Effects of Different Soil Moistures on the Yield, Water Use Efficiency of Solar Greenhouse Tomatoes in Liaoning, China

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Abstract. Developing water-saving irrigation is an important guarantee for the sustainable development of agriculture. And the research of how to use limited water resources to obtain the best yield, water use efficiency is a hot topic at present. In this paper, the optimum irrigation schedule is achieved by setting different water treatment schemes, optimizing the tomato yield, water use efficiency indexes. The result shows, when soil water rate is controlled within 70%~75%, 60%~65%, 80%~85%, 75%~80% of field capacity respectively in different developing stages, the tomato yield is the highest, which can reach 54050.27 kg/hm²; the water use efficiency is the highest, which can reach 27.1 kg/m³; and it is the best water-saving, high-yield, high-quality planting treatment.

1. Introduction
The facility agriculture plays an important role in the agricultural development in China. Among them, the cultivation facility, namely solar greenhouse for fresh vegetable production is the most representative, it is a highly efficient cultivation facility for vegetable preservation, not only low investment but also energy saving and the essence of which is to obtain the best crop yields and higher production efficiency in controlled environment (Liu Xiao et al. 2013, Li Rui et al. 2013). However, the use efficiency problem of agricultural irrigation water cannot be ignored. According to the experience of past facilities cultivation, the water demand of vegetables is large, but the actual irrigation efficiency can only reach 20%~30%, the crops absorb only about 25% of this(Gautier H et al. 2009). Moreover, unscientific irrigation system and inappropriate irrigation methods are the main reasons for waste water resources, but also easily lead to pests and diseases, and crop yields reduction. Some studies have shown that, according to the climatic conditions of different regions, selecting the appropriate water-saving irrigation technology to optimize the crop irrigation system and achieve effective use of water resources is imminent (Sinan Gercek ET al. 2009). Therefore, complying with the urgent requirements of the times, focusing on water-saving irrigation theory, integrating theory with practice to achieve sustainable use of water-saving society, and developing water-saving irrigation technology are significantly extraordinary (Zhu Min ET al. 2012).

In this paper, tomatoes were taken as the research object, and Liao-Shen type III solar greenhouse was selected. Through pot cultivation mode combined with drip irrigation under film, the laws of tomato water consumption were summarized. The tomato yield and water use efficiency were taken into account in order to form irrigation mechanism, and further to obtain reasonable irrigation system
for greenhouse tomatoes, which is used to provide guidance for a high yield and efficient theoretical in practical production.

2. Material and Methods

2.1. General situation of test area

The experiment was conducted in the greenhouse (Liao-Shen type III) of comprehensive test base of Shenyang Agricultural University (41°44′23′′N, 123°27′02′′E) in Shenyang, Liaoning province from May to September in 2013. Gravity drip irrigation as the irrigation mode, a drip irrigation belt covered by plastic film was set on the barrel, and the irrigation pipes diameter=16mm, thickness=0. 6 mm and were put at an interval of 30 cm, rate of flow =2. 4L/h. Experimental soil has a good soil fertility, unit weight= 1. 01g/cm³ and field capacity= 40%. Soil physical and chemical properties are listed in table 1.

| Total N (g/kg) | Total P (g/kg) | Total K (g/kg) | Available N (g/kg) | Available P (g/kg) | Available K (g/kg) | Organic matter (g/kg) | PH |
|----------------|----------------|----------------|--------------------|--------------------|--------------------|-----------------------|-----|
| 2.59           | 2.34           | 30.25          | 102.42             | 1196.97            | 326.25             | 19.6                  | 6.38 |

2.2. Experiment design

The experiment was conducted with tomatoes planted in barrels with a height of 60cm and a diameter of 50cm and 50cm clay inside, the barrels had double bottoms with an interval of 10cm between with the upper one having 7 holes for ventilation and leaking water, the lower one having one hole with a draining pipe to drain water and measure the amount of leaking water. There are gauze, pebbles, gauze, and compacted soil from the bottom to the top in the barrels, with TDR gauging pipes to monitor the change of soil humidity content with the help of hot air drying method, the arrangements are shown in figure 1.

![Figure 1 Test arrangement](image)

There are 13 treatments during the experiment with each repeated 3 times, the growth of tomatoes is divided into 4 stages, that is, the seedling stage, blooming and fruiting stage, prime fruiting stage and late fruiting stage. Because it is hard to determine a precise minimum of irrigation, a range of minimum irrigation is set for each treatment, when soil humidity content runs below the range, water is added until it reaches the maximum of irrigation which equals to the water holding capacity of the field. Irrigation water capacity for each treatment is got according to the following formula.

\[ m = (\theta_f - \theta) \times s \times h \times p \]  

(1)
In the above formula, \( m \) is the consumption of water for each irrigation, \((m^3)\); \( \theta_f \) is field water capacity, that is, the maximum of soil water content; \( \theta \) is the volumetric water content of soil, that is, the actually measured soil water content on average; \( s \) is the acreage of experiment area \((m^2)\); \( h \) is the depth of wetting layer \((m)\); \( p \) is the rate of soil humidity = 0.9.

According to related researches, tomato is a kind of vegetable with shallow roots mainly concentrated at the soil layer of 30cm, the planned depth of wetting layer for tomato at different growth stages is shown in table 2.

**Table 2** Planned depth of wetting layer at tomato different growth stages

| Growth stages (cm) | Seedling stage | Blooming and fruiting stage | Prime fruiting stage | Late fruiting stage |
|--------------------|----------------|-----------------------------|----------------------|---------------------|
| Planned moisture layer in soil | 20 | 40 | 40 | 40 |

Water balance is calculated in soil layer of 40 cm. Low limit of irrigation control is regarded as the index of control soil water. The scheme of water treatments in each stage is shown in table 3.

**Table 3** Different water treatment schemes of irrigation regime of tomatoes

| Treatment | Seedling stage (%) | Blooming and fruiting stage (%) | Prime fruiting stage (%) | Late fruiting stage (%) |
|-----------|---------------------|---------------------------------|--------------------------|------------------------|
| 1         | 80–85               | 80–85                           | 80–85                    | 80–85                  |
| 2         | 50–55               | 75–80                           | 80–85                    | 75–80                  |
| 3         | 60–65               | 75–80                           | 80–85                    | 75–80                  |
| 4         | 70–75               | 75–80                           | 80–85                    | 75–80                  |
| 5         | 70–75               | 50–55                           | 80–85                    | 75–80                  |
| 6         | 70–75               | 60–65                           | 80–85                    | 75–80                  |
| 7         | 70–75               | 70–75                           | 80–85                    | 75–80                  |
| 8         | 70–75               | 75–80                           | 50–55                    | 75–80                  |
| 9         | 70–75               | 75–80                           | 60–65                    | 75–80                  |
| 10        | 70–75               | 75–80                           | 70–75                    | 75–80                  |
| 11        | 70–75               | 75–80                           | 80–85                    | 50–55                  |
| 12        | 70–75               | 75–80                           | 80–85                    | 60–65                  |
| 13        | 70–75               | 75–80                           | 80–85                    | 70–75                  |
| Planned moisture layer in soil /cm | 20 | 40 | 40 | 40 |

* The lower limit of soil water content is based on percentage of field moisture rate, and the upper limit is field moisture rate.
3. Results and Discussion

3.1. Effects of Different Soil Moisture on Tomato Yield, Water Consumption and Water Use Efficiency

In the paper, the effect of water on tomato yield, water use efficiency and water consumption of tomatoes were studied, and the water productivity was calculated based on the yield, which provided the theoretical basis for optimizing tomato irrigation system. And the formula is as follows:

\[ \text{WUE} = \frac{Y}{W} \]  

In the above formula, \( Y \) is the yield of per unit area, \((m^2)\); \( W \) is the irrigation water of per \((m^3/hm^2)\).

The water use efficiency of tomatoes under different water treatments is shown in Table 4, and the effects of different water treatments on tomato yield, irrigation amount and water use efficiency are shown in Figure 2.

| Treatment | Water demand mm | Yield kg/hm\(^2\) | Water use efficiency kg/m\(^3\) |
|-----------|-----------------|-------------------|-------------------------------|
| 1         | 234.03          | 47900.93          | 20.47                         |
| 2         | 193.09          | 46500.14          | 24.08                         |
| 3         | 198.25          | 47441.61          | 23.93                         |
| 4         | 205.82          | 46326.96          | 22.51                         |
| 5         | 204.64          | 52550.82          | 25.68                         |
| 6         | 199.45          | 54050.27          | 27.10                         |
| 7         | 202.07          | 52903.18          | 26.18                         |
| 8         | 195.11          | 41600.29          | 21.32                         |
| 9         | 197.68          | 41936.31          | 21.21                         |
| 10        | 208.26          | 45000.39          | 21.61                         |
| 11        | 211.88          | 48000.27          | 22.65                         |
| 12        | 208.94          | 48950.41          | 23.43                         |
| 13        | 209.98          | 46500.84          | 22.15                         |

By Duncan test, the letters indicate a significant difference of 5% level.

The Table 4 and Figure 2 showed that, (1) Full irrigation treatment 1, water treatment scheme is 80% ~ 85% of field capacity in whole growth period, and the maximum water demand and yield is 234.03mm and 47900.93 kg/hm\(^2\) respectively, water use efficiency is the lowest, only 20.47%, did not achieve the purpose of water-saving irrigation. Moreover, indicating that in practical production, this view of with the most water can get the highest yield is wrong, full irrigation is not the best management model \( t \) (Patel Neclam et al. 2008); (2) the highest water use efficiency was treatment 6, the highest value was 27.1kg/m\(^3\), the corresponding yield reached 54050.27 kg/hm\(^2\), the water demand during whole growth period is 199.45mm, the water use efficiency was 32.3% higher than that of treatment 1, which is full irrigation. The soluble sugar increased by 35%, the vitamin C increased by 25% and the sugar-acid ratio increased by 26%, which was the best treatment for high yield and efficiency; (3) The yield of tomato in treatment 8 was the lowest, which was 41600.29 kg/hm\(^2\), and that of treatment 9 was 41936.31 kg/hm\(^2\). The corresponding water demand during the whole growth period were 195.11mm and 197.68mm respectively, and the water use efficiency was 21.32 kg/m\(^3\), 21.21 kg/m\(^3\) respectively. The water demand during the whole growth period was low, but the yield was low accordingly. The results showed that the decrease of soil water content was not conducive to...
the fruit yield during the prime period, and the minimum of irrigation was too low during the fruit enlargement period, which led to the limit of tomato growth (Topcu S. et al. 2007). (4) the yield of treatment 11 and treatment 12 were 48000.27 kg/hm² and 48950.41 kg/hm² respectively. However, the water demand in the whole growth period was 211.88 mm and 208.94 mm respectively, and water use efficiency was 16.4% and 13.5% lower than that of treatment 6. This showed that adequate water demand is a necessary condition for tomato in the later stage of fruit, water shortage will lead to a direct reduction in yield.

Figure 2 Comparison of production and water use efficiency under different water treatments

3.2. Relationship between Yield and Water Consumption of Tomato in Solar Greenhouse
This paper studied the relation between total yield and total water consumption of tomato in greenhouse in different moisture condition. Using regression analysis, it came out that relation between yield and water consumption is quadratic parabola, regression equation was shown in Eq. 3:

\[ Y = -0.367x^2 + 173.64x - 34017.14 \]  

In the above formula, Y is total yield of tomato with kg/hm² as its unit; x is total water consumption in whole growth stage with mm as its unit; \( R^2 = 0.977 \), which is significant level.

The maximum yield is 54050.27 kg/hm², and corresponding water consumption is 199.45 mm in the whole growth period. The yield and water consumption shows a parabolic relationship, the yield increases with the increase of water consumption to reach the maximum, but if water consumption is greater than specific amount, the yield will present decline in the law. When the water consumption is less than 199.45 mm, the tomato yield is positively correlated with water consumption, and when the water consumption is more than 199.45 mm, the tomato yield is negatively correlated with it, and decrease with the increase of water consumption. The experimental results of this paper can be a reference for future researches and as guidance for irrigation. By using the growth law and irrigation rules of tomatoes found in this research, the sustainable development could be promoted as well as the economic benefits (Tinglu F et al. 2005).

4. Conclusion
This paper made a comprehensive evaluation of tomato yield, water use efficiency and quality under small tube irrigation by using principal component analysis method, and got an optimal irrigation
regime for tomato in solar greenhouse during the whole developing stage: In seedling stage, infuse water 2 times, irrigation quota is 15~16 mm; In flowering and fruiting stage, infuse water 3 times, irrigation quota is 15~17 mm; In full fruit-bearing stage, infuse water 5 times, irrigation quota is 15~17 mm; In the late period of fruit-bearing stage, infuse water 4 times, irrigation quota is 10~13 mm. The total irrigation quota is 190~220 mm during the whole developing stage.

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