Water–fertilizer coupling effect on the growth traits of winter wheat under conditions of light and small sprinklers

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Abstract. Light and small sprinklers were used to irrigate winter wheat fields. The distribution and migration of water and nitrogen in soil during winter wheat growth period were analyzed. Moreover, the growth traits of winter wheat were monitored. It is demonstrated that water–fertilizer coupling effect had a significant impact on the migration of water and nitrogen in soil and the growth traits of winter wheat under conditions of light and small sprinklers. Under the same condition of irrigation quota, although the content of moisture in soil was slightly reduced with the increase of the amount of fertilizer, the impact of the amount of fertilizer on the content of moisture in soil is much more insignificant than that of irrigation quota. The content of nitrate nitrogen (NO_3--N) in soil was increased with an increasing amount of fertilizer, especially when the value of irrigation quota was low. On the other hand, under the same condition of amount of fertilizer, the content of nitrate nitrogen (NO_3--N) in soil was decreased with an increasing value of irrigation quota, especially when the value of irrigation quota was high. Hence, an ultra-high value of irrigation quota will aggravate the leach of nitrate nitrogen in soil. The water–fertilizer coupling effect and yield of winter wheat could be optimized by improving irrigation scheme, optimizing irrigation quota, and optimizing the amount of fertilizer.

Keywords. Light and small sprinkler, Coupling effect, Moisture in soil, Nitrate nitrogen, Growth traits.

1 Introduction

Winter wheat is an important crop in China. In 2020, 24 million $hm^2$of winter wheat in China yielded more than 122 million tons of grains. North China is the main producing region of winter wheat, which is located in the middle latitudes with significantly seasonal changes, exhibiting a warm temperate continental monsoon climate. The region is rich in heat resources and has a large atmospheric temperature difference. The temperature is as high as that of subtropical regions in summer. The warm period is long and coincides with

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precipitation period. The winter is longer and temperature is lower, but generally it is no problem for over wintering of chimonophilous crops. The annual average temperature generally ranges from 8 to 14 ℃. The crops have a long growing period. The accumulative temperature is around 3200 to 4500 ℃, which is favorable to the growth of winter wheat[1]. However, with the development of economics, the shortage of water resources has become increasingly prominent. Therefore, the development of water-saving irrigation and optimization of utilization of water resources are effective approaches to promote winter wheat production and achieve the sustainable development of local agriculture.

Light and small sprinklers are different from pipeline-type sprinklers. In detail, the light and small sprinklers exhibit high irrigation intensity and have a faster impact on the microclimate of field, and the temperature of canopy of farmland is lowered while the humidity is increased after sprinkling irrigation. Generally speaking, sprinkling irrigation humidifies soil and supplies water to crops in the manner of raining, and the distribution of moisture across the soil is significantly different from that of conventional surface irrigation[2-3]. In cold seasons, the heat situation of canopy of crops can be improved through sprinkling irrigation. Besides, the photosynthetic rate of crops will be increased and transpiration intensity will be decreased after sprinkling irrigation. As a result, the water consumption of crops is decreased while yield of grains and efficiency of water usage are increased. In particular, the effect of sprinkling irrigation on the microclimate of field and growth of winter wheat is reflected by an increased ratio of productive tiller, a higher content of roots in the surface, and higher water productivity[4].

Nitrogenous fertilizer is a major limiting factor in crop production and accounts for >60% of the total consumed amount of fertilizer in China in recent years[5]. Because of unreasonable irrigation and fertilization manners, the utilization efficiency of nitrogenous fertilizer of main crops such as winter wheat, rice, and maize was only 28% to 41%[6]. An excess of water fertilizer leads to higher loss of soil nitrogen due to nitrogen-containing gas and leaching of nitrates. Consequently, the yield could not be significantly increased in a long run and pollution was caused, which have been paid attention to[7-8]. JuanSui et al. studied the effects of water–fertilizer coupling on the distribution and immigration of water and nitrogen in farmland under drip irrigation[9]. It was reported that the distribution and immigration of nitrate nitrogen and ammonia nitrogen in soil were significantly affected by irrigation system, amount of fertilizer, and the water–fertilizer coupling effect. Hongmei Zhang et al. studied effects of irrigation quota and nitrogen fertilizing levels on the immigration of water and nitrogen in soil, growth of crops, and yields of winter wheat and summer corn fields under the condition of sprinkling irrigation[10].YongshenFan et al. compared the growth traits of winter wheat in three different manners of irrigation, and suggested that sprinkling irrigation was more beneficial for the growth, yield, and quality of crops compared to traditional surface irrigation[11]. In addition, the effect of water–fertilizer coupling on water and nitrogen contents in soil was also studied, and it was concluded that volatilization of ammonia ammonium sulfate and ammonium nitrate was increased under the influence of high content of moisture in soil[12-18]. However, most of these studies were performed under conditions of drip irrigation or pipeline-type sprinkling, and the effect of immigration of water and nitrogen in soil on the growth straits of crops under the condition of light and small sprinklers still needs to be investigated.

Herein light and small sprinklers were subjected to winter wheat fields on high, medium, and low levels of irrigation and fertilization independently. On the basis of monitoring the variation of immigration of water and fertilizer in soil and growth straits of winter wheat in different growth periods, the influence of water–fertilizer coupling conditions on the immigration and the growth straits was presented. This is beneficial for the development of irrigation technology to improve yields of winter wheat and the utilization efficiency of water and fertilizer in soil.

2 Materials and methods

The test base was located in the ‘RenminShengli’ Canal irrigation district, Xinxiang City, Henan Province. This district was located at35°18 ' N and 113°54' E in the north of Henan province, to the north of the Yellow River, and to the south of Taihang Mountains. With a warm temperate continental climate, the four seasons of the distinct are distinct from each other. The annual average temperature was 14°C. The highest temperature was determined in July with an average of 27.3°C while the lowest temperature was measured in January with an average of 0.2°C. The average of annual rainfall was 573.4 mm. The district possesses a frost-free period of 220 days and duration of sunshine of 2400 hours in a year. Xinxiang City was located in both the Yellow River Basin and the Haihe River Basin and 78% of the total area of the city was plain with fertile soil. Light and heat was abundant in the region. The trials were conducted in Qiliying test base of Farmland Irrigation Institute, Chinese Academy of Agricultural Sciences.290,000 hm^2 of winter wheat was planted and functions as the main crop in the district.

2.1 Experimental scheme

Nine blocks with similar soil texture were selected in the test area to plant the same variety of winter wheat at the same time. Nine water–fertilizer coupling schemes were separately implemented in the nine blocks using light and small sprinklers (Table 1). The light and small sprinklers were truss-type and self-propelled with a spray width of 26m and tunable propel velocity. 600kg/km2 base fertilizer was fertilized in the winter wheat fields before planting. For the emergence and soundness of seedling, irrigation with a quota of 750m3/hm2was performed before sowing. According to the local traditional fertilizing scheme, the winter wheat fields were fertilized with urea during the stage of green-up. The fertilizer was dissolved and spread with light and small sprinklers in the manner of spraying and drip washing. The experimental time was from 2017 to 2020, with the same planting pattern and experimental treatment. The average value of the same measurement point was obtained in data processing. The growth characteristics of winter wheat were averaged over three years.

Table 1. Irrigation schemes of winter wheat fields at different fertilizing amount.

Scheme	Fertilizing amount/(kg/hm^2)	Irrigation quota/ (m^3/hm^2)				Total irrigation quota/(m^3/hm^2)
		Green-up stage	Jointing stage	Heading stage	Milk stage	
T_1	300	600	600	750	600	2550
T_2	180	600	600	750	600	2550
T_3	120	600	600	750	600	2550
T_4	300	450	450	600	450	1950
T_5	180	450	450	600	450	1950
T_6	120	450	450	600	450	1950
T_7	300	300	300	450	300	1350
T_8	180	300	300	450	300	1350
T_9	120	300	300	450	300	1350

Notes:T_1:high water and high fertilizer scheme; T2: high water and middle fertilizer scheme;T3: high water and low fertilizer scheme;T4: middle water and high fertilizer scheme; T5: middle water and middle fertilizer scheme； T6: middle water and low fertilizer scheme; T7: low water and high fertilizer scheme; T8: low water and middle fertilizer scheme; T9: low water and low fertilizer scheme.

2.2 Entries in observation and methods

Water content and nitrogen content in the soil of the test area were determined and the growth of winter wheat was monitored. 20points in each test block, i.e. a total of 180points, were sampled. In these sampling points, the water contents and nitrogen contents in soil layers with a depth of 0–20,20–40,40–60,60–80,80–100, and 100–120cm were determined before irrigation, after irrigation, in day one after irrigation, in day two after irrigation, and in day three after irrigation. Daily meteorological data such as temperature and rainfall were periodically measured and recorded with an automatic weather station in the test region. The measurement was lasted from the first irrigation to the last irrigation. On the other hand, the growth of winter wheat was monitored from the period of seedling establishment. Parameters of plant height, ear number, thousand kernel weight, and yields were measured to correlate the water–fertilizer coupling effect with the variation of contents of water and nitrogen in soil and growth traits of winter wheat.

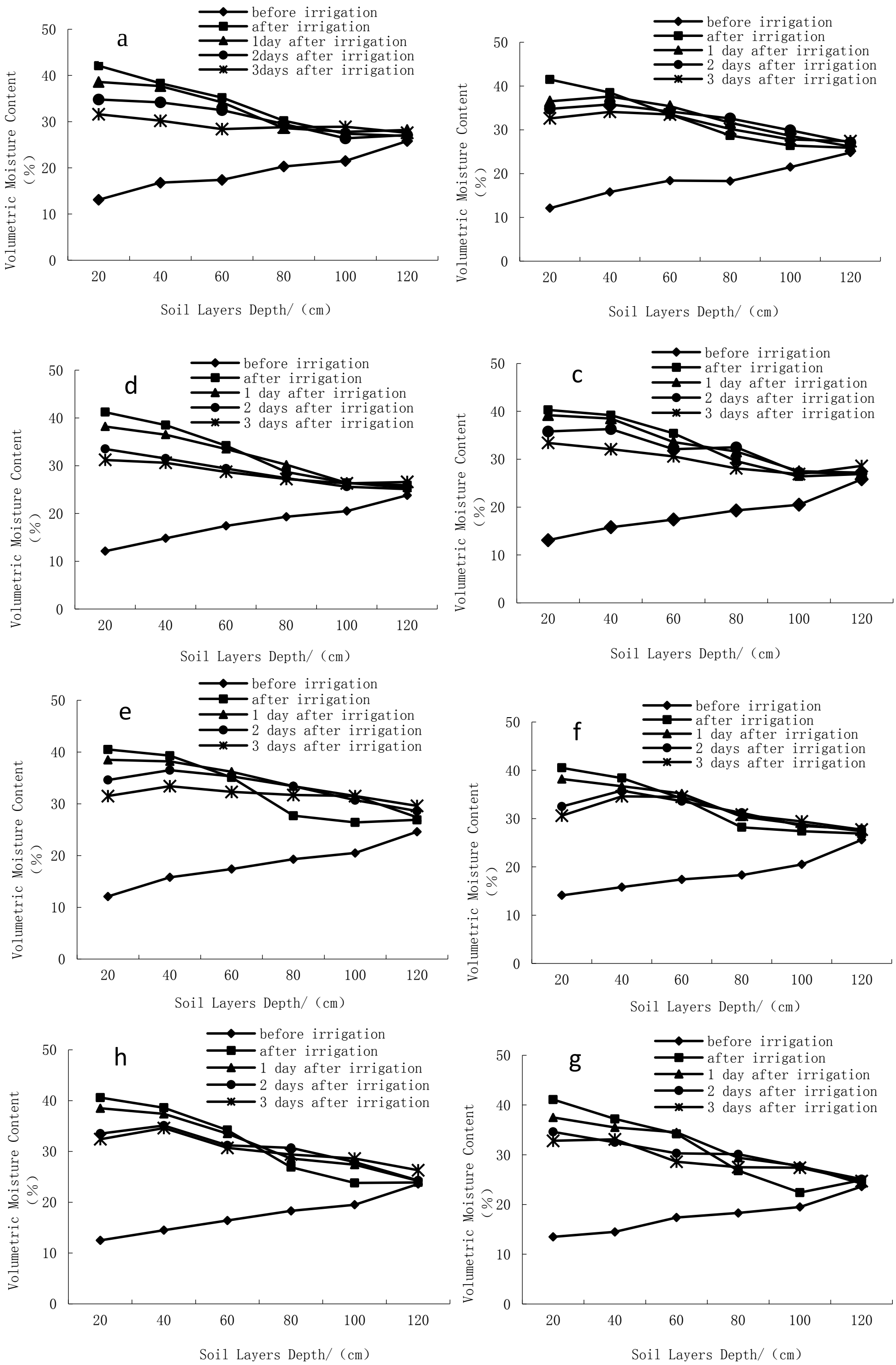
3 Results and analysis of immigration of water and nitrogen in soil

3.1 Variation of contents of moisture in different soil layers after irrigation

Because the irrigation quota varied among different growth periods of the winter wheat, the change of moisture in soil and different water–fertilizer coupling effects under the influence of irrigation should be analyzed during the same growth period. The heading period, known as a critical growth period of winter wheat, was analyzed. The variations of contents of moisture in soil layers at different depths under different conditions of water–fertilizer coupling effect before and after irrigation are illustrated in Figure 1. With the same irrigation quota, the variations of contents of moisture in soil were more significant at larger fertilizing amounts (T_1, T_2, and T_3) and the contents of moisture in soil decreased over time. At a low irrigation quota (T_7, T_8, and T_9), the influence of fertilizing amount on contents of moisture in soil was more significant. At the same amount of fertilizer, the content of moisture in soil increased with the irrigation quota. Thus, water–fertilizer coupling effect affected the variation of content of moisture in soil to a certain extent, which was more prominent at a low irrigation quota. In the same irrigation scheme, the content of moisture in winter wheat-root-layer-soil decreased slightly faster at a larger fertilizing amount, indicating that a larger fertilizing amount favors the absorption of moisture in soil by winter wheat at the same irrigation quota. Although the fertilizing amount had an impact on the content of moisture in soil, the content of moisture in soil was dominated by the irrigation quota.

3.2 Variation of the content of moisture in soil during the entire growth period

The variation of content of moisture in soil was measure at intervals of a cycle of irrigation during the entire growth period of winter wheat. In each irrigation scheme, only the variation of content of moisture in soil layer at the depth of 0–80cm was focused because this layer has a significant effect on the growth of winter wheat. Dates of irrigation and measurement during each growth period of winter wheat are listed in Table 2. The variations of contents of moisture in soil in different schemes are illustrated in Figure 2.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before irrigation
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Volumetric Moisture Content (%)
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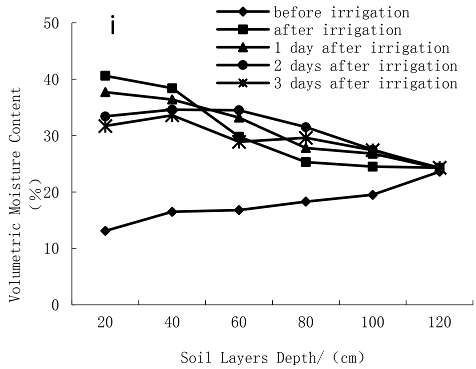
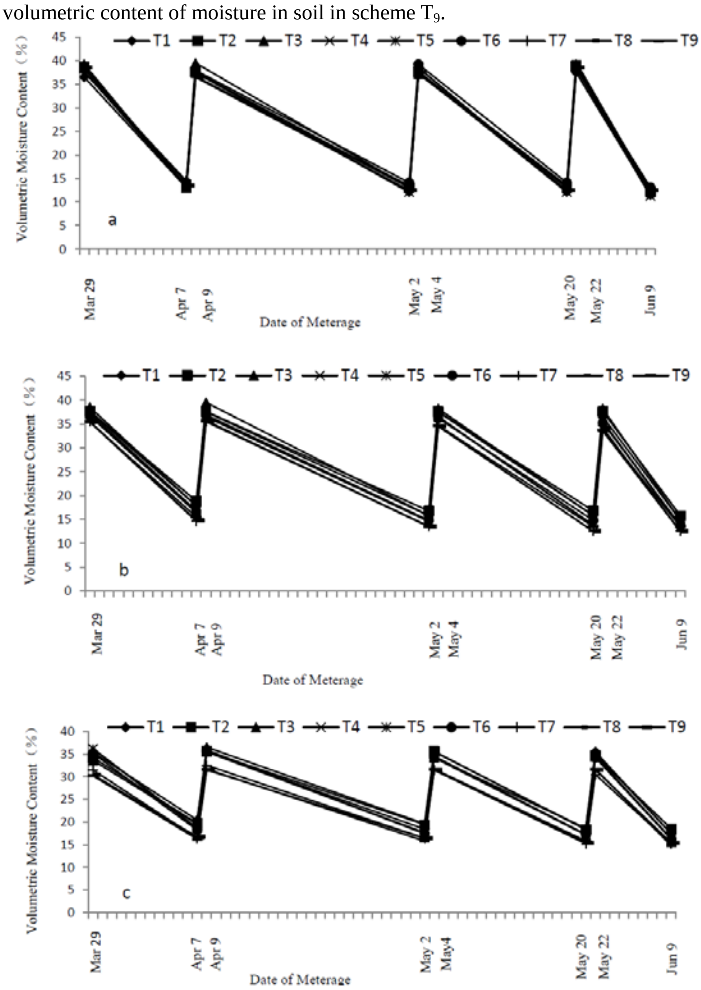


Fig. 1. Profiles of contents of moisture in different soil layers after irrigation.

Notes: a. variation of the volumetric content of moisture in soil in scheme T_1;b.variation of the volumetric content of moisture in soil in scheme T_2;c.variation of the volumetric content of moisture in soil in scheme T_3;d.variation of the volumetric content of moisture in soil in scheme T_4;e. variation of the volumetric content of moisture in soil in scheme T_5;f.variation of the volumetric content of moisture in soil in scheme T_6;g.variation of the volumetric content of moisture in soil in scheme T_7;h.variation of the volumetric content of moisture in soil in scheme T_8;i. variation of the volumetric content of moisture in soil in scheme T_9.



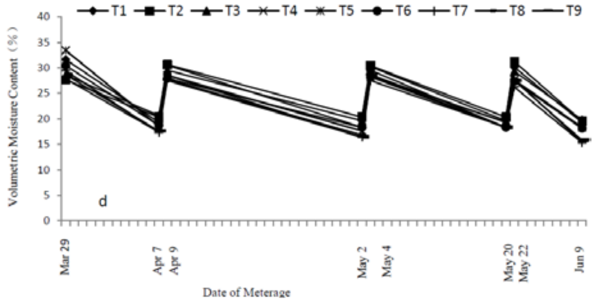


Fig. 2. Variations of contents of moisture in soil layers at the depth of (a) 0–20 cm, (b) 20–40 cm, (c) 40–60 cm, and(d) 60–80 cm in different schemes with different water–fertilizer coupling effects.

Table 2. Dates of irrigation and measurement during each growth period of winter wheat(day/month).

Vegetation period	Green-up stage	Jointing stage	Heading stage	Milk stage
Date of irrigation	28/03	08/04	03/05	21/05
Date of determination	29/03	09/04	04/05	22/05

Thus, the moisture content in soil significantly varied at different irrigation quota or indifferent growth period of winter wheat. The moisture content increases with an increasing value of irrigation quota, which is also affected by fertilizing amount and water–fertilizer coupling effect. Under conditions of the same irrigation quota the moisture content in soil with a high fertilizing amount was significantly lower than that in other schemes. However, the impact of fertilization on moisture contents in soil was negligible compared with the impact of irrigation quota. After the heading period, the moisture contents in soil changed significantly, indicating that winter wheat required more water during heading period, flowering period, and milk period.

3.3 Variation of contents of nitrate nitrogen in soil

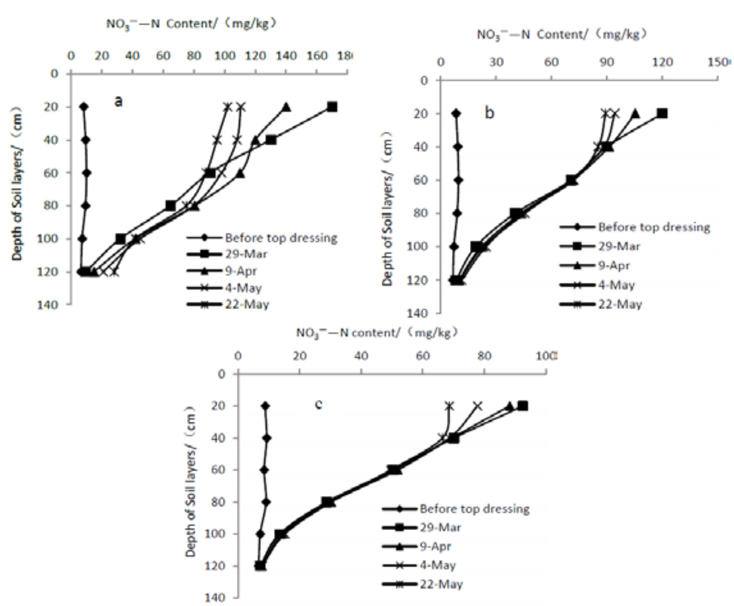


Fig. 3. Variations of contents of nitrate nitrogen in soil under the condition of medium irrigation quota in schemes (a) T4, (b)T5, and (c) T6.

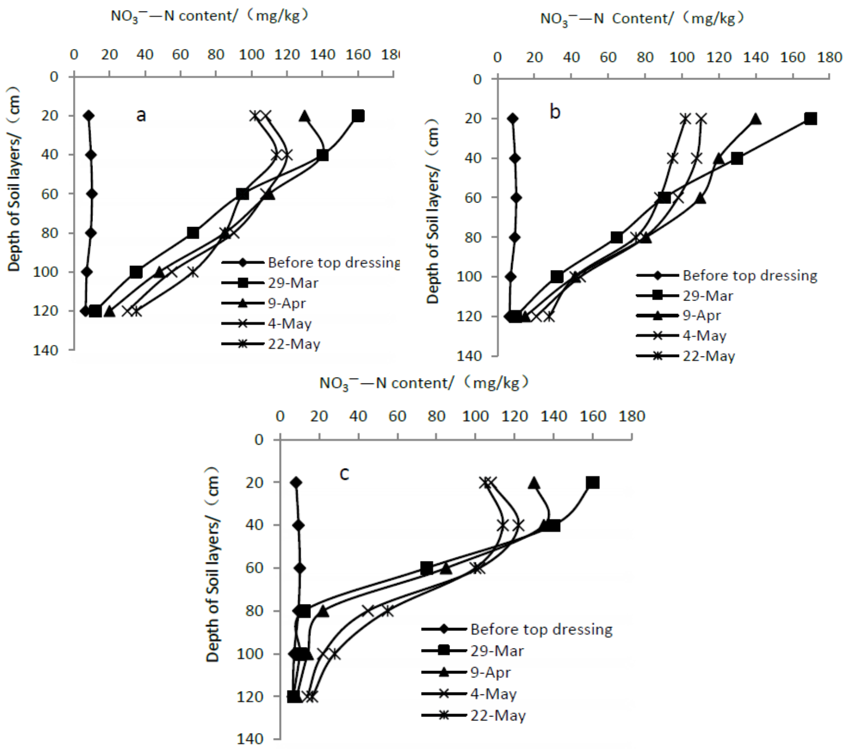


Fig. 4. Variations of contents of nitrate nitrogen in soil with a high fertilizing amount in schemes (a) T_1, (b) T_4, and (c) T_7.

For instance, under the condition of the same medium irrigation quota (T_4, T_5, andT_6 in Figure 3), contents of nitrate nitrogen in soil layers with depths of 0–80cmsignificantly varied while the variations were reduced with an increasing depth in soil. A most dramatic variation of contents of nitrate nitrogen took place in scheme T_4 with a high fertilizing amount. In soil layers with depths of 80–120cm, contents of nitrate nitrogen were markedly increased after irrigation and were increased with the increase of fertilizing amount. On the other hand, with the same fertilizing amount(T_1, T_4, and T_7 in Figure 4),contents of nitrate nitrogen in soil layers with depths of 0–80cm also significantly varied. Compared with those before irrigation, the contents of nitrate nitrogen were increased to a small extent in layers with depths of 80–120cm under conditions of high irrigation quota and large fertilizing amount (T_1).In contrast, the contents of nitrate nitrogen were slightly increased under conditions of medium irrigation quota and large fertilizing amount (T_4). And, the contents of nitrate nitrogen were hardly increased under conditions of low irrigation quota and large fertilizing amount (T_7). These results suggest that the downward immigration velocity of nitrate nitrogen increases with the increase of irrigation quota, and the possibility of leach is higher under conditions of high irrigation quota and large fertilizing amount than those under conditions of medium/low irrigation quota and large fertilizing amount.

Generally speaking, under conditions of the same irrigation quota and same irrigation cycles, contents of nitrate nitrogen in soil were increased with an increasing amount of fertilizer, especially at low irrigation quota (T_7, T_8, and T_9). Moreover, under conditions of the same amount of fertilizer, the content of nitrate nitrogen in each soil layer decreases with the increase of irrigation quota, especially under conditions of a large fertilizing amount (T_1, T_4, and T_7), indicating that a high irrigation quota run the risk of the leach of nitrate nitrogen in soil.

4 Results and analysis of water–fertilizer coupling effect on the growth traits of winter wheat

4.1 The influence on growth period of winter wheat

By monitoring the entire growth period of winter wheat, we observed that, under conditions of a high irrigation quota (T_1, T_2, and T_3), the growth period at a large fertilizing amount (T_1) was longer than those at a medium fertilizing amount (T_2) and at a small fertilizing amount (T_3) by 2 and 4 days respectively. On the other hand, under conditions of a large fertilizing amount (T_1, T_4, and T_7), the growth period at a high irrigation quota (T_1) was longer than those at a medium irrigation quota (T_4) and at a small irrigation quota (T_7) by 3 and 5 days respectively. It is concluded that the increase of fertilizing amount prolonged the growth period of winter wheat to a certain extent under the condition of the same irrigation quota. Accordingly, the increase of irrigation quota also prolonged the growth period of winter wheat under the condition of the same fertilizing amount. Hence, irrigation quota, irrigation scheme, fertilizing amount, and the water–fertilizer coupling effect a comprehensive effect on growth period of winter wheat.

4.2 The influence on plant height of winter wheat

The monitoring results of the height of winter wheat under the condition of a high irrigation quota (T_1, T_2, and T_3) show that the height of winter wheat is the maximum at a large fertilizing amount (T_1). Furthermore, the height reached a minimum at a low fertilizing amount. On the other hand, under the condition of a large fertilizing amount (T_1, T_4, and T_7), the height reached a maximum at a high irrigation quota (T_1) and a minimum at a low irrigation quota (T_7). Thus, under the condition of the same irrigation quota, the fertilizing amount can increase the height of winter wheat to a certain extent. Moreover, the height of winter wheat will be increased by a higher irrigation quota under the condition of the same fertilizing amount. To summarize, the height of winter wheat was dependent on irrigation quota, irrigation scheme, fertilizing amount, and the water–fertilizer coupling effect.

4.3 The influence on growth traits of winter wheat

Table 3. The plant height(ph), ear number(en), ear length(el), average number of grains per ear(angpe), kernel weight(kw) and yield of winter wheat in the different schemes.

Scheme	ph/(cm)	en/(ears/m^2)	el/(cm)	angpe/(grains)	kw/(g)	yield/(kg/hm^2)
T_1	67.5	565.6	6.1	31.3	49.8	8820
T_5	64.3	584.8	6.2	31.5	50.5	9307.5
T_9	62.8	551.3	5.9	29.8	47.7	7840

The growth traits of winter wheat in schemes T_1, T_5, and T_9were monitored. It is demonstrated that the height of winter wheat reached a maximum at a high irrigation quota and a large fertilizing amount (T_1), and reached a minimum at a low irrigation quota and a small fertilizing amount (T_9). The largest ear number, the highest value of thousand kernel weight, and the highest yield were observed at a medium irrigation quota and medium fertilizing amount (T_5). On the contrary, the smallest ear number, the lowest value of thousand kernel weight, and the lowest yield occurred at a low irrigation quota and low fertilizing amount (T_9). In detail, the ear number in scheme T_5was3.4% and 6.1%higher than that in schemesT_1andT_9 respectively. The length of ear in scheme $T_5$was higher than that in schemes $T_1$and$T_9$by 1.6% and 5.1% respectively. The value of thousand kernel weigh tin scheme $T_5$was 1.4% and 5.9% higher than that in schemes T_1andT_9 respectively. The yield in scheme T_5was5.5% and 18.7% higher than that in schemes T_1andT_9 respectively. In conclusion, a medium irrigation quota and a medium fertilizing amount (T_5) were favorable to the production of winter wheat. Therefore, an appropriate irrigation scheme, medium irrigation quota, medium fertilizing amount, and water–fertilizer coupling effect facilitate the production of winter wheat.

5 Conclusions

Effects of different water–fertilizer coupling effects in nine schemes on the variations of water and nitrogen in soil and growth traits of winter wheat were presented. The content of moisture in soil varied significantly during different growth periods or at different irrigation quota. Although the content of moisture in soil is dependent on irrigation quota, the content is also affected by fertilizing amount and water–fertilizer coupling effect to a much smaller extent. Generally speaking, a higher irrigation quota results in a higher content of moisture. Under the condition of the same irrigation quota, the content of moisture in soil decreases with an increasing fertilizing amount.

Under the condition of the same irrigation quota and same irrigation cycles, the content of nitrate nitrogen in soil increases with the increase of fertilizing amount, especially at a lower irrigation quota. Under the condition of the same fertilizing amount, the content of nitrate nitrogen in soil layers decreases with the increase of irrigation quota, especially at a higher irrigation quota. A high value of irrigation quota may result in the leaching of nitrate nitrogen.

Under the condition of light and small sprinklers, the water–fertilizer coupling effect affects the growth traits of winter wheat on different levels. At the same irrigation quota, an increased fertilizing amount prolongs the growth period of winter wheat to a certain extent and facilitates the growth of winter wheat. Moreover, at the same amount of fertilizing amount, an increase of irrigation quota also prolongs the growth period and also favors the growth. An optimization of irrigation scheme, irrigation quota, fertilizing amount, and water–fertilizer coupling effect will promote the production of winter wheat.

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