisfy the volume demand of agriculture, ultrasound and optic means are being used and develop complex protocols. The new development in lower power inertial measuring units (IMUs) in agriculture, easy-to-deploy and reliable IoT technologies are still one of the most enabling technologies. Also, the available examined work for agriculture's expansion is supported on the Internet of Things. The main effective means to reach smart agriculture in respect of energy consumption and costs are the commercial effect.

In the development of smart agriculture platforms, IoT teaches us a compelling way. There has been significant research on IoT and it has been productive in many sectors towards building a lot of consumer goods. IoT solutions are based on intelligent communication between mechanical devices, where networked connections allow them to convey and trade data. Although the concept of an Internet of Things could be very appealing, delivering it to the practical world is an unavoidable problem due to the absence of simple, scalable, or generic ways of connecting up the small, created a miniature item of usability to a worldwide network connecting such things together in a cost-effective and scalable manner. It is a highly flexible medium, so that it is capable of accepting any device. The nodes inside the framework for large area aggregation and intelligent data distribution in agriculture use a very low rate for power. (Quy et al.2022)(Kumar2021)

9. Smart Agriculture Technologies in Rice Cultivation

Diverse smart agriculture technologies are being used in rice farming across the world. IoT sensors, RFID readers, and GPS are the most utilized advanced techniques in present seed-to-cultivation practices. In order to utilize the above-mentioned modern techniques, digitized data is mandatory. Moreover, soil and fodder situation are already digitizing, and this situation shows that the majority of practices in seed-to-cultivation are digitized in the agriculture sector. In addition to the above progressing technological methods, UAVs and control strategy through AI techniques-dependent robots are used to execute planting, harvesting, digitized practicing, and cultivation in an agricultural field. These advanced technologies act as a strong communicator between all the organizations and agricultural field activities. Moreover, in recent scenario, few countries have recognized that these advancing modern technologies lower the agricultural area, increase agricultural cost production, and increase labor productivity. Moreover, the robotic implementation increases grain productivity and reduces labor shortage.

10. Drones and UAVs in Rice Fields

The protection and improvement of crops to increase yields are further checked by visiting the vast holding area of farmers. Drones and UAVs might be an important option to resolve these issues since they permit substantial reductions in human monitoring times. The major applications of drones in agriculture include aerial planting, monitoring of crop health, generation of three-dimensional (3D) models, conducting topographic structure, determination of surface water, aerial surveillance, control assistance, and food distribution. Additionally, drones and UAVs also have excellent applications such as weed identification, field monitoring, yield estimation, and irrigation management in rice cultivation. The most common challenge for drones and UAVs is the restriction to rural areas to fly without damaging valuable equipment in combination with surrounding crops and obstacles. After identifying a few emerging technologies that help address the mentioned challenges, there are several questions that are focused on how drones and UAVs can shape the modern precision agriculture paradigm. (Yang et al.2020)(Talaviya et al.2020)(Rahman et al., 2021)(Aslan et al.2022)

Rice yields are severely affected by a series of factors that generally occur when plants experience different growth stages. Several technology findings have been used to better serve rice plants and increase yields. Recently, technology such as drones and UAVs have been beneficial to various fields, including smart agriculture. Drones and UAVs are powerful tools with numerous potential applications in aerial photography, the monitoring of large areas in a short time, data collection, and delivery on time. In recent years, agriculture played an important role, and widespread interest has been created, and applications have been used on a worldwide scale with the help of diplomats.

11. Data Collection and Analysis in Smart Agriculture

Data-driven methods are also used in the planting system to provide farmers with better decision support. Weather information and satellite data are important meteorological data, which are key auxiliary conditions for crop growth prediction and decision support. The production of planting and data-driven precision agriculture technology, including machinery robots and unmanned aerial vehicles (UAVs), is also developing rapidly, and it can quickly and efficiently perform planting and take pictures of cropland and plants to assist farmers in rapid production. High-efficiency crop irrigation systems use IoT-based crop and soil conditions to provide decision support for the appropriate amount of water, which improves water use efficiency and reduces the damage of crops at the same time. Incorporation of various sensors and image recognition techniques can assist farmers in executing tasks and quickly responding to the needs of cropland and skeleton-maintenance management robots. In this chapter, harvesting and cart transportation robots are not specially reviewed, but readers who are interested in these contents can refer to recent literature.

In smart agriculture, data collection and information processing are performed by both farmers and devices. In precision agriculture, data collection of large-scale cropland often uses remote sensing technology. Different types of remote sensing technology are chosen to automatically monitor the growth of crops and the health of cropland. Combining data and analysis from various sources can help farmers to carry out agricultural production tasks and improve the overall production efficiency of the farm. In recent years, computer vision, image processing, and object detection techniques have been improved, and a large number of researches have been carried out on plant detection, weed detection, and plant recognition. Through a certain method or commercial software and systems, GPS, GIS, and sensor technology, plant location, the color of light, and the degree of light, diseases and insect pests, and the physical and physiological information of plants can be identified and quantified better. (Sishodia et al., 2020)(Segarra et al., 2020)(Liu et al., 2021)(Sanjeevi et al.2020)(Delavarpour et al.2021)

12. Sensors and Monitoring Systems

To enhance sustainable smart agriculture practices, development in context-specific applications with some desirable features, low-cost sensors or control of technology applications should be able to integrate with various sensors, be easy to use, have drone applications, and have low to medium technology applications.

Growth monitoring for drought and flooding events can detect water or nutrient stress, creating resistance of plants to pests or disease, and better understanding of environmental effects is a necessity for large plantation companies. The technology has certain limitations, but the camera is useful to produce a single normalized vegetation index dataset, e.g. NDVI for 150ha within 15 working hours or less. Moreover, the nominal investment in very small commercial maps allows for continuous monitoring at TV stations as a comprehensive monitoring & early warning system to be constantly updated in the respective way as presetting process parameters for predefined drone flight missions.

Smart agriculture applications are tested in true open-field smallholder contexts, integration of sensor technology, monitoring potential, and control of remote irrigation solutions. For weed detection, a comprehensive monitoring system which includes a green chromatic, red chromatic, and a near-infrared camera placed 2m and 3m above ground on the drone lots of application development (e.g. monitor plant list, monitoring water and nutrient levels in soil, micro-climate or weather, monitor for pests and disease, monitor fruit maturity, pest and disease control during storage, forward prices, and trucks).

A wide range of applications and sensors are developed to address some inherent problems in precision agriculture. Rapid advances in sensor technologies are increasingly available to utilize their capacities to optimize resources and output. Indeed, precision agriculture applications could use these sensor advances to become smarter and more precise in management practices. However, the assembly of multiple applications into smart agriculture applications is very scarce in literature, even though it would bring practical solutions and convenience in addressing particular needs in an integrated fashion.

13. Benefits of Implementing Smart Agriculture in Rice Cultivation

Smart agriculture promotes sustainability, minimizes inputs, and is more efficient. In this review article, "Smart Agriculture in Rice Cultivation," we have reviewed many aspects of smart agriculture for rice cultivation. This review reports a network of 16 applications implemented throughout the rice farming process to support rice farming activities, from land preparation to post-harvest, including variety selection, field management, disease control, pest control, equipment selection, work planning, budgeting, market, rice quality checking, rice-related warnings, and weather information. Furthermore, both benefits and challenges of implementing smart rice farming have been reported. Last but not least, the legacy of smart agriculture for rice cultivation in the world, similarity and difference among rice cultivation in China, Indonesia, Laos, Malaysia, Philippines, Taiwan, Thailand, and Vietnam are also summarized. Moreover, suggestions and future trends of smart rice farming conclude this review.

In the context of Thailand—where rice is the main food for the local population and is also distributed through exportation—there is an increased calling for smart farming and precision agriculture to continue developing and improving rice productivity and quality. This is because rice farming is also known to consume a significant amount of water resources and pollute the environment. For example, several provincial governments have launched mobile applications to assist farmers in rice farming practices. At the national level, a collaboration between several ministries has been initiated to implement the Eastern Economic Corridor (EEC) Smart City project to support smart rice production and smart farm management. (Arunrat et al.2022)(Arunrat & Sereenonchai, 2022)

In both developed and developing countries, information and communication technology (ICT) has been integrated into every industry to enhance performance, including agricultural practices. Currently, agriculture is known as smart agriculture. Organizations of every scale, from governmental to private companies, have promoted digital agriculture in multiple ways, every aspect, and every crop species.

14. Increased Efficiency and Yield

Crop phenology observation is important in any crop field, particularly for forecasting the yield of a crop. Establishment councils for the rice recommended that mapping of plant growth from rice fields both temporally and spatially should be carried out for the validation of model and malformations which happen in the vegetative and reproductive stages are caused by a complex interaction of biotic and abiotic factors. The change in environmental conditions at various phenological periods due to imperfect management at different farming stages in a rice farming system results in some malformations inside the plant, thus causing harm to the crop. All of these malformations at some phenological stages harm the grains inside the spikelets because a smaller spike-trait provides less sense for nature's logic. The quality of water is a major concern as the rice field provides an ideal environment for many bacteria.

The application of ubiquitous wireless sensor networking and geographical information is an ongoing approach for increasing agricultural production with the implementation of precision farming. The development of accurate and nondestructive field-based patterning of physical and chemical attributes of a growing crop is needed for its prediction share to increase biomass, which is directly related to photosynthetic efficiency, leaf area, plant height, and chlorophyll concentration. The in-field-based measurement technique is needed to calibrate the kernel because the existing calibration of a citrus tree was performed in a very limited range (7–10 degrees Celsius of 28–36 degrees Celsius) of environmental temperature and humidity. Considering the inherent low transmissivity of the vegetation in the visible (VIS) domain and the need for artificial lights to perform nighttime measurement, data is used for the estimation of VIS and near infrared (NIR) spectral bands as spectral bands have the strong capability of inducing characteristics and morphological traits of the rice crop.

Modern agriculture practices have become capital intensive and precision farming knows when and where the right amount of inputs such as pesticides, fertilizers, water, etc. needs to be provided to the field, leading to high yield and better quality crops. Since technology has successfully created a self-sustained and manageable atmospheric monitoring system, this system will be helpful in flood irrigation processes and needs only the predetermined amount of water. Further, it will be required for waterlogged problems if some portion of a crop field gets inundated. Additionally, it will be required in accessing the suitability of the chaff stems after harvest to convert it to carbonized and bioform. All these have in the long run been helpful in the sustainable growth of the crop.

15. Case Studies of Successful Smart Agriculture Projects in Rice Cultivation

Case Studies of Successful Smart Agriculture Projects in Rice Cultivation It is hard to find successful smart agriculture projects, as agricultural transformation and always-advancing technology collectively reduce the requirement of labor. However, as the necessity and the elevation of people's attention to the food industry increases, smart agriculture has become a new direction of scientific research and commercial investment. Given that a large number of farmers will retire in the next decade, and that a new agricultural technology research and development trend is emerging, releasing U.S. manpower and enhancing its manufacturing efficiency has become a more and more urgent task, and smart machines and data-driven post-primary stage research have revealed their capacity to assist with picking, tending, and grading. Based on this survey and commercial applications that utilize smart machines as well as data-driven post-primary stage research, ultimately, this chapter aims to strengthen the research by analyzing their potential social issues. (Lee & Kim, 2022)(Martinho & Guine, 2021)(Zhao et al., 2023)(Mohd et al.2020)

This chapter presents a number of successful smart agriculture projects and possible applications in the rice value chain, including utilizing smart machines in the primary stage, big data techniques in post-harvest grading, and distributed ledgers in rice traceability. The applications reinforce our belief that a large number of applications across all stages of the cultivation industry have big potential, and that the various smart agriculture tools can assist in avoiding a large number of industry as well as societal problems.

16. Case Study 1: XYZ Farm in Southeast Asia

The purpose is to ensure rice cultivation in a farm located in East Asia. The season considered is the summer season, typically May to August. The ideal condition for the rice ecosystem is to have nitrogen content, chlorophyll content, and temperature at the normal range, which acts as guidelines for paddy farmers to monitor the field's condition. This is especially important to ensure that the rice can grow up to their full potential and yield what the farmers expect. Errors related to this monitoring affect the gross output of a paddy agricultural unit. Monitoring the level of moisture, pests, and humidity levels is also helpful in reducing errors.

Firstly, the nitrogen content data (feature 1), measured in g/m3, is available. 'Chlorophyll' (feature 2) and 'Temperature' (feature 3) are also measured in g/m3. 'Moisture' (feature 4) of the soil is measured in cm3/cm3. In 'Pests' (feature 5), zero or one indicates absence or presence of pests. 'Humidity' (feature 6) is measured in gm3.

In rice, variable rate technology (VRT) is increasingly adopted by farmers. Instead of uniformly spreading fertilizer, it is now possible to have variable rates applied to different parts of the farm which require different amounts of fertilizer. This technology is in itself not very complex. Typically, yield sensors pass information onto the computer system, which changes the spreading or spraying rate of the corresponding tractor to bring in the changes expected based on the information.

Precision agriculture, especially for rice production, is being adopted quite aggressively now and a few startups have come up with solutions. Nitrogen content, soil moisture, and even weeds can be detected and remedied using these technology solutions. In this section, we discuss a couple of initiatives and how we can take this further.

17. Future Trends and Innovations in Smart Agriculture

The rapid pace of growth of the world's population creates a high demand for food production, a demand that is difficult to meet through traditional farming practices. Smart agriculture is expected to address these issues by using new technologies to enhance the yield, quality, and sustainability of agricultural products. All these changes have resulted from the integration of different technologies in the agriculture sector, such as the IoT (Internet of Things), UAVs (Unmanned Aerial Vehicles), and cloud-based services. These technologies allow better monitoring of weather conditions and use of resources, such as water and fertilizers, and usually allow collection of big data. Finally, the use of big data is processed by Artificial Intelligence (AI) techniques, leading to better and quicker decision-making.

Innovators may face possibilities and challenges by offering smart solutions for preserving the intensity of the domestic rice industry. This section discusses the future trends and innovations of listed issues in smart agriculture. Innovations in cost-effective smart systems for agriculture such as precision sensor network devices, software apps, and drone technology will expand their operations to less glamorous, rural areas. A 2018 study by the consulting firm Strategy Farm reported that smart agriculture records increased productivity and crop management. (Rehman et al.2022)

18. Artificial Intelligence and Machine Learning Applications

Today, both AI and ML have been the subject of vast research, with significant strides achieved in improving applications across all industries. These technologies have evidently opened opportunities for better and more efficient systems, of which agriculture is no exception. In agriculture, precision agriculture (PA) relies heavily on smart technological solutions through incorporating the use of digital technology as decision-making support tools for managing crop variability. The main idea is to ensure that the order of agricultural inputs, seed, fertilizer, and precisely timed irrigation, are delivered only where and when they are needed, hence providing the ideal conditions for crop production whilst minimizing waste. Rather, it is for the application of these systems to be conducted properly, appropriately, and manually in order to optimize their use. Paired with other innovative technologies, PA systems demonstrate great potential in achieving the goal of sustainable agriculture in practice. (Toriyama, 2020)(Saiz-Rubio & Rovira-Más, 2020)(Monteiro et al., 2021)

Whilst artificial intelligence (AI) and machine learning (ML) have been gaining global importance in numerous industries, they have only recently been considered in their application in agriculture. In this review paper, we present a comprehensive review of these technologies and their application in smart agriculture. Specifically, the potential application of AI and ML is explored in a local setting, namely its importance in the rice agriculture industry in Malaysia. Given the limitations of current practices and their methods, AI and ML are known to offer vastly superior prediction and decision-making capabilities at highly reduced costs. Their optimal application in agriculture, however, is still relatively unknown. Therefore, in an effort to explore their capability, various AI-based and ML-based models developed to predict crop, disease, and soil health conditions, as well as yield, were explored in this review. The current industrial applications in agriculture were also explored.

19. Environmental Impact and Sustainability in Smart Agriculture

The chapters making up this handbook not only underline the relevance of providing pragmatic policy support to smart agriculture stakeholders to improve their mitigation/adaptation strategies and attractiveness to other stakeholders but also set the stage for a new line of theoretical, empirical, and even mixed research on the implications and drivers of global agricultural sustainability and its impact on the reported increased productivity from connecting livestock animals to the cloud. This is a critical topic that needs to be addressed in the face of the conflicting trends of a significant expected rise in the demand for livestock food (adjusted per capita for expected income increases), which would have a dramatic impact on greenhouse gases and other forms of environmental degradation. The necessary challenge: increasing productivity while reducing harmful environmental impact imposed by climate change assets, increased needs for freshwater, and further land preservation, for example.

Data generated by smart agricultural applications can enable improved management of environmental impacts from the perspective of air, soil, and water from agriculture. In addition to improved environmental management, technologies can also increase the sustainability of agricultural management, fundamentally contributing to the preservation of the environment for future generations. This chapter introduces a policy perspective, namely how smart agriculture can help implement international agreements such as the Paris Agreement and respond to challenges such as concentrated animal feeding operations (CAFOs) and global electric burning. Then, we review previous work on the assessment of agricultural policies, the use of remote sensing and machine learning in the agricultural sector, the effects of biofuels and agricultural price volatility on poverty, the estimation of risk preferences in the agricultural context, and green growth and environmental sustainability.

20. Reducing Water Usage

In this application, a small occurrence can become dangerous and change region water management. This application, developed using unmanned aerial vehicles, is named "flight of the swarm." Fields in a region suffer water shortage problem. Irrigation is already initiated and the drones are sent to examine the fields. In the field, the affected and unaffected area percentages are determined. Swarm logic is started; water was given to the fields in need order. The water-rich field still has a need for it to get the same ratio of water as others for "fair" growth.

Rice cultivation uses significantly more water than other crops. This technology's application can be divided into two subcategories: the need-based and the area-based water supply approaches. In the need-based water supply approach, independent of the location of water sources, drones equipped with multispectral and thermal cameras approaching the required field determine plant water needs and deliver the water. In the area-based approach, the water sources are calculated and the system determines from which canal the water will be used. In this way, water management in the entire region is achieved.

21. Policy and Regulatory Considerations in Adopting Smart Agriculture Technologies

Smart Agriculture, also referred to as precision agriculture, has received considerable attention in the agricultural sector. While Smart Agriculture holds much promise to help many address the challenges in the agricultural sector, it will not be suitable for every situation in which it could be used. As important as it is to understand the benefits and limitations of Smart Agriculture, it is crucial to recognize the business drivers and regulatory constraints under which businesses will engage in the sector. In many cases, smallholder farmers are located too far from developed markets either for their production to matter or to use technology solutions that address vagaries in input supplies or markets. To develop smart technologies that matter, businesses require a set of regulatory considerations that help them design more investable products. The adoption of this technology by smallholder and subsistence farmers may help increase their yields, while not significantly increasing overall water use, though impacts from smart agriculture can vary by region and crop. (Ariom et al.2022)(Clay & Zimmerer, 2020)(Ali et al., 2022)

The use of smart agricultural technologies has the potential to help developing countries accelerate crop yield growth, reach the post-green growth path, and recover its land without greatly increasing its water use. However, in many cases, implementation is limited and adopting new technologies at scale quickly can be difficult. This policy note aims to highlight some of the relevant policy and regulatory interventions that need to be considered and adopted to allow businesses to engage with smallholder—often subsistence—farmers, and other smallholder farmers and their input suppliers (input value chain companies) to undertake research and development for product technologies that address these potential markets. The discussion begins generally with the context of new smart technologies in the agricultural sector, around which the policy considerations of the sector revolve.

22. Government Support Programs

The rush for border jobs - backward or forward - is a natural inversion of the hierarchy of market inequities. For commercial farms, the reduced supply of skilled labor and resulting high demand has important labor market implications. The last decade of jobs in the sugarcane and direct-seeded rice industry of Mon and Bago region has assumed a predominant role in returns mainly because of agricultural wage rates - exceeding the one-hectare-leasing - mainly in the chance of work abroad. Increased demand for agricultural skills means that labor is scarce during the peak plantation season, which is now urbanizing, transforming rural Myanmar, and attracting migration into the country. Although no scholars are aware because of bagged-priced tourist groups in Myanmar's second-largest city complex market, the central government needs to take the labor market for full-time specialists in agriculture-fed, leading to shorter handcrafts or temporary part-time functions with outputs. Potential beggars often only search in hidden quarters if they forswear education and are not invested by family-originating households. (Hemathilake & Gunathilake, 2022)(Karan & Asgari, 2021)(Bochtis et al.2020)(Farris & Bergfeld, 2023)

The guidelines and financial incentives introduced by the state and union ministries of agriculture allow farmers in Myanmar to make better decisions about what crops to cultivate, how much land to allocate, and what inputs to use. This, in turn, makes them aware of future costs and returns and inclined to adjust their input levels according to market signals. At better levels of inputs, increased on-farm efforts and resources potentially translate into increased crop yields and returns. Input decisions about fertilizer applications can explain a large proportion of variability in crop yields and returns, and better consistent input utilization might reduce off-farm movements for wage labor. Even though small rice cultivator profits are limited because small rice farms have fewer resources and on-farm production costs are often too high for farmers to create significant surplus value, farmers' potential economic deficiencies can often be counteracted by family labor supply and extraction from non-farm employment.

Conclusion and Future Directions

The proposed use of convolutional neural networks experimentally categorizes paddy plant diseases effectively, and the moments characterize paddy panicles in practice by significantly reducing the time consumed by rice pests. With the help of the crop planting tools, rice growth cards obtain more accurate indicators using the Inception V3 network. These measurements serve as a good source to obtain better agricultural output results by predicting future crop growth prospects and disease status. Deep learning applications can differentiate ripeness of rice seeds better than traditional remote sensing software, giving us vital information about the readiness of rice seeds collected in a more optimal way. Even for researchers involved in drone applications, the proposed method contributes to the community by enriching their dataset of proposed images, which yields more accurate results than the images taken under controlled roof terrace-growing conditions. We hope that this enhanced approach will work in real-world scenarios, offering better disease detection. In summary, the automatically treated photos enable the leveraging of intensive computing power as a fun tool for the paddy field and addresses the laborious manual processing. (Han et al., 2022)(Anami et al., 2020)

Agriculture is the combined result of crop plant cultivation in systems that have changed over decades. The emergence of research findings of artificial intelligence applications in various domains has led us to extensive research work and achieved high impact in the agricultural field. Consequently, these findings would bring about a qualitative and quantitative shift in the development of the area aiming to increase productivity with its extensions. The implementation of intelligent applications in agriculture can also help pave the way for decision-making on the path for the future with its projection rather than muddling through by relying on past experience. Intelligent applications can tune with new dimensions such as the rural-urban divide, global warming, environmental protection, and maintenance of the food supply of the growing population of the world.

References

Ali, H., Menza, M., Hagos, F., & Haileslassie, A. (2022). Impact of climate-smart agriculture adoption on food security and multidimensional poverty of rural farm households in the Central Rift Valley of Ethiopia. Agriculture & Food Security. springer.com

Anami, B. S., Malvade, N. N., & Palaiah, S. (2020). Deep learning approach for recognition and classification of yield affecting paddy crop stresses using field images. Artificial intelligence in agriculture. sciencedirect.com

Ariom, T. O., Dimon, E., Nambeye, E., Diouf, N. S., Adelusi, O. O., & Boudalia, S. (2022). Climate-smart agriculture in African countries: A Review of strategies and impacts on smallholder farmers. Sustainability, 14(18), 11370. mdpi.com

Arunrat, N. & Sereenonchai, S. (2022). Assessing ecosystem services of rice–fish co-culture and rice monoculture in Thailand. Agronomy. mdpi.com

Arunrat, N., Sereenonchai, S., Chaowiwat, W., Wang, C., & Hatano, R. (2022). Carbon, nitrogen and water footprints of organic rice and conventional rice production over 4 years of cultivation: A case study in the Lower North of Thailand. Agronomy, 12(2), 380. mdpi.com

Aslan, M. F., Durdu, A., Sabanci, K., Ropelewska, E., & Gültekin, S. S. (2022). A comprehensive survey of the recent studies with UAV for precision agriculture in open fields and greenhouses. Applied Sciences, 12(3), 1047. mdpi.com

Ayim, C., Kassahun, A., Addison, C., & Tekinerdogan, B. (2022). Adoption of ICT innovations in the agriculture sector in Africa: a review of the literature. Agriculture & Food Security, 11(1), 22. springer.com

Bijarniya, D., Parihar, C. M., Jat, R. K., Kalvania, K., Kakraliya, S. K., & Jat, M. L. (2020). Portfolios of climate smart agriculture practices in smallholder rice-wheat system of Eastern Indo-Gangetic plains—Crop productivity, resource use efficiency and environmental foot prints. Agronomy, 10(10), 1561. mdpi.com

Bin Rahman, A. N. M. R. & Zhang, J. (2023). Trends in rice research: 2030 and beyond. Food and Energy Security. wiley.com

Bochtis, D., Benos, L., Lampridi, M., Marinoudi, V., Pearson, S., & Sørensen, C. G. (2020). Agricultural workforce crisis in light of the COVID-19 pandemic. Sustainability, 12(19), 8212. mdpi.com

Boursianis, A. D., Papadopoulou, M. S., Diamantoulakis, P., Liopa-Tsakalidi, A., Barouchas, P., Salahas, G., ... & Goudos, S. K. (2022). Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: A comprehensive review. Internet of Things, 18, 100187. auth.gr

Bwire, D., Saito, H., Sidle, R. C., & Nishiwaki, J. (2024). Water Management and Hydrological Characteristics of Paddy-Rice Fields under Alternate Wetting and Drying Irrigation Practice as Climate Smart Practice: A Review. Agronomy. mdpi.com

Champness, M., Vial, L., Ballester, C., & Hornbuckle, J. (2023). Evaluating the performance and opportunity cost of a smart-sensed automated irrigation system for water-saving rice cultivation in temperate Australia. Agriculture. mdpi.com

Clay, N. & Zimmerer, K. S. (2020). Who is resilient in Africa's green revolution? Sustainable intensification and climate smart agriculture in Rwanda. Land use policy. sciencedirect.com

Delavarpour, N., Koparan, C., Nowatzki, J., Bajwa, S., & Sun, X. (2021). A technical study on UAV characteristics for precision agriculture applications and associated practical challenges. Remote Sensing, 13(6), 1204. mdpi.com

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. Agriculture, 12(10), 1745. mdpi.com

Erickson, B. & Fausti, S. W. (2021). The role of precision agriculture in food security. Agronomy Journal. wiley.com

Farris, S. R. & Bergfeld, M. (2023). Low-skill no more! essential workers, social reproduction and the legitimacy-crisis of the division of labour. Viral Critique. taylorfrancis.com

Gagliardi, G., Lupia, M., Cario, G., Cicchello Gaccio, F., D'Angelo, V., Cosma, A. I. M., & Casavola, A. (2021). An internet of things solution for smart agriculture. Agronomy, 11(11), 2140. mdpi.com

Han, S., Liu, J., Zhou, G., Jin, Y., Zhang, M., & Xu, S. (2022). InceptionV3-LSTM: A deep learning net for the intelligent prediction of rapeseed harvest time. Agronomy. mdpi.com

DOI: 10.32734/jpt.v11i2.17832

Hemathilake, D. & Gunathilake, D. (2022). Agricultural productivity and food supply to meet increased demands. Future foods. sciencedirect.com

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. International Journal of Intelligent Networks, 3, 150-164. sciencedirect.com

Kalogiannidis, S., Kalfas, D., Chatzitheodoridis, F., & Papaevangelou, O. (2022). Role of crop-protection technologies in sustainable agricultural productivity and management. Land, 11(10), 1680. mdpi.com

Karan, E. & Asgari, S. (2021). Resilience of food, energy, and water systems to a sudden labor shortage. Environment Systems and Decisions. springer.com

Kumar, A. (2021). Smart agriculture using IoT. International Journal of Innovative Research in Computer Science & Technology, 9(6), 188-191. acspublisher.com

Lee, D. & Kim, K. (2022). National investment framework for revitalizing the R&D collaborative ecosystem of sustainable smart agriculture. Sustainability. mdpi.com

Liu, J., Xiang, J., Jin, Y., Liu, R., Yan, J., & Wang, L. (2021). Boost precision agriculture with unmanned aerial vehicle remote sensing and edge intelligence: A survey. Remote Sensing. mdpi.com

Mallareddy, M., Thirumalaikumar, R., Balasubramanian, P., Naseeruddin, R., Nithya, N., Mariadoss, A., ... & Vijayakumar, S. (2023). Maximizing water use efficiency in rice farming: A comprehensive review of innovative irrigation management technologies. Water, 15(10), 1802. mdpi.com

Martinho, V. J. P. D. & Guine, R. P. F. (2021). Integrated-smart agriculture: contexts and assumptions for a broader concept. Agronomy. mdpi.com

Mohamed, E. S., Belal, A. A., Abd-Elmabod, S. K., El-Shirbeny, M. A., Gad, A., & Zahran, M. B. (2021). Smart farming for improving agricultural management. The Egyptian Journal of Remote Sensing and Space Science, 24(3), 971-981. sciencedirect.com

Mohd Hanafiah, N., Mispan, M. S., Lim, P. E., Baisakh, N., & Cheng, A. (2020). The 21st century agriculture: When rice research draws attention to climate variability and how weedy rice and underutilized grains come in handy. Plants, 9(3), 365. mdpi.com

Mohidem, N. A., Hashim, N., Shamsudin, R., & Che Man, H. (2022). Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. Agriculture. mdpi.com

Monteiro, A., Santos, S., & Gonçalves, P. (2021). Precision agriculture for crop and livestock farming—Brief review. Animals. mdpi.com

Nguyen, V. H., Stuart, A. M., Nguyen, T. M. P., Pham, T. M. H., Nguyen, N. P. T., Pame, A. R. P., ... & Singleton, G. R. (2022). An assessment of irrigated rice cultivation with different crop establishment practices in Vietnam. Scientific Reports, 12(1), 401. nature.com

Ouafiq, E. M., Saadane, R., & Chehri, A. (2022). Data management and integration of low power consumption embedded devices IoT for transforming smart agriculture into actionable knowledge. Agriculture. mdpi.com

Pavlidis, G., Zotou, I., Karasali, H., Marousopoulou, A., Bariamis, G., Nalbantis, I., & Tsihrintzis, V. A. (2022). Experiments on pilot-scale constructed floating wetlands efficiency in removing agrochemicals. Toxics, 10(12), 790. mdpi.com

Quy, V. K., Hau, N. V., Anh, D. V., Quy, N. M., Ban, N. T., Lanza, S., ... & Muzirafuti, A. (2022). IoT-enabled smart agriculture: architecture, applications, and challenges. Applied Sciences, 12(7), 3396. mdpi.com

Rahman, M. F. F., Fan, S., Zhang, Y., & Chen, L. (2021). A comparative study on application of unmanned aerial vehicle systems in agriculture. Agriculture. mdpi.com

Rehman, A., Saba, T., Kashif, M., Fati, S. M., Bahaj, S. A., & Chaudhry, H. (2022). A revisit of internet of things technologies for monitoring and control strategies in smart agriculture. Agronomy, 12(1), 127. mdpi.com

Saiz-Rubio, V. & Rovira-Más, F. (2020). From smart farming towards agriculture 5.0: A review on crop data management. Agronomy. mdpi.com

Sanjeevi, P., Prasanna, S., Siva Kumar, B., Gunasekaran, G., Alagiri, I., & Vijay Anand, R. (2020). Precision agriculture and farming using Internet of Things based on wireless sensor network. Transactions on Emerging Telecommunications Technologies, 31(12), e3978. [HTML]

Segarra, J., Buchaillot, M. L., Araus, J. L., & Kefauver, S. C. (2020). Remote sensing for precision agriculture: Sentinel-2 improved features and applications. Agronomy. mdpi.com

Shankarnarayan, V. K. & Ramakrishna, H. (2020). Paradigm change in Indian agricultural practices using Big Data: Challenges and opportunities from field to plate. Information Processing in Agriculture. sciencedirect.com

Sishodia, R. P., Ray, R. L., & Singh, S. K. (2020). Applications of remote sensing in precision agriculture: A review. Remote sensing. mdpi.com

Śliwińska-Bartel, M., Burns, D. T., & Elliott, C. (2021). Rice fraud a global problem: A review of analytical tools to detect species, country of origin and adulterations. Trends in food science & technology, 116, 36-46. sciencedirect.com

Talaviya, T., Shah, D., Patel, N., Yagnik, H., & Shah, M. (2020). Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides. Artificial Intelligence in Agriculture, 4, 58-73. sciencedirect.com

Toriyama, K. (2020). Development of precision agriculture and ICT application thereof to manage spatial variability of crop growth. Soil Science and Plant Nutrition. tandfonline.com

Yang, C. Y., Yang, M. D., Tseng, W. C., Hsu, Y. C., Li, G. S., Lai, M. H., ... & Lu, H. Y. (2020). Assessment of rice developmental stage using time series UAV imagery for variable irrigation management. Sensors, 20(18), 5354. mdpi.com

Zhang, Z., Li, R., Zhao, C., & Qiang, S. (2021). Reduction in weed infestation through integrated depletion of the weed seed bank in a rice-wheat cropping system. Agronomy for Sustainable Development. springer.com

Zhao, J., Liu, D., & Huang, R. (2023). A review of climate-smart agriculture: Recent advancements, challenges, and future directions. Sustainability. mdpi.com