Effects of topdressing ratio and frequency on the dry matter, yield, and quality of tomato and celery under a small amount of continuous subsurface drip irrigation

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Abstract: Compared with conventional full irrigation, the existing water-saving irrigation method achieves the purpose of water saving by actively controlling soil moisture. High-frequency irrigation can make the ideal conditions for soil water movement and root absorption of water and nutrients. This research used a plot experiment in a greenhouse and set up different fertilization amounts and frequencies during the growth stage to study the effects of small-amount and continuous subsurface drip irrigation on the dry matter, yield, and quality of tomato and celery. The results showed that the frequency of topdressing had a great influence on the dry matter accumulation of tomatoes, and the amount of topdressing had little effect on the fresh weight of the upper part of a tomato plant. The application of high-frequency fertilizer increased the dry matter accumulation in the underground part of the tomato. Under the premise given amount of total fertilization, the growth rate and yield of tomatoes were positively correlated with the amount of topdressing. The optimum fertilization frequency was 1 time during the first fruit stage, 3 times for the second fruit stage, and 5 times for the third fruit stage, the yield during the fourth stage was increased with higher frequency, and the topdressing was started ahead of the fourth fruit stage when the diameter of fruit was 40 mm. The lower fertilization frequency during the early stage and higher fertilization frequency during the later stage can increase the yield of celery. The higher ratio of topdressing, the higher frequency during the early growth stage, and the lower frequency during the later stage can achieve the best quality of celery.

Keywords: fertilization frequency, continuous subsurface drip irrigation, topdressing fertilizer, tomato, celery
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1 Introduction

The problem of water shortage is a worldwide problem, it restricts the output of global food. China is a largely agricultural country, and the shortage of water resources has caused a serious shortage of agricultural water. In addition, the uneven spatial and temporal distribution characteristics of water resources also restrict the production level of maize, wheat, and other major crops in China. Drip irrigation has the potential to reduce subsurface drainage, control soil salinity and increase yield by applying water both precisely and uniformly compared with furrow and sprinkler irrigation[1]. Drip irrigation is more effective and cheaper if a large amount of soil can be wetted with each emitter without losing water or nutrients below the root zone[2]. Water is one of the important factors which affect the growth and fruit of tomatoes, and the nutrition, fruit acceptance, and market grade of tomatoes are assured by appropriate water and fertilization management[3]. So optimal irrigation scheduling is critical for the planting of tomatoes.

There are problems such as low soil fertility and incorrect fertilizer methods in many regions that restricted the development of agriculture and caused food security, China has become the largest fertilizer production and consumption country in the world. Applying large amounts of nitrogen fertilizer, the unreasonable proportion of NPK fertilization, and the wrong fertilization method can not promote the growth of crops even cause the waste of fertilizer found in recent years, it does not conform to China's sustainable development strategy and will cause further deterioration of soil physical and environment. Therefore improving the utilization of fertilizer in grain production in China is very important. Greenhouse is the best choice for improving the quality and quantity of tomatoes, it is not only higher yield but also free from dust, insect, disease, and pest. Besides, its favorable environment can make the size of the fruit remain uniform.

Irrigation water is the only source for the application of water to tomatoes in the greenhouse[4]. The positive role of tomato on

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human health has been ascribed principally to its vitamin C content and carotenoids constituents[5-7], particularly lycopene and b-carotene[8-9], that accumulate in plasma and tissues in relation to tomato intake[10,11]. Then much research has considered the quality of tomatoes in terms of irrigation amount and frequency[12-16], while there is little literature regarding the influence of fertilization practices under the small amount and continued irrigation on the quality of tomatoes, even if this aspect is of utmost importance[4,17].

Baryosef[18] found that when the concentration of N was (140±40) mg/L, the yield of tomato was the highest. Singandhupe et al.[19] found that the yield of tomatoes reached the maximum when the amount of nitrogen was 104.7 kg/hm^2 under the condition of drip fertilization with urea as fertilizer. Soumya et al.[20] found that significantly higher total dry matter was recorded with the application of Mono Ammonium Phosphate and Potassium Nitrate at 125% of recommended NPK through drip irrigation at 60 d after transplanting. Etissa et al.[21] found that maximum fruit yield was estimated from regression lines of applying 105 kg N/hm^2 and 85 kg P/hm^2 under furrow irrigated experiment (continuously cultivated field). Kibria et al.[22] said that application of 50 t/hm^2 biogas plant residues resulted in the highest growth and yield and lycopene content of tomato. Scholars have begun to do a lot of research on the growth, yield, and quality of crops under the condition of water and fertilizer integration. The frequency and amount of fertilization are needed to be explored when tomato yield and quality reach the maximum under the small amount and continuous subsurface drip irrigation.

Celery is the vegetable crop with the highest total nutrient removal and largest returns on investment in fertilizer[23]. Celery is extremely sensitive to water stress, and the pithiness of petioles, a common quality problem in drip-irrigated fields, can result from even short-term water stress. Celery is most sensitive to water stress during the last 4-5 weeks before harvest[24]. Because celery is a shallow-rooted crop, it draws up most water from the topsoil. Drip systems, unlike sprinkler systems, usually wet only a portion of the soil. In intensive horticulture, the management of mineral nutrition is a key factor in determining the yield and nutrition level of vegetable crops[25,26]. In practice, excessive supplies of mineral nutrients often occur because it is believed that high fertilizer inputs can result in high crop yields[27].

A small amount and continuous subsurface drip irrigation (SAC-SDI) is one of subsurface drip irrigation, providing water directly and evenly along plant roots with extra-slow speed (1-200 mL/h). The water control tip is the core of the SAC-SDI system (Figure 1), comprised of a filter membrane, and a bundle of parallel capillary tubes[28]. Like subsurface irrigation, SAC-SDI lines are also buried in the soil, and water is supplied to the plant root zone directly. Small amounts and continuous irrigation methods had good effects on the plant growth but also the yield and quality of tomato and celery. Many researchers studied the effects of the small amount and continuous irrigation on soil moisture and nitrogen distribution, and their conclusion were relatively consistent. However, there was no consistent conclusion about the effects on yield and quality of tomato and celery. In addition, the influence of different nitrogen amount applications on the yield and quality of tomato and celery had little conclusion under the small amount and continuous irrigation.

The difference is that water and fertilizer can be applied to the root system slowly and continuously. SAC-SDI is a relatively water-saving way of positive pressure irrigation, the water amount is one percent to one-thousandth of drip irrigation. Compared with ordinary irrigation methods, SAC-SDI produces less underground leakage and soil surface water evaporation.

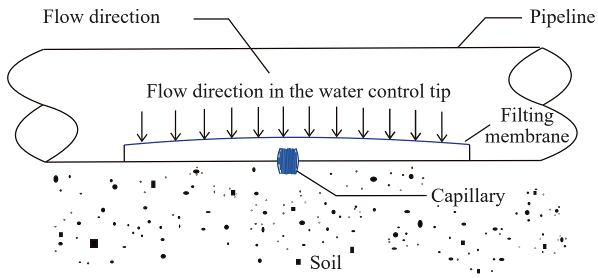


Figure 1 Cutaway view of water control tip

2 Materials and methods

2.1 Experiment site

The experiment was carried out from April to November 2015 at the Tongzhou Experimental Station of China Agricultural University, Beijing, China. The experiment station was located in a semi-arid and semi-humid continental monsoon climate zone, the annual average sunshine is 2250-2600 h, the annual frost-free period is 185-190 d, the annual average precipitation is 550-600 mm, the annual average evaporation is 1826.1 mm[29].

The physical properties of the soil in the experiment area are listed in Table 1.

Table 1 Physical properties of soil in the experiment area

Index	0-20 cm	20-40 cm	40-70 cm
Bulk density/g·cm^{-3}	1.45	1.64	1.57
Field water holding capacity/%	27.60	24.64	28.61
Porosity	0.4176	0.4147	0.4499

2.2 Experiment materials

The experiment variety for tomatoes is "Zhongyan 998" provided by Beijing Zhongyanyinongzhongmiao Science and Technology Ltd. It is an early-maturing variety, with moderate leaf volume, high seedlings, and pink fruit.

The experiment variety for celery is "American White Celery" planted on 28th September and harvested on 26th November, the first time for fertilization was on 4th November and the second time was on 10th November.

2.3 Experiment design

Tomato and celery were planted in the spring and autumn shed located towards the south with a double ridge cultivation pattern, the ridge height is 20 cm, ridge width is 75 cm, row spacing is 60-90 cm, groove center distance is 150 cm, the plant spacing was 33 cm (equal to dripper spacing). Each irrigation tape was arranged along each row and buried at 15 cm under the soil. The water head was 6 m, and the drip discharge was 0.06 L/h. It provided a small amount and continuous irrigation water to the root zone of tomatoes. The daily irrigation amount is 5 mm. Eight experimental plots were set. The length of each plot was 8 m, and the width was 7.5 m. The tomato was planted on 4th April and harvested on 24th July 2015. Topdressing began when the diameter of the fruit grew up to 40 mm (like the size of walnuts) at the beginning of the fruit stage. Experiment treatment factors include topdressing frequency and different fertilizer ratios of base and topdressing, different experiment treatments are shown in Table 2. The total fertilizer amount was 1042.2 kg/hm^2 and there was no difference in the amount of base fertilizer in each plot. In this experiment, the ratio of topdressing and fertilizer was 1/2 in treatment A1, B1, C1, D1, 2/3 in treatment A2, B2, C2, D2, i.e., the topdressing amounts were

521.1 kg/hm² and 694.8 kg/hm² (240 N kg/hm² and 320 N kg/hm² inside, respectively). The local topdressing amount was 900 kg/hm².

Table 2 Experiment treatments for tomato

Treatment	The ratio of topdressing fertilizer/ base fertilizer	First fruit stage	Second fruit stage	Third fruit stage	Tourth fruit stage
A1	1/2	One time	One time	One time	One time
B1		Three times	Three times	Three times	Three times
C1		Five times	Five times	Five times	Five times
D1		One time	One time	Five times	Five times
A2	2/3	One time	One time	One time	One time
B2		Three times	Three times	Three times	Three times
C2		Five times	Five times	Five times	Five times
D2		One time	One time	Five times	Five times

Celery was planted on 28th September and harvested on 26th November. For celery, the base fertilizer is 4 m³ cow manure and 50 kg compound fertilizer (N-P-K: 18-22-5), the topdressing only used compound fertilizer (N-P-K: 24-12-14). Normally the local topdressing is 225 kg/hm². But the topdressing amount was 50% of the local topdressing for treatments A1, B1, C1, and D1, and 70% for treatments A2, B2, C2, and D2 in this experiment.

Fertilization started when the tomato grew up to 40 mm (diameter). There were four fertilization periods in total and each fertilization period is 5 d for tomatoes, they were from 7th June, 14th June, 21st June, and 4th July. During each period, fertilization frequency was one time for treatment A, three times in total for treatment B, and five times in total for treatment C. For treatment D, fertilization frequency was one time during the first and second fruit stages, and five times during the third and fourth fruit stages. Fertilization started on the first day, the time between every two fertilization was the same for treatments B, C, and D during each stage (Table 3).

Table 3 Experiment treatments for celery

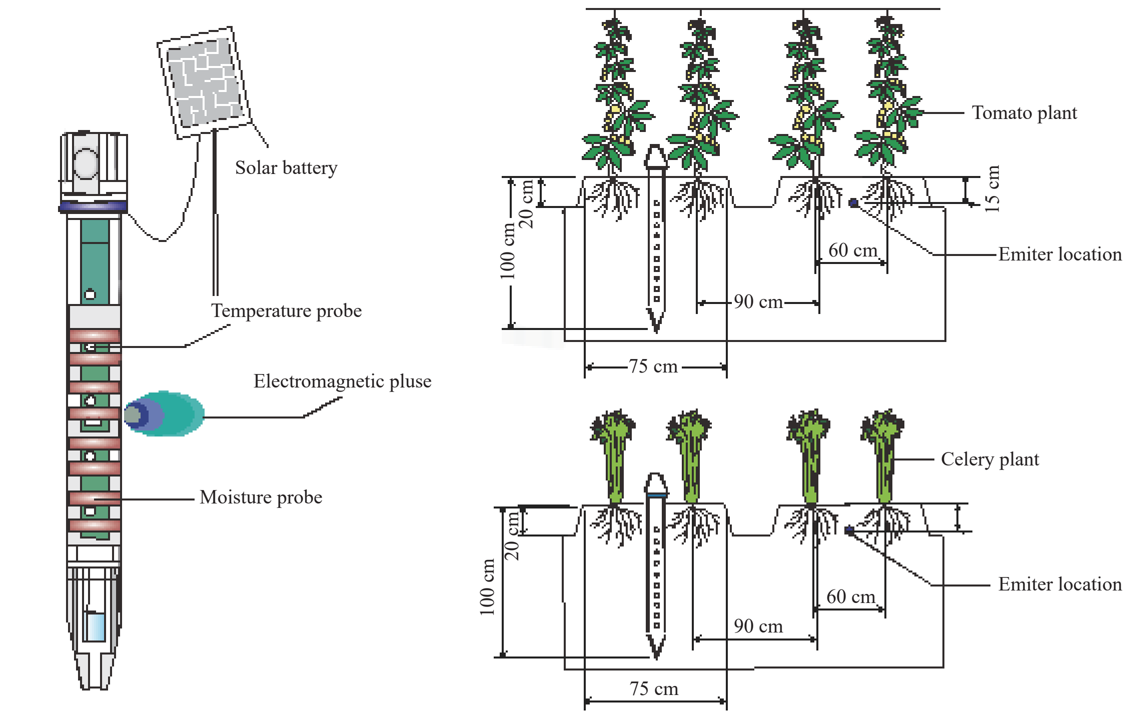
Treatment	The ratio of topdressing fertilizer/base fertilizer	The first fruit stage	The second fruit stage
A1	1/2	One time	1 time
B1		Three times	3 times
C1		Five times	5 times
D1		One time	5 times
A2	2/3	One time	1 time
B2		Three times	3 times
C2		Five times	5 times
D2		One time	5 times

It is similar to celery. There were two fertilization periods in total and each fertilization period is 5 d for celery, they were from 4th and 10th November. During each period, fertilization frequency was one time for treatment A, three times in total for treatment B, and 5 times in total for treatment C. For treatment D, fertilization frequency was one time during the first fruit stage, five times during the second fruit stage. Fertilization started on the first day, the time between every two fertilization was the same for treatments B, C, and D during each stage.

2.4 Determination methods

2.4.1 Soil moisture

The soil moisture content was determined automatically every hour by the Insentek sensor (Beijing Oriental Ecological Technology Ltd., Co., Beijing, China). It is an apparatus powered by solar energy for can monitor real-time soil moisture (Figure 2).



a. Structure and principle of an Insentek sensor b. Experiment layout and installation details of an Insentek sensor

Figure 2 Design and layout of Insentek sensor

2.4.2 Growth of tomato and celery

From the end of each fertilization period to the start of the next fertilization period, three destructive sampling includes selecting roots, stems and leaves on the ground and underground parts were randomly done for each treatment. Firstly measured the fresh weight of the sample, then put the sample into the oven at 105°C after 30 min, then adjust the oven temperature to 80°C for 4 h, and finally measured the dry weight of the sample[30].

2.4.3 Tomato yield

In the whole plot, the tomato was accumulated, and red tomatoes were selected to reach 80% and above. At random, 20 strains were selected in each plot.

2.4.4 Celery yield

When celery was harvested, the yield of each plot was calculated separately.

2.4.5 Fruit quality of tomato

The growth period of tomato was divided into the early stage (15th June-26th June), middle stage (27th June-7th July), and late stage (8th July-24th July), and the quality of fruit at each stage was measured separately.

1) The content of nitrate was determined by the colorimetric method of salicylic acid[31];

2) The content of ascorbic acid was measured with the 2,6-dichloroindophenol titrimetric method[32];

3) Total soluble sugar content was determined by the anthrone colorimetric method[33];

4) The titratable acidity content was determined by means of titration with NaOH (0.1 mol/L) until pH=8.1, expressing the results in grams of anhydrous citric acid per 100 g[34];

5) The sugar-acid ratio was the ratio of soluble sugar content to titratable acid content[35].

2.4.6 Quality of celery

The quality of celery was determined by sampling before harvest.

1) The content of ascorbic acid was measured with the 2,6-dichloroindophenol titrimetric method[32];

2) Total soluble sugar content was determined by anthrone colorimetry[33];

3) The crude fiber content was determined by the acid-detergent method.

3 Results

As shown in Figure 3, The total irrigation amount is 170 mm, including 70 mm before fertilization, and 5 mm/d after fertilization with SAC-SDI. Five irrigation cycles in total, each one lasting for 5 d were from 7th June, 14th June, 21st June, 28th June, and 4th July.

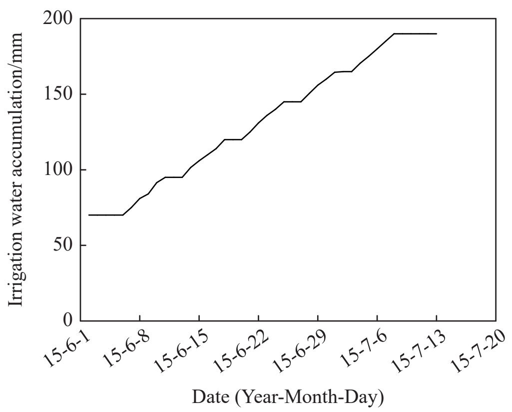


Figure 3 Irrigation water accumulation

The changing trend of soil moisture content in different treatments is shown in Figure 4. The moisture content of each treatment was slightly different but the trend was the same. While the trend was the same, the soil moisture content had less change during the growth period for tomatoes than for celery. Generally, the soil moisture content raised during the irrigation period and decreased were 34%-40%.

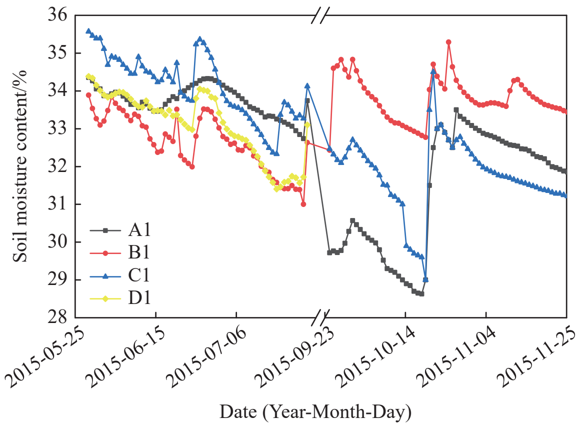


Figure 4 Soil moisture content in the growth stage

As show in Figure 5, because the irrigation schedule was similar, the changing trend of soil moisture content in different treatments was also similar. The soil moisture content at 0-20 cm raised rapidly (30%-34%), and it raised slowly under 20 cm (34%-40%).

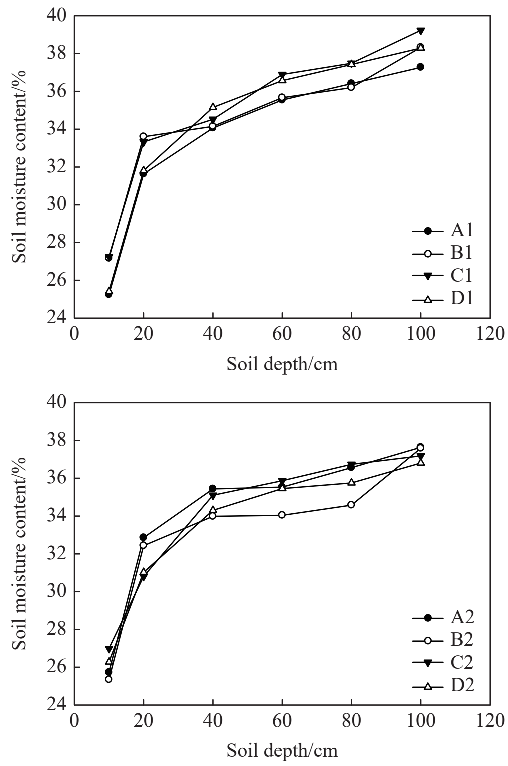


Figure 5 Soil moisture content at different depths in soil

3.1 Effects of the fertilization amount and frequency on drymatter of tomato

As shown in Figure 6, dry matter accumulation in treatments B1, B2, C1, and C2 were obviously higher than in treatments A1, A2, D1, and D2 because of higher fertilization frequency during the first fertilization cycle. During the second fertilization cycle, dry matter accumulation of treatments B1, B2, C1, and C2 was still higher than that of A1, A2, D1, and D2. During the third fertilization cycle, dry matter accumulation of treatments C1 and C2 was higher than that of treatments A1, D1, A2, and D2. But the drymatter accumulation of treatment B1 had no significant difference with treatment A1 and D1, dry matter accumulation of treatments C2 and D2 began to become higher than treatments A2 and B2 during the third fertilization cycle. During the fourth fertilization period, dry matter accumulation of treatment A1, B1 had no significant difference. After the fourth fertilization period, dry matter accumulation nearly stayed the same. The dry matter accumulation rate of each treatment remained. There was no significant difference between A2, D2, and B2, C2, except that A2 and D2 were higher than B2 and C2.

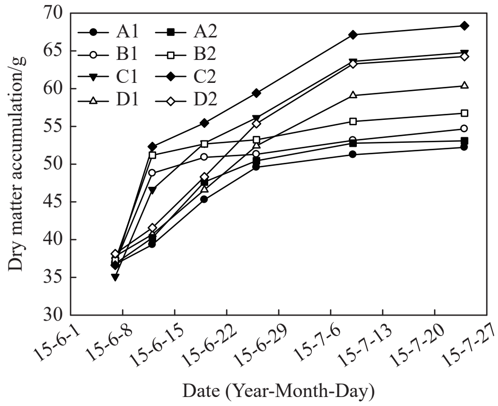


Figure 6 Dry matter of tomato plant above the soil

Figure 7 shows the effect of different fertilization frequency on dry weight of tomato plant in the upper part of the ground before uprooting, fertilization frequency and dry matter accumulation was positively correlated, dry matter of treatment D1 and D2 were less than treatment C1 and C2, treatment D1 and D2 were higher than treatment B1 and B2. The results showed that the topdressing frequency of later two fruit period had more influence on the dry matter accumulation of tomato plant above the soil.

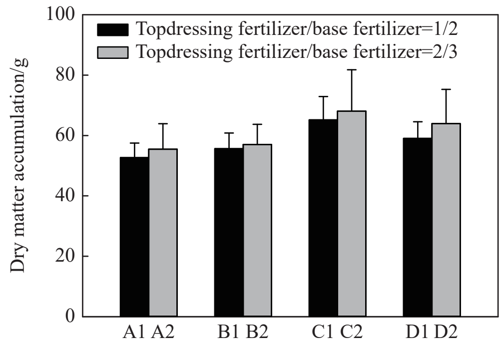


Figure 7 Effects of different topdressing frequencies on the dry matter quality of tomato plants above the soil

From Figure 6 and Figure 8, it can be obtained that the dry matter of the underground part and the upper part of the ground was nearly the same. In the first fertilization period, the underground dry matter accumulation of treatment C1 was higher than that of treatment A1 and D1. Dry matter accumulation showed C2>B2>D2>A2 when the ratio of topdressing fertilizer and base fertilizer was 1/2, but there was no significant difference in treatment B2, D2, and A2. The dry matter accumulation rate of treatment C1 during the second fertilization cycle decreased but was still higher than that of treatment A1, D1, and B1. The accumulation rate of dry matter in treatment C2 was still the highest in the second fertilization cycle. In the third fertilization period, dry matter accumulation of treatment was higher than that of treatment A1 and B1, but lower than treatment C1. It was the same with the dry matter accumulation in the upper part of the ground during the fourth fertilization cycle, the dry matter accumulation rate of the underground part for each treatment had no significant change, still C1>D1>B1>A1, until the end of the experiment, dry matter accumulation relations remained. The dry matter accumulation rate in treatment B2 and D2 had no significant difference and the cumulative amount is more than treatment A2. The curve fitting function and parameters are

A1: y=−0.011x^2+937.88x−2E+07, R^2=0.9834;

B1: y=−0.0122x^2+1040.5x−2E+07, R^2=0.7941;

C1: y=−0.0176x^2+1495.8x−3E+07, R^2=0.9737;

D1: y=−0.0107x^2+915.27x−2E+07, R^2=0.9923.

The curve fitting function of A1, C1, and D1 were good, R^2> 0.95, compared with B1.

A2: y=−0.013x^2+1105.2x−2E+07, R^2=0.9822;

B2: y=−0.0138x^2+1177.5x−3E+07, R^2=0.7758;

C2: y =−0.0183x^2+1560.8x−3E+07, R^2=0.9331;

D2: y=−0.013x^2+1111.1x−2E+07, R^2=0.9908.

The curve fitting function of A2, C2, and D2 were good, R^2> 0.90, compared with B2.

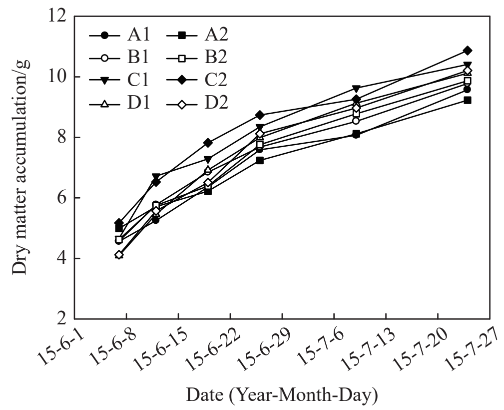


Figure 8 Dry matter quality change trend in underground

Figure 9 shows the effect of different fertilization frequency on the matter of tomato plants underground before uprooting. Compared with Figure 3, it can be seen that the topdressing amount was more important for dry matter of underground plant, underground dry matter accumulation of treatment A2 decreased, compared with treatment A1. The dry matter of treatment C2 increased more than that of treatment C1 with the same topdressing frequency. There were significant differences among the four treatment groups.

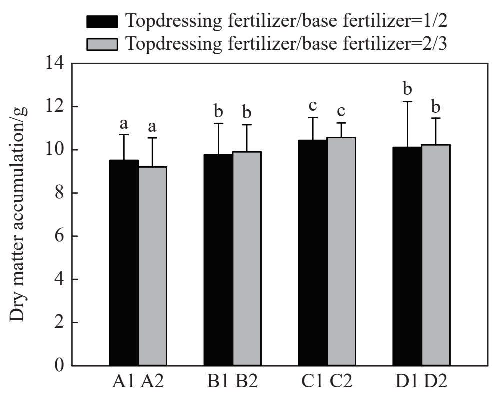


Figure 9 Effect of different topdressing frequency on the dry matter of tomato plant underground

3.2 Comparison of tomato yield and growth speed under different fertilization ratios and topdressing frequency

From Figure 10, it can be obtained that yield was positively correlated with topdressing frequency under certain fertilization amount.

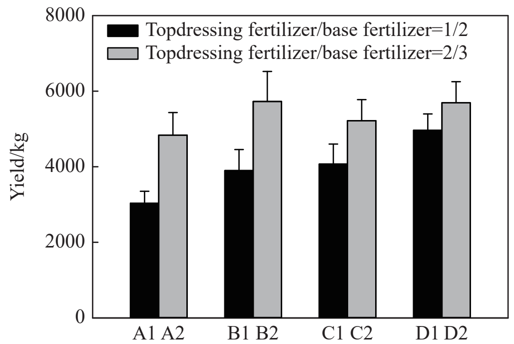


Figure 10 Comparison of yield under different fertilization ratios and topdressing frequencies

The yield of treatment D1 (topdressing frequency was 1 time during the first and second fruit stages, then the topdressing was equally divided into 5 times during the third and fourth fruit stages) was the highest when the ratio of base and topdressing fertilizer was 1/2. It proved that reducing the single amount of fertilization and increasing the frequency of fertilization under the small amount and continuous subsurface drip irrigation was a highly efficient system.

When the ratio of base and topdressing fertilizer was 2/3, the yield of treatment B2 was highest. In addition, the topdressing fertilizer amount was 694.8kg/hm^2 in total, and the amount of fertilization per fruit stage was 173.7 kg/hm^2. In the local greenhouse, the amount of topdressing fertilizer per fruit stage was 225kg/hm^2. So topdressing fertilization amount was 77.2% of local greenhouse tomato planting. It also proved the same results as treatment D1.

From Figure 10, it can be seen that the corresponding yield for treatment with larger topdressing fertilization amount was higher than that for treatment with less topdressing fertilization amount under the same fertilization frequency. The yield of treatment with the different fertilization frequencies under the same fertilization ratio was basically the same. Although the total yield of treatment B2 was higher than that of treatment D2, it was not significant.

3.3 The effect of fertilization ratio and fertilization frequency on tomato quality

3.3.1 Average nitrates content

Figure 11 shows the changing trend of average nitrate content during the three periods, it increased first and then decreased with fertilization frequency increased. Moreover, the nitrate content in the fruit increased significantly with the fertilization amount increased. The fruit nitrate content for treatment A2, B2, C2, and D2 were 12.6%, 10.46%, 19.33%, and 25.25%, it was higher than that for treatment A1, B1, C1, and D1.

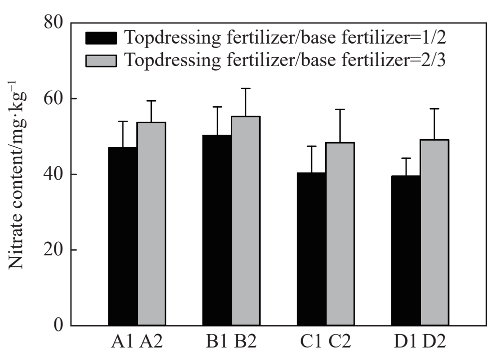
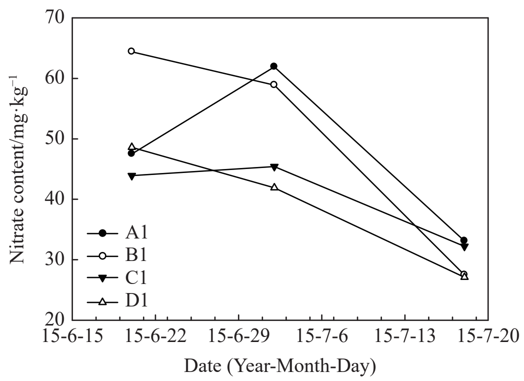
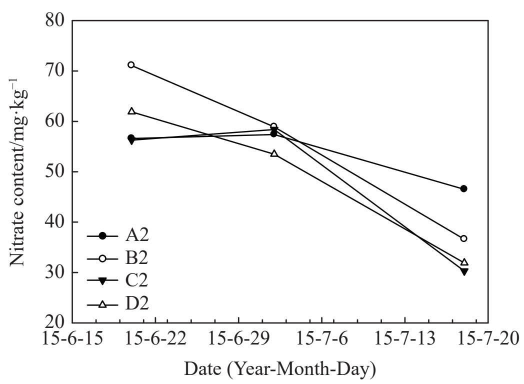


Figure 11 Comparison of average nitrates content

Figure 12 shows that the average nitrate content increased first and then decreased in the three fruit periods for each treatment with the increase in fertilization frequency. Treatments D1 and D2 were the lowest among those treatments. It illustrated that fertilization frequency increase within a certain range can promote the increase of fruit nitrate content, however, beyond this certain range, it will inhibit the synthesis of nitrate in the fruit. For example, with the same fertilization ratio, treatment A1 was higher than treatment C1 by 17.28%, treatment A2 was higher than treatment C2 by 10.69%, and treatment A1 was 21.11% higher than treatment D1 which was with low frequency in the first and high frequency in the later. Treatment A2 was 8.96% higher than treatment D2 which was with low frequency in the first and high frequency in the latter. Treatment B1 was 38% higher than the average of A1, C1, and D1 in the early fruit stage, while treatment B2 was 22% higher than the average of A2, C2, and D2. During the mid-term fruiting stage, the average of treatments A1 and B1 were 38.37% higher than the average of treatment C1 and D1, but there were no significant differences among treatments A2, B2, C2, and D2. At the end of the fruit stage, there were no significant differences in treatment A1, B1, C1, and D1. However, treatment A2 was 41% higher than the average of treatment B2, C2, and D2. It can be seen that after increasing the topdressing ratio, the difference between the treatments decreased in both the early fruit stage and the middle fruit stage, but increased in the later fruit stage.



a. When the ratio of topdressing fertilizer and base fertilizer was 1/2



b. When the ratio of topdressing fertilizer and base fertilizer was 2/3

Note: a. When the ratio of topdressing fertilizer and base fertilizer was 1/2; b. when the ratio of topdressing fertilizer and base fertilizer was 2/3.

Figure 12 Nitrate content change trend

From Figure 11, treatments B1 and B2 showed the highest average nitrate content in the fruit period. The accumulation of nitrate in the fruit reached the maximum when the fertilization is divided into three times per fruit stage, and the nitrate accumulation was the lowest when the fertilization frequency was raised to five times per fruit stage.

3.3.2 The content of ascorbic acid

Figure 13 shows the increase of the fertilization ratio decreased the content of ascorbic acid. The ascorbic acid in treatment A2, B2, C2, and D2 decreased by 43.55%, 34.8%, 20.41%, and 35.09% compared with treatment A1, B1, C1, and D1, respectively. It can be seen that the content of ascorbic acid reduced with the increase in the fertilization ratio. However, increasing the fertilization ratio while increasing the frequency can slow down the reduction of ascorbic acid.

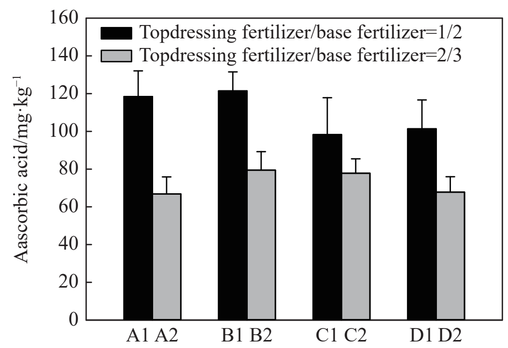
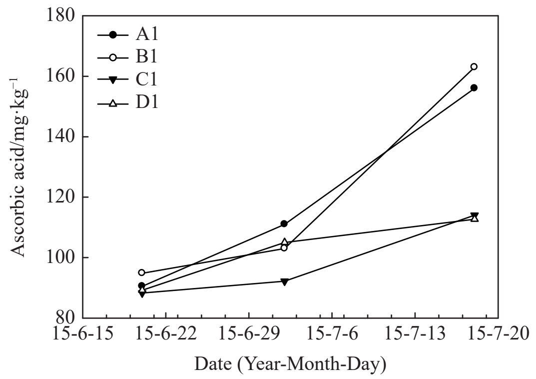
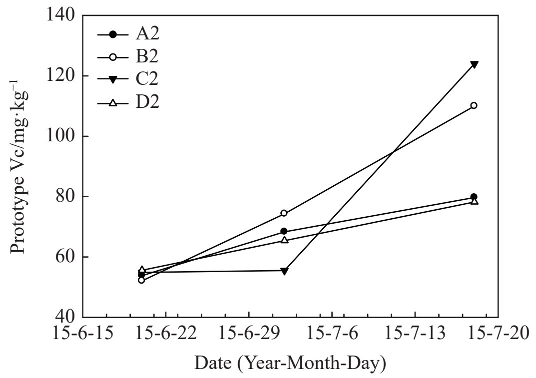


Figure 13 Comparison of average ascorbic acid content

From Figure 14, the content of ascorbic acid in fruit increased along with the growth of tomato fruit. There was no significant difference between those treatments at the early fruit stage when the fertilization ratio was low. There was no significant difference between the changing trend of treatment A2 and D2 in the whole



a. When the ratio of topdressing fertilizer and base fertilizer was 1/2



b. When the ratio of topdressing fertilizer and base fertilizer was 2/3

Note: a. When the ratio of topdressing fertilizer and base fertilizer was 1/2; b. When the ratio of topdressing fertilizer and base fertilizer was 2/3

Figure 14 Ascorbic acid changing trend

fruit stage. So topdressing frequency had little effect on the content of ascorbic acid. When the ratio of topdressing and base fertilizer was 2/3, it was suggested that topdressing was in low frequency at the early fruit stage and the later fruit stage.

From Figure 14, with the increase in fertilization ratio, the average content of ascorbic acid for treatment A2 decreased by 43.55% compared with treatment A1 in the early fruit stage. The average ascorbic acid content for treatments A1, B1, and D1 was 15.32% higher than treatment C1, which was 59.06% higher than treatments A2 and D2 in the middle fruit stage. The average of ascorbic acid content for treatments A1, B1, and D1 was 43.11% higher than the maximum of treatment B2 in the middle fruit stage, and 91.59% higher than the minimum of treatment C2, while treatment B2 was 33.87% higher than treatment C2. The average of treatment A1 and B1 at the end of the fruit stage was 75.8 % and 50% higher than the average of treatment A1, B1, C1, and D1, and the average of treatment A1, B1, and D1 at the middle fruit stage was higher than treatment A1, D1 by 40.07% at the end of fruit stage. It proved that the average ascorbic acid content in fruit increased by 13.35% and 32.44%, respectively. In the middle fruit stage, the change for treatment A1 was the largest with an increase of 22.65 %, it was the smallest for treatment C1 with an increase of 4.42 %. Compared with the middle fruit stage, it had the largest change with an increase of 52.25 % for treatment B1 and for treatment D1 with the smallest increase of 7 % at the end of the fruit stage.

3.3.3 Total soluble sugar content

From Figure 15, it can be seen that under the same fertilization frequency, improving the topdressing ratio would reduce the total soluble sugar content of tomatoes. The total soluble sugar content of treatment A2, B2, C2 and D2 decreased by 4.07%, 11.86%, 3.52% and 3.89% compared with treatments A1, B1, C1 and D1, respectively. The fertilization methods of three times per fruit stage improved the decline trend of total soluble sugar content. But the overall change was not significant. Except for treatment B2 was significantly smaller than treatment B1. Topdressing frequency has little effect on the total soluble sugar content. At the less level of topdressing, the content increased by 3.34% when the topdressing frequency increased from 1 time to 3 times per fruit stage. When the frequency increased from 3 times to 5 times, the content decreased by 5.8%. However, at the higher fertilization level, it decreased by 3.8% after the topdressing frequency increased from 1 time to 3 times, and when the fertilization frequency increased from 3 times to 5 times, it increased by 4.23%. The difference was not obvious after increasing topdressing frequency.

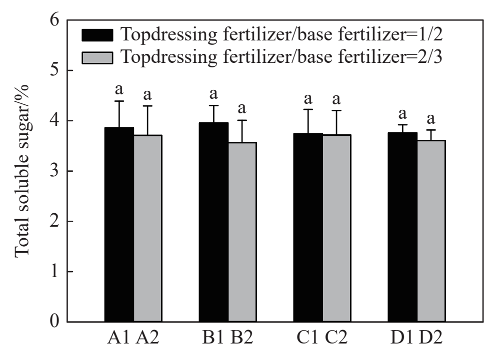
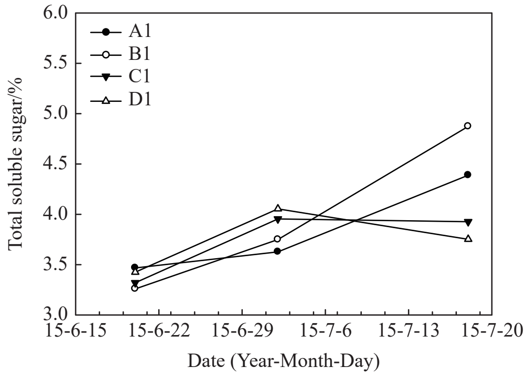


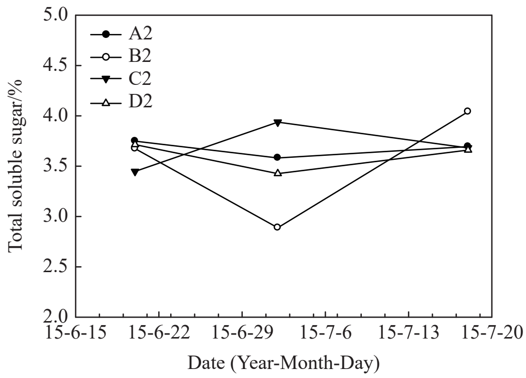
Figure 15 Comparison of total soluble sugar content

From Figure 15, it can be seen that the trend of total sugar content increased at first and then decreased with the increase of fertilization frequency when the ratio of topdressing fertilizer and base fertilizer was 1/2. Fertilization frequency had little effect on the total sugar content at the first and second fruit stage because there was no significant difference between treatments C1 and D1 were only fertilized one time respectively at those stages. When the ratio of topdressing and base fertilizer was 2/3, the changing trend of total sugar content decreased at first and then increased. There was no significant difference between treatments C2 and D2 and the same as between treatments C1 and D1. Compared with the treatments A1, D1, and A2, D2, it can be found that the total sugar content decreased under the condition of topdressing one time at the first and second fruit stages and five times at the last two fruit stages. There were no significant differences among the four treatment groups.

From Figure 16, it can be seen that in the whole fruit stage, the change of total sugar content under different fertilization frequencies was different when the ratio of topdressing fertilization and base fertilization was 1/2. The total soluble sugar content was higher when the topdressing fertilization was 1 time and 3 times per fruit stage under the low topdressing level. Under the high topdressing level, the total soluble sugar content was higher when topdressing was divided into 5 times during the fruit stage. It showed that low fertilization frequency increased the amount of single fertilizer, then excessive fertilizer reduced the total soluble sugar content. However, as shown in Figure16., total soluble sugar content increased by 39.72% for the treatment C2 from the middle fruit stage to the end of the fruit stage, when the fertilization was 3 times per fruit stage under higher fertilization level. At the low fertilization level, treatment C1 was 29.87% higher than that at the same fruit stage with the same fertilization frequency. The fertilization frequency was 3 times per fruit stage from the middle fruit stage, the total soluble sugar content was higher because the amount of topdressing increased appropriately.



a. Topdressing fertilizer/base fertilizer=1/2



b. Topdressing fertilizer/base fertilizer=2/3

Figure 16 Total soluble sugar change trend

3.3.4 Titratable acidity content of Tomato

It can be seen from Figure 17, the titratable acidity content in fruit reduced with the increase of topdressing ratio under the same fertilization frequency. The content of titratable acidity decreased by 8.33%, 5.05%, 5.71%, and 2.86%, respectively. When the ratio of topdressing fertilizer and base fertilizer was 1/2, titratable acidity content decreased firstly and then increased with the increase of fertilization frequency. When the ratio of topdressing fertilizer and base fertilizer was 2/3, the changing trend of titratable acidity content was the same as the low topdressing ratio, which decreased firstly and then increased with the increase of topdressing frequency, and reached the lowest when the topdressing frequency was 3 times. There were no significant differences among the four treatment groups.

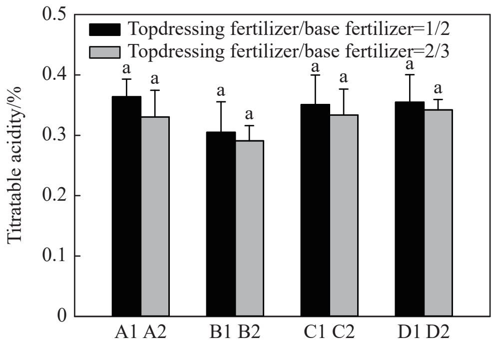
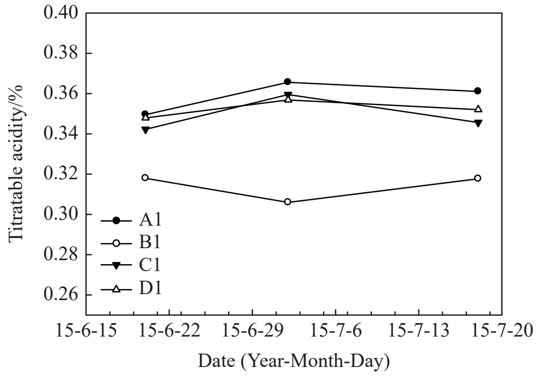
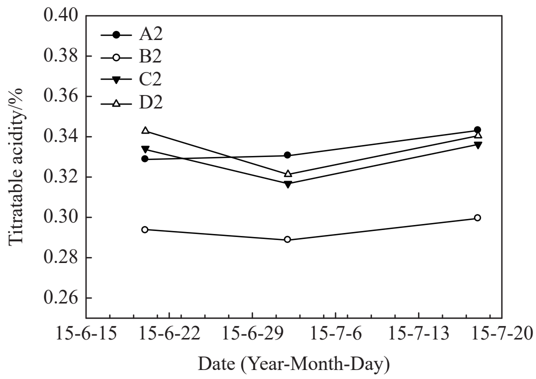


Figure 17 Comparison of titratable acidity content

From Figure 18, it can be seen that when the ratio of topdressing fertilizer and base fertilizer was 1/2, the variation trend of titratable acidity content under different fertilization frequencies was nearly the same in the fruit stage, however, as for the treatment of different fertilization amount was different. Except for treatment B1, the titratable acidity content between the other treatments were



a. Topdressing fertilizer/base fertilizer=1/2



b. Topdressing fertilizer/base fertilizer=2/3

Figure 18 Titratable acidity change trend basically the same, and the change was not significant with the growth. The titratable acidity content of treatment B1 was significantly lower than that of other treatments, but it did not change significantly with the extension of the period of fruit stages.

From Figure 18, it can be seen that when the ratio of topdressing fertilizer and base fertilizer was 2/3, the increase of fertilization had little effect on the titratable acidity content in fruit along with the growth. Moreover, treatment B2 was still significantly lower than the other treatments, but there was no significant difference between treatments A2, C2, and D2.

3.3.5 Sugar acid ratio

From Figure 19, it can be seen that when the ratio of topdressing fertilizer and base fertilizer was 1/2, the sugar acid ratio increased firstly and then decreased with the increase of fertilization frequency. There was no significant difference between treatment D1 and C1. While the ratio of topdressing fertilizer and base fertilizer was 2/3, the sugar acid ratio increased first and then decreased with the increase of fertilization frequency. However, the changes in treatment D2 and C2 were different from treatment C1 and D1, which showed that treatment C2 decreased slightly when the fertilizer amount was less than treatment D2.

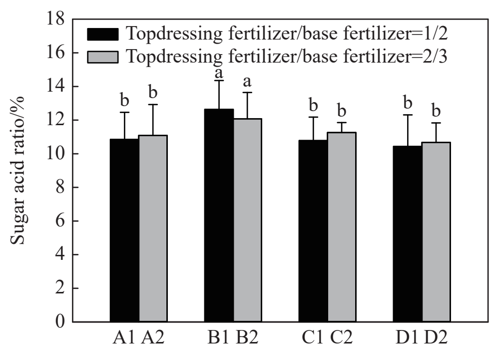


Figure 19 Comparison of sugar acid ratio in different treatments

It can be seen that from Figure 19 under the same fertilization frequency, except for treatment B1 and B2, the other treatment were higher in sugar acid ratio than those with higher topdressing amount. Under the same fertilization frequency, increasing the amount of fertilizer had a great influence on the sugar-acid ratio. There were significant differences between the B treatment group and A, C, and D treatment groups.

According to the analysis of total soluble sugar, the soluble sugar content of treatment when fertilizer was applied three times per fruit stage was higher than other treatments. Moreover, under this topdressing frequency, the titratable acid was smaller than the other treatments. Therefore, a higher sugar-acid ratio was obtained when topdressing 3 times per fruit stage even with the smallest amount of topdressing.

3.4 Effects of the fertilizer ratio and fertilization frequency on the dry matter of celery

The ratio of root and leave under different topdressing ratio and topdressing frequency was shown in Figure 20, each treatment had three columns which represented the percentage of dry matter in root and stem on 4th Nov, 10th Nov, and 26th Nov. Celery stem was the main edible part, the dry matter of stem for treatment B1, C1, C2, and D2 were increasing during the whole growth period, especially it was the largest for treatment C2. However, the increase of dry matter for stem was more, and the ratio of root and leave was sharply decreased for treatments B1, C1, and D2. The dry matter of stem decreased for treatments D1 and A2, and the other two treatments showed a trend of increasing first and then decreasing. The dry matter of stem for treatments B1 and C2 reached a higher peak at the end of the reproductive period compared to the other treatments.

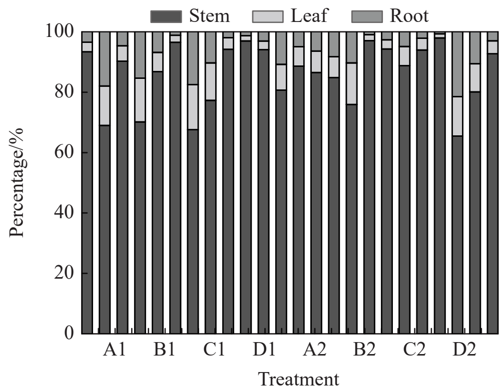


Figure 20 Percentage of roots and leaves under different topdressing ratio and topdressing frequency

3.5 Comparison of yield and growth rate under different fertilizer ratio and topdressing frequency for Celery

The difference between the yield under different topdressing ratios and topdressing frequencies was not significant. The basic yield ranged from 150-200 g, which was increased slowly with the increase of fertilization frequency. The yield order between the treatment from small to large were A1, B1, C1, D1, A2, B2, C2, D2, the highest was treatment D1 with 192.01 g, and the lowest was treatment A1 with 146.09 g. Yield varied obviously with the topdressing ratio, the fertilization method with the ratio of topdressing fertilizer and base fertilizer was 2/3 was more beneficial to the yield compared with the ratio of topdressing fertilizer, and base fertilizer was 1/2 in treatments A, B, and C. However, the yield of treatment D1 was more than treatment D2. It can be concluded that under the condition of a certain fertilization ratio, lower fertilization frequency in the early growth period and higher frequency in the later period were more beneficial to the increase of celery yield. When the fertilization ratio of topdressing fertilizer and base fertilizer was 1/2, it was always more beneficial to the increase of celery yield. There were significant differences between A and B treatment groups and C and D treatment groups (Figure 21).

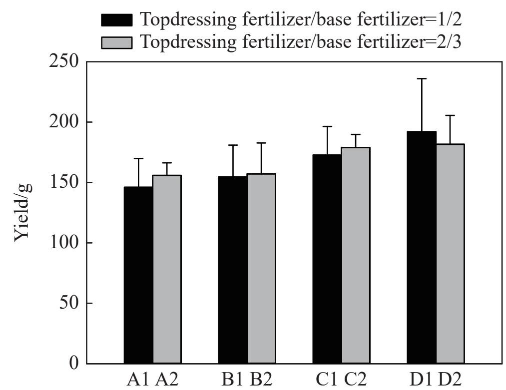


Figure 21 Comparison of celery yield under different fertilization ratio and topdressing frequency

3.6 Effects of fertilization ratio and fertilization frequency on the quality of Celery

The content of ascorbic acid for the celery was shown in Figure 22, when the ratio of topdressing fertilizer and base fertilizer was 1/2, the content of ascorbic acid increased firstly and then decreased, the rank from large to small were C1, B1, A1, D1. However, there was a decline trend when the ratio of topdressing fertilizer and base fertilizer was 2/3, the rank from large to small were A2, B2, C2, D2. The highest was about 108 mg/kg for treatment A2. It can be seen that increasing the fertilization frequency to a certain did not increase the content of ascorbic acid. The frequency of fertilization which was once a week can be more beneficial to the accumulation of ascorbic acid in celery.

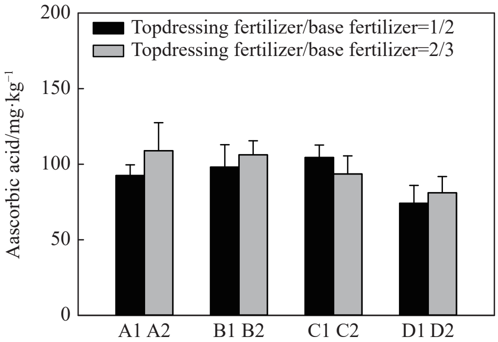


Figure 22 Comparison of average ascorbic acid content

The content of total soluble sugar for the celery were shown in Figure 23. When the ratio of topdressing fertilizer and base fertilizer was 1/2, the content of total soluble sugar increased firstly and then decreased, the rank from large to small were C1, B1, A1, D1. The content of total soluble sugar increased firstly, then decreased, and finally increased, the rank from large to small were B2, C2, D2, A2 when the ratio of topdressing fertilizer and base fertilizer was 2/3. The highest was about 1.15% for treatment A2. It can be seen that under the fertilization frequency of once a week and twice a week when the ratio of topdressing fertilizer and base fertilizer was 2/3, the total soluble sugar was higher and increased with the frequency of fertilization. When the ratio of topdressing fertilizer and base fertilizer was 1/2, the total soluble sugar is higher under fertilization three times a week, one time in the first fruit stage and five times in the second fruit stage, respectively. Then the low frequency of early fertilization and high frequency of later fertilization reduced the total soluble sugar content in celery.

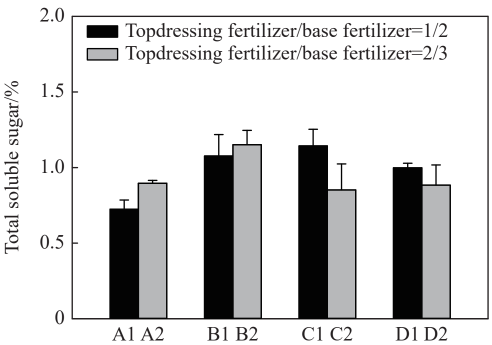


Figure 23 Comparison of total soluble sugar content

The content of crude fibers for the celery were shown in Figure 24. When the ratio of topdressing fertilizer and base fertilizer was 1/2, the content of crude fiber increased firstly, then decreased, and finally increased, the rank from large to small were B1, D1, A1, C1. When the ratio of topdressing fertilizer and base fertilizer was 2/3, the trend increased first and then decreased. The highest was about 1.61% for treatment C2. It can be seen that the crude fiber was higher when the ratio of topdressing fertilizer and base fertilizer was 1/2 under the fertilization frequency of once a week. As for the fertilization, the frequency increased to twice a week, the crude fiber when the ratio of topdressing fertilizer and base fertilizer was 2/3 was more than the ratio of topdressing fertilizer and base fertilizer was 1/2. And under the frequency of fertilization was five times per week, and the crude fiber content in celery was higher when the ratio of topdressing fertilizer and base fertilizer was 2/3.

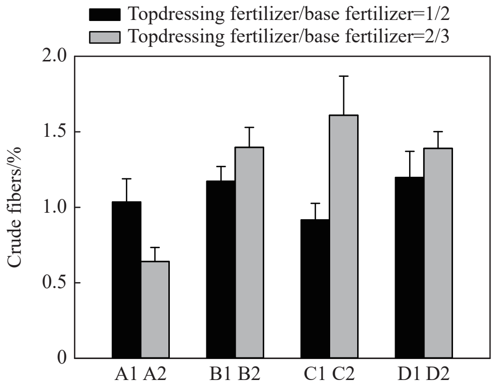


Figure 24 Comparison of crude fibers content

4 Discussion

A small amount of irrigation is of great significance for reducing water leakage loss in the field[36]. The small amount and continuous subsurface drip irrigation only affect soil moisture at 0-40 cm, with less impact on deep soil. Fertilizer application had an important effect on tomato yield[36]. When the ratio of topdressing fertilizer and base fertilizer was 1/2, the effect on the accumulation of dry matter in the underground tomato plant was more obvious for treatment C1. When the ratio of topdressing fertilizer and base fertilizer was 2/3, the effect on the accumulation of dry matter in the underground tomato plant was more obvious for treatment C2.

The difference in nitrate content in fruit decreased with the growth of fruit, and the difference in change trend decreased in the fruit period. The difference reached the minimum at the end of the fruit stage when the ratio of topdressing and base fertilizer was 1/2. When the ratio comes to 2/3, the minimum was reached at the middle fruit stage. The difference at the end of the fruiting stage had a slight increase. However, NC content, which increased with the amount of N, was the highest in treatment B2, which was consistent with the results of Kuscuet et al[37]. In addition, NC content in this study was well below the national standard (600 mg/kg) recommended by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (GB18407.12001), which indicated that tomatoes produced under the current strategies of N management were acceptable and healthy.

The content of ascorbic acid decreased with the increase of fertilizer amount, because of the increased amount of added N when N supplied was below 240 kg/hm^2. While it began to decrease when N supplied was above 320 kg/hm^2, Zhang et al[38] and Kuscuet et al[37] reported similar results.

The taste of tomatoes is largely determined by the soluble sugar and organic acid content and their ratio[25]. The effect of different fertilization levels on the sugar acid ratio of tomatoes is very significant[36]. The fertilization which got higher total sugar content was 5 times per stage under the lower fertilization level at the middle fruit stage and end of fruit stage, then the amount of fertilizer was properly increased and supplied 3 times per stage. The titratable acidity content in fruit decreased first and then increased when the topdressing frequency was increased under the same topdressing ratio. That is, the lowest titratable acidity content can be achieved by topdressing 1 time, 3 times, and 5 times per stage. There was no significant difference between treatments A2, C2, and D2 when the amount of topdressing fertilizer was large.

The ammonium sulfate treatment during the early growth stage tended to obtain the highest yield and N content but the lowest harvest[39]. However, in this experiment, the frequency of early fertilization in each growth period was lower, and the higher frequency of later fertilization was more beneficial to increasing the celery yield. There was little difference between 336 and 504 kg/ha urea ammonium nitrate treatment on most plant parameters throughout the growth period[39]. It was more beneficial to increase celery yield when the ratio of topdressing fertilizer and base fertilizer was 1/2. Phosphorus and potassium fertilizer should be applied preplant to get the maximum benefit from their use[23]. A better approach would be to either eliminate the practice of top-dressing or top-dress only a token amount (20-50 lb N/acre), concentrating instead on applying more N through fertigation later in the season, when the crop is better able to utilize it[40]. It can be seen that the higher ratio of topdressing, the higher frequency of early-stage fertilization and the lower frequency of late-stage fertilization can get the better the quality for celery.

5 Conclusions

The topdressing frequency affected dry matter accumulation. Taking the dry matter accumulation above the soil into consideration, medium fertilization frequency treatments (B1, B2) increased obviously during the first two fruit periods, while the high fertilization frequency treatments (C1, C2) increased obviously during the later two fruit periods. The amount of topdressing had little effect on the fresh weight of the tomato plant above the soil. The effect of high fertilization frequency (C1, C2) on the accumulation of dry matter in the underground tomato was more obvious.

On a certain amount of fertilizer, the growth rate and yield of tomato was positively correlated with the topdressing amount. With the growth of tomatoes, increasing the frequency of fertilization in every fertilizer cycle was a good scheme. The results showed that 1 times fertilization in the first fruit stage. 3 times fertilization in the second fruit stage, 5 times fertilization in the third fruit stage, and in the fourth fruit stage increased the topdressing frequency and began topdressing fertilization before the tomato grew to 40 mm (walnut size).

The results showed that the ratio of fertilizer and frequency of fertilization had different effects on tomato quality. Compared with the other topdressing frequency, the content of nitrate and total soluble sugar in fruit was the largest when the topdressing was 3 times, but the titratable acidity content was the smallest. Increasing the total amount of fertilizer will increase the nitrate content in fruit, and reduce the content of ascorbic acid, titratable acidity, and total soluble sugar in tomatoes.

The early fertilization frequency was lower, and later fertilization frequency was higher, which was beneficial to increase the celery yield. When the fertilization amount reached a certain level, it was more beneficial to increase the celery yield when the ratio of topdressing fertilizer and base fertilizer was 1/2. However, the celery quality showed the opposite results compared with the yield. It can be concluded that the higher ratio of topdressing, the higher frequency at an early stage, and the lower frequency at a later stage can get the better quality for celery.

Acknowledgements

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