EFFECTS OF WATER-SAVING IRRIGATION COMBINED WITH CONDITIONER ON YIELD, NUTRIENT ABSORPTION AND QUALITY OF DRY DIRECT SEEDING RICE

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节水灌溉与调理剂结合对旱直播稻产量、养分吸收及品质影响

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DOI: https://doi.org/10.35633/inmateh-69-41

Keywords: *Water saving irrigation, Dry direct seeding, Growth, Output, Nutrient absorption, Quality*

ABSTRACT

Dry direct seeding cultivation technology of rice is an important aspect of rice production and management. Six treatments were designed in this paper, and that is, T1 (conventional irrigation), T2 (conventional irrigation + conditioner), T3 (30% water-saving irrigation), T4 (30% water-saving irrigation + conditioner), T5 (50% water-saving irrigation), T6 (50% water-saving irrigation + conditioner). The results showed that in the three separate irrigation treatments, 30% water-saving irrigation was conducive to the growth of dry direct seeding rice at the tillering stage, jointing and booting stage, and 50% water-saving irrigation was more conducive to the growth of rice at grain filling stage. Compared with no application of amendments, all kinds of treatments could significantly promote the growth of dry direct seeding rice. Under the condition of water-saving irrigation of 30%, higher dry matter quality, yield and nutrient absorption can be obtained. The total dry matter quality and rice yield of T4 treatment with 30% water-saving irrigation and conditioner were the highest, which were 99.90 g/pot and 37.76 g/pot respectively, compared with conventional treatment (T1) was 37.60% and 45.96% higher, and this treatment had obvious effect on nitrogen and potassium absorption. In terms of quality impact, water saving was 30%. Irrigation conditions are conducive to the improvement of rice processing quality, appearance quality and nutritional quality, especially after the application of conditioner, the overall rice quality is improved. This study has a certain reference value for water-saving irrigation, promoting nutrient utilization, stable yield and high quality of dry direct seeding rice.

摘要

水稻旱直播栽培技术是水稻生产管理中重要方面。本文设计了 6 个处理，即 T1（常规灌溉）、T2（常规灌溉+调理剂）、T3（节水 30%灌溉）、T4（节水 30%灌溉+调理剂）、T5（节水 50%灌溉）、T6（节水 50%灌溉+调理剂）。结果表明：单独三种灌溉方式处理中，节水 30%灌溉有利于旱直播稻分蘖期和拔节孕穗期的生长，节水 50%灌溉更有利于灌浆期水稻生长。相对未施调理剂处理，各种施用调理剂处理均可显著促进旱直播稻长势。节水 30%灌溉条件下能够获得较高干物质量、产量与养分吸收量，其中节水 30%灌溉与调理剂结合的 T4 处理总干物质量和稻谷产量最高，分别为 99. 90 g/盆、37. 76 g/盆，分别较常规处理（T1）高出 37. 60%、45. 96%，并且该处理在氮钾吸收方面均作用明显。在品质影响方面，节水 30%灌溉条件有利于稻谷加工品质、外观品质与营养品质提升，尤其施用调理剂后总体稻谷品质有所改善。该研究对旱直播稻节水灌溉、促进养分利用、稳产优质具有一定参考价值。

INTRODUCTION

Rice is one of the most important food crops for mankind and plays a decisive role in global food security *(Peng and Khush, 2003; Nguyen and Ferrero, 2006).* In China's conventional rice production, excessive water input and low fertilizer utilization rate are caused by leaching under heavy water irrigation and surface evaporation, which seriously restricts the production efficiency and sustainable development of China's rice production system, especially in the production areas with tight water resources in North China. Dry direct seeding water-saving technology is a light and simple rice cultivation technology that saves water, labor and cost without seedling raising and transplanting and directly planting seeds in the field *(Kuma and Ladha, 2011).*

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Some scholars have found that compared with conventional flooding irrigation, drip irrigation and dry direct seeding can save 63.88% of irrigation water in the whole growth period, and the water use efficiency of leaves and yield can be increased by 31.5% and 2.7 times respectively, which is conducive to promoting the growth, development and yield formation of rice *(Wei et al., 2018). Bi et al. (2019)* also pointed out that under the water-saving irrigation of 80% and 60% of the traditional irrigation, the water use efficiency increased significantly, and the yield did not decrease significantly. In addition, intermittent irrigation in paddy field can reduce irrigation water consumption, reduce nitrogen and phosphorus leakage and surface loss, and improve the utilization of soil nitrogen and phosphorus. *Peng et al. (2011)* found in the study on nitrogen and phosphorus leaching loss of the paddy field that compared with flooding irrigation, the leaching loss of N and P under controlled irrigation was significantly reduced.

There are significant differences in the needs of soil physical and chemical properties between dry direct seeding rice and conventional rice, and the application of soil conditioner can improve soil properties and significantly promote the growth and development of rice. According to the relationship between soil, crop and environment and the action mechanism of conditioner, some scholars divide soil conditioner into three types: nutrient type, passivation type and coordinated type. Among them, nutrient type and coordinated type conditioner play a more prominent role in improving soil properties and promoting rice growth. As a coordinated conditioner, such as biochar, it has the characteristics of rich micropore structure and large specific surface area and has a good improvement effect on soil structure, permeability, nutrient absorption and utilization *(Steiner et al., 2008; Novak et al., 2009; Masulili et al., 2010)*. The study further shows that the application of biochar can significantly improve rice yield and nitrogen absorption, so as to improve nitrogen utilization. As a nutritional conditioner, humic acid has strong adsorption capacity and complexation due to its containing a variety of active groups. It can improve the content of soil available nutrients, and then has a significant effect on improving root activity and promoting crop root development, which is conducive to crop growth. In addition, rice is a typical silicon loving crop. As a nutritional conditioner, silicon residue material can promote the absorption of nutrient elements by plants, which is conducive to the growth and development of rice and improve rice quality *(Ma and Takahashi, 1990; Hou, 2020; Salisbury and Ross, 1992).*

Purpose of this paper: (i) Deeply study the effects of water-saving irrigation and conditioner application on growth, yield, nitrogen, phosphorus and potassium absorption and quality of dry direct seeding rice; (ii) Deeply study the comprehensive effects of water management and Regulator Application in the cultivation technology of dry direct seeding rice; (iii) The purpose is to provide theoretical reference for the development of water-saving cultivation of dry direct seeding rice in production areas with large water constraints.

MATERIALS AND METHODS

Test soil properties

The experiment was carried out in the greenhouse of the West Campus of Tianjin Agricultural University. The soil used for the experiment was collected from 0-20 cm topsoil of grain field in Houyou Town, Dameng Village, Wuqing District, Tianjin. The test soil type was light meadow soil with light soil texture, not saline soil. Specific soil physical and chemical properties are shown in Table 1.

Table 1

Soil Physical and chemical properties

Index	Index value	Index	Index value
Organic matter (g kg^{-1})	21.21±1.55	CEC (cmol kg^{-1})	15.54±0.02
Total nitrogen (g kg^{-1})	1.86±0.078	Available potassium (mg kg^{-1})	212.37±0.05
Available phosphorus (mg kg^{-1})	34.56±7.85	Nitrate nitrogen (mg kg^{-1})	10.51.±0.02

Test crop

Early rice, variety is Jinyuan E28. The variety is a japonica conventional rice, with an average growth period of 170 ~ 180 d in Beijing, Tianjin and Tangshan.

Test materials

The comprehensive conditioner is composed of biochar, silicon slag material and humic acid. 30% of the conventional application amount of each conditioner material is prepared respectively, that is, biochar 2,4000 kg/hm^2 + silicon slag material 225 kg/hm^2 + humic acid 1500 kg/hm^2.

Rice husk biochar: purchased from Tianjin Adel Biomass Technology Co., Ltd. and made of rice husk materials, with organic carbon content of 450 g/kg, pH 10.5 and specific surface area of 292 m^2/g. Silicon slag material: it is purchased from Zhejiang Yinyi Group Co., Ltd. and is solid powder. After testing, the main component is porous active silica, with silica content of 84%, organic carbon content of 7.19 g/kg, pH 2.4 and specific surface area of 80-97 m^2/g. Humic acid: purchased from Tianjin X- humate International Trade Co., Ltd., solid powder, pH 5.3, specific surface area 2000 m^2/g.

Test treatment and management

The test time is from June to November 2020. Six treatments are designed, namely T1 (conventional irrigation), T2 (conventional irrigation + conditioner), T3 (30% water-saving irrigation), T4 (30% water-saving irrigation + conditioner), T5 (50% water-saving irrigation) and T6 (50% water-saving irrigation + conditioner). They are repeated for three times, with a total of 18 pots (the specification of the test pot is 40 cm high, 38 cm diameter and 35L total volume), and each basin contains 20 kg of soil. The sowing amount is 6 kg / 667 m^2, i.e. 1.25 g/pot, the sowing depth is 3 cm, the row spacing is 10 cm, and each pot is planted longitudinally in 3 rows. The irrigation volume of conventional flooding irrigation in the whole growth period is 700 m^3 / 667 m^2; moist irrigation is used to irrigate small water and keep the soil moist. The irrigation amount in the whole growth period is 500 m^3 / 667 m^2, which is 70% of the conventional irrigation amount, each irrigation in key water demand period ensures the physiological water demand of rice at the tillering stage, booting and heading stage and grain filling stage, timely replenish water. The irrigation amount in the whole growth period is 350 m^3 / 667 m^2, which is 50% of the conventional irrigation amount. The total irrigation amount of each basin shall be converted according to the proportion of soil weight of each basin to the weight of arable soil per mu of farmland (160000 kg). Conditioner refers to the application of 66.67 g biochar + 30.62 g silicon conditioner + 4.17 g humic acid in each basin.

Water and fertilizer management: after seedling emergence, the summer high temperature period is from June to August, and irrigation is conducted each 3-4 d. Each irrigation amount is 4L for conventional flooding irrigation, 3L for 30% water-saving irrigation and 2L for key water demand period; during booting and grain filling period from September to November, water shall be irrigated each 7-8 d. Each irrigation amount is 3L for conventional flooding irrigation, 2L for moist irrigation and 1.5L for key water demand period. Water shall be cut off 7 d before harvest. In the whole growth period, pure N 20 kg / 667m^2, P_2O_5 6 kg / 667 m^2 and K_2O 5 kg / 667 m^2 were applied. Nitrogen fertilizer is applied four times: base fertilizer (1 g/pot), tillering stage (0.5 g/pot), jointing and booting stage (0.5 g/pot) and grain filling and fruiting stage (0.5 g/pot), which are applied at 40%, 20%, 20% and 20% respectively, that is, the base topdressing ratio is 4:6, which is provided in the form of urea. Phosphorus and potassium are applied as base fertilizer at one time, with 0.75 g P_2O_5 and 0.625 g K_2O applied in each pot in the form of diammonium and potassium sulfate. The nitrogen in diammonium phosphate needs to be deducted in the calculation of urea application rate of base fertilizer.

Test methods

Tillering stage, jointing booting stage and grain filling stage are important growth stages affecting rice growth, grain filling and yield. This experiment investigated the growth of dry direct seeding rice in these three key periods.

Plant height: the height from stem base to spike tip, measured with a tape measure; Chlorophyll: the top three leaves, take the average value of the front, middle and rear parts, and measure it with chlorophyll meter (SPAD-502); Photosynthetic rate: the top three leaves were measured by photosynthetic rate meter (CI-340). Leaf area: the top three leaves are inverted, the leaf length and width are measured with a tape measure, and the correction coefficient method (leaf length) is adopted × Leaf width × 0.7348) calculated leaf area *(Yu et al., 2007).*

At maturity, all dry direct seeding rice in each basin shall be harvested as a whole. After natural air drying, the stem, leaf, root and ear of dry direct seeding rice shall be separated, and each part shall be weighed respectively to calculate the dry matter mass.

Brown rice rate and milled rice rate are the evaluation indexes of rice grading. Brown rice rate refers to the percentage of the weight of brown rice processed by ridge rice machine to the weight of total rice. Milled rice rate refers to the percentage of the weight of milled rice after removing the husk of brown rice to the weight of total rice. Chalkiness is the main character to measure the appearance quality of rice; Chalky grain rate refers to the percentage of chalky rice grains in the whole rice sample *(Zhou et al, 2021).*

The rice is milled into brown rice by ridge rice mill (Korean Shuanglong Company, Model SY88-TH), and then milled into milled rice by rice mill (Japan Sasaki Company, Model CBS300AS (1)). The rate of brown rice, milled rice and chalkiness are determined according to GB/T 17891—1999: high quality rice and NY/T 83—2017: Method for determination of rice quality. The particle length, particle width and surface area shall be measured by the particle evaluator (Model: RGQI20) produced by Sasaki Company of Japan. Nutrition and taste quality are mainly reflected by protein content, amylose content, fatty acid content and taste value, in which taste is an important index to measure rice quality. Japan Sasaki Company has established and developed rice taste evaluation system and taste detection instrument, which can scientifically reflect taste quality. The protein content, amylose content, fatty acid content and taste value are measured by the taste analyzer (Model RLTA10B) produced by Sasaki Company in Japan. The taste value is calculated by the near-infrared spectroscopic analysis method by measuring the protein, amylose and fatty acid content of granular rice.

After the plant samples were digested with concentrated sulfuric acid-H_2O_2, the contents of total nitrogen, total phosphorus and total potassium in each part were determined by Kjeldahl method, vanadium molybdenum yellow colorimetry and flame photometry *(Michalowski et al., 2013).*

The nitrogen absorption of each part was calculated:

$$Nitrogen\ absorption = dry\ matter\ mass \times nitrogen\ content \tag{1}$$

The phosphorus absorption of each part was calculated:

$$Phosphorus\ absorption = dry\ matter\ mass \times phosphorus\ content \tag{2}$$

The potassium absorption of each part was calculated:

$$Potassium\ absorption = dry\ matter\ mass \times potassium\ content \tag{3}$$

Data processing and analysis

The data were processed by Excel 2010, analyzed by One-way ANOVA with SAS 9.4 software, and tested by Duncan method and LSD method.

RESULTS

Growth statuses of dry direct seeding rice under different treatments

As shown in Table 2, at the tillering stage, under the same water irrigation conditions, the plant height, leaf color value, leaf area and photosynthetic rate of dry direct seeding rice treated with conditioner were better than those without application, among which T4 was the best. Compared with T3, the plant height was significantly higher by 3.75%, and the leaf area, leaf color value and photosynthetic rate were higher by 61.87%, 9.37% and 13.21% respectively. From different irrigation conditions, under the condition of wetting irrigation, the growth condition was obvious. Except plant height, other indexes were significantly higher than conventional irrigation and critical water requirement irrigation. Among them, the growth of T4 was the best by combination of conditioner and 30% water-saving irrigation, and plant height, leaf color value, leaf area and photosynthetic rate were significantly higher than those of conventional treatment T1 by 4.92%, 28.79%, 2.33% and 9.53% respectively.

As shown in Table 3 and Table 4, in jointing booting stage and filling stage, under the same water irrigation conditions, the growth status of each treatment shows the same law as that in tillering stage, that is, T2, T4 and T6 are significantly better than T1, T3 and T5. From different water irrigation conditions, the jointing booting stage is the same as the tillering stage. Under 30% water-saving irrigation, the growth advantage is obvious. Among all treatments, T4 has the best growth, and its plant height, leaf color value, leaf area and photosynthetic rate are 6.34%, 23.84%, 22.20% and 11.90% higher than T1 respectively; the leaf color value and photosynthetic rate in the filling stage were different from those in the first two stages. It was better under irrigation in the key water demand stage. Compared with the conventional treatment T1, T6 was significantly higher by 75.68% and 87.50% respectively.

In conclusion, the application of conditioner can significantly promote the growth of dry direct seeding rice. In tillering stage and jointing booting stage, 30% water-saving irrigation is obviously conducive to the growth of dry direct seeding rice, while in grain filling stage, the irrigation management mode in key water demand stage is more conducive to the growth and development of dry direct seeding rice and promote ripening. The combination of 30% water-saving irrigation and conditioner T4 grows better in the early stage of growth, T6 has advantages in the middle and late stage.

Table 2

Growth status of dry direct seeding rice at tillering stage under different treatments

Treatment	Plant height (cm)	Leaf area (cm^2)	Leaf color (SPAD value)	Photosynthetic rate (μmol/(m^2·s))
T1	66.00±2.55b	29.70±1.83c	37.30±2.34b	24.65±3.68c
T2	68.25±2.17a	32.63±1.50b	37.57±0.77b	26.75±2.23b
T3	66.75±3.90b	23.63±1.17d	34.90±4.14c	23.85±1.25c
T4	69.25±2.28a	38.25±1.60a	38.17±278a	27.00±1.90a
T5	48.50±5.02d	21.49±0.86e	26.87±1.73d	19.60±3.25d
T6	52.00±1.22c	22.95±1.14d	27.73±1.27d	21.45±1.13d

Note: Different small letters in the same column represent significant differences between treatments (P < 0.05). The same below.

Table 3

Growth status of dry direct seeding rice at jointing booting stage under different treatments

Treatment	Plant height (cm)	Leaf area (cm^2)	Leaf color (SPAD value)	Photosynthetic rate (μmol/(m^2·s))
T1	82.75±2.77b	38.55±2.02c	31.53±1.77c	21.00±2.23b
T2	88.75±2.55a	45.23±1.65b	33.53±234b	21.15±1.90b
T3	81.50±3.77b	46.06±1.14b	33.90±2.85b	19.60±3.25c
T4	88.00±3.02a	47.74±1.46a	38.53±4.14a	23.50±1.25a
T5	51.50±1.12d	29.76±1.06e	21.67±1.73d	17.75±3.68d
T6	71.00±2.45c	38.78±1.24d	32.73±1.27c	18.25±1.13c

Table 4

Growth status of dry direct seeding rice at filling stage under different treatment

Treatment	Plant height (cm)	Leaf area (cm^2)	Leaf color (SPAD value)	Photosynthetic rate (μmol/(m^2·s))
T1	82.75±1.92b	41.66±2.02b	14.97±0.95e	3.60±0.25c
T2	86.25±2.17a	48.28±1.80a	16.93±234d	2.45±0.88d
T3	84.50±1.66c	37.63±1.58c	15.93±278e	3.85±0.45c
T4	88.25±3.11a	38.25±1.60c	18.93±4.14c	4.00±0.90b
T5	51.50±2.06d	28.43±1.86e	22.27±1.27b	4.65±0.96b
T6	69.50±2.29c	30.95±1.14d	26.30±1.73a	6.75±1.23a

Dry matter quality and yield of dry direct seeding rice under different treatments

It can be seen from Figure 1 that the dry matter quality of each treatment of dry direct seeding rice is stem and leaf > rice > root, in which the proportion of stem and leaf is 40.1%-54.1%, and the proportion of rice is 24.0%-41.4%. The total dry matter mass of each treatment T4 > T2 > T1 > T3 > T6 > T5. Under the same water irrigation conditions, the treatment with conditioner can obtain higher dry matter mass. The total dry matter mass of T4 of each treatment is the largest, which is 99.90 g/pot, 21.68% higher than that of T3 without treatment. Among the three water irrigation methods, the total dry matter quality of 30% water-saving irrigation is better than that of conventional irrigation and irrigation in key water demand period. T3 in the treatment without conditioner is significantly better than T1 and T5, and T4 and T2 in the treatment with conditioner are not significantly different, which is 24.25% higher than T6. The total dry matter quality of T4 was significantly better than that of T1, which was 37.60% higher. The rice yield and total dry matter quality showed the same law. The maximum rice yield of T4 was 37.76 g/pot, which was significantly better than that of other treatments, followed by T2 which was 35.86 g/pot, and there was no significant difference between them. T4 was 11.06% and 14.32% higher than T3 and T6, and 45.96% higher than that of conventional treatment T1.

In conclusion, the application of soil conditioner can significantly promote the dry matter accumulation of dry direct seeding rice and have a significant effect on the improvement of rice yield. Under 30% water-saving irrigation, dry direct seeding rice can obtain higher dry matter quality and yield, which is not significantly different from conventional irrigation. The combination of 30% water-saving irrigation and conditioner is the best for T4 biomass accumulation.

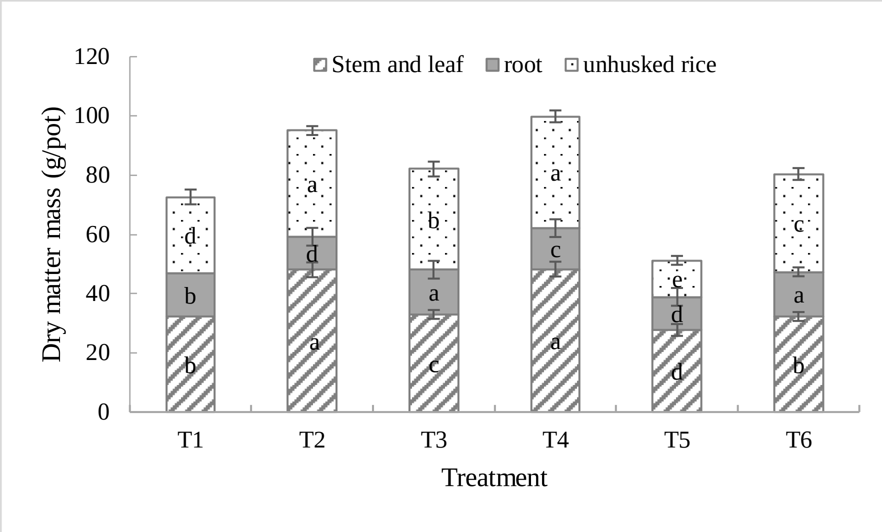

Fig. 1 - Dry matter quality of dry direct seeding rice under different treatments

Note: Different upper and lower case letters represent significant differences among treatments (P < 0.05). The same below.

Nitrogen uptake of dry direct seeding rice under different treatments

As shown in Figure 2, under the same water irrigation conditions, the total nitrogen absorption is T2 > T4 > T1 > T3 > T6 > T5, that is, the nitrogen absorption of the treatment with conditioner is significantly better than that without treatment, and the stem, leaf and rice parts also show the same law. Among the three water irrigation methods, the nitrogen uptake under 30% water-saving irrigation (T3, T4) is not different from that under conventional irrigation (T1, T2), but significantly better than that in key water demand period (T5, T6). The total nitrogen uptake of T2 combined with conventional irrigation and conditioner was the largest, which was 0.84 g/pot, followed by T4 combined with 30% water-saving irrigation and conditioner, which was 0.80 g/pot. The maximum nitrogen uptake of rice T2 was 0.44 g/pot, followed by T4 which was 0.41 g/pot. The two treatments did not reach significant difference, but were significantly higher than other treatments. Compared with T1 and T3 without conditioner, T2 and T4 were 42.45% and 37.71% higher respectively. In conclusion, the application of conditioner can promote the nitrogen absorption of dry direct seeding rice and promote the nitrogen absorption and transformation of rice and stem and leaf, so as to improve the yield; the nitrogen absorption of dry direct seeding rice under 30% water-saving irrigation was significantly better than that in the key water demand period, but there was little difference with conventional irrigation, indicating that water-saving irrigation had no significant effect on nitrogen absorption at 70%.

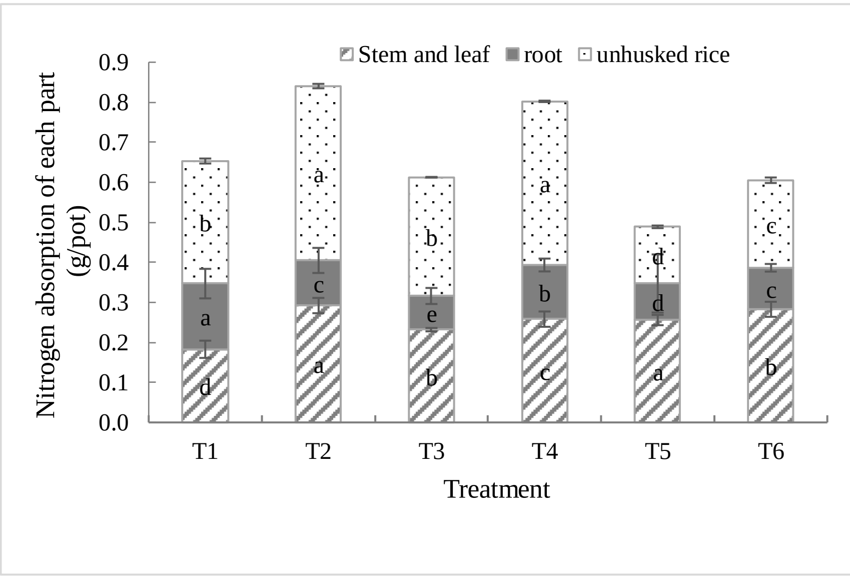

Fig. 2 - Nitrogen uptake in different parts of dry direct seeding rice

Phosphorus uptake by dry direct seeding rice under different treatments

As shown in Figure 3, the phosphorus uptake of different parts of each treatment showed that stem and leaf > rice > root. Under the same water irrigation conditions, the overall phosphorus absorption was T2 > T6 > T1 > T5 > T4 > T3. The effect of regulator application was the same as that of nitrogen absorption. Among the three water irrigation methods, the key water demand period irrigation is significantly higher than 30% water-saving irrigation, and there is little difference from conventional irrigation. The maximum total phosphorus uptake of each treatment T2 is 0.25 g/pot, followed by T6 which is 0.24 g/pot. The rules of rice parts are the same. The combination of conventional irrigation and conditioner T2 and the combination of irrigation and conditioner T6 in key water demand period are significantly better than other treatments, which are 0.10 g/pot and 0.11 g/pot respectively. There is no significant difference between them.

Compared with T1 and T3 without conditioner under the same irrigation conditions, T2 and T6 are 25.00% and 47.89% higher respectively. In conclusion, the application of conditioner can promote the phosphorus absorption of dry direct seeding rice. Conventional irrigation and irrigation in key water demand period are conducive to the phosphorus absorption of dry direct seeding rice and its stems and leaves.

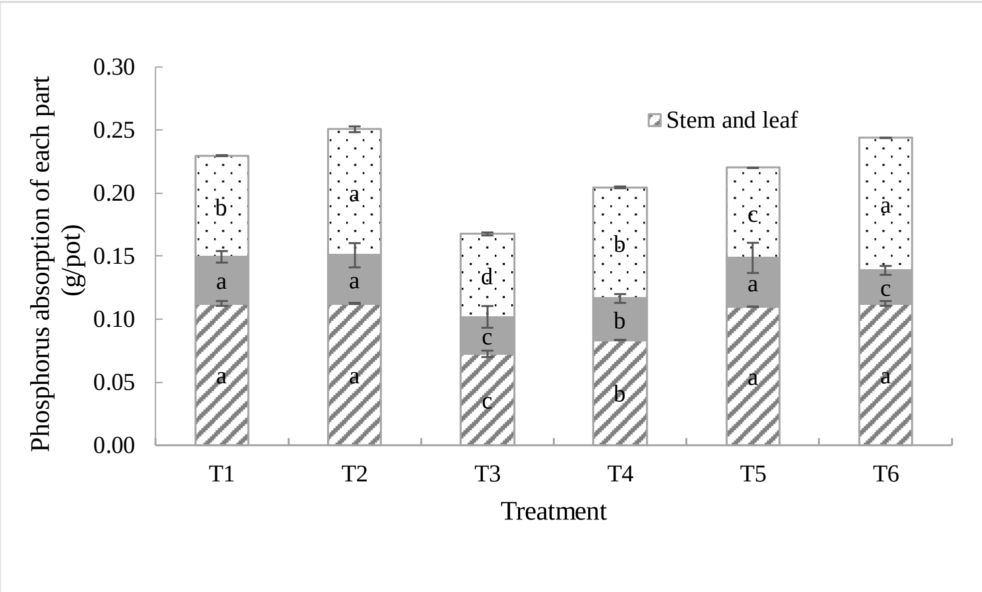

Fig. 3 - Phosphorus absorption in different parts of dry direct seeding rice

Potassium uptake by dry direct seeding rice under different treatments

As shown in Figure 4, the proportion of potassium uptake by stem and leaf parts of each treatment is the largest. Under the same water irrigation conditions, the overall performance is T2 > T4 > T1 > T3 > T6 > T5. After the application of conditioner, the potassium uptake is significantly higher than that of no treatment; among the three water irrigation methods, 30% water-saving irrigation is significantly higher than that in the key water demand period, and has little difference from conventional irrigation. In each treatment, the maximum total potassium uptake of T2 was 1.649 g/pot, followed by T4, which was 1.483 g/pot; the potassium uptake of T2 and T4 was 0.947 g/pot and 0.923 g/pot respectively, which was significantly better than other treatments. There was no significant difference between the two treatments.

Compared with T1 and T3 without conditioner, T2 and T4 were 22.93% and 17.35% higher respectively.

In conclusion, stem and leaf are the main parts of dry direct seeding rice to absorb potassium. The application of conditioner is conducive to the absorption and operation of Assimilates in stem and leaf of dry direct seeding rice, and can significantly improve potassium absorption. Among the three water management methods, conventional irrigation and 30% water-saving irrigation are more conducive to promote potassium absorption.

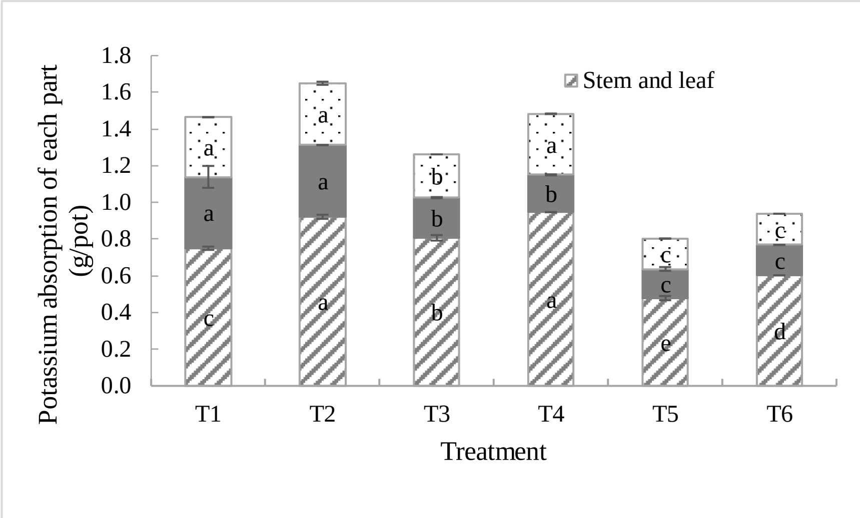

Fig. 4 - Potassium uptake in different parts of dry direct seeding rice

Processing and appearance quality of dry direct seeding rice under different treatments

It can be seen from Table 5 that the conditioner and moisture have certain effects on the processing and appearance quality of dry direct seeding rice. Under the same water irrigation conditions, the processing quality and appearance quality of the treatment with conditioner were better than those without treatment. The brown rice rate and milled rice rate of T4 treatment were the best, which were 30.64% and 1.46% higher than those of T3 without conditioner, respectively; In terms of appearance quality, the chalky grain rate of T4 was the smallest, 12.50%, 30.56% lower than T3, followed by T2 treatment, 16.50%, 25.00% lower than T1. T4 had the best overall performance in grain shape.

Among the three water irrigation methods, the brown rice rate and milled rice rate are T3 > T1 > T5, T4 > T2 > T6, and the chalky grain rate is T3 and T4, that is, 30% water-saving irrigation is conducive to improving rice processing quality, reducing chalky grain rate and improving appearance quality.

Table 5

Processing and appearance quality of dry direct seeding rice under different treatments

Treatment	Brown rice rate (%)	Milled rice rate (%)	Chalky grain rate (%)	Grain length (mm)	Grain width (mm)	Surface area (mm^2)
T1	90.02b	74.61cd	22.12b	4.37±1.09bc	2.34±0.30bc	8.49±2.64b
T2	92.07a	77.40b	16.50c	4.51±0.94ab	2.36±0.31b	8.56±2.16b
T3	91.69a	75.48c	22.00b	4.38±1.03bc	2.34±0.28bc	8.53±2.57b
T4	95.03a	79.61a	12.50d	4.55±1.01a	2.46±0.29a	9.40±2.65a
T5	86.69c	72.75e	23.00a	4.27±0.99cd	2.25±0.30cd	8.28±2.31b
T6	87.58c	73.78de	18.00c	4.33±1.05cd	2.32±0.30bcd	8.47±2.48b

Nutrition and taste quality of dry direct seeding rice under different treatments

Amylose content directly affects the physicochemical properties and taste of rice. It is an important index to evaluate the cooking and eating quality. If the protein content exceeds 9%, it will affect the taste value, and there is a significant negative correlation between gliadin and taste value. It can be seen from Table 6 that under the same water irrigation conditions, the nutritional quality of rice increased significantly after the application of conditioner, while the eating quality was significantly lower than that without application treatment.

Among the three water irrigation methods, the nutrient quality was the highest under 30% water-saving irrigation and the next under conventional irrigation. The contents of protein, amylose and fatty acid in T4 treatment were higher, which were 49.38%, 7.42% and 27.85% higher than those in T1 treatment. In terms of taste quality, the application of conditioner reduced the taste value, and the three irrigation methods had no significant effect on the taste quality of dry direct seeding rice under the same conditions.

Table 6

Nutrition and taste quality of dry direct seeding rice under different treatments

Treatment	Protein/%	Amylose/%	Fatty acid/(mg/100g)	Taste value
T1	8.00d	20.90b	22.84c	55.0a
T2	11.50b	22.12a	29.10a	49.0b
T3	8.80d	20.95b	23.85b	56.0a
T4	11.95a	22.45a	29.20a	49.5b
T5	8.00d	20.80b	22.95c	56.5a
T6	10.70c	22.45a	29.15a	49.0b

DISCUSSION

Different water irrigation methods have different effects on rice growth, yield and quality. In the results of this study, under the irrigation management in the key water demand period (T6 and T5), the plant height is low in the early stage of growth, and the chlorophyll content and photosynthetic rate of leaves are increased in the middle and late stage.

In this study, the photosynthetic rate of T6 was lower at the tillering stage and 68.75% higher than that of T4 in the middle and late growth stage, which was consistent with the research results of *Yu (2017).* Drought control caused the decrease of leaf water content and the intensification of leaf transpiration, and the accumulation of organic matter increased under the condition of consuming unit water. In addition, water stress developed the roots of dry direct seeding rice in the middle and late growth stage, The photosynthetic rate under irrigation in the key water demand period of grain filling period is significantly higher than that under 30% water-saving irrigation, indicating that moderate water-saving irrigation according to the law of crop water demand can also promote the normal growth of dry direct seeding rice.

LV et al. (2016) showed that the dry matter quality of dry wet alternate irrigation was 9.15% and 13.45% higher than that of conventional irrigation and wet irrigation respectively, and the irrigation yield and nitrogen absorption in the key water demand period of this experiment were lower than that of 30% water-saving irrigation, which may be due to the high root shoot ratio of dry direct seeding rice under severe dry wet alternate irrigation in the key water demand period, and the increase of dry matter accumulation rate was concentrated in the root, In the late heading stage, they compete for photosynthetic products with grains, resulting in low yield. Under 30% water-saving irrigation, the water is relatively sufficient, and the root vitality will not be too vigorous. In terms of phosphorus absorption, the phosphorus absorption of irrigated rice in the key water demand period is significantly higher than that of 30% water-saving irrigation, which may be due to the accelerated internal operation of crops under moderate drought, which promotes the transportation of phosphorus from the stem and leaf to rice.

He and Tian (2015) also showed in the study that appropriate water stress slows down the filling speed, is conducive to the accumulation of nutrients, makes the grains plumper, and is conducive to the reduction of rice chalkiness. At the same time, the contents of protein and amylose are also increased, but serious water deficit will reduce rice quality. The results also confirmed this point. The processing and appearance quality under 30% water-saving irrigation were better than that under conventional irrigation, the nutritional quality was also significantly improved, and the rice quality was lower under irrigation in the key water demand period.

The application of conditioner can obtain higher total dry matter mass and nutrient absorption. *Hardy et al. (2017)* found that biochar treatment significantly improved the potassium absorption of double cropping rice, which was conducive to the transport of assimilates from rice stems and leaves to grains, and finally increased the yield. Biochar combined with nitrogen fertilizer significantly increased rice grain yield by 44.89%, increased aboveground nitrogen absorption by 66.27 kg/hm^2, and greatly improved nitrogen absorption. In this experiment, the conditioner treatment (T2, T4 and T6) has obvious advantages in biomass and nutrient absorption, which may be due to the strong adsorption of biochar surface, which can adsorb a large number of polyphenol compounds, provide carbon source for microorganisms, improve microbial activity and promote mineralization, so as to promote nitrogen fixation. On the other hand, biochar has developed pore structure and high stability. Nutrient retention can be achieved by retaining water in soil micro- and mesopores, so as to enhance the absorption capacity of nitrogen *(Lu et al., 2021)* and promote the upward absorption of nitrogen in soil. The application of silicon can significantly improve the content of grain nitrogen and phosphorus, while humic acid can strengthen nitrogen absorption and promote the development of roots.

The application of conditioner can improve rice quality. The study of *Shi et al., (2021)* shows that the combined application of biochar and nitrogen fertilizer can improve the appearance quality of rice such as milled rice rate, chalkiness and grain length, as well as the nutritional quality such as amylose and protein. The study of *Yang et al., (2021)* shows that silicon application has a significant effect on the improvement of rice quality. The content of protein and amylose is high, which has a negative effect on eating quality. In this experiment, the content of protein, amylose and fatty acid in T4 treated with conditioner is significantly higher than that in untreated treatment, which is consistent with the study of *Khan et al., (2008).* Biochar contains high potassium and many trace elements such as Ca, Mn and Zn, which can promote the synthesis of related enzymes in plants. The application of silicon conditioner balanced the content of nitrogen, phosphorus and potassium, while humic acid could accelerate the absorption and operation of nutrient elements. The combination of the three had a good effect on improving rice quality.

The optimal combination of soil conditioner and water has a positive effect on crop yield and nutrient absorption. *Cao et al., (2021)* showed that under the dry wet alternative irrigation mode, biochar combined with slow-release/stable compound fertilizer can synergistically promote the smooth nitrogen absorption, distribution and operation of rice, and significantly improve the population quality, nitrogen utilization and nitrogen availability of rice field. The application of soil modifier clinoptilolite under energy regulated irrigation significantly improved rice yield, nitrogen utilization and rice quality. The combination of soil conditioner and drip irrigation improved the yield and quality of apple, and the contents of total nitrogen and total potassium in leaves and fruits increased significantly, with significant positive interaction. The results showed that under the combination of 30% water-saving irrigation and conditioner, the biomass and nutrient absorption of dry direct seeding rice were not lower or even higher than those of conventional treatment, indicating that the interaction between conditioner and water had a significant positive effect on dry direct seeding cultivation technology.

CONCLUSIONS

Among the three irrigation methods, in terms of growth, 30% water-saving irrigation can promote the growth of dry direct seeding rice at tillering stage and jointing booting stage, and irrigation in key water demand stage is more conducive to the growth of rice at grain filling stage. In terms of biomass and nutrient absorption, 30% water-saving irrigation can obtain higher dry matter quality, yield and nitrogen and potassium nutrient absorption, and there is no significant difference with conventional irrigation, but it has no obvious effect on phosphorus absorption. In terms of quality, 30% water-saving irrigation conditions are conducive to the improvement of rice processing quality, appearance quality and nutritional quality, followed by conventional irrigation conditions. The irrigation conditions in the key water demand period are general. The three irrigation methods have no significant impact on rice eating quality under the same conditions.

The application of soil conditioner can significantly promote the growth and development of dry direct seeding rice. In terms of growth, the treatment with conditioner (T2, T4 and T6) is significantly better than the treatment without conditioner (T1, T3 and T5).

Among all treatments, T4 (30% water-saving irrigation + conditioner) has the best growth in the early growth stage of dry direct seeding rice, and T6 (irrigation in key water demand period + conditioner) has obvious growth advantages in the middle and late growth stage. In terms of biomass, yield and nutrient absorption, the dry matter quality of each treatment was stem and leaf > rice > root, of which rice accounted for 24.0%-37.8%.

The total dry matter quality and rice yield of T4 combined with 30% water-saving irrigation and conditioner were the highest, 99.90 g/pot and 37.76 g/pot respectively, 37.60% and 45.96% higher than those of conventional treatment (T1), which played an obvious role in nitrogen and potassium absorption. The absorption of phosphorus was 13% lower than that of conventional treatment.

The total dry matter mass and rice yield of T2 combined with conventional irrigation and conditioner were slightly lower than those of T4, the difference was not significant, and there was no difference in nitrogen and potassium absorption between the two treatments, but the phosphorus absorption of T2 was significantly higher than that of T4 by 22.4%. In terms of quality, the overall rice quality was improved after the application of conditioner. Among them, the brown rice rate and milled rice rate of T4 treatment were the highest, the chalky grain rate was lower, and the nutritional qualities such as protein, amylose and fatty acid content were higher, 49.38%, 7.42% and 27.85% higher than that of conventional treatment (T1), respectively. However, the eating quality of T4 treatment was significantly lower than that of no conditioner treatment.

In conclusion, the application of soil conditioner can significantly promote the growth, nutrient absorption and yield of dry direct seeding rice and is conducive to the improvement of rice processing, appearance quality and nutritional quality. 30% water saving irrigation combined with conditioner (T4) is conducive to early growth, higher dry matter quality and yield, and improves nitrogen and potassium absorption and rice processing, appearance quality and nutritional quality of dry direct seeding rice. 50% water saving irrigation combined with conditioner (T6) is conducive to late growth and obvious effect of promoting phosphorus absorption.

ACKNOWLEDGEMENTS

This study was financially supported by the Chinese soil as a Fund Project: Key Scientific and Technological Support Project of Tianjin Key R & D plan (19YFZCSN00290), National Key R & D Plan Project (2016YFD0801006) and Tianjin University "Discipline Leading Talent Training Plan" Project (J01009030705). We thank our team members Wang Dafeng, Wang Wei, Xia Yujing and Zhang YingKe for helpful discussions.

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