Effects of water-nitrogen coupling on growth and yield of densely planted maize in the Hexi Oasis irrigation area

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Abstract. In order to explore the influence of different water-nitrogen coupling models on the growth and development, yield formation and water-nitrogen utilization efficiency of densely planted maize, a total of 10 treatments were set up by setting up three irrigation levels and three nitrogen application gradients , and a contrast treatment CK, to study the influence of different water-nitrogen coupling models on the growth condition of densely planted maize, yield, and to provide theoretical basis for the establishment of a densely planted maize water-fertilizer integration and efficient irrigation nitrogen application scheme and the rational utilization of water-nitrogen resources. It will provide theoretical basis for the establishment of efficient irrigation and nitrogen application program and rational utilization of water and nitrogen resources in closely planted maize.

Keywords: Maize; water-nitrogen coupling; soil environment; growth characteristics; yield; Hexi Oasis irrigation area.

1. Introduction

The Hexi Corridor is located on a plateau with an arid climate, and the traditional agricultural irrigation methods are facing many challenges, especially the shortage of water resources restricts the further development of agriculture [1]. In this context, how to efficiently utilize limited water resources to ensure the healthy growth of crops has become a major problem in front of farmers and agricultural researchers [2]. Drip irrigation technology is an efficient way to utilize water resources by dripping water directly into crop roots through a piping system, which is able to precisely regulate the amount of water required by each crop [3]. Drip irrigation systems offer significant advantages over traditional diffuse or sprinkler irrigation methods [4]. First, drip irrigation reduces evaporation and deep seepage of water, ensuring that water is delivered precisely to the root system, greatly improving the efficiency of water utilization [5]. Due to the precise delivery of water to the roots, the crop root system is able to grow in a suitable humidity environment, avoiding the phenomenon of uneven crop growth caused by uneven water [6]. Moreover, due to the more uniform water penetration, the nutrient absorption of the crop is more balanced, the overall growth momentum is healthier, and the quality of the crop has been significantly improved [7]. In addition to water control, drip irrigation technology also offers advantages such as energy savings and increased crop yields [8]. By reasonably adjusting the drip irrigation flow rate, the amount of water can be adjusted according to the needs of different crops, which reduces energy consumption and the waste of water resources [9]. In addition, drip irrigation technology can greatly improve the productivity of crops, especially for those crops that are more sensitive to water demand, the application of drip irrigation technology can significantly improve the yield and quality [10-11]. In the Hexi Corridor region, the application of drip irrigation technology not only improves the water conservancy conditions of local agriculture, but also promotes the process of agricultural modernization [12]. In particular, the cultivation of grain crops such as maize can obtain more stable yield and high quality agricultural products with the support of drip irrigation technology [13]. In order to investigate the effects of different water-nitrogen coupling models on the growth and development of densely planted maize, yield formation and water and nitrogen utilization efficiency, we set up three irrigation levels (W1 low-water irrigation, W2 medium-water irrigation, and W3 high-water irrigation) and three nitrogen application gradients (N1 low-nitrogen, N2 medium-nitrogen, and N3 high-nitrogen), and set up a contrast treatment, CK, with a total of 10 treatments, to study the effects of different water-nitrogen coupling models on the growth, yield, and development of closely planted maize, as well as to investigate the effects of different water-nitrogen coupling models on the growth, yield, and development of closely planted maize. A total of 10 treatments were set up to study the effects of different water and nitrogen coupling models on the growth and yield of densely planted maize, and to provide a theoretical basis for the establishment of a water-fertilizer-integrated high-efficiency irrigation and nitrogen application scheme for densely planted maize and the rational use of water and nitrogen resources

2. Test materials and method

2.1 Test Materials

Fertilizer for test: Salt-free N-P-K liquid fertilizer provided by Gansu Advance Biotechnology Development Co. The ratio of N-P-K in the first liquid fertilizer was 160-40-40 g/L, the ratio of N-P-K in the middle liquid fertilizer was 120-80-40 g/L, and the ratio of N-P-K in the late liquid fertilizer was 120-40-80 g/L.

2.2 Test Varieties

The silage maize variety for testing was Zhengde 3001.

2.3 Overview of the Test Site

The experimental area is located in Jing'an Township, Zhangye City, at longitude 100°26′56″E, latitude 38°51′15″N. It has a temperate arid climate, with a multi-year average temperature of 7°C, an annual average of 190 d in the growing period, an annual average of 147 d in the frost-free period, and an average of 3,085 h of sunshine, and an average of 130 mm of precipitation per year.The soil type of the experimental site is a scrub-desert soil, and the soil basal nutrients are 8.47 pH, The soil base nutrients were pH 8.47, organic matter 13.1 g/kg, total nitrogen 0.75 g/kg, alkaline dissolved nitrogen 120.7 mg/kg, effective phosphorus 30.2 mg/kg, quick-acting potassium 516 mg/kg, and total water-soluble salts of soil 3.3 g/kg.

2.4 Experimental Design

The experiment was set up with 10 treatments (Table 1), three replications for each treatment and a total of 30 plots in a randomized block design. The plots were 600 m2 (50 m long × 12 m wide), separated by ridges with a base width of 25 cm and a height of 20 cm, and surrounded by a protection zone with a width of 1 m. Semi-film-covered, flat-crop, wide and narrow rows were planted at a planting density of 7,500 plants/mu with a row spacing of 60 cm for the wide rows (between the films) and 40 cm for the narrow rows (on the films), and with a plant spacing of 18 cm. Sowed on April 26, 2024, mu of pure P_2O_5 15kg, k_2O 6kg, of which all organic fertilizer, phosphate, potash and 30% nitrogen fertilizer combined with pre-sowing ground preparation focused on deep application of fertilizer, the remaining 70% of the nitrogen fertilizer in the nodulation period, the large trumpet period as a follow-up fertilizer were applied. Other management with the field.

Table 1. Experimental program

Deal with	Process name	Nitrogen application (kg/hm^2)	Field water holding capacity (%)
W1N1	low water and low nitrogen	225	65~70
W2N1	medium water and low nitrogen	225	70~75

W3N1	high water and low nitrogen	225	75~80
W1N2	low water and medium nitrogen	300	65~70
W2N2	medium water and medium nitrogen	300	70~75
W3N2	high water and medium nitrogen	300	75~80
W1N3	low water and high nitrogen	375	65~70
W2N3	medium water and high nitrogen	375	70~75
W3N3	high water and high nitrogen	375	75~80
CK	contrast	0	65~70

2.5 Measurement Items and Methods

2.5.1 Indicators of agronomic traits

After maize harvest, five disease-free maize plants with small differences in growth were randomly selected in each experimental plot and brought back to the laboratory for measurement after sampling. The roots of the plants were removed, and the plant height was determined with a tape measure with a range of 300 cm, measuring the maximum distance from the bottom of the stem to the growing point of the maize, recording five sets of data, and calculating the average value as the average plant height of the maize in the test plot. The 0.01mm vernier calipers were used to determine the stem diameter of the plant, and the stem diameter of the upper, middle and lower three heights of the stalks of the plant was selected for the determination part, and the average value was calculated as the stem diameter of the maize in the test plot.

2.5.2 Yield

When the maize was ripe and harvested individually by plot, dried, threshed and counted, the actual yield of each treatment was obtained as the average of the yields of the three replicated plots. In each plot, 20 plants were randomly taken for indoor seed testing to determine the indicators of ear diameter, ear length, ineffective ear length, the number of rows of ears and the number of grains in a row. Spike length was measured by a scale with an accuracy of 0.1cm; spike thickness and bald tip were measured by 0.01mm vernier calipers, of which spike diameter was measured at the upper, middle and lower three positions of the spike, and the average value was calculated as spike diameter; the number of spike rows and the number of spike rows were determined by counting method.

2.6 Data Organization and Analysis

Data processing and statistics were performed using Excel 2007 software, and one-way analysis of variance (ANOVA) was performed using SPSS 19.0, the results were expressed as "mean±standard deviation", and the significance of difference was determined by $P<0.05$.

3. Results and Analysis

3.1 Growth analysis of densely planted maize under different water-nitrogen coupling models

The changes of growth indexes of densely planted maize under different water-nitrogen coupling models are shown in Table 2. Plant height of all treatments showed different degrees of growth compared with CK, among which W3N3 treatment had the highest plant height, which was significantly increased by 22.25% ($P<0.05$) compared with the CK, and W1N1 treatment had the smallest plant height, which was at the same level with the CK ($P>0.05$); at the same level of irrigation, the plant height increased with the increase of nitrogen application, and the highest mean plant height was found at the level of W3, which was 19.01% significantly higher than CK. At the same level of nitrogen application, the highest plant height was recorded at N3 level, which was 22.26% higher than that of CK; the thinnest maize stalk was recorded in W1N1 treatment, which was 10.29% lower than that of CK, and the coarsest stalk was recorded in W3N3 treatment, which was 7.13% higher than that of CK; at the same level of nitrogen application, the thickness of the stalk was reduced by 4.02% in N1 level, while it increased by 1.61% in N2 and 6.29% in N3; the thickness of the stalk was reduced by 4.02% in N1 level, and increased by 1.61% in N2 and 6.29% in N3; and the thickness of the stalk was increased by 1.61% in N2 and 6.29% in N3; the height of maize plants increased with increasing N application. At the same irrigation level, stem thickness decreased with the decrease of irrigation, which was significantly decreased by 4.40% at the W1 level compared to CK, and significantly increased by 4.40% at the W3 level compared to CK. Leaf area index was higher than CK in all treatments except W1N1 and W1N2 treatments, with W3N3 treatment having the highest leaf area index, which was significantly increased by 20.54% over CK. In summary, adequate water and nitrogen fertilizer supply can significantly promote the growth and development of maize and increase its biomass and photosynthetic efficiency.

Table 2. Growth of densely planted maize under different water-nitrogen coupling models

Deal with	Plant height (cm)	Stem thickness (mm)	leaf area index (TAI)
W1N1	266.3de	19.36f	5.35e
W2N1	279.1cd	21.09e	6.01d
W3N1	302.4b	21.69d	6.23bc
W1N2	286.7c	20.84e	5.88d
W2N2	309.6ab	22.16c	6.19c
W3N2	311.5a	22.78ab	6.45b
W1N3	300.9b	22.61bc	6.27bc
W2N3	316.8a	23.08a	6.84b
W3N3	319.7a	23.12a	7.16a
CK	261.5e	21.58d	5.94d

3.2 Analysis of economic traits of ears of densely planted maize under different water-nitrogen coupling models

Changes in economic traits of densely planted maize ears under different water-nitrogen coupling models are shown in Table 3. Compared with the CK, the ear length and ear girth of W3N3 treatment increased significantly by 14.15% and 7.72% respectively compared with CK, followed by W2N3 treatment, and W1N1 treatment was the lowest, which was significantly reduced by 9.87% and 5.46% compared with CK. the bald tips of ears in W2N1 and W2N2 treatments were significantly lower than the rest of the treatments; the number of rows of ears in W1N1 and W1N2 treatments was 14.5, which was significantly lower than that of the remaining treatments; the number of grains and row grain weight of ears was significantly reduced by 5.23% compared with the CK. W1N1 and W1N2 treatments were 14.5 rows, significantly lower than the rest of the treatments, a significant reduction of 5.23% compared with the CK; the number of spikes and row grain weight is one of the main constituting factors of yield, the test showed that the effect of flooding and nitrogen application had a significant impact, W2N3 and W3N3 treatments spikes of grain number of 730.1 grains, 747.3 grains, respectively, compared with the CK treatments increased significantly by 10.45%, 13.06%. The number of grains in rows of each treatment ranged from 41.5 to 47.3 grains, with W3N3 treatment having the highest number of grains up to 47.3 grains, followed by W2N3 with 46.8 grains, which were significantly increased by 9.49% and 8.33%, respectively, compared with CK. Under the same irrigation level, the magnitude of each index was in the following order: W3>W2>W1; under the same nitrogen application level, the magnitude of each index was in the following order: N3>N2>N1. The results showed that adequate water and nitrogen fertilizer supply could significantly promote maize ears development and increase yield potential.

Table 3. Economic traits of ears of densely planted maize under different water-nitrogen coupling models

Deal with	Ear length (cm)	Ear girth (cm)	Blunt (cm)	Number of spike rows (rows)	Number of grains in row (grains)	Number of grains in spike (grains)
W1N1	21.06f	5.02f	1.10c	14.5d	41.5g	601.8f
W2N1	21.58e	5.39d	0.85f	14.7cd	42.7f	627.7e
W3N1	22.43cd	5.45cd	1.16b	15.1bc	43.9d	662.9cd
W1N2	22.05d	5.36de	1.03de	14.5d	43.6de	632.2e
W2N2	22.76c	5.51bc	0.75g	15.3b	44.1cd	674.7c
W3N2	23.16b	5.59b	0.98e	15.5ab	45.8bc	709.9b
W1N3	22.87c	5.48c	1.13bc	14.8c	44.5c	658.6d
W2N3	24.03a	5.65ab	1.09cd	15.6a	46.8ab	730.1ab
W3N3	24.28a	5.72a	1.23a	15.8a	47.3a	747.3a
CK	21.27ef	5.31e	0.92e	15.3b	43.2e	661.0cd

3.3 Yield analysis of densely planted maize under different water-nitrogen coupling models

Changes in yield of densely planted maize under different water-nitrogen coupling models are shown in Table 4. Under the same irrigation level, the acreage yield of W1N2 was significantly increased by 21.48% compared with that of W1N1, and W1N3 was decreased by 6.00% compared with that of W1N2, which indicated that under low-water irrigation conditions, excessive nitrogen application would instead lead to a decrease in yield.Under the W2 level, the yield showed that W2N3>W2N2>W2N1, and under the W3 level, the yield of W3N2 was significantly increased compared with that of W3N1 by 24.64%, but the yield of W3N3 decreased by 2.97% compared with W3N2. At the same level of nitrogen application, the change in yield was shown as high water > medium water > low water. It can be seen that the highest yield of 20103.90 kg/mu was W3N2 treatment, followed by W3N3 and W2N3 treatments.

Table 4. Yield of densely planted maize under different water-nitrogen coupling models

Deal with	Plot yield (kg/plot)				Unit yield (kg/hm^2)
	I	П	Ш	on average	
W1N1	743.85	716.77	724.67	728.43	12146.55g
W2N1	780.27	760.28	760.27	766.94	12788.70f
W3N1	976.07	944.83	981.03	967.31	16129.95d
W1N2	885.23	864.67	904.68	884.86	14755.05e
W2N2	1052.45	1005.50	1024.10	1027.35	17131.05cd
W3N2	1207.27	1190.65	1218.97	1205.63	20103.90a
W1N3	853.33	812.07	830.00	831.80	13870.20e
W2N3	1095.05	1051.66	1102.02	1082.91	18057.60bc
W3N3	1200.44	1167.89	1141.25	1169.86	19507.35ab
CK	800.39	769.72	764.55	778.22	12976.80f

4. Conclusion

Water and nitrogen are important factors affecting maize growth and development, nutrient uptake, and grain yield. It was analyzed that maize ear length, ear diameter, row grain number and ear grain number behaved differently under different water-nitrogen couplings, and that both irrigation and nitrogen application could increase maize yield, and that applying a certain amount of nitrogen fertilizer could reduce the harmful effects of water on maize stress, and on the contrary, over-application of nitrogen would have a reverse effect on maize yield increase. Comprehensive comparison of maize yield and ear traits under different water-nitrogen coupling, W3N2 treatment (high water and medium nitrogen) is the best, i.e., the application of nitrogen is 300 kg/hm2, and the irrigation amount reaches 75%~80% of the water holding capacity of the field can be used as the irrigation and nitrogen application program for dense maize planted by under-membrane drip irrigation.

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