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Effect of rhizosphere aeration by subsurface drip irrigation with tanks on the growth of 'Red Globe' grape seedling and its absorption, distribution and utilization of urea-^{15}N

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ABSTRACT

Aerated irrigation can promote plant growth, increase yield and improve fruit quality, but the study on the effect of aeration irrigation on the absorption and metabolism of plant urea is relatively few. In this study, subsurface drip irrigation (SDI) with tanks technique and ^{15}N tracer techniques were utilized to investigate the effect of the rhizosphere aeration treatment on plant growth and urea absorption, distribution and utilization of 'Red Globe' grape seedlings. The results indicated that the net photosynthetic rate, stomatal conductance and transpiration rate of the leaves increased with the aeration treatment in the same irrigation period. Soil urease and nitrate reductase of the aeration treatment were significantly higher than those from the no aeration treatment at the first, third, and fifth day after irrigation, but the difference was not significant between seedlings of the two treatments at the seventh and ninth day after irrigation. However, experiments that determined the absorption and utilization of the urea-^{15}N in plants indicated that the Ndff values of the plant parts were significantly lower with aeration than those without aeration (CK).The distributions of ^{15}N in these two treatments in the same parts were distinctly different except for the leaves, and the ^{15}N utilization rate (3.46%) of plants with aeration was noticeably obviously lower than that of the CK plants (9.63%).The results showed that when urea was used as the nitrogen source, the rhizosphere aeration treatment performed by SDI with tanks reduced the ability of the organs to absorb nitrogen, and altered the distribution of nitrogen in the different parts of the grape plants. Therefore, we concluded that rhizosphere aeration could improve plant photosynthesis and soil urease and nitrate reductase activity, but it had negative effects on urea uptake, indicating that rhizosphere aeration and urea application did not have synergistic effects.These results suggest that it is not suitable for aeration irrigation when urea is used as nitrogen fertilizer.

1. Introduction

Soil environmental quality has been a serious concern in China (Hu et al., 2017). Long-term and frequent cultivation under greenhouse conditions and the application of a great deal of chemical fertilizer, leads to soil compaction and secondary salinization (Yang et al., 2016). Thus, soil aeration is very important for the normal growth and development of crops. Because aeration irrigation can improve the root soil aeration conditions without significantly increasing cost (Ben-Noah and Friedman, 2016), it has recently become the focus of research in China and other countries (Jacobsen and Hjelmsø, 2014; Lei et al., 2017). The results have indicated that aeration irrigation can increase the content of oxygen in the soil, promote soil carbon dioxide emissions, enhance soil respiration, and improve soil aeration (Abuarab et al., 2013). Chen et al. (2010) found that aeration irrigation can help crop growth and development, and increase production. Their results indicated that aeration treatment after irrigation in potted maize plants can improve the root activity, the photosynthetic performance of the plants and their quality (Bhattarai et al., 2005). Studies using tomato, soybean and other crops also verified the effectiveness of aeration

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treatment after irrigation (Bhattarai et al., 2008; Niu et al., 2012; Li et al., 2016a). However, most of the studies have focused on the effects of aeration irrigation on crop growth and development, and few studies have reported on the nitrogen absorption, distribution and utilization under aeration irrigation.

Nitrogen is one of the mineral nutrient elements necessary for grape growth and development. Thomidis et al. (2016) showed that an adequate supply of nitrogen can promote germination of vines, increase fruit yield, and improve the quality of grapes. Urea ($CO(NH_2)_2$) is a white crystal with good solubility, high nitrogen content and fewer destructive effects on the soil (Wang et al., 2016). It has been widely used as water-soluble fertilizers in the integration of water and fertilizer in drip irrigation (Sun et al., 2016). However, the effects of aeration irrigation on the absorption and utilization of urea have not been reported. Therefore, conducting research on the effects of aeration on grape growth, urea absorption and metabolism has important theoretical and practical significance for both scientific research and for determining effective utilization of aeration irrigation periods.

SDI with tanks is carried out based on the actual demands in the arid areas of fruit production to effectively solve the problems of the root floatation caused by surface irrigation. In addition, traditional drip irrigation is not effective on perennial crops such as fruit trees and it has the problem of the small range of fruit trees in the root zone. A new water-saving drip irrigation technology (has been authorized by the national patent) has been developed by our research team through combining drip irrigation technology with “hole storage and fertilizer technology” put forward by Academy member Shu Huairui. Previous studies have shown that the technology has some advantages in promoting rooting, water saving and fruit yield (Yu et al., 2013, 2014). Rhizosphere aeration based on SDI with tanks has been proposed to serve as a new irrigation technique to grow forest and fruit trees in arid regions. However, there is no report on the effect of this technology on the growth and development of fruit trees. Based on these reasons, this study utilized 2 years old ‘Red Globe’ grape seedlings in pots to determine the effect of rhizosphere aeration under SDI with tanks on the growth, absorption and metabolism of urea using the ^{15}N tracer technique, which will provide a theoretical basis for further research on the use of SDI with tanks for scientific and effective aeration.

2. Materials and methods

2.1. Experimental design

The experiment was conducted from April to October in 2016 in the greenhouse of the Experimental Station (45° 19′N, 86° 03′E) at the Agricultural College of Shihezi University. Two-year-old Red globe grape seedlings were planted on May 9th in a pot with an upper diameter of 35 cm, a bottom diameter of 30 cm, a height of 25 cm and its volume is about 20.77 L. The pots soil used sieved soil from the 0–20 cm depth of the vineyard of the experimental station. The experiment used a water-fertilizer-air integration system based on SDI with tanks for aeration treatment (Fig. 1). The experiment utilized the aeration treatment and without aeration (CK) with replicates of 15 plants which resulted in a total of 30 plants. The same amount of irrigation was used in each treatment, and the other variables were consistent between the two treatments. The treatment with aeration began 15 d after planting (Fig. 2). The soil was aerated every two days for 20 min at a time and from 9:00 to 9:20A.M. (Beijing time). Fifteen days after aeration, 2 g of urea-^{15}N was applied to 15 pots (Shanghai Institute of Chemical Industry production, abundance of 10.08%, also used below).

2.2. Measurement indices and methods

2.2.1. Plant biomass determination

After 31 days of aeration treatment, five grape plants with uniform growth were randomly selected for each destructive sampling. The root and soil were washed on the 100 mesh steel screens to minimize root loss. The whole plant was divided into leaves, new shoots (Shoot top 10 cm), old branches (branches of last year), new branches (branches of this year), fine roots (diameter < 2 mm) and thick roots (diameter > 2 mm). The samples were treated with water, detergent, water, 1% hydrochloric acid and rinsed three times with deionized water, and then dried at 105 °C before being for 15 min at 80 °C, which resulted in a constant weight. After weighing, the samples were crushed in a mill and then sifted through a 150-mesh sieve. The samples were then bagged.

2.2.2. Determination of the photosynthetic performance

After three days of urea applied, the photosynthetic performance parameters were measured at 1, 3, 5, 7 and 9 days after irrigation during the same irrigation period, using the LI-COR photosynthesis system. 5 plants with uniform growth were randomly selected for each treatment, and the fifth, sixth, and seventh leaves from the top of the vine that had been fully exposed to light were selected to determine the leaf net photosynthetic rate (Pn), stomatal conductance (Gs), transpiration rate (Tr) and instantaneous water use efficiency (Wue) and gas exchange parameters using the photosynthetic system described above. The measurement utilized an open gas path, and the CO_2 gas was collected from the relatively stable 2–3 m above the soil. The light intensity was stabilized at 1350 μmol m^{-2} s^{-1} using an artificial light source, the flow velocity is 500 umol s^{-1}, and the measuring time was from 11:00–12:00 A.M. (Bejing time).

2.2.3. Determination of enzyme activity in the rhizosphere soil

The sampling time of soil sample was consistent with the time of photosynthetic index measurement. Root drilling method through using same located soil cores (5 cm diameter × 20 cm depth) in each pots, collected 10–20 cm rhizosphere soil under the ground surface and mixed it into one sample, and each treatment was repeated 5 times. Soil urease activity was measured by phenol sodium hypochlorite colorimetry (Lu, 2000) and the nitrate reductase was determined by phenol two sulfonic acid colorimetry (Li et al., 2008).

2.2.4. Determination of nitrogen absorption and distribution of plants

The content and abundance of the nitrogen was determined from the bagged samples isolated as described in 2.2.1, and the percentage of nitrogen and the ^{15}N abundance was determined using a ZHT-03 instrument (Beijing Analytical Instrument Factory) on a mass spectrometer (Institute of Atomic Energy, Chinese Academy of Agricultural Sciences)

The Ndff (%) of each part of the plant refers to the contribution rate of ^{15}N to the total nitrogen content of the organ in the plant (Sun et al. 2016). The utilization rate of the plant's ^{15}N refers to the ratio of ^{15}N absorption by the plant to the ^{15}N application in nitrogen fertilizer. The calculations of ^{15}N refer to Li et al. (2011), and calculation formula as follows:

Ndff% = (^{15}N abundance in plant samples% − natural abundance %)/(^{15}N abundance in fertilizer% − natural abundance%) × (100)

Total nitrogen content (g) = dry matter mass (g) × percent of nitrogen

^{15}N absorption content (mg) = Total nitrogen content (g) × Ndff % × (1000)

Nitrogen Fertilizer Distribution Rate% = ^{15}N absorption content from various parts (mg)/^{15}N total absorbed content (mg) × (100)

Nitrogen utilization rate% = [Ndff × total nitrogen content (g)]/fertilizer amount(g) × (100)