Asia Pacific Academy of Science Pte. Ltd.

Pollution Study 2022, 3(1), 1990.
https://doi.org/10.54517/ps.v3i1.1990

Article

Impact of reduced fertilizer application on the yield and non-point source pollution from Yongyou rice cultivation

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CITATION

Mao Q, Zhou J. Impact of reduced fertilizer application on the yield and non-point source pollution from Yongyou rice cultivation. Pollution Study. 2022; 3(1): 1990. https://doi.org/10.54517/ps.v3i1.1990

ARTICLE INFO

Received: 25 June 2022
Accepted: 15 July 2022
Available online: 25 July 2022

Abstract: In the major grain production regions of China, agricultural non-point source pollution and the eutrophication of adjacent surface waters due to the excessive use of chemical fertilizers continue to be significant issues. To address the irrational traditional fertilization practices of farmers and to mitigate agricultural non-point source pollution, a fertilization reduction project was initiated in Jiangshan City. This project aimed to investigate the impact of reducing fertilizer application by 10% to 30% on the yield of Yongyou 15 rice variety and the loss of nutrients (total nitrogen, total phosphorus, and total potassium) in the surface runoff from paddy fields, relative to the farmers' standard fertilization practices. The findings indicated that reducing the conventional fertilizer dosage by 10% to 20% did not lead to a significant decrease in rice yield, with the yield being highest at a 10% reduction. Following fertilization, the nutrient concentration in the paddy field drainage rapidly reached a peak within one hour, after which nitrogen, phosphorus, and potassium concentrations decreased sharply by 25.9% to 66.0%, 70.1% to 88.3%, and 25.0% to 52.5%, respectively, within 24 hours. Subsequently, all nutrient levels continued to decline gradually until the end of the experiment. This suggests that the risk period for nutrient loss, which also corresponds to a high-risk period for non-point source pollution, occurs within a few days after fertilization, particularly if the paddy field is drained due to heavy rain or artificial means. The reduction in chemical fertilizer significantly influenced the nutrient content in the paddy field drainage. One hour after fertilization, reducing the conventional fertilization rate by 10% to 30% resulted in decreases in the concentrations of total nitrogen, total phosphorus, and total potassium in the drainage by 3.7% to 68.2%, 26.3% to 64.8%, and 5.8% to 57.5%, respectively. This approach holds significant potential for enhancing economic benefits and safeguarding the ecological environment in rice cultivation.

Keywords: reducing fertilization; Yongyou 15; rice; nutrient loss; non point source pollution

Rice is one of the main food crops in China, with a rice area of 2.969 in 2019 × 10^7 hm^2, total output 2.096 × 10^{11} kg [1], with the area and output ranking second after that of corn, providing a basic guarantee for China's food security. As a basic element of agricultural production, chemical fertilizer has played an important role in increasing rice yield [2,3]; however, while chemical fertilizer has greatly increased crop yield, it has also led to people's dependence on it, which not only leads to the phenomenon of increasing fertilizer without increasing production, but also pollutes the air, soil and water, bringing huge environmental pressure to the sustainable development of agriculture [3,4]. Ma et al. [2] analyzed the contribution of chemical fertilizer to grain production by using the panel data model. They believed that since 2000, China's chemical fertilizer input has exceeded the optimal application amount in economics and entered the stage of diminishing marginal return. Under the condition that the input of other factors is relatively stable, increasing the amount of chemical fertilizer will not bring about the expected increase in production, but will increase the production cost and increase the risk of polluting the agricultural production environment. They suggested that the amount of chemical fertilizer applied should be appropriately reduced.

In recent years, many technicians have carried out research on the impact of fertilizer reduction on rice production and environmental pollution, and achieved great results. Liu et al. [5] conducted a reduction test on the customary nitrogen application amount. The results showed that under the condition of reducing 10% nitrogen fertilizer, the rice yield was not affected and the total nitrogen loss rate of surface runoff decreased by 9.2%; Shen et al. [6] applied different slow-release fertilizers to reduce the yield by 20% and 25%, but the rice yield increased by 8.8% and 5.0%. However, there are relatively few studies on the effect of fertilizer reduction on nitrogen and phosphorus in paddy field drainage at the same time. Therefore, under the condition of conventional fertilization, this paper studied the effect of fertilizer reduction treatment on the nitrogen and phosphorus content in the field water layer and rice yield, in order to optimize the scientific fertilization technology of reducing non-point source pollution without rice yield reduction, and provide technical support for improving the agricultural ecological environment.

1. Materials and methods

1.1. Test materials

The experiment was conducted in the rice field of Jianai family farm, Huqian village, Hecun Town, Jiangshan City. The test site has a typical subtropical monsoon climate, and the agricultural production is mainly rice planting. The soil of the test field is slightly acidic, with clay texture and high content of organic matter. The specific physical and chemical properties are total nitrogen 14 $g \cdot kg^{-1}$, available phosphorus 224.1 $mg \cdot kg^{-1}$, available potassium 48.0 $mg \cdot kg^{-1}$, organic matter 27.1 $g \cdot kg^{-1}$ and pH 5.42.

The tested rice variety was Yongyou 15. The fertilizer is 45% compound fertilizer (N 15%, P_2O_5 15%, K_2O 15%), urea (N46 %) and potassium chloride (K_2O 60%).

1.2. Treatment design

There were 5 treatments: no fertilization (CK); conventional fertilization (CF) for farmers: N 210 $kg \cdot hm^{-2}$, P_2O_5 90 $kg \cdot hm^{-2}$, K_2O 150 $kg \cdot hm^{-2}$; farmers' conventional fertilization and chemical fertilizer shall be reduced by 10% (90% CF); 20% reduction of conventional fertilization and chemical fertilizer for farmers (80% CF); farmers' conventional fertilization and chemical fertilizer shall be reduced by 30% (70% CF). The small area is 35 m^2, repeated for 3 times, and arranged in random blocks. 30 cm × 30 cm wide for inter district use. The high ridge is separated by independent irrigation and drainage, and the ridge is covered with black film to avoid mutual leakage of water and fertilizer between communities. Protective rows are set around.

Rice will be sown on 5 June 2020, transplanted on 1 July, and matured and harvested on 30 October. The base fertilizer was applied on the test field on 28 June, and the amount of N, P_2O_5 and K_2O fertilizer accounted for 26.7%, 62.5% and 37.5% of the total fertilizer respectively. After the base fertilizer was applied to each plot, the iron rake was used to manually mix the fertilizer into the arable soil, and the rest of the fertilizer was directly applied to the surface of the paddy field as Topdressing on 9 July. The management of irrigation water and pest control in each community shall be carried out in a unified manner with reference to the habits of local farmers.

1.3. Investigation and analysis

Before the test, a soil sample was collected from the paddy field to represent the test soil properties and analyze the soil total nitrogen, available phosphorus, available potassium, organic matter and ph. At the mature stage of rice, the yield of each plot is calculated by actual cutting. After the rice is dried in the sun, the water content is measured, and finally converted into the rice yield with 14% water content.

During the experiment, the flooded layer of about 2 cm was maintained within one week after transplanting. After the application of base fertilizer and top dressing, the paddy field ponding samples were collected. After the drainage outlet was drained for 10 min, 1 kg of irrigation water was collected and put into polyethylene bottles for sealing in time. Three samples were collected repeatedly in each plot. At first, water samples were collected at 1 and 4 h after fertilization, and then samples were collected every day for 5 consecutive days (not collected on the fourth day after topdressing). A total of 7 water samples were collected after base fertilizer and 6 water samples were collected after topdressing. All samples shall be sent to the local laboratory for analysis of total nitrogen, total phosphorus and total potassium. The samples were digested with K2S2O8-naoh and analyzed by UV spectrophotometry and flame photometer respectively. The nutrient loss of surface runoff is calculated by multiplying the volume of paddy water by the nutrient depth of the day.

1.4. Statistical methods

The average yield of rice among different treatments and the nutrient content of water samples at the same time were statistically analyzed by dps9.5, multiple comparisons were made by LSD method, and the significance was tested at the level of $p < 0.05$. The correlation diagram was made by origin9.0 software.

2. Results and analysis

2.1. Output

Figure 1 shows that the yield of fertilizer treatment is 4.0%~13.4% higher than that of no fertilizer treatment. Among them, 90%CF treatment had the highest yield, which was 6863.5 $kg \cdot hm^{-2}$, significantly higher than CK and 70% CF treatment, and had no significant difference with CF and 80% CF. The results showed that the conventional fertilization amount of farmers was high, while the reduction of chemical fertilizer by more than 30% was low, which had a negative impact on rice yield, while the reduction of 10%~20% had no significant impact on rice yield, especially the reduction of chemical fertilizer by 10% was the best amount of chemical fertilizer.

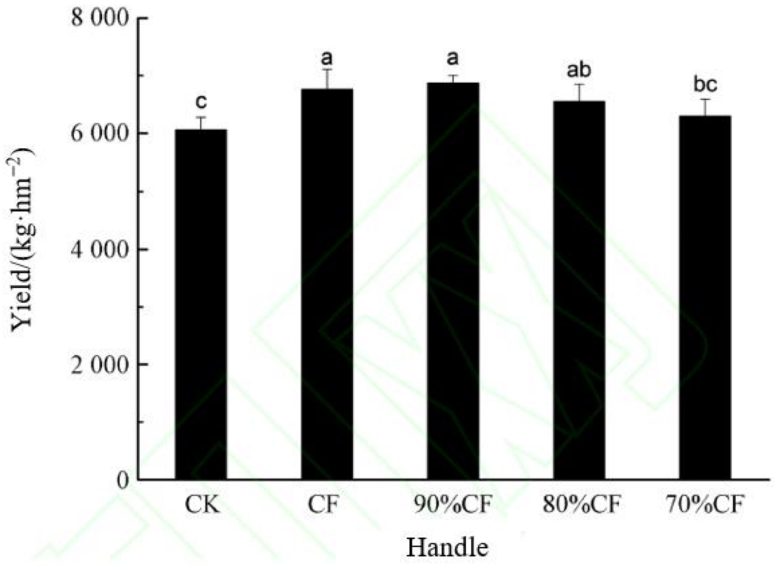

Figure 1. Rice yield of different treated water.

There was no same small letter between columns, indicating significant difference between groups ($p < 0.05$).

2.2. Field water nutrients

As shown in **Figure 2**, the nutrient content in the field ponding increased rapidly after deep application of base fertilizer, and the total nitrogen and total potassium content reached the peak at 4 h, which were 61.6 and 64.6 mg·L^{-1} respectively, 9.7 and 6.6 times that of no fertilizer (CK), with significant difference. At 24 h, the content remained high (60.1 and 63.3 mg·L^{-1}). Two days after fertilization, there was a heavy rainstorm (**Figure 3**). From 30 June to 1 July, the average daily rainfall reached more than 150 mm. All irrigation ponding in the test field was discharged through surface runoff, and the contents of total nitrogen and total potassium in the remaining ponding rapidly decreased to CK level. At 72 h, the contents of total nitrogen and total potassium in fertilization treatment increased, and were significantly higher than CK, which were 3.6 times and 2.9 times of CK. Then it decreased gradually, and there was no significant difference with CK.

The change of total phosphorus content in paddy field ponding was different from that of nitrogen and potassium. Total phosphorus reached its peak at 2.4 mg·L^{-1} after 1 h of fertilization, and rapidly decreased to 0.5 mg·L^{-1} after 4 h. After 24 h, it was basically the same as CK. The above results showed that the content of nitrogen and potassium in the paddy field ponding remained high after applying base fertilizer, and decreased and stabilized at a low level after at least 96 h, while the content of phosphorus in the paddy field ponding rapidly decreased to the level of the unfertilized paddy field after reaching the peak value about 1 h, and the content of phosphorus in the paddy field ponding was extremely unstable.

Figure 4 shows that the chemical fertilizer has been basically dissolved 1 h after topdressing, and the contents of total nitrogen, total phosphorus and total potassium in the accumulated water on the field surface have rapidly increased to the peak (nitrogen 269.7 mg·L^{-1}, phosphorus 72.2 mg·L^{-1}, potassium 98.0 mg·L^{-1}), and then gradually decreased. Among them, the total nitrogen content in ponding decreased significantly after 24 h of fertilization. Compared with 1 h after fertilization, the total nitrogen content in each fertilization treatment decreased by 25.9%~66.0%, and the decline increased with the increase of fertilizer dosage, and then decreased slowly. Compared with the total nitrogen content of CF, there was no significant difference between 90% CF and 80% CF within 96 h after fertilization, while 70% CF was significantly lower than that of CF treatment. By 120 h, 70% CF treatment had dropped to CK level.

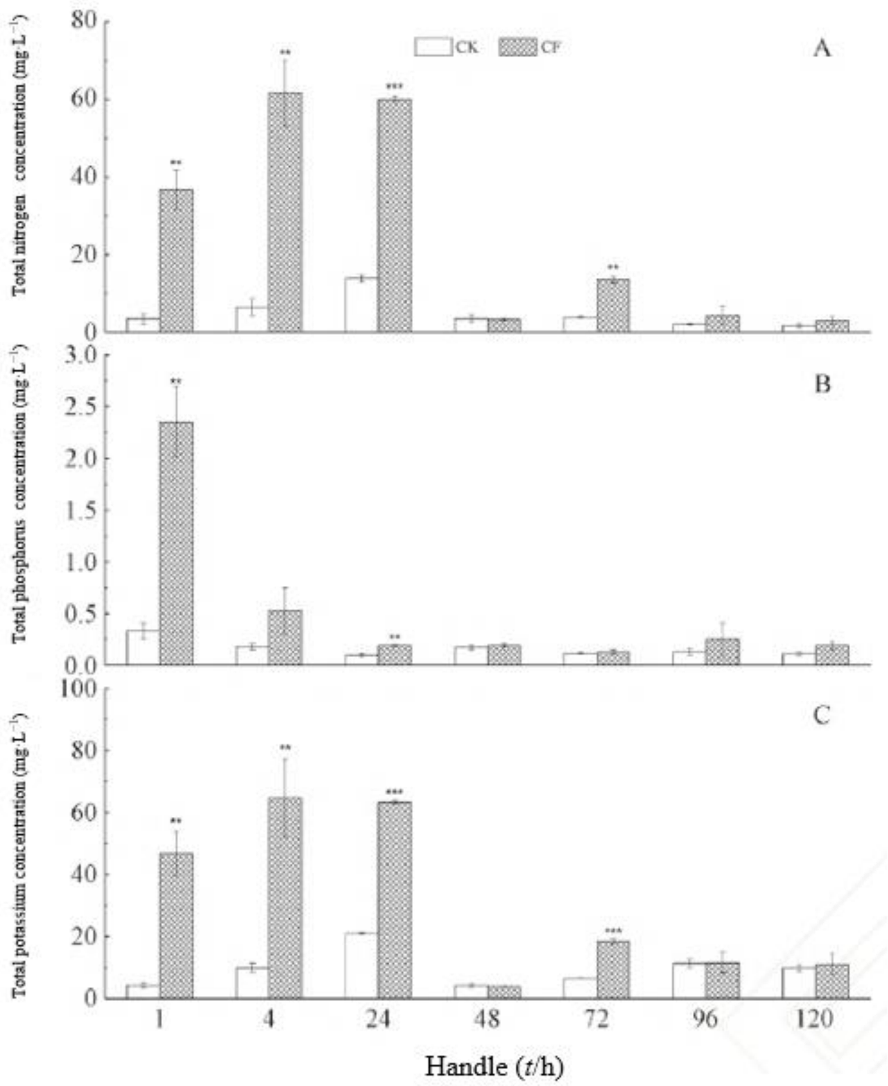

Figure 2. Nutrient content of field drainage at different time after base fertilizer application.

Compared with the same time, ** was significant ($p < 0.05$), and **** was extremely significant ($p < 0.001$).

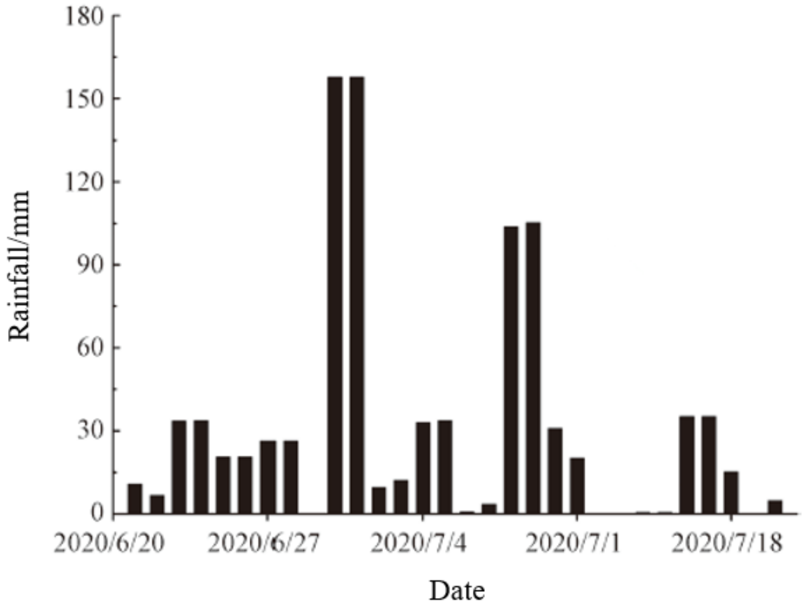

Figure 3. Rainfall of rivers and mountains from 20 June to 20 July 2020.

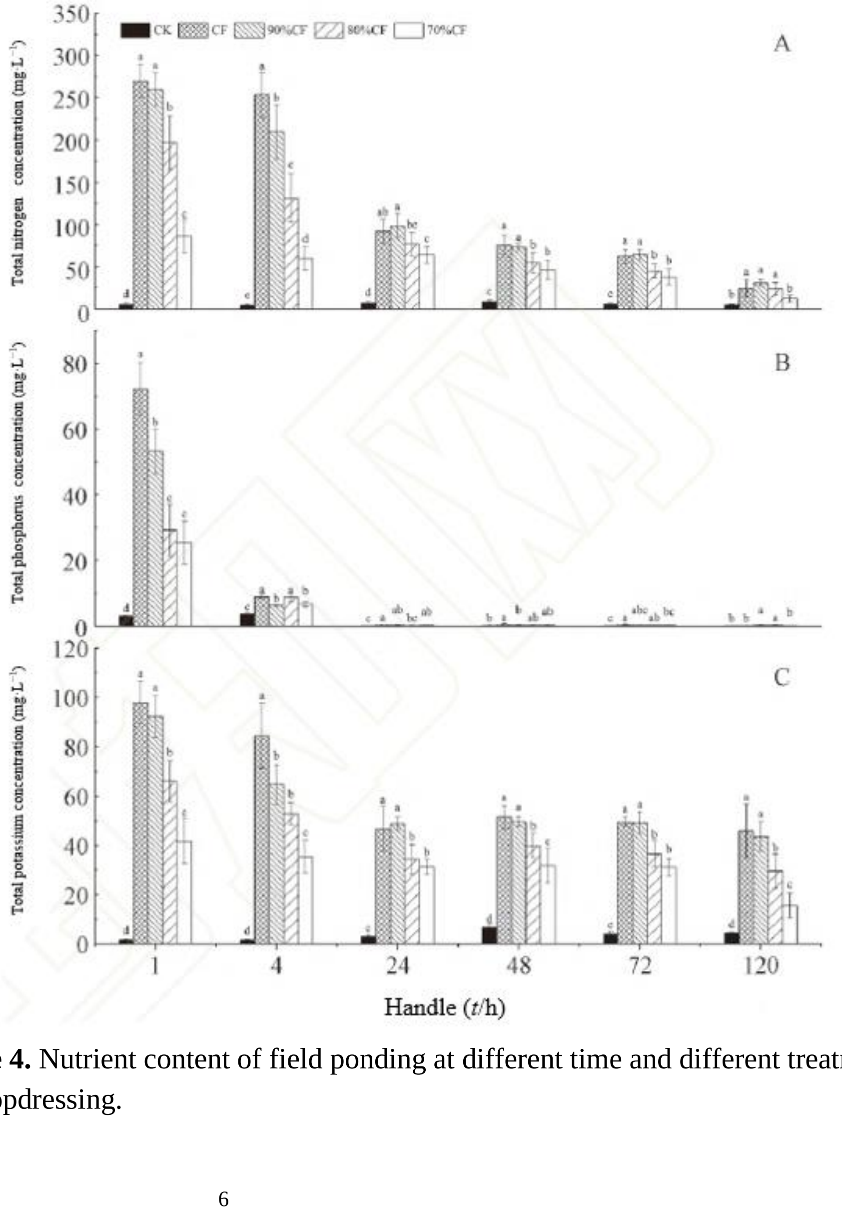

Figure 4. Nutrient content of field ponding at different time and different treatment after topdressing.

The change of total phosphorus content in ponding was similar to that after base fertilizer application. The peak value of each fertilizer application treatment reached at 1 h (25.4~72.2 mg·L^{-1}), which showed that the high fertilizer treatment was significantly higher than the low fertilizer treatment, and it dropped by 70.1%~88.3% at 4 h, both significantly higher than CK, and dropped to a very low level at 24 h, and then it was 0.13~0.57 mg·L^{-1} in all treatments.

The change of total potassium content was relatively mild. At 24 h, it decreased by 25.0%~52.2% from the peak value, and then changed little at the end of the test, and remained at a high level until the end of the test. In the whole test period, CF and 90% were compared at the same time. There was no same small letter between columns, indicating that the difference between groups was significant ($p < 0.05$). CF treatment was always significantly higher than 80% CF and 70% CF treatment. The above results showed that reducing the amount of chemical fertilizer could significantly reduce the nutrient content in paddy water, and the decline rate of nutrient content in paddy water was $p > n > n$.

2.3. Non point source pollution

Two days after the application of base fertilizer in this test, a heavy rainstorm occurred, and the rainfall in 24 h reached more than 150 mm (**Figure 3**), causing the ponding in the test field to flow out completely. The contents of total nitrogen and total potassium in the ponding in the next day's fertilization treatment decreased rapidly by 94.6% and 94.0%, the same level as CK (**Figure 2**). In the early stage of the experiment, the irrigation water was basically kept at about 2 cm. This rainstorm caused the loss of total nitrogen and potassium in the fertilization area to reach 12.0 and 12.7 kg·hm^{-2} through surface runoff. After removing soil nutrients (CK), the loss of nitrogen and potassium accounted for 16.4% and 15.1% of the base fertilizer application. The phosphorus content in the ponding has dropped to a very low level, indicating that the rainstorm has a great impact on the diversion of nitrogen and potassium nutrients from paddy fields. At the same time, it can be seen from **Figures 2** and **4** that the nutrient content of paddy water after fertilization decreases with the extension of time, and also decreases significantly with the reduction of fertilization amount, indicating that the amount of fertilization, the time of rainstorm and the interval after fertilization have an impact on the nutrient loss of paddy field. The lower the amount of fertilization and the longer the time after fertilization, the less the nutrient diversion loss of paddy field caused by rainfall, and the lower the risk of pollution to surrounding water bodies.

3. Discussion

3.1. Fertilizer reduction and rice production

There is a close relationship between the increase of grain yield and the change of chemical fertilizer application amount. The contribution rate of chemical fertilizer to the yield in China was as high as 56.81% [2]. However, due to the habit of relying too much on chemical fertilizer for a long time, the phenomenon of excessive use of chemical fertilizer is widespread, resulting in the rise of production costs, the decline of fertilizer utilization rate, the decline of economic benefits, etc. [7–9]. Even in rice, excessive chemical fertilizer (especially nitrogen fertilizer) is easy to cause rice greed at the mature stage, under the condition of high temperature and high heat, a large amount of nutrients accumulated in the plant and could not be transferred to the grain, but the final yield decreased [7], which verified the truth that "when things reach extremes, they will reverse". In this experiment, the highest rice yield is the conventional fertilization reduction of 10%, and the reduction of 10%~20% on the basis of conventional fertilization has no significant effect on rice yield, which is consistent with Zhao et al. [10] that excessive application of nitrogen and phosphorus fertilizer has no significant effect on rice yield. It shows that the current agricultural main body still has the problem of excessive use of chemical fertilizer, and there is a large space for chemical fertilizer reduction.

3.2. Fertilizer reduction and agricultural non-point source pollution

In order to reduce agricultural non-point source pollution and continuously improve the quality of ecological environment, reducing fertilization is the key work advocated by the Chinese government in agricultural production, and it is also one of the main means to solve the eutrophication of surface water, the high content of nitrate nitrogen in groundwater and the low utilization rate of nutrients. Compared with the conventional fertilization of farmers, appropriately reducing the amount of chemical fertilizer will not only not reduce the yield, but also increase the yield due to improving the population structure of rice, improving the photosynthesis and nutrient transfer capacity of leaves [11], improving the nutrient utilization efficiency of rice and reducing the nutrient loss of rice fields, so as to avoid the risk of water pollution [5,10,12]. In this experiment, after applying topdressing for 1h, the contents of total nitrogen, total phosphorus and total potassium in paddy water increased rapidly, and the increase decreased with the decrease of topdressing. Compared with conventional fertilization, the total nitrogen, total phosphorus and total potassium decreased significantly by 27.1%, 59.5%, 32.7% and 68.2%, 64.8% and 57.5% when the fertilizer was reduced by 20% and 30%. Because the nutrient content in the paddy water was directly related to non-point source pollution [13,14], it showed that reducing fertilization was conducive to reducing the risk of non-point source pollution. Wang et al. [15] investigated the loss of nitrogen in rice field in the application test of different nitrogen amounts. The results showed that the nitrogen loss increased exponentially with the increase of nitrogen application amount. Sun et al. [16] showed through the geographic information system technology scenario analysis that the application amount of nitrogen and phosphorus in rice fields decreased by 10% respectively, and the loss of nitrogen and phosphorus through surface runoff decreased by 7.6% and 3.0% respectively, and believed that the loss of phosphorus was more easily affected by soil properties. After 5 days of balance, the nitrogen content of top dressing in ponding has decreased by 86.1%~91.1%, and the risk of pollution to surrounding water bodies by drainage has decreased significantly; as the soil has a strong phosphorus fixation capacity [13,17], the phosphorus content in the ponding has been in a very low state after 24 h (all < 0.5 $mg \cdot L^{-1}$). After 5 days, the 30% reduction treatment is even lower than the class III limit of the surface water quality standard (<0.2 mg·L^{-1}), and there is no risk of non-point source pollution; the potassium content is still maintained at a high level. In case of rainstorm or drainage loss, it is still large. The results showed that the pollution of paddy field ponding nutrient outflow to the surrounding environment was mainly in a period of time after fertilization, and there was a "critical period of pollution risk". Irrigation and drainage before and after the critical period were conducive to greatly reducing the pollution to the surrounding water environment. Sun et al. [16] also believed that the loss of nutrients in paddy field through surface runoff was mainly within 1 week after fertilization, in which the loss of nitrogen runoff was mainly within 1 week after fertilization, and the loss of phosphorus was mainly within 3~5 d, after which the content of nitrogen and phosphorus stabilized at a very low level. Ji et al. [18] found in the investigation of double cropping rice in subtropical hilly and mountainous areas that the high risk period of nitrogen and phosphorus loss is 5 days after the application of base fertilizer and 10~15 days after the application of top dressing. Lentz et al. [19] even believed that the effect of time after fertilization on nutrient loss caused by surface runoff of irrigated fields was greater than the change of fertilization amount. The conclusions of this study are basically consistent with them. However, due to the short time of experimental investigation, it is difficult to confirm whether the contents of nitrogen and potassium other than phosphorus have been reduced to the lowest point, so it is necessary to carry out a further experiment with a longer investigation time.

4. Summary

Under the experimental conditions, the farmers' customary fertilization amount could be reduced by 10%~20% without significantly affecting the rice yield. The suitable fertilization amounts of nitrogen, phosphorus and potassium for rice were 168~189, 72~81 and 120~135 kg·hm^{-2} respectively. In the process of rice surface application (topdressing), reducing the amount of conventional fertilizer applied by farmers by 10%~20% can effectively reduce the nutrient content of paddy water, and the total nitrogen, total phosphorus and total potassium decreased by 3.7%~27.1%, 26.3%~59.5% and 5.8%~32.7% respectively. At the same time, with the extension of time after fertilization, the nutrient content in ponding decreased gradually, and the decreasing rate was phosphorus > nitrogen > potassium. Phosphorus decreased and stabilized at a very low level 24 h after fertilization, and the risk of environmental pollution was low; the nitrogen content decreased by more than 80% after 5 days, and the pollution risk was significantly reduced. It is suggested that farmers choose the appropriate time for fertilization, try to avoid rainstorm or artificial drainage within 5 days after fertilization, so as to reduce the loss of nutrients in paddy fields and reduce the risk of agricultural non-point source pollution.

Funding: Fertilizer reduction and efficiency increase project of the Ministry of Agriculture and Rural Areas.

Conflict of interest: The authors declare no conflict of interest.

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