Effects of water-nitrogen interaction on sunflower growth, grain filling, and Yield in an arid oasis region

Xietian Chen [1, 2, 3, a], Hengjia Zhang [1, b, *], Haiyan Li [3, c]

[1] College of Agriculture and Biology, Liaocheng University, Liaocheng, Shandong 252059, China;

[2] Yimin Irrigation Experimental Station, Hongshui River Management Office, Zhangye, Gansu 734500, China;

[3] College of Water Conservancy and Hydropower Engineering, Gansu Agricultural University, Lanzhou, Gansu 730070, China.

[a] gsaucxt@163.com, [b] zhanghengjia@lcu.edu.cn, [c] lihaiyan@gsau.edu.cn

Abstract. To address the critical challenges of water scarcity and nitrogen over-application in the arid regions of northwest China, a field experiment was conducted to investigate the impacts of water-nitrogen interaction on plant growth, yield formation of sunflower under mulched drip irrigation in arid oasis region of Northwest China. The experiment comprised three irrigation levels (W1: 55-65% of field capacity (FC); W2: 65-75% FC; W3: 75-85% FC) and four nitrogen (N) application rates (N0: 0 kg ha^{-1} control; N1: 120 kg ha^{-1}; N2: 180 kg ha^{-1}; N3: 240 kg ha^{-1}). The results showed that when comparing W3 to W2, the differences in plant height, stem diameter, and yield at maturity were not statistically significant. However, under W1 treatment, these three indicators exhibited significant reductions of 13.07%, 11.79%, and 21.96%, respectively. Furthermore, when the N application rate exceeds 180 kg ha^{-1}, the increases in plant height, stem diameter, and yield become negligible; there may even be a declining trend observed. Among all combinations of water and N treatments, the W3N2 treatment yielded the highest output at 5247.7 kg ha^{-1}. Therefore, to optimize growth and maximize sunflower yield in the arid oasis regions of northwest China, W3N2 treatment is recommended as an effective combination strategy for sunflower cultivation.

Keywords: Water-nitrogen interaction; Yield; Plant growth; Sunflower.

1. Introduction

Sunflower (*Helianthus annuus* L.), as a stress-tolerant crop with substantial biomass and well-developed root systems, exhibits remarkable saline-alkali tolerance, barren soil adaptability, and drought resistance [1-2]. Its cultivation in arid regions has demonstrated significant advantages in enhancing grain yield, kernel plumpness, and commercial quality [3]. Owing to its broad regional adaptability and notable economic value, sunflower cultivation has been progressively expanding in the Hexi Oasis irrigated area of northwest China in recent years, establishing itself as a characteristic cash crop for improving agricultural economic returns in this region. This irrigation district, located in the arid climate zone of northwest China and sustained by meltwater from the Qilian Mountains, possesses distinct agricultural advantages including pronounced diurnal temperature variation and relatively high soil fertility, making it a crucial grain and oil production base in northwestern China [4]. However, water scarcity combined with frequent drought events has resulted in substantial crop yield losses. More critically, extensive irrigation practices and imbalanced water-fertilizer management—characterized by excessive groundwater exploitation and flood irrigation techniques—have led to a complex interplay of issues: water-soil resource wastage, inefficient water-fertilizer utilization, and soil ecological degradation [5]. These challenges have severely constrained the sustainable development of regional agriculture [6]. Therefore, rational allocation of regional land and water resources and optimization of water and fertilizer management strategies are the inevitable requirements for ensuring sustainable production of oasis agriculture in northwest China.

Current research on sunflowers predominantly focuses on the individual effects of single factors on crop growth and yield [7], while limited studies have investigated the synergistic interactions between water and N under film drip irrigation conditions in relation to sunflower growth and yield formation. Therefore, this study aims to examine the effects of varying water and N application rates on the growth parameters (plant height, stem diameter) and yield formation of sunflowers in the Hexi Oasis region. The research results will provide a useful theoretical basis for saving water and fertilizer and increasing yield of sunflower in oasis area of northwest China.

2. Materials and methods

2.1 Study site description

The experiment was conducted at the Yimin Irrigation Experimental Station in Zhangye City, Northwest China, from April to September 2021. The average elevation of the area is 1970 meters above sea level, with the highest annual temperature reaching 37.1 ℃, and the average annual temperature being 6℃. The growing season for crops benefits from ample sunshine, with a duration of approximately 1200 hours. According to meteorological data from 2015 to 2021, the long-term average annual rainfall in the area is about 200 mm, and the evaporation rate is 1970 mm. The soil texture at the experimental site is light loam soil with moderate fertility, with a pH of 7.22, a soil bulk density of 1.46 g cm-3, a field water capacity of 24%, and a groundwater level lower than 20 meters.

2.2 Experimental design

The experiment was designed with a randomized block design, including two factors: irrigation level and N application rate, comprising a total of 12 water and N treatments with three replicates. Three soil water gradients were employed: W1 (55%–65% field capacity, FC), W2 (65%–75% FC), and W3 (75%–85% FC); four N application levels were established: no N (N0), low N (N1, 120 kg ha–1), medium N (N2, 120 kg ha–1), and high N (N3, 120 kg ha–1). The experimental crop, a typical local dominant variety "JK601", was sown on May 1, 2021 and harvested on September 18, 2021. The experimental fertilizers were urea (N fertilizer), superphosphate and potassium chloride. All phosphate fertilizer, potassium fertilizer and 40% N fertilizer were used as base fertilizer, and were directly sprayed into the experimental field before sowing. The remaining 60% N fertilizer was applied twice by a fertilizer applicator at the buding stage and flowering stage.

2.3 Measurements and methodologies

2.3.1 Growth indexes

After sunflowers entered the seedling stage, 5 healthy plants were randomly selected from each plot for labeling, so as to track and measure the growth morphological indexes of sunflowers at the seedling stage, buding stage, flowering stage and maturity stage. Plant height: The height from the base to the top of the plant was measured with steel tape (accuracy 1 mm); Stem diameter: using electronic digital display vernier caliper to measure the diameter of plant stalk.

2.3.2 Grain filling rate

After the sunflowers reached the flowering stage, 15 uniformly grown plants from each plot were labeled. Seed samples were collected at 7, 14, 21, 28, 35 and 42 days after anthesis. Sampling was conducted in a fan-shaped pattern from the inner circle to the outer circle of the sunflower head. Three heads were selected from each plot, and 100-seeds were collected from each head. The collected seeds were subsequently dried to a constant weight, and the the weight of 100-seeds was determined.

2.3.3 Yield

After the seeds are mature, the actual weight of each plot is measured and finally converted to the yield per unit area.

2.4 Data analysis

Excel 2010 and Origin 2019b were used for data sorting and plotting, respectively. SPSS 19.0 software was used to organize and analyze the data, and one-way analysis of variance (ANOVA) and two-way analysis of variance were used to evaluate the significance difference.

3. Results

3.1 Plant height

As shown in Fig. 1, irrigation and N application had extremely significant effects on the plant height of edible sunflower at each growth stage (P<0.01). The interaction of irrigation and N application (W × N) had significant effects on plant height at each growth stage (P>0.05). In all water and N treatments, the plant height of W3N3 treatment was the highest at all growth stages and reached 243.83 cm at maturity stage, respectively. Under the same N application, the plant height of each growth stage increased with the increase of irrigation level. Compared with the W1 irrigation level, the plant height at the W2 irrigation level increased by 15.51%, 6.48%, 9.27% and 9.44% at the seedling, budding, flowering and maturity stages, respectively. Similarly, the height of W3 increased by 18.88%, 10.03%, 14.22% and 15.03%, respectively. Under the same irrigation conditions, plant height increased first and then tended to be stable with the increase of N application. In addition, under mild water deficit (W2) and full irrigation (W3) treatment, increasing N application rate increased plant height, while under moderate water deficit (W1) treatment, high N application rate (N3) reduced plant height, indicating that excessive N application would inhibit plant development when plants were subjected to severe drought stress.

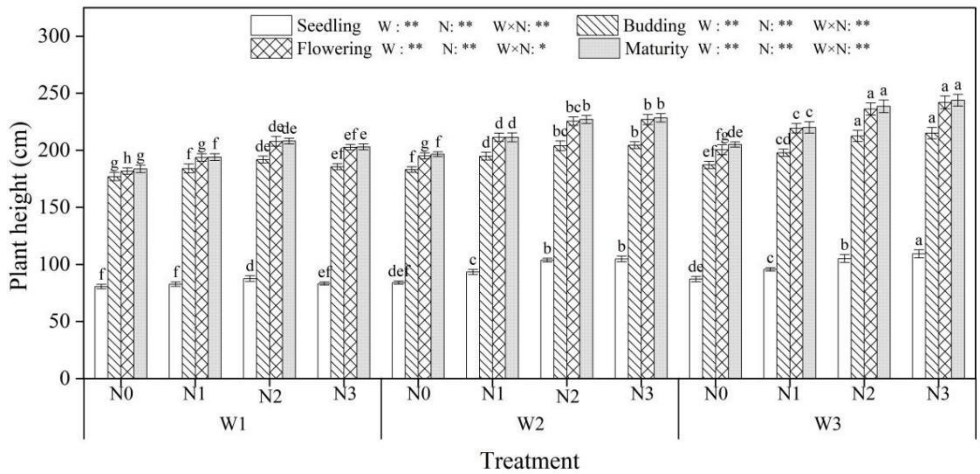

Fig. 1 Effects of different water-nitrogen treatments on plant height at different growth stages

3.2 Stem diameter

As shown in Fig. 2, the plant height of sunflower increased first and then decreased with the progress of growth period. At seedling stage and bud stage, the vegetative growth of plants was vigorous, and the stem diameter increased rapidly, and the stem diameter growth reached the maximum at flowering stage. At maturity, the plant begins to senescence, the water in the stem is gradually lost, and the stem atrophies, resulting in a decrease in stem thickness. The results of variance analysis showed that irrigation, N application and their interaction had very significant effects on the plant height of edible sunflower in each growth stage (P<0.01). Among all treatments, the maximum stem diameter was obtained by W3N2 treatment, which reached 39.88 mm at flowering stage, respectively, and there was no significant difference compared with W2N2 treatment (P>0.05). From the main effect of irrigation, stem diameter increased with the increase of irrigation level. The plant height treated with W2 level was significantly increased by 11.11%, 11.02%, 11.37% and 11.40% compared with W1 level (P<0.05), respectively. There was no significant difference in plant height between W2 and W3 levels. Under the same irrigation level, the plant height of two years increased first and then decreased with the increase of nitrogen application, and the peak value was obtained under N2 treatment. Taking the flowering stage as an example, the plant height of W2N3, W2N1 and W2N0 treatment decreased by 2.45%, 9.80% and 19.45%, respectively, compared with that of W2N2 treatment. The plant height of W3N3, W3N1 and W3N0 treatment decreased by 2.89%, 9.72% and 18.65%, respectively, compared with that of W3N2 treatment.

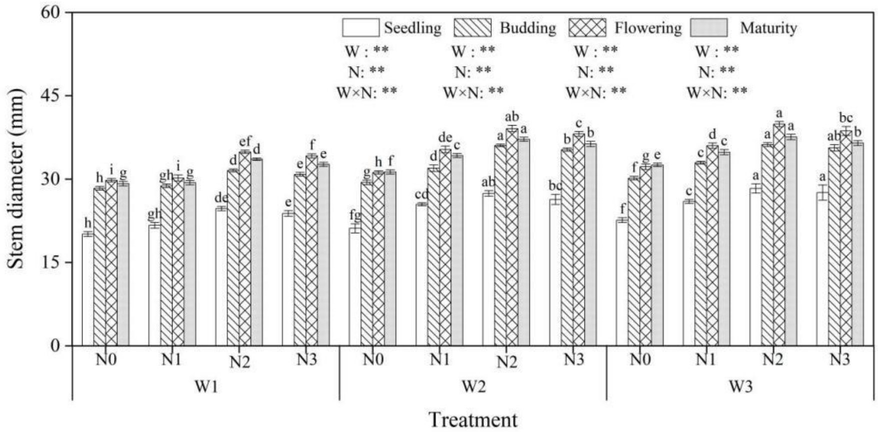

Fig. 2 Effects of different water-nitrogen treatments on stem diameter at different growth stages

3.3 Sunflower grain filling

Fig. 3 illustrates the dynamic process of grain filling under different irrigation and N application treatments. After the onset of the grain filling period, the 100-seed weight of sunflowers showed a rapid increase across all treatments until the 28th day post-anthesis, after which the rate of increase gradually slowed. Significant differences in 100-grain weight were observed among treatments with varying irrigation levels and N applications. Specifically, an increase in deficit irrigation levels led to a significant reduction in hundred-grain weight accumulation. For instance, by the 42nd day post-anthesis, the hundred-grain weight under the W1 treatment was 7.32% lower than that under the W3 treatment. Under the same irrigation level, both no N application (N0) and low N application (N1) significantly reduced the accumulation of hundred-grain weight. From the 7th to the 42nd day post-anthesis, the growth curves for N0 and N1 consistently remained below those for N2 and N3; conversely, the accumulation patterns for N2 and N3 were largely similar. For example, by the 28th day post-anthesis, the 100-grain weight for N0 was 13.77% lower compared to N3. Similarly, N1 also showed reductions of 8.18% during the same period.

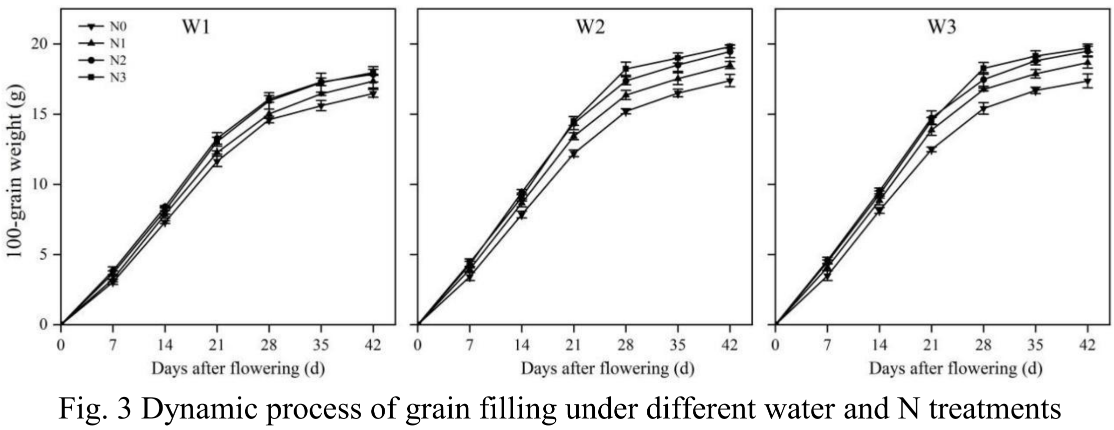

Fig. 3 Dynamic process of grain filling under different water and N treatments

3.4 Yield

As shown in Fig. 4, the effects of irrigation and N application and their interactions on yield reached a very significant level (P<0.01). Among all treatments, W3N2 treatment had the best yield, while W1N0 treatment had the lowest yield. In addition, there was a positive correlation between yield and irrigation level, namely W1>W2>W3. Compared with W3, the yield of W1 and W2 decreased significantly by 21.97% and 5.10%, respectively. Under the same irrigation level, sunflower yield increased first and then decreased with the increase of N application. The highest yield was found at N2 level. Compared with N0, the yield of N1, N2 and N3 treatments increased by 29.30%, 74.92% and 45.90%, respectively.

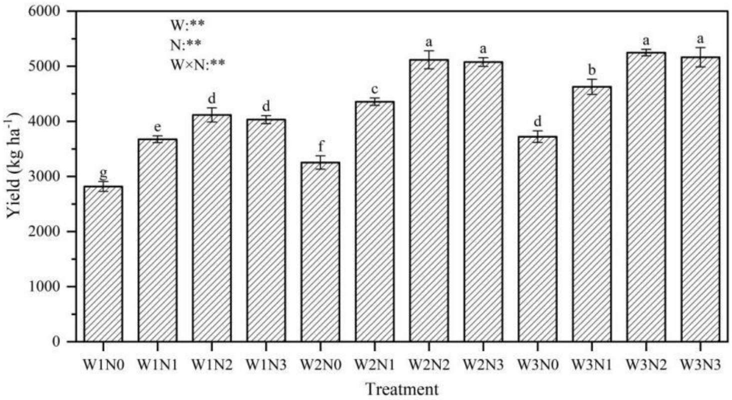

Fig. 4 Effects of different water-N treatments on sunflower yield

4. Discussion

Crop growth indicators can effectively respond to plant growth and its adaptability to growing areas [8]. In agricultural production, efficient irrigation water N application pattern is one of the important prerequisites for promoting normal plant growth [9]. The results showed that when the amount of N applied reached a certain level, the plant height and stem diameter did not increase and even showed a downward trend. Mild water deficit (W2) had no significant effect on growth indexes, while moderate water deficit (W1) was not conducive to growth. This is consistent with the results of previous studies. For example, Xie et al. [10] found that the regulation of severe water deficit led to maize plant dwarfing and weak stress resistance, while mild water deficit had no significant impact on maize growth and development and dry matter accumulation rate.

Within the range of reasonable application amount of water and N, the grain yield and components of sunflower can be effectively improved, and the water and N use efficiency can be improved [11]. In this study, W3N2 treatment had the highest yield; When the N application rate exceeded 180 kg ha-1, the higher the N application rate, the slower the nutrient accumulation rate of sunflower plants, which was not conducive to crop yield increase. Our results are consistent with those of Karam et al. [12], who found that mild water deficit can improve the 1000-grain weight, dish number, grain yield and oil yield of edible sunflower, because mild water deficit can reduce the empty bacterial rate of sunflower to compensate for the reduced yield caused by water deficit, and there is no significant difference in the final yield performance compared with that under adequate irrigation. Previous comparative experiments found that the impact of water and N coupling on the growth of sunflower was more significant than that of irrigation or N application alone, and the yield and net benefit of sunflower would reach the highest when the amount of irrigation and fertilizer application was close to 80% of the crop water requirement and the amount of conventional fertilizer application, respectively [14].

5. Conclusions

The coupling of water and N has a significant impact on the plant height, stem diameter, grain filling, and yield of sunflowers. Overall, increasing irrigation and N application enhances the plant height, stem diameter, 100-grain weight, and yield. Compared to full irrigation (W3), the differences in plant height, stem diameter, and yield at maturity under mild water deficit (W2) treatment were not significant, while these three indicators under moderate water deficit (W1) treatment were significantly reduced by 13.07%, 11.79%, and 21.96%, respectively. When the N application rate exceeds 180 kg ha-1, the increases in plant height, stem diameter, and yield are not significant, and there may even be a declining trend. Among all water and N treatments, the W3N2 treatment achieved the best yield. Therefore, mild water deficit irrigation (65%-75% FC) combined with a moderate N application rate (180 kg ha-1) can be recommended as the optimal combination for sunflower cultivation in the arid oasis regions of northwest China.

Acknowledgment

This work was mutually supported by the National Natural Science Foundation of China (No. 52269008, 51669001), the Industrial Support Plan Project of Gansu Provincial Department of Education (No. 2022CYZC-51), the Key Research and Planning Projects of Gansu Province (No. 18YF1NA073), the Scientific Research Foundation for High-level Talented Scholars (No. 318042401) of Liaocheng Universtiy, the Science Foundation of Shandong Province (No. ZR2024MC190), and the Open Project of Liaocheng Universtiy Landscape Architecture Discipline (No. 31946221236).

References

[1] Ahmad, S.; Muhammad, S.; Abdul, S.; Abdul, Q.; Muhammad, I.; Sami-Ul, I.; Rashid, A.; Abdulrahman, A. Achene yield and oil quality of diverse sunflower (Helianthus annuus L.) hybrids are affected by different irrigation sources. J. King Saud Univ. Sci. 2022,34:4-4.

[2] Mukherjee, A. Effect of Integrated Nutrient Management in Sunflower (Helianthus annuus L.) on Alluvial Soil. Curr. Sci. 2019, 117: 1364-1368.

[3] Li, Z.Z.; Fontanier, C.; Dunn, B. Physiological response of potted sunflower (Helianthus annuus L.) to precision irrigation and fertilizer. Sci. Hortic- Amsterma.2020, 3:270-270.

[4] Tian, Y. C.; Bai, X. Y.; Wang, S.J.; Qin, L. Y.; Li, Y. Spatial-temporal Changes of Vegetation Cover in Guizhou Province, Southern China. Chinese. Geogr. Sci.2017,27:25-38.

[5] Li, Y.; Huang, G.H.; Chen, Z. J.; Xiong, Y. W.; Huan, Q. Z. Effects of irrigation and fertilization on grain yield, water and nitrogen dynamics and their use efficiency of spring wheat farmland in an arid agricultural watershed of Northwest China. Agric. Water Manag.2022,260.

[6] Hou, X. Y.; Chang, B.; Yu, X. F. Land use change in Hexi corridor based on CA-Markov methods. Trans. Chin. Soc. Agric. Eng.2004,5: 286-291.

[7] Wang, L.; Zhang, H. J. Effects of Drip Irrigation Deficit Adjustment Under Mulch on Water Consumption. Photosynthetic Characteristics, and Quality of Edible Sunflower in Hexi Oasis. J, Soil. Water Conserv.2020,34:209-216.

[8] Demir. Inter and intra row competition effects on growth and yield components of sunflower (Helianthus annuus L.) under rainfed condition. J. Anim Plant. Sci. 2020, 30,147-153.

[9] Dong, K. Yun, Y. Field experiment on growth and yields of winter wheat under different water and nitrogen treatments. Trans. Chin. Soc. Agric. Eng.2008,24:36-40.

[10] Xie, Y. H.; Li, L.; Hong, J. P. Effects of nitrogen application and irrigation on grain yield, water and nitrogen utilizations of summer maize. Plant Nutr. Fert. Sci. 2012,18:1354-1361.

[11] Katrin, K.; Birgit, W.; Hütsch, S. How does the harvest index affect water-use efficiency and nutrient-utilization efficiency of sunflowers (Helianthus annuus L). J. Agron. Crop Sci.2019, 205: 519-532.

[12] Karam et al. Karam, F., Lahoud, R., Masaad, R., Kabalan, R., Breidi, J., Chalita, C., Rouphael, Y. Evapotranspiration, seed yield and water use efficiency of drip irrigated sunflower under full and deficit irrigation conditions. Agric. Water Manage.2007, 90: 213-223.

[13] Sinha, I.; Buttar, G.S.; Brar, A.S. Drip irrigation and fertigation improve economics, water and energy productivity of spring sunflower (Helianthus annuus L.) in Indian Punjab. Agric. Water Manag.2017,185:58-64.