Chapter

Smart Rice Precision Farming Schemes in Sub-Saharan Africa: Process and Architecture

Abraham Ayegba Alfa, John Kolo Alhassan, Olayemi Mikail Olaniyi and Morufu Olalere

Abstract

Smart farming integrates information, communication, and control technologies in agricultural practices. Recently, crop enterprise management through smart precision farming technologies are antidotes to uncontrollable soil and environmental factors compounded by climate change. Farm production planning utilizes enormous data generated from the field by human agents and IoT devices, but is often unreliable and inaccurate. These cause low yield, high losses, inferior quality of farm produce, overuse or underuse of fertilizers, increased costs, and inefficient farm management. Traditionally, analyzing rice cropping yields is time-inefficient and tasking, which led to quicker IoT adoption. Aside insufficient data sharing infrastructure, data privacy problem is widespread The blockchain technology is useful for verifying the reliability, accuracy, and authenticity of IoT data generated from fields for the production planning. In the future, dynamic systems (smart rice farming) and model-based control systems can be applied to understand the physical process and valuable factors of production. This paper provides a comprehensive state-of-the-art process and architectural survey on impacts of uncontrollable environmental factors, smart precision framework, security and privacy architectures or solutions for improving rice crop production. Again, a new taxonomy is developed to guide researchers, advance the course of rice production, and improve yields across sub-Saharan Africa.

Keywords: Climate change, rice, precision farming, smart farming, data, security, privacy, blockchain, IoT, inaccuracy, unreliability

1. Introduction

The world's global population is nearly 7.8 billion in 2020 and projected to be 9.7 billion in 2050. Accordingly, these persons need additional 70% of food against the present backdrop of diminishing natural resources such as water and land caused by urbanization, climatic changes, soil erosion, and water shortages. The coping mechanisms for the climate change phenomenon and food security can be best tackled with precision agriculture (or smart farming) [1]. Researchers are exploring viable alternative rice farming methods as means to increase production in peatlands because of their potential to be easily converted into arable farmlands. Rice growth has been impacted mostly by acidic soil and water, irrigation, and rice variety adaptation [2].

This approach holds great promise for better returns and optimizing farming efforts including higher profitability, wastage reduction, and higher productivity. Though, it is nearly impossible for farmers to obtain full-grasp of the various variability linked to the environment because of large inherent uncertainties. Smart farming practice offers to provide farmers the opportunity to simplify and automate the process of acquiring and analyzing farm data, which leads to faster, intelligent, and automated decision-making. The spate of climate change globally has further informed the greatest desire of governments to safeguard food security through maintenance and growth of agricultural production. These rapid climate changes in various abiotic factors including rainfall, drought, temperature, flooding, and solar radiation continue to adversely impact rice production at different stages of growth [3]. The information provided by crops can become a veritable tool for modern agricultural practice in the quest for environmental protection, food production sustainability, cost savings, and improved decision-making [4].

In particular, smart farming makes use of the concept of precision farming to raise farm produce through the understanding and knowledge of the variability of a crop field. It carries out the analysis of the environmental factors and distributes the different inputs based on the specificity of the site (or farmland). This holds great promise for better returns and optimizing farming efforts including higher profitability, wastage reduction, and higher productivity. Though, it is nearly impossible for farmers to obtain full-grasp of the various variability linked to the environment because of large inherent uncertainties. The smart farming practice offers to provide farmers the opportunity to simplify and automate the process of acquiring and analyzing farm data, which leads to faster, intelligent, and automated decision-making [5].

Cultivated land use layout adjustment mechanism for crop planting suitability is concerned with the refinement and deepening of land use transformation. This is of great importance in optimizing the allocation of cultivated land resources and ensuring food security. Presently, farmers and stakeholders infrequently take into account the land suitability for crops when using cultivated land, which results in a mismatch between crop distribution and resource conditions including water, heat, and soil, and adversely affects the ecological security and utilization efficiency of cultivated land. Although, land suitability analysis for crops is a function of crop requirement and land characteristics reflected in final decisions conducted through a multi-criteria evaluation approach [6].

Crop simulation models are used to forecast the impacts of climate change on yield levels, and to identify adaptation strategies [7]. Nevertheless, crop quality has been almost neglected in available studies, despite its relevance to the economic and nutritional value of agricultural products. The few available studies [6, 8, 9] on the impacts of climate change on crop quality are aligned to this trend, depicting an overall decline in many cereal crops. The impacts of climate change were highly divesting on rice milling and cooking suitability performed in the main European rice district, Northern Italy, which cuts harvest into about half of entire production areas.

The projected decay in rice quality due to climate change strengthens the need for modeling studies to forecast its trend in the near future, considering the connections with the stability and utility-safety-quality-nutritive components of food security. Indeed, the expected increase in thermal regimes and in the frequency of weather extremes may cause a higher incidence of damaged grains and reduced head rice yield even in rice top producing areas causing a decreased stability of food production

[7]. The largest impact of climate change on milling suitability was due to the high number of quality variables affected by temperature changes [7].

Water management for rice cultivation is considered a major parameter for low rice yields and large yield gaps. A number of technologies has been investigated by AfricaRice and its partners in the quest to identify their strengths and overcome certain water-related problems. While other studies accounted for fewer rice suitability conditions on lowlands such as rice yield, water productivity, migration of iron toxicity, and water use on the farm field [3].

2. Traditional rice farming vs. smart precision rice farming

Rice (*Oryza spp.)* is an imperative staple food in sub-Saharan Africa. The consumption of rice has risen sharply since the early 1960s because of rising per capita consumption, demographic growth, and urbanization. Regardless of the swelling rate of consumption of rice, local production is within half of demand, and imports usually complement the difference [3]. The obvious shortfalls in rice production across the sub-Saharan Africa are due to concentration of farming activities in smaller rice production areas, and poor yield [3]. The rainfed rice system viability will be impacted by temperature changes and rainfall instability caused by climate changes. Aside from this, other rice cropping systems have emanated in recent times including rainfed upland, rainfed lowland, irrigated lowlands, deep water, and mangrove, which irrigated stand out as most promising [8].

Consequently, the demand and consumption of rice continue to increase significantly as the population grows. In fact, a lot of imported rice is occasioned by low rice production in several nations of Africa in attempt to provide food security. These have further amplified the need to increase rice farming in existing and new lands in order to effectively deploy scarce water resources and nutrients, which serve as limiting factors in both upland and lowland rice growing areas as an important staple crop [10].

Rice is notably the second topmost after wheat consumed grain globally. It has low protein but high carbohydrate composition. Aside from that, it is a rich energy meal for people, which has spiked the demand especially in developing economies [11, 12]. Three most common rice varieties are the lowland Thai species (such as Pathumthani 1, RD57, and RD41), which can be cultivated through transplanting and dry direct seedlings. These are well-known to survive in alternative wetting and drying water supply regime [13]. It needs a minimum of 120 days from time of seedling to harvesting. Thailand, the Philippines, Vietnam, China, and Bangladesh are the world's top producers of rice, which contribute significantly to their Gross Domestic Product (GDP), and economic comparative advantage. Aside from the traditional ways of conserving water and maintenance of soil fertility with adequate mineral content (such as Potassium, Phosphorus, and Nitrogen), there is slow adoption of technologies. The low yields of rice continue to worry farmers and researchers, which is attributed to poor soil fertility, adverse weather, water scarcity, pest attacks, and uncontrollable environmental factors. There is the reluctance of farmers to utilize modern technologies due to uncertainties about safety/privacy and perceived influence on farming yields or outcomes [13, 14]. In sub-Saharan Africa, the lowland rice farming requires keeping the concentrations of phosphorus and water supply at optimal levels for increased yields, which are problematic in meeting the demands for the commodity [10]. The suitability of fields for rice production is associated with socioeconomic and natural factors; thereby impacting the yields.

Climate, topography, and soil indicators characterize the natural conditions of crop planting, which the prerequisite factors are affecting crop suitability. The indicators and criteria for evaluating suitability of land for cropping can be classified into restrictive and nonrestrictive indicators. The restrictive indicators have specific criteria for different crops with the most suitable range, maximum threshold, and minimum threshold, while the nonrestrictive indicators have no specific suitability standards, which need to be further defined. In the case of rice cropping, climatic, terrain, soil, and management factors were noted as impacting the suitability of rice cropping determined by means of [6]. Rice is majorly grown in three environments: rainfed upland, rainfed lowlands, and irrigated lowlands. In all rice-growing environments, the yield gap (that is, the difference between the potential yield in irrigated lowland or water-limited yield in rainfed lowland and upland, and the actual yield obtained by farmers) is largely caused by a wide range of constraints associated with water. Therefore, water management for rice cultivation is impacted by water-related constraints including drought, flooding, iron toxicity, and soil salinity. These required preconditions to achieve higher yield and quality against uncontrolled production factors such as continuous flooding [3].

The theory of precision farming (or precision agriculture) relies on the observing, measuring, and responding to the variability in crop fields or parts of livestock management [5, 10]. It entails applying inputs when and where needed. The precision farming is considered to be the third phase of the revolution in agriculture only trailing behind mechanization and the green revolutions. The main imports of this concept are to increase and maintain the sustainability of crop production and animal rearing through the use of IoT, Artificial Intelligence (AI), robotics, and big data [4]. Smart farming implies the adoption of information and communication technology (ICT) in agriculture [15]. Often, this is referred to as data-driven agriculture in which robotic solutions are incorporated into artificial intelligence techniques for the purpose of attaining the sustainable agriculture of the future [4]. The focus on linking IoT within the sensor networking system is emerging in smart and precision farming. Reason is that IoT is capable of acquiring information (such as the moisture rate), and broadcasting to the user in wireless setups.

The traditional methods of farming are incapable of satisfying the feeding needs of people across the globe. So, IoT-driven smart farming becomes an unavoidable mode of agricultural information management. Smart farming can provide remote monitoring and control of a farm equipment to improve the productivity and quality and prevent disasters. Nevertheless, certain technical hurdles need to be addressed in terms of smart farming including lack of data sharing infrastructure because no mechanism is available to provide privacy protection in sharing sensitive agriculture data leading to irregular monitoring of farming systems [16]. Again, proper management of farm resources such as water, fertilizers, and seed quality has direct influence on the produce. Universally, majority of farms are still operating at small-scale levels covering a number of acres due to over-reliance on customary farming practices. The outcomes are often low yield, high crop losses, overuse or inadequate use of fertilizers, and soil spoilage [17].

The focus on linking IoT devices within the sensor networking system is emerging in smart and precision farming. Reason is that IoT devices are capable of acquiring information (such as the moisture rate) and broadcasting to the user in wireless setups. Therefore, farmers become significantly aware of the state of the farm field remotely in order to perform computation, collect data, and link with other nodes throughout the region of interest [18]. In particular, majority of IoT devices are susceptible to compromises and hacks, which render their ensuing data unreliable for productive ventures. Again, IoT devices have limited computational, memory, and network aptitude. These make them more prone to attacks against endpoint devices, such as tablets, smartphones, or PCs [19]. The IoT is targeted at improving human life and releasing vast economic value. But, insufficient data security and trust in contemporary IoT have stood in way of full exploitation and adoption [20].

The notion behind smart farming system is to intellectualize management of crop enterprises involved in deployment of precision farming technologies. This paradigm hampers the knowledge bases and multi-agent technologies to advance coordinated decisions on planning, distribution, control, and optimization of enterprise resources on real-time basis [21]. In particular, farm production planning relies heavily on enormous data generated from the field such as the soil infiltration characteristics by human agents and IoT devices, but, is often manipulated and tempered, rendering them unreliable and inaccurate for appropriate modeling procedures [22].

Traditional approaches for crop (such as rice) investigation and analysis of soils are time-inefficient and tasking, which led to the quest to deploy IoT and secure data for providing remote soil and environmental parameters monitoring. Smart farming is facing insufficient data sharing infrastructure because of poor mechanisms to broadcast sensitive agriculture data in a privacy-protected form [16].

Again, the future trends and behaviors of dynamic systems such as rice farming and model-based controls are applied to understand the physical process and valuable factors of production [23]. Therefore, prediction tasks are conducted by smart and precision-based systems, which rely heavily on data powered by IoT devices and things.

IoT-based systems are highly susceptible to attacks, that is, manipulation and tampering of data on unsecured over long-distance wireless network coverage. Likewise, the privacy of device owners is not guaranteed due to autonomous data sharing across diverse entities including cloud, fog, and Internet [24]. Whenever threats of any kind can be successfully launched on wireless data transmission channels or storage infrastructures, privacy leakage will happen more quickly from insider or outsider agents [25].

IoT is the main motivation for a paradigm leap to a truly connected world in which everyday objects become interconnected, capable of communicating directly with each other, and capable of collectively offering smart services [26]. Therefore, in several of these applications, the data collected by IoT is sensitive and must be kept private and secure [27]. Several issues have continued to limit the widespread utilization of IoT as reported by numerous scholars as follows: According to Yang *et al*. [28], IoT device safety remained the topmost challenge due to attacks such as Mirai's Botnets of Things (DDoS). There is no adequate data protection mechanism at present for IoTs. The number of device types (homogeneity and heterogeneity) affects security of IoT. The devices are low-resource type and relatively expansive in quantity.

The Blockchain technology has the potential of providing privacy preservation in IoT-based smart farming for its sensitive data generation and communication in decentralized scenarios [29], as well as the overall improvement of farming practice or produce. The usefulness of blockchain technology in providing distributed things security services including confidentiality, privacy, provenance, authentication, and integrity was highlighted by Salman *et al.* [30]. Accordingly, authentication and confidentiality are attainable through the public key cryptography (that is, encryption and signature approaches). There is a need to investigate the various blockchain approaches in large-scale and real-world situations for performance assessments,

Farming types	Traditional rice farming	Smart precision rice farming
Scale	Subsistence or small	Large
Strengths	Natural ways of conserving water and maintenance of soil fertility. Natural conditions reliant.	Controllable and management of production factors. High deployment of technology. Data-driven farming.
Weaknesses	Scarce water resources and nutrients. Low yields. Uncontrollable environmental factors. Large uncertainties.	Low adoption of technology. Limited computational, memory, and network aptitude. IoT or data are vulnerable to privacy compromises.
Method(s)	Rainfed lowlands	Rainfed uplands and irrigated lowlands.
Human intervention	High	Low
Quality of Yield	Low	High
Research funding prospect(s)	Low	High
Modeling procedure	Inaccurate and time-consuming.	Accurate and faster.
Generation	Pre-Internet era	Post-Internet era
Key terms	Basic farm tools, and mechanization.	Data, technology, computer-aided decision-making, and IoT.

Table 1.
Distinction between traditional and smart precision rice farming.

especially in smart precision farming. The key distinctions between the traditional rice farming and smart precision rice farming are depicted in **Table 1**.

3. Impacts of farm parameterization on rice production

In agriculture, the fertility of soil refers to the capacity of soil to support crop growth by supplying required soil nutrients, as well as suitable biochemical, and physical properties as a growing environment for plants. Particularly, majority of the available research investigated a few indicators, such as rice yield, water use, and water productivity at the field level. There are sparingly limited works on the cost–benefit of water management technologies, enabling conditions, and business models for their large-scale adoption, with regard to their impact on farmers' livelihoods (women and youths) [3]. Besides, water management design for crop diversification, landscape-level water management, and iron toxicity mitigation, particularly in lowlands have received strained attention. More so, climate, topography, and soil indicators are natural conditions and prerequisites for determining rice cropping suitability.

Rice consumption has steadily increased in sub-Saharan Africa while domestic rice production hardly meets the demand. There are five rice cropping systems in West Africa including rainfed upland, rainfed lowlands, irrigated lowlands, Deepwater, and Mangrove swamps [8]. But, the irrigated rice systems hold promise for the future in numerous ways: Firstly, the average rice yield in irrigated lowland is better than yields in rainfed lowland, and rainfed upland. Secondly, due to temperature changes, rainfall variability, and expected future climate change impacts in rainfed rice systems, improvements in farmers' adaptive capacity due to the expansion of irrigation facilities may reduce rice production losses. Although, irrigated rice holds tremendous potential in fulfilling many West African countries' agendas of becoming rice self-sufficient, geospatial analysis to assess potentially irrigable land is often unexplored.

In particular, realizing the rice planting environmental patterns are capable of enhancing natural and human-environmental resources, which support sustainability in the long run. Rice yields are impacted by soil, topography, climate, farmland management, agricultural mechanization, and many other artificial environmental factors. These are required for planning and improving the high-precision systems for forecasting rice yields [9]. The new challenges and expectations of subsequent research efforts can be in the following ways:

i. The development of localized solution to solve rice production and food sustainability in horrendous climatic conditions in sub-Saharan Africa.

ii. The use of precision technique for environmental parameters optimization and soil characterization in smart rice farming.

iii. The privacy of data stored in the cloud is improved with blockchain technology.

iv. The privacy problem of blockchain technology can be demystified with lightweight cryptographic scheme in order to improve reliability and trust of cloud data storage.

In particular, farm production planning relies heavily on enormous data generated from the field, such as the soil infiltration characteristics by human agents and IoT devices, but, is often manipulated, and tempered, rendering them unreliable and inaccurate for appropriate modeling procedures [22].

According to Banerjee, Lee, & Choo [31], there is lack of publicly obtainable dataset from IoT devices deployed for farming practices (such as rice) because of non-existing data sharing standards for enforcing integrity in order to assist researchers.

4. Existing frameworks of smart farming systems

The spate of climate change globally puts burden on governments in safeguarding food security through increased agricultural production. These rapid climate changes radiations continue to adversely impact rice production throughout growing stages based on different abiotic factors, such as rainfall, drought, temperature, flooding, and solar [32]. Precision farming is based on the observing, measuring, and responding to the variability in crop fields for strategic management [1, 5, 33]. It entails applying inputs when and where needed as means of sustaining crop production. The basic problems facing agricultural production are crop selection, decision-making, and supporting systems for better crop yield. Agriculture prediction is associated with natural parameters including temperature, soil fertility, water quality, water volume, season, and crop prices. A smart crop monitoring and tracking framework composed of sensors, mobile applications, IoT cameras, and big data analytics were proposed by [34]. While the hardware component consists of an Arduino UNO, a variety of sensors, and a Wi-Fi module without privacy preservation strategy.

An information-based management cycle for advanced agriculture was proposed by [4]. The framework contains crop sensing objects, platform, data warehouse, decision system, and actuation. There is no consideration for privacy of collected data throughout the cycle. Smart farming drive in part targeted the wireless sensor network in the attempt to deal with the developing problems of global warming. Sensors have potentials to effectively collect the farming environmental parameters for making smarter and faster decisions using computer-based solutions. Crop yield depends greatly on the ability of farmers to make faster and accurate decisions [18].

One key problem facing society at present is the privacy and security of available data. There are issues surrounding collection, storage, integration, and transformation of data to support the needs of agri-food (Mushroom production) due to widespread deployment of evolving technologies. Apart from competitive advantage and increased production, environment variables need to be regulated because of their direct relationship to production control system. One form of farming was understudied by [35], which is an extension mushroom farm distributed process control system using IoT and Blockchain to facilitate distributed data collected on environmental indicators to supplement the production control system for mushroom farming. Again, there is improvement in farm management information system available to managers of farms. But, precision farming is expected to have comprehensive decision support system from its subsystems with privacy in mind.

The evolving ecosystem control system and technology are still incapable of providing the required intelligence for rural farms. Inadequacy of precise information and communication negatively impacts the farm production management, which was overtaken by IoT rather than conventional farming practice [36]. This led to introduction of framework for constructing fresh technology and application for IoT-based farming. They enhance farming processes, monitoring, and welfare of farms and farmers with unrestricted access to data in real time. Of course, there is greater leap toward food sustainability by means of connected objects. The potential of IoT to advance farming sector and food sustainability for populace was undertaken by [22]. Smart farming is a potent coping mechanism for extreme weather and climatic conditions as well as massive demands for farm produce. This enhances productivity and grows cleaner food to cater to exploding population. In the complete framework for the smart farming system, processes and requirements left out the most important component, that is, privacy of data generated from IoT devices or transmitted across vulnerable public channels.

In [24], the promise of fog computing and wireless networks to interconnect farm bases distributed in rural setups became feasible. To this end, a scalable network structure for controlling and monitoring farms in rural areas evolved with cross-layered channel access and routing schemes. There are noticeable improvements in latency, sensing, and actuating but, chances of tampering and manipulating data are highly probable. Specifically, the gaiasense™ smart farming framework is composed of IoT devices (or GAIAtrons), cloud computing services (or GAIA Cloud), and smart farming (SF) advisory services (or GAIA SmartFarm) [37]. However, privacy of data was not considered.

The coping mechanism for the climate change phenomenon and food security can be best tackled with precision and smart farming [1]. Typically, smart precision farming system frameworks are composed of IoT data acquisition, IoT data storage, data sharing, and IoT data analytics as depicted in **Figure 1**.

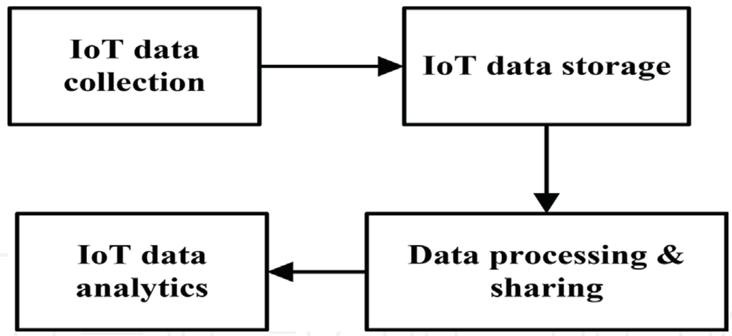

Figure 1.
The typical framework of smart precision farming system.

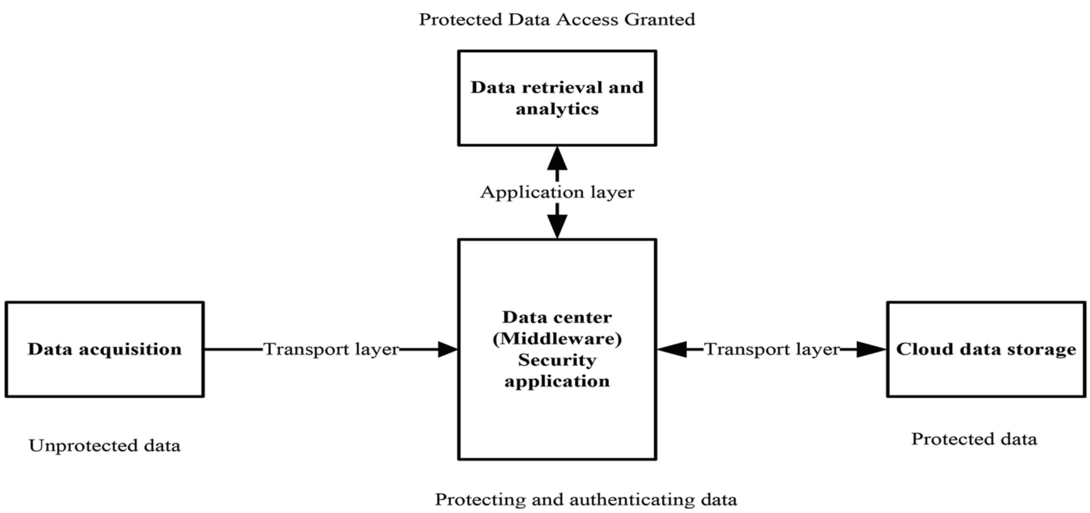

Figure 2.
The data privacy protection strategy for smart rice farming scheme.

The issue of privacy of data is topmost when IoT and blockchain technologies are deployed for smart precision farming practices. Therefore, this paper proposes a new framework leveraging the shortfall of aforementioned frameworks to develop a smart precision system for determining the suitability of environmental and soils for rice cropping. On the other hand, the complete model of data and transactions protection strategy proposed by this paper for smart precision rice farming system is shown in **Figure 2**.

In **Figure 2**, the data privacy protection strategy commences at the IoT device **transport layer** by offloading the protecting operation based on **lightweight cryptosystem** to develop at the middleware (or data center). Then, the protected data is broadcast to the blockchain cloud data storage at the **middleware layer** transport layer. The protected data can be accessed through **authenticating operations** at the application layer.

5. Future architecture of smart precision Rice farming systems

The traditional methods of farming are incapable of satisfying the feeding needs of people across the globe. So, the IoT-driven smart farming becomes an unavoidable mode of agricultural information management. But, insufficient data security and trust in contemporary IoT have stood in way of full exploitation and adoption [38].

The strengths of precision models depend on available, reliable data about farmland, soil characterization, infiltration characteristics, and chemical nutrients, which are often difficult to attain due to distributed and complex nature of harvesting and analyzing data in developing countries. The structure of the proposed smart rice precision is composed of rice farm field parameters composed of the sensors, embedded system, and the cloud storage.

The research process design is subdivided into four main steps discussed as follows:

Phase 1 is data capturing: This is entirely the requirements and problems specification for the proposed scalable solutions.

Phase 2 is the formation of a data encryption model: The phase includes formulation lightweight cryptosystem to generate sizes of keys and block-ciphers, which protect data against privacy compromises in smart farming scenario.

Phase 3 is the formation of data processing model: The phase includes the use of data mining, machine learning, and forecasting estimators for understanding the variability of data captured.

Phase 4 is the development: This involves the implementation of the proposed permissioned blockchain-based smart precision rice farming.

Phase 5 is the evaluation: It includes testing the proposed smart rice precision system with selected dataset to ascertain the performance.

The structure of the proposed smart rice precision is composed of rice farm field parameters composed of the sensors, embedded system, and Blockchain security in the cloud storage as shown in **Figure 3**.

In **Figure 3**, the series of events for the proposed secure smart rice farming data are indicated with letters A-E due to the distinct roles played throughout the data lifecycle.

Event A: This entails deployment of field sensors and GPS to capture distinct parameters required for rice farming and production broadcast across embedded system unit.

Event B: The data are sent from embedded system unit and received at the Blockchain. Then, the proposed lightweight cryptosystem is to be used for data key generation and hashes.

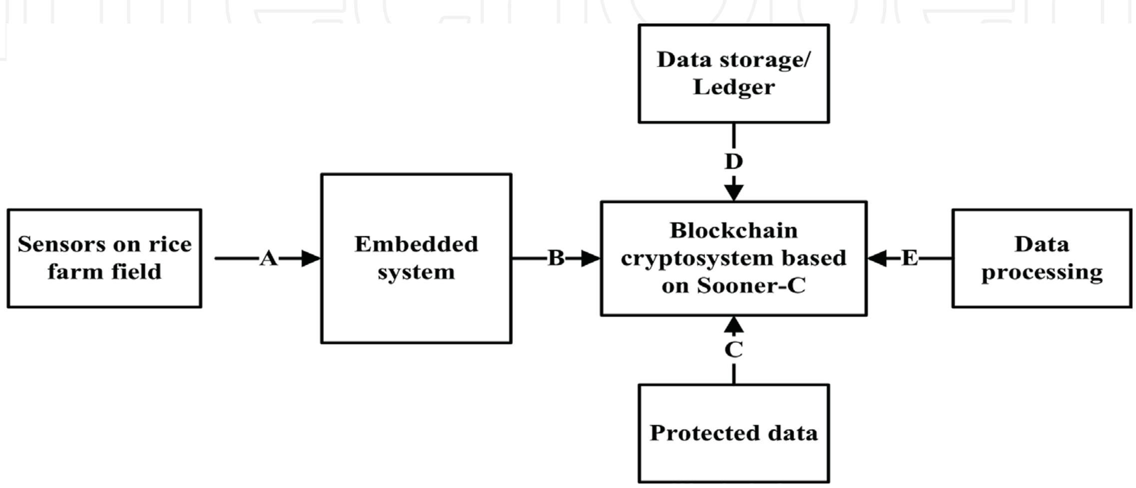

Figure 3.
The events modeling of smart precision rice farming system.

Event C: The encrypted data are stored on the distributed ledger provided by Permissioned Blockchain (PBC).

Event D: The data are protected using the lightweight scheme for effective processing and computation in order to enforce privacy.

Event E: The data processing can be performed on protected data using proof-of-work. This way the security and privacy of data are preserved.

The research concerning smart precision rice farming can border on the following aspects including data acquisition, data analytics, climatic factors, soil factors and water conservations, environmental factors, and topology/toposequence as illustrated in **Figure 4**.

Figure 4 provides the direct relationships between the rice production and uncontrollable environmental factors debacle in sub-Saharan Africa. The process of overcoming the climate change problems requires that, the challenges of rice field dataset and the inaccurate decision-making about parameters required for rice production. In particular, IoT data controls, governance, and privacy/security continue to bedevil their progress. The method with reoccurring assurances to withstand the shocks of climate change phenomenon is the smart farming, which utilizes IoT (sensors and actuators) to harvest dataset from the field to the point of usage. Precision farming relies on smart datasets to project parameter dynamics at certain points in time especially climate, soil, and environmental factors. The combination of the two technologies ignites the potential to increase rice production despite large instability in climatic conditions around the sub-Saharan Africa. There is a need to the redesign data transmission channels and network connectivity between IoT devices and the cloud storage infrastructure for data privacy and effective exchanges.

The key solutions for improving the fight against climate dynamics are appropriate data warehousing from numerous IoT placed on the rice fields; secure and privacy-protected data sharing among stakeholders, data providence by means of blockchain technology; and the use of high-performance AI techniques including machine learning, deep learning, and natural processing. In this way, the process of arriving at quicker, safe, and accurate, decision-making can be automated concerning suitability of lands for rice crop production as against the less-effective manual approaches. This taxonomy adds to the knowledge of the relevant players in rice production and climate controls by minimizing wastage and parameter forecasting.

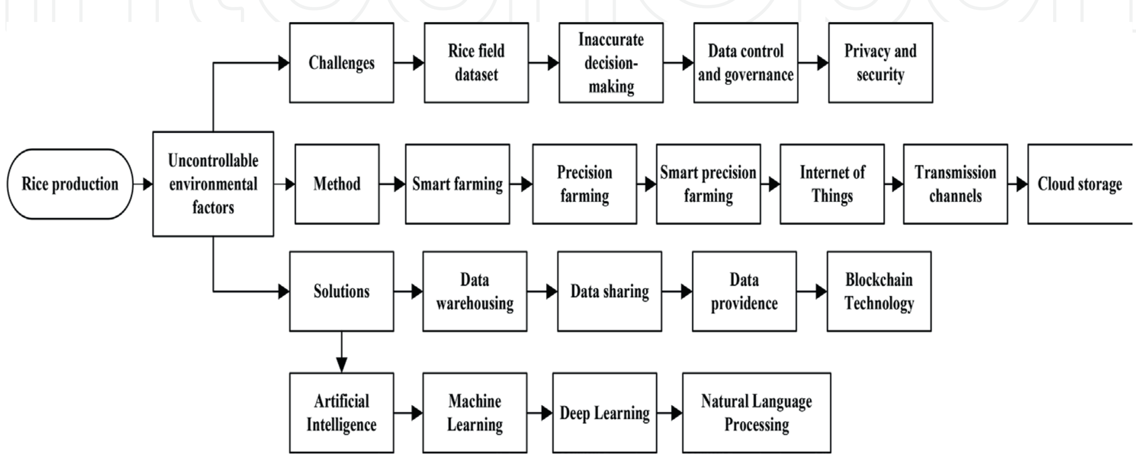

Figure 4.
Taxonomy of smart precision farming for rice production.

6. Conclusion and recommendations

Population growth is exponential, yet land is a limited and precious resource on the planet. Thus, it is critical to utilize that fixed resource sustainably in order to meet rising food demand without damaging the land with improper land practices. To reduce the undesirable impact of environmental features on agricultural productivity and on land, land suitability analysis is the first and foremost step for environmental management and sustainable agriculture. Land suitability assessments not only aid in increasing crop yields but also in maintaining healthy soil conditions for bountiful output. Rice planting suitability depends on slope and geomorphological formations. This paper developed a framework for smart precision rice farming system that utilizes sensors, blockchain technology, and AI approaches for determining the environmental factors, soil fertility, and suitability of farmlands for rice cultivation in semi-humid climatic zone of sub-Saharan Africa. The proposed framework attempts to improve the renowned syn. Jenks (natural breaks) method for seasonal farming practices. The devastating effects of climate change on rice production will continue to worsen with attendant negative implications on productivity and rice farming practices in sub-Saharan Africa. Though, the proposed smart precision rice farming systems can effectively deal with the climate change debacle in the short and long runs.

The key recommendations from this paper include development of full-fledged smart precision farming systems for the local farming scenarios in order to reduce resource wastages and environmental hazards while increasing rice crop health; development of effective lightweight privacy-preserving schemes in smart data centers for data governance and providence; the adoption of viral and high-performance analytical mechanisms to support faster and accurate decision-making process on rice production planning and parameters estimations. The target audience for this paper is primarily the research community, farmers, and investors by providing them with supportive tools, knowledge, and decision-making mechanisms on process and architecture of smart precision rice farming schemes. The outcomes shall be helpful to government donors, regulatory agencies, and international organizations on the need to improve and adopt responsible technology to combat hunger, low rice production, resource wastages, resource conservation, and climate problems through smart systems and AI.

Author details

Abraham Ayegba Alfa[1,2*], John Kolo Alhassan[2], Olayemi Mikail Olaniyi[2] and Morufu Olalere[2]

1 Confluence University of Science and Technology, Osara, Nigeria

2 Federal University of Technology, Minna, Nigeria

*Address all correspondence to: mikail.olaniyi@futminna.edu.ng

References

[1] Alfred R, Obit JH, Chin CPY, Haviluddin H, Lim Y. Towards paddy rice smart farming: A review on big data, machine learning, and rice production tasks. IEEE Access. 2021;**9**:50358-50380

[2] Fawzi NI, Qurani IZ. Lesson learned from the development of sustainable rice farming in peatland. IOP Conference Series in Earth Environmental Science. 2021;**752**:1

[3] Dossou-yovo ER, Prasad K, Akpoti K, Danvi A, Duku C, Zwart SJ. Field crops research thirty years of water management research for rice in sub-Saharan Africa: Achievement and perspectives. Food Crops Research. 2022;**283**:108548

[4] Saiz-Rubio V, Rovira-Más F. From smart farming towards agriculture 5.0: A review on crop data management. Agronomy. 2020;**10**:2

[5] Bala JA, Folorunso TA, Olaniyi OM, Daniya E. Design of an Agribusiness Innovative and Autonomous Robot System for Chemical Weed Control for Staple Food Crops Production in Sub-Saharan Africa. In: Che FN, Strang KD, Vajjhala NR, editors. The Advances in Business Information Systems and Analytics (ABISA). Hershey, PA: IGI Global; 2021. pp. 234-262

[6] Song G, Zhang H. Cultivated land use layout adjustment based on crop planting suitability: A case study of typical counties. Land. 2021;**10**(107):1-19

[7] Cappelli GA, Bregaglio S. Model-based evaluation of climate change impacts on rice grain quality in the main European rice district. Food Energy. 2021;**10**(4):1-22

[8] Akpoti K, Dossou-yovo ER, Zwart SJ, Kiepe P. The potential for expansion of irrigated rice under alternate wetting and drying in Burkina Faso. Agricultural Water Management. 2021;**247**:106

[9] Li D, Liang J, Wang X, Wu S, Xie X, Lu J. Rice yield simulation and planting suitability environment pattern recognition at a fine scale. International Journal of Geo-Information. 2021;**10**(612):1-19

[10] Bauw P et al. Field crops research combining phosphorus placement and water saving technologies enhances rice production in phosphorus-deficient lowlands. Food Crop Research. 2019;**236**(March):177-189

[11] Thakur D, Kumar Y, Kumar A, Singh PK. Applicability of wireless sensor networks in precision agriculture: A review. Wireless Communication. 2019;**107**(1):471-512

[12] Özkan B, Dengiz O, Turan İD. Site suitability assessment and mapping for rice cultivation using multi-criteria decision analysis based on fuzzy - AHP and TOPSIS approaches under semihumid ecological condition in delta plain. Paddy Water Environment. 2019;**17**(4):665-676

[13] Ullah H, Rahimi AZ, Datta A. Growth and yield of lowland rice as influenced by potassium application and cultivation method under alternate wetting and drying water regime. Journal of Plant Nutrition. 2019;**42**(13):1529-1542

[14] Zhuang Y, Zhang L, Li S, Liu H, Zhai L, Zhou F, et al. E ff ects and potential of water-saving irrigation for rice production in China. [internet].

Agricultural Water Management. 2019;**217**:374-382

[15] Bacco M, Barsocchi P, Ferro E, Gotta A, Ruggeri M, Bacco M, et al. The digitisation of agriculture: A survey of research activities on smart farming. Array. 2019;**3**:1000

[16] Patil AS, Tama BA, Park Y, Rhee KH. A Framework for Blockchain Based Secure Smart Green House Farming. Singapore: Springer Verlag; 2018. pp. 1162-1167

[17] Na A, Isaac W, Varshney S, Khan E. An IoT based system for remote monitoring of soil characteristics. In: 2016 International Conference on Information Technology (InCITe)- The Next Generation IT Summit on the Theme - Internet of Things: Connect your Worlds. Noida, India: Institute of Electrical and Electronics Engineers; 2016. pp. 316-320

[18] Surai S, Kundu R, Ghosh R, Bid G. An IoT based smart agriculture system with soil moisture sensor. Journal of Innovation Research. 2018;**1**(1):39-42

[19] Ahmad M, Salah K. IoT security: Review, blockchain solutions, and open challenges. Future Generation Computer System. 2018;**82**:395-411

[20] Wang X, Zha X, Ni W, Ping R, Guo YJ, Niu X. Survey on blockchain for internet of things. Computer Communication. 2018;**136**:10-29

[21] Skobeleva PO, Simonovac EV, Smirnova SV, Budaeve DS, Voshchuke GY, Morokovd AL. Development of a Knowledge Base in the "smart farming" system for agricultural Enterprise management. Procedia Computer Science. 2019;**150**:154-161

[22] Mat I, Kassim MRM, Harun AN, Yusoff IM. Smart agriculture using internet of things. In: 2018 IEEE Conference on Open Systems (ICOS). Langkawi, Malaysia; 2019. pp. 54-59

[23] Yu W, Pacheco M. Impact of random weights on nonlinear system identification using convolutional neural networks. Information Science. 2018;**477**:1-14

[24] Ahmed N, De D, Hussain I. Internet of things (IoT) for smart precision agriculture and farming in rural areas. IEEE Internet of Things Journal. 2018;**5**(6):4890-4899

[25] Qiu M, Gai K, Zhao H, Liu M. Privacy-preserving smart data storage for financial industry in cloud computing. Concurrnce Computer Programming Expertise. 2017;**30**:1-10

[26] Georgakopoulos D, Jayaraman PP. Internet of things: From internet scale sensing to smart services. Computing. 2016;**98**(10):1041-1058

[27] Kouicem DE, Bouabdallah A, Lakhlef H. Internet of things security: A top-down survey. Computer Networks. 2018;**141**:1-24

[28] Yang Y, Yang Y, Chen J, Liu M. Application of blockchain in internet of things. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Switzerland: Springer Verlag; 2018. pp. 73-82

[29] Ejaz W, Anpalagan A. Blockchain Technology for Security and Privacy in Internet of Things. Switzerland: Springer, Charm; 2018. pp. 47-55

[30] Salman T, Zolanvari M, Erbad A, Jain R, Samaka M. Security services using blockchains : A state of the art survey. IEEE Communication Surveys and Tutorials. 2019;**21**(1):858-880

[31] Banerjee M, Lee J, Choo KKR. A blockchain future for internet of things security: A position paper. Digit Commununication Networks. 2018

[32] Hussain S, Huang J, Huang J, Ahmad S, Nanda S, Anwar S, et al. Rice production under climate change: adaptations and mitigating strategies. In: Environment, Climate, Plant and Vegetation Growth. Switzerland: Springer; 2020. pp. 659-686

[33] Mizik T. How can precision farming work on a small scale? A systematic literature review. Precision Agriculture. 2022;**4**(3):149-160

[34] Phasinam K, Kassanuk T, Shabaz M. Applicability of internet of things in smart farming. Journal of Food Quality. 2022;**2022**:1-7

[35] Branco F, Moreira F, Martins J, Au-Yong-Oliveira M, Gonçalves R. Conceptual approach for an extension to a mushroom farm distributed process control system: IoT and blockchain. In: Rocha Á et al., editors. WorldCIST'19 2019, AISC 930. Switzerland: Springer; 2019. pp. 738-747

[36] Hari Ram VV, Vishal H, Dhanalakshmi S, Meenakshi Vidya P. Regulation of water in agriculture field using Internet of Things. In: 2015 IEEE Technological Innovation in ICT for Agriculture and Rural Development (TIAR). Chennai, India; 2015. pp. 112-115

[37] Kalatzis N, Marianos N, Chatzipapadopoulos F. IoT and data interoperability in agriculture: A case study on the gaiasenseTM smart farming solution. Global IoT Summit. 2019;**2019**:1-6

[38] Wang X, Zha X, Ni W, Liu RP, Guo YJ, Niu X, et al. Survey on blockchain for Internet of Things. Computer Communications. 2019;**136**:10-29