Application of machine learning techniques and the Internet of Things for smart, sustainable agriculture

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Abstract. The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) has been extensively utilized in the agricultural sector for an extended duration in conjunction with various other sophisticated computing technologies. In the past few years, there has been a notable advancement in greenhouse development within the agricultural sector, driven by the guidance of information technology and resulting in increased productivity. The IoT encompasses a range of intelligent systems and remote monitoring technologies, including those that support sustainable development. This study examines the accessibility of information technology in the context of training and developing smart systems and forecasting models within organizations, focusing on real-time applications using Machine Learning (ML) and AI techniques. This paper aims to enhance the efficacy of agricultural sustainable growth governance by investigating the Smart Sustainable Agriculture (SSA) platform, utilizing IoT and ML technology as its foundation. Hence, a proposed system called Remote Sensing Aided Framework for Smart Sustainable Agriculture (RSAF-SSA) aims to enhance the fulfillment of greenhouse agriculture prerequisites by applying ML techniques and the IoT. The proposed methodology employs AI and ML technologies to strengthen the green development prospective industry's capacity to manage financial resources and foster innovative trends in agricultural product development. Also, this study integrates the requirements for sustainable development in the field of SSA by establishing a Smart Agriculture (SA) platform that utilizes IoT and ML. Additionally, experimental designs are devised to assess the effectiveness of the system platform developed in this work. With 50 IoT devices, the Irrigation Control Ratio (ICR) and Agricultural Production Ratio (APR) for the proposed RSAF-SSA achieve a noteworthy efficiency rate of 95.8% and 95.3%, respectively.

1 Introduction

Agriculture has been a crucial and indispensable activity for the sustenance of human civilization for several millennia. Establishing this relationship has led to the progression of agricultural practices, primarily through utilizing labor-intensive techniques employed in

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conventional farming. The exponential growth of the world population, projected to reach 9.55 billion by 2055, has necessitated an immediate requirement to achieve equilibrium between demand and supply by employing novel technologies [1] for augmenting agricultural output. This phenomenon significantly strains natural resources, as the agricultural sector currently utilizes 70% of the global surface water supply for crop irrigation. The scarcity of resources and the consequences of climate change will inevitably lead to significant obstacles in producing adequate nutritious food to sustain the population [2]. The SSA initiative is a worldwide endeavor to conserve resources and promote sustainable agriculture practices. In recent times, scholars have increasingly embraced the concept of the IoT [3].

Numerous investigations have focused on the acceptance and use of IoT in farming, agriculture, and watering [17]. In various regions worldwide, numerous private enterprises and organizations are presently directing their attention toward exploring novel technologies to establish an enhanced agricultural ecosystem. The abovementioned domains encompass mechanical and economic facets, engineering, food sellers, and computing. Nevertheless, farming procedures exhibit fragmentation, leading to various challenges, such as the complexities associated with operating and managing intelligent machinery, sharing and handling data, and evaluating and archiving data [5]. Hence, it is imperative to promote collaboration while establishing standards for intelligent agriculture while concurrently improving compatibility among diverse participants, systems, and technologies.

The utilization of IoT and AI technologies holds promise for facilitating a beneficial revolution in conventional agriculture [6]. This encompasses several advantages, such as (a) enhanced utilization of data obtained from intelligent agricultural sensors, (b) effective management and regulation of internal operations within the intelligent agricultural setting (which includes crop harvesting and storage governance), (c) decreased waste and cost savings; (d) augmentation of business productivity through the automation of conventional processes; and (e) enhancement of product quality and quantity. One significant obstacle lies in the prompt dissemination of necessary information to farmers. AI possesses considerable potential in effectively tackling the pressing challenges conventional agriculture encounters. In recent decades, significant research and practical implementation of AI in various domains has been done. These domains include SA, robotics, farming optimization, administration, automation, agricultural intelligent systems, knowledge-based systems, and systems for decision-making [7].

The field of SSA continues to face a shortage of research and development efforts. This deficiency is compounded by intricate challenges stemming from the disintegration of agricultural procedures [8]. These challenges include overseeing IoT and AI machinery, sharing and administrating data, establishing integration, and evaluating and storing substantial volumes of generated data. This study aims to investigate the current utilization of IoT/AI technologies in the context of SSA. Additionally, it seeks to create a technical framework for IoT/AI systems that can support SSA platforms. The primary objective is to address the issue of fragmentation in conventional agricultural practices and contribute to the advancement of SA globally. This will be achieved by launching a SSA platform as a potential solution.

This research paper thoroughly examines the utilization of ML methodologies and the integration of the IoT within the domain of intelligent and environmentally conscious agriculture. This paper seeks to enhance knowledge in agricultural innovation by examining the synergistic relationship between two transformative technologies. It aims to provide insights into the potential advantages, obstacles, and ethical implications associated with the endeavor to achieve a more intelligent and sustainable future for worldwide agriculture.

2 Related works

In pursuing agricultural innovation and sustainability, integrating ML techniques, the IoT and Remote Sensing (RS) technologies emerge as a leading force in transformative progress. The convergence of these advanced technologies presents the potential to transform conventional farming methods by incorporating intelligent capabilities into all agricultural operations. This survey examines the methodologies, implementations, and outcomes of merging IoT and RS in the context of SSA, drawing from existing research.

Phasinam and colleagues (2022) developed a practical approach to implementing IoT in SA. The implementation involves integrating IoT devices for continuous agricultural observation and data collection [9]. The study highlights how IoT has enhanced decision-making and effectiveness in agriculture. The results show improved resource allocation and agricultural productivity. This approach improves operational efficiency and promotes sustainable farming. However, upfront costs and data security concerns should be considered.

Raj et al. (2021) proposed the importance of IoT in Agriculture 4.0. The methodology analyzes relevant literature and research on implementing IoT technologies in agriculture [10]. Implementation requires information synthesis for in-depth analysis. This study analyzes IoT applications in modern agriculture using survey data. The results show Agriculture 4.0's widespread implementation and future benefits. This method allows for precision agriculture and informed decision-making. However, infrastructure development and data portability issues may be issues.

Jin et al. (2020) developed a DL predictor for sustainable precision agriculture. This predictor is based on an IoT system [11]. The methodology involves integrating a DL model with IoT devices for easy data input. The execution involves training the model with agricultural data. A predictive tool for environmentally conscious precision farming is the result. The results show improved agricultural parameter prediction. One benefit of using DL models is improved resource allocation accuracy and efficiency. However, these models are complex, which may be a drawback.

Lim et al. (2022) implemented an IoT system in smart microalgae farming to promote sustainable agricultural practices [12]. The methodology uses IoT devices to monitor and control microalgae cultivation parameters. Our technological system improves microalgae cultivation, advancing SA methodologies. Microalgae productivity and resource use increased significantly. This method improves cultivation control. The initial costs of setting up the system and the technical expertise needed to operate it are drawbacks to consider.

Wongchai et al. (2022) proposed an AI-enabled soft sensor and IoT framework for SA in their study. This framework employs an ensemble DL architecture. The methodology introduces a soft sensor using ensemble DL techniques and IoT devices for data input [13]. Execution includes model training and validation. The result is a SA prognostic tool. Results show improved agricultural parameter prediction precision. This method allows precise monitoring and decision support. However, model interpretation and high-quality information may present drawbacks.

Liu's (2021) study introduced a cutting-edge analysis platform that uses IoT and ML to promote sustainable agricultural development. The methodology uses IoT devices for data collection and ML models for analysis [14]. A sophisticated platform with intelligent capabilities is implemented. The product is a comprehensive SA-facilitating analytical tool. The outcome values illuminate agricultural practices and resource efficiency. This approach allows for informed decision-making and sustainable practices. Consider potential drawbacks, such as data privacy and compatibility issues.

Zhou et al. (2022) explored AI and ML techniques to promote sustainable agricultural practices in the newly emerging manufacturing industry. The authors emphasized integrating these technologies on the IoT platform [15]. The methodology integrates AI, ML, and IoT

devices for data-driven decision-making. The implementation includes model training and validation. The result is a comprehensive framework for sustainable agricultural practices focusing on environmental conservation and ecological balance. The results show improved agricultural efficacy and sustainability. The benefits of this approach include resource efficiency and environmental conservation. The need for robust technological platforms and strict data security may be a drawback.

In summary, this literature review has explored the wide-ranging and ever-evolving field of research on utilizing ML methodologies and the IoT in combination with RS technologies for achieving SSA [16]. The amalgamation of information acquired from diverse studies highlights the profound capacity of these technologies to optimize the management of resources, improve the accuracy of yield prediction, and cultivate a more ecologically aware agricultural industry. The incorporation of an RSAF arises as a crucial element, guaranteeing that the implementation of cutting-edge technologies is not solely efficient but also conducted in a manner that upholds ethical and responsible practices [4].

3 Remote Sensing Aided Framework for Smart Sustainable Agriculture through the Application of ML techniques and the IoT

This paper presents a novel methodology for the controlled deployment and sensing of agricultural products. The report investigated the incorporation of IoT technology into regulatory networks and communication networks, specifically focusing on their application in agricultural production. Implementing IoT technology in the agricultural sector has facilitated the development sensing and controlling systems for farming and greenhouse farming settings. The present methodology is employed to effectively manage the financial assets associated with a prospective green development industry while simultaneously promoting innovative modes of agricultural production.

In agricultural manufacturing, remote notifications are transmitted via a supplementary platform to gather crucial real-time data on temperature, moisture, and ground signals. It is imperative to obtain instantaneous information on farm goods by utilizing the Short Message Service (SMS), mobile, and wireless communication framework to gain insights necessary for effective production management. The system comprises devices for remote sensing surveillance, applications for distant gathering of data receivers, and mobile internet-based applications. The data handling-zone surveillance system consists of a smart network, an internet connectivity device, a data gathering unit, and a system configuration management unit. The remote sensor's recipient comprises three main units: a client interaction unit, a network connectivity unit, and an access management unit. These modules facilitate communication with the RS tools for developing the application for mobile surveillance systems via network communication techniques.

Farmers can employ AI to address weed-related challenges by integrating computer vision, automation, and ML techniques. The utilization of AI has facilitated farmers' targeted application of pesticides, enabling them to spray areas where weed infestations are present selectively. This is made possible through the data collection capabilities of AI, which effectively monitors the growth and distribution of weeds. As a consequence of this, a significantly reduced quantity of chemicals was required for the treatment of the entire field. The application of AI in agriculture enables farmers to promptly identify specific areas within their fields that necessitate irrigation, fertilization, or pesticide application. Moreover, the implementation of advanced farming methods, such as vertical cultivation, has the potential to increase food production while simultaneously reducing resource consumption.

Due to the implementation of precision agriculture techniques, farmers can optimize resource utilization, specifically reducing water, fertilization, and seed requirements while enhancing crop yields. Farmers can acquire detailed insights into their agricultural output at

a micro-scale by employing sensors and mapping techniques, leading to enhanced resource conservation and reduced environmental impact.

The concentration allows farmers in remote areas to remotely monitor and control multiple factors in greenhouse cultivation, including CO_2 levels, soil moisture, temperature, and sunlight. Additionally, the concentration allows for the adjustment of greenhouse operations based on estimated soil moisture levels. The utilization of IoT technology in the agricultural sector can enhance the overall operational efficiency of individual companies and the manufacturing process. The utilization of this technology has the potential to significantly facilitate the dissemination of knowledge and the seamless exchange of data across various mobile devices.

3.1 RSAF for SSA

This paper has dedicated significant effort towards developing intelligent cultivation patterns utilizing IoT technologies within the agricultural sector. Through a comprehensive analysis of various challenges and issues faced in crop cultivation, the IoT has presented a remarkable paradigm shift in agriculture. The prevailing inclination towards innovation expects farmers to employ IoT technology to identify and address the challenges encountered in agricultural operations, including water management deficiencies and productivity concerns. The challenges encountered by the IoT have been identified, and efforts have been made to develop affordable options for mitigating these difficulties. Technology-driven surveillance networks facilitate the collection and transmission of data from sensors to a cloud server. The sensors efficiently gather information to comprehensively assess the entire system for data about diverse atmospheric conditions. The crop's assessment factor involves tracking environmental circumstances and crop production. A multitude of factors have a substantial impact on the productivity of crop yields, as well as the effective supervision of agricultural fields. These factors include soil and crop monitoring, removing unwanted objects, and mitigating wildlife disturbances. Furthermore, the IoT offers comprehensive administration of asset capabilities, enabling the efficient utilization of limited resources to enhance productivity.

Fig. 1 illustrates the utilization of IoT technologies in the context of SA, specifically in the domain of RS. The system showcases agricultural advancements that facilitate cost-efficient and seamless practical interactions, ensuring safety and optimal connection among particular greenhouses, cattle, and agriculturalists. The farming industry that utilizes IoT devices is employed to enhance the farming process and enable continuous tracking. The IoT has played a significant role in the advancement of farming practices. This includes the development of cloud platforms, database schemas, and programs, as well as identifying security issues and obstacles. Various IoT techniques and guidelines have been adopted by numerous organizations and individuals worldwide in the field of agriculture. A sensitivity analysis has been conducted within the context of an IoT-based agri-environmental system to gain insights into the growth and development of crops. This paper examines the challenges and advancements in IoT-based SSA, aiming to enhance agriculture productivity.

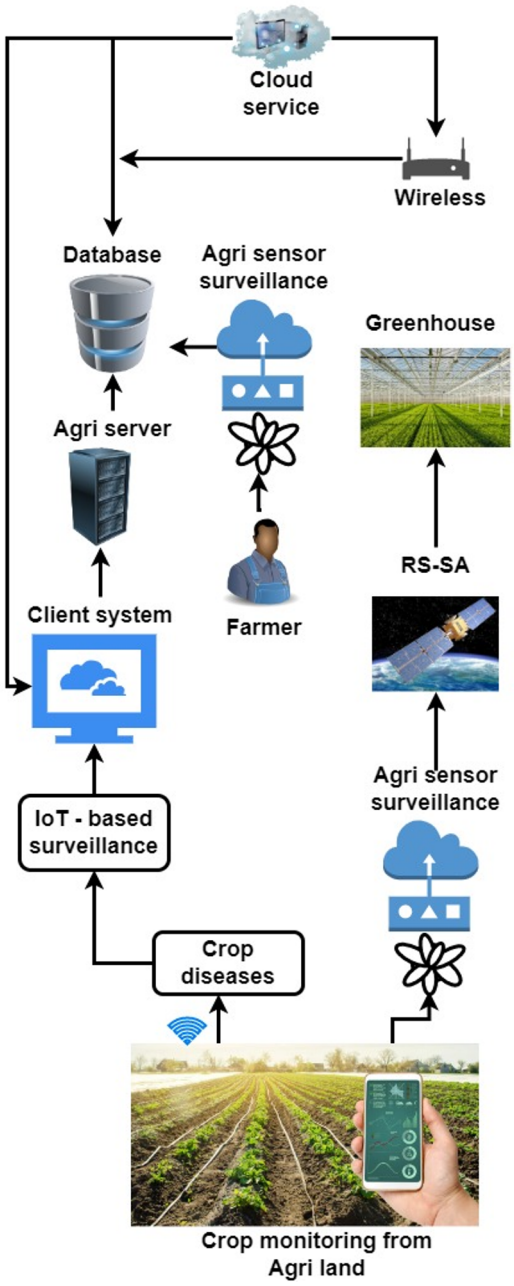

Fig. 1. Utilization of IoT technologies with RS in the context of SA

Based on prior research, this study incorporates agricultural methods as an investigative resource. The IoT refers to the network of interconnected physical devices. Identifying pertinent components that support the IoT is a crucial technological aspect in the context of SA. A comprehensive examination has been conducted on the communication network of the IoT, encompassing the cloud's architecture and software interface, as well as the topologies through which devices are interconnected in agricultural protocols. Discussions have occurred regarding various application domains and their corresponding smartphone and

sensor-based applications. The utilization of IoT technology in agriculture has brought to the forefront several significant challenges about security and privacy. This study examines the primary manufacturing sectors that are currently engaged in researching industrial advancements in IoT-based agriculture. This paper examines the measures implemented by different countries to standardize smart IoT agriculture practices. The obstacles and problems that can be addressed in agriculture-based IoT technology have been brought to attention.
RS is a technique that involves the measurement of rebounded and radiation released from a certain distance to identify and track the physical characteristics of a particular area. This method is commonly employed using satellite or aircraft platforms. Scientists can perceive and gather information about the Earth using cameras that capture RS images. Non-invasive nutrient detection approaches involve using optical sensors that utilize reflectance spectroscopy to quantify the refraction and intake of energy from soil particles and nutrient ions. Additionally, electromagnetic detectors are employed, which utilize ion-selective substrates.
The efficacy of irrigation methods in crop cultivation is contingent upon their ability to sustain soil quality. The primary objective of the irrigation manager is to maintain soil moisture within specified lower and upper thresholds. The upper limit signifies a greater water retention capacity of the soil, while the lower limit represents the threshold at which the soil's moisture level is constrained. The moisture level in the soil is denoted as:

$$F = \nabla\{e[mean(M(t), C(t))]\}, F \in [f_u, u = 1,2 \dots \dots .. U] \quad (1)$$

In equation (1), where F is a vector and ∇ represents the gradient operator. The function $e[mean(M(t), C(t))]$ denotes the average of the functions $M(t)$ and $C(t)$. The vector F is defined as $F \in [f_u, u = 1,2 \dots \dots .. U]$.

The calculation of soil moisture, denoted as $M(t)$, is determined as per equation (1). In this context, the term "e" refers to the typical volume of soil moisture, while rainy-level propagation $[mean(M(t), C(t))]$ represents the average volumetric moisture content of the soil. The irrigation of agricultural land is denoted as f_u, is contingent upon the soil potential $C(t)$ and soil moisture $M(t)$. In agricultural production, a preconfigured set of labeled soil $[f_u, u = 1,2 \dots \dots .. U]$ is utilized, where the variable u represents the upper bound indicating the water holding capability.

The primary objective of irrigated farming is to maintain soil moisture levels within optimal thresholds. The upper limit delineates the maximum ability to hold water in the soil. On the contrary, the lower threshold denotes the level of soil moisture content. Any value below this threshold indicates the requirement for irrigation. The capacity of the Earth, specifically its water-holding capabilities, plays a crucial role in implementing irrigation strategies within the agricultural sector.

$$WH_{max}^{zr} = \sigma(F, mean\ M(t)) \quad (2)$$

WH_{max}^{zr} denotes the maximum water-holding capacity of the soil. $\sigma(F, mean\ M(t))$ is the correlation between plants and soil moisture. The presence of moisture at a soil depth (in mm) at a period 't' is denoted as:

$$WH_t^{zr} = 1000 \times M(t).RTr \quad (3)$$

where RTr is the plant root thickness. The water deficiency in the agricultural land (in mm) at a period 't' is given as

$$WH_t^{ze} = WH_{max}^{zr} - WH_t^{zr} \quad (4)$$

WH_{max}^{ze} is the upper limit for water holding capacity, and its value can be 0. WH_t^{zr} can reach the maximum value of water holding capacity WH_{max}^{zr}.

$$NNS = BN \times N_t \tag{5}$$

The computation of the nitrogen nutritional score is discussed in equation (5). Various plant species are examined to assess the grade of grain by analyzing their Nitrogen Nutritional Score (NNS) and the total nitrogen content N_t present in their biomass. These signals are commonly employed to assess the need for agricultural fertilizers and make necessary adjustments in their application. The calculation of nitrogen intake, denoted as NIq, involves multiplying the N_t of the plant component by the dry biomass BN of the plant.

The concept of NNS is founded upon the notion that there exists an inverse relationship between biomass and N_t, whereby an increase in biomass results in a decrease in N_t. To determine the measured N_t, it is necessary to identify the minimum N_t value essential for attaining the highest biomass during a specific stage of progress.

4 Results and discussion

The enhancement of agricultural productivity has prompted significant attention towards developing SSA strategies. These strategies aim to address current challenges and optimize the utilization of resources for agricultural production efficiency. The effectiveness and comprehensiveness of this technology in quantifying field-based data have been demonstrated. The advancement of SA production is driven by the utilization of RS technology, which allows for the collection of field data through artificial sensors that are widely available. Numerous evaluations are available for RS applications, with recent studies emphasizing the potential utilization of RS in assessing nutritional conditions in agricultural products. The system presents novel methods for retrieving data that communication services can swiftly access. The performance of the proposed RSAF-SSA has been compared with the Risk model (RM) and Random Forest Regression Algorithm (RF-RA).

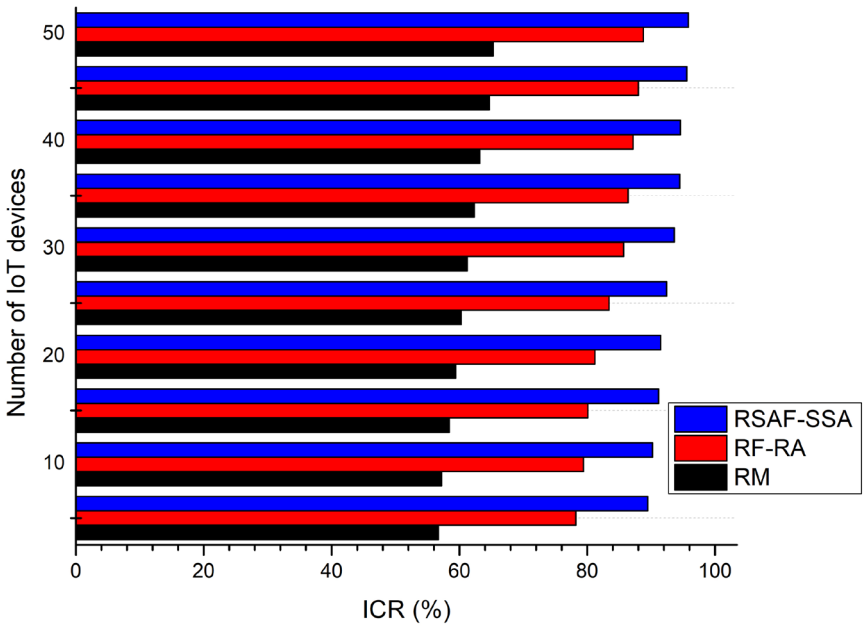

Fig. 2. ICR (%) comparison of various methods for varying numbers of IoT devices

The ICR is a metric employed to evaluate the efficiency and efficacy of irrigation techniques. Water use efficiency generally pertains to quantifying the ratio between the

quantity of water utilized in agricultural fields and the theoretical or ideal quantity of water necessary for optimal crop growth. The ICR serves as a crucial metric for assessing the effectiveness of irrigation systems in managing and utilizing water resources. Fig. 2 illustrates the comparison of ICR percentages among different methods, as the number of IoT devices varies. With the increasing proliferation of IoT devices, it is observed that all three methods demonstrate a positive trend in ICR, indicating their capacity to adjust irrigation practices in response to dynamic environmental conditions.

Nevertheless, the RSAF-SSA method consistently performs better than the other methods, exhibiting higher ICR percentages for all device quantities. With a total of 50 IoT devices, the ICR for the RSAF-SSA achieves a noteworthy efficiency rate of 95.8%. This highlights its superior performance in optimizing irrigation compared to the methods of RM and RF-RA. The statement mentioned above implies that incorporating smart sensor aggregation into a resource allocation framework greatly improves the accuracy and efficiency of irrigation control. This makes RSAF-SSA a promising strategy for attaining sustainable and water-efficient agricultural practices.

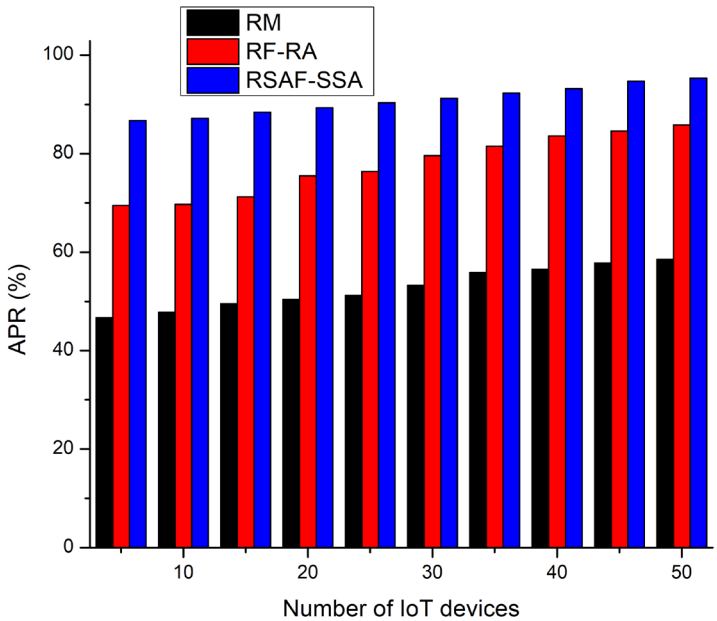

Fig. 3. APR (%) comparison of various methods for varying numbers of IoT devices

The APR is frequently employed as a metric for assessing the productivity or yield of agricultural endeavors about specific input variables. The constituents of the ratio may exhibit variability contingent upon the specific context. Yet, it frequently entails the juxtaposition of agricultural output, such as crop yield, with the resources or inputs allocated to the production process. The input factors encompass a range of elements, including land, water, moisture, and fertilizers. As the proliferation of IoT devices continues, it is evident that all three methods demonstrate a notable upward trajectory in the APR, thereby highlighting their potential to augment agricultural productivity. It is worth noting that the RSAF-SSA method consistently exhibits superior performance compared to the RM and RF-RA methods across various device quantities, thereby showcasing higher percentages of APR. With 50 IoT devices, the RSAF-SSA system demonstrates a notable APR of 95.3%, surpassing the performance of both RM and RF-RA. The observation mentioned above emphasizes the efficacy of integrating intelligent sensor aggregation into a framework for

allocating resources, thus emphasizing the superiority of RSAF-SSA as a method for optimizing agricultural production and resource utilization. The findings indicate that this approach substantially contributes to attaining increased agricultural yields, considering the input variables provided. This underscores its capacity to promote sustainable and effective agricultural methodologies.

5 Conclusion

This study aims to improve the effectiveness of governance in promoting sustainable agricultural growth. This will be achieved by examining the SSA platform, which is built upon the foundation of IoT and ML technology. Therefore, the Remote Sensing Aided Framework for Smart Sustainable Agriculture (RSAF-SSA) is a system that seeks to improve the fulfillment of requirements for greenhouse agriculture by utilizing ML techniques and the IoT. The proposed methodology enhances the capacity of the prospective green development industry to manage financial resources and promote innovative trends in agricultural product development. This paper aims to incorporate the principles of SSA by developing a Smart Agriculture (SA) platform that leverages the IoT and ML technologies. Furthermore, the experimental designs are formulated to evaluate the efficacy of the system platform developed in this study. The proposed RSAF-SSA demonstrates a significant efficiency rate of 95.8% for the ICR and 95.3% for the APR, with 50 IoT devices.

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