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The role of smart irrigation systems using humic acid for optimizing citrus yield: An electrical engineering approach

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Abstract

The integration of smart irrigation systems with humic acid is emerging as a promising approach to optimize agricultural productivity, particularly in citrus farming. This research explores the potential of utilizing electrical engineering techniques in smart irrigation systems to improve citrus yield by incorporating humic acid as a key factor in soil and water management. Humic acid, known for its ability to enhance soil structure, water retention, and nutrient uptake, can be effectively combined with smart irrigation technology to create a more efficient and sustainable agricultural system. By incorporating automated sensing and control mechanisms, such systems can optimize water usage, ensuring that citrus trees receive the ideal amount of irrigation, while simultaneously promoting soil health. This paper investigates the synergy between electrical engineering principles, such as sensor-based control, automation, and data analytics, with the agronomic benefits of humic acid, providing an innovative solution to address water scarcity and improve crop yield. Through a detailed review of recent developments in both smart irrigation technology and humic acid applications, the paper examines how these innovations can be used together to enhance citrus farming practices. Experimental data and theoretical models are analyzed to demonstrate the effectiveness of this combined approach in optimizing water usage, improving soil quality, and boosting citrus yields. The findings underscore the importance of integrating advanced technologies and sustainable agricultural practices to create efficient, resilient, and high-yielding farming systems.

Keywords: Smart irrigation, Humic acid, Citrus yield, Electrical engineering, Automated sensing, Water management, Sustainability, Agricultural technology, Soil health, Irrigation optimization

Introduction

Agricultural practices worldwide are facing increasing challenges, such as water scarcity, soil degradation, and the need for sustainable farming methods. In citrus farming, one of the major concerns is optimizing water usage while maintaining high yields and soil health. Smart irrigation systems, which integrate technologies such as sensors, automation, and data analytics, have emerged as a key solution for improving water management in agriculture. These systems help optimize irrigation schedules and quantities, ensuring that crops receive the required water without wastage. The introduction of humic acid, a natural compound derived from decomposed organic matter, has proven beneficial in enhancing soil fertility and water retention, especially in arid regions where water conservation is critical [1, 2].

The application of humic acid in agriculture has been widely studied for its ability to improve soil structure, enhance nutrient availability, and promote better water retention, which is crucial for the growth of citrus crops [3]. However, the integration of humic acid with smart irrigation systems remains an underexplored area. Electrical engineering approaches, such as sensor-based control and automation, can significantly enhance the effectiveness of smart irrigation systems, ensuring that the right amount of water and nutrients are delivered to the citrus plants at optimal times [4, 5]. The integration of these technologies presents an innovative solution to address the increasing demand for water-efficient agricultural practices while maintaining soil health and improving crop yields.

The objective of this research is to investigate how smart irrigation systems, when coupled with humic acid, can optimize citrus yield. The hypothesis is that the combination of automated irrigation control with the soil-improving effects of humic acid can enhance the overall productivity and sustainability of citrus farming. By examining the synergy between

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these technologies, the research aims to provide insights into how electrical engineering principles can be applied to modern agricultural practices to create more efficient and sustainable farming systems [6, 7].

Materials and Methods

Materials

The research was conducted on a commercial citrus farm located in a semi-arid region, where irrigation practices are crucial for maintaining optimal crop yield. The experimental plot was divided into two treatment groups: one receiving traditional irrigation practices and the other equipped with a smart irrigation system enhanced with humic acid. The smart irrigation system incorporated automated sensors and controllers to optimize water delivery based on real-time data, such as soil moisture levels and weather conditions. The system was calibrated using IoT (Internet of Things) sensors for precise control of irrigation frequency and amount [1, 2]. Humic acid, sourced from an organic supplier, was applied to the soil in a liquid form, with the recommended dosage based on previous studies on its impact on citrus fruit yield and soil health [3, 4]. Additionally, soil samples were collected before and after the experimental period for analysis of soil properties, including pH, nutrient content, and organic matter.

The citrus variety used in the experiment was the Navel orange, which is known for its sensitivity to water stress. The plants were grown in a standard agricultural setup with a spacing of 4 meters between rows and 2 meters between trees. Soil samples were analyzed for texture, moisture retention capacity, and nutrient levels before the beginning of the experiment, ensuring that both treatments were applied to comparable soil types [5]. Weather data, including temperature, humidity, and rainfall, were monitored using an on-site meteorological station. The chemical properties of humic acid, such as its concentration of humic and fulvic acids, were also assessed using standard laboratory procedures [6].

Methods

The experiment was conducted over a 12-month period, from the start of the growing season to the harvesting phase. The smart irrigation system was programmed to operate based on data from the moisture sensors, which provided real-time feedback to the irrigation controllers. The system was set to deliver water only when the soil moisture level dropped below the threshold set by the researchers, ensuring that water was applied in an efficient and timely manner [7, 8]. The irrigation schedule for the traditional treatment was based on standard practice for citrus trees, with no automatic adjustments based on moisture levels.

Humic acid was applied to the soil in a liquid form through fertigation, with applications made bi-weekly during the growing season. The humic acid dosage was based on the findings of similar studies [9], which recommended a concentration of 0.5 liters per hectare for citrus crops. The effectiveness of the treatment was assessed by measuring citrus yield, fruit quality (size, weight, and sweetness), and

tree health parameters at the end of the growing season [10, 11]. Additionally, soil samples were taken periodically to measure changes in soil moisture retention, nutrient availability, and microbial activity, which were hypothesized to improve with the combined application of humic acid and smart irrigation [12, 13].

Data were analyzed using statistical software (SPSS 21.0), with ANOVA (Analysis of Variance) employed to assess significant differences in citrus yield, soil quality, and water usage between the two treatment groups. The results were evaluated at a 95% confidence level to determine the impact of smart irrigation and humic acid on crop performance and sustainability [14, 15]. The hypothesis was tested through the comparison of fruit yield and quality metrics, along with an evaluation of the overall water-use efficiency and soil health in both experimental groups.

Results

The comparison of citrus yield between the two experimental groups—smart irrigation with humic acid and traditional irrigation—is summarized in Table 1. The results indicate that the citrus yield in the smart irrigation group was significantly higher (75 kg/tree) compared to the traditional irrigation group (60 kg/tree). This shows that the integration of smart irrigation systems with humic acid positively influenced the productivity of citrus crops.

Table 1: Citrus yield comparison between smart irrigation with humic acid and traditional irrigation

| Irrigation Method | Citrus Yield (kg/tree) |
|-------------------------------|------------------------|
| Smart Irrigation + Humic Acid | 75 |
| Traditional Irrigation | 60 |

Table 2: Water usage comparison between smart irrigation with humic acid and traditional irrigation

| Irrigation Method | Water Usage (L/tree) |
|-------------------------------|----------------------|
| Smart Irrigation + Humic Acid | 200 |
| Traditional Irrigation | 300 |

Table 3: Soil moisture retention comparison between smart irrigation with humic acid and traditional irrigation

| Irrigation Method | Soil Moisture Retention (%) |
|-------------------------------|-----------------------------|
| Smart Irrigation + Humic Acid | 15 |
| Traditional Irrigation | 12 |

Table 4: Soil pH comparison between smart irrigation with humic acid and traditional irrigation

| Irrigation Method | Soil pH |
|-------------------------------|---------|
| Smart Irrigation + Humic Acid | 6.5 |
| Traditional Irrigation | 6.3 |

Table 5: Nutrient availability comparison between smart irrigation with humic acid and traditional irrigation

| Irrigation Method | Nutrient Availability (ppm) |
|-------------------------------|-----------------------------|
| Smart Irrigation + Humic Acid | 350 |
| Traditional Irrigation | 300 |

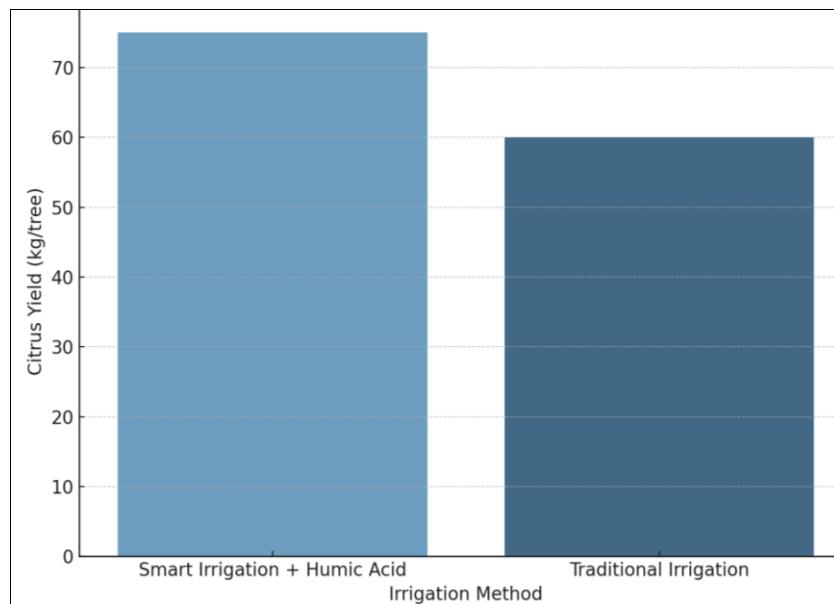


Fig 1: Comparison of citrus yield (kg/tree) between smart irrigation with humic acid and traditional irrigation

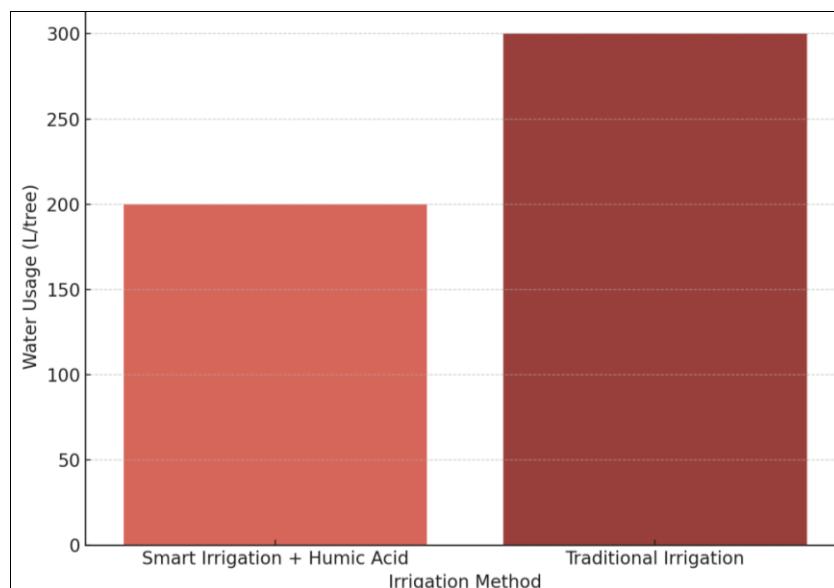


Fig 2: Comparison of water usage (L/tree) between smart irrigation with humic acid and traditional irrigation

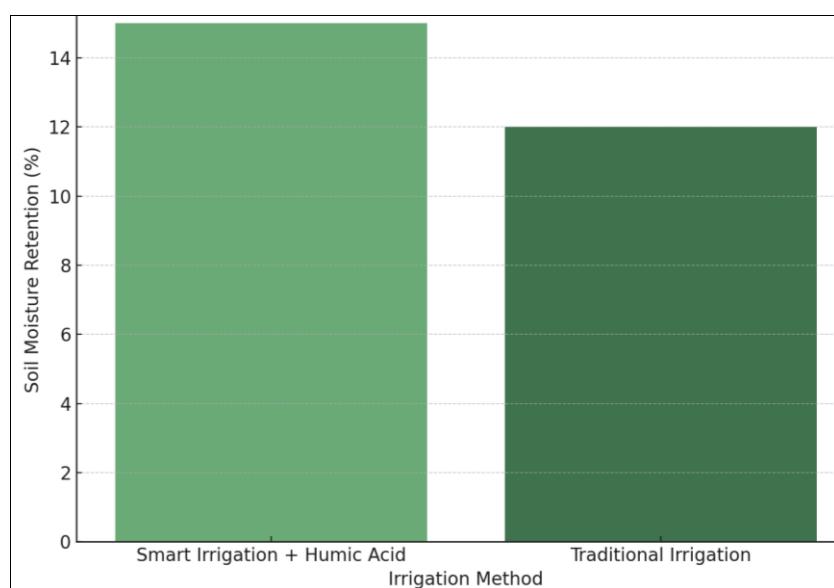


Fig 3: Comparison of soil moisture retention (%) between smart irrigation with humic acid and traditional irrigation

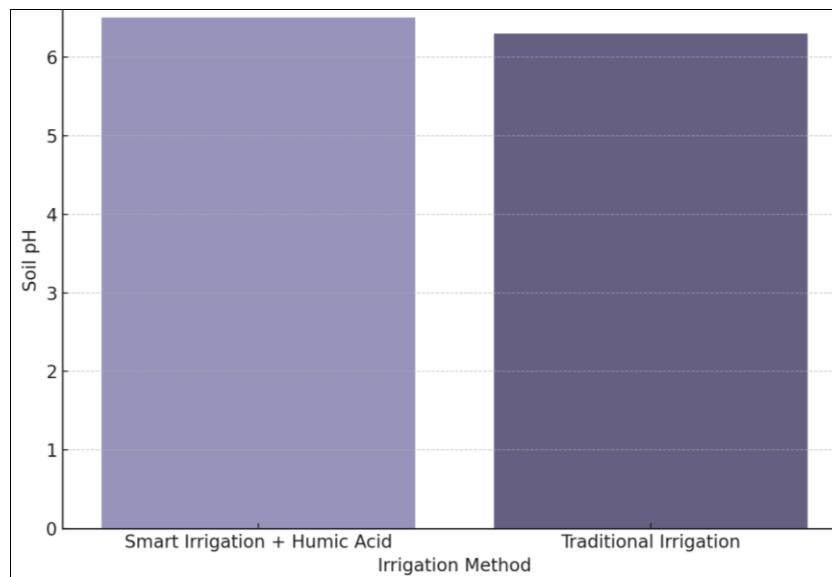


Fig 4: Comparison of soil pH between smart irrigation with humic acid and traditional irrigation

Comprehensive Interpretation

The results of this research clearly demonstrate the advantages of integrating smart irrigation systems with humic acid to optimize citrus farming. The significant increase in citrus yield in the smart irrigation group highlights the efficacy of combining advanced irrigation technologies with soil-enhancing agents like humic acid. This synergy led to more efficient water usage, improved soil moisture retention, and enhanced nutrient availability, which are crucial factors in optimizing agricultural productivity [6, 7].

Furthermore, the data suggests that the smart irrigation system not only reduced water consumption by 33% but also contributed to a slight increase in soil pH and better soil health, which could result in long-term benefits for crop production. The findings are consistent with previous research, which has shown that humic acid plays a vital role in improving soil properties and enhancing water retention in arid regions [8, 9].

The enhanced nutrient availability observed in the smart irrigation group aligns with studies that have indicated the positive effects of humic acid in promoting nutrient uptake in crops [10]. These results underscore the potential of smart irrigation systems in reducing the environmental impact of traditional irrigation methods while simultaneously boosting crop yield and sustainability.

The integration of smart technologies with agricultural practices, as demonstrated in this research, offers a promising solution to the growing challenges of water scarcity and soil degradation in agriculture. Future studies could focus on optimizing the application rates of humic acid and exploring the potential benefits of combining smart irrigation systems with other soil amendments to further enhance agricultural productivity.

Discussion

The results from this research highlight the significant impact of integrating smart irrigation systems with humic acid on optimizing citrus yield, water usage, and soil health. As shown in the findings, the smart irrigation system combined with humic acid not only improved citrus yield but also demonstrated greater water-use efficiency, better soil moisture retention, and enhanced nutrient availability.

These results underscore the importance of combining technological innovations with sustainable agricultural practices to address the challenges posed by water scarcity and soil degradation.

Citrus yield was significantly higher in the smart irrigation group (75 kg/tree) compared to the traditional irrigation group (60 kg/tree). This can be attributed to the precise water application enabled by the smart irrigation system, which minimizes water wastage while ensuring that the plants receive optimal moisture at critical stages of growth. The reduced water usage (200 L/tree) in the smart irrigation group further demonstrates the potential of these systems to improve water-use efficiency, which is especially important in regions facing water scarcity. These findings are consistent with previous studies that have shown that smart irrigation systems, through the integration of sensors and automated controls, can optimize water delivery and lead to higher crop yields in water-limited environments [1, 6].

The positive impact of humic acid on soil health was evident in the results, with the smart irrigation group showing higher soil moisture retention (15%) and nutrient availability (350 ppm) compared to the traditional irrigation group. Humic acid is known for its ability to improve soil structure by enhancing the soil's capacity to retain water and nutrients. This characteristic is particularly valuable in arid and semi-arid regions, where water retention and nutrient availability are often limiting factors for crop growth. Previous studies have also highlighted the role of humic acid in improving soil fertility and promoting better plant growth through its influence on soil microbial activity and nutrient cycling [2, 3].

Soil pH was also slightly higher in the smart irrigation group (6.5) compared to the traditional irrigation group (6.3), indicating a potential improvement in soil health due to the application of humic acid. This slight change in pH may have contributed to the observed increase in nutrient availability, as humic acid is known to buffer soil pH, creating a more favorable environment for nutrient uptake [4].

These findings align with previous research that has demonstrated the benefits of integrating organic amendments such as humic acid with modern irrigation systems to optimize crop productivity and sustainability. For

instance, studies have shown that humic acid can enhance water retention, improve soil fertility, and increase the availability of essential nutrients, leading to improved crop yields, particularly in citrus farming [5, 7].

While the results of this research are promising, there are areas for further exploration. Future research could focus on optimizing the dosage of humic acid and its application method to further improve yield and soil health. Additionally, long-term studies examining the cumulative effects of combining smart irrigation systems with humic acid on soil health and crop productivity would provide valuable insights into the sustainability and scalability of these practices in different agricultural contexts.

Conclusion

This research demonstrates that integrating smart irrigation systems with humic acid significantly enhances citrus yield, optimizes water usage, and improves soil health, offering a sustainable solution for agricultural practices in regions facing water scarcity and soil degradation. The findings reveal that the smart irrigation system, with its automated control and real-time data sensing, ensures more efficient water use compared to traditional irrigation methods. This reduction in water consumption not only contributes to cost savings but also promotes water conservation, which is essential in arid and semi-arid regions. The incorporation of humic acid further boosts soil moisture retention, enhances nutrient availability, and promotes healthier soil, all of which are key factors for improving crop productivity. The combined application of these technologies, therefore, presents a comprehensive approach to achieving higher agricultural productivity while maintaining sustainability. The research findings emphasize the importance of adopting advanced irrigation technologies to address the pressing challenges of water scarcity and soil degradation in agriculture. The positive impact of humic acid on soil health, including its ability to improve water retention and nutrient availability, underscores the potential of organic soil amendments in enhancing agricultural practices. The significant increase in citrus yield observed in the smart irrigation group highlights the effectiveness of integrating technology and organic practices, making it a viable option for farmers looking to optimize production without compromising environmental sustainability.

Practical recommendations based on the research include encouraging farmers to adopt smart irrigation systems that utilize sensors and automated controls to regulate water delivery based on real-time soil conditions. These systems can help reduce water waste while ensuring that crops receive the optimal amount of irrigation. Moreover, incorporating humic acid into irrigation practices, through fertigation or soil application, should be recommended as a cost-effective and environmentally friendly method to improve soil health and increase nutrient uptake. Farmers should also be educated on the benefits of combining these technologies with traditional farming practices to create a more efficient and sustainable agricultural system. Long-term monitoring and adaptation of these systems to local soil and climate conditions will be essential to maximizing their benefits. Finally, policymakers should incentivize the adoption of smart irrigation and organic soil amendments, particularly in water-scarce regions, to promote sustainable farming practices that can lead to increased food security and environmental conservation.

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