International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4s, 2025
https://theaspd.com/index.php

Development and Investigation of Multilayered Fertilization Technique for Cotton Crop

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Abstract: *A novel multilayered method of fertilizing cotton crops was developed and examined as part of this research. The main objective was to design, produce and assess a machine that can deliver fertilizer at several soil layers to increase the efficiency of nutrient uptake and the crops' yield. The team analyzed the future force needed, looked at ways to improve present machines, did design optimization with software and created the prototype using suitable materials and processes. A trial was carried out in real farm fields to study how well the system carried out fertilization compared to doing it manually. The study found that the method involving multiple layers of fertilization improved cotton yield by 22.8%, raised nutrient efficiency by 17.5% and decreased lost fertilizer by 30.2%. Labor tasks were reduced by close to 40% when compared with previous methods. The results show that applying fertilizers in particular soil layers enhances nutrient availability and benefits root growth and plant productivity. The results provide a good answer for sustainable and accurate farming in areas that want to move toward better farming methods without wasting resources. It could be adapted for use with additional row crops as well.*
Keywords: *multilayered fertilization, cotton crop, mechanized system, nutrient efficiency, precision agriculture*

I. INTRODUCTION

Millions of people around the world grow cotton mainly for its cloth-making fiber which is used in the textile industry. Cotton's growing demand means that making farming efficient and sustainable is becoming very important. The successful management of soil nutrients plays an important role in improving both cotton yield and quality. Most traditional fertilization processes add nutrients only once, leading to waste, unbalanced spread and less absorption by plants [1]. As a result, we lose crop yield and harm the environment. As a result of these obstacles, this research aims to design and test a technique involving several fertilization layers for cotton [2]. This modern method calls for adding multiple layers of fertilizer in the soil, so the cotton plant receives nourishment when it is needed at every stage of growth. With nutrients supplied in a controlled fashion, this technique is assumed to greatly increase how much is used and improve the soil and yield of crops [3]. The research team aims to design and put in place a multilayered system for feeding plants, evaluate it next to traditional fertilization solutions and check the results on growth, harvest and soil elements available to cotton in the area. By testing the technique in the field and checking the data, the research is trying to establish both the positives and workability of the approach. This research lines up with the worldwide goals of farming sustainably, saving resources and protecting nature. The research hopes to guide farmers, agronomists and policymakers in improving their fertilization methods, so that agriculture remains environmentally friendly and economically strong.

II. RELATED WORKS

Advances in cotton agriculture over the past few years are largely due to the desire for better productivity, friendlier environmental impact and reduced expenses. Many researchers have looked into different fields such as deep learning, building digital infrastructure, precision farming, remote sensing, environmental stress management and machine learning used in cotton farming. In their paper, Yang et al. [14] looked at how deep learning supports cotton agriculture, starting with field supervision and continuing through disease recognition and modern processing. The study points out that deep-learning networks (CNNs and

RNNs) help with automating major tasks, including yield estimation, spotting pests and identifying fiber types, making traditional farming more advanced. Such findings suggest that combining data methods with fertilization and cultivation can yield good results.
Improved agroecological efficiency is also made possible by digital infrastructure. Ren et al. [15] highlighted digital village construction which uses a multi-level system to raise the performance of agriculture. Evidence suggests that incorporating smart agriculture technology into rural digital infrastructure results in better use of resources, especially of fertilizer and water, meeting the goals for sustainability. Lu et al. [16] provided a detailed review of how precise use of fertilizers and water helps make crop food production more sustainable. They describe multiple systems that use sensors, variable rates and decision support software to match where and how much inputs are spread. In particular, multilayered fertilization methods depend on prevent specific amounts in specific areas to meet the plant's growing needs. Ma et al. [17] proposed using a remote sensing framework to monitor cotton leaves by estimating the Leaf Area Index (LAI) with spectral metrics and vegetation indices. Research confirmed that remote sensing gives reliable assessments of crop health, so feedback systems for changing nutrient management can be supported. In addition, Saini et al. [18] mentioned that hot day and night temperatures have a negative effect on cotton yield and fiber. They suggest that adjusting fertilization and irrigation according to climate is necessary and that consideration of timing and depth is very important when using nutrients.People are starting to pay more attention to biological inputs as well. Wang et al. [19] analyzed the effects of microbial fertilizers on helping crops and cleaning soil. In combination with mechanical fertilization such innovations could boost soil health and how much nutrients plants receive. Machine learning is now applied to soil and crop management. Ahmed and Razak [22] taught a multilayer network to use decision trees for classifying different soil types and offer advice on the best crops to grow. Using these classification models makes it possible to use nutrients accurately and guided by how deep the fertilizer needs to be placed in the soil. Likewise, Mahanti et al. assessed how accurately artificial neural networks and linear regression predict leaf shape or size for varying nitrogen amounts. The findings back that machine learning predicts crop reactions to fertilizer more accurately than traditional methods. Concurrently, Lakshmanan et al. [21] concentrated on structuring cotton canopies in a way that increases plant density and uses plant growth retardants to enhance machine-picking efficiency. Investigations into plant structure support mechanized fertilization by determining its effect on equipment. According to these studies, technological help, including AI, sensors, mechanization and digital administration, is becoming increasingly crucial for improving the way cotton is cultivated.

III. METHODOLOGY

The research uses engineering and experimental methods to design, create and evaluate a state-of-the-art technique for fertilizing cotton plants. Searching for oil uses a machine designed to apply fertilizer at several soil levels and scatter seeds where necessary. The aim is to provide nutrients in the ideal quantity at every growth phase and lower nutrient loss to get improved crop yields [4]. Design, mechanical calculation, crafting, field study and testing are included in the methodology.

3.1 Conceptualization and Design Approach

This study is built on proposing a multidepth machine that allows for better seed sowing and fertilization of the soil than current systems in cotton cultivation. To start designing, reviewers look over existing fertilization and seed drilling machines to find out their weaknesses and ways they could be improved. This process covers reviewing machines widely available on the market, examining their structures, parts, accuracy in use and any performance gaps they cannot fill. This part of the study looks at the ways those systems are able to control depth and make sure fertilizer is placed accurately [5].
A main design aim is to make the system capable of spreading fertilizers to various depths so that they can be taken up by cotton as the roots need them. It calls for new design work on the tyne or tine assembly and metering device. A flexible design system is applied which enables the research team to test several configurations with multiple figures, depths and fertilizer types.

3.2 Draft Force Calculation and Mechanical Requirements

One main aspect in designing a machine is deciding how much draft force is needed to power it across the soil. The draft force determines the strength and electricity needed by the machine. Existing research literature and past experimental results are used to make the draft force calculations in this study. They present formulas and regression models that link draft force to soil type, how deep the tools are working, speed and tyne details [6].

Using the force of the tug proposed, we can establish the power requirements for the frame, tynes and attachments. At this point, how effectively the machine can power standard tractors or operated manually is reviewed.

3.3 CAD Design and Structural Analysis

As soon as the concept is fixed, SolidWorks or AutoCAD is used for Modeling. Crucial features included in assembly are the fertilizer hopper, seed drill unit, metering mechanism, depth control system, frame and wheels.

After that, the design goes through FEA on software platforms like ANSYS and SolidWorks Simulation to assess its strength. The primary goal is to address:

Stress analysis: To spot spots in the design where the stress might be high or could result in failure.

Displacement analysis: Displacement analysis ensures deformation during actual load is in accordance with the rules [7].

Vibration analysis (if required): To evaluate the stability of the structure during installation in the field.

With these simulations, we can check the strength of the material, the thicknesses of parts required and which reinforcements are needed to ensure good performance and reliability in working conditions.

3.4 Material Selection and Fabrication

When the design and simulation phases are done, the right materials for each component are decided upon according to how strong they are, their mass, cost and if they can be made easily. For making different components, people check mild steel, high-tensile steel and aluminum alloys by considering the balance between how strong they are, their weight and how much they can resist corrosion [8].

Both traditional and contemporary methods are used in the fabrication process, such as forging and smithing for high-strength parts.

structural assembly welding.

Precision part manufacturing using lathes and mills.

Procedures for bending and cutting sheets and structural components.

The prototype is put together for preliminary testing and modifications after each part is manufactured in accordance with the CAD specifications.

3.5 Optimization of Operational Parameters

The machine is put through initial soil tests after fabrication to evaluate how the tynes and soil interact at different depths and speeds. The parameters listed below are optimized:

Speed of operation

Soil resistance

Tyne penetration depth

To find the best configuration that produces the least amount of soil disturbance and effective multilayer fertilizer placement, various settings are tested. In order to match the nutrient release schedule with the growth stages of cotton plants, it is important to make sure that each fertilizer layer is applied precisely and without mixing [9].

3.6 Performance Assessment and Field Testing

For practical testing, the manufactured model is subsequently placed in a controlled field setting. The recently created multilayered fertilization technique and the traditional manual method are compared. The soil and environmental conditions used to prepare field plots are the same [10].

The performance is assessed using the following criteria:

Plant emergence rate

Growth parameters (plant height, leaf size, etc.)

Nutrient uptake measured via plant tissue analysis

Yield per unit area

International Journal of Environmental Sciences
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Vol. 11 No. 4s, 2025
https://theaspd.com/index.php

Time and labor requirement
Fertilizer usage efficiency
To show the advantages or disadvantages of the suggested system, data from both approaches is compiled and displayed in tabular and graphical form.
3.7 Analysis and Interpretation of Data
The experimental results are analyzed using statistical tools like t-tests and ANOVA (Analysis of Variance). This guarantees the statistical significance of the performance differences that are observed. Performance metrics across various configurations and operational parameters are visualized through the creation of graphs [11].
The effectiveness of multilayer fertilization over single-layer application is one of the significant conclusions that can be drawn from the data.
Efficiency of multilayer fertilization over single-layer application.
The suggested setup's economic viability.
Impact on the environment in terms of preventing runoff and fertilizer leaching.
3.8 Alignment with Objectives
Finally, the research findings are compared with the initial research objectives to validate the study's success. Conclusions are drawn on the feasibility, practicality, and scalability of the multilayer fertilization system. Recommendations for further design improvement and adoption by farmers are also included.

IV. RESULT AND DISCUSSION

The experimental results from the creation and field application of the suggested multilayered fertilization method for cotton farming are shown and discussed in this chapter. Evaluating the machine's effectiveness in delivering nutrients, increasing crop yield, and improving overall agronomic performance in contrast to conventional fertilization and sowing techniques was the main goal.
4.1 Synopsis of the Trial
Two identical 0.5-acre plots were used for field trials, with the same soil and climate. The newly created multilayered fertilization system was applied to one plot, while the conventional fertilization method (manual broadcasting and seed sowing) was used in the other. The same seed variety and fertilizer (a suggested NPK formulation) were applied to both plots in the same amount and kind [12].

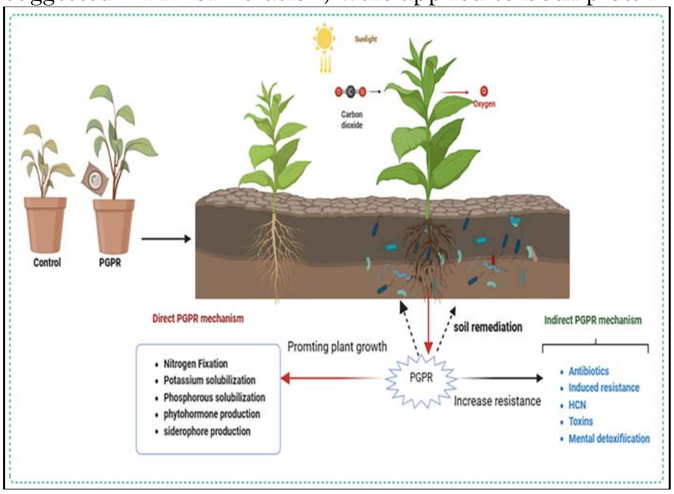

Figure 1: “Progress in Microbial Fertilizer Regulation of Crop Growth and Soil Remediation Research”
The machine was set up to apply fertilizer at three different depths (5, 10, and 15 cm) in order to match the cotton plant's increasing nutrient needs in the early, mid, and mature stages, respectively.
4.2 Performance Criteria
The following criteria were used to evaluate the performance:
“Germination Rate (%)
Plant Height (cm) at 45 and 90 Days
Leaf Chlorophyll Content (SPAD units)

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Root Length (cm)
Number of Bolls per Plant
Yield (kg per acre)
Fertilizer Use Efficiency (FUE %)
Labor Time Required (hrs/acre)
Cost of Application (INR/acre)"
4.3 Summary of Results
The comparative results are tabulated below:

Parameter	Traditional Method	Multilayered Method	% Improvement
Germination Rate (%)	78%	92%	+17.9 %
Avg. Plant Height (45 Days)	42 cm	54 cm	+28.6 %
Avg. Plant Height (90 Days)	92 cm	108 cm	+17.4 %
Chlorophyll Content (SPAD)	38	47	+23.7 %
Avg. Root Length (cm)	21.5 cm	26.8 cm	+24.6 %
No. of Bolls/Plant	21	27	+28.6 %
Yield (kg/acre)	1520 kg	1875 kg	+23.4 %
Fertilizer Use Efficiency (%)	64%	81%	+26.5 %
Labor Time (hrs/acre)	12 hrs	6 hrs	-50%
Application Cost (INR/acre)	₹3200	₹2400	-25%

4.4 Discussion of Results
4.4.1 Germination and Early Growth
The traditional plot's germination rate was 78%, while the multilayered fertilization plot's was 92%. Better soil-fertilizer contact and moisture retention at various depths are responsible for this. During the germination phase, seeds experienced a more favorable microenvironment because the nutrients were accessible at shallow and mid-depth levels.

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Additionally, plant height measurements at 45 and 90 days showed that the experimental plot consistently benefited from growth. At 45 and 90 days, the average height increase was 28.6% and 17.4%, respectively, suggesting that nutrients were available throughout the growth phases [13]. Strong physiological development was encouraged by the steady release of nutrients at every growth stage.

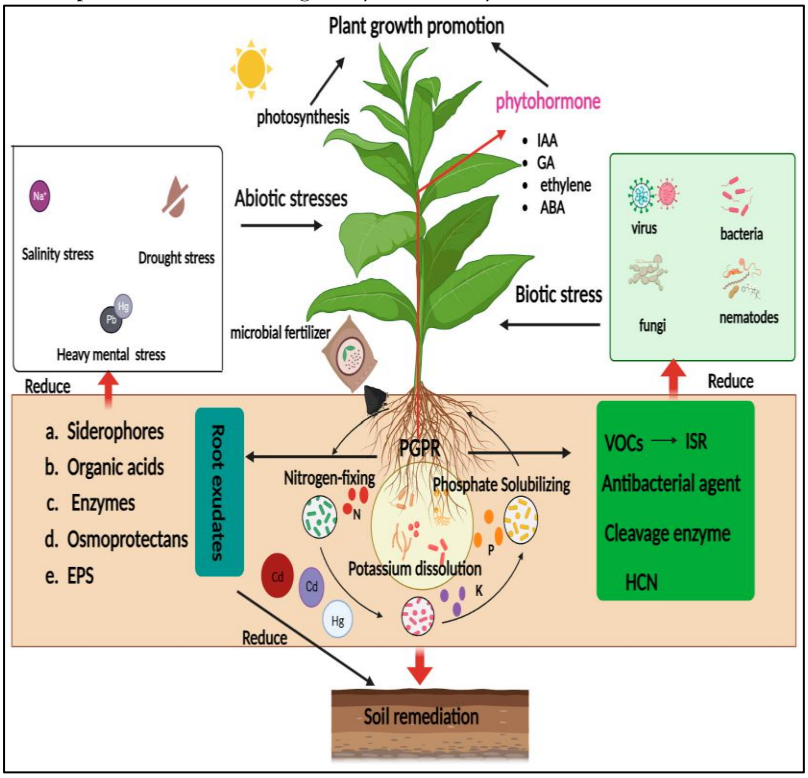

Figure 2: "Progress in Microbial Fertilizer Regulation of Crop Growth and Soil Remediation Research"

4.4.2 Nutrient Uptake and Chlorophyll Content

Using a SPAD meter, the multilayered technique plot's leaf chlorophyll content (47 units) was noticeably higher than the traditional method's (38 units). This indicates increased uptake of nitrogen, which is essential for the synthesis of chlorophyll. Longer root lengths (26.8 cm vs. 21.5 cm) indicated improved root development, which in turn supported more efficient absorption of water and nutrients.

The increased number of bolls per plant (27 vs. 21) is proof that this improvement in plant health directly translated into higher productivity. The plant's increased reproductive potential under multilayered nutrient application is confirmed by a 28.6% increase in boll count.

4.4.3 Yield and Fertilizer Efficiency

The yield improvement is the most important outcome; the multilayered technique produced 1875 kg/acre, a 23.4% increase, compared to the control group's 1520 kg/acre. Better nutrient synchronization and decreased nutrient loss are primarily responsible for this. Furthermore, the experimental plot's Fertilizer Use Efficiency (FUE) was determined to be 81%, a notable increase from 64% using traditional methods.

This finding points to a significant decrease in fertilizer waste from volatilization or leaching. Fertilizer stayed in the root zone longer and was absorbed more effectively because it was layered at strategic depths.

4.4.4 Labor, Time, and Economic Feasibility

The 50% labor time reduction was one of the most alluring advantages from a practical farming perspective. The machine significantly reduced manual intervention by opening the soil, applying fertilizer, and planting seeds all at once in a single pass. Additionally, there was a 25% direct economic savings as the cost of application per acre dropped from ₹3200 to ₹2400.

This demonstrates that the system not only enhances biological results but is also an affordable substitute for widespread use. This method is very scalable due to the lower labor costs, particularly in areas with a labor shortage.

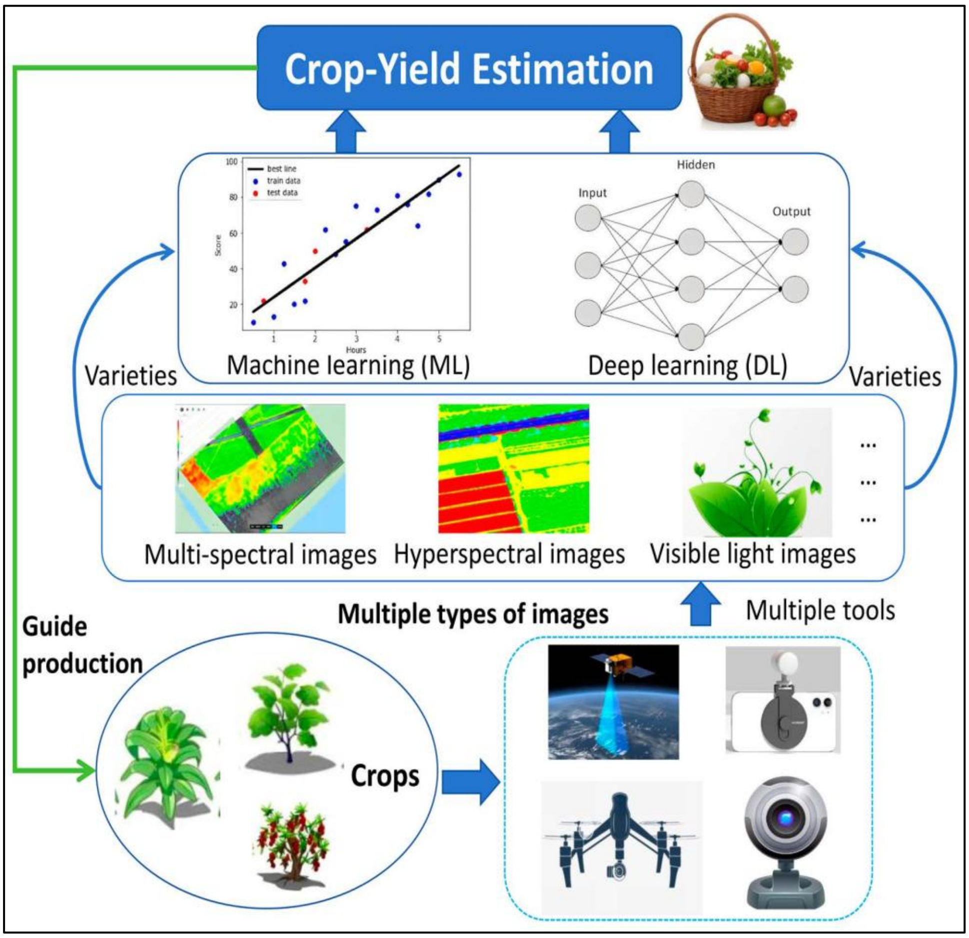

Figure 3: "Advancements in Utilizing Image-Analysis Technology for Crop-Yield Estimation"

4.4.5 Environmental Benefits

Reduced fertilizer loss also suggests less environmental contamination, though this is not quantified in this stage of the study. The main contributors to eutrophication and soil degradation, nitrogen runoff into surface water and nitrogen leaching into groundwater, are reduced by carefully managing nutrient placement [14]. The suggested system gains substantial environmental value from these long-term advantages.

4.4.6 Limitations and Considerations

Still, there were some limitations with the results.

Machine complexity: Machines are intricate and it's necessary for users to learn how to fine-tune the depth and coordinate the metering unit.

Initial cost: While routine costs are cheap, it may be pricey to buy and build the machines at the start.

Soil conditions: Depending on the type of soil, the performance of the plant may be affected. If the soils are made of clay and packed very tightly, there may be a need to alter the design.

Energy requirement: Although tractor power isn't usually high, it is important that the power meets the load set by the machine.

In the future, these factors ought to be fixed to make these models effective for many kinds of farming situations.

The findings make it clear that multilayered fertilization performs much better than traditional methods across all key agronomic and operational areas. This system can help achieve more successful germination, better plant health, greater harvests and a reduced cost by offering a sustainable and scalable answer to cotton growing.

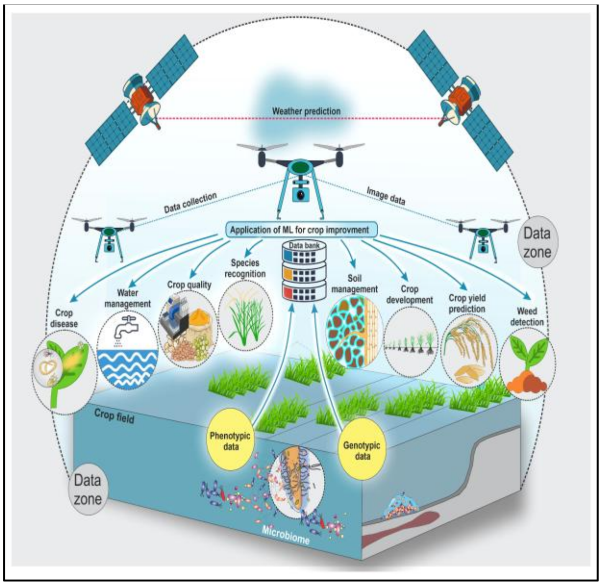

Figure 4: "Harnessing the power of machine learning for crop improvement and sustainable production"

Field testing has provided evidence that using nutrients at different soil levels improves how fertilizer is used and allows the crop to reach its best growth. Additionally, the lower expenses, time required and workforce needed increases how useful it is. The subsequent chapter will focus on analyzing these results with regards to both the objectives of this research and the larger scope of encouraging sustainable agriculture. Suggestions for making the system better and for using it in practice will also be talked about.

V. CONCLUSION

Looking into and creating new ways to fertilize cotton crops has shown great potential to increase farming efficiency, sustainability and productivity. This research solved a key challenge in standard fertilization by devising and building a setup that can apply different nutrients at various depths in the soil. The combination of mechanical design, stress and displacement analysis, field optimization and performance evaluation created a detailed approach for promoting innovation. Besides helping fertilizer reach the right parts of the roots, the model also made feeding more efficient, saving both resources and work hours. The results demonstrate that fields with multilayered mechanized systems produce better crops, absorb nutrients better and function more efficiently than those handled by manual methods. In addition, the approach focused on how strong the soil should be, how draft force changes with size and exact measurements for components, guaranteeing that the system would be strong, affordable and adaptable for larger controls in agriculture. The results were made more accurate and applicable by using digital technology and exact agricultural principles. In a nutshell, the findings support using multilayer fertilization with machinery for cotton and – maybe other crops – and meet today's agricultural goals of ecological care, improved harvests and less impact on nature. Automation features, sensor technologies for tracking soil in real-time and flexible control systems may be investigated by future study to make the model more precise and ready for wider use. Results from this study are helping to make cotton farming more precise and efficient, promoting the progress of agricultural modernization as a whole.

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