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Research Article

Effects of Rhizosphere Ventilation on Soil Enzyme Activities of Potted Tomato under Different Soil Water Stress

In order to improve the growing environment of root zone, and investigate the effects of different rhizosphere ventilation environments on soil enzyme activities, we supplied gas for potted tomato by air compressor, and set three irrigation levels (70–90% field capacity). Each irrigation level has different ventilation volume coefficient (0.4, 0.8, 1.2, and 1.6) with the reference standard as 50% soil porosity. The results showed that the changing trend of soil catalase, urease, and dehydrogenase activity showed the first increase and then the decrease in the tomato growth period, and activities of soil catalase, urease, and dehydrogenase under the ventilation treatment are higher than those of the non-ventilation. When the irrigation level was 80% the field capacity and the ventilation coefficient was 0.8, the activities of three soil enzyme reached the highest value. Their activities of soil catalase, urease, and dehydrogenase were particularly sensitive to rhizosphere ventilation in fruit expanding process. Tomato had more dry matter accumulation and output under the ventilation treatment than that of the non-ventilation. The results prove that rhizosphere ventilation can improve the potted tomato root zone environment, increase the soil enzyme activity, and promote the nutrients uptake, thus promoting plant growth and fruit output and improving soil quality.

Keywords: Catalase activity; Dehydrogenase activity; Soil quality; Urease activity

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1 Introduction

Soil enzymes can affect decomposition of organic matter in soil and soil fertility improvement [1–3] and plant growth. Soil enzymes are specific catalyst for different organic matter in soil. Because soil enzyme is involved in the biochemical processes of decomposition of organic matter, and soil has the metabolic capacity [4–23], soil enzyme activity is an important indicator of soil microbial activity and soil fertility evaluation [9–11]. Soil catalase formed by biological respiration process and the biochemical oxidation of organic matters can be widely found in soil, and it can promote the decomposition of toxic hydrogen peroxide in organisms (including soil), so it has a certain detoxification property. It also can be used to indicate the strength of the soil oxidation and is closely related to the decomposition of organic matter, and it can affect soil fertility [12–35]. Soil urease is produced by soil microbes; it can catalyze the decomposition of urea into ammonia, carbon dioxide, and water that is beneficial for plants absorption, which is important for improving the utilization of soil nitrogen and promoting nitrogen cycle. Dehydrogenase mainly live in living biological cells can catalyze redox reactions and promote the dehydrogenation of organic matter, which is an important sensitive indicator of soil activity and quality [35–47]. In addition to soil moisture, temperature, and humidity can affect soil enzyme activity. Soil air permeability and soil air composition and other factors can also affect soil enzyme activity. Therefore, the effect of rhizosphere ventilation on soil enzyme activity for potted tomato is significant to elucidate the principles of rhizosphere ventilation that can improve soil quality and promote plant growth, further optimizing the cultivation technology of potted tomato [23, 24, 39–47]. Many scholars study the soil permeability and soil air components in combination with plant growth, the results showed that soil has higher carbon dioxide content and lower oxygen content compared to atmosphere. When the oxygen content is poor and the carbon dioxide content increased to a certain degree in root zone, the plant will have a negative impact [25–39]. When the plant roots are during hypoxia condition, it may accelerate the root cell death, while O_2 can remain root activity in extreme conditions [28, 29, 39–47]. The soil is more suitable for the breeding of bacteria when the CO_2 content is high in soil, and it can inhibit plant growth [30–32]. Suitable soil ventilation volume can promote plant growth and improve fruit yield and quality [33–35]. Soil enzyme is involved in all biochemical reactions in soil, it is an important indicator to evaluate the soil quality [40–47], so the soil enzyme activity has got more and more attention [36, 37]. There are many studies about the effect of high CO_2 concentrations on soil enzyme activity at home and abroad, but the conclusions are not entirely consistent [36–47]. In summary, so far the research about the

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direct impact of rhizosphere ventilation on soil enzyme activity was relatively less. We set different levels of ventilation and irrigation levels to study potted tomato rhizosphere soil enzyme activities, in order to obtain the appropriate water and gas combination for improving the crop root environment, raising crop production, and providing related theoretical basis for sustainable soil resources utilization.

2 Materials and methods

2.1 Tested materials

The test was carried out in three grade platform terrace of central Shaanxi plain from July to November in 2010, in which the average annual sunshine hour is 2163.8 h, the frost-free period is 210 days, in August the rainfall is frequent, so it is a humid zone in arid region. The tested tomato is named *Tian Ze Chun Lei*. In the test the gas content of rhizosphere ventilation is the same as air. The test soil is Lou soil, which was gotten from the 20 cm depth land surface, the main physical properties of the testing soil are shown in Tab. 1.

2.2 Tested method

Plastic barrels with upper diameter 28.5 cm, bottom diameter 21 cm, and height 24.5 cm are used as cultivation container. We put a plastic hose with inner diameter 8 mm in spiral form at the bottom of the plastic barrel, and tied one end of the hose to prevent gas leakage. The hose has eight special gas outlets in its wall, each hole's diameter is 2 mm and every two holes' interval is 10 cm, and we let the other end of the hose stay outside to link with air compressors. In order to prevent the holes clogging, the hose and soil are separated with floss silk, then load soil layer by layer and make soil compacted by hammer until there are 13 kg soil in the barrel. It took 20 days breeding seedlings in the greenhouse, then the seedlings with the same growth vigor were transplanted into the barrel, every barrel had one seedlings and its soil surface was covered after transplanting to prevent soil surface evaporation. We controlled irrigation level with the measuring cylinder, ventilation started immediately after irrigation to ensure that the soil is not completely filled by water. The inlet-end was clamped with a clip after ventilating. All treatments had the same fertilization level as the local normal levels.

In the test we set irrigation level and ventilation volume as variables. *L* (low irrigation level) means that the irrigation amount was 70% of field capacity, *M* (mid irrigation level) means that the irrigation amount was 80% of field capacity, and *H* (high irrigation level) means that the irrigation amount 90% of field capacity. Ventilation treatment is controlled by air compressors and is executed once every second day. By taking 50% of soil porosity as the standard ventilation volume, the standard ventilation can be calculated according to Eq. (1):

$$V_a = \frac{\pi h f (1-\theta)}{1000} \quad (1)$$

In the equation V_a is the volume of soil air (L); h the planned irrigation depth (cm); r the radius of the cultivation container (cm); f the soil porosity; θ is the initial volumetric water content (%).

Four ventilation coefficients were set under each irrigation level, *T*1 means the ventilation volume is 0.4 times as the standard; *T*2 means the ventilation volume is 0.8 times as the standard; *T*3 means the ventilation volume is 1.2 times as the standard; *T*4 means the ventilation volume is 1.6 times as the standard. *T*0 means no ventilation. There are 15 treatments in total, with every treatment having eight repeats.

2.3 Measurement items and methods

At the end of each growth stage two repeats with the same growth vigor were damaged to measure shoot, leaf, and root dry mass of tomato plants. At the same time we collected soil samples from 15 cm depth of rhizosphere soil with drill, with each repeat having four samples. When the soil samples become air-dried soil, they will be selected through 1-mm sieve to measure the soil enzyme activity. The activity of catalase was measured by titration; the activity of urease was measured by indophenol colorimetry; the activity of dehydrogenase was measured by triphenyl tetrazolium chloride method. In maturity stage we chose four repeats in every treatment for measuring plant height, stem diameter, and yield.

2.4 Data processing

We used DPS software to collect data, and differences analysis was processed by Duncan new multiple range method.

3 Results and discussions

3.1 Effects of rhizosphere ventilation on enzyme activities under different soil water content

3.1.1 Catalase activity

Table 2 shows the catalase activity under ventilation and irrigation treatments. It can be seen from Tab. 2 that soil catalase activity increased slowly in the flowering and fruit expanding stages while decreased in mature stage, which showed the first increase and then the decrease with the growth of tomato. The catalase activity reached the maximum in fruit expanding stage. For this test the flowering stage was in August, the fruit expanding stage was in September, and maturity stage in October. Soil catalase activity showed significant seasonal variation because it was affected significantly by temperature.

As it can be seen from Tab. 2, rhizosphere ventilation can increase soil catalase activity compared to no ventilation treatments, and in every growing stage the activity of soil catalase showed the first increase and then the decrease when the ventilation volume increased all along under every irrigation level. The soil catalase activity of *T*2 treatment was the maximum between all treatments

Table 1. The main physical properties of testing soil

Dry density ($g\,cm^{-3}$)	Field capacity ($g\,kg^{-1}$)	Wilting water level ($g\,kg^{-1}$)	Total nitrogen content ($g\,kg^{-1}$)	Organic matter content ($g\,kg^{-1}$)
1.25	230	67	0.98	9.51

Table 2. Soil catalase activity under different rhizosphere ventilation treatments (mL g^{-1})

Treatment	FS	FES	MS
*LT*0	0.518^{C}	0.814^{E}	0.461^{BCD}
*LT*1	0.646^{ABC}	0.868^{BCDE}	0.627^{AB}
*LT*2	0.811^{ABC}	1.061^{ABC}	0.653^{A}
*LT*3	0.749^{ABC}	0.974^{ABCD}	0.593^{ABC}
*LT*4	0.705^{ABC}	0.827^{CDE}	0.577^{ABC}
*MT*0	0.574^{BC}	0.611^{E}	0.218^{E}
*MT*1	0.993^{ABC}	1.166^{AB}	0.336^{DE}
*MT*2	1.074^{A}	1.296^{A}	0.593^{ABC}
*MT*3	1.051^{AB}	1.264^{A}	0.624^{AB}
*MT*4	0.880^{ABC}	1.061^{ABC}	0.330^{DE}
*HT*0	0.599^{ABC}	0.696^{DE}	0.411^{CD}
*HT*1	0.686^{ABC}	0.733^{CDE}	0.486^{ABCD}
*HT*2	0.918^{ABC}	1.196^{AB}	0.580^{ABC}
*HT*3	0.749^{ABC}	1.193^{AB}	0.493^{ABCD}
*HT*4	0.661^{ABC}	1.014^{ABCD}	0.443^{BCD}

Different capital letters after the data in every column indicate significant differences levels ($p < 1\%$).
FS, flowering stage; FES, fruit expanding stage; MS, mature stage.

under the same irrigation level. In the flowering stage the difference of the soil catalase activity was not very significant; in the fruit expanding and mature stages the difference between *LT*2 treatment and no ventilation treatment was very significant while the difference between ventilation treatments was not very significant under low irrigation level. The difference of soil catalase activity was very significant between *MT*2 and *MT*0 treatments in the flowering and fruit expanding stages, and the difference between ventilation and no ventilation treatments was also very significant in the mature stage under the mid-irrigation level. In the flowering and mature stages there were not very significant differences of soil catalase activity between all treatments, and in the fruit expanding stage the soil catalase activities of *HT*2 and *HT*3 treatments were very significant higher than *HT*0 treatment under high irrigation level. In addition to the flowering and mature stages under low irrigation level and of fruit expanding stage under high irrigation level, the soil catalase activity showed the first increase and then the decrease as the order of $T2 > T3 > T1 > T4 > T0$.When the ventilation coefficient is 0.8 the soil catalase activity reached maximum. It can be seen from all above that soil air content can increase soil catalase activity when it is proper, which is an important factor to affect soil catalase activity. It also proved that the *T*2 treatment may be the optimum air content for soil respiration, thus increasing the soil catalase activity while the soil catalase activity can also be affected by other factors such as the plant's own growth conditions.

However, rhizosphere ventilation had different effects on soil catalase activity in every growth stage. In flowering stage (August) soil catalase activity is mainly determined by soil temperature because of the higher temperature, so the ventilation treatment had no very significant effect on soil catalase in this stage. In fruit expanding stage the soil catalase activity is sensitive to soil air content. When the ventilation coefficient was 0.8 the soil catalase activity increased significantly compared to no ventilation treatment. The reason for obvious soil catalase activity increase in fruit expanding stage under ventilation treatment is that the tomato growth reached the peak and the temperature and humidity were appropriate during this time, so the appropriate amount of soil air can stimulate soil catalase activity reaching its highest value. When the tomato reached the mature stage it began getting old, and organic matter content in soil was decreasing, and the metabolic capability of microorganisms was decreasing, so the soil enzyme activity decreased. At this time the soil air content had less effect on soil enzyme activity. All the results above suggested that in the fruit expanding stage the rhizosphere ventilation has great effect on soil catalase activity, thus promoting the growth of tomato and improving fruit production.

In addition, the soil water content had great effect on soil catalase activity. When the ventilation volume was constant, the soil catalase activity under mid-irrigation level was higher than that under other two irrigation levels in flowering and fruit expanding stages. The soil catalase activity showed $M > H > L$ under ventilation treatments except *T*4 treatment that showed $MT4 > LT4 > HT4$ in flowering stage and *T*1 treatment that showed $MT1 > LT1 > HT1$ in fruit expanding stage, whatever the soil catalase activity reached the maximum under mid-irrigation level. The soil water content has directly effect on the soil enzyme activity, so the appropriate soil water content can increase soil enzyme activity. The reason for soil catalase activity to have no regular changes with the irrigation levels changing in mature stage may be that the plant own growth conditions and temperature were main factors affecting soil catalase activity when the plant grew old.

3.1.2 Urease activity

Table 3 shows soil urease activity under rhizosphere ventilation and irrigation treatments. From Tab. 3 it can be seen that the soil urease activity showed the first increase and then the decrease with the plant growing and reaching the maximum in fruit expanding stage and had the same changing law with soil catalase activity. Temperature directly affecting urease activity led to the same trend between urease and catalase activity.

As it can be seen from Tab. 3, the soil urease activity also showed the first increase and then the decrease with the increase of ventilation volume under ventilation treatment and was higher than that of no ventilation in each irrigation level because rhizosphere ventilation improved soil air environment, further raising soil quality. The soil urease activity had very significant difference between *LT*2 and other treatments in flowering and fruit expanding stages while

Table 3. Soil urease activity under different rhizosphere ventilation treatments (mg g^{-1} day^{-1})

Treatment	FS	FES	MS
*LT*0	1.155^{GH}	1.526^{H}	0.762^{DEF}
*LT*1	1.841^{EF}	1.901^{GH}	1.572^{CDE}
*LT*2	2.633^{BC}	2.910^{DE}	2.005^{BC}
*LT*3	1.956^{DEF}	2.138^{FGH}	1.841^{BC}
*LT*4	1.703^{FG}	1.756^{GH}	1.125^{CDEF}
*MT*0	1.097^{H}	1.953^{GH}	0.198^{F}
*MT*1	1.273^{GH}	2.253^{FG}	0.514^{F}
*MT*2	3.516^{A}	4.836^{A}	3.601^{A}
*MT*3	2.789^{BC}	3.833^{BC}	2.765^{AB}
*MT*4	2.298^{CDE}	2.631^{EF}	1.793^{BCD}
*HT*0	2.492^{BCD}	3.446^{CD}	0.606^{EF}
*HT*1	2.590^{BC}	3.551^{C}	1.185^{CDEF}
*HT*2	2.973^{B}	4.749^{A}	2.063^{BC}
*HT*3	2.790^{BC}	4.686^{A}	1.993^{BC}
*HT*4	2.654^{BC}	4.216^{AB}	1.962^{BC}

Different capital letters after the data in every column indicate significant differences levels ($p < 1\%$).
FS, flowering stage; FES, fruit expanding stage; MS, mature stage.

it had no very significant difference in mature stage by showing $T2 > T3 > T1 > T4 > T0$ in each growth stage of tomato plants in low irrigation level. The soil urease activity in other two irrigation levels showed $T2 > T3 > T4 > T1 > T0$ in each growth stage. The soil urease activity under *MT*2 treatment had very significant difference compared to other treatments in flowering and fruit expanding stages in mid-irrigation level, and the soil urease activity under *MT*2–*MT*4 treatments were much higher than that under *MT*0. In high irrigation level there were no very significant differences between every treatment in flowering stage, in fruit expanding, and mature stages *HT*2–*HT*4 treatments had higher soil urease than those without ventilation treatment, but there were no very significant differences between ventilation treatments. Maybe the soil air content is suitable for crop roots and soil microbial metabolism under *T*2 treatment because, and promote enzyme secretion increasing, thereby, increasing the soil urease activity, but urease activity is also affected by soil organic matter and plant own conditions and other factors. So the suitable amount of air in soil can significantly increases urease activity and promotes plant growth.

The soil urease activity was significantly affected by ventilation in every irrigation Level. When the ventilation coefficient is 0.8, urease activity under *LT*2 (2.633 mg g^{-1} day^{-1}) treatment is higher than that under *LT*0 (1.155 mg g^{-1} day^{-1}), increasing by 2.28 times, urease activity under *MT*2 (3.516 mg g^{-1} day^{-1}) treatment is higher than that under *MT*0 (1.097 mg g^{-1} day^{-1}), increasing by 3.31 times, urease activity under *HT*2 (2.973 mg g^{-1} day^{-1}) treatment is higher than that under *HT*0 (2.492 mg g^{-1} day^{-1}), increasing by 1.19 times in flowering stage; in fruit expanding stage urease activity under *LT*2 (2.910 mg g^{-1} day^{-1}) treatment is higher than that under *LT*0 (1.526 mg g^{-1} day^{-1}), increasing by 1.91 times, urease activity under *MT*2 (4.836 mg g^{-1} day^{-1}) treatment is higher than that under*MT*0 (1.953 mg g^{-1} day^{-1}), increasing by 2.48 times, urease activity under *HT*2 (4.749 mg g^{-1} day^{-1}) treatment is higher than that under *HT*0 (3.446 mg g^{-1} day^{-1}), increasing by 1.38 times. In tomato growth period rhizosphere ventilation has large effect on soil urease, especially in flowering and fruit expanding stages when urease activity can be significantly increased and promote crop growth under *T*2 treatment.

When the ventilation volume is constant, soil urease activity increased with the soil water content increasing, which indicated that soil moisture directly affects urease activity. The reason why when the ventilation treatment was *T*2 in the mid-irrigation level soil urease activity reached the highest value in its different growth stages may be that the ratio of water and air content is more appropriate for soil respiration and microbe growth and metabolism. It was proved that soil water and air content influencing soil urease activity are interacted with each other. While urease activity did not increase with soil moisture under *T*1 treatment in flowering and mature stages, the soil urease activity was also affected by plant root growth and other factors.

3.1.3 Dehydrogenase activity

Table 4 is soil dehydrogenase activity change under rhizosphere ventilation and irrigation treatments. The soil dehydrogenase activity increased at first and then decreased and reached its maximum in fruit expanding stage, whose changes as the same as those preceding two enzyme.

It can be seen from Tab. 4, soil dehydrogenase activity changed as $T2 > T3 > T4 > T1 > T0$ in each growth stage of the same irrigation level in addition to flowering stage of mid-irrigation level that changed as $MT2 > MT3 > MT1 > MT4 > MT0$. Soil dehydrogenase activity showed the increase and then the decreases with the ventilation volume increasing, and the *T*2 treatment had the highest soil dehydrogenase activity. Dehydrogenase present in all living organisms cells, therefore, soil dehydrogenase activity are closely related with the growth and metabolism of microbe. The soil air content directly impacts the growth and metabolism of microbe, and suitable air content can significantly increase soil dehydrogenase activity.

Table 4. Soil dehydrogenase activity under different rhizosphere ventilation treatments (mg g^{-1} day^{-1})

Treatment	FS	FES	MS
*LT*0	0.064^{a}	0.082^{c}	0.058^{c}
*LT*1	0.078^{a}	0.090^{bc}	0.080^{abc}
*LT*2	0.112^{a}	0.131^{ab}	0.109^{a}
*LT*3	0.098^{a}	0.113^{abc}	0.104^{ab}
*LT*4	0.079^{a}	0.099^{abc}	0.086^{abc}
*MT*0	0.072^{a}	0.084^{bc}	0.071^{bc}
*MT*1	0.085^{a}	0.101^{abc}	0.072^{bc}
MT2	0.120^{a}	0.146^{a}	0.096^{ab}
*MT*3	0.098^{a}	0.121^{abc}	0.095^{ab}
*MT*4	0.081^{a}	0.109^{abc}	0.089^{abc}
*HT*0	0.077^{a}	0.090^{bc}	0.079^{abc}
*HT*1	0.083^{a}	0.098^{bc}	0.080^{abc}
*HT*2	0.100^{a}	0.119^{abc}	0.092^{ab}
*HT*3	0.092^{a}	0.111^{abc}	0.087^{abc}
*HT*4	0.092^{a}	0.102^{abc}	0.087^{abc}

Different letters after the data in every column indicate significant differences levels ($p < 5\%$).

Soil dehydrogenase activity had different response to ventilation in different growth stages. Under the same irrigation level, there were no significant differences between ventilation and no ventilation treatment in flowering and mature stages. In the fruit expanding stage when ventilation coefficient was 0.8, dehydrogenase activity under *LT*2 treatment was significantly higher than *LT*0, and the former is 1.60 times as the latter, also showing significant differences between *MT*2 and *MT*0 treatments. Soil dehydrogenase activity perhaps mainly depends on temperature and crop itself in flowering and mature stages, the ventilation treatment increased soil dehydrogenase activity but not significant; while in fruit expanding stage ventilation had significant effect on soil dehydrogenase activity because other factors achieved their best conditions; so at this stage appropriate amount of soil air can significantly increase soil dehydrogenase activity.

However, soil dehydrogenase activity did not show a certain law with the irrigation level increasing. The reason is that the soil dehydrogenase activity is not only affected by soil water content but also by soil properties, temperature, and crop own growth, and many other factors, and the interaction between multiple factors is not be clear for soil dehydrogenase activity.

3.2 Effects of rhizosphere ventilation irrigation on growth of potted tomato

3.2.1 Plant dry matter accumulation

Figure 1 shows plant dry matter accumulation and root/shoot ratio under rhizosphere ventilation and irrigation treatments. It can be

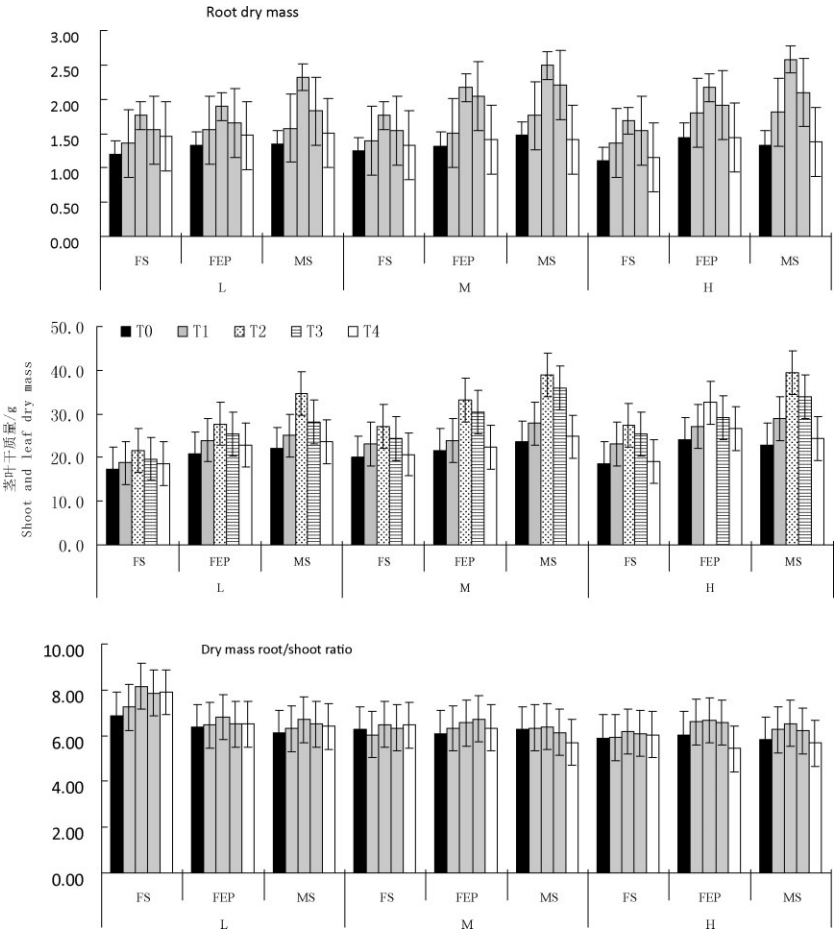

Figure 1. Plant dry mass and root/shoot ratio under different rhizosphere ventilation treatments.

seen that rhizosphere ventilation had great impact on the growth of tomato plants. The dry matter accumulation and root/shoot ratio were significant larger under ventilation treatment than that under non-ventilation and reached the maximum under *T*2 treatment in each irrigation level. Plant dry matter accumulations of tomato leaves, stems, and root increased with plant growth; in the mature stage shoot and leaf and root dry weight under *LT*2 treatment were higher than that under *LT*0 treatment, increasing by 57.36 and 72.49%, respectively; shoot and leaf and root dry weight under *MT*2 treatment were higher than that under *MT*0 treatment, increasing by 65.95 and 68.81%, respectively; shoot and leaf and root dry weight under *HT*2 treatment were higher than that under *HT*0 treatment, increasing by 93.26 and 72.46%, respectively. Root/shoot ratio had no significant differences between ventilation and non-ventilation treatments in addition to flowering stage of low irrigation level. There were growth differences between plants, which may mainly determine the value of tomato root/shoot ratio.

When the ventilation volume is constant, tomato shoot and leaf, root dry weight did not change much with the irrigation levels changing. It further proved that the rhizosphere ventilation have a direct impact on the growth of tomato, especially on the root dry matter accumulation.

3.2.2 Plant height and stem diameter

Figure 2 shows plant height and stem diameter in mature stage under rhizosphere ventilation and irrigation treatments. From Fig. 2 we can see that plant height varies under different ventilation treatment in every irrigation level when entering mature stage and all have the highest value under *T*2 treatment. Tomato plants under ventilation treatment were higher than non-ventilation treat-

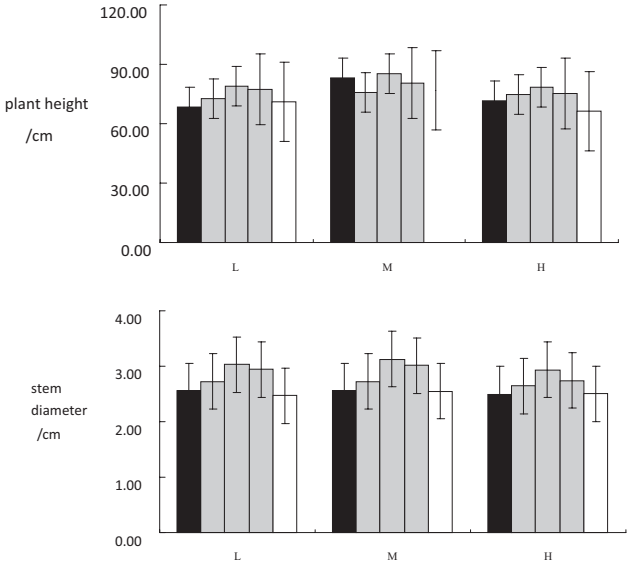

Figure 2. Plant height and stem diameter under different rhizosphere ventilation treatments.

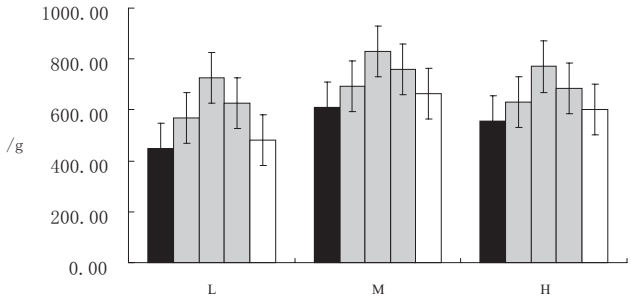

Figure 3. Tomato output under different rhizosphere ventilation treatments.

ment in low irrigation level; in mid-irrigation level non-ventilation plants were the second highest after that of *T*2 treatment, and ventilation plants except *T*4 treatment were higher than that of non-ventilation in high irrigation level. It showed that excessive soil water will lead to tomato plants ''spindling'' and is not conducive to dry matter accumulation while rhizosphere ventilation can alleviate this situation. Plant stem diameter changed as $T2 > T3 > T1 > T4 > T0$ in every irrigation level. When the ventilation volume is constant, stem diameter did not show significant change law with the irrigation water changing. Therefore, the appropriate ventilation volume can promote the growth of tomato plants, and increase the accumulation of dry matter.

3.2.3 Yield of potted tomato

Figure 3 shows the yield of potted tomato under rhizosphere ventilation and irrigation treatments. It can be seen that in every irrigation level the ventilation treatment had significantly higher yield than that of non-ventilation treatment; the changing trend is expressed as $T2 > T3 > T1 > T4 > T0$, and tomato yield under *T*2 treatment was significantly higher than that of other treatments, which indicates that the tomato yield is sensitive to rhizosphere ventilation. When the ventilation volume was constant, potted tomato yield changes with irrigation level also showed the first increase and then the decrease and reached the maximum in mid-irrigation level. Therefore, the potted tomato had the maximum yield in mid-irrigation level when the ventilation coefficient is 0.8, which indicates that the rhizosphere environment directly affects crop yield.

4 Discussion

Soil enzymes are secreted by the residues of plant roots, soil animals, and their remains and micro-organisms can catalyze this complex organic material into simple inorganic compounds in soil and make them easy for plant absorption and utilization. Soil moisture, air, and heat conditions have significant impact on the enzyme activity [1, 8–19]. The experimental results show that the activity of catalase affected significantly by temperature first increased and then decreased in growth stages of tomato, and reached its maximum in fruit expanding stage, which is in agreement with other scholars' results [21–23]. In different growth stages, ventilation soil catalase activity was higher than non-ventilation treatment, and in the fruit expanding stage soil catalase activity was significantly affected by ventilation; appropriate ventilation can significantly increase the soil catalase activity, and the optimal combination is *MT*2. Soil urease activity has the maximum value in fruit expanding stage, and rhizosphere ventilation that significantly increased the urease activity than those without ventilation treatment and reached the highest value under *MT*2 treatment has great effect on soil urease activity. Soil dehydrogenase activity has its maximum under *MT*2 treatment in fruit expanding stage. Our studies have shown that ventilation significantly improved cultivation substrate ventilation condition, and ventilation increased enzyme activity of matrix compared with conventional cultivation, which has the same results with other experiment [20, 32–39]. The soil environment changes under ventilation treatment, and O_2 and CO_2 concentration in soil, which further change the metabolic activity of microorganisms [18, 22], so soil catalase, urease, and dehydrogenase activity increase. Different ventilation volume makes the different gas proportion, so the impact on soil enzyme activities are not the same, and the results showed when the ventilation coefficient is 0.8 the soil enzyme activity reached the maximum, but the mechanism is not clear [41–43].

The results showed that the rhizosphere ventilation can promote plant growth, significantly increase dry matter accumulation and tomato yield, and increase root/shoot ratio of tomato plants compared to non-ventilation treatment but the difference was not significant. In every irrigation level when the ventilation coefficient is 0.8 dry matter accumulation of tomato plants reached the maximum; when the ventilation coefficient is 0.8 tomato yield is the most in mid-irrigation level. Sun et al. studied effect of different ventilation space on the growth of tomato plant, the results showed that ventilation could enhance the accumulation of dry matter, and the appropriate air space can increase fruit yield [9]. Chen et al. [5], Guo et al. [11] and Jia et al. [21] also showed that rhizosphere ventilation can increase dry matter accumulation. These results are consistent with this article. The reason lies in the fact that rhizosphere ventilation improved crop root growth environment, and improved nutrient uptake of roots, thus promoting plant growth and increasing yield [24–27, 39–47].

The suitable amount of ventilation volume (*T*2) can make the O_2 and CO_2 concentration of soil air achieve better conditions that is better for microbial growth and metabolism, so leading to the increased soil enzyme activity, which is particularly evident in fruit expanding stage with the maximum. However, those factors that affect soil enzyme activity are too many; they may also include the interaction between factors. Our study only investigated the effect of ventilation soil and moisture on soil enzyme activity, and multi-factor interaction effects on soil enzyme activities remains to be further studied [40–47].

5 Conclusions

On the basis of our current results and previous studies, we have the following conclusions.

(1) Rhizosphere ventilation can increase soil catalase, urease, and dehydrogenase activity of potted tomato plants; soil catalase, urease, and dehydrogenase activity changes as the first increase and then the decrease in the growth stage of tomato plants, and they reached the highest value when the ventilation coefficient is 0.8 in mid-irrigation level in every growth stage; in fruit expanding stage they are particularly sensitive to soil air content.
(2) When the ventilation coefficient is 0.8 plants grow better and have more yield. Therefore, suitable amount of ventilation

volume can improve the tomato rhizosphere soil environment, increase the soil enzyme activity, promote uptake of nutrients, improve plant growth, and increase fruit yield and soil quality.

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