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# Avaliação de um sistema integrado de tecnologia digital e verde para a produção sustentável de soja na região de Huang-Huai-Hai, China

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## Evaluating an integrated digital and green technology system for sustainable soybean production in the Huang-Huai-Hai Region, China

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**ABSTRACT:** China's soybean industry currently faces significant challenges, including low cultivation efficiency and environmental degradation caused by traditional, uniform farming practices. To address these issues, this study systematically evaluated the application of an Integrated Digital and Green Technology (IDGT) system—incorporating unmanned aerial vehicle (UAV) multispectral remote sensing, novel controlled-release fertilizers, and soil amelioration techniques—on soybean production in the Huang-Huai-Hai region. Field experiments were conducted to compare the IDGT system with Traditional Conventional Practice (TCP). The results demonstrated that the IDGT system significantly improved soil physicochemical properties, rapidly restoring soil pH to an optimal 6.8 and increasing soil organic matter by 28.3% compared to TCP. Additionally, UAV-based precision variable-rate spraying reduced pesticide application by 33.3% while maintaining a high aphid mortality rate of 88.5%. Agronomically, the IDGT system enhanced crop vigor, drastically reduced root disease and lodging rates, and ultimately achieved an 18.6% increase in soybean grain yield. In conclusion, the integration of digital and green technologies provides substantial agronomic and environmental benefits, offering a highly effective and sustainable path for modernizing soybean production.

**Key words:** soybean production, digital agriculture, UAV remote sensing, Soil amelioration, precision pest control.

## Avaliação de um sistema integrado de tecnologia digital e verde para a produção sustentável de soja na região de Huang-Huai-Hai, China

**RESUMO:** A indústria da soja na China enfrenta atualmente desafios significativos, incluindo a baixa eficiência de cultivo e a degradação ambiental causada por práticas agrícolas tradicionais e uniformes. Para lidar com essas questões, este estudo avaliou sistematicamente a aplicação de um sistema Integrado de Tecnologia Digital e Verde (Integrated Digital and Green Technology- IDGT) incorporando sensoriamento remoto multiespectral por veículos aéreos não tripulados (VANT), novos fertilizantes de liberação controlada e técnicas de melhoria do solo na produção de soja, na região de Huang-Huai-Hai. Adicionalmente, experimentos de campo foram conduzidos para comparar o sistema IDGT com a Prática Convencional Tradicional (TCP). Os resultados demonstraram que o sistema IDGT melhorou significativamente as propriedades físico-químicas do solo, restaurando rapidamente o pH do solo para um nível ideal de 6,8 e aumentando a matéria orgânica do solo em 28,3% em comparação com a TCP. Além disso, a pulverização de precisão com taxa variável baseada em VANT reduziu a aplicação de pesticidas em 33,3%, mantendo uma alta taxa de mortalidade de pulgões de 88,5%. Agronomicamente, o sistema IDGT aumentou o vigor das culturas, reduziu drasticamente as taxas de doenças radiculares e acamamento e, por fim, alcançou um aumento de 18,6% na produtividade de grãos de soja. Em conclusão, a integração de tecnologias digitais e verdes proporciona benefícios agrônômicos e ambientais substanciais, oferecendo um caminho altamente eficaz e sustentável para a modernização da produção de soja.

**Palavras-chave:** produção de soja, agricultura digital, sensoriamento remoto por VANT, melhoria do solo, controle de precisão de pragas.

### 1 INTRODUCTION

Soybeans are one of the most important crops in the world. They are not only the largest source of high-quality animal feed protein but also the second largest source of vegetable oil (LI et al., 2023). However, against the backdrop of deepening national food security strategies, China's soybean industry faces a triple challenge: high external dependency (reaching 85% in 2020), low cultivation efficiency, and weak international competitiveness (KONG et al., 2024). While traditional soybean farming relies

heavily on uniform, broad-scale chemical inputs, this approach often leads to soil degradation, low fertilizer utilization, and increased environmental risks (LI et al., 2026). Consequently, there is an urgent need to transition toward green agricultural development by optimizing resource use and adopting innovative management strategies.

In recent years, emerging digital agriculture and green production technologies such as unmanned aerial vehicle (UAV) multispectral remote sensing, new controlled-release fertilizers, and targeted soil improvement technologies have

provided new paths for enhancing agricultural productivity (CAROPPO et al., 2026). Theoretically, UAV multispectral remote sensing can accurately identify the distribution of pests and diseases by obtaining real-time spectral data of crop canopies, thereby achieving variable pesticide application and reducing the input of chemicals (LI et al., 2025). The new coated controlled-release fertilizer aims to match the nutrient requirements of soybeans at different growth stages and improve the utilization rate of fertilizers (DONG et al., 2023). Soil improvement technology plays a crucial role in remediating soil acidification and compaction caused by long-term unreasonable fertilization and optimizing the micro-environment of root systems (JIANG et al., 2025). Although the international scientific community has made considerable progress in soybean breeding, functional genomics and abiotic stress response, the comprehensive agronomic verification of the above-mentioned digital and green agricultural technologies in the actual soybean production system is still very limited (TIAN et al., 2025). The existing literature usually only focuses on the laboratory or small-scale verification of a single technology. There remains a paucity of scientific reports featuring rigorous field experimental designs of such integrated technology packages within specific agroecosystems.

To address this gap, this study utilized the Shandong Yucheng Soybean Technology Village, a representative agricultural system in China's Huang-Huai-Hai region, as an empirical experimental site. We systematically evaluated the effect of the integrated application of the new controlled-release fertilizer and soil improvement technology based on unmanned aerial vehicle multispectral remote sensing

on the agronomic traits' performance of soybeans. This study will clarify the applicability of the above-mentioned technologies in the soybean planting system of the Huang-Huai-Hai region, providing a scientific basis for digital technology to empower green and efficient soybean production.

## MATERIALS AND METHODS

### Site description

The field experiments were conducted at the Yucheng Comprehensive Experimental Station of the Chinese Academy of Sciences (116.57°E, 36.83°N) (Figure 1), located in the central North China Plain and represents a typical agro-ecological zone in the Huang-Huai-Hai plain, where the soil parent material is derived from the Yellow River alluvium, predominantly comprising fluvo-aquic and salinized fluvo-aquic soil. The climate is a warm-temperate semi-humid monsoon climate. The average temperature in this area in 2025 is 13.3 °C, the extreme minimum temperature is around -15 °C, the extreme maximum temperature is 41 °C, and the average annual precipitation is approximately 780 to 800 mm.

To fully capture the technological efficacy from strictly controlled environments to real-world applications, the field trials were spatially distributed across two distinct functional zones: the core experimental zone within the Soybean Technology Courtyard, and the farmer demonstration zones in surrounding villages. The core experimental zone was used for strictly controlled agronomic trials, while the farmer demonstration zones were utilized to assess the technologies' scalability and performance under actual field degradation and pest outbreak scenarios.

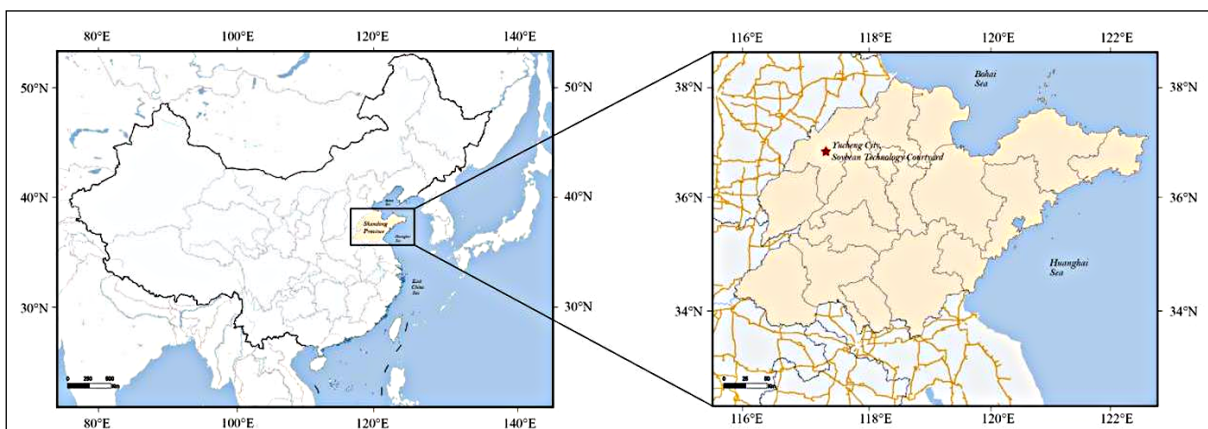


Figure 1 - Location map of Yucheng Science and Technology Courtyard, Shandong.

### Experimental design and treatments

To systematically evaluate the effects of digital and green technologies on soybean production, a controlled field experiment was conducted. The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replicates. The test soybean variety was the locally dominant “Lu Dou 11”.

The experiment compared two main agricultural management systems: the Traditional Conventional Practice (TCP) and the Integrated Digital and Green Technology (IDGT) system. Each experimental plot measured 2350 m<sup>2</sup> (47 m × 50 m) to ensure sufficient buffer zones and accurate yield assessments (Figure 2). The specific treatment details are as follows:

**Traditional Conventional Practice (TCP):** This treatment represented standard local farming practices without soil amendments. A traditional compound fertilizer (N-P-K: 15-15-15) was applied as a single basal application at a rate of 0.075 kg/m<sup>2</sup>. For pest and disease control, a traditional uniform pesticide application method was employed, applying 0.525 ml/m<sup>2</sup> regardless of the spatial distribution of pests.

**Integrated Digital and Green Technology (IDGT):** This treatment integrated soil improvement,

novel fertilizers, and drone-based precision management. (1) Soil Improvement: Prior to planting, the soil was amended with 0.225 kg/m<sup>2</sup> of quicklime evenly spread on the surface, followed by deep tilling to a depth of 25 cm. Additionally, 3 kg/m<sup>2</sup> of well-rotted organic fertilizer was applied to improve soil aggregate structure and increase organic matter content. (2) Fertilization: A novel “sulfur-coated + resin-coated” controlled-release fertilizer was applied as a single basal application at a reduced rate of 0.06 kg/m<sup>2</sup>. (3) Precision Pesticide Application: During the pest outbreak period, a multispectral camera mounted on a drone was used to map the field and analyze the red to near-infrared band ratio to precisely monitor aphid density. Based on the monitoring data, a variable-rate application strategy was executed: areas with severe infestation (>35 aphids/plant) received 0.375 ml/m<sup>2</sup>; moderately infested areas (20–35 aphids/plant) received 0.3 ml/m<sup>2</sup>; and lightly infested areas (<20 aphids/plant) received 0.225 ml/m<sup>2</sup>.

Except for the defined technological interventions, all plots received identical standardized field management (e.g., planting density, irrigation, and weeding) to ensure that the management systems were the only variable factors influencing the outcomes.

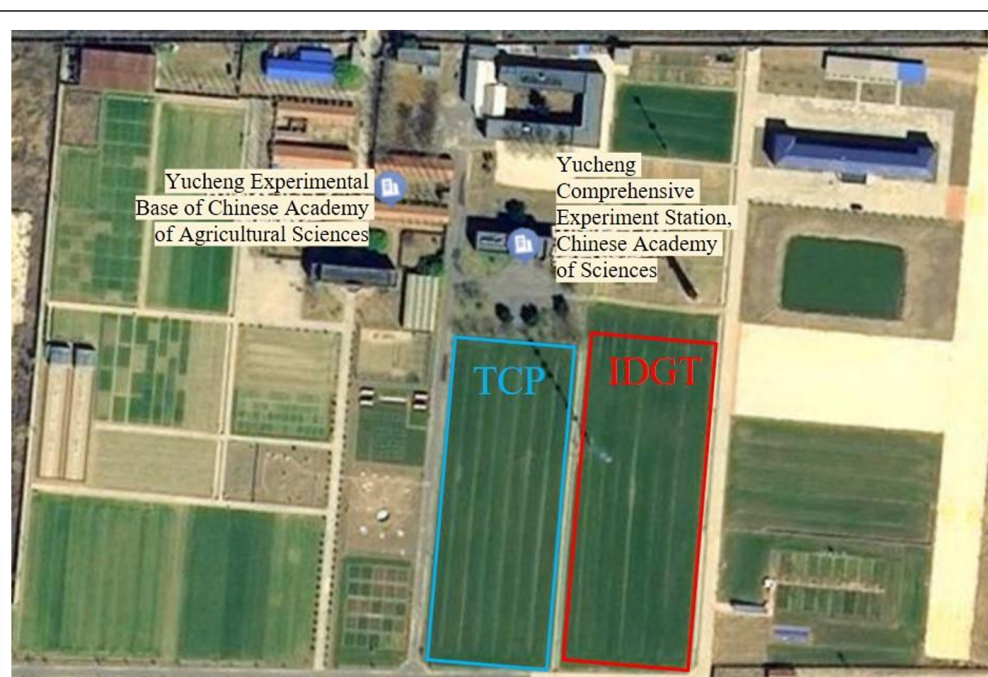


Figure 2 - Remote sensing images of the Integrated Digital and Green Technology (IDGT) and Traditional Conventional Practice (TCP) test fields.

### 1 *Evaluated variables and analytical procedures*

2 To comprehensively assess the effectiveness  
3 of the Integrated Digital and Green Technology  
4 (IDGT) system compared to the Traditional  
5 Conventional Practice (TCP), multidimensional data  
6 including soil physicochemical properties, agronomic  
7 traits, soybean quality, and pest control efficacy were  
8 systematically collected and analyzed.

#### 10 *(1) Soil Physicochemical Analysis*

11 To monitor the dynamic changes in the soil  
12 environment following the amelioration treatments,  
13 soil samples were collected from the 0–20 cm arable  
14 layer in each plot. A five-point sampling method was  
15 employed to ensure representativeness. To evaluate  
16 the short-term effects of quicklime application, soil  
17 pH was continuously monitored at 15, 30, 45, and 60  
18 days after treatment using a standard pH meter (soil-  
19 to-water ratio of 1:2.5). Furthermore, soil organic  
20 matter content and total nitrogen were quantified using  
21 the potassium dichromate volumetric method and the  
22 Kjeldahl method (HE et al., 2025); respectively, which  
23 provided the basis for calculating nitrogen fertilizer  
24 utilization efficiency and soil carbon sequestration  
25 capacity in the 0–20 cm layer.

#### 27 *(2) Agronomic traits and yield components*

28 Soybean growth indicators, including plant  
29 height and stem diameter, were regularly monitored  
30 throughout the growth cycle to evaluate plant vigor.  
31 Ten representative plants were randomly selected  
32 from the center of each plot for morphological  
33 measurements. The incidence of root disease and the  
34 crop lodging rate were determined at the pod-setting  
35 and maturity stages, respectively, by calculating the  
36 percentage of affected plants against the total number  
37 of plants surveyed in each plot. At full maturity, the  
38 crop was manually harvested. The grain yield per  
39 square meter and the hundred-seed weight were  
40 precisely measured after adjusting the seed moisture  
41 content to a standard 13%.

#### 43 *(3) Pest control efficacy and drone monitoring assessment*

45 The accuracy of the drone-based  
46 multispectral remote sensing was validated by  
47 comparing the drone-identified infested zones  
48 (derived from the red to near-infrared band ratio)  
49 with actual ground-truth manual scouting data. The  
50 overall identification accuracy was then calculated.  
51 To evaluate the precision pesticide application  
52 efficacy, the baseline aphid density (aphids/plant)  
53 was surveyed prior to the drone spraying. A post-

application assessment was conducted 7 days later  
to record the number of surviving aphids, which was  
used to calculate the aphid mortality rate and evaluate  
the variable-rate pest control effectiveness.

### 6 *Statistical analysis*

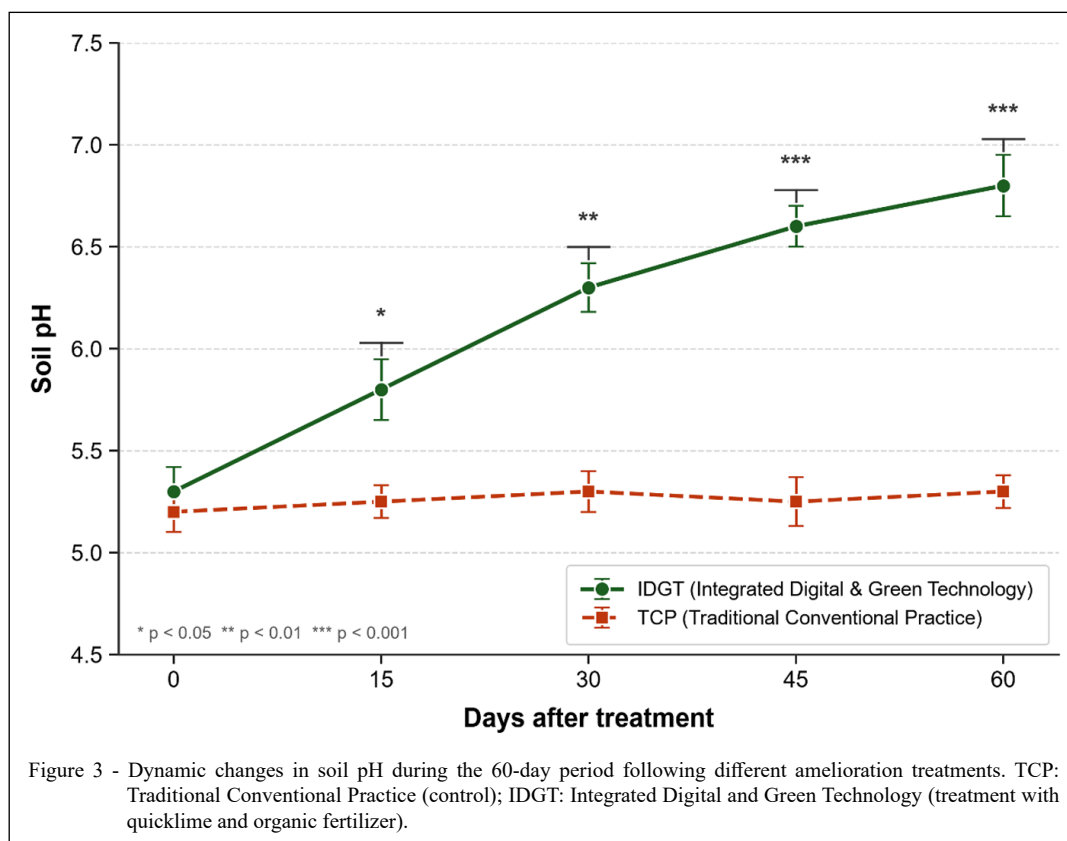
7 All data collected from the field experiments  
8 and laboratory analyses were statistically processed  
9 using SPSS (version 26.0, IBM Corp., Armonk, NY,  
10 USA). Prior to the significance test, all datasets were  
11 checked for normal distribution and homogeneity of  
12 variance using the Shapiro-Wilk test and Levene's  
13 test, respectively. Data are presented as the mean  $\pm$   
14 standard deviation (SD) of the three replicates.

15 To determine the effects of the agricultural  
16 management systems on soybean growth, soil  
17 physicochemical properties, and yield components,  
18 an independent samples t-test was performed to  
19 compare the differences between the Traditional  
20 Conventional Practice (TCP) and the Integrated  
21 Digital and Green Technology (IDGT) treatments.  
22 Statistical significance was declared at a probability  
23 level of  $P < 0.05$ . All graphical representations of the  
24 data were generated using OriginPro 2025 (OriginLab  
25 Corp., Northampton, MA, USA).

## 27 **RESULTS AND DISCUSSION**

### 29 *Improvement of soil physicochemical properties by integrated amelioration*

31 The integrated amelioration strategy  
32 implemented in the IDGT system significantly  
33 improved the baseline soil physicochemical  
34 properties. Prior to the experiment, the soil was  
35 severely acidified due to long-term conventional  
36 fertilization, with an initial pH of approximately  
37 5.3. Following the combined application of  
38 quicklime and well-rotted organic fertilizer, the soil  
39 pH in the IDGT plots exhibited a rapid and steady  
40 recovery. As shown in figure 3, the soil pH in the  
41 IDGT treatment increased to  $5.8 \pm 0.1$  at 15 days,  
42  $6.3 \pm 0.2$  at 30 days, and eventually stabilized at  
43 an optimal  $6.8 \pm 0.1$  by 60 days post-treatment. In  
44 contrast, the pH in the TCP plots remained highly  
45 acidic ( $5.2 \pm 0.2$ ) throughout the observation  
46 period, demonstrating a highly significant difference  
47 between the two management systems ( $P < 0.01$ ).  
48 Furthermore, the soil organic matter (SOM) and total  
49 nitrogen (TN) contents in the 0–20 cm arable layer  
50 were significantly enhanced. At the pod-setting stage,  
51 the SOM in the IDGT treatment reached  $24.5 \pm 1.4$   
52 g/kg, which was 28.3% higher than that in the TCP  
53 treatment ( $19.1 \pm 1.2$  g/kg) ( $P < 0.05$ ). Similarly, the



1 TN content significantly increased from  $1.25 \pm 0.08$   
2 g/kg in TCP to  $1.62 \pm 0.11$  g/kg in IDGT ( $P < 0.05$ ).

3 The substantial alleviation of soil acidity  
4 in the IDGT system is primarily attributed to the rapid  
5 neutralization reaction of quicklime. The hydrolysis  
6 of quicklime directly consumes free hydrogen ( $H^+$ )  
7 ions and displaces exchangeable aluminum ( $Al^{3+}$ )  
8 ions from soil colloids, thereby rapidly mitigating  
9 aluminum toxicity to soybean root development  
10 (FAGERIA et al., 2008). Concurrently, the addition  
11 of organic fertilizer played a synergistic role in  
12 soil structural restoration. The decomposition of  
13 organic amendments continuously releases humic  
14 substances that promote the formation of water-  
15 stable macroaggregates, which not only enhances the  
16 soil's acid-buffering capacity but also improves soil  
17 porosity and aeration. This synergistic mechanism is  
18 highly consistent with the findings of (MATISIC et  
19 al., 2024; DIACONO et al., 2010), who emphasized  
20 the indispensable role of organic amendments in  
21 rebuilding soil structure and stabilizing pH in degraded  
22 agricultural lands. By effectively restoring the soil  
23 pH to the optimal range (6.5–7.0) for *Rhizobium*  
24 nodulation, this integrated amelioration approach

provided a superior rhizosphere microenvironment  
for soybean growth, laying a robust physicochemical  
foundation for the subsequent improvements in plant  
vigor and crop yield.

#### *Responses of agronomic traits, yield, and nutritional quality*

The synergistic effects of soil amelioration  
and novel controlled-release fertilizers within the IDGT  
system significantly enhanced the agronomic traits  
and final yield of soybeans (Table 1). Morphological  
measurements showed that plant height in the IDGT  
plots ( $85.4 \pm 3.2$  cm) was significantly greater than in  
the TCP plots ( $76.5 \pm 2.8$  cm) ( $P < 0.05$ ). Concurrently,  
the incidence of root disease and the lodging rate were  
dramatically reduced in the IDGT treatment to  $6.7 \pm 1.2\%$   
and  $6.0 \pm 0.8\%$ , respectively, compared to  $25.3 \pm 2.5\%$   
and  $18.0 \pm 1.5\%$  in the TCP treatment ( $P < 0.01$ ).  
At maturity, the IDGT system achieved a remarkably  
higher grain yield of  $0.357 \pm 0.012$  kg/  
m<sup>2</sup> compared to the TCP yield of  $0.301 \pm 0.015$  kg/m<sup>2</sup>  
( $P < 0.01$ ). This 18.6% yield increase was primarily  
driven by a significant improvement in the hundred-  
seed weight, which increased from  $20.8 \pm 0.4$  g (TCP)

Table 1 - Effects of different agricultural management systems on agronomic traits, yield, and quality of soybeans.

| Indicators                       | TCP           | IDGT             |
|----------------------------------|---------------|------------------|
| Plant height (cm)                | 76.5 ± 2.8    | 85.4 ± 3.2*      |
| Root disease incidence (%)       | 25.3 ± 2.5    | 6.7 ± 1.2**      |
| Lodging rate (%)                 | 18.0 ± 1.5    | 6.0 ± 0.8 **     |
| Grain yield (kg/m <sup>2</sup> ) | 0.301 ± 0.015 | 0.357 ± 0.012 ** |
| Hundred-seed weight (g)          | 20.8 ± 0.4    | 22.5 ± 0.3*      |

noise. Subsequently, utilizing image processing software such as ENVI, Regions of Interest (ROIs) are precisely delineated based on the RTK GPS coordinates to extract the mean spectral reflectance of the crop canopy for soybeans sampling plot.

Extensive correlation analyses reveal that specific spectral bands—particularly the Red Edge (e.g., 730 nm), Green (e.g., 560 nm), and Near-Infrared (NIR, e.g., 840 nm) regions—are highly sensitive to aphid-induced physiological stress. This spectral sensitivity is primarily attributed to chlorophyll degradation and significant canopy structural alterations, such as severe leaf curling and a reduction in LAI caused by aphid feeding. By integrating these sensitive bands, spectral indices including the Triangular Vegetation Index (TVI), Difference Vegetation Index (DVI), and Red-Edge Vegetation Stress Index (RVSI) are computed to amplify the stress signals (CAO et al., 2015; BROGE et al., 2001).

The IDGT system, incorporating drone-based multispectral remote sensing, significantly optimized pest management. The drone system achieved a 92.5% accuracy in identifying aphid infested zones by analyzing the red to near-infrared reflectance ratio, which is highly sensitive to chlorophyll degradation caused by aphid feeding. As shown in figure 4, the IDGT precision spraying reduced total pesticide application from 0.525 ± 0.015 ml/m<sup>2</sup> (TCP) to 0.350 ± 0.010 ml/m<sup>2</sup> (IDGT), representing a 33.3% reduction ( $P < 0.01$ ). Despite the reduced chemical input, the post-application assessment revealed that the IDGT system maintained a high aphid mortality rate of 88.5 ± 2.1%, showing no significant difference compared to the traditional uniform spraying (89.2 ± 1.8%) ( $P > 0.05$ ). This indicated that variable-rate application based on spatial pest density can effectively control outbreaks while minimizing non-target chemical pollution. These findings align with recent advancements in digital agriculture, which demonstrated that UAV-based multispectral imaging is a robust tool for real-time crop stress monitoring and precision agrochemical delivery.

#### Policy recommendation

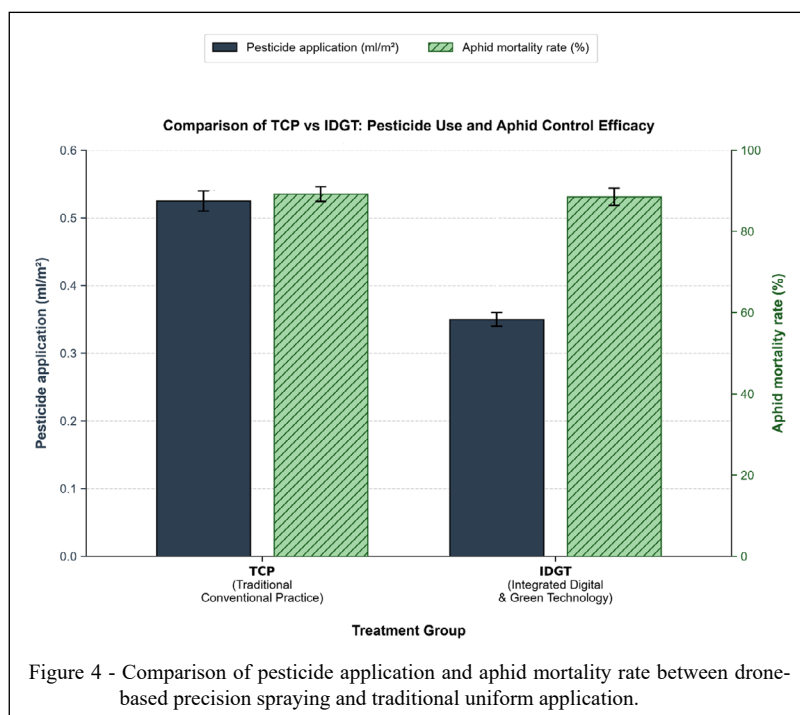
Based on the empirical evidence demonstrating the significant agronomic advantages of the Integrated Digital and Green Technology (IDGT) system, the following policy recommendations are proposed to facilitate the modernization and sustainable development of the soybean industry:

to 22.5 ± 0.3 g (IDGT). The superior yield and quality performances are primarily attributed to the nutrient release pattern of the “sulfur-coated + resin-coated” fertilizer, which synchronizes perfectly with the nitrogen demand peak during the soybean pod-setting and grain-filling stages. This synchronization, as supported by (JIANG et al., 2024; MIYATAKE et al., 2019), optimizes the carbon flow in carbon-nitrogen metabolism, thereby facilitating protein accumulation and preventing premature senescence associated with late-season nitrogen deficiency commonly observed in traditional broadcasting methods.

#### Efficacy of drone-based remote sensing and precision pest control

The precise monitoring and subsequent control of aphid infestations rely on a systematic UAV-based remote sensing workflow integrated with synchronous ground truth investigations. Initially, high-resolution multispectral or imaging hyperspectral data are acquired using advanced UAV platforms (e.g., DJI Phantom 4 Multispectral or octocopters equipped with UHD-185 imaging spectrometers) under optimal, clear, and low-wind meteorological conditions. To ensure spatial fidelity and high-quality image mosaicking, flight parameters are strictly standardized, typically utilizing a flight altitude of 30–50 m, a forward overlap of 75%–80%, and a side overlap of 60%–65%. Concurrently, high-precision RTK GPS devices (e.g., Huace S10-RTK) are deployed to record the exact geographic coordinates of ground sampling plots.

The raw aerial imagery undergoes rigorous preprocessing, including image stitching, geometric correction, and radiometric calibration via reference panels or onboard ambient light sensors, to effectively eliminate atmospheric and environmental



1 (1) Implement targeted subsidies for precision and  
2 green technologies

3 Although the IDGT system significantly  
4 reduces long-term average production costs and  
5 increases overall revenue, the initial transition requires  
6 specialized inputs, such as novel controlled-release  
7 fertilizers and UAV-based multispectral services.  
8 Policymakers should reform generic agricultural  
9 subsidies by directing financial incentives specifically  
10 toward the procurement of precision agriculture  
11 equipment and eco-friendly soil amendments.  
12 Targeted financial support will effectively lower the  
13 initial adoption barrier for smallholder farmers.

15 (2) Strengthen agro-tech extension and digital  
16 capacity building

17 The successful implementation of  
18 variable-rate pesticide application and precision  
19 fertilization relies heavily on accurate data acquisition  
20 and interpretation. It is crucial to institutionalize  
21 collaborative extension models, akin to the “Science  
22 and Technology Courtyard,” which foster deep  
23 integration among research institutions, local  
24 governments, and farming communities. Grassroots  
25 training programs must be prioritized to enhance  
26 farmers’ digital literacy, ensuring they can effectively  
27 interpret remote sensing data and execute precision  
28 management protocols.

(3) Establish ecological compensation mechanisms for  
sustainable agriculture

Given the IDGT system’s proven  
capacity to reduce chemical fertilizer and pesticide  
usage, improve water use efficiency, and enhance  
soil carbon sequestration, a robust ecological  
compensation framework should be established.  
Governments should explore mechanisms to  
financially reward farmers and agricultural  
cooperatives that adopt sustainable practices and  
actively mitigate agricultural non-point source  
pollution. Such ecological dividends will stimulate  
the endogenous motivation of agricultural entities to  
pursue green development pathways.

CONCLUSION

This study systematically evaluated  
the application of an Integrated Digital and Green  
Technology (IDGT) system in soybean production.  
The empirical results demonstrated that the IDGT  
system—incorporating drone-based variable-rate  
spraying, novel controlled-release fertilizers, and soil  
amelioration, provides substantial agronomic benefits  
over traditional farming practices. Technologically,  
the system effectively remediated soil acidification  
(restoring pH to 6.8) and utilized multispectral  
imaging to reduce pesticide application by 33.3%

while maintaining high pest control efficacy. Agronomically, the optimized nutrient release and improved rhizosphere environment significantly enhanced crop vigor, ultimately resulting in an 18.6% increase in grain yield.

However, it is important to note that these findings are derived from a localized field study in the Huang-Huai-Hai plain. While the IDGT system exhibits strong potential to address the core challenges of low efficiency and environmental degradation in traditional agriculture, its broad scalability requires further validation. Future research should focus on multi-location and multi-year field trials across diverse pedoclimatic zones to systematically evaluate the long-term stability and regional adaptability of these integrated technological interventions.

## DATA AVAILABILITY STATEMENT

Data supporting the results and conclusions of this study are available and may be requested from the author upon reasonable request.

## ACKNOWLEDGEMENTS

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## DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

## AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

## DECLARATION OF USE OF ARTIFICIAL INTELLIGENCE

No AI tools were used in the preparation of this manuscript.

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