The Impact of Water and Nitrogen Management on the Growth and Yield of Potatoes

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Abstract. This study employed a two-factor three-level experiment to investigate the effects of water and nitrogen regulation on the growth and yield of potatoes. The results indicated that: (1) Under equal irrigation water, there was no significant correlation between plant height and nitrogen application rate (the T5 treatment reached the peak), nitrogen application significantly affected stem diameter from tuber formation to starch accumulation period, and high nitrogen promoted leaf area expansion in the later growth stage; (2) Under equal nitrogen application, the W1 medium water treatment significantly increased plant height, stem diameter and leaf area ($P<0.01$); (3) The interaction effect of water and nitrogen had a highly significant impact on the number of tubers, single plant tuber weight and yield. The optimal water and nitrogen regulation scheme for potatoes in the Hexi Oasis area was the T5 treatment (medium water and medium nitrogen), which achieved the maximum yield through the coordinated optimization of water and nitrogen ratios.

Keywords: Water and Nitrogen Regulation; Potato; Hexi Oasis; Yield; Growth.

1. Introduction

Potato (Solanum tuberosum L.) plays an important role in the food supply and the agricultural economy as one of the globally important food crops[1]. It plays an important role in the food supply and the agricultural economy. In agricultural production, the planted area and production of potatoes have been growing continuously, and its position in global food production is becoming more and more prominent[2]. In agricultural production, the area under cultivation and production of potatoes continues to grow, and their role in global food production is becoming increasingly prominent. As the population grows and the demand for food rises, the question of how to achieve sustainable production of potatoes, improve their yield and quality, and at the same time protect and improve the soil environment has become an urgent issue in the field of agricultural science and technology.

Our country's agricultural water use faces numerous challenges, including limited per capita water resources and uneven distribution both temporally and spatially. This issue is particularly pronounced in the arid regions of Northwest China, where the scarcity of water resources significantly hampers agricultural development and triggers a series of ecological and environmental problems[3]. Currently, agricultural water consumption in China accounts for 63% of total water usage[4]; however, the efficiency of irrigation water utilization and natural precipitation remains low. Additionally, the insufficient utilization rates of fertilizers and water exacerbate the tension surrounding these vital resources. Arid and semi-arid areas constitute 52.7% of the nation's land area, with drought-related losses accounting for half of all losses from natural disasters. Water scarcity emerges as a critical factor constraining sustainable agricultural development in China[5]. There is an urgent need to further promote water-saving agriculture practices and enhance overall water-use efficiency to ensure national food security while fostering green agricultural development[6].

Reasonable management of water and nitrogen can significantly enhance the efficiency of crop utilization of these resources, promote robust growth, and improve stress resistance in potatoes, thereby boosting overall production performance[7]. Conversely, improper management practices may result in resource wastage, environmental pollution, and disruption of ecological balance. Consequently, conducting comprehensive research on the impacts of water and nitrogen regulation on potato yield, quality, and soil health is crucial for guiding agricultural production practices while achieving efficient resource utilization and ensuring environmental sustainability.

2. Materials and methods

2.1 Experimental site

The study was conducted from April to September 2024 at the Yimin Irrigation Experimental Station (100°43′E, 38°39′N; 1970m a.s.l.) in Minle County, Gansu Province, China. Located in the cold-arid oasis irrigation zone of the Hexi Corridor, the station features a continental desert grassland climate: annual precipitation 183-345mm, evaporation 2000mm; mean annual temperature 7.6℃, sunshine duration 3000 hours, and frost-free period 165 days. The experimental field contains light loam soil with plow layer (0-60cm) parameters: bulk density 1.4g/cm³, field capacity 24%, and deep groundwater table.

2.2 Experimental design

The experiment was designed as a split-plot experiment with two factors: irrigation level as the main factor and nitrogen application rate as the subplot factor. The main factor consisted of three levels: W0 (full irrigation, 65%-75% of field capacity, FC), W1 (mild water deficit, 55%-65% FC), and W3 (moderate water deficit, 45%-55% FC). The subplot factor also had three levels: high nitrogen N1 (240 kg • ha-1), medium nitrogen N2 (185 kg • ha-1), and low nitrogen N3 (130 kg • ha-1). Top-dressing was applied during the tuber formation stage, with a base-to-top-dressing ratio of 6:4. The experimental design included nine treatments, each with three replications.

2.3 Experimental Indicators and Measurements

At each growth stage, three potato plants per plot were sampled for morphological measurements: plant height (tape measure), stem diameter (vernier caliper), and leaf area (hole-cutting method). Yield assessment involved excavating three 2m × 1.8 m row sections for total biomass determination, with 10 representative plants selected for tuber mass quantification to calculate per-plant and per-hectare yield parameters.

2.4 Data processing and analysis

Data processing was conducted in Microsoft Excel 2019 (Microsoft Corp, USA). Graphical representations were generated with Origin 2018 (OriginLab Corp, USA). Statistical evaluations were performed using SPSS 27.0 (IBM Corp, USA).

3. Results

3.1 Effect of Different Water and Nitrogen Management on Potato Plant Height

The plant height of potatoes refers to the distance from the base of the plant near the ground to the top growth center of the main stem, which is one of the important indicators for evaluating the growth condition of potatoes. As shown in Figure 2. The growth pattern of potato plant height under different water and nitrogen management shows an initial increase followed by a decrease as the growth stage progresses, with the peak value reached at the end of the tuber bulking stage. The results of plant height at different growth stages under various water and nitrogen treatments indicate that the irrigation level has a highly significant effect on plant height throughout the entire

growth period of potatoes (P<0.01). The nitrogen application level and the interaction between the two factors significantly affect plant height in the later growth stages but have no significant impact during the seedling stage and the tuber formation stage. During the seedling stage, plant height is positively correlated with both irrigation and nitrogen application levels. The highest plant height was observed under treatment T1 (21.77cm), followed by treatment T2 (21.47cm), with the lowest height under treatment T9 (18.83cm). In the later growth stages of potatoes, when the nitrogen application rate is the same, plant height follows the order: moderate water > high water > low water. When the irrigation level is the same, plant height follows the order: medium nitrogen > high nitrogen > low nitrogen. Under combined water and nitrogen treatments, the highest plant height was observed under treatment T4, while the lowest was under treatment T7.

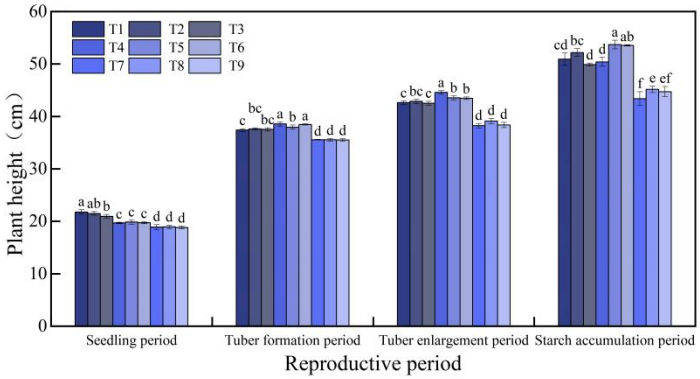

Fig 1. The response of potato plant Height to water and nitrogen at different growth stages

3.2 Effect of Different Water and Nitrogen Management on Potato Stem Diameter

Potato stem diameter, measured at the base of the main stem, supports aerial organs and facilitates the transport of photosynthetic products to tubers, driving tuber expansion, starch accumulation, and yield enhancement. It constitutes a critical morphological parameter for evaluating potato growth.As shown in Figure 2, The effect of irrigation levels on plant height persists throughout all growth stages. The medium water treatment shows the best performance after the tuber formation stage, possibly due to the physiological adaptation induced by water stress. The nitrogen application level has a significant impact during the tuber formation and starch accumulation stages, with the medium nitrogen being the most effective. Excessive or insufficient nitrogen application is unfavorable. The interaction between water and nitrogen is significant during the tuber formation and expansion stages, with the medium water + medium nitrogen combination being the optimal choice, indicating that the synergy of water and nitrogen is crucial for enhancing plant height. Under low water conditions, even with increased nitrogen application, it is difficult to compensate for the reduction in plant height caused by water deficiency, suggesting that water is the limiting factor. In production, it is recommended to adopt a medium water + medium nitrogen water and nitrogen management model to balance resource utilization and maximize plant height, with particular attention during the period from tuber formation to starch accumulation.

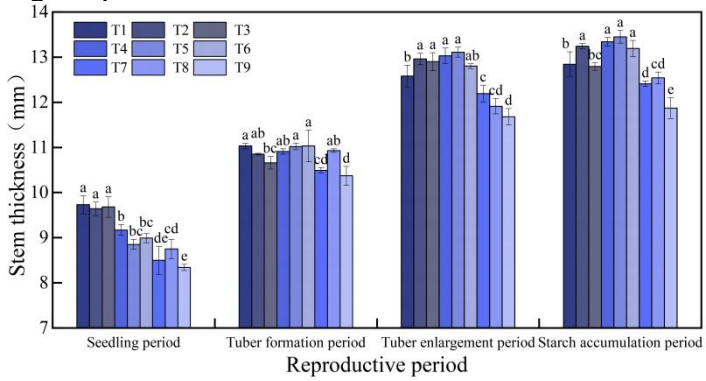

Fig 2. The response of potato plant Stem Diameter to water and nitrogen at different growth stages

3.3 Effect of Different Water and Nitrogen Management on Potato Leaf Area

Leaf area is the primary organ for photosynthesis in crops and is closely related to the synthesis, accumulation, and translocation of dry matter in potatoes. As shown in Figure 3,The level of irrigation has a highly significant effect on leaf area. During the seedling stage and tuber formation stage, the highest leaf area is observed under high irrigation, while the lowest is under low irrigation, indicating that sufficient irrigation significantly promotes leaf area growth during the seedling stage. However, during the tuber bulking stage, the optimal leaf area is achieved under moderate irrigation, while low irrigation severely inhibits leaf area. The nitrogen application level has no significant effect during the seedling stage ($P>0.05$), although leaf area is slightly higher under high nitrogen treatment. However, in the later growth stages of potatoes, high nitrogen significantly increases leaf area. The interaction between irrigation and nitrogen application is significant during the tuber formation stage, bulking stage, and starch accumulation stage. The combination of moderate irrigation and high nitrogen performs best during the tuber bulking stage (9651cm2) and starch accumulation stage (4747cm2), which may be the result of the synergistic promotion of photosynthesis by water and nitrogen.The combination of low irrigation and low nitrogen has the most significant inhibitory effect on leaf area across all growth stages.

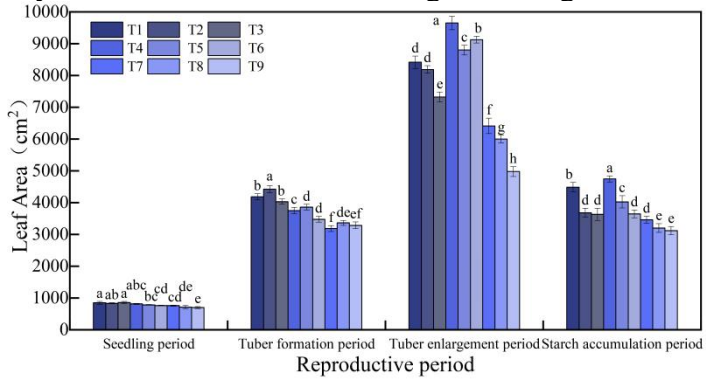

Fig 3. The response of potato plant Leaf Area to water and nitrogen at different growth stages

3.4 Effect of Different Water and Nitrogen Management on Potato Yield and Its Constituent Factors

As shown in Table 1, irrigation levels have highly significant effects on all yield indicators. The moderate irrigation treatment performs best across all yield indicators, with significantly higher single-tuber weight and overall yield compared to high and low irrigation treatments. For example, the highest yield is achieved under moderate irrigation with medium nitrogen (40.24kg), followed by moderate irrigation with high nitrogen (39.75kg). The high irrigation treatment has a relatively lower yield, but it can still maintain a relatively high yield under medium nitrogen conditions (36.35kg), although significantly lower than the moderate irrigation treatment. The low irrigation treatment has the lowest yield (e.g.,only 20.98kg under low irrigation with low nitrogen), indicating that insufficient water severely inhibits yield.Nitrogen application levels have no significant effect on the number of tubers but have highly significant effects on single-tuber weight, single-plant tuber weight, and overall yield. The medium nitrogen level generally performs best, especially under moderate irrigation conditions, where yield reaches its peak. The effects of high and low nitrogen levels vary depending on the irrigation conditions: under low irrigation, reduced nitrogen application leads to a sharp decline in yield, with high nitrogen treatment significantly outperforming medium and low nitrogen treatments.The interaction between irrigation and nitrogen application has highly significant effects on the number of tubers, single-plant tuber weight, and overall yield, indicating that the two factors need to be optimized in combination. The combination of moderate irrigation and medium nitrogen is optimal, suggesting that moderate irrigation and appropriate nitrogen application can maximize yield.

Table 1. Effects of Different Water and Nitrogen Treatments on Potato Yield Indices

Treatments	Yieid index			
	Number of whole potatoes	Weight per potato(g)	Weight of whole potatoes(kg·plant-1)	Yieid(t·ha-1)
T1	3.52±0.07b	138.43±7.86ab	487.02±21.52b	34.67±1.14d
T2	3.94±0.08a	136.03±4.29ab	535.89±25.10ab	36.35±1.17c
T3	3.74±0.08ab	131.36±3.63b	491.92±21.73b	34.34±0.61d
T4	4.11±0.08a	141.45±3.16a	580.80±5.71a	39.75±0.39ab
T5	4.04±0.09a	145.36±4.00a	587.90±22.84a	40.24±0.79a
T6	4.11±0.07a	136.33±4.98ab	559.68±15.50a	38.31±1.06b
T7	3.35±0.63b	118.98±3.16c	397.53±63.58c	27.21±1.10e
T8	2.75±0.10c	114.20±5.52c	314.12±20.80d	23.50±1.01f
T9	2.73±0.12c	101.65±6.30d	277.28±22.98d	20.98±0.49g
Significance levels				
IL	**	**	**	**
NL	ns	**	**	**
IL* NL	**	ns	**	**

Note:IL represents the irrigation level, and NL represents the nitrogen application level.Different letters above the bars indicate a significant difference at $p<0.05$ according to the Duncan test. ** indicates $P < 0.01$; * indicates $0.01 < P < 0.05$; ns indicates not significant.

4. Discussion

Water is the key factor limiting potato plant height, with low water levels significantly suppressing plant height, especially during the later growth stages[8]. An appropriate amount of nitrogen application can maximize plant height under sufficient or moderate water conditions, particularly during the starch accumulation period; the combination of moderate water and medium nitrogen is optimal, balancing resource use efficiency and plant height growth. The impact of irrigation levels on potato stem diameter is evident throughout all growth stages, with moderate water treatment performing best after the tuber formation stage, possibly due to physiological adaptations induced by water stress[9]. Nitrogen application levels significantly affect stem diameter during the tuber formation and starch accumulation stages, with medium nitrogen being the most effective; both excessive and insufficient nitrogen levels are detrimental. The interaction between water and nitrogen is significant during the tuber formation and bulking stages, with the combination of moderate water and medium nitrogen being the best. In production, it is recommended to adopt a water and nitrogen management strategy of moderate water and medium nitrogen to balance resource utilization and maximize efficiency, with particular attention needed during the tuber formation to starch accumulation stages. Insufficient irrigation significantly suppresses leaf area across all growth stages[10], but under moderate water conditions, combining with high nitrogen can maximize leaf area during the tuber bulking and starch accumulation stages. High nitrogen levels significantly promote leaf area during the tuber formation, bulking, and starch accumulation stages[11], but have limited effects during the seedling stage. Potato yield is optimized under moderate water deficit and medium nitrogen levels; both excessive and insufficient irrigation reduce yield, and nitrogen application under low water conditions has limited effectiveness. It is suggested to prioritize ensuring an appropriate irrigation level and combine it with medium nitrogen application to enhance yield.

5. Conclusions

Considering the growth indices of potato plant height, stem diameter, leaf area, and yield, under the experimental conditions, when the irrigation level was maintained at 65%–75% of field capacity and the nitrogen application rate was 185kg·ha^{-1}, the growth indices of potatoes were optimized, and the yield reached its maximum (40.24t·ha^{-1}). The number of tubers per plant and the weight of tubers per plant also reached 4.04 and 587.90g, respectively. This combination of water and nitrogen is suitable for potato production under the film-drip irrigation conditions in the Hexi Oasis.

Acknowledgments

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