Study on Suitable Water Resource Irrigation Rate of Tomato under Solar Greenhouse in Autumn

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Abstract. The shortage of water resources is increasing worldwide. For saving water resources, the study of horticultural plant water saving irrigation technology has greatly ecological and social significance. In this experiment, tomato was used as the test material with drip irrigation technology. Under same fertilizer rate, three levels of irrigation water were set: High irrigation Water (HW), Medium Irrigation Water (MW) and Low Irrigation Water (LW). The effects of different Irrigation levels on growth, yield, water use efficiency and soil nutrient content were investigated. The results show that the plant height and the accumulation of soil nutrients declined while the yield and water use efficiency increased with the decrease of irrigation rate. The average plant height of LW tomato was significantly lower than that of HW. Compared with HW, tomato yield and water use efficiency under LW increased by 6.6% and 65.4%, respectively, and the average irrigation rate decreased by 55.21%. The accumulation of N, P and K under LW in the 40–60cm soil layer was significantly lower than HW by 37.3%, 78.5% and 60.9%, respectively. LW has a positive effect on the increase of tomato yield and the reduction of nutrient leaching and accumulation.

1. Introduction

China is a country with a serious shortage of water resources. The effective utilization rate of water resources is only 30% to 40%. Agriculture water accounts for about 70% of the effective water consumption. Therefore, study on agricultural water saving is of great significance for the rational use of water resources (Hu et al., 2018). Tomato needs large water consumption. Traditional agriculture usually adopts furrow irrigation which lead to waste of water resources, eutrophication of groundwater, and loss of nutrient leaching (Fan et al., 2011; Liu et al., 2019; Zhang et al., 2016). Drip irrigation is recognized as one of the irrigation technologies with the best water-saving effect. The drip irrigation area in Israel accounts for more than 70% of the total cultivated land area, and the maximum water use efficiency of greenhouse drip irrigation can reach 95%. Although the application area of drip irrigation technology has increased in China at present, most agricultural production still uses a large amount of irrigation and fertilization (Yin et al., 2018).

Water and fertilizer are important environmental factors that affect the growth of crops. Previous studies have shown that increasing irrigation rate can significantly reduce the tomato irrigation water use efficiency and increase the accumulation of N₂O in soil (Shang et al. 2020; Li et al. 2020; Liu et al. 2018). Tomato quantity is significantly reduced, and soil nutrients show a tendency to migrate deeper with the increase of drip irrigation water (Li et al. 2019). However, the quantity of irrigation and fertilization has changed too much, and there are few reports on the irrigation index of tomato in the
greenhouse in the Huanghuai region of China. Although studies have shown that low irrigation rate has a good effect on crop yield and water use efficiency, effects of different irrigation levels on crop growth and nutrient accumulation in different soil layers has less research under drip irrigation. Therefore, this experiment investigated the change of tomato yield, water production efficiency and soil nutrient accumulation under different irrigation rate, which provide reference for saving water and improving vegetable production.

2. Methods

2.1. Experimental Site
The experimental site is located in Huayuankou Township, North Suburb, Zhengzhou City, Henan Province (N 34°16´~34°58´; E 112°32´~114°14´). It has a warm temperate continental climate, with an average annual temperature of 14.4°C. The rainfall is 640.9mm, the frost-free period is 220 days, and the annual sunshine time is about 2400h. The experimental greenhouse is a Dutch Wenluo glass greenhouse (length 50 m×width 30 m). The basic nutrient content of the experimental site is shown in tab.1.

Table 1. The primary soil nutrients content in experimental field.

| Soil depth (cm) | available N (mg/kg) | available P (mg/kg) | available K (mg/kg) | soil bulk density (g/cm³) |
|-----------------|---------------------|---------------------|---------------------|--------------------------|
| 0~20            | 72.64               | 53.74               | 370.29              | 1.17                     |
| 20~40           | 49.08               | 19.47               | 163.71              | 1.25                     |
| 40~60           | 35.27               | 11.84               | 93.15               | 1.25                     |

2.2. Experimental Design and Method
The tomato variety ‘Fanshuai No.2’ was used. Three treatments are: HW (High Irrigation Water), MW (Medium Irrigation Water), LW (Low Irrigation Water). After the tomato is planted, the irrigation system of each treatment in different growth periods is shown in Tab.2. The types and quantities of fertilizers used in each treatment are the same (Tab.3). Each irrigation rate is measured by a water meter, and fertilizer is applied with the irrigation water.

Table 2. The design of irrigation after tomato planing (Irrigation unit: ml/day•plant).

| Treatment | Weeks after planing | Irrigation rate(m³/667m²) |
|-----------|---------------------|----------------------------|
|           | 1~4                 | 5~8 | 9~10 | 11~12 | 13~18 |                  |
| HW        | 780                 | 1040| 1300 | 1040 | 520   | 4680             |
| MW        | 600                 | 800 | 1000 | 800  | 400   | 3600             |
| LW        | 420                 | 560 | 700  | 560  | 280   | 2520             |

Table 3. Quantities of fertilizing after tomato transplanted in different stage.

| Types of fertilizer | Weeks after tomato planting |   |   |   |   |   |
|---------------------|-----------------------------|---|---|---|---|---|
| Ca(NO₃)₂·4H₂O       | 1~4                         | 0 | 0 | 12.08 | 9.66 | 4.83 |
| Urea                | 5~8                         | 0 | 0 | 5.19  | 2.88 | 1.03 |
| KH₂PO₃             | 9~10                        | 0 | 0 | 6.04  | 4.83 | 2.42 |
| K₂SO₄              | 11~12                       | 0 | 0 | 0     | 14.93| 1.19 |
| MgSO₄              | 13~18                       | 0 | 0 | 13.73 | 10.98| 5.49 |

The seeds were sown on July 19, planted on August 6, and ended on December 25, 2019. A
randomized block test design was used, repeated 3 times. The cultivation ridge is 10m length, the ridge distance is 1.7m, the ridge width is 0.7m, and the plot area is 17m². Adopt One-ridge double-row high-ridge cultivation. The plant spacing is 0.4m, drip irrigation under the film, and 25 plants are planted in each plot. During site preparation, 750 kg/667m² of dried chicken manure and 35 kg of three-element compound fertilizer (N-P₂O₅-K₂O: 15-15-15) are applied as base fertilizer. After the tomato is planted, the planting water is 45m³/667m², and the basic soil samples are taken at 24h. The sampling location is shown in Fig. 1. When the tomato harvesting is finished, the second soil sample is collected at each site. The soil samples taken are used to determine the soil moisture and nutrient content. Tomatoes are pruned with a single stalk pruning, leaving 2 leaves for topping after the tomato grows to the 5th inflorescence. After planting, the tomato plant height and stem diameter were measured once a week.

![Figure 1. Sample design of soil moisture and nutrient determination.](image)

2.3. Measurement Methods
Water content in the soil was expressed by the ratio of the mass of water to dry soil. The fresh soil samples were weighed, and then placed in an oven to dry at 80 °C for 24h, and then weighed. Water use efficiency (WUE) is calculated as weight of fresh fruit divided by water consumed (Liu et al. 2003). The content of available N in the soil was determined according to (Ye et al. 2011); the content of available P is determined by spectrophotometry (Wu et al. 2020); the content of available K is determined by flame photometer (Chen et al. 2016).

After transplanting, tomatoes were watered and marked with 10 plants for each treatment. The plant height is measured from the ground to the growth point; Stem diameter is determined at 1cm above the second leaf of the plant. The fresh and dry weight of aboveground and underground was determined. The yield of the plot was recorded.

2.4. Data Analysis
Data analysis was performed using DPS7.05. The tomato growth index used the average stem diameter and plant height from 11 to 14 weeks after tomato planting. The difference of N, P and K content in different soil layers between the transplant and harvest were analyzed.

3. Results
3.1. The Effect of Different Treatments on Average Stem Diameter and Plant Height
Tab. 4 shows that as the irrigation rate decreases, the average plant height decreases first and then increases. The average plant height of HW tomato was significantly higher than that of the other two treatments. There was no significant difference in average plant height between MW and LW and no significant difference in average tomato stem diameter between the three treatments.
Table 4. The Effect of different treatments on stem diameter and plant height of tomatoes.

| Treatment | Average tomato stem diameter (11-14 weeks after planting(mm)) | Average tomato plant height (11-14 weeks after planting(mm)) |
|-----------|-------------------------------------------------|-------------------------------------------------|
|           | Week 11   | Week 12   | Week 13   | Week 14   | Week 11   | Week 12   | Week 13   | Week 14   |
| HW        | 11.9a     | 12.2a     | 12.4a     | 12.5a     | 167.4a    | 172.2a    | 173.2a    | 175.1a    |
| MW        | 12.5a     | 12.7a     | 12.8a     | 12.9a     | 156.4b    | 160.0b    | 164.2b    | 166.4b    |
| LW        | 12.1a     | 12.3a     | 12.5a     | 12.6a     | 155.2b    | 159.5b    | 164.8b    | 167.4b    |

3.2. The Effect of Different Treatments on Biomass of Tomato Plants

Fig. 2 shows that with the decrease of irrigation rate, the average content of fresh matter and dry matter in the aboveground part and underground part of tomatoes decreased. The average single plant aboveground and underground fresh matter of HW were significantly increased by 4.8% and 38.1% respectively compared with LW, and the dry matter underground increased significantly by 11.9% and 13.0% compared with MW and LW, respectively. There was no significant difference in the average aboveground dry matter per plant of tomato.

![Graphs showing the effect of different treatments on tomato biomass](image)

Figure 2. The effect of different treatments on the accumulation of tomato per plant aboveground and underground.

3.3. The Effect of Different Treatments on Tomato Yield and Water Production Efficiency

Tab. 5 shows that with the decrease of irrigation rate, the average yield per 667m² of tomato and water production efficiency showed an upward trend. The yield and water production efficiency of tomato under LW were significantly higher than the other two treatments, and the average irrigation amount per 667m² was significantly lower than the other two treatments, its output and the water production
efficiency increased significantly by 6.6% and 65.4% compared to HW and increased significantly by 5.7% and 34.9% compared to MW, respectively. The difference in yield between HW and MW is not significant.

Table 5. The Effect of different treatments on tomato yield and water production efficiency.

| Treatment | Production (kg/667m²) | Irrigation of the whole stage (m³/667m²) | Water productivity (kg/m³) |
|-----------|------------------------|------------------------------------------|---------------------------|
| HW        | 5082.21b               | 284.60a                                  | 17.86c                    |
| MW        | 5123.63b               | 233.98b                                  | 21.90b                    |
| LW        | 5418.03a               | 183.37c                                  | 29.55a                    |

3.4. The Effect of Different Treatments on the Accumulation of Soil Nutrients
Tab. 6 shows that with the decrease of irrigation rate, the accumulation of N and P in the 0–60 cm soil layer decreased, and the accumulation of K in the 20–60 cm soil layer decreased. Compared with HW, in the 0–20 cm, 20–40 cm and 40–60 cm soil layers of LW, the accumulation of N decreased by 33.6%, 31.7% and 37.3%, and the accumulation of P decreased by 35.6%, 31.2% and 78.5%. The accumulation of K in the 0–20 cm soil layer was 3.2 times higher than that in HW, and the 20–40 cm and 40–60 cm soil layers were reduced by 30.6% and 60.9% compared with HW, respectively. The accumulation of elements in each soil layer of MW was significantly lower than that of HW, higher than that of LW.

Table 6. The Effect of different treatments on the changes of soil available N, available P and available K.

| soil depth(cm) | treatment number | available N(mg/kg) | available P(mg/kg) | available K(mg/kg) |
|----------------|------------------|--------------------|--------------------|--------------------|
| 0–20           | HW               | +50.77a            | +70.32a            | +23.75c            |
|                | MW               | +40.83b            | +56.98b            | +67.81b            |
|                | LW               | +33.72c            | +45.29c            | +100.73a           |
| 20–40          | HW               | +24.20a            | +62.62a            | +81.47a            |
|                | MW               | +23.53b            | +52.94b            | +73.29b            |
|                | LW               | +16.53c            | +43.04c            | +56.56c            |
| 40–60          | HW               | +15.59a            | +3.63a             | +89.58a            |
|                | MW               | +13.74b            | +1.32b             | +56.80b            |
|                | LW               | +9.77c             | +0.78c             | +35.03c            |

4. Discussion
Water and fertilizer is one of the main components of the cost of production materials in facility vegetable production, which affects the output and quality of vegetables and directly determines the output benefits of facility vegetables (Fu et al. 2020; Li et al. 2002) confirmed that the N fertilizer applied in the season can be leached to a depth of 200 cm after the vegetable harvest, and the leaching loss of the fertilizer is very serious. In this experiment, the high irrigation rate accumulated available K into the deep soil, wasting water resources, affecting the increase of tomato water production efficiency and yield, while the low irrigation rate reduced the accumulation of N, P, K and other elements in the deep soil, and it reduces the consumption of water resources and enables tomato to obtain higher yield and water production efficiency.

5. Conclusion
With the decrease of irrigation in this experiment, the average plant height of HW tomato was significantly higher than that of the other two treatments. The average content of fresh matter and dry
matter per plant in the aboveground part were significantly increased by 38.1% and 13.0%.
The average yield per 667 m² of tomato and water production efficiency showed an upward trend.
Compared with HW and MW, the yield of tomato in LW increased significantly by 6.6% and 5.7%,
respectively, the water production efficiency increased significantly by 65.4% and 34.9%, and the
average irrigation volume per 667 m² decreased significantly by 55.21% and 27.60%.
The accumulation of available K in the 0~20 cm soil showed an upward trend, the accumulation of
available N, P in the 0~20 cm soil layer and the accumulation of available N, P, K in the 20~60 cm
soil layer all showed a downward trend. The accumulation of available N, P and K in the soil of LW in
the 40~60 cm soil layer was reduced by 37.3%, 78.5% and 60.9% respectively compared with HW,
reducing the downward migration and leakage of nutrients.
Reducing tomato irrigation can not only increase tomato production and reduce nutrient leaching, but
also save water resources.

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