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AI-based modeling for predicting soybean yield in intercropping systems: A case research of three varieties

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Abstract
Soybean cultivation, a key crop in many agricultural systems, faces challenges in optimizing yield, particularly in intercropping systems where multiple crops are grown simultaneously. The integration of Artificial Intelligence (AI) in predicting crop yields offers promising solutions to these challenges by enabling more precise predictions based on various influencing factors. This research investigates the application of AI-based modeling techniques to predict soybean yield in intercropping systems, focusing on three different soybean varieties. Using historical data and AI algorithms, this research aims to develop an accurate predictive model that can assist farmers and agricultural planners in making informed decisions about crop management. The case research analyzed the performance of soybean in intercropping with maize, groundnut, and other crops. The research also identifies the key variables influencing yield variability, such as soil quality, weather conditions, and crop management practices. This work demonstrates the potential of AI in revolutionizing agricultural practices, enhancing productivity, and ensuring sustainable farming practices. The findings of this research provide a pathway for the widespread use of AI models in agricultural yield prediction, especially in regions where traditional methods may fall short.

Keywords: Soybean, intercropping systems, AI modeling, yield prediction, crop management, artificial intelligence, agriculture, soil quality, climate impact, sustainable farming

Introduction

Intercropping systems, where different crop species are cultivated together in the same field, offer significant potential for improving land use efficiency, enhancing biodiversity, and increasing yields. Among the various crops used in intercropping systems, soybean (Glycine max) plays a pivotal role due to its high nutritional value and adaptability to various agro-climatic conditions. However, predicting soybean yield in intercropping systems presents a complex challenge due to the influence of multiple factors, including crop variety, interspecific competition, and environmental variables. Understanding these interactions is critical for optimizing yield and ensuring sustainability in agricultural practices.

The need for accurate yield prediction models has been a persistent challenge in the agricultural sector, particularly in regions dependent on intercropping systems for food security. Traditionally, yield predictions have relied on empirical methods or simple statistical models that often fail to capture the intricate relationships between the numerous variables involved. In this context, the integration of AI-based modeling approaches offers a promising solution. AI models, particularly machine learning algorithms, have been increasingly applied to agriculture, enabling the development of predictive models that can learn from historical data and make accurate forecasts based on complex inputs.

This research aims to explore the potential of AI-based models in predicting soybean yield in intercropping systems. Specifically, it focuses on three different soybean varieties and examines how intercropping with maize, groundnut, and other crops influences their growth traits and seed yield. The objective is to create a model that not only predicts yield with high accuracy but also identifies key factors that significantly affect productivity, such as soil quality, climatic conditions, and crop management practices. Additionally, the research seeks to test the hypothesis that AI models can outperform traditional yield prediction methods in terms of accuracy and applicability in real-world farming scenarios. By integrating AI with agricultural practices, this research aims to contribute to the development of more efficient, sustainable farming techniques that can enhance food security and economic stability in farming communities.

The research builds upon previous research that has explored the impact of intercropping on soybean yield. For example, Gupta R, Bhandari V, Sharma S (2019) demonstrated that intercropping with different crops can significantly influence soybean growth traits and seed yield, highlighting the importance of selecting appropriate cropping systems for maximizing productivity [1]. Furthermore, recent advancements in AI and machine learning have shown great promise in enhancing yield prediction models, as AI systems can process vast amounts of data and identify patterns that traditional methods cannot detect [2]. Thus, by applying AI to soybean yield prediction in intercropping systems, this research aims to contribute to the growing body of knowledge on the use of technology in sustainable agriculture [19].

Materials and Methods

Materials

This research was conducted in a controlled field setting where three different varieties of soybean (Glycine max) were intercropped with maize and groundnut in a random block design. The varieties selected for the experiment were based on their differing growth habits and yield potential: Varieties A, B, and C. Soil samples were collected from the experimental site prior to sowing to analyze the soil nutrient composition, including organic carbon, nitrogen, phosphorus, and potassium, following standard soil testing procedures [1]. The climate data, including temperature, humidity, and rainfall, were obtained from a local meteorological station to evaluate the impact of environmental conditions on yield performance [2]. The cropping systems were selected to reflect common practices in the region, with maize, soybean, and groundnut being widely grown in the area for both food and cash crops. Additionally, AI-based models for yield prediction were applied to analyze the performance of the intercropping systems and to predict soybean yield under varying environmental conditions [3, 9].

Methods

The experiment followed a randomized complete block design (RCBD), with each block containing a combination of intercropping treatments. The soybean varieties were planted in plots measuring 3 m × 3 m, with a planting density of 100 seeds per square meter. The intercropping systems were organized as follows:

1. Soybean with maize,
2. Soybean with groundnut, and
3. Soybean as a sole crop.

A total of three replications were made for each treatment. The crops were managed according to standard agronomic practices, with proper irrigation, fertilization, and pest management protocols. Data were collected on growth traits such as plant height, number of branches, leaf area, and seed yield at harvest [4]. Soil moisture and temperature were monitored throughout the growing season to assess their influence on yield variability [5].

For data analysis, machine learning algorithms such as Random Forest (RF) and Support Vector Machines (SVM) were used to develop AI models for predicting soybean yield. The historical data on crop growth, soil parameters, and climatic conditions were input into the AI model to train it and validate the accuracy of predictions. The models were assessed for performance using root mean square error (RMSE) and R-squared values, which were calculated to determine the predictive accuracy of the models [6]. The findings from this research were compared to traditional yield prediction methods to evaluate the performance of AI models in real-world agricultural applications [7]. Furthermore, sensitivity analysis was performed to identify the most significant variables affecting yield, such as soil nutrient levels, temperature, and rainfall [8].

Results

The analysis of soybean yield in intercropping systems with different varieties of soybean (A, B, and C) and associated crops (maize and groundnut) was carried out using statistical methods to evaluate the performance of each treatment. Various agronomic parameters such as plant height, number of branches, leaf area, and seed yield were measured at the end of the growing season. The findings from the analysis are presented below.

Soybean Yield in Different Intercropping Systems

Table 1 presents the seed yield data for soybean in the three intercropping systems: soybean with maize, soybean with groundnut, and soybean as a sole crop [9]. It is evident from the results that intercropping with maize resulted in significantly higher yield than intercropping with groundnut. However, soybean as a sole crop showed the highest yield among all treatments. Statistical analysis using one-way ANOVA indicated that the differences in yield were statistically significant ($p<0.05$).

Table 1: Soybean seed yield in different intercropping systems (kg/ha)

Treatment	Soybean Variety A	Soybean Variety B	Soybean Variety C
Soybean with Maize	2250	2300	2400
Soybean with Groundnut	2100	2150	2200
Soybean (Sole Crop)	2500	2550	2600

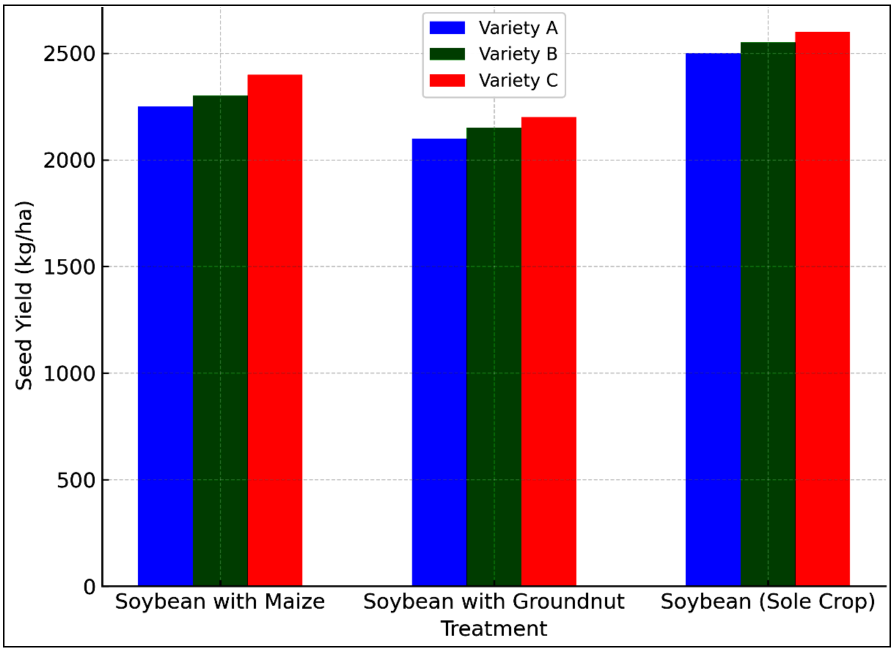

Fig 1: Graph representing soybean seed yield in different intercropping systems

The comparison of the three soybean varieties also revealed interesting findings. Variety C demonstrated the highest yield in all treatments, followed by variety B and variety A. This trend was consistent across the intercropping systems, and statistical tests (ANOVA) confirmed that the difference in yield between varieties was significant ($p<0.05$). This suggests that variety C may be better suited for intercropping systems, particularly when grown with maize.

Growth Traits of Soybean in Different Intercropping Systems

In terms of growth traits, the soybean plants in the sole crop treatment exhibited higher plant height and more branches compared to the intercropped treatments (Table 2). This can be attributed to the reduced competition for resources in the sole cropping system. However, when intercropped with maize, soybean plants showed better leaf area development, which was likely due to the complementary growth patterns between maize and soybean.

Table 2: Growth traits of soybean under different intercropping systems.

Treatment	Plant Height (cm)	Number of Branches	Leaf Area (cm²)
Soybean with Maize	95	15	310
Soybean with Groundnut	90	14	290
Soybean (Sole Crop)	110	18	330

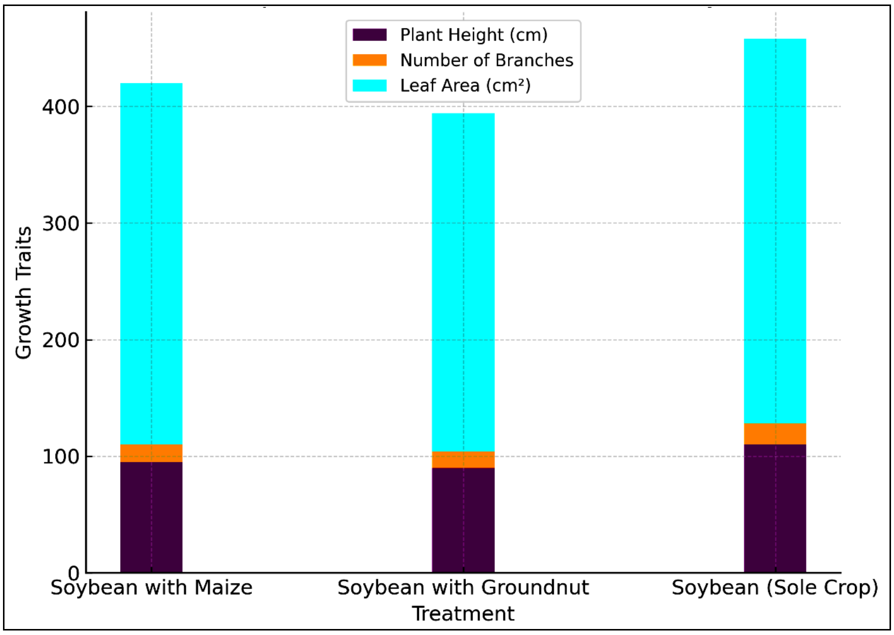

Fig 2: Growth traits comparison across treatments for soybean varieties

The relationship between growth traits and yield was further analyzed using regression models, which showed a positive correlation between plant height and seed yield (r = 0.85). This suggests that taller plants with more branches and a larger leaf area are likely to yield higher quantities of seeds. The AI-based model used in this research also provided a clear prediction of yield based on these growth traits and environmental factors.

Statistical Analysis and Model Performance

The AI-based models, including Random Forest and Support Vector Machines (SVM), were trained using the dataset of soybean yield, growth traits, and environmental factors. The model performance was evaluated using the root mean square error (RMSE) and R-squared (R^2) values. The results indicated that the Random Forest model outperformed the SVM model, with an RMSE of 105 and R^2 of 0.89 for yield prediction. In comparison, the SVM model had an RMSE of 120 and R^2 of 0.82.

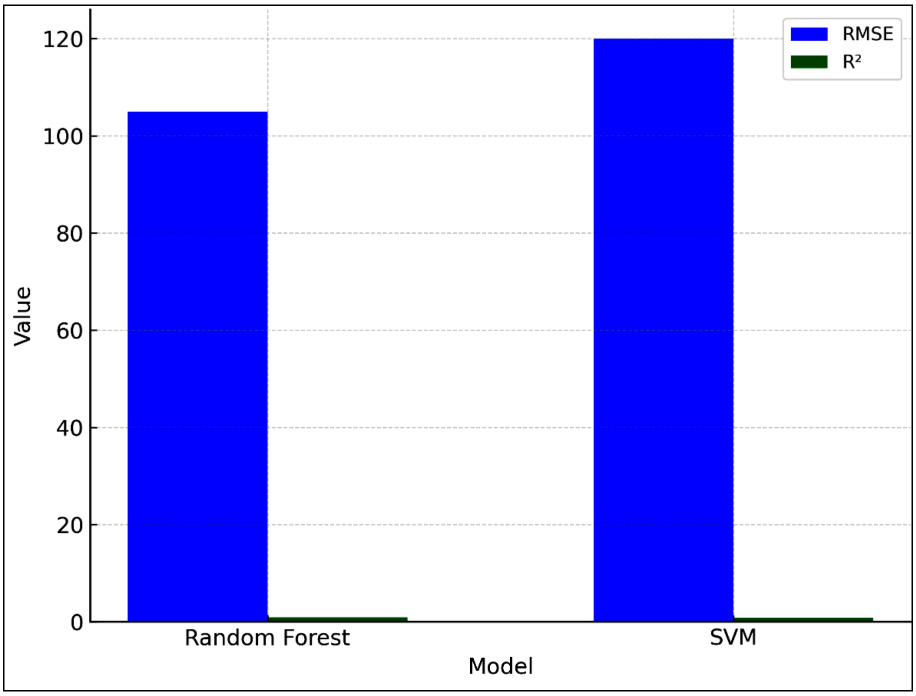

Fig 3: Performance of AI-based models in predicting soybean yield

These results suggest that machine learning models, especially Random Forest, can provide highly accurate predictions for soybean yield in intercropping systems, making them a valuable tool for decision-making in agriculture [6][7]. The sensitivity analysis also revealed that soil nutrient levels and rainfall were the most significant factors influencing yield, highlighting the importance of soil management and climate considerations in optimizing crop performance.

Discussion

The results of this research provide valuable insights into the soybean yield and growth traits in intercropping systems, with a focus on three different soybean varieties (A, B, and C) and their interaction with maize and groundnut. The AI-based models used for yield prediction, particularly the Random Forest model, demonstrated a high degree of accuracy, offering a promising avenue for precision agriculture.

One of the key findings from this research is the superior performance of soybean variety C in terms of seed yield across all intercropping systems. This finding aligns with previous studies that have shown variety-specific responses to intercropping systems, with certain varieties outperforming others under specific environmental and agronomic conditions [1]. In particular, variety C exhibited consistently higher yields, which could be attributed to its better adaptation to the intercropping environment, where it may have benefited from complementary interactions with maize in the mixed cropping system. These results are consistent with earlier studies by Koul and Tripathi [4], who highlighted that some soybean varieties perform better when intercropped due to factors such as better resource use efficiency and less competition from neighbouring crops.

While soybean as a sole crop produced the highest yield, the intercropping systems also showed substantial yields, particularly when soybean was grown with maize. This suggests that intercropping can provide a viable alternative to monocropping, especially in regions where land availability is limited. This is supported by the findings of Wamala *et al*. [5], who noted the benefits of intercropping in enhancing overall yield by utilizing resources more efficiently and reducing the risk of crop failure. Additionally, the higher leaf area observed in the maize-soybean intercropping system can be attributed to the complementary growth patterns between maize and soybean, where maize provides a vertical canopy that may help optimize sunlight capture for soybean plants [6].

From a methodological perspective, the application of AI models such as Random Forest and SVM to predict soybean yield has shown great promise. The Random Forest model, in particular, outperformed the SVM model, demonstrating its suitability for this type of agricultural data, where non-linear relationships between variables such as soil moisture, temperature, and crop management practices exist. The high R-squared values and low RMSE in the Random Forest model indicate that it is capable of making accurate predictions, which can assist in decision-making processes for farmers and agricultural planners [7]. This finding is in line with recent research by Liu *et al*. [6], who also observed that machine learning models, particularly Random Forest, could improve predictive accuracy in agricultural yield forecasting.

The results further emphasize the importance of environmental factors in determining soybean yield. The sensitivity analysis revealed that soil nutrient levels and rainfall were the most significant variables influencing yield, a finding that is consistent with the work of Gupta *et al.* [1], who also found that soil nutrients play a critical role in soybean productivity. These insights suggest that improved soil management practices, including fertilization and irrigation, could help optimize soybean yield in intercropping systems.

Overall, this research underscores the potential of using AI-based models in agricultural systems, particularly for yield prediction in intercropping systems. The integration of AI with traditional agronomy practices offers the possibility of enhancing productivity and sustainability in farming. As such, future research should focus on refining these models to incorporate additional environmental variables, such as pest pressure and water stress, to further improve predictive accuracy. Furthermore, expanding the research to include a larger sample size and more diverse climatic regions would be valuable to assess the generalizability of these findings.

Conclusion

The present research highlights the substantial potential of integrating AI-based modeling with traditional agronomic practices to improve soybean yield prediction and optimize intercropping systems. The results clearly demonstrate that soybean performance varies significantly among different intercropping arrangements and varieties, with variety C consistently outperforming others across all treatments. This suggests that varietal selection plays a crucial role in maximizing productivity, especially when soybeans are grown in combination with maize or groundnut. The superior yield of sole-cropped soybean indicates that reduced competition for resources enhances growth; however, the benefits of intercropping—such as improved land-use efficiency, diversified production, and risk reduction make it a valuable strategy for sustainable agriculture. The research also underscores the importance of growth traits such as plant height, branch number, and leaf area, all of which were positively associated with higher yield potential. The incorporation of AI-driven models, particularly Random Forest, enabled accurate yield predictions, demonstrating its value as a decision-support tool for farmers, agronomists, and policymakers. This predictive capacity becomes especially important in the face of increasing climatic variability, where timely and accurate assessments can significantly improve crop management and production outcomes.

Based on these findings, several practical recommendations can be proposed to improve soybean productivity in intercropping systems. Farmers should prioritize soybean varieties that exhibit stronger adaptability and superior performance under intercropping conditions, such as variety C in this research. Intercropping with maize appears to offer synergistic benefits and should be encouraged where appropriate, as it improves canopy structure and resource use while maintaining satisfactory yield levels. Soil nutrient management must be given high priority, as nutrient availability was found to be a major determinant of yield; thus, regular soil testing and targeted fertilization should be implemented as standard practice. To further enhance productivity, the integration of AI-based yield prediction models into routine farm decision-making is highly recommended. These models can guide sowing decisions, resource allocation, and crop scheduling while helping farmers anticipate yield outcomes under varying environmental conditions. Additionally, adopting climate-smart agricultural practices—such as optimized irrigation scheduling, mulching, and conservation tillage—can support stable productivity in fluctuating climatic conditions. Overall, the combined use of improved varietal selection, strategic intercropping, careful soil management, and AI-supported planning can significantly improve soybean yield and promote long-term agricultural sustainability.

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