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Application of vermicompost improves strawberry growth and quality through increased photosynthesis rate, free radical scavenging and soil enzymatic activity

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ABSTRACT

Vermicompost (VC) is thought to improve soil quality and plant yield. However, the effect and mechanism of VC on strawberry growth and quality are not well known. The objectives of this study were to investigate the effects of VC on the morphological and physiological indexes of strawberry and on the microbial properties of soil and to analyze the potential mechanisms of VC on the growth and development of strawberry. A pot experiment was conducted in a randomized design under solar greenhouse conditions. The treatments were six different volumetric ratios of VC to soil: 100% soil (control, CK); 10% VC + 90% soil (VC10); 20% VC + 80% soil (VC20); 30% VC + 70% soil (VC30); 40% VC + 60% soil (VC40); 50% VC + 50% soil (VC50). In this study, VC not only increased growth attributes such as biomass production, plant height and leaf area but also improved fruit yield, mean fruit weight, and the contents of soluble sugar and vitamin C. Notably, chlorophyll content and net photosynthetic rate increased significantly at the white fruit stage. Additionally, 20% and 30% VC addition dramatically improved superoxide dismutase activity and reduced malondialdehyde content. We also found significant improvements in soil microbial and enzyme activity, cation exchange capacity and root activity with the application of VC compared with the control. Overall, VC had a positive effect on strawberry growth and quality, which was attributed to increases in photosynthesis rate, free radical scavenging, and soil enzymatic activity.

1. Introduction

Recent conventional agriculture is characterized by excessive use of chemical fertilizers, herbicides, and pesticides (Li et al., 2007; Gill and Garg, 2014), which leads to serious environmental problems, such as water contamination, soil salinization and degradation (Ju et al., 2009), and loss of biodiversity (Minuto et al., 2006; Gill and Garg, 2014). To address these problems, sustainable agriculture is urgently required. Vermicomposting is a cost-effective and viable method for proper and efficient management of livestock manure (Garg et al., 2006).

Vermicompost (VC) is from the interactions of earthworms and microorganisms in the breakdown of organic matter and is a nutrient-rich and microbiologically active organic amendment (Lazcano and Dominguez, 2010; Hu et al., 2004). VC can increase the capacity to retain plant available nutrients because of the high porosity, large surface area and water holding capacity (Edwards and Burrows, 1988; Orozco et al., 1996; Chaudhuri et al., 2000). Therefore, the potential is considered huge for VC and growing crops, vegetables and fruits (Edwards et al., 2011).

Several studies show that the growth of many fruits is affected by VC amendments in the greenhouse (Arancon et al., 2003; Arancon et al., 2004b; Atiyeh et al., 2000b) and in the field (Najar and Khan, 2013; Wang et al., 2010; Singh et al., 2008). Atiyeh et al. (2000a) reported on the effects of pig manure VC on the growth and yield of tomatoes cultivated in a greenhouse. Applied to tomato, VC increases yield and vitamin C under 60–70% of field capacity compared with horse compost, chicken compost and chemical fertilizer (Yang et al., 2015). Arancon et al. (2005) studied the influence of VC from food waste and paper waste on the growth and yield of peppers, and application of VC significantly increased plant shoot biomass and marketable fruit weights and decreased yields of non-marketable fruit of peppers. Additionally, VC improved pineapple yield and fruit weight and increased average length, width and number of leaves per plant (Chaudhuri et al., 2016).

The improvement of plant growth with use of VC may result from its nutrients and biologically active substances (Warman and AngLopez,

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2010). Many plant growth regulators including auxins, gibberellins, humic acids (Atiyeh et al., 2002) and cytokinins of microbial origin (Tomati et al., 1988) are found in VC. Additionally, the activity of soil enzymes such as urease, phosphomonoesterase, phosphodiesterase and arylsulfatase increases significantly with VC application (Albiach et al., 2000). Additionally, microbial biomass also plays an important role in plant growth and crops in the field. Despite the available literature on the effects of VC on crops in the field and on fruit quality, the effect and mechanism of VC on strawberry growth and fruit quality have not been reported. In this study, we investigated the influence of VC on soil fertility, plant growth and fruit quality and analyzed the potential mechanisms by which VC promotes strawberry growth and quality, which is information that will help in understanding the effects of VC on improving strawberry growth and development.

2. Materials and methods

2.1. Plant material

Plants of strawberry (*Fragaria* × *ananassa* Duch.) cultivar 'Yanli' were used for the experiment. VC was purchased from Shenyang Haohai Company (Shenyang, China). The composition of VC and soil is shown in Supplementary Table 1. A pot experiment was conducted in a solar greenhouse at Shenyang Agricultural University, Shenyang, China.

2.2. Experimental design

Tests were conducted as a factorial experiment in a randomized design with twenty replications under greenhouse conditions. Six combinations were tested with the following volumetric ratios of VC to soil: 100% soil (control, CK); 10% VC + 90% soil (VC10); 20% VC + 80% soil (VC20); 30% VC + 70% soil (VC30); 40% VC + 60% soil (VC40); 50% VC + 50% soil (VC50). All treatments received fertilizer (2 g·L^{-1} fused calcium-magnesium phosphate) at the beginning of the experiment. Healthy and uniform plants of 'Yanli' strawberry were planted in pots (20 cm diameter, 18 cm height) on December 23, 2015. One plant was per pot, and twenty pots (replications) were used in this experiment. After planting, all plants were immediately watered to 100% of field capacity with 0.2% N, P and K fertilizer (20-5-10). This fertilizer was also used at 30 and 60 days after planting. All treated strawberry plants were watered every three days with 500 mL of water during the entire experimental period.

2.3. Analysis of plant growth and fruit yield

Plant height, leaf area, petiole length and leaf number were measured at the flowering stage, green fruit stage, fruit ripening stage and after harvest. Data were collected from ten randomly selected plants from each treatment. All primary fruits of each plant were harvested and weighed. After harvesting primary fruits, three randomly selected plants were used to measure plant biomass as dry weight. Two months later, ten randomly selected plants from each treatment were used to test the propagation coefficient.

2.4. Fruit quality analysis

Three randomly selected primary fruits collected at 30 days after pollination from each treatment were used to test fruit quality, including total acidity, vitamin C and soluble solids content (SSC). The three fruits were ground together in liquid nitrogen as a sample pool, and three biological replicates were included. SSC was analyzed by an Abbe refractometer (Atago Co. Ltd., Tokyo, Japan). Soluble sugar was determined by anthrone colorimetry (Dische, 1962). Titratable acid was tested by sodium hydroxide (Zhang et al., 1994). The content of vitamin C was determined by molybdenum blue colorimetry (Ma et al., 2006).

2.5. Photosynthetic parameter test

Three leaves from each plant were selected at the white fruit stage and were used for testing photosynthetic characteristics of each treatment. A CIRAS-2 portable photosynthesis apparatus (PP-System, Hitchin, UK) was used to measure photosynthetic rate (Pn), transpiration rate (E), stomatal conductance (Gs) and intercellular CO_2 concentration (Ci). Chlorophyll was determined by ethanol-acetone extraction (Zhang, 1986).

2.6. SOD, MDA and root activity analyses

Superoxide dismutase (SOD) activity and malondialdehyde (MDA) content were measured at the white fruit stage for three leaves chosen from each plant. Three roots of each treatment at the white fruit stage were collected to determine root activity. MDA content was determined by thiobarbituric acid (Zhao et al., 1994). The activity of SOD was measured by the method of N-blue tetrazolium photoreduction (Shen et al., 1996). Root activity was determined with triphenyltetrazolium chloride (Zheng et al., 2008).

2.7. Soil analyses

Soil samples were collected from the surface of roots. Three randomly selected plants from each treatment were used to collect soil samples at a depth of 0–5 cm at the base of the plant, and then plant and animal residues were removed from the soil. After the samples were mixed, a portion of the soil was immediately analyzed for soil microbial activity, and the rest was air-dried and passed through a 1 mm sieve. Analysis of all soil samples included three biological replicates. The activity of three enzymes in soil was analyzed using air-dried soil as described previously (Guan, 1986). Catalase activity was determined by back-titrating residual H_2O_2 with 0.002 mol L^{-1} $KMnO_4$ and is presented as ml g^{-1}. Urease activity was measured using phenol-sodium hypochlorite colorimetry and is presented as mg g^{-1} d^{-1}. Sucrase activity was determined by 3,5-dinitrosalicylic acid colorimetry and is presented as mg g^{-1}. Microbial biomass carbon (MBC) and microbial biomass N (MBN) were immediately determined in field-moist subsamples after sampling using the chloroform fumigation extraction method (Lu, 1999). Cation exchange capacity (CEC) was determined by the 1-N ammonium acetate method (Lu, 1999).

2.8. Statistical analyses

Data are presented as the mean value ± standard deviation (SD) based on ten replicates for morphological indices and three replicates for physiological indices and soil properties. Analysis of variance (ANOVA) was performed to determine the significance of the differences among responses of strawberry with different combinations of VC and soil. Differences among means were tested by *Duncan's* multiple range tests ($p \leq 0.05$).

3. Results

3.1. Effects of VC on strawberry growth

To test the effect of VC on strawberry growth and development, six different combinations of volumetric ratios of VC to soil were examined to analyze phenotypic parameters of strawberry, including plant height, leaf area, leaf number and petiole length at the flowering, green fruit, and ripening periods and after harvest (Fig. 1). We found application of VC significantly improved leaf area, petiole length, leaf number and plant height compared with those of the control. Addition of 30% VC (V30) resulted in the highest leaf area (81.45 cm^2 at the flowering period and 121.61 cm^2 at the green fruit period) and greatest plant height (27.75 cm at the flowering period and 28.86 cm at the green fruit