Effects of water and nitrogen regulation on water consumption characteristics and yield of eggplant in a cold and arid oasis region of Northwest China

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Abstract. This study conducted a one-year field experiment to investigate the impacts of different water and nitrogen application strategies on the water consumption characteristics, yield, and WUE of eggplants in the cold and arid regions of Northwest China. The experiment included three irrigation levels (50-60%, 60-70%, and 70-80% of field capacity) and three nitrogen application levels (215 kg/ha, 270 kg/ha, and 325 kg/ha).The results demonstrated that both irrigation and nitrogen application significantly influenced the water consumption characteristics, WUE, and yield of eggplants. Increasing irrigation levels led to a significant rise in water consumption, particularly under high nitrogen conditions. Mild water deficit significantly enhanced WUE and yield while reducing resource input. Moderate nitrogen application promoted yield increases, whereas excessive nitrogen had no significant positive effect on yield and could even have negative consequences. These findings provide a theoretical foundation for optimizing water and nitrogen management in eggplant cultivation in arid regions of Northwest China, especially in improving yield and resource use efficiency.

Keywords: Water and nitrogen management; Eggplant ; Water use efficiency ; Yield.

1. Introduction

Eggplant (Solanum melongena L.) is a crop that belongs to the Solanaceae family and the Solanum genus. It is recognized as an important economic vegetable crop on a global scale[1]. China stands out as the leading country in both the production and consumption of eggplant[2]. As one of the primary vegetable crops in China, eggplant is abundant in various nutrients, including proteins, vitamins, and alkaloids found within its flesh[3]. Additionally, its skin contains high levels of anthocyanins, flavonoids, and other beneficial compounds that possess significant edible and medicinal properties[4]. With the enhancement of economic conditions, there is a growing concern among individuals regarding the nutritional value and quality of vegetables[5]. The quality of eggplants is influenced not only by genetic factors but also significantly affected by environmental conditions[6]. Water and nitrogen are critical elements that impact crop biomass accumulation, as well as being closely associated with both crop yield and quality[7]. Consequently, the establishment of effective water and nitrogen management strategies is essential for enhancing local eggplant yield and fruit quality, while simultaneously improving crop water use efficiency and nitrogen utilization rates.

The traditional management approach posits that high levels of irrigation and nitrogen application can enhance crop yields. However, in water-scarce arid regions, increasing irrigation does not necessarily result in a significant yield increase, leading to potential water wastage. While deficit irrigation can be advantageous for yield formation to some extent, severe water shortages will ultimately lead to reduced yields[6]. Therefore, it is essential to establish a moderate balance regarding the quantity of water used. By measuring soil water consumption features, yield, and water use efficiency under various water and nitrogen treatments, this research aimed to explore the influence of these management practices on the aforementioned parameters in eggplant cultivation. The findings are anticipated to provide a scientific theoretical framework as well as practical guidance for developing effective water and nitrogen management strategies that promote high-yield and high-quality eggplant production in the arid regions of Northwest China.

2. Materials and methods

2.1 Overview of the experimental site

The field experiment was conducted from May to September 2024 at the Yimin Irrigation Experiment Station, located within the Hongshui River Management Office in Minle County, Zhangye City, Gansu Province (100° 47′ E, 38° 35′ N). The station is situated at an altitude of 1970 meters. The annual average temperature is recorded at 7.6℃, with a maximum temperature reaching up to 33.6℃. During the entire growth period of the experiment, total rainfall amounts to approximately 131.9 mm, and the average frost-free period throughout the year is about 150 days. The soil composition in this experimental region consists primarily of light loam, with groundwater levels exceeding depths of 20 meters and no indications of salinization affecting the area.

2.2 Experimental design

The experiment selected the locally suitable eggplant variety "Lanzha No. 2," known for its resistance to diseases and pests, as the test variety. During the flowering and fruit setting stage of eggplant, irrigation amounts were established at three levels: 50% - 60% of field capacity (moderate water deficit), 60% - 70% of field capacity (mild water deficit), and 70% - 80% of field capacity (adequate irrigation). For all other growth stages, irrigation was maintained at a level between 70% - 80% of field capacity. Nitrogen fertilizer application rates were classified into three categories: low nitrogen (270 kg/ha), medium nitrogen (325 kg/ha), and high nitrogen (215 kg/ha). A control treatment (CK) was designated as full irrigation throughout the entire growth period without any nitrogen application. The experiment comprised a total of ten treatments, including one CK control treatment. Each treatment was replicated three times, resulting in a total of thirty experimental plots.

2.3 Measurements and calculations

2.3.1 Soil moisture

In each experimental plot, the midpoint between two randomly selected adjacent eggplant plants was used as the sampling point. Soil samples were collected at 20 cm intervals down to a depth of 100 cm, resulting in five samples. Prior to placing the soil samples into aluminum boxes, the weight of each empty aluminum box was recorded. The fresh weight of the soil samples was then measured. Subsequently, the aluminum boxes containing the soil samples were placed in an oven for drying, and the dry weight was determined after drying. Finally, the moisture content of each sample was calculated based on the difference between the fresh and dry weights[4].

2.3.2 Water consumption and Water use efficiency

Crop water consumption can be calculated using the following formula[13]:

$$ET = P + I + U - D - R - \Delta W$$

where ET, P, I, U, D, R, and ΔW represent water use (mm), precipitation (mm), irrigation water (mm), groundwater recharge (mm), drainage water (mm), surface runoff (mm), and change in soil water storage (cm3 cm-3) between the beginning and end of the measurement cycle, respectively. In this experiment, the groundwater table was below 20 meters and drip irrigation was used, so U = 0 and R = 0.

The following formula is used to determine the water use efficiency (WUE) of crops[12]:

$$WUE = \frac{Y}{ET}$$

where Y represents the yield of eggplant per unit area (kg • ha-1), and ET represents water consumption (mm).

2.3.3 Yield

After the eggplants enter the fruit development stage, fruits are harvested sequentially from each experimental plot, and the yield of each plot is recorded. Once the final harvest is completed, the total yield for each experimental treatment is calculated.

2.3.4 Statistical analysis

The data from each group were analyzed and calculated using Excel 2021. To evaluate the significance of differences in relevant data among various treatments, the Duncan multiple comparison test was conducted using SPSS software. Origin 2022 was utilized for graphical representation.

3. Results

3.1 Water consumption

The average water consumption of eggplants under different water and nitrogen regulation treatments is illustrated in Figure 1. The single-factor effect of irrigation significantly influenced water consumption ($P < 0.05$), while the single-factor effect of nitrogen application had an extremely significant impact on water use efficiency ($P < 0.01$). There were no significant differences in water consumption among W3N1, W3N2, and W3N3 ($P > 0.05$), with their average water consumption increasing by 9.43% compared to the control (CK). Under the same nitrogen application level, water consumption increased as irrigation volume increased. Specifically, the water consumption of W3N2 was 22.35% and 31.09% higher than that of W2N2 and W1N2, respectively ($P < 0.05$). Similarly, the water consumption of W3N3 was 11.19% and 27.63% higher than that of W2N3 and W1N3, respectively ($P < 0.05$).

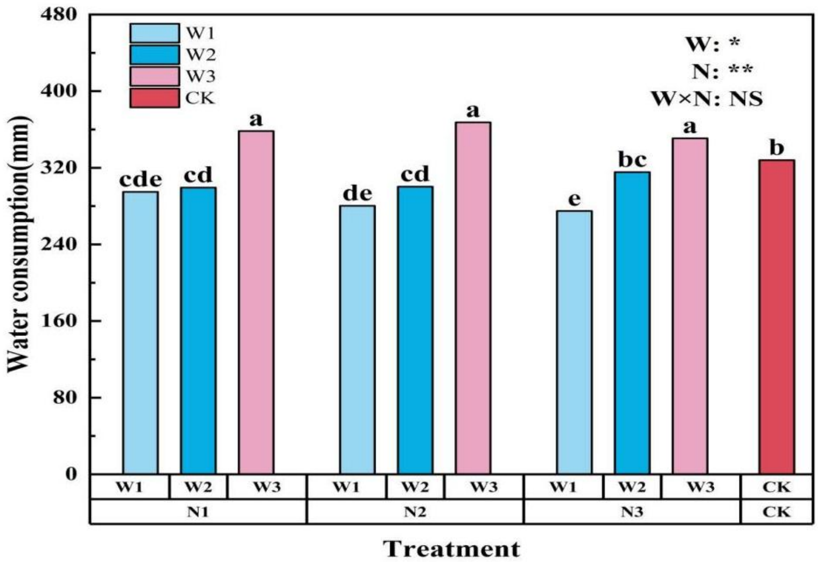

Fig. 1 Effects of water and nitrogen regulation on crop water consumption

3.2 Yield

During the one-year experiment (Figure 2), irrigation, nitrogen application, and the interaction between water and nitrogen all had extremely significant effects on yield ($P < 0.01$). Under the same nitrogen application level, yield increased with increasing irrigation levels. Specifically, W2N2 and W2N3 achieved the highest yields, with no significant difference between them ($P > 0.05$). Compared to W1N2, their average yield increased significantly by 20.13%, and compared to the control (CK), it increased by 36.47%. Under the same irrigation level, yield initially increased and then decreased as nitrogen application increased. Notably, the yield of W3N2 was significantly higher than that of W3N1 and W3N3, increasing by 17.49% and 6.69%, respectively ($P < 0.05$).

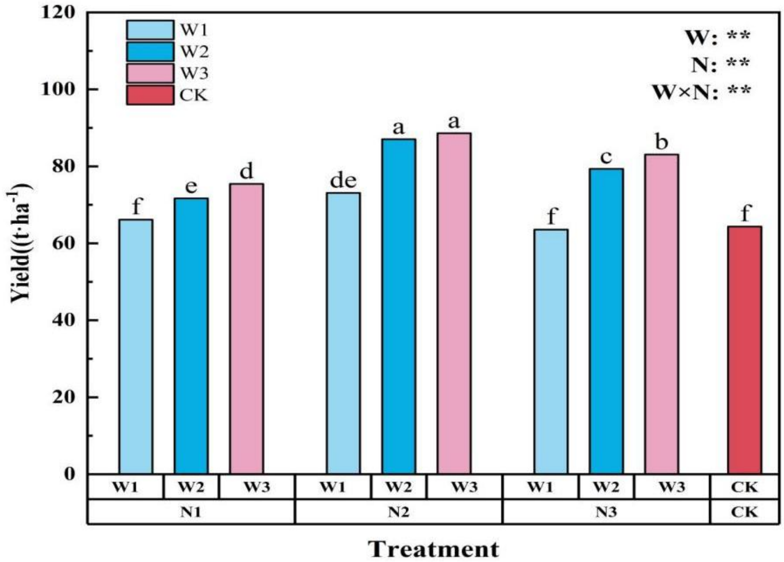

Fig. 2 Effects of water and nitrogen regulation on crop yield

3.3 WUE

The water use efficiency (WUE) of eggplants under different water and nitrogen treatments is illustrated in Figure 3. The single-factor effects of irrigation and nitrogen application had extremely significant impacts on WUE ($P < 0.01$), while the interaction effect between water and nitrogen had a significant impact on WUE ($P < 0.05$). Under the same nitrogen application level, WUE initially increased and then decreased with increasing irrigation amounts. Specifically, W2N2 exhibited the highest WUE, which was significantly higher by 11.11% and 20.33% compared to W1N2 and W3N2, respectively, and by 47.96% compared to the control (CK) ($P < 0.05$). Under the same irrigation level, WUE also followed an initial increase followed by a decrease as nitrogen application increased. Notably, the WUE of W2N2 was significantly higher by 20.83% and 15.08% compared to W2N1 and W2N3, respectively.

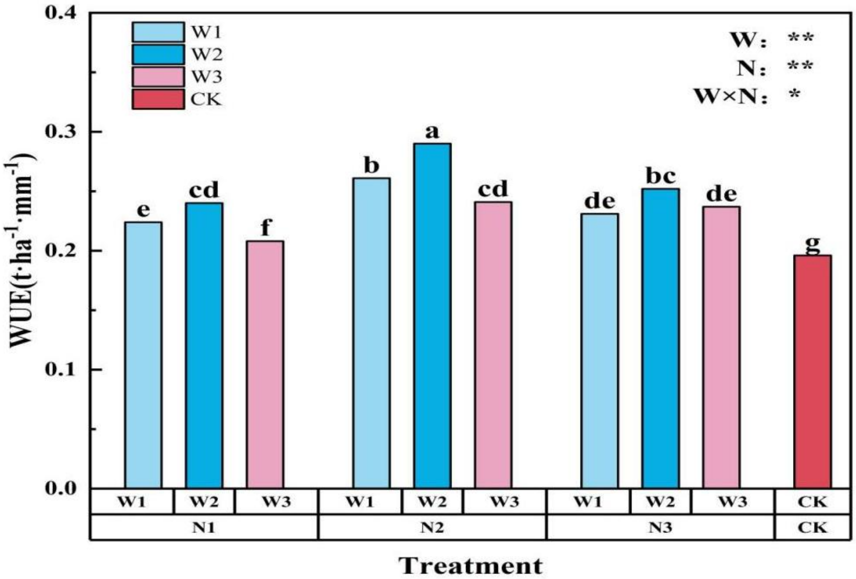

Fig. 3 Effects of water and nitrogen regulation on WUE

4. Discussion

4.1 Effects of water and nitrogen regulation on crop water consumption characteristics and WUE

Reasonable water and nitrogen management measures not only promoted crop growth but also significantly influenced crop water consumption and water use efficiency (WUE). This study demonstrated that as irrigation levels increased, the water consumption of eggplants exhibited an upward trend. Particularly at high nitrogen levels, increased irrigation led to a significant rise in water consumption. This phenomenon might be attributed to sufficient water promoting plant growth, especially the expansion of leaf area and root development, thereby enhancing transpiration and water absorption capacity[10]. This study also demonstrated that nitrogen application could significantly enhance WUE, which initially increased with rising irrigation or nitrogen levels but subsequently decreased. This trend could be attributed to nitrogen ’ s role in forming essential organic compounds such as proteins, chlorophyll, enzymes, and vitamins within plants, which were critical for yield and quality formation[4]. Nitrogen application promoted leaf growth and chlorophyll synthesis, thereby enhancing photosynthetic capacity and improving nutrient supply[9]. These findings aligned with those of Li et al (2024), where moderate irrigation and nitrogen application, through complementary and synergistic effects, improved resource utilization efficiency[12]. While appropriate irrigation could enhance WUE and yield, excessive irrigation might lead to overly vigorous plant growth, which paradoxically reduced WUE. Therefore, reasonable control of irrigation levels was essential for optimizing both water use and yield performance in eggplants.

4.2 Effects of water and nitrogen regulation on crop yield

This study demonstrated that under the same irrigation level, an appropriate nitrogen application rate significantly enhanced yield, while excessive nitrogen had little to no effect on yield improvement or may even have had a negative impact. This phenomenon could be attributed to the fact that an appropriate amount of nitrogen advanced leaf emergence, increased leaf size, and prolonged leaf lifespan, thereby providing essential nutrients for fruit development[13]. Conversely, excessive nitrogen increased the leaf area index of eggplants , leading to higher transpiration rates and reduced photosynthetic efficiency, which was detrimental to yield formation[4]. Appropriate water conditions were crucial for increasing stomatal conductance and promoting photosynthesis[11]. Under drought stress, root tips synthesized abscisic acid (ABA) to sense the lack of available soil moisture and transported ABA to the aboveground parts, causing stomata to close and reducing transpiration[14]. Water deficiency could also lead to plasma membrane damage, leaf injury, and decreased photosynthetic capacity, all of which contributed to reduced yield[15]. These findings aligned with the research of Singh et al (2021).

5. Conclusions

Irrigation and nitrogen application significantly influence the water consumption characteristics, WUE, and yield of eggplants. Research results indicated that both W3N2 and W2N2 treatments achieved the highest yields, with no statistically significant differences between them. Notably, W2N2 exhibited the highest water use efficiency (WUE) and consumed less water compared to W3N2. The study further revealed that nitrogen application significantly influenced water consumption in eggplants. Specifically, as irrigation levels increased, so did water consumption. Moreover, mild water stress could enhance WUE and yield while simultaneously reducing resource inputs. These results provide a theoretical foundation for optimizing water and nitrogen management in eggplant cultivation in the cold and arid regions of Northwest China, particularly in improving yield and resource use efficiency. However, variations in altitude and climate conditions across different regions may necessitate distinct water and nitrogen management strategies.

Therefore, further research is required to explore the impact mechanisms of these strategies on eggplant yield, quality, and resource use efficiency in diverse environments.

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