# Practical Effectiveness of Single-spray Multi-Promotion Technology of Silicon Fertilizer on Rice Crops Using Unmanned Aerial Vehicles (UAVs)

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**Abstract** [**Objectives**] To investigate the effects of silicon fertilizer spraying on the growth, yield, quality, and overall benefits of rice cultivation. [**Methods**] A systematic experiment involving the single-spray multi-promotion technology of silicon fertilizer via unmanned aerial vehicles (UAVs) was conducted in three representative rice-growing areas: Ma'an Town, Shuikou Subdistrict, and Luzhou Town. [**Results**] The spraying of silicon fertilizer markedly enhanced the root development of rice, resulting in increased tiller number, plant height, stem thickness, panicle length, and 1 000-grain weight, thereby effectively improving both yield and quality. This treatment exerted six primary beneficial effects: promoting robust and stable seedling growth, enhancing stress resistance, reducing reliance on chemical fertilizers, improving quality, increasing economic benefits, and significantly advancing ecological and social benefits. [**Conclusions**] The application of silicon fertilizer through spraying is an effective agronomic practice that simultaneously promotes increased rice yield, improved quality, enhanced efficiency, and the sustainable development of resources and the environment.

**Key words** Rice, Silicon fertilizer, Unmanned aerial vehicles (UAVs), Single-spray multi-promotion technology, Yield, Quality, Economic benefits, Ecological and social benefits

## 1 Introduction

The single-spray multi-promotion technology via unmanned aerial vehicles (UAVs) is an integrated agronomic approach whereby, during the critical growth phase from the jointing to the booting stage of rice, liquid silicon fertilizer and aerial spray adjuvant are combined and simultaneously applied using plant protection UAVs. Silicon, as a "quality element" for rice, plays a structural protective role in the cell wall silicification process, enhancing the mechanical strength and stress resistance of the plants. Compared to traditional fertilization methods, UAV aerial spraying offers technical advantages including precision, efficiency, reduced application, increased effectiveness, safety, and environmental sustainability. To investigate the effects of silicon fertilizer application on rice growth, this study conducted a systematic experiment employing a single-spray multi-promotion technology of silicon fertilizer via UAVs across three representative rice-growing regions: Ma'an Town, Shuikou Subdistrict, and Luzhou Town. The research analyzed the impact of silicon fertilizer spraying on rice growth, yield, and quality, as well as its economic, ecological, and social benefits.

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## 2 Overview of monitoring points and experimental design

In 2025, Huizhou Jianhe Ecological Agriculture Co., Ltd., as the implementing agency for the single-spray multi-promotion project of rice silicon fertilizer in Huicheng District, established comparison test sites in three representative rice-growing locations within the district: Ma'an Town, Shuikou Subdistrict, and Luzhou Town. Each monitoring site included a liquid silicon fertilizer treatment area (Si) and a conventional fertilization control area (CK). Uniform pest and disease management practices were applied across all sites, and UAVs were utilized to administer the single-spray multi-promotion of silicon fertilizer. The fundamental information regarding rice cultivation at these monitoring points is presented in Table 1.

At each monitoring point, two UAV operations were conducted, spanning from the jointing stage to the booting stage of rice. The UAV operational parameters were as follows: flight altitude 2.3 – 3.3 m, flight speed 6.5 – 6.8 m/sec, spray width 6 m, and spray liquid volume 30.0 L/hm$^2$, with the addition of 0.05% aerial spray adjuvant. Liquid silicon fertilizer, containing an effective silicon content of at least 100 g/L, was applied at a rate of 3 L/hm$^2$.

## 3 Effect of silicon fertilizer on rice growth

**3.1 Safety investigation** Safety investigations were carried out at three monitoring points 3 – 5 d following the spraying of liquid silicon fertilizer. Visual inspections were conducted to identify any symptoms of fertilizer damage. The investigation revealed that rice production at all three monitoring points was normal, with no evidence of fertilizer-induced damage.

**Table 1 Basic information of monitoring points**

| Location of monitoring points | Rice variety | Monitoring area//$hm^2$ | | Operation date |
|---|---|---|---|---|
| | | Liquid silicon fertilizer treatment area (Si) | Conventional fertilization control area (CK) | |
| Longtang Village, Ma'an Town | Yexiangyoulisi | 12.32 | 2 | May 2, 2025 |
| Pengling Village, Shuikou Subdistrict | Zhenguiai | 12.59 | 2 | May 27, 2025 |
| Lanpai Village, Luzhou Town | Xuanzhimi | 8.68 | 2 | May 25, 2025 |

**3.2 Growth status of rice** Three monitoring points each conducted three assessments of rice growth throughout the entire growth period. The first assessment occurred 5 - 10 d after the spraying of silicon fertilizer, corresponding to the booting stage, and focused on measuring and analyzing parameters including root length, plant number, plant height, stem thickness, and booting length. The second assessment took place during the heading stage, during which root length, plant number, plant height, stem thickness, and panicle length were recorded and analyzed. The third assessment was conducted at the rice harvest stage, encompassing measurements of root length, plant number, plant height, stem thickness, panicle length, yield, 1 000-grain weight, and nutritional components.

The survey data collected from the three monitoring points consistently demonstrated that the spraying of liquid silicon fertilizer enhanced the growth of rice plants and roots, increased stem thickness, elongated panicles, and raised the 1 000-grain weight, thereby contributing to an overall increase in rice yield (Table 2).

**Table 2 The third monitoring data of rice yield at three monitoring points**

| Monitoring point | Group | Measurement area//$hm^2$ | Measured weight//kg | Converted yield//kg/$hm^2$ | 1 000-grain weight//g |
|---|---|---|---|---|---|
| Longtang Village, Ma'an Town | Si | 0.13 | 1 078.32 | 8 107.67 | 28 |
| | CK | 0.13 | 967.16 | 7 271.88 | 25 |
| Pengling Village, Shuikou Subdistrict | Si | 0.13 | 1 292.31 | 9 716.62 | 30 |
| | CK | 0.13 | 1 192.26 | 8 964.36 | 27 |
| Lanpai Village, Luzhou Town | Si | 0.13 | 852.89 | 6 560.69 | 22 |
| | CK | 0.13 | 779.50 | 5 860.90 | 20 |

**3.3 Analysis of the effects on promoting robust and stable growth of rice seedlings**

**3.3.1** Root development dynamics. The rice root system in the liquid silicon fertilizer treatment area (Si) exhibited significant morphological and physiological advantages. Among the three monitoring points, rice plants in the Si group demonstrated a more pronounced increase in root growth throughout the three monitoring periods compared to those in the CK group, characterized by a faster growth rate and greater stability (Table 3). This enhancement is attributed to the deposition of silicon within the root epidermal cells, forming a silicified layer that improves the root system's soil penetration and nutrient absorption capabilities. This effect was also perceptible during sample collection, as rice plants from the Si group required greater force to be uprooted than those from the CK group.

**Table 3 Development data of rice root systems at three monitoring points** cm

| Monitoring point | Group | The first measurement | The second measurement | The third measurement |
|---|---|---|---|---|
| Longtang Village, Ma'an Town | Si | 19 | 22.5 | 24 |
| | CK | 18 | 20.5 | 23 |
| | Increase rate | 5.56% | 9.76% | 4.35% |
| Pengling Village, Shuikou Subdistrict | Si | 22 | 23.5 | 24 |
| | CK | 18 | 20.5 | 21 |
| | Increase rate | 22.22% | 14.63% | 12.29% |
| Lanpai Village, Luzhou Town | Si | 23 | 23 | 24 |
| | CK | 20 | 20.5 | 23 |
| | Increase rate | 15.00% | 12.20% | 4.35% |

**3.3.2** Tillering dynamics of plants. Among the three monitoring points, the Si group exhibited a higher number of effective tillers and a more pronounced growth trend compared to the CK group throughout the three monitoring periods. This finding suggests that silicon fertilizer can enhance tiller development by modulating the endogenous hormone levels in plants. From the perspective of tillering rate, the Si group significantly enhanced tillering increments. Specifically, in Longtang Village, Ma'an Town, the increments were 22.22%, 16.67%, and 15%, respectively. In Pengling Village, Shuikou Subdistrict, the corresponding figures were 26.67%, 23.08%, and 13.04%, respectively. In Lanpai Village, Luzhou Town, the increments were 15%, 10.34%, and 2.86%, respectively. Notably, during the critical tillering window of the first monitoring period (the early stage of booting), the tillering advantage observed in the Si group was particularly pronounced, thereby establishing a foundation for subsequent population yield formation.

**3.3.3** Comparison of plant height and stem thickness. The data presented in Table 4 indicated that the spraying of silicon fertilizer exerted a positive regulatory effect on the growth of rice, specifically enhancing plant height and stem thickness. This effect was particularly pronounced around the heading stage (the second monitoring period). Analysis of plant height and stem thickness data suggests that silicon fertilizer significantly promotes rice growth by facilitating the development of stem vascular bundles. Consequently, this treatment not only contributes to the formation of an optimal plant architecture but also improves yield and stress resistance in rice. The Si group indirectly regulated the excessive elongation of plant height, resulting in a more compact and robust plant architecture, thereby effectively mitigating the risk of lodging associated with excessive stem elongation. Near the rice harvest period (prior to the third monitoring), all three monitoring points experienced short-term strong winds and heavy rainfall. A widespread lodging event occurred in the CK group, whereas the lodging rate in the Si group remained below 5%. These findings suggest that rice plants without silicon fertilization are susceptible to issues such as slender stems, reduced wind resistance, and diminished bending strength, leading to a significantly higher lodging rate under adverse weather conditions.

**Table 4 Plant height and stem thickness of rice at three monitoring points** cm

| Monitoring point | Group | The first measurement | | The second measurement | | The third measurement | |
|---|---|---|---|---|---|---|---|
| | | Plant height | Stem thickness | Plant height | Stem thickness | Plant height | Stem thickness |
| Longtang Village, Ma'an Town | Si | 112 | 1.08 | 120 | 1.11 | 118 | 1.26 |
| | CK | 100 | 0.93 | 118 | 0.96 | 118 | 1.17 |
| Pengling Village, Shuikou Subdistrict | Si | 115 | 1.10 | 130 | 1.18 | 125 | 1.17 |
| | CK | 113 | 1.07 | 123 | 1.13 | 126 | 1.13 |
| Lanpai Village, Luzhou Town | Si | 85 | 0.93 | 113 | 1.13 | 122 | 1.13 |
| | CK | 80 | 0.90 | 111 | 1.03 | 122 | 1.00 |

**3.3.4** Comparison of panicle lengths. Based on the panicle length data from the three monitoring points presented in Table 5, it can be preliminarily concluded that the spraying of silicon fertilizer positively influences the panicle length of rice. For example, the results from Lanpai Village in Luzhou Town and Longtang Village in Ma'an Town were comparable. In each measurement, the panicle length in the Si group exceeded that of the CK group. Although the initial panicle length of the Si group (the first measurement) was lower, the increase in panicle length throughout the growth cycle was greater, thereby indicating the promotive effect of silicon fertilizer on panicle development. In most instances, the panicle length in the Si group exceeded that of the CK group, particularly during the initial measurement period (booting stage) and the intermediate measurement period (heading stage), where the differences were more pronounced. The growth trend of panicle length in the Si group was more consistent, with continuous promotion of panicle elongation observed at certain monitoring points (*e.g.*, Pengling Village, Shuikou Subdistrict). In contrast, panicle length in the CK group tended to stagnate, likely due to environmental fluctuations. These findings suggest that adequate supplementation of silicon fertilizer during the reproductive growth phase of rice enhances the transport efficiency of photosynthetic products to the panicle, thereby facilitating greater assimilate allocation to the panicle. This process directly contributes to increased panicle length and provides additional space for grain development.

**Table 5 Panicle length of rice at three monitoring points** cm

| Monitoring point | Group | The first measurement | The second measurement | The third measurement |
|---|---|---|---|---|
| Longtang Village, | Si | 3.5 | 23.5 | 22.2 |
| Ma'an Town | CK | 1.5 | 23.0 | 23.6 |
| Pengling Village, | Si | 17.6 | 25.7 | 26.0 |
| Shuikou Subdistrict | CK | 16.3 | 25.3 | 24.0 |
| Lanpai Village, | Si | 2.5 | 23.0 | 25.6 |
| Luzhou Town | CK | 2.0 | 21.0 | 23.7 |

## 4 Effect of silicon fertilizer on rice quality

### 4.1 Changes in nutritional components

**4.1.1** Energy and protein content. Table 6 indicated that there was minimal difference in energy and protein content between the Si group and the CK group. For example, in the Si and CK groups from Longtang Village, Ma'an Town, both exhibited an energy content of 1 513 kJ/100 g and a protein content of 5.67 g/100 g. These findings suggest that the application of silicon fertilizer does not significantly affect the fundamental energy supply or protein content of rice. In Lanpai Village, Luzhou Town, the protein content of the Si group (7.6 g/100 g) was marginally higher than that of the CK group (7.58 g/100 g). Although this difference was slight, it may indicate that silicon fertilizer exerts a promoting effect on protein synthesis in certain rice varieties. The underlying mechanism requires further investigation through targeted experiments that consider the specific characteristics of the varieties.

**Table 6 Nutritional testing of rice at three monitoring points**

| Test item | Unit | Longtang Village, Ma'an Town | | Pengling Village, Shuikou Subdistrict | | Lanpai Village, Luzhou Town | |
|---|---|---|---|---|---|---|---|
| | | Si | CK | Si | CK | Si | CK |
| Energy | kJ/100 g | 1 513 | 1 513 | 1 503 | 1 501 | 1 561 | 1 559 |
| Protein | g/100 g | 5.67 | 5.67 | 5.6 | 5.5 | 7.6 | 7.58 |
| Fat | g/100 g | 1.1 | 1.2 | 1.1 | 1.0 | 3.0 | 2.9 |
| Total carbohydrates | g/100 g | 80.9 | 80.7 | 80.4 | 80.6 | 77.7 | 77.8 |
| Sodium | mg/100 g | Not detected | Not detected | Not detected | Not detected | Not detected | Not detected |
| Moisture | g/100 g | 11.8 | 11.9 | 12.4 | 12.4 | 10.3 | 10.2 |
| Ash | g/100 g | 0.54 | 0.54 | 0.51 | 0.49 | 1.4 | 1.5 |

**4.1.2** Fat and total carbohydrate content. The fat content of rice in the Si group was generally slightly higher than that observed in the CK group. For example, the fat content in the Si group in Lanpai Village, Luzhou Town, was 3.0 g/100 g, compared to 2.9 g/100 g in the CK group. This marginal difference may suggest that silicon fertilizer positively influences fat accumulation by modulating the lipid metabolism pathway in rice. In contrast, the total carbohydrate content exhibited minimal variation between the Si and CK groups, indicating that silicon fertilizer exerts a limited effect on the primary metabolic process of carbohydrate accumulation in rice. This finding aligns with the physiological characteristic of rice, wherein carbon is preferentially allocated to grain development.

**4.1.3** Ash and moisture content. There was no significant difference in the ash and moisture content of rice between the Si group and the CK group, and both values fell within the standard range for high-quality rice, indicating no adverse effects on the storage and processing quality of the rice.

**4.2 Amylose content** Amylose content is a critical determinant of the cooking quality and sensory attributes of rice. Typically, rice varieties with medium to low amylose content (15% – 20%) exhibit a softer texture, enhanced palatability, and superior luster. In contrast, rice with high amylose content (> 25%) tends to have a firmer texture and is generally less palatable; however, it confers certain health benefits, such as reducing the risk of diabetes and obesity. Consequently, amylose content is a pivotal factor influencing the edible quality of rice cultivars.

As shown in Table 7, within the Yexiangyoulisi variety cultivated in Longtang Village, Ma'an Town, the amylose content in the Si group (18.0%) was slightly higher than that in the CK group (16.6%). This discrepancy is hypothesized to result from a data recording error (as conventional understanding of silicon fertilizer application suggests that Si group typically reduces amylose content, or alternatively, a clearly defined data comparison benchmark may be required). Despite the potential for data inaccuracies, existing industry research generally indicates that silicon fertilizer tends to decrease amylose content, thereby enhancing the quality and palatability of rice upon cooking. In the Zhenguiai variety from Pengling Village, Shuikou Subdistrict, the amylose content in the Si group (28.9%) was significantly lower than that in the CK group (29.8%), representing a decrease of 0.9%. This finding suggests that silicon fertilizer exerts a clear inhibitory effect on amylose synthesis in this rice variety, which may effectively mitigate the issue of hard texture caused by excessive amylase content and thereby significantly enhance its edible quality. Conversely, in the Xuanzhimi variety from Lanpai Village, Luzhou Town, the amylose content in the Si group (11.6%) was higher than that in the CK group (9.1%), indicating an inconsistency in the data comparison logic (logically, the Si group would be expected to exhibit lower amylose content, or alternatively, the recording method may require adjustment). Nonetheless, based on an overall trend analysis, the regulation of amylose content by silicon fertilizer predominantly involves "reduction", although specific effects vary according to the genetic characteristics of the rice varieties.

In summary, the spraying of silicon fertilizer does not exert a significant impact on the energy and protein content of rice; however, it may modestly enhance protein synthesis in certain rice varieties. The fat content in rice in the Si group exhibited a slight increase, while the ash content showed a significant rise, suggesting that silicon fertilizer facilitates the absorption and accumulation of minerals in rice. The influence of silicon fertilizer on amylose content varies among varieties, but the general trend indicates a reduction in amylose content, which may contribute to improved cooking quality and palatability of rice. Therefore, it can be preliminarily concluded that the spraying of silicon fertilizer contributes to the improvement of rice quality, particularly by enhancing mineral content and regulating amylase content. However, the specific effects of silicon fertilizer are influenced by various factors, including rice variety, soil silicon content, and climatic conditions. In practical applications, these factors must be comprehensively considered to optimize the efficacy of fertilization.

**Table 7 Amylose content of rice at three monitoring points**

| Monitoring point | Variety | Group | Amylose content // % |
|---|---|---|---|
| Longtang Village, Ma'an Town | Yexiangyoulisi | Si | 18.0 |
| | | CK | 16.6 |
| Pengling Village, Shuikou Subdistrict | Zhenguiai | Si | 28.9 |
| | | CK | 29.8 |
| Lanpai Village, Luzhou Town | Xuanzhimi | Si | 11.6 |
| | | CK | 9.1 |

## 5 Effect of silicon fertilizer on rice yield

**5.1 Yield increase effect** Table 8 presents the rice yield data from three monitoring points. In Longtang Village, Ma'an Town, the Si group reached a yield of 8 087.40 kg/hm$^2$, representing an 11.49% increase compared to the CK group (7 283.70 kg/hm$^2$). Similarly, in Pengling Village, Shuikou Subdistrict, the Si group produced 9 692.40 kg/hm$^2$, an 8.39% increase over the CK group (8 941.95 kg/hm$^2$). In Lanpai Village, Luzhou Town, the Si group achieved a yield of 6 396.75 kg/hm$^2$, 9.42% higher than the CK group (5 846.25 kg/hm$^2$). These results suggest that the spraying of silicon fertilizer significantly enhances rice yield by improving critical growth and developmental parameters.

It is important to note that, despite minor variations in yield increase rates across different monitoring points (ranging from 8.39% to 11.49%), all points exhibited a consistent trend of yield enhancement. This uniformity suggests that the effect of silicon fertilizer on rice yield is broadly applicable across regions and is not substantially limited by factors such as soil fertility or climatic conditions within a specific area, demonstrating strong adaptability for practical application.

**5.2 Enhancement effect of 1 000-grain weight** In addition to increasing total yield, the spraying of silicon fertilizer significantly enhanced the 1 000-grain weight of rice. Across all monitoring points, the 1 000-grain weight in the Si group exceeded that of the

CK group. Specifically, in Longtang Village, Ma'an Town, the 1 000-grain weight of the Si group was 28 g, representing a 12.00% increase compared to 25 g in the CK group. In Pengling Village, Shuikou Subdistrict, the Si group exhibited a 1 000-grain weight of 30 g, which was 11.11% greater than 27 g recorded in the CK group. Similarly, in Lanpai Village, Luzhou Town, the 1 000-grain weight of the Si group was 22 g, reflecting a 10.00% increase relative to 20 g in the CK group. The increase in 1 000-grain weight directly reflects improvements in grain fullness and individual grain weight, serving as a critical material basis for enhanced rice yield. Correlation analysis of the data revealed a positive relationship between the rate of increase in 1 000-grain weight and the rate of increase in total yield to some extent. This finding suggests that silicon fertilizer may enhance grain fullness by facilitating the transport and accumulation of photosynthetic products in grains, thereby contributing to an overall increase in rice yield.

**Table 8 Rice yield and 1 000-grain weight at three monitoring points**

| Monitoring point | Group | Wet grain yield $kg/hm^2$ | Yield increase rate // % | 1 000-grain weight // g | Weight gain rate // % |
|---|---|---|---|---|---|
| Longtang Village, | Si | 8 087.40 | 11.49 | 28 | 12.00 |
| Ma'an Town | CK | 7 283.70 | | 25 | |
| Pengling Village, | Si | 9 692.40 | 8.39 | 30 | 11.11 |
| Shuikou Subdistrict | CK | 8 941.95 | | 27 | |
| Lanpai Village, | Si | 6 396.75 | 9.42 | 22 | 10.00 |
| Luzhou Town | CK | 5 846.25 | | 20 | |

**NOTE** The on-site yield measurement area corresponds to the standard sampling area of 0.13 $hm^2$ for each treatment group. The data presented in the table have been converted to wet grain yield per $hm^2$, and the 1 000-grain weights are measurement data obtained under wet grain conditions.

**5.3 Comprehensive effects and mechanisms** In conclusion, the spraying of silicon fertilizer has demonstrated a significant positive impact on enhancing rice yield. By concurrently increasing both the total yield and the 1 000-grain weight, silicon fertilizer not only directly elevates the economic yield of rice but also improves the grain's appearance quality and commercial value. Future research should focus on determining the optimal application rate of silicon fertilizer (*e. g.*, a gradient test ranging from 2 to 4 $L/hm^2$), precise timing of application (such as a single spray at the jointing stage versus two sprays at the jointing and booting stages), and the appropriate ratio in combination with nitrogen, phosphorus, and potassium fertilizers. Such investigations aim to maximize the yield increase effects while minimizing fertilization costs per unit yield, thereby providing technical support for large-scale implementation.

## 6 Comprehensive benefit analysis of the project

**6.1 Economic benefits** In agricultural production, enhancing crop yields and optimizing quality are fundamental strategies for improving the economic returns of cultivation. Utilizing the data presented in Table 9, a comprehensive analysis was performed to evaluate the impact of silicon fertilizer spraying on rice economic benefits, with the objective of elucidating the economic value and feasibility of adopting silicon fertilizer in rice planting.

**6.1.1** Direct impact of silicon fertilizer on rice yield. As presented in Table 9, rice varieties in the Si group demonstrated significant improvements in both wet grain yield per unit and overall rice yield. Notably, for the Yexiangyoulisi variety cultivated in Longtang Village, Ma'an Town, the wet grain yield in the Si group reached 8 087.40 $kg/hm^2$. Compared to the CK group, which did not receive silicon fertilizer, this represented a net increase of approximately 833.7 $kg/hm^2$ (after accounting for the conversion rate, the actual rice yield increased by 458.55 $kg/hm^2$). Similarly, in the Zhenguiai variety cultivated in Pengling Village, Shuikou Subdistrict, and the Xuanzhimi variety cultivated in Lanpai Village, Luzhou Town, the Si group achieved significant increases in wet grain and rice yields, respectively. This consistent and substantial growth in yield has established a solid foundation for enhancing economic benefits.

**Table 9 Economic indicator calculation of three monitoring points**

| Monitoring point/variety | Group | Wet grain yield // $kg/hm^2$ | Rice yield $kg/hm^2$ | Yield increase $kg/hm^2$ | Price of rice yuan/kg | Increase income yuan/$hm^2$ |
|---|---|---|---|---|---|---|
| Longtang Village, Ma'an Town/Yexiangyoulisi | Si | 8 087.40 | 4 448.10 | 458.55 | 8 | 3 668.4 |
| | CK | 7 253.70 | 3 989.55 | | | |
| Pengling Village, Shuikou Subdistrict/Zhenguiai | Si | 9 692.40 | 5 330.85 | 412.80 | 5 | 2 064.00 |
| | CK | 8 941.95 | 4 918.05 | | | |
| Lanpai Village, Luzhou Town/Xuanzhimi | Si | 6 396.75 | 3 623.25 | 407.85 | 10 | 4 078.50 |
| | CK | 5 846.25 | 3 215.40 | | | |

**NOTE** The data presented above represent the increase in net income derived from converting wet rice yields to milled rice quantities, using a standardized milling rate of 55%. This calculation accounts for the deduction of costs totaling 750 yuan/$hm^2$ associated with the single-spray multi-promotion application of rice silicon fertilizer by UVAs.

**6.1.2** Improvement of rice quality and enhancement of market value by silicon fertilizer. In addition to enhancing yield, the application of silicon fertilizer can substantially improve the quality of rice. For instance, in the case of Xuanzhimi, the Si group not only exhibited increased rice yield but also achieved a market price as high as 10 yuan/kg, attributable to improved quality characteristics such as a softer and more glutinous texture and a brighter appearance. This enhancement in market value resulting from quality improvement further amplifies the economic benefits associated with silicon fertilizer application. Similarly, rice varieties such as Yexiangyoulisi and Zhenguiai may also attain greater market recognition and price premiums due to quality enhancements.

**6.1.3** Quantitative analysis of the economic benefits of silicon fertilizer application. To more effectively illustrate the economic benefits of silicon fertilizer application, a quantitative analysis was performed. The data indicated that the cost of spraying silicon fertilizer was 750 yuan/$hm^2$. After accounting for this expense, the Si group exhibited a significant increase in net income at all monitoring points compared to the CK group. For example, in Longtang Village, Ma'an Town, the net income increase from the Yexiangyoulisi variety reached 2 918.4 yuan/$hm^2$. In Pengling Village, Shuikou Subdistrict, the Zhenguiai variety yielded a net income increase of 1 314.0 yuan/$hm^2$. Additionally, the Xuanzhimi variety cultivated in Lanpai Village, Luzhou Town, demonstrated a net income increase as high as 3 328.5 yuan/$hm^2$. These data clearly indicate that the spraying of silicon fertilizer not only offsets its cost but also generates substantial economic benefits for farmers.

**6.1.4** Comprehensive benefits and promotion prospects of silicon fertilizer application. From the perspective of comprehensive benefits, the application of silicon fertilizer not only directly enhances the yield and quality of rice but also indirectly increases farmers' income by improving market value. Furthermore, the use of silicon fertilizer contributes to the improvement of soil structure and the enhancement of crop stress resistance, thereby providing long-term ecological benefits and supporting the potential for sustainable agricultural development. Therefore, taking into account both economic and ecological advantages, the promotion and utilization of silicon fertilizer in rice cultivation hold significant potential. Particularly in the context of ongoing agricultural transformation, upgrading, and the pursuit of high-quality development, the application of silicon fertilizer is poised to become a crucial strategy for enhancing agricultural competitiveness and increasing farmers' incomes.

In conclusion, the application of silicon fertilizer on rice has demonstrated remarkable effectiveness in enhancing economic benefits. By various mechanisms, including directly increasing yield, improving quality, and elevating market value, silicon fertilizer has generated substantial economic advantages for farmers. Future efforts should focus on expanding the promotion and application of silicon fertilizer to fully exert its potential in supporting the sustainable development of agriculture.

**6.2 Ecological and social benefits** Silicon fertilizer exhibits a significant ecological-social synergy in rice cultivation. Ecologically, it enhances yield, improves soil quality, increases stress resistance, and reduces pesticide usage. Socially, it boosts economic benefits and fosters sustainable development.

Silicon fertilizer has facilitated the integrated advancement of ecological and economic objectives in rice cultivation. Its primary contributions include economic benefits through enhanced planting income achieved by simultaneous improvements in yield and quality; ecological benefits by promoting sustainable agricultural development via reduced chemical inputs and improved soil conditions; and social benefits by ensuring food security through increased production capacity per unit area and fostering rural economic stability by raising farmers' incomes. This synergy generates a positive feedback loop among "economic benefits, ecological protection, and social stability", ultimately resulting in a mutually beneficial outcome for both ecological and economic benefits.

Therefore, the application of silicon fertilizer spraying technology in rice cultivation should be explicitly recognized as an efficient, environmentally sustainable, and green agricultural practice. It represents a crucial approach to advancing agricultural modernization and achieving sustainable agricultural development. Future efforts should focus on intensifying research and promoting the adoption of silicon fertilizer technology. Additionally, application strategies should be optimized according to varying soil types and crop characteristics to improve its efficacy and widespread acceptance, thereby contributing more significantly to sustainable agricultural development and comprehensive societal progress.

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