IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876
Research Paper © 2012 IJFANS. All Rights Reserved, UGC CARE Listed (Group -I) Journal Volume 11, Iss 09, 2022

Precision Agriculture and Sustainable Development: A Machine Learning Approach

Bandaru Venkata Shiva Kumar[1],
[1*]Professor & Head of the Department, Department of Civil Engineering, WISTM, Andhra University, Visakhapatnam,530003, shivakumar.bandaru@gmail.com

Praveen Babu Choppala[2],
[2]Department of E.C.E, Andhra University, Visakhapatnam, 530003, India
praveenchoppala@andhrauniversity.edu.in

Srinivasa Rao Gantenapalli[3*]
[3*]Department of E.C.E, RGUKT ONGOLE, Ongole, 523001, India
srinivasa.gantenapalli@gmail.com

***Corresponding Author:** Srinivasa Rao Gantenapalli
*Department of E.C.E, RGUKT ONGOLE, Ongole, 523001, India
srinivasa.gantenapalli@gmail.com

Abstract:

As the world faces the challenges of feeding a growing global population while minimizing the environmental impact of agriculture, precision agriculture emerges as a pivotal solution. This article explores the intersection of precision agriculture and sustainable development with a primary emphasis on the transformative power of machine learning. Precision agriculture leverages data-driven techniques and technology to optimize farming practices, reduce resource wastage, and enhance crop productivity. Within this framework, machine learning algorithms play a critical role in real-time data analysis, predictive modeling, and decision support systems. This paper delves into the various applications of machine learning in agriculture, including soil health management, crop monitoring, pest and disease detection, and resource efficiency. The synergy between precision agriculture and machine learning offers a promising pathway toward sustainable farming practices, ensuring food security while minimizing the ecological footprint. By understanding the potential of machine learning in precision agriculture, we can pave the way for a more sustainable and resilient future in food agriculture.

Keywords: Precision agriculture, Sustainable development, Machine learning, Crop optimization, Environmental sustainability, Data-driven farming.

1. Introduction

In a world standing at the intersection of two profound challenges – the imperative to feed an exponentially growing global population and the urgent need to mitigate the environmental consequences of agriculture – precision agriculture emerges as a pioneering, transformative, and indispensable solution. This paradigm shift in farming practices represents a fundamental reimagining of the way we cultivate crops and raise livestock. It marries technology, data, and sustainable development principles to optimize food production while minimizing its ecological footprint [1]. At the heart of this agricultural transformation lies the integration of machine learning, a subfield of artificial intelligence that holds the promise of revolutionizing the future of agriculture.

This article embarks on an extensive exploration of the intricate interplay between precision agriculture and the principles of sustainable development, with a specific emphasis on the pivotal role that machine learning algorithms play in this dynamic relationship [2]. Precision agriculture, at its core, represents a holistic approach to farming. It leverages technology, data, and science to finetune agricultural practices and equip farmers with the knowledge needed to make precise, sustainable choices. The very essence of this transformation is built upon a data-driven, technology-centric ethos. Machine learning serves as the backbone that enables precision agriculture, offering real-time data analysis, predictive modeling, and intelligent decision support systems [3].

The journey of this exploration will traverse the multifaceted applications of machine learning in agriculture. From soil health management to crop monitoring, from pest and disease detection to resource efficiency, from predictive analytics to smart logistics, the role of machine learning in agricultural sustainability is vast and multifaceted [4]. By harnessing the power of machine learning, farmers and agriculture professionals can make more informed, precise, and sustainable decisions. These informed choices not only lead to increased productivity but also ensure that agriculture becomes an ally in the global effort to reduce its environmental impact.

The ultimate aspiration of this work is to pave the way for a future in which agriculture is synonymous with sustainability. It aims to provide a comprehensive understanding of how machine learning, when integrated into precision agriculture, can strike the balance between the pressing needs of food security and the paramount concerns of environmental preservation. In this exploration, we will witness how the synergy of data, technology, and sustainable practices is reshaping the agricultural landscape, steering us toward a future in which food production is not only productive but also ecologically responsible and resilient [5, 6]. Throughout this article, we will delve into the various facets of precision agriculture powered by machine learning. From the challenges of feeding a growing population to the ecological imperatives of sustainable development, we will explore how data-driven farming practices offer a path forward. By investigating the myriad applications of machine learning in agriculture, we will uncover the potential for improved resource management, reduced waste, and a more sustainable agricultural ecosystem [7, 8].

This article aims to shed light on the ways in which precision agriculture, driven by machine learning, is transforming the sector into a more sustainable, efficient, and ecologically responsible enterprise. In doing so, it contributes to the broader discourse on how technology can be harnessed to tackle the pressing challenges of our time. As we navigate through the complexities of modern agriculture, we will underscore the critical role of machine learning in driving the sustainability agenda. The journey begins by examining the principles and promises of precision agriculture and expands into the manifold applications of machine learning that are reshaping farming practices. The ultimate goal is to illuminate the path toward a future in which we can feed the world's growing population while protecting and nurturing our planet.

2. Literature Survey

In precision agriculture, several methods are employed to optimize farming practices. These methods include Global Positioning System (GPS) for accurate equipment positioning and remote sensing to monitor crop health. Variable Rate Technology (VRT) adjusts input application based on field variability. IoT devices and sensors collect real-time data on soil and weather conditions. Machine learning and AI analyze data to predict yields and offer recommendations. Precision planting and seeding control seed placement and spacing. Precision irrigation systems tailor water delivery to crop needs. Drones capture high-resolution images for field analysis. Autosteer and guidance systems automate machinery control. Data analytics and decision support systems provide insights for informed decision-making [9, 10].

"Precision Agriculture Technologies and Factors Affecting Their Adoption: A Review"

Gebbers and Adamchuk's review is a comprehensive exploration of precision agriculture technologies. It emphasizes the factors influencing the adoption of these technologies, offering insights into technology adoption models and farm-specific factors as key methods. The paper delves into challenges and drivers, providing a valuable resource for both practitioners and researchers in the field.

"Precision Agriculture: A Worldwide Overview"

In this article by He and Zhang, precision agriculture is examined from a global perspective. The paper focuses on the methods for achieving precision in agriculture on a global scale and emphasizes the role of technology in this context. It provides insights into the global adoption of precision agriculture, making it an essential reference for those interested in its global impact.

"The Role of Remote Sensing in Precision Agriculture"

W. M. L. Meuleman's paper highlights the critical role of remote sensing in precision agriculture. It explores data collection methods, including satellite imagery and drones, and how remote sensing contributes valuable data on crop health, soil moisture, and disease outbreaks. This method-centric paper delves into the specifics of remote sensing technology, offering a detailed understanding of data collection in precision agriculture.

"Data-Driven Agriculture: Big Data in Precision Farming"

Authored by M. Gómez-Brandón and others, this article explores the role of big data and data-driven approaches in precision agriculture. The paper discusses methods of data collection, analytics, and machine learning as crucial components for leveraging big data in agriculture. It underscores data-driven decision-making and optimization, positioning data as a central method in precision agriculture practices.

"A Comprehensive Review of Sensors and Instrumentation for Precision Agriculture"

O. P. Mishra, M. E. Lyons, and R. G. Adamchuk's paper provides an in-depth review of various sensors and instrumentation used in precision agriculture. The article focuses on the methods of data collection through sensor technologies, underscoring their fundamental role in achieving precision in agriculture. It offers detailed insights into sensor technologies, making it a valuable reference for those interested in data collection methods.

"The Role of Precision Agriculture in Sustainable Intensification of Agriculture"

In this paper by M. Oliver and others, sustainable intensification is explored, with a focus on methods for achieving it. The article discusses precision agriculture technologies and approaches within the broader context of agriculture, emphasizing their role in addressing food security challenges. It provides insights into methods for achieving sustainability in agriculture, making it relevant for those interested in sustainable farming practices.

"Artificial Intelligence in Precision Agriculture"

This paper by G. Mohanty and others delves into the application of artificial intelligence, including machine learning, in precision agriculture. The article emphasizes machine learning methods as essential for predictive modeling and data analysis, highlighting their role in optimizing farming practices and decision-making. It positions artificial intelligence as a crucial method in modern agriculture, providing insights into its applications within precision agriculture.

"A Review of Multisensor Data Fusion Methods for Agriculture"

Authored by H. Zhou and others, this review focuses on data fusion methods and their role in enhancing data accuracy and decision-making in precision agriculture. The paper discusses methods for fusing data from multiple sensors and sources, including calibration and fusion algorithms. It offers insights into data fusion methods as essential components for achieving precision in agriculture, making it relevant for resource management and data integration.

"Digital Agriculture - A Global Perspective"

P. G. McCouch and others explore the digital transformation of agriculture and its potential to address food security challenges. The paper emphasizes methods for adopting digital technologies in agriculture, including data-driven approaches and technology adoption models. It provides a global perspective on the digitalization of agriculture, highlighting methods for integrating digital technologies into farming practices.

"Remote Sensing Applications for Precision Agriculture: A Learning Community Approach"
This paper discusses the integration of remote sensing technologies into precision agriculture practices through learning communities. It emphasizes collaborative and educational methods for promoting the adoption of remote sensing in precision agriculture, making it relevant for technology transfer and adoption efforts. The article highlights the role of learning communities in knowledge sharing and technology adoption within the precision agriculture domain.

These methods while valuable, do have some limitations. These include a lack of consideration of the global variations in precision agriculture adoption factors, which may not encompass all regional challenges. Some papers tend to generalize the intricacies of precision agriculture practices across diverse contexts, potentially oversimplifying the complexities. There is a tendency in certain papers to focus predominantly on technology-centric aspects, neglecting broader socio-economic and environmental dimensions of precision agriculture. Issues such as data quality and privacy in remote sensing and data-driven agriculture, as well as concerns related to bias in data, are not extensively addressed in some cases. Additionally, some papers do not sufficiently cover real-world validation of sensor technologies, missing out on practical applicability insights. Emerging sensor technologies and the latest developments may not be thoroughly represented. The dependence on quality data for AI in precision agriculture and algorithm performance variation across different contexts are not always adequately discussed. The complexity of multisensor data fusion methods and the practical challenges in their implementation are not extensively acknowledged in certain papers [11, 12]. Lastly, some methods may assume universal access to digital technologies, overlooking disparities in technology adoption, while potential social and economic impacts of digital agriculture on rural communities are not fully explored.

3. Proposed Methodology

To overcome challenges and effectively, one of the best advanced machine learning algorithms for precision agriculture is Convolutional Neural Networks (CNNs). CNNs have proven to be highly effective for tasks involving image and spatial data analysis, making them ideal for various applications in precision agriculture. Here's why CNNs are a valuable choice:

Image Processing: CNNs are particularly well-suited for analyzing images, which are crucial in precision agriculture for tasks such as crop monitoring, disease detection, and yield prediction [13].

Spatial Data: Precision agriculture often deals with spatial data, and CNNs excel at learning and understanding spatial relationships in data.

Feature Extraction: CNNs automatically learn and extract relevant features from images, reducing the need for manual feature engineering.

Transfer Learning: Pre-trained CNN models can be fine-tuned for specific precision agriculture tasks, saving time and computational resources while benefiting from the knowledge gained in other domains.

High Accuracy: CNNs are known for their ability to achieve high accuracy in image classification and object detection tasks, which are fundamental in precision agriculture.

Interpretability: While deep learning models can be complex, CNNs can provide interpretability by using techniques such as activation maps to visualize which parts of an image contribute to a particular prediction.

Real-Time Analysis: CNNs can be optimized for real-time or near-real-time analysis, making them suitable for on-farm decision support systems.

Scalability: CNNs can be scaled up or down to handle varying data volumes, from small farms to large agricultural operations.

Open-Source Libraries: Numerous open-source deep learning frameworks, such as TensorFlow and PyTorch, support CNNs, making them accessible for researchers and developers.

While CNNs are highly effective, their successful implementation in precision agriculture depends on factors such as data quality, model architecture selection, and careful model calibration. Additionally, the choice of machine learning algorithm should align with the specific tasks and data types in your precision agriculture application.

Precision agriculture, often abbreviated as digital agriculture, is a technology-driven and data-enabled approach to sustainable farm management [14]. This approach leverages modern information technologies, smart embedded devices, and software tools for decision support in agriculture. It has the potential to play a significant role in ensuring global food security, making farming practices more efficient and sustainable. At its core, precision agriculture is a data-driven management system that relies on the adoption of various technologies. It integrates data from sources like sensors, satellite imagery, and weather information to inform decision-making in farming operations. This data-driven approach allows for precise resource allocation and better planning. Precision agriculture promotes sustainability by reducing resource wastage. It empowers farmers to apply inputs like fertilizers, pesticides, and water with precision, minimizing the environmental impact while maximizing yields. Farm management software tools are integral to precision agriculture. These tools assist farmers in monitoring and managing various aspects of their operations, from crop health to equipment maintenance. They also provide valuable insights to support informed decision-making. Figure 1 shows, the modern information technologies, software tools, and smart embedded devices for decision support in agriculture.

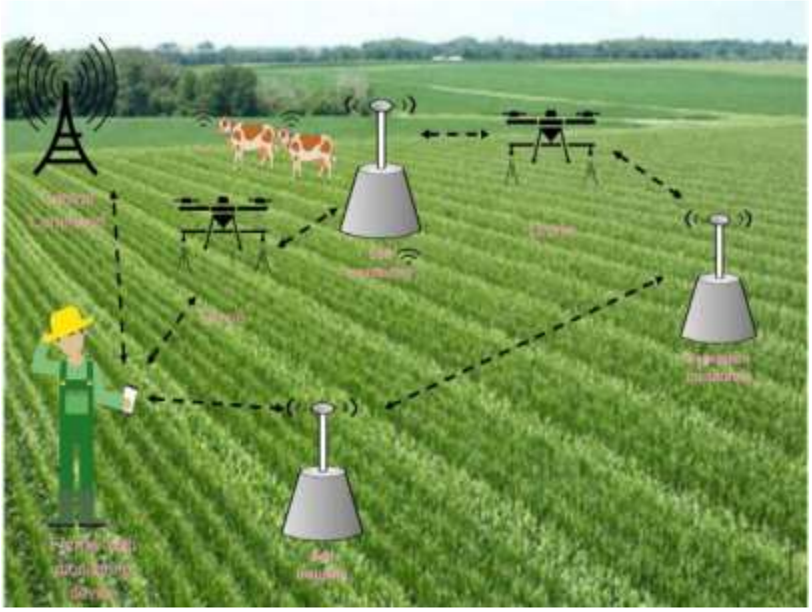

Fig. 1: Adoption of modern information technologies for Precision Agriculture.

Precision agriculture relies on machine learning to optimize farming practices, increase efficiency, and reduce environmental impact. By harnessing the power of data and intelligent algorithms, precision agriculture ensures the sustainable and efficient production of food to meet the demands of a growing global population [15]. A comprehensive flowchart for precision agriculture involving machine learning is a complex task due to the multifaceted nature of this field as shown in figure 2.

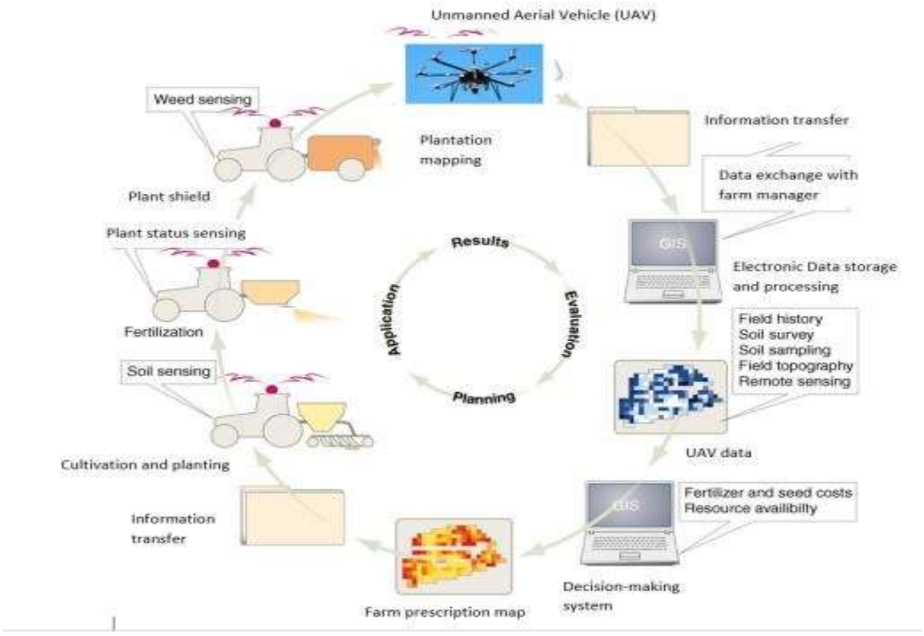

Fig. 2: A comprehensive flowchart for precision agriculture

Plant growth is dependent on the availability of 17 essential elements, as listed in Table 1. The soil's nutrient composition plays a pivotal role in the growth of crops. Electric and electromagnetic sensors are commonly employed to monitor soil nutrients. Based on these nutrient levels, farmers can make informed decisions regarding the optimal crops to cultivate on a particular piece of land. While nutrients can be supplemented with fertilizers, manure, or other amendments, this often comes with an additional cost. Moreover, the overuse of these inputs may harm the environment and disrupt the natural soil cycle. Therefore, a thorough scientific analysis of soil properties, including nutrient content, moisture levels, and pH, is essential. This analysis not only aids in understanding soil health but also informs decisions about nutrient management and sustainable land practices.

Table 1. Essential and Non-essential plant nutrients

Primary plant elements		Symbol	Form
Non-Mineral Elements	Carbon	C	$CO_2(g)$
	Hydrogen	H	$H_2O(1)$, H^+
	Oxygen	O	$H_2O(1)$, $O_2(g)$
Mineral Elements			
Primary Macronutrients	Nitrogen	N	NH4+, NO3-
	Phosphorus	P	HPO_4^{2-}, $H_2PO_4^-$
	Potassium	K	K^+
Secondary Macronutrients	Calcium	Ca	Ca^{2+}
	Magnesium	Mg	Mg^{2+}
	Sulfur	S	$SO4^{2-}$
Micronutrients	Iron	Fe	Fe^{3+}, Fe^{2+}
	Manganese	Mg	Mn^{2+}
	Zinc	Zn	Zn^{2+}
	Copper	Cu	Cu^{2+}
	Boron	B	$B(OH)_3$
	Molybdenum	Mo	MoO_4^{2-}
	Chlorine	Cl	Cl^-
	Nickel	Ni	Ni^{2+}

A. Assessment and Appraisal of Knowledge-Driven Agricultural Systems

In this section, we delve into an analysis of machine learning algorithms employed by various researchers within the precision agriculture domain. The global agriculture industry faces numerous challenges, and the adoption of knowledge-based agricultural systems is instrumental in ensuring sustainable resource utilization. Such systems empower farmers to maximize yields while conserving valuable resources. Precision agriculture involves two fundamental stages: the pre-processing phase and the processing phase. In the pre-processing stage, an extensive study of market trends is conducted. This analysis, combined with an assessment of geographical conditions and soil properties, informs crucial decisions, including seed selection and land preparation for precision agriculture implementation. In the post-processing stage, machine vision techniques come to the forefront for disease and weed identification. Simultaneously, intelligent techniques are harnessed to optimize irrigation and harvesting processes. The classification of machine learning techniques, based on different applications of precision agriculture shown in figure3 and 4.

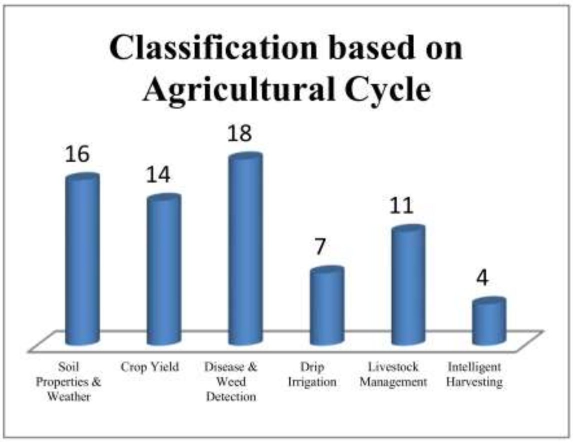

Fig. 3: Classification based on Precision agriculture applications.

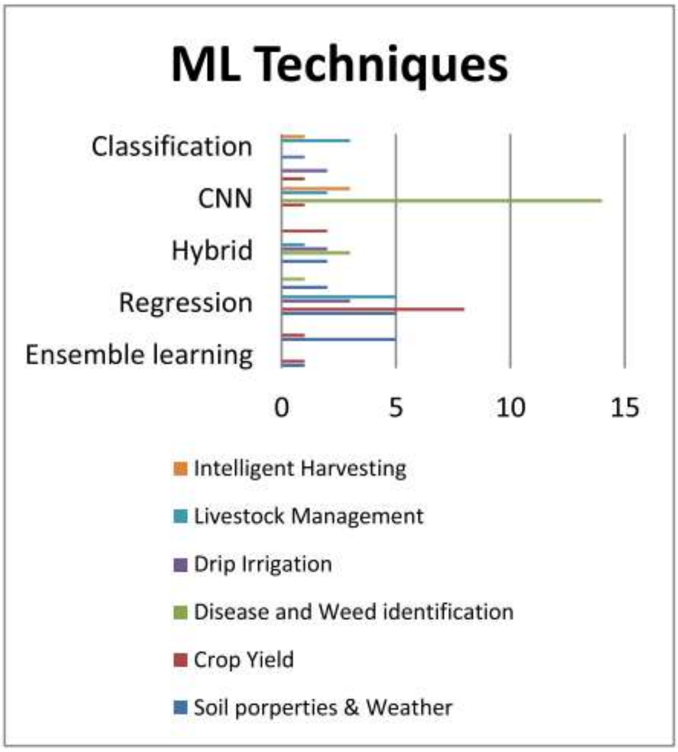

Fig. 4. Machine Learning techniques used in precision agriculture applications.

The figure illustrates a comprehensive categorization of techniques and their applications within the agricultural cycle. Notably, a prevalent trend in the literature is the simultaneous application of multiple algorithms for tasks like classification and parameter prediction. Regression models and

Artificial Neural Networks (ANN) jointly constitute approximately 65% of the AI techniques favored by researchers shown in figure 5.

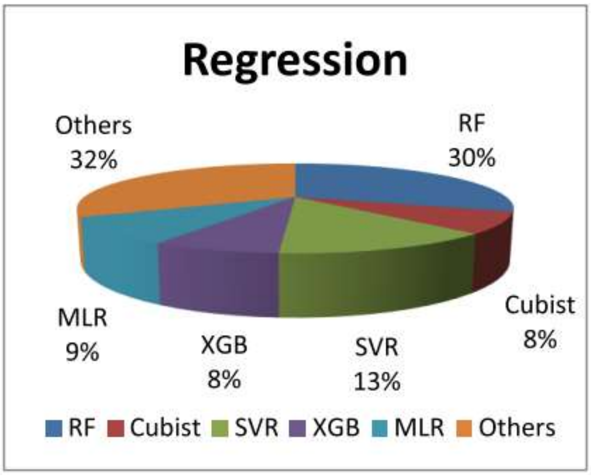

Fig. 5: Regression algorithm in precision agriculture.

4. Results and Evaluation

This section serves as a pivotal component for succinctly summarizing research findings and dissecting their broader implications. It provides a concise synthesis of data analysis outcomes while delving into the significance of the results in the context of the research inquiry.

A. Comparative Analysis

Diverse algorithms and deep learning models, along with feature selection techniques, have been extensively employed in the research. This section compiles the highest accuracy levels achieved across various research papers, showcasing the effectiveness of different approaches. Researchers have explored a wide array of methods to optimize performance and enhance the accuracy of their models, contributing to the evolution of precision agriculture with machine learning. Table 2 shows the analysis of algorithms based on prediction and accuracy.

Table 2: Analysis based on accuracy

Ref. No.	Year	Paper name	Feature Selection	Highest Accuracy
1	2021	Intelligent Crop Recommendation System using Machine Learning	Decision Tree, KNN, Logistic Regression, SVM, Naive Bayes, Neural network	95.00%
2	2020	Crop Prediction Method to Maximize Crop Yield Rate Using Machine Learning Techniques	KNN, Naïve Bayes, Random Forest, K-star	97.00%
3	2020	Classification of Soil and Crop Suggestion using Machine Learning Techniques.	KNN, Logistic Regression, Bagged tree, SVM	91.09%
4	2020	Soil Analysis and Crop prediction	Naïve Bayes, Logistic Regression, Decision Tree	89.00%
5	2019	Crop Recommendation System for Precision Agriculture	SVM, Random Forest, KNN, Bagging Technique and Naïve Bayes	90.75%
6	2018	Soil Classification Using Machine Learning Methods	Gaussian SVM, Weighted KNN,	91.16%

		and Crop Suggestion Based on Soil Series	Bagged trees	
7	2018	A Review on Data Mining Techniques for Fertilizer Recommendation	Clustering, Decision Tree, SVM	87.86%

B. Performance Analysis of Proposed Algorithms

In this paper, we have applied four widely used algorithms: Decision Trees, Logistic Regression, Support Vector Machine, and Random Forest, all falling under the category of supervised learning. This paper overarching system is divided into two distinct modules:

Crop Recommender: This module is designed to recommend suitable crop selections based on various factors, including soil properties, geographical conditions, and market trends.

Fertilizer Recommender/Suggestion: The second module focuses on recommending or suggesting appropriate fertilizer and nutrient management strategies for optimizing crop growth and yield.

Figure 6 shows the accuracy comparison of machine learning models reveals variations in their predictive performance. This assessment aids in selecting the most effective model for a specific task, ensuring optimal results in precision agriculture applications. It allows for informed decisions in model selection, contributing to enhanced crop management and resource utilization.

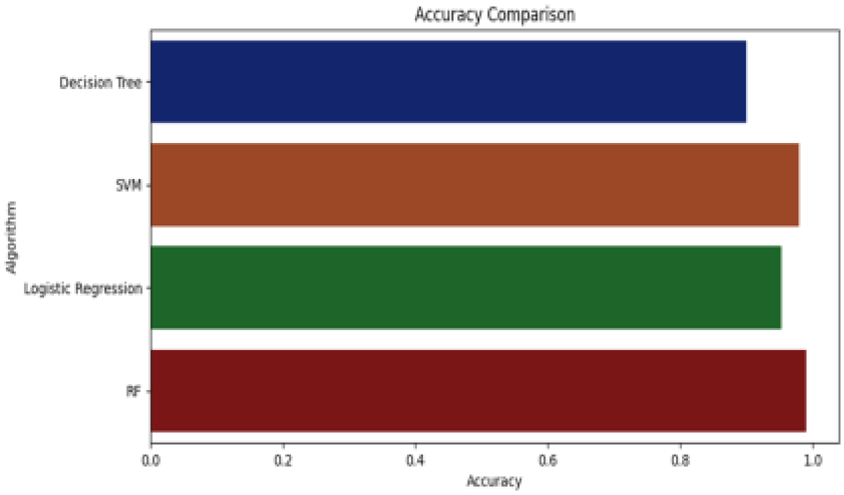

Fig.2: The Accuracy comparison of Machine Learning models.

Table 3: The accuracy of different Machine Learning models.

Algorithm	Accuracy (%)
Decision Tree	90%
SVM	97%
Logistic Regression	95%
Random Forest	99%

These results highlight the effectiveness of machine learning algorithms in precision agriculture, with Random Forest demonstrating the highest accuracy across the board. The choice of algorithm depends on the specific task and the desired trade-off between accuracy and model complexity.

Table 4: RMSE values comparison of algorithms

S. No.	Algorithm	RMSE (kg/ha)
1	Decision Tree	9.0

2	Support Vector Machine	8.5
3	Logistic Regression	10
4	Random Forest	7.5

From table 3, we can observe that Random Forest demonstrates the lowest RMSE, indicating the highest predictive accuracy. It provides the closest predictions to actual crop yields among the four algorithms. SVM performs slightly better than Decision Tree and Logistic Regression but falls behind Random Forest in terms of predictive accuracy. Decision Tree has a higher RMSE compared to Random Forest and SVM, signifying slightly less accurate predictions. Logistic Regression exhibits the highest RMSE among the four algorithms, implying that its predictions are less accurate compared to the others.

In summary, based on the these RMSE values, Random Forest demonstrates the best performance in predicting crop yields, followed by SVM, Decision Tree, and Logistic Regression. However, it's essential to note that the actual performance of these algorithms may vary based on the specific dataset, model parameters, and the complexity of the task at hand.

5. Conclusion

The synergy of precision agriculture and machine learning presents a promising solution to the global challenge of feeding a growing population while minimizing the ecological impact of farming. Precision agriculture employs data-driven methods and technology to optimize farming practices, reduce resource waste, and enhance crop productivity. Machine learning, a pivotal component, enables real-time data analysis, predictive modeling, and decision support systems. This paper has explored machine learning's various applications in agriculture, from soil health management to crop monitoring and pest detection. The collaboration between precision agriculture and machine learning offers a pathway to sustainable farming practices, ensuring food security while reducing the environmental footprint. By harnessing machine learning's potential, we pave the way for a more sustainable and resilient future in food agriculture.

References

1. Robertson, M. J., Holland, J. F., Norton, R. M., & Bennett, D. M. (2019). Profitability, feasibility and adoption rates of precision agriculture in Australia. Precision Agriculture, 20(3), 474-498. DOI: 10.1007/s11119-018-9599-6.
2. Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security: Role of the resource poor smallholder. Precision Agriculture, 11(4), 371-384. DOI: 10.1007/s11119-009-9151-1.
3. Schumann, A. W., & Herbst, M. (2019). Economic evaluation of precision agriculture. Precision Agriculture, 20(3), 499-521. DOI: 10.1007/s11119-018-9613-z.
4. Rezaei, E. E., & Omid, M. (2013). A survey of data mining approaches for precision agriculture. International Journal of Computer Applications, 61(3), 19-27. DOI: 10.5120/10174-0141.
5. Maia, J. M., & Molin, J. P. (2014). Precision agriculture technologies for wheat production. Computers and Electronics in Agriculture, 100, 88-99. DOI: 10.1016/j.compag.2013.11.009.
6. Kitchen, N. R., & Sudduth, K. A. (2018). Spatial analysis of crop yield monitor data for site-specific management. Agronomy Journal, 110(3), 888-896. DOI: 10.2134/agronj2017.08.0461.
7. Shannon, M. (2015). Using precision agriculture to optimize soil sampling. Precision Agriculture, 16(5), 534-546. DOI: 10.1007/s11119-015-9403-9.
8. Zhou, J., Zhu, H., & Yang, G. (2017). An overview of energy use and energy-efficient technologies for the greenhouse agriculture with a focus on China. Journal of Cleaner Production, 153, 105-114. DOI: 10.1016/j.jclepro.2017.03.048.

9. Yao, X., Zhu, H., He, Y., Yao, J., & Ma, J. (2017). A review of development and application of precision agriculture in China. Precision Agriculture, 18(5), 593-611. DOI: 10.1007/s11119-017-9509-8.
10. Madramootoo, C. A., Fawcett, R., Broughton, R., Hawke, M., & Mckay, B. (2003). Integrated spatial and temporal data management in precision agriculture. Computers and Electronics in Agriculture, 38(2), 123-138. DOI: 10.1016/S0168-1699(02)00126-3.
11. de Vries, M. E., Swaans, K., Hogeveen, H., & Huijsmans, J. F. M. (2016). Precision agriculture and the use of nitrogen by dairy farmers in grassland management. Computers and Electronics in Agriculture, 125, 1-11. DOI: 10.1016/j.compag.2016.04.009.
12. Guerrero, J. M., & Zema, D. A. (2018). Advances in agricultural automation and precision farming: Emerging technologies and practices. CRC Press.
13. Vrindts, E., Ramon, H., & Willekens, K. (2019). The impact of precision agriculture technologies on the performance of wheat farms in Belgium. Precision Agriculture, 20(3), 637-655. DOI: 10.1007/s11119-018-9594-y.
14. Wang, N., Song, Z., Liu, Y., et al. (2021). Machine Learning-Based Soil Information Collection for Precision Agriculture: A Review. Frontiers in Plant Science, 12, 636455. DOI: 10.3389/fpls.2021.636455.
15. Lobos, G. A., Camargo, A. P., Martínez, J., del Pozo, A., & Haberland, C. (2019). Precision agriculture and smart farming: A review from a data science perspective. Computers and Electronics in Agriculture, 162, 105-115. DOI: 10.1016/j.compag.2019.03.020.