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Original Research Paper

Effects of Different Water and Fertilizer Couplings on the Yield and Soil Environment of Greenhouse Tomatoes in Liaoning, China

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ABSTRACT

There are increasingly serious ecological environmental pollution problems caused by the increased use of fertilizers in the process of agricultural production, therefore the rational application of fertilizers is a major way to prevent and control the pollution caused by fertilizers, so as to maximize the utilization efficiency and reduce the runoff and volatilization of fertilizers. The experiment was conducted in the greenhouse (LiaoShen I type) with different water and fertilizer couplings to establish yield models of tomatoes, monitor the index of soil environment and nutrients during the growth of tomatoes, and finally to search for optimal management modes of water and fertilizer. The results show that the optimum amount of nitrogen, phosphate and kalium fertilizer are 565kg/hm^2, 375kg/hm^2 and 150kg/hm^2 respectively, with the irrigation quota of 200mm and the yield of tomato being 50000kg/hm^2. The experimental coupling of water and fertilizer will provide a scientific guidance for the cultivation of greenhouse tomatoes with high yield, high efficiency and less pollution in Liaoning province.

INTRODUCTION

Liaoning province is an important production base for greenhouse produce in northern China. Nitrogen, phosphate and kalium fertilizer are necessary nutrients for the growth of tomatoes-one of the large-demanded greenhouse vegetables in Liaoning (Sun Jian et al. 2014, Li bo et al. 2014), but with the improvement of multi-cropping index and the increase of production intensity, the nutritional structure of soil has been destroyed, and improper fertilization has become a major restriction factor in vegetable cultivation. For a long time, there is a low utilization rate of irrigation water and fertilizer, as well as a severe waste of water and fertilizer resources, which causes a great economic loss and more severely problems of environmental pollution, such as water eutrophication, soil compaction, the decline of cycle and transformation rate of nutritional elements, and insecure produce, etc. (Sonsez Sahriye et al. 2010). The primary cause is that the traditional mode of too much fertilizer and frequent irrigation is not scientific and unable to stimulate the coupling effects of water and fertilizer, but causing a huge loss of irrigation water and fertilizer, and a severe crisis of water resource as well as environment pollution (Pernice et al. 2010). Therefore, a rational fertilization and water conservation is an effective way to maintain soil virtuous cycle to keep the balance of agricultural ecosystem, as well as the sustainable and stable development of agriculture (Zhu Min et al. 2012).

The research takes greenhouse tomatoes as experimental objects to search for optimal management modes of water and fertilizer by setting different water and fertilizer couplings, establishing yield models, and analysing single factor effects as well as interaction effects, the findings will greatly improve the environment of agricultural production, solve the problems of environmental pollution, and finally provide a theoretical basis for the realization of sustainable development of agriculture.

MATERIALS AND METHODS

The experiment was conducted in the greenhouse (Liao Shen I type) of comprehensive test base of Shenyang Agricultural University (41°44’23”N, 123°27’02” E) in Shenyang, Liaoning province from March to July in 2014, with a planting mode of double lines at one width ridge, combined with a drip irrigation under mulch. Experimental soil has a good soil fertility, a unit weight of 1.24g/cm^3 and a field capacity of 39%. Soil physical and chemical properties are listed in Table 1.

Experiment design: The structure and dimension of experimental greenhouse are shown in Fig. 1. The experiment involves 20 treatments of water and fertilizer couplings with each treatment being repeated for 3 times, a cultivation mode of double lines at one width ridge with a line space of 40cm and a plant space of 30cm, as well as 6 barrels for water supply. The experimental plots are 3 meters long and 0.8

Table 1: Soil physical and chemical properties.

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
2.46	2.25	20.27	175.21	378.95	103.18	26.89	7.09

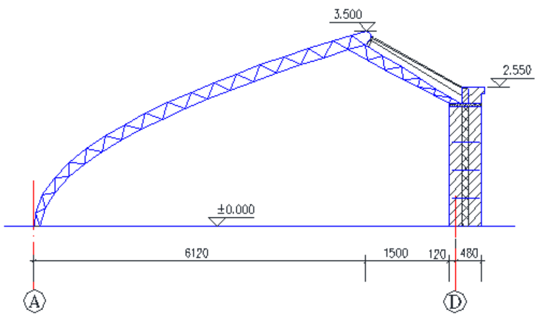

Fig. 1: The greenhouse for experiment.

meters wide, and arranged with a north-south symmetry with a TDR in the middle of each plot to monitor the change of soil moisture content.

Experiment scheme: The experiment adopts a composite design of quadratic regression rotation, setting nitrogen(x_1), phosphate(x_2), kalium(x_3) and irrigation water volume(x_4) as four factors, with 5 levels for each factor. The basal level for irrigation water volume is set when there is no irrigation, and the basal level for nitrogen, phosphate and kalium is set when the amount of nitrogen, phosphate and kalium is zero. The water and fertilizer treatment scheme for tomatoes is given in Table 2, and the level code of experimental factors is listed in Table 3.

RESULTS AND DISCUSSION

Establishment of tomato yield models with different water and fertilizer couplings: Tomato yield models under water and fertilizer couplings can be listed with a quadratic regression rotation model as follows:

$$Y = b_0 + \sum_{j=1}^{p} b_j x_j + \sum_{i \triangleleft j} b_{ij} x_i x_j + \sum_{j=1}^{p} b_{jj} x_j^2 \qquad ...(1)$$

Where, Y is the actual yield with different treatments with kg/hm^2 as its unit; b_j is monomial coefficient; x_j is the dependent variable after linear transformation; b_{ij} is the interaction coefficient of mathematical models; b_{jj} is the dependent variable after linear transformation; p is the number of factors; and j is the sequence number of factors.

A mathematical regression equation of the relationship between tomato yield and water and fertilizer couplings is given as follows, with a multiple regression analysis of tomato yield under different treatments with nitrogen, phosphate and kalium as variables and tomato yield as dependent variables.

$$Y = 55021.37 + 2690.07X_1 + 4693.12X_2 + 946.15X_3 + 3468.21X_4 + 3476.15X_1X_2 - 3476.15X_1X_3 - 643.81X_1X_4 - 1789.45X_2X_3 - 643.81X_2X_4 - 2468.32X_3X_4 - 1089.46X_{12} - 1468.75X_{22} - 2046.78X_{32} - 1567.34X_{42} \qquad ...(2)$$

Where X_1, X_2, X_3 and X_4 respectively represents nitrogen, phosphate, kalium and irrigation water volume, Y is the yield of tomatoes, after a hypothetical test, sig<0.01, indicating that the results are highly significant; 0.01< sig <0.05, indicating that the results are significant; 0.05< sig, indicating that the results are not significant; meanwhile R^2=0.94. The analysis shows that there is a highly significant level of regression equation of tomato yield, nitrogen, phosphate, kalium and irrigation water volume, and a highly significant level of different factors. The model shows the effects of different water and fertilizer couplings on tomato yield, with actually measured values being quite consistent with expected ones, and can provide a better guidance for tomato production (Nong et al. 2010).

Significant test results of major factor effects are listed in Table 4.

It can be seen from Table 4 that the amount of nitrogen, the volume of irrigation water, and the interaction between nitrogen and irrigation water volume all affect tomato yield, with a significant and highly significant level respectively, which indicates that the amount of nitrogen is a principal factor to affect tomato yield, and irrigation water volume also has a great effect.

Analysis of single factor effects: The partial regression submodel of single factor to tomato yield can be listed as follows with water, nitrogen, phosphate and kalium being at the level of zero.

Nitrogen:

$$Y = 55021.37+2690.07X_1-1089.46X_1^2 \qquad ...(3)$$

Phosphate:

$$Y = 55021.37+4693.12X_2-1468.75X_2^2 \qquad ...(4)$$

Kalium:

$$Y = 55021.37+946.15X_3-2046.78X_3^2 \qquad ...(5)$$

Irrigation water volume:

$$Y = 55021.37+3468.21X_4-1567.34X_4^2 \qquad ...(6)$$

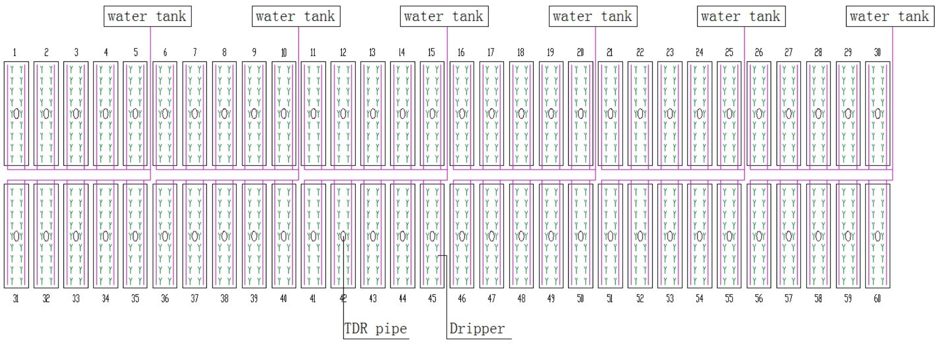

Fig. 2: Experiment floor plan.

Table 2: Water and fertilizer treatment scheme.

Code level	Fertilizer usage N (kg/hm^2)	P (kg/hm^2)	K (kg/hm^2)	Water (mm)
-1.682	0	0	0	100
-1	180	150	150	150
0	315	300	300	200
1	445	450	450	325
1.682	565	600	600	400

Table 3: Experimental factor level code and yield of tomatoes.

Treatment	Code level X_1(N)	X_2(P)	X_3(K)	X_4(W)	Yield kg/hm^2
1	-1	-1	-1	-1	48312.26
2	-1	-1	1	1	48954.22
3	-1	1	-1	1	40263.43
4	-1	1	1	-1	42346.23
5	1	-1	-1	1	48946.54
6	1	-1	1	-1	38698.25
7	1	1	-1	-1	51583.57
8	1	1	1	1	50249.58
9	-1.682	0	0	0	54486.29
10	1.682	0	0	0	54363.45
11	0	-1.682	0	0	54385.23
12	0	1.682	0	0	54956.12
13	0	0	-1.682	0	51645.28
14	0	0	1.682	0	53695.59
15	0	0	0	-1.682	53692.23
16	0	0	0	1.682	51038.56
17	0	0	0	0	53692.19
18	0	0	0	0	54435.18
19	0	0	0	0	54265.33
20	0	0	0	0	53725.53

Note: -1.682, -1, 0, 1 and 1.682 represent values of experimental factors at different levels

Relations between tomato yield and nitrogen, phosphate, kalium and water are indicated in Fig. 3. It can be seen that there is a linear relation between yield and nitrogen when only the amount of nitrogen varies, when the amount of nitrogen ranges from -1.682 to 1.682, tomato yield increases with the increase of nitrogen, and there is a positive correlation between them. Tomato yield reaches the maximum of 59863.45kg/hm^2 when X_1 is 1.682 and nitrogen reaches 565kg/hm^2.

There is a curvilinear relation between yield and phosphate when only the amount of phosphate varies, and the maximum of yield occurs when phosphate reaches 0.5. When the amount of phosphate ranges from -1.682 to 0.5, tomato yield increases with the increase of phosphate, and there is a positive correlation between them. When phosphate ranges from 0.5 to 1.682, tomato yield decreases with the increase of phosphate, and there is a negative correlation between them. Tomato yield reaches the maximum of 55069.37kg/hm^2 when X_2 reaches 0.5 and phosphate reaches 375kg/hm^2.

There is a curvilinear relation between yield and kalium when only the amount of kalium varies, and the maximum of yield occurs when kalium is 0. When the amount of kalium ranges from -1.682 to 0, tomato yield increases with the increase of kalium, and there is a positive correlation between them. When kalium ranges from 0 to 1.682, tomato yield decreases with the increase of kalium, and there is a negative correlation between them. Tomato yield reaches the maximum of 54969.37kg/hm^2 when X_3 is 0 and kalium reaches 150kg/hm^2.

There is a curvilinear relation between yield and irrigation water when only the volume of irrigation water varies, and the maximum of yield occurs when there is no irrigation. When the volume of irrigation water ranges from -1.682 to 0, tomato yield increases with the increase of water volume, and there is a positive correlation between them. When irrigation water volume ranges from 0 to 1.682, tomato yield decreases with the increase of water volume, and there is a negative correlation between them. Tomato yield reaches the maximum of 55091.53kg/hm^2 when X_4 is 0 and irrigation quota reaches 200mm.

Optimal modes of water and fertilizer can be achieved on the basis of above analysis, the probability of tomato yield to go beyond 50000kg/hm^2 is 90% when irrigation quota reaches 200mm, and the amount of nitrogen, phosphate and kalium reaches 565kg/hm^2, 375kg/hm^2 and 150 kg/hm^2 respectively, with the modes we can avoid the waste of water and fertilizer, protect soil environment and help establish a green and low-carbon agricultural cultivation management mode.

Analysis of interaction effects: It can be seen from the results of regression equations and the hypothetical test that there is a significant interaction between nitrogen and water.

$$Y = 55021.37+2690.07X_1+3468.21X_4-643.81X_1X_4-1089.46X_1^2-1567.34X_4^2 \quad ...(7)$$

The partial regression sub-model about tomato yield and the interaction between nitrogen and water is as follows when kalium and phosphate are kept at 0 level.

Interaction effects of water and nitrogen, phosphate as well as kalium are depicted in Fig. 4. It can be seen that tomato yield increases and then decreases with the increase of nitrogen when irrigation water volume keeps constant. The yield increases with the decrease of water when nitrogen keeps constant and below 0 level, and the yield increases with the increase of water when nitrogen is above 0 level, which indicates that a high yield can be achieved with a mode of low nitrogen combined with little water, or a mode of high nitrogen combined with much water. When nitrogen is at 0 level, tomato yield with different irrigation treatments reaches the maximum, indicating that there is a positive interaction between nitrogen and water (Kong Qinghua et al. 2010).

Effects of different water and fertilizer couplings on fertilizer utilization and distribution: Residual amount of available nitrogen, phosphate and kalium in soil after the experiment is depicted in Figs. 5, 6 and 7 respectively.

It can be seen from Fig. 5 that there is a regular spatial distribution of available nitrogen under different treatments, presenting a line with a tilt angle of 45°, where available nitrogen ranges from 200 mg/kg to 400 mg/kg for treatment 1, 2, 3, 4 and 9, significantly less than that of other treatments (350 mg/kg to 500 mg/kg), and keeps from 100 mg/kg to 200mg/kg in depth of 20cm to 80cm when code level is from -1.682 to 0, indicating that the application of nitrogen is good for tomato root absorption so as to promote the growth of tomato (Lin Xingjun et al. 2011a).

It can be seen from Fig. 6 that available phosphate ranges from 200 mg/kg to 400 mg/kg in depth of 20cm, from 50 mg/kg to 250 mg/kg in depth of 60cm, and from 100 mg/kg to 200 mg/kg in depth of 80cm, and in depth of 0cm to 60cm there is a similar distribution trend, but no regular distribution with the increase of soil depth (Liu Yuchun et al. 2009).

It can be seen from Fig. 7 that there is an "S" type spatial distribution of kalium with little difference for each treatment and a basically consistent regularity. Available kalium ranges from 350 mg/kg to 500 mg/kg in depth of 20cm, from 300 mg/kg to 450 mg/kg in depth of 40cm and 60cm, and from 100 mg/kg to 300 mg/kg in depth of 80cm, meanwhile

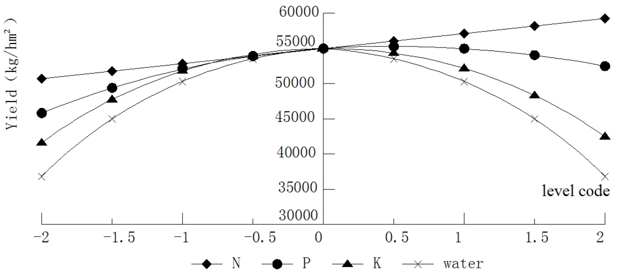

Fig. 3: Relations between tomato yield and N, P, K and water.

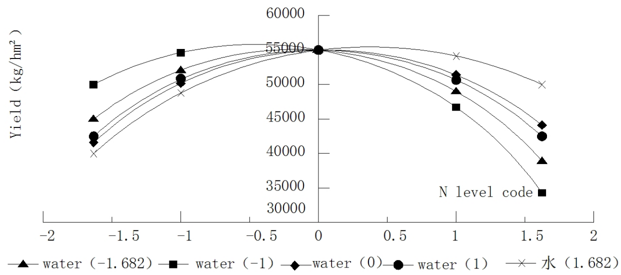

Fig. 4: Interaction effects of water and nitrogen on tomato yield.

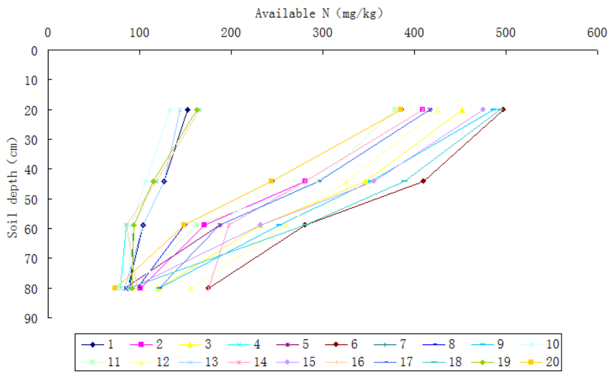

Fig. 5: Available N in different depth of soil.

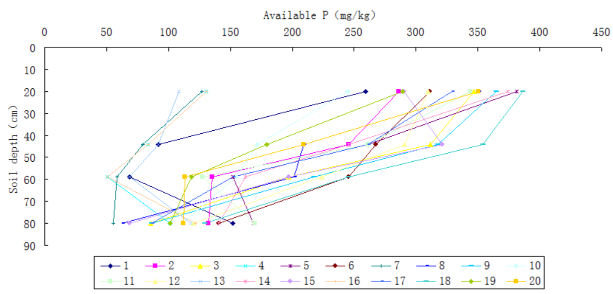

Fig. 6: Available P in different depth of soil.

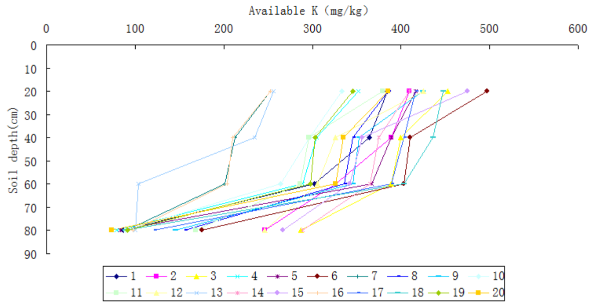

Fig. 7: Available K in different depth of soil.

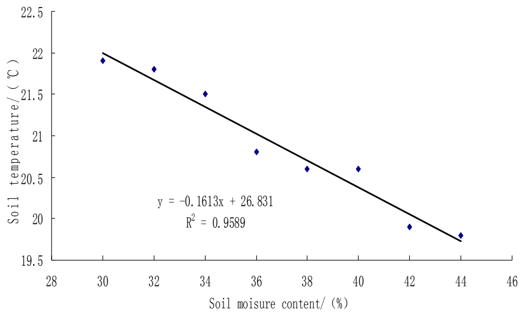

Fig.8: The relation between soil temperature and soil moisture content.

available kalium of other treatments is more than that of treatment 3, 5 and 13.

Analysis of interaction between soil moisture content and soil temperature: soil temperature has a significant influence on soil moisture content, if soil moisture is fitting, soil temperature will be improved in a certain degree, thus having a positive influence on crop growth. The sample data of relation between soil temperature and soil moisture content in one irrigation cycle during tomato full fruiting period is shown in Fig. 8.

After an analysis of the data in Fig. 8, the following equation is obtained.

$$Y = -0.1613X+16.831 \quad ...(8)$$

Where, X is soil moisture content (%), Y is the soil temperature (°C), the correlation coefficient between them is 0.9589 (R^2), indicating that there is a significant correlation between them.

The findings show that there is a negative correlation between soil temperature and soil moisture content, that is, the former increases with the decrease of the latter. Soil moisture evaporation can be prevented by mulching plastic film, while soil with high moisture content absorbs more heat than that with low content for high specific heat capacity of water, thus the former has a lower temperature than the latter.

Path analysis of soil temperature and environmental factors: Path analysis is an analytical procedure where the correlation between independent variables and dependent variables is broken into the direct impact degrees of the independent variables on the dependent variable, as well as the indirect impact degrees of other correlated independent variables on the dependent variables (Lin Xingjun et al. 2011b). The experiment takes the temperature of soil in depth of 5cm (see Table 5), and analyses the correlation (see Table 6) between the temperature and other environmental factors with a path analysis

It can be seen from Table 6 that: (1) the correlation coefficient between soil moisture content and soil temperature is -1.064, and the direct path coefficient is -0.7021, indicating that the increase of soil moisture content leads to the decrease of soil temperature, that is, the indirect effect of greenhouse temperature and illumination intensity is negative, while the indirect effect of greenhouse humidity is positive; (2) the correlation coefficient between soil temperature and greenhouse temperature is 0.8213, and the direct path coefficient is 0.7346, indicating that the indirect effect of illumination intensity and soil moisture content is positive, while the indirect effect of greenhouse humidity is negative, the increase of greenhouse temperature leads to the increase of soil temperature; (3) the indirect effect of soil moisture content and greenhouse temperature is positive, the indirect effect of greenhouse humidity is negative, while the direct path coefficient of illumination intensity to soil temperature is positive, showing a negative correlation, the correlation coefficient between illumination intensity and soil temperature is -0.0361, and the direct path coefficient is 0.2061, which is caused by the significant negative indirect effect of illumination intensity to greenhouse humidity; (4) the correlation coefficient between greenhouse humidity and soil temperature is -0.3264, and the direct path coefficient is 0.8643, indicating that the indirect effect of illumination intensity, greenhouse temperature and soil moisture content is negative, and the increase of greenhouse humidity leads to the decrease of soil temperature.

CONCLUSIONS

1. Optimal modes of water and fertilizer are those where irrigation quota reaches 200mm, the amount of nitrogen, phosphate and kalium reaches 565kg/hm^2, 375 kg/hm^2 and 150kg/hm^2 respectively, and the probability of tomato yield to go beyond 50000kg/hm^2 is 90%.
2. There is a regular spatial distribution of available nitrogen under different treatments, presenting a line with a tilt angle of 45°, the amount of residues of available nitrogen in soil depends on the application amount of nitrogen, presenting a positive correlation between them.

Table 4: Significant test results.

	X_1	X_2	X_3	X_4	X_1^2	X_2^2	X_3^2	X_4^2	X_1X_2	X_1X_3	X_1X_4	X_2X_3	X_2X_4	X_3X_4
Sig.	0.000 **	0.272	0.203	0.031 *	0.446	0.468	0.103	0.263	0.346	0.157	0.000 **	0.237	0.461	0.413

Note: The results are highly significant when sig <0.01, significant when 0.01< sig <0.05, and unsignificant when 0.05< sig.

Table 5: Measured data of environmental factors and soil temperature.

Date	March 14	April 7	April 14	May 7	May 14	May 28	June 7	June 14	June 28
Moisture content (%)	28.41	27.71	27.66	26.83	26.29	25.99	25.59	25.36	25.15
Temperature (°C)	7.8	9.2	9.8	11.2	12.3	14.3	15.2	16.3	17.1
Humidity (%)	0.744	0.795	0.741	0.737	0.758	0.758	0.742	0.723	0.701
Illumination intensity (lux)	971	826	918	956	901	857	915	963	1031
5cm soil temperature (°C)	7.3	8.7	8.8	10.6	11.7	13.2	14.1	15.2	16.5

Table 6: Path analysis of environmental factors and soil temperature.

	Correlation coefficient	Direct path coefficient	Indirect path coefficient			
			Moisture content	Temperature	Humidity	Illumination intensity
Moisture content	- 1.064	- 0.8134		- 0.5761	0.4762	- 0.1516
Temperature	0.8213	0.7346	0.5324		- 0.5943	0.1486
Humidity	- 0.3264	0.8643	- 0.4015	- 0.5461		- 0.2431
Illuminationintensity	- 0.0361	0.2016	0.3042	0.3012	- 0.8431	

In depth of 0cm to 60cm, the amount of residues of available phosphate in soil has a similar distribution trend and increases with the increase of soil depth, but has no regular distribution; there is an "S" type spatial distribution of kalium with little difference for each treatment and a basically consistent regularity.

3. The significant correlation, as well as indirect effects of soil moisture content and greenhouse temperature to soil temperature, indicate that soil moisture content and greenhouse temperature are two important factors that cannot be ignored if we want to improve the growth environment of tomatoes, and to provide a fitting soil temperature for tomato growth.

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