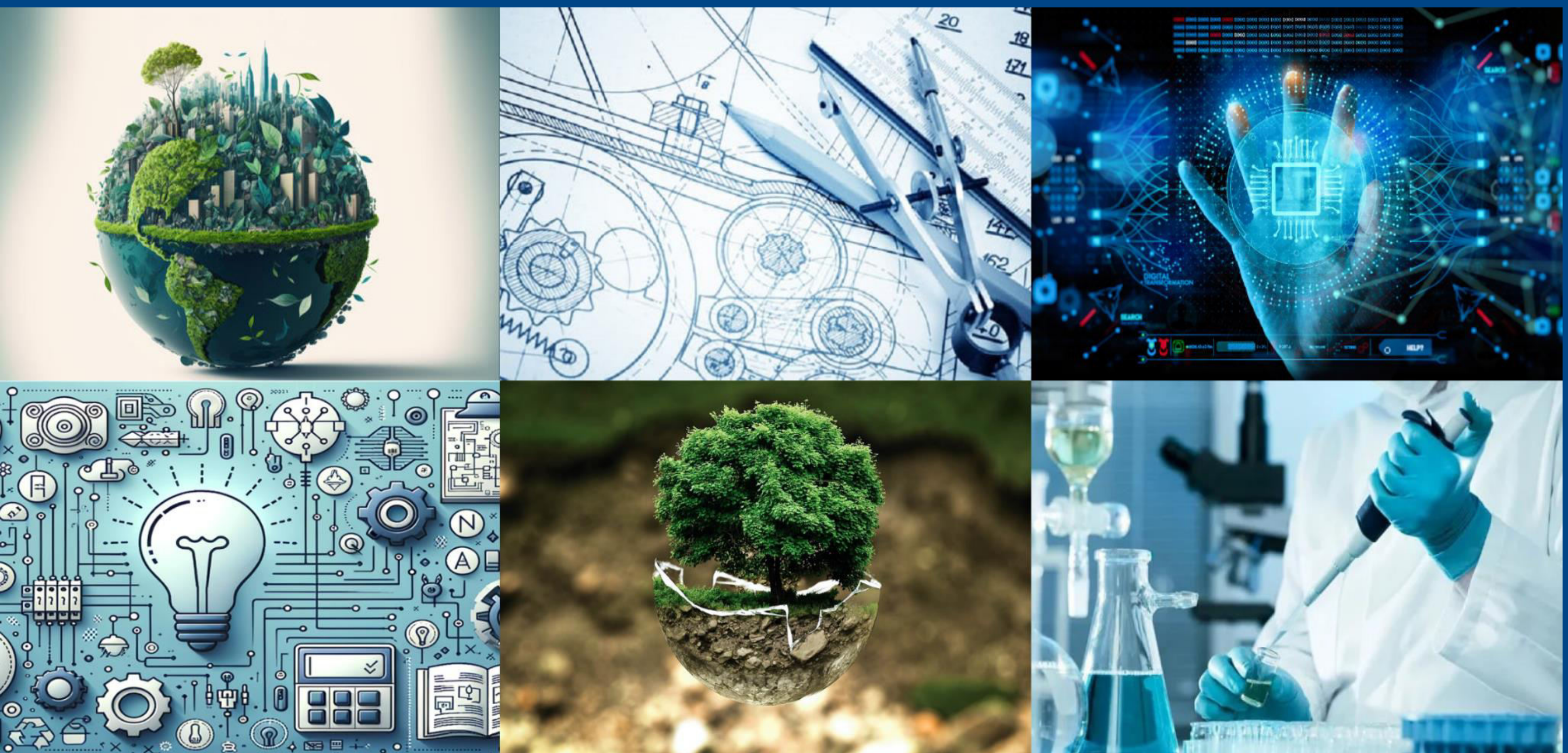
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 6, June 2025

© 2025 IJMRSET | Volume 8, Issue 6, June 2025| DOI:10.15680/IJMRSET.2025.0806053

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Precision Agriculture - IoT and Data Analytics for Optimal Yield and Resource Use

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ABSTRACT: In the near future, realizing the most yields in crops with a limited resource input is very key to the sustainability of food production in agriculture. Traditionally, farmers make crop yield predictions using experience-based techniques that often lacked precision and efficiency. The integration of the Internet of Things technology and data analytics, therefore, ushered in a transition phase in agriculture by enhancing precision and efficiency in crop management practices. The second paper explores the power of fusing IoT and data analytics in precision agriculture in crop yield prediction and resource management. Real-time climatic data and soil nutrient status are captured by IoT-enabled sensors, providing dynamic insights into variables of crop growth. These machine learning algorithms, run with predictive modeling techniques on this real-time data, provide improved predictive accuracy and permit informed decisions on agricultural operations.

KEYWORDS: IoT(Internet of Things), Sensor, Data Analytics, Machine Learning, Crop Yield Prediction, Soil Quality, Smart Farming, Precision Agriculture, VRT(Variable Rate Technology).

I. INTRODUCTION

Agriculture has traditionally relied on the experiential knowledge of farmers toward crop yield prediction and resource management. While this approach is extremely useful, it is usually not up to par in terms of precision and efficiency regarding the modern challenges brought forward by climate change, soil degradation, and scarcity in resources. Indeed, this need for innovative solutions to optimize crop yields and resource utilization has become more pressing than ever before.

These problems could be addressed by the onset of the Internet of Things and development in data analytics. The IoT technology makes it possible for real-time monitoring of environmental conditions and soil health through an interlinked series of sensors. As such, these sensors will, therefore, empower farmers to comprehend the several dynamics that affect crop growth at detailed and changing levels—starting from the content levels of water and other nutrients in the soil to temperature and other climatic conditions.

Moreover, when combined with IoT, data analytics uses the huge amount of generated data to drive meaningful patterns and predictions. Machine learning algorithms, being a subset of artificial intelligence, become one very vital component in data analytics. Such algorithms could function in the analysis of historical and real-time data to better predicate crop yields and give actionable insights on resource management.

In this research paper, the integration of IoT with data analytics is considered one of the paradigm shifts in farming precision agriculture. This paper targets the field deployment of IoT-enabled sensors in predictive modeling crop yields using machine learning techniques. It tries to bring out how the fusion of these technologies can enhance decision-making processes in agriculture to optimize resource use and improve crop productivity.

This data-driven approach can help modern agriculture shift from mere experiential to more scientific and effective methods of farming. While this goes on to increase yields, it contributes greatly to the sustainability of farming and continues to allow food security a midst a growing global population and environmental challenges.

II. LITERATURE REVIEW

Khan et al. [1], review applications of Internet of Things technologies in the sector of precision agriculture with regard to increasing agricultural productivity and sustainability. They explain how IoT solutions can monitor a lot of factors in an agricultural system: soil, crop health, and environment. This paper contributes to the identification of some challenges that lie ahead with regard to connectivity issues and data security and lays out several future research directions, such as the integration of IoT with advanced analytics and artificial intelligence to improve decision-making and operational efficiency.

Gupta et al. [2], review the role of IoT in irrigation systems within smart farming. Such cutting-edge developments in IoT technologies reviewed include those with sensors that track soil moisture and weather conditions to optimize irrigation practices. The authors discuss the various benefits related to these technologies, such as increasing water use efficiency and better crop management. However, they also address such challenges as the high cost of implementation and the need for effective strategies in managing data.

Singh et al. [3], discuss how IoT and big data analytics can be harnessed to enhance crop management. This paper provides a detailed review of the IoBT-based technologies and analytics techniques applied in monitoring and optimizing several agricultural operations. It mentions big data's benefits in better decision-making and the efficient use of resources while citing challenges such as data integration and the need for advanced analytical tools.

Patel et al. [4], recently elaborated on trends and innovations in the role of big data and IoT in precision agriculture. The paper discusses how IoT technologies generate large volumes of data and how big data analytics is used for processing information in order to improve agricultural practice. The focus is put on some recent innovations, such as advanced techniques of data analytics and integrated systems of IoT, on which challenges in data security and system complexity are discussed.

Garcia et al. [5], center attention on IoT-based smart irrigation systems and their impacts on precision agriculture. They review the state of the art with the latest trends in sensors and IoT systems, mainly for irrigation, with a special emphasis on how these technologies provide real-time data regarding soil and environmental conditions. This makes irrigation controllable with precision for better efficiency in water use and crop productivity. The paper investigates the incorporation of IoT systems into the incorporation of data analytics in the scheduling of irrigation for optimal results and also addresses issues relating to the cost of technology and data incorporation.

Marjani et al. [6], give an insight into the architecture and opportunities of big IoT data analytics within the context of precision agriculture. In the process, they describe how innumerable IoT technologies, using interconnnected sensors, are able to generate large volumes of data related to soil conditions, climate, and crop health. The paper underlines the role of machine learning algorithms in the analysis of said data to make better predictions for crop yield and management of resources. They also identify some open research challenges such as data integration and system complexity, that need to be addressed to leverage the full benefits from IoT and big data analytics for agricultural insight.

Cassman, K. G. [7], The program is directed at the ecological intensification of the cereal production systems for higher crop yields with better environmental health. This review essentially lays emphasis on optimizing resource use, water, nutrient, and land through better genetics combined with improved management techniques together with precision agriculture methods. The paper lays stress on maintaining soil quality through conservation methods, organic matter management, and balanced nutrient application. Hence, precision agriculture—together with such farming strategies as remote sensing and variable rate technology, and data analysis—features prominently in the success of efficient crop management that is at the same time sustainable. This study will therefore incorporate these methodologies to attain high productivity while being environmentally friendly.

Johnson et al. [8] provide a comprehensive analysis of the integration of IoT technologies with unmanned aerial vehicles (UAVs) in precision agriculture. The paper explores how UAVs equipped with IoT sensors can monitor large agricultural areas, providing real-time data on crop health, soil conditions, and pest infestations. The authors discuss the benefits of using UAVs for precision spraying, seeding, and monitoring, which can lead to more efficient resource use and improved crop yields. They also address the challenges related to the deployment of UAVs in farming, such as

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

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regulatory issues, the need for skilled operators, and the high initial investment costs. The paper suggests future research directions, including the development of autonomous UAV systems and the integration of machine learning algorithms for real-time decision-making in agriculture.

Brown et al. [9] examine the role of blockchain technology in enhancing data security and transparency in IoT-based precision agriculture. This review focuses on how blockchain can be utilized to secure the vast amounts of data generated by IoT devices, ensuring that the data is tamper-proof and trustworthy. The paper highlights potential use cases, such as tracking the origin of agricultural products, ensuring the integrity of supply chains, and automating transactions through smart contracts. The authors also discuss the challenges of integrating blockchain with IoT, including the scalability of blockchain systems, the energy consumption of blockchain operations, and the need for standardized protocols across different IoT devices and platforms.

Lee et al. [10] investigate the application of artificial intelligence (AI) in conjunction with IoT technologies to develop predictive models for precision agriculture. The paper details how AI algorithms can analyze data collected from IoT sensors to predict crop yields, detect early signs of disease, and optimize irrigation schedules. The authors emphasize the importance of combining AI with IoT to not only enhance productivity but also to enable sustainable farming practices by reducing water and chemical use. The paper also identifies several challenges, such as the need for high-quality data, the complexity of model training, and the potential biases in AI algorithms that could impact decision-making in agriculture

Zhang et al. [11] review the application of IoT and robotics in automating precision agriculture tasks, such as planting, weeding, and harvesting. The paper highlights how IoT sensors can work in tandem with robotic systems to perform agricultural tasks with high precision and minimal human intervention. The authors discuss the advantages of using robotics in agriculture, including increased efficiency, reduced labor costs, and the ability to perform tasks in challenging environments. They also explore the challenges faced by the adoption of robotics in farming, such as the need for advanced control algorithms, the high cost of robotic systems, and the integration of these technologies with existing agricultural practices.

Rodriguez et al. [12] provide an overview of the potential of IoT-enabled smart greenhouses in improving the efficiency of controlled environment agriculture (CEA). The paper explores how IoT sensors can monitor and control various environmental parameters inside greenhouses, such as temperature, humidity, and light levels, to create optimal growing conditions for crops. The authors discuss the benefits of smart greenhouses, including increased crop yields, reduced resource use, and the ability to grow crops year-round. They also address the challenges associated with implementing smart greenhouse systems, such as the need for robust sensor networks, the high initial setup costs, and the requirement for continuous monitoring and maintenance.

III. METHODOLOGY

A. IoT Technology Integration:
The most fundamental aspect of precision agriculture involves the implementation of Internet of Things technologies. IoT sensors are, therefore, spread across agricultural systems to track critical variables concerning soil moisture, crop health, and environmental conditions. Indeed, as noted by, the real-time data provided is very instrumental in making informed decisions regarding crop management. The use of IoT systems has been implemented in optimizing irrigation practices by continuously measuring soil moisture and weather conditions, as explained.

B. Data Collection and Analytics
All information gathered from these IoT sensors needs to be processed using big data analytics. [3] Emphasize in this regard that sophisticated analytics techniques are applied in making sense of the data related to soil conditions, crop health, and climate. In fact, machine soil conditions, crop health, and climate. In fact, machine learning algorithms, as discussed [6], go through this data to make better predictions regarding crop yield and optimize resource usage. Such data, integrated with that coming from IoT devices, can be used in building predictive models of crop performance and to optimize input use.

C. Remote sensing and aerial imaging
These include minute details regarding the crops and fields, taken through aerial photography captured with the help of

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drones and satellites. These technologies capture information from a distance on crop health, growth patterns, and other environmental parameters. This data will give an all -round view of the fields to any farmer when integrated with information obtained from IoT sensors. It can generate highly detailed maps and reports to guide interventions on targeted irrigation, fertilization, and pest management. It improves monitoring in the field, data accuracy, and the speed of problem detection and resolution for better crop management.

D. Data Storage

Huge volumes of data from the IoT sensors will be stored in cloud-based storage facilities. An appropriate platform for storing this data will be selected, such as ThingSpeak, Microsoft Azure, or AWS [4]. These platforms support a range of various cloud services that can be used in a number of diverse data management applications, including IaaS and PaaS. This includes data storage, processing, and analysis [4]. The agricultural data considered sensitive will be secured to maintain the privacy of its owners [1].

E. Optimization and Decision-Making

Data-driven decisions are taken on the type of practice that ensures optimum yield with maximum resource utilization. This includes VRT, which involves variable rate application of water and other inputs to the crop at exactly the right level and time. Doing so improves crop productivity and gives an edge to resource-use efficiency. Note that the integration of IoT with advanced data analytics allows for the dispensation of precise control over agricultural practices, leading to better management outcomes.

IV.IMPLEMENTATION

A. Tools Used in the Implementation:

1. IoT Sensors:

These sensors are spread over the agricultural field and control the various parameters of the agricultural field, like soil moisture, temperature, humidity, and crop health. Some of the different types of sensors are soil moisture sensors, weather stations, crop health monitors, etc., essential in the gathering of real-time data.

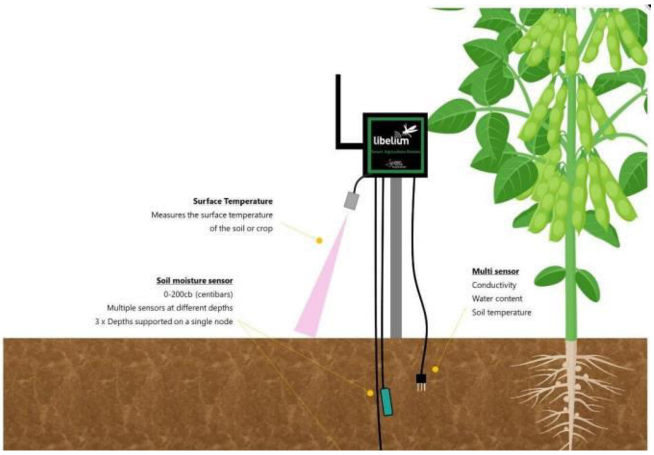

Fig 2: Sensor

1.Remote Sensing Technology:

Aerial images and data are captured in remote sensing technology to give a detailed analysis of agricultural fields. High- resolution images and environmental data from above are drawn by extractors such as drones like the DJI Phantom and satellites including Landsat and Sentinel.Satellite data canbe used for crop health and growth monitoring in most agricultural management platforms, such as Climate FieldView or John Deere Operations Center; all GIS systems like ArcGIS or QGIS, for spatial analysis; precision agriculture tools, like Trimble Ag Software, for field-specific applications; and on research sites like Google Earth Engine or NASA Earthdata for long-term studies and monitoring. These applications help in better decision-making, resource management, and more yield in agriculture. This, therefore, enables farmers to monitor crop health and growth patterns, field conditions, among others, thus helping greatly in decision-making and efficient management.

3.Data Analytics Platforms:
Storage and processing of this enormous volume of data to be generated by the IoT sensors can be done through various platforms like Google Cloud, AWS, or Azure. These platforms offer scalable solutions toward data management and analytics.

4.Machine Learning Algorithms:
Algorithms used in predictive modeling incorporate regression models, decision trees, and neural networks. These algorithms use past trend data and real-time data to predict crop yield and optimize resource management.

B. Algorithm Used:
1.Regression Models:
These algorithms are pretty critical in predicting continuous outcomes like crop yield, using possibly generated data from sensors across IoT devices. More specifically, regression algorithms build models that consider historicaland real-time sensor data to approximate the impact of factors such as moisture and level of nutrients in the soil on crop productivity. This helps make informed decisions on resource allocation and adjustments to the best practices in agriculture to optimize yield.

2.Decision Trees:
Decision trees allow users to create a model thatmakes decisions based on certain specified conditions andinput parameters. They can support decision-making for crop management practices in precision agriculture by analyzing the possible scenarios and their outcomes. Decision trees will help determine the optimal irrigation schedule or fertilizer application rate given current soil and weather conditions.

3.Neural Networks:
The neural networks come in handy in ascertaining complex patterns and making predictions in the case of huge datasets that are complex in nature. They are particularly very good at handling nonlinear relationships between variables common in agriculture data. A neural network can use huge amounts of data from many different IoT sensors to predict crop performance, detect anomalies, and optimize resource management strategies with high accuracy and predictive power.

C. Plan for Implementation:
Integration of IoT Sensors:
Design a mesh of IoT sensors across the agricultural fields for capturing data relating to soil conditions, crop health,and other environmental factors. See that the setup and the maintenance of the sensors are done appropriately for capturing the data correctly.
Data Collection and Storage
Collect data from IoT sensors using data analytics platforms. As part of this, data pipelines would need to be set up to handle real-time data influx. Clean and preprocess the data before any analysis begins.

1.Remote Sensing and Aerial Imaging
The integration of remote sensing and aerial imaging is the achievement of higher levels of monitoring and management in fields through aerial data. It basically involvesthe use of drones and satellites in capturing minute information of crops and fields from the air. Remote sensing technologies are employed for the collection of data regardingcrop health, growth patterns, and the environment. It is through this information from IoT sensors, together with the aerial data, that a farmer gets a befitting view of the field conditions.Integrate data from remote sensing with IoT sensor data for getting detailed field conditions. This integrated data can be put to detailed mapping and reporting, which guides precise interventions in targeted irrigation, fertilization, and pest management that optimizes crop management to improveyields.

2.Application of Machine Learning Algorithm
Design and train machine learning models on historical data and real-time inputs obtained from IoT sensors. Use regression models in crop yield predictions and decision trees or neural networks in instances where complex decision-making processes are involved. Validate and test the models for accurate and reliable prediction results.

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3.Data - Driven Decision - Making

Data-driven decision-making takes the results from the analysis of datasets to make prudent decisions inagriculture. Mainly, such post-analyses are to identify trends and patterns in output from machine learning models andremote sensing data. Such post-analysis truly instigates practical insights and recommendations for the optimization of critical farming activities like irrigation, fertilization, and pest management. Thereafter, the recommendations are implemented in the field with continuous monitoring to assesscrop performance and resource use. Perhaps in this way, the farming practices would be optimized to get better returns in terms of better yield and efficient use of resources.

4.Evaluation and Optimization

The result of the overall process is targeted at evaluation and optimization, which is focused on assessing theeffectiveness of the employed strategies and making necessaryimprovements. Their nature—that is, IoT systems, data analytics, and applied models of machine learning—are regularly assessed for performance. Feedback from the field should be collected to determine areas that need improvement. Fine-tuning of the sensor placement, data processing algorithms, and machine learning models is then done while accounting for the results of the evaluation. Thereafter, periodic reviews would be made for continuous improvement and adaptation to changing conditions, so the agricultural practices are efficient and effective.

A comprehensive action plan will help in strengthening precision agriculture with the help of IoT technologies and advanced data analytics to ensure better crop yields and optimized resource management.

V. RESULTS

It has brought about a very high level of accuracy in crop yield prediction by implementing machine learning algorithms on regression models and neural networks. This kind of model shall therefore make use of real-time data fromthe IoT sensors, besides the historical data, to come up with accurate forecasts that help a farmer allocate resources and optimize the use of inputs like water, fertilizers, and pesticides for maximum productivity if presented with them. The IoT sensor data analytics platform integrates the optimization of resource usage by decision trees and neural networks to determine how best to use these resources given the prevailing conditions in the field. This has brought about huge cost savings and sustainability- oriented farming practices, such as variable rate technology, which adjusts the application rate in real-time, reducing wastage.

In addition, data-driven soil management improved soils in terms of checking soil moisture, nutrient, and organic matter levels, hence successful conservation practices such as no-till farming and cover croppings. Above all, it has been data analytics and machine learning that have really made real- time decision-making processes possible so as to act on timeagainst issues like pest invasion, diseases, or bad weather. This proactive approach makes sure that crops get the right treatment at the right time, reducing risks and leading to overall better health.

Overall, precision agriculture techniques increased efficiencyand sustainability in crop yield production systems by realising greater yields using fewer resources and reducing the environmental footprint caused by agricultural activities. Only integration with state-of-the-art technologies, therefore, would provide for economically viable and environmentally responsible farming practices that would contribute towards long-term agricultural sustainability. Vast data from IoT sensors, complemented by machine learning algorithms for analysis of these sensors, forms a basis from which to derive valuable insights into complexities in crop management and hence provides continuous improvement in the traditional way of farming towards a more precise, scientific endeavor.

VI. CONCLUSION

These findings prove the high potential of the fusion of IoT and data analytics in precision agriculture for the attainment of optimal yields and resource use. Besides crop yield prediction, technologies such as IoT sensors, machine learning algorithms, and data analytics platforms will help farmers improve crop yield predictions to a great extent, optimize resource management, and ensure better quality soil. This will ensure that there is real-time data analyses so that the application of the inputs could be very precise to minimize losses, reduce environmental impacts, and promote efficiency and sustainability. In doing this, not only is productivity increased, but it would be economically viable and environmentally friendly. Continued flows of insights from data pave the way for continued improvements in agricultural practice, ushering in an era of farming that is more precise, sustainable, and resilient. These are

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technologies farmers need to embrace if they are to deal with food security and environmental health for generations to come.

Such integration has to ensure farmers make timely decisions in response to threats like invasions by pests and adverse weather conditions that may compromise the health of the crops and eventual yields. In addition, the precision that the IoT and data analytics give further enables the adoption of state-of-the-art soil conservation techniques to be used in no-till farming and cover cropping for the maintenance of soil fertility and ecological balance. Equally important, they are appropriate in terms of scalability toward applications in smallholder farms and large-scale agricultural enterprises and, in the process, able to diffuse and impact.

It is holistic farming: it serves not only the immediate challenges in our farming today, but is future-proof, ensuring long-term sustainability and resilience within global food-producing systems. It shall enable agriculture to move to a future where technology-based, precision agriculture assures optimized resource use and productivity increase, along with reduced impact on the environment.

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