

Effects of Deficit Irrigation on Growth Characteristics and Yield Formation of Potato in Hexi Oasis Irrigation District

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Abstract. To explore the optimal irrigation mode for potato in the Hexi Oasis Irrigation District, this study established different regulated deficit irrigation (RDI) treatments (full irrigation: 65% – 75% FC; mild deficit: 55% – 65% FC; moderate deficit: 45% – 55% FC) to investigate their effects on potato growth characteristics and yield formation. Results showed that plant height and stem diameter decreased with increasing water deficit severity. Dry matter accumulation exhibited a similar trend, with the highest photosynthetic capacity observed under full irrigation (CK). The highest yield was achieved under the WD3 treatment (42,963.97 kg·ha⁻¹). In conclusion, mild water deficit during the seedling and tuber formation stages is most conducive to potato growth and yield formation in the Hexi Oasis Irrigation District, achieving water-saving and high-yield objectives.

Keywords: Potato; Regulated deficit irrigation; Growth characteristics; Yield; Hexi Oasis Irrigation District.

1. Introduction

Against the backdrop of global climate change and population growth, food security has become increasingly critical. Potato (*Solanum tuberosum* L.), the fourth-largest staple crop globally, serves as a vital source of carbohydrates and plays a key role in global food security [1]. Particularly in arid and semi-arid regions, potato is a significant food and economic crop due to its high water-use efficiency and adaptability [2]. However, limited and unevenly distributed water resources make irrigation management a decisive factor influencing potato yield and quality [3]. The Hexi Oasis Irrigation District, located in the arid northwest of China, relies on potato as a primary economic crop. Yet, the response mechanisms of potato growth and yield to irrigation levels remain insufficiently understood in this region [4]. Therefore, studying the effects of different irrigation regimes on potato growth characteristics and yield formation is crucial for optimizing water resource allocation and enhancing potato productivity and quality in this area[5].

In recent years, extensive research has been conducted globally on the impact of irrigation levels on crop growth and yield. Studies indicate that appropriate irrigation significantly promotes crop development, improves yield, and enhances water-use efficiency [6]. However, excessive or insufficient irrigation negatively affects crops. Over-irrigation not only wastes water but may also lead to soil salinization and nutrient loss, thereby inhibiting growth[7], while under-irrigation induces water stress, impairing photosynthesis and nutrient uptake, ultimately reducing yield [8]. As a water-sensitive crop, potato exhibits pronounced responses to irrigation levels [9]. Previous studies highlight that the tuber initiation and bulking stages are most sensitive to water demand, with irrigation management during these phases directly determining final yield [10]. Nevertheless, systematic research on the effects of different irrigation levels on potato growth and yield in the Hexi Oasis Irrigation District remains limited [11]. This study aims to evaluate the impacts of regulated deficit irrigation on potato growth characteristics, water-use efficiency, and yield formation through field experiments, providing a scientific basis for efficient irrigation management in this region [12].

2. Materials and methods

2.1 Study Site

The field experiment was conducted in 2023 at the Yimin Irrigation Experimental Station (100°43'E, 38°39'N; average altitude: 1,970 m) in Minle County, Gansu Province. The area features a continental desert-steppe climate with low annual precipitation, high evaporation, an average temperature of 7.6°C, a frost-free period of approximately 150 days, annual sunshine duration of 3,000 hours, annual rainfall of 150-200 mm (concentrated in June-August), and average annual evaporation of 1,638 mm. The soil is light loam with moderate fertility, a groundwater depth exceeding 20 m, negligible upward recharge, and no salinization.

2.2 Experimental Design

The Atlantic potato cultivar was planted on April 26 using ridge-furrow planting with plastic film mulching (plant spacing:20 cm; sowing depth:17 cm). A randomized block design was adopted, with three irrigation levels: full irrigation (65%-75% FC, CK), mild deficit (55%-65% FC: WD1, WD3, WD5, WD7), and moderate deficit (45%-55% FC: WD2, WD4, WD6, WD8). Additional treatments included combinations of deficit stages (WD9: mild + mild; WD10: moderate + mild; WD11: mild + moderate; WD12: moderate + moderate). Each plot measured 7 m² (1.4 m × 5 m), with 13 ridges (ridge width: 0.8 m; spacing: 0.2 m). Three replicates per treatment resulted in 39 plots. Base fertilizers included compound fertilizer (585 kg·ha⁻¹), urea (300 kg·ha⁻¹), calcium superphosphate (675 kg·ha⁻¹), and potassium sulfate (337.5 kg·ha⁻¹), consistent with local practices.

2.3 Measurements and methodologies

2.3.1 Morphological Measurements

Plant height (measured with 0.1 cm precision steel tape) and stem diameter (measured with 0.02 mm precision vernier caliper) were recorded every 7 days after emergence for five tagged plants per plot.

2.3.2 Yield and Component Analysis

At harvest, 1 m² section from the middle of each plot was sampled. Six plants per plot were evaluated for tuber number per plant, tuber weight, longitudinal diameter, and transverse diameter. Yield was calculated based on actual weight.

2.4 Statistical Analysis

Data were processed in Excel 2019 and analyzed using SPSS 26.0 for independent t-tests. Figures were generated with Origin 2021. Significance levels were set at $P < 0.05$ and $P < 0.01$.

3. Results

3.1 Effects of Water Deficit on Growth Characteristics

3.1.1 Plant Height

Plant height, a key indicator of potato growth, is influenced by genetics and irrigation levels (Figure 1). All treatments showed similar growth trends: slow during the seedling stage, rapid during tuber initiation and bulking, and stable or declining during starch accumulation. Mild deficit treatments (WD1, WD9, WD11) reduced plant height by 28.23%-56.65% compared to CK during the seedling stage, while moderate deficits (WD2, WD10, WD12) caused reductions of 42.65%-59.43%. Treatments WD9 - WD12 (two-phase deficits) exhibited 22.57%-34.61% reductions during tuber initiation, with WD11 showing the greatest decline (34.61%). Re-watering during tuber bulking and starch accumulation led to compensatory growth in mild deficit treatments (WD1, WD3), but moderate deficits persistently inhibited growth (6.13%-15.79% lower than CK).

Severe early deficits (WD11, WD12) resulted in irreversible height reductions (31.30%-34.35%), likely due to root system impairment.

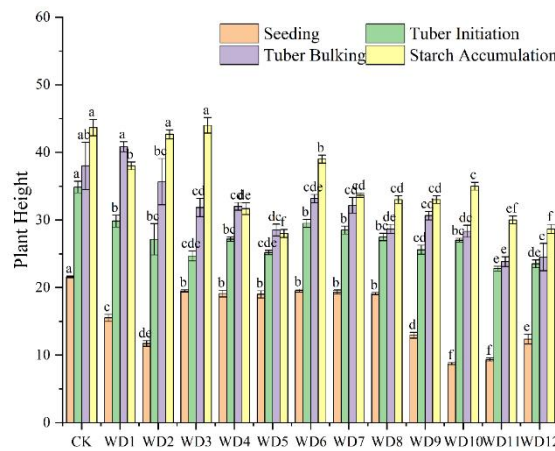


Figure 1 Effect of different water treatments on potato plant height

3.1.2 Stem Diameter

Stem diameter followed a growth pattern similar to plant height but was more sensitive to early water deficits (Figure 2). CK maintained the highest stem diameter. Mild deficits (WD1, WD9, WD11) reduced stem diameter by 2.75%-14.31% during the seedling stage, while moderate deficits (WD2, WD10, WD12) caused 16.94%-19.78% reductions. Re-watering induced compensatory effects (1.67%-6.76% increases in WD10-WD12), but tuber bulking and starch accumulation stages showed no significant differences, as growth shifted to underground organs.

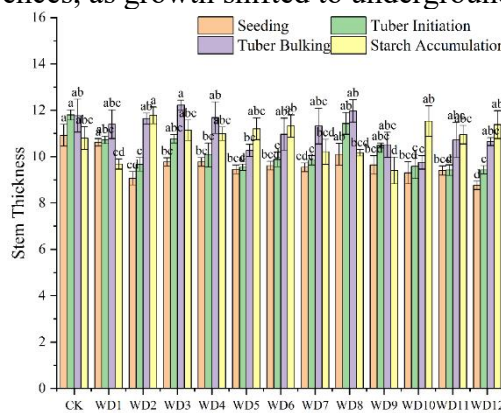


Figure 2 Effect of different water treatments on potato stem thickness

3.2 Effects of Water Deficit on Yield and Components

As shown in Table 1, the number of tubers per potato plant ranged from 2.20 to 3.67. The CK treatment (full irrigation) exhibited the highest tuber number per plant (3.67). Water deficit during the seedling stage did not significantly affect tuber number, whereas water deficit during the tuber initiation stage resulted in a significant reduction of 27.25% compared to CK. Combined water deficit during both the seedling and tuber initiation stages led to a more pronounced decline in tuber number (36.51%–40.05%). The tuber weight per plant was highest under CK (516.43 g), with no significant impact observed under mild water deficit during the seedling and tuber initiation stages. The yields of WD1, WD2, and WD3 treatments were comparable to CK, with WD3 achieving the highest yield (42,963.97 kg·ha⁻¹). Specifically, WD2 and WD3 increased yield by 0.18% and 3.17%, respectively, while WD1 decreased yield by 2.40%. Moderate water deficit during the tuber initiation stage and water deficit during the tuber bulking stage significantly reduced yield by 6.85%–25.71%, indicating that maintaining adequate water supply during the tuber bulking stage is critical for yield formation. The lowest yield (25,679.56 kg·ha⁻¹) occurred under WD12 (moderate

deficit during both seedling and tuber initiation stages). This is likely attributed to excessive water deficit inducing stunted plant growth, which could not recover to full irrigation levels even with subsequent re-watering.

Table 1. Effect of water regulating deficit of potato yield and its components in drip Irrigation under mulch

Treatment	Tuber number per plant	Single potato weight (g)	Longitudinal diameter (mm)	Transverse diameter (mm)	Tuber Yield (kg hm ⁻²)
CK	3.67a	516.43a	84.42b	71.03ab	41645.32ab
WD1	3.33ab	508.11a	94.7a	72.1a	40648.53ab
WD2	3.45ab	524.23a	81.18c	61.51c	41719.92ab
WD3	2.67b	532.88a	82.03ab	67.71a	42963.97a
WD4	2.67b	476.63a	83.19ab	68.46ab	38793.47b
WD5	3.45ab	477.84a	82.69ab	71.36a	38570.3b
WD6	3.56ab	379.21bc	83.68ab	69.59ab	30936.89cd
WD7	3.33ab	409.34b	77.46d	64.96bc	32414.13c
WD8	3.45ab	357.98bc	81.91ab	68.42ab	29805.09cd
WD9	2.33bc	365.85bc	78.47d	65.37bc	28972.46 cde
WD10	2.33bc	351.95c	81.54ab	61.08c	29079.59 cde
WD11	2.33bc	375.16bc	82.1ab	67.45ab	28109.3de
WD12	2.20c	333.82c	82.18ab	68.32ab	25679.56 e

4. Discussion

4.1 Morphological Responses to Water Deficit

The observed reductions in plant height and stem diameter under increasing water deficit severity underscore the sensitivity of potato growth to irrigation levels. The significant declines in these morphological characteristics during the seedling stage, particularly under moderate deficits, suggest that early-stage water stress can severely impair vegetative growth. This is consistent with previous studies indicating that water stress during critical growth stages can restrict root and shoot development, thereby limiting overall plant biomass accumulation [8,9]. However, the compensatory growth observed in mild deficit treatments during the tuber bulking and starch accumulation stages indicates that potatoes possess a degree of resilience to water stress, especially when re-watering occurs at later stages. This suggests that strategic irrigation management, such as mild deficit irrigation during the seedling stage, may optimize water use without significantly compromising plant growth.

4.2 Yield

The highest yield achieved under the WD3 treatment (mild deficit during seedling and tuber initiation stages) supports the notion that strategic water-saving irrigation can enhance productivity while conserving water resources. This finding is particularly significant for arid regions like the Hexi Oasis Irrigation District, where water scarcity is a major constraint on agricultural production. The results also highlight the importance of avoiding severe water deficits during the tuber initiation and bulking stages, as these periods are highly sensitive to water stress and directly influence final yield [2,9]. The observed yield reductions under moderate and severe deficits during these critical stages further emphasize the need for precise irrigation management to balance water conservation and yield optimization.

5. Conclusion

Based on comprehensive analysis of potato growth and yield indicators, the optimal irrigation strategy involves implementing mild regulated deficit irrigation (RDI) during the tuber formation stage, maintaining soil relative water content (SRWC) at 55%-65%, while keeping SRWC at 65%-75% during other growth stages. This demonstrates that timely and moderate RDI significantly enhances potato yield, showing critical implications for potato cultivation in the Hexi Oasis irrigation district. Although this experiment focused on growth parameters and yield performance, the potential advantages of RDI in improving water use efficiency and tuber quality remain to be systematically investigated through targeted studies.

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