INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
19–1105/2020/23–3–515–521
DOI: 10.17957/IJAB/15.1316
http://www.fspublishers.org

Full Length Article

Preventive Effect of Vermicompost against Cucumber Fusarium Wilt and Improvement of Cucumber Growth and Soil Properties

Xingzhe Zhang[1,2], Rina Sa[2,3], Jiyang Gao[1], Chunlong Wang[1], Dawei Liu[1] and Yanju Zhang[1*]
[1]*College of Agronomy, Northeast Agricultural University, Harbin, China*
[2]*Mudanjiang Branch, Heilongjiang Academy of Agricultural Science, Mudanjiang, China*
[3]*Heilongjiang Academy of Agricultural Science, Harbin, China*
[*]For correspondence: zhangyanju1968@163.com
Received 09 July 2019; Accepted 02 November 2019; Published 04 February 2020

Abstract

An experiment was conducted to explore the preventive effect of vermicompost on cucumber Fusarium wilt and to investigate the growth, yield and fruit quality of cucumber plants inoculated with *Fusarium oxysporum*. Vermicompost and soil at different proportions (100% soil+0% vermicompost, 75% soil+25% vermicompost, 50% soil+50% vermicompost, 25% soil+75% vermicompost and 0% soil+100% vermicompost) were applied to cucumber plants inoculated with *F. oxysporum*. The alkali-hydrolysable nitrogen content, available phosphorus content, available potassium content, total porosity, organic matter content, sucrose activity, urease activity and neutral phosphatase activity of the soil in which the cucumber plants were grown consistently increased with increasing vermicompost proportion in the soil. However, the specific gravity of the soil consistently decreased with increasing vermicompost proportion. All of the vermicompost treatments significantly decreased the incidence of Fusarium wilt and the nitrate content of the cucumber fruit but significantly increased the heights, stem diameters and leaf areas of the plants and the soluble sugar content, soluble protein content and yield per plant of the fruit. Among the different treatments, the treatment of 50% soil+50% vermicompost was the most effective at inhibiting cucumber Fusarium wilt and improving the growth, fruit quality and yield of cucumber plants infected with *F. oxysporum*. Therefore, vermicompost supplied at moderate proportions may decrease the incidence of cucumber Fusarium wilt and improve plant growth, yield per plant and fruit quality by improving the soil.

Keywords: Cucumber; Fruit quality; Fusarium wilt; Plant Yield; Vermicompost

Introduction

Cucumber (*Cucumis sativus* L.), an economically important vegetable of the Cucurbitaceae family (Azad *et al.* 2013), is the 4th most widely cultivated vegetable in the world, after cabbage, onion and tomato (Monamodi, 2013). With the development of horticulture industry, the cultivated area of cucumber is increasing annually. In China, approximately 1,155,840 hectares are currently used for cucumber cultivation, yielding an estimated 61,949,094 tons. Several biotic and abiotic factors are responsible for low production in cucumber, with disease being the most prominent biotic factor. Fusarium wilt, caused by *Fusarium oxysporum*, is an important disease that limits cucumber production worldwide (Raza *et al.* 2016). *F. oxysporum* is a soil-borne pathogen and survives in soil for many years, and it cannot be controlled by simple methods such as crop rotation (Leoni 2013). Due to environmental and health concerns, nonchemical practices are encouraged over the large-scale use of pesticides and chemicals (Dankwah 2015). Therefore, it is essential to identify a nonpolluting substance that can prevent cucumber Fusarium wilt while causing little harm to humans or other animals.

Vermicomposting, a form of composting, utilizes earthworms and microorganisms to metabolize organic matter in raw materials including agricultural, industrial and urban wastes, which contain proteins, nucleic acids, fats, and carbohydrates (Shetinina *et al.* 2019; Hashem *et al.* 2018). Vermicomposts, being rich in nutrients and humic substances, have high cation exchange capacities and moisture contents (García *et al.* 2014). In recent decades, vermicomposting has received much attention due to its highly conservative use of water and fertilizers and its large surface area, strong adsorption capacity and high porosity (Zaller 2007; Charu *et al.* 2019). Studies on the effects of vermicompost in floating systems have shown that the addition of vermicompost to seedling substrates can substantially shorten seedling emergence time and prevent damage caused by soil pests and soil-borne diseases (Amit *et al.* 2018; Sharmila and Jeyanthi 2019). Vermicompost plays an important role in the prevention of soil-borne disease epidemics among cucumber seedlings (Selvaraj

To cite this paper: Zhang X, R Sa, J Gao, C Wang, D Liu, Y Zhang (2020). Preventive effect of vermicompost against cucumber fusarium wilt and improvement of cucumber growth and soil properties. *Intl J Agric Biol* 23:515–521

2011). However, there are few reports on optimal vermicompost for preventing Fusarium wilt and promoting the growth of cucumber plants.

The aims of the present study were to investigate changes in the growth indices, quality indices and fruit production of cucumber plants after treatment with different proportions of vermicompost and inoculation with *F. oxysporum* and to determine the optimum proportion of vermicompost in soil to use in cucumber cultivation. This study can serve as a theoretical and technical reference for applications of vermicompost in the prevention of vegetable disease.

Materials and Methods

Climatic conditions of the experimental field

The research site is in the north temperate zone and continental monsoon area (rainy and hot during the summer; cold and arid during the winter) of China that receives an average annual precipitation of 549 mm.

Plant materials and tested strains

The cucumber line 649 is susceptible to the pathogen *F. oxysporum*. Seeds of this line were obtained from the Cucumber Laboratory of Northeast Agricultural University. Isolate H28 of *F. oxysporum* f. spp. *cucumerinum* was supplied by the Plant Pathology Laboratory of Northeast Agricultural University, China.

Experimental design

The experiment was conducted at Northeast Agricultural University, China (126°63'E and 45°44'N; Harbin, China) in 2015 and 2016. The experimental soil was derived from the cultivation layer (0–20 cm) of an experimental field of the University. Vermicompost, bought in Shunli Village in Shuangcheng District, Heilongjiang Province, was generated from cow dung by earthworms. Vermicompost and soil were mixed in pre-determined proportions (volumetric ratios). Five treatments (designated A_0, A_1, A_2, A_3 and A_4) were prepared. The treatments comprised of soil and vermicompost at different percentages as follows: A_0, 100% soil+0% vermicompost; A_1, 75% soil+25% vermicompost; A_2, 50% soil+50% vermicompost; A_3, 25% soil+75% vermicompost; and A_4, 0% soil+100% vermicompost. Each experimental plot had an area of 2 m^2, and three biological replicates were used. The soil was treated and fully mixed with the pre-determined proportions of vermicompost by the fertilization method before the seedlings were transplanted. The treated soil was sampled for measurements of nutrient content, physicochemical properties, and enzymatic activities. Seedlings were grown in late May 2015 and transplanted to the greenhouse after the 4th real leaf unfolded.

Disease incidence and preventive effect of vermicompost

Isolate H28 of *F. oxysporum* was incubated in liquid potato-sucrose medium with shaking (120 rpm) at 28°C for 7 days. Spores were filtered through a double layer of cheesecloth, and the suspension was centrifuged at 4,000 × *g* for 10 min. The spores were then resuspended in distilled water, and the concentration was adjusted to 1×10^7 spores mL^{-1}.

Isolate H28 was inoculated by pouring the spore suspension on the roots (Zhou *et al.* 2010). One hundred milliliters of *F. oxysporum* per plant was inoculated *via* root irrigation 7 days after transplantation. Disease occurrence was investigated 10~14 days after inoculation, and the degree of disease occurrence was recorded according to previously described standards for disease levels (Singh *et al.* 1999): 0, no apparent symptoms; 1, vascular discoloration of both hypocotyl and epicotyl, stunting; 2, similar to 1 but with marked stunting, wilting; 3, dead or almost dead seedlings.

$$\text{Disease incidence (\%)} = \frac{\text{Diseased plant number}}{\text{Total plant number}} \times 100$$

$$\text{Preventive effect (\%)} = \left(1 - \frac{\text{Disease incidence of treatments}}{\text{Mean disease incidence of the control}}\right) \times 100$$

Investigation of plant growth indices

The plant height, stem diameter, leaf area, leaf number and dry matter accumulation of 10 cucumber plants from each of three biological replicates were measured during the full-fruit period. The length (D) and width (W) of the 3rd, 4th and 5th leaves were measured. Leaf area = 14.61 - 5.0 × (D) + 0.94 × (D^2) + 0.47 × (W) + 0.63 × (W^2) - 0.62 × (D) × (W).

Determination of photosynthetic pigments

The contents of photosynthetic pigments were determined using the ethanol acetone method (Zhang *et al.* 2009). Photosynthetic pigments were extracted from fresh samples in 80% acetone. Each extract was centrifuged at 3,000 × *g* for 5 min. The absorbance of the supernatant was measured at 470, 645, and 663 nm with a UV-754 spectrophotometer (Zealquest Scientific, Shanghai, China). Contents of Chlorophyll (Chl) *a*, Chl *b*, Chl (*a*+*b*) and Car were calculated using adjusted extinction coefficients. Pigment contents were expressed as mg^{-1} (fresh mass, FM).

Determination of cucumber fruit quality and yield per plant

Vitamin C, free amino acid, soluble sugar, soluble protein and nitrate contents were measured by 2,6-dichlorophen-based colorimetry, ninhydrin staining, anthrone-based colorimetry, Coomassie brilliant blue G-250 staining and salicylic acid-based colorimetry, respectively (Li 2003). The weight of each cucumber fruit from each plant was measured using an electronic balance, and the yield per plant was calculated.

Assay of soil nutrient content and physicochemical properties

Sampled soils from the different treatments were subjected to natural-air drying and filtered through 1-mm and 0.25-mm screens for assaying soil nutrient contents and physicochemical properties. Total nitrogen content, total phosphorus content, total potassium content, alkali-hydrolysable nitrogen content, available phosphorus content, available potassium content, organic matter content, bulk density, specific gravity, total porosity, electrical conductivity (EC) and pH values were measured as described by Higashikawa *et al.* (2010).

Determination of soil enzymatic activities

Soil saccharase, urease and neutral phosphatase activities were measured by 3,5-dinitrosalicylic acid-, indigo-, and disodium phenyl phosphate-based colorimetric methods, respectively (Guan, 1986).

Statistical design and analysis

Data were statistically analyzed by using the SPSS statistical program (version 20) with a randomized block design model, and mean values were compared using Duncan's multiple range test (DMRT) at $P < 0.05$.

Results

Preventive effects

The preventive effects of the treatments with different vermicompost percentages in the media against cucumber wilt disease are listed in Table 1. The A_1, A_2, A_3 and A_4 treatments all significantly ($P < 0.05$) decreased the disease incidence in cucumber, indicating their preventive effects against cucumber wilt disease. Among the treatments, the A_2 treatment had the strongest preventive effect in both years. The preventive effects of the A_2 treatment were 58.82 and 63.47% in 2015 and 2016, respectively.

Plant growth attributes

Plant height, stem diameter, leaf area, leaf number and dry matter weight per cucumber plant all increased from A_0 to their maximum values at A_2 and declined thereafter with increasing vermicompost proportion in both years (Table 2). A_1, A_2 and A_3 significantly ($P < 0.05$) increased these five growth attributes of the cucumber plants relative to the A_0 values in both years. Relative to the corresponding values in plants subjected to the A_0 treatment, plant height, stem diameter, leaf area, leaf number and dry matter weight per plant increased by 20.6, 9.1, 45.1, 41.9 and 642.1%, respectively, under the A_2 treatment in 2015 and by 30.3, 3.8, 46.4, 42.4 and 105.6%, respectively, in 2016. The percentage increase of dry matter per plant of cucumber was greater than the percentage increases of the other four

Table 1: Preventive effects against cucumber wilt disease of vermicompost at different proportions in media in 2015 and 2016

Year	Treatment	Disease incidence (%)	Preventive effect (%)
2015	A_0	32.08 ± 4.08a	-
	A_1	16.98 ± 2.31d	47.06 ± 3.82b
	A_2	13.21 ± 1.08e	58.82 ± 5.97a
	A_3	20.75 ± 2.52c	35.29 ± 4.21c
	A_4	26.42 ± 2.54b	17.65 ± 1.85d
2016	A_0	43.17 ± 3.89a	
	A_1	20.37 ± 3.21c	52.81 ± 5.28b
	A_2	15.77 ± 1.89d	63.47 ± 5.28a
	A_3	24.16± 3.21c	44.04 ± 4.15c
	A_4	31.82 ± 3.08b	26.29 ± 3.25d

Different lowercase letters indicate significant differences at the 0.05 level (P<0.05). This notation also applies to the other tables below

attributes. The changes in the five growth parameters indicated that the addition of vermicompost can promote the growth of cucumber plants.

Photosynthetic pigments

the contents of chl *a*, chl *b* and car in leaves of cucumber all increased from a_0 to their maximum values at a_2 and declined thereafter with increasing vermicompost proportion in both years (table 3). the increases of contents of chl *a*, chl *b* and car in the a_2 treatment were greater in 2015 than in 2016. Relative to the corresponding contents in plants subjected to the a_0 treatment, the contents of chl *a*, chl *b* and car in the a_2 treatment were increased by 142.9, 240.0 and 53.8%, respectively, in 2015 and by 140.8, 173.3 and 45.6%, respectively, in 2016. chl ($a + b$) content in 2015 was higher than that in 2016 in each treatment.

Yield per plant and fruit quality

The yield per plant, Vitamin C content, free amino acid content, soluble sugar content and soluble protein content of cucumber fruit showed the greatest values under A_2 and declined at higher vermicompost proportions. However, the nitrate content of the cucumber fruit was lowest under A_2 and then increased with increasing vermicompost proportion in both years (Table 4). Relative to the corresponding values in plants subjected to the A_0 treatment, the yield per plant, Vitamin C content, free amino acid content, soluble sugar content and soluble protein content of cucumber fruit under the A_2 treatment were increased by 30.7, 69.3, 20.9, 45.0 and 54.7%, respectively, in 2015, and by 28.5, 80.4, 21.8, 48.0 and 56.9%, respectively, in 2016. The nitrate contents of the cucumber fruit in 2015 and 2016 were decreased by 37.3 and 37.6%, respectively, under the A_2 treatment relative to the contents in the A_0 treatment. In each treatment, the yield per plant was higher in 2015 than in 2016, but the nitrate content was lower in 2015 than in 2016.

Soil nutrient content

The effects of the vermicompost treatments on soil nutrient contents are presented in Table 5. The contents of total

Table 2: Effect of vermicompost at different proportions in media on the growth of cucumber plants

Year	Treatment	Plant height (cm)	Stem diameter (cm)	Leaf area (cm^2)	Leaf number	Dry matter weight per plant (g)
2015	A_0	191.6 ± 9.7d	0.673 ± 0.057e	328.2 ± 31.9e	3.1 ± 0.2c	0.384 ± 0.049d
	A_1	212.7 ± 18.5b	0.717 ± 0.069b	457.8 ± 44.1b	3.9 ± 0.7b	0.543 ± 0.051b
	A_2	231.0 ± 22.7a	0.734 ± 0.072a	476.3 ± 44.5a	4.4 ± 0.5a	0.628 ± 0.072a
	A_3	194.4 ± 13.7c	0.712 ± 0.063c	441.8 ± 38.9c	4.0 ± 0.3ab	0.541 ± 0.061b
	A_4	180.7 ± 15.3e	0.705 ± 0.048d	355.5 ± 32.4d	3.7 ± 0.2b	0.442 ± 0.048c
2016	A_0	188.5 ± 19.7d	0.685 ± 0.059c	331.8 ± 31.7d	3.3 ± 0.4d	0.417 ± 0.039e
	A_1	224.1 ± 22.9b	0.698 ± 0.072bc	438.4 ± 42.5b	3.8 ± 0.2c	0.698 ± 0.072b
	A_2	245.7 ± 23.6a	0.711 ± 0.070a	485.9 ± 45.9a	4.7 ± 0.5a	0.853 ± 0.091a
	A_3	200.8 ± 12.8c	0.702 ± 0.071b	451.2 ± 36.1b	4.2 ± 0.4b	0.602 ± 0.052c
	A_4	190.2 ± 9.7cd	0.686 ± 0.064c	378.1 ± 31.2c	3.5 ± 0.3cd	0.582 ± 0.051d

Table 3: Effect of vermicompost at different proportions in media on the contents of photosynthetic pigments in the leaves of cucumber plants

Year	Treatment	Chl *a* (mg g^{-1} FM)	Chl *b* (mg g^{-1} FM)	Chl (*a* + *b*) (mg g^{-1} FM)	Car (mg g^{-1} FM)
2015	A_0	6.3 ± 0.8c	1.5 ± 0.2c	7.8 ± 0.6d	0.520 ± 0.047c
	A_1	9.6 ± 0.3b	2.7 ± 0.3b	12.3 ± 1.8b	0.736 ± 0.068a
	A_2	15.3 ±2.8a	5.1 ± 0.2a	20.4 ± 2.7a	0.800 ± 0.074a
	A_3	9.2 ± 3.2b	2.6 ± 0.2b	11.8 ± 1.2c	0.758 ± 0.081a
	A_4	9.1 ± 3.1b	2.6 ± 0.1b	11.7 ± 1.0c	0.640 ± 0.071b
2016	A_0	4.9 ± 0.41d	1.5 ± 0.1e	6.4 ± 0.8d	0.456 ± 0.038b
	A_1	7.6 ± 0.73b	2.9 ± 0.2b	10.5 ± 1.1b	0.720 ± 0.066a
	A_2	11.8 ± 1.5a	4.1 ± 0.3a	15.9 ± 1.6a	0.802 ± 0.071a
	A_3	6.2 ± 5.8bc	2.3 ± 0.2c	8.5± 0.8c	0.738 ± 0.071a
	A_4	6.0 ± 6.8c	2.1 ± 0.1d	8.1 ± 0.7c	0.496 ± 0.045b

Table 4: Effect of vermicompost at different proportions in media on cucumber fruit quality

Year	Treatment	Vitamin C (mg•g^{-1})	Free amino acid (mg•g^{-1})	Soluble sugar (%)	Soluble protein (mg•g^{-1})	Nitrate (mg•g^{-1})	Yield per plant (g)
2015	A_0	0.283 ± 0.033d	0.297 ± 0.031b	2.978 ± 0.031e	1.537 ± 0.197e	0.279 ± 0.025a	1.413 ± 0.115c
	A_1	0.402 ± 0.051b	0.301 ± 0.033b	4.057 ± 0.411b	2.157 ± 0.223b	0.194 ± 0.028cd	1.690 ± 0.017ab
	A_2	0.479 ± 0.044a	0.359 ± 0.041a	4.319 ± 0.445a	2.378 ± 0.298a	0.175 ± 0.018d	1.847 ± 0.134a
	A_3	0.367 ± 0.039c	0.289 ± 0.029b	3.864 ± 0.369c	1.953 ± 0.205c	0.215 ±0.022bc	1.615 ± 0.201b
	A_4	0.274 ± 0.031d	0.253 ± 0.026c	3.658 ± 0.397d	1.729 ± 0.159d	0.236 ± 0.026b	1.532 ± 0.167bc
2016	A_0	0.301 ± 0.044d	0.285 ± 0.031c	3.128 ± 0.412d	1.438 ± 0.113d	0.295 ± 0.031a	1.368 ± 0.112cd
	A_1	0.441 ± 0.058b	0.314 ± 0.032b	3.987 ± 0.423b	2.058 ± 0.325b	0.224 ± 0.025b	1.527 ± 0.165b
	A_2	0.543 ± 0.061a	0.347 ± 0.035a	4.628 ± 0.501a	2.256 ± 0.301a	0.184 ± 0.019d	1.758 ± 0.185a
	A_3	0.385 ± 0.032c	0.293 ± 0.031c	3.582 ± 0.402c	2.064 ± 0.201b	0.204 ± 0.022c	1.397 ± 0.178c
	A_4	0.311 ± 0.038d	0.244 ± 0.026d	3.275 ± 0.385d	1.638 ± 0.179c	0.228 ± 0.028b	1.258 ± 0.124d

nitrogen, total phosphorus, total potassium, alkali-hydrolysable nitrogen, available phosphorus and available potassium in the soil gradually increased with increasing vermicompost proportion. Significant ($P < 0.05$) differences in total nitrogen, total phosphorus, total potassium, alkali-hydrolysable nitrogen, available phosphorus and available potassium contents were observed among the treatments. The total nitrogen content under A_1, A_2, A_3 and A_4 was 42.1, 78.0, 135.6 and 159.4% higher, respectively, than that of the control. The total phosphorus content under A_1, A_2, A_3 and A_4 was 8.5, 51.7, 66.9 and 104.2% higher, respectively, than that of the control. The total potassium content was 7.9, 55.1, 166.3 and 198.8% higher, respectively, than that of the control. The alkali-hydrolysable nitrogen content was 69.6, 95.6, 143.0 and 239.6% higher, respectively, than that under the A_0 treatment. The available phosphorus content was 116.9, 162.3, 232.4 and 371.3% higher, respectively, that that of the control; and the available potassium content was 67.3, 230.4, 315.2 and 472.3% higher, respectively, than that under the A_0 treatment.

Soil physicochemical properties

The effects of the vermicompost treatments on the physicochemical properties of the soil are presented in Table 6. The bulk density and specific gravity of the soil consistently decreased with increasing vermicompost proportion, whereas the total porosity, organic matter content, EC and pH values of the soil consistently increased with increasing vermicompost proportion. There were significant ($P < 0.05$) differences in soil organic matter content and EC between the control treatment and each of the other vermicompost treatments. The soil specific gravity under A_1, A_2, A_3 and A_4 was 2.9, 12.9, 18.6 and 25.7% lower, respectively, than that of the control. The soil organic matter content under A_1, A_2, A_3 and A_4 was 158.7, 276.0, 320.9 and 389.2% higher, respectively, than that of the control; and the soil EC value at A_1, A_2, A_3 and A_4 was

Table 5: Effect of vermicompost at different proportions in media on soil nutrient contents in 2015

Treatment	Total nitrogen ($g \cdot kg^{-1}$)	Total phosphorus ($g \cdot kg^{-1}$)	Total potassium ($g \cdot kg^{-1}$)	Alkali-hydrolysable nitrogen ($mg \cdot kg^{-1}$)	Available phosphorus ($mg \cdot kg^{-1}$)	Available potassium ($mg \cdot kg^{-1}$)
A_0	2.355 ± 0.325e	0.118 ± 0.019e	40.8 ± 4.7e	68.2 ± 7.2e	14.6 ± 1.4e	661 ± 68e
A_1	3.346 ± 0.338d	0.128 ± 0.015d	44.0 ± 4.5d	115.6 ± 12.3d	31.6 ± 3.2d	1106 ± 97d
A_2	4.193 ± 0.448c	0.179 ± 0.016c	63.2 ± 7.3c	133.4 ± 13.5c	38.2 ± 3.7c	2184 ± 302c
A_3	5.548 ± 0.659b	0.197 ± 0.021b	108.5 ± 12.1b	165.7 ± 20.1b	48.5 ± 4.5b	2744 ± 289b
A_4	6.109 ± 0.762a	0.241 ± 0.023a	121.8 ± 18.2a	231.4 ± 25.4a	68.7 ± 6.6a	3783 ± 341a

Table 6: Effects of vermicompost at different proportions in media on the physicochemical properties of the soil in 2015

Treatment	Bulk density ($g \cdot cm^{-3}$)	Specific gravity ($g \cdot cm^{-3}$)	Total porosity (%)	Organic matter ($g \cdot kg^{-1}$)	Electrical Conductivity ($\mu s.cm^{-1}$)	pH
A_0	1.811 ± 0.201a	0.704 ± 0.072a	61.3 ± 4.7d	29.4 ± 2.5e	307 ± 28e	6.63 ± 0.75d
A_1	1.792 ± 0.164a	0.683 ± 0.070a	62.0 ± 7.2d	76.2 ± 7.8d	699 ± 70d	6.70 ± 0.71cd
A_2	1.763 ± 0.152a	0.615 ± 0.064b	65.3 ± 7.3c	110.7 ± 10.8c	680 ± 64c	6.76 ± 0.64bc
A_3	1.714 ± 0.125a	0.577 ± 0.061c	66.8 ± 6.2b	123.9 ± 12.7b	1535 ± 102b	6.83 ± 0.63ab
A_4	1.702 ± 0.163a	0.527 ± 0.049d	69.4 ± 7.0a	144.0 ± 18.6a	1598 ± 131a	6.89 ± 0.61a

Table 7: Effects of vermicompost at different proportions in media on soil enzymatic activities in 2015

Treatment	Sucrose activity ($mg \cdot g \cdot h^{-1}$)	Urease activity ($mg \cdot g \cdot h^{-1}$)	Neutral phosphatase activity ($mg \cdot g \cdot d^{-1}$)
A_0	0.821 ± 0.079e	3.481 ± 0.385e	0.821 ± 0.076e
A_1	1.237 ± 0.134d	6.136 ± 0.664d	2.136 ± 0.228d
A_2	1.466 ± 0.152c	7.590 ± 0.801c	2.894 ± 0.278c
A_3	1.793 ± 0.125b	8.733 ± 0.864b	4.170 ± 0.457b
A_4	2.215 ± 0.278a	9.254 ± 0.937a	4.683 ± 0.477a

127.7, 111.6, 400.0 and 420.4% higher, respectively, than that of the control.

Soil enzymatic activities

The effects of the vermicompost treatments on soil enzymatic activities are presented in Table 7. The activities of sucrose, urease and neutral phosphatase in the soil consistently increased with increasing vermicompost proportion. The A_1, A_2, A_3 and A_4 treatments all significantly ($P<0.05$) increased the activities of sucrose, urease and neutral phosphatase in the soil relative to the activities under the A_0 treatment. The soil sucrose activity in A_1, A_2, A_3 and A_4 was 50.0, 78.0, 118.3 and 169.5% higher, respectively, than that of the control. The soil urease activity in A_1, A_2, A_3 and A_4 was 76.1, 118.1, 150.9 and 165.8% higher, respectively, than that of the control. The soil neutral phosphatase activity in the A_1, A_2, A_3 and A_4 treatments was 159.8, 252.4, 408.5 and 470.7% higher, respectively, than that of the control.

Discussion

In the present study, we observed significant increases in alkali-hydrolysable nitrogen content, available phosphorus content, available potassium content, total porosity, organic matter content and EC and a significant decrease in specific gravity upon treatment with vermicompost at different proportions in soil. Plants depend on soil for survival, and the nutrient content and physicochemical properties of soil are key factors that affect plant growth (Lucia *et al.* 2013). Studies have shown that vermicompost application can improve the quality, water retention ability, nutrient content and enzymatic activity of soil (Zhang *et al.* 2015; Goswami *et al.* 2017). Zimny *et al.* (2009) reported that vermicompost application decreased soil bulk density and increased soil porosity. Long-term application of vermicompost was found to improve the organic matter content, alkali-hydrolysable N content, available P content, available K content and EC of soil (Cheng *et al.* 2007). Previous studies reported that sucrose, urease and neutral phosphatase activities all increased with increasing vermicompost percentage (Nair *et al.* 2009; Srilakshmi *et al.* 2011). Our results indicated that vermicompost can substantially improve the fertility of rhizospheric soil and the physicochemical properties of cucumber plants and fruit.

In the present study, vermicompost at all the studied proportions significantly decreased the incidence of cucumber wilt disease. There have been few reports of the effects of vermicompost on soil-borne diseases. A previous study demonstrated that vermicompost application could alter the structure of the soil microbial community (Verdenelli *et al.* 2012). Moreover, inhibitory effects of biological composts (other than vermicompost) on soil borne diseases have been reported. Mengesha *et al.* (2017) reported that the microbial communities in non-aerated compost teas can suppress bacterial wilt. The results of Joshi *et al.* (2009) suggested that the application of composts and compost extracts derived from poultry manure and *Urtica* spp. has the potential to provide effective control of diseases and improve yield in bean under field conditions. The inhibition of 50% vermicompost on cucumber wilt disease may be due to a decrease in the activity of *Fusarium oxysporum* resulting from the alteration of soil microbial community structure.

In our present study, the concentrations of chlorophyll and carotenoids were significantly increased by 50% vermicompost relative to control treatment. The contents of leaf photosynthetic pigments are important indexes of the photosynthetic capacity of plants (Zou *et al.* 2018). Chlorophyll and carotenoids are the main photosynthetic pigments of higher plants (Singh *et al.* 2017). The leaf chlorophyll content of plants is a useful indicator of plant tolerance to biotic or abiotic stress (Hosseinzadeh *et al.* 2018). Alamri *et al.* (2019) reported that lettuce infested with *E. rostratum* exhibited higher contents of Chl *a*, Chl *b* and Car than did control lettuce. Mg participates directly in chlorophyll synthesis. Compared to other organic fertilizers, vermicompost fertilizer contains higher levels of nutrients, such as N, P, K, Ca and Mg, and of micronutrients, such as Fe, Zn, Cu and Mn (Suthar 2009; Tognetti *et al.* 2013). For these reasons, increasing the uptake of Mg ions is associated with upregulated chlorophyll synthesis (Hosseinzadeh *et al.* 2016). Carotenoid content is proportional to the content of chlorophyll that protects it (Hosseinzadeh *et al.* 2017). Accordingly, the increased carotenoid content observed under 50% vermicompost treatment in the present study was associated with increased chlorophyll contents. Gupta *et al.* (2014) showed that the addition of vermicompost to potting media in appropriate quantities has significant positive effects on the growth and flowering of marigold seedlings, including positive effects on plant biomass, plant height, and the numbers of buds and flowers. In addition, it has been reported that vermicompost leachate can increase some growth attributes, such as biomass production, plant height and leaf area (Bidabadi *et al.* 2016). In the present study, plant height, stem diameter, leaf area, leaf number and dry matter weight per plant increased by 20.6–30.3%, 3.8–9.1%, 45.1–46.4%, 41.9–42.4% and 105.6–642.1%, respectively, under the 50% vermicompost treatment relative to the control treatment. Similarly, Patil (2010) found that total fresh biomass production was higher with the application of biofertilizer than under control treatment. Our results are also consistent with results of Liu *et al.* (2011), who used organic manure and inorganic fertilizer on *S. rebaudiana.* VITAMIN CL could improve the plant biomass by supplementing plant nutrients and producing growth hormones.

In this study, treatment with 50% soil and 50% vermicompost significantly increased yield, Vitamin C content, free amino acid content, soluble sugar content and soluble protein content of cucumber fruit but significantly decreased the nitrate content of the fruit. Beneficial effects of vermicompost on fruit quality and yield have been demonstrated across a wide range of plants (Mahmud *et al.* 2018; Trandel *et al.* 2018). Wang *et al.* (2010) reported that treatment with vermicompost and soil provided a ratio of 4:7 increased the soluble sugar, soluble protein, Vitamin C, total phenol and total flavonoid contents of Chinese cabbage by 62, 18, 200, 25 and 17%, respectively, relative to the contents under treatment with soil alone. Kaur *et al.* (2018) reported that the use of vermicompost and its by-products to cultivate *W. somnifera* can effectively enhance the plant's yield and bioactive compound contents. These results are consistent with a recent report that fruit yield, phenols and vitamin C in cucumber fruit increased under vermicompost application. A possible cause of the observed enhancements of growth, yield and fruit quality in cucumber may be the occurrence of some biostimulants and plant growth regulators of microbial origin in the vermicompost. Our findings demonstrate that vermicompost supplied in moderate proportions can improve plant growth, fruit quality and yield in cucumber plants infected with *F. oxysporum*.

Conclusion

Treatment by mixing 75% soil with 25% vermicompost could substantially improve the fertility of rhizospheric soil, the physicochemical properties of cucumber plants and fruit, and effectively improve plant growth, fruit quality and yield of cucumber plants infected with Fusarium wilt, and thus decrease disease incidence of cucumber Fusarium wilt.

Acknowledgement

This work was funded by National Natural Science Foundation of China (31171792), Key Projects of Heilongjiang Natural Science Foundation (ZD2016003) and University Nursing Program for Young Scholars with Creative Talents in Heilongjiang Province (UNPYSCT-2016146).

References

Alamri SAM, M Hashem, YS Mostafa, NA Nafady, KAM Abo-Elyousr (2019). Biological control of root rot in lettuce caused by *Exserohilum rostratum* and *Fusarium oxysporum via* induction of the defense mechanism. *Biol Cont* 128:76–84

Amit MP, VV Angadi, DN Kambrekar (2018). Effect of integrated nutrient management on red leaf index, insect pest and disease in cotton and soybean intercropping system. *Intl J Plant Soil Sci* 21:1–7

Azad AK, A Sardar, N Yesmin, M Rahman, S Islam (2013). Eco-Friendly pest control in cucumber (L.) field with botanical pesticides. *Nat Resour* 4:404–409

Bidabadi SS, M Afazel, SD Poodeh (2016). The effect of vermicompost leachate on morphological, physiological and biochemical indices of *Stevia rebaudiana* Bertoni in a soilless culture system. *Intl J Recycl Org Waste Agric* 5:251–262

Charu G, D Prakash, S Gupta, MA Nazareno (2019). Role of vermicomposting in agricultural waste management. *Sustain Green Technol Environ Manage* 6:257–261

Cheng HU, ZP Cao, YR Luo, YL Ma (2007). Effect of long-term application of microorganismic compost or vermicompost on soil fertility and microbial biomass carbon. *Chin J Eco-Agric* 15:48–51

Dankwah KA (2015). Assessment of organophosphate pesticide residues on cabbage (*Brassica oleracea*) at the farm gate in the Atwima Nwabiagya District, Ghana. *Res J Environ Toxicol* 5:180–202

García AC, FG Izquierdo, RLL Berbara (2014). Effects of humic materials on plant metabolism and agricultural productivity. *In: Emerging Technoloies and Management of Crop Stress Tolerance,* Vol 18, pp: 449–466. Academic Press, Philadelphia, Massachusetts, USA

Goswami L, A Nath, S Sutradhar, SS Bhattacharya, A Kalamdhad, K Vellingiri, KH Kim (2017). Application of drum compost and vermicompost to improve soil health, growth, and yield parameters for tomato and cabbage plants. *J Environ Manage* 200:243–252

Guan SY (1986). *Soil Enzymes and their Research Methods.* Agricultural Press, Beijing, China

Gupta R, A Yadav, VK Garg (2014). Influence of vermicompost application in potting media on growth and flowering of marigold crop. *Intl J Recycl Org Waste Agric* 3:47

Hashem M, AM Moharam, FEM Saleh, SA Alamri (2018). Biocontrol efficacy of essential oils of cumin, basil and geranium against Fusarium wilt and root rot of basil. *Intl J Agric Biol* 20:2012–2018

Higashikawa FS, CA Silva, W Bettiol (2010). Chemical and physical properties of organic residues. *Rev Bras Cienc Solo* 34:1742–1752

Hosseinzadeh SR, H Amiri, A Ismaili (2018). Evaluation of photosynthesis, physiological, and biochemical responses of chickpea (*Cicer arietinum* L. *cv. Pirouz*) under water deficit stress and use of vermicompost fertilizer. *J Integr Agric* 17:2426–2437

Hosseinzadeh SR, H Amiri, A Ismaili (2017). Nutrition and biochemical responses of chickpea (*Cicer arietinum* L.) to vermicompost fertilizer and water deficit stress. *J Plant Nutr* 40:1–8

Hosseinzadeh SR, H Amiri, A Ismaili (2016). Effect of vermicompost fertilizer on photosynthetic characteristics of chickpea (*Cicer arietinum* L.) under drought stress. *Photosynthetica* 54:87–92

Joshi D, KS Hooda, JC Bhatt, BL Mina, HS Gupta (2009). Suppressive effects of composts on soil-borne and foliar diseases of French bean in the field in the western Indian Himalayas. *Crop Prot* 28:608–615

Kaur A, B Singh, P Ohri, J Wang, R Wadhwa, SC Kaul, PK Pati, A Kaur (2018). Organic cultivation of ashwagandha with improved biomass and high content of active withanolides: use of vermicompost. *PLoS One* 13:1–18

Leoni C (2013). *Crop rotation design in view of soilborne pathogen dynamics. A methodological approach illustrated with Sclerotium rolfsii and Fusarium oxysporum f. spp. cepae*. Wur Wageningen Ur

Li HS (2003). *Principle and Technology of Plant Physiology and Biochemistry Experiment*. Higher Education Press, Beijing, China

Liu XY, GX Ren, Y Shi (2011). The effect of organic manure and chemical fertilizer on growth and development of *Stevia rebaudiana* Bertoni. *Ener Proc* 5:1200–1204

Lucia BD, G Cristiano, L Vecchietti, L Bruno (2013). Effect of different rates of composted organic amendment on urban soil properties, growth and nutrient status of three Mediterranean native hedge species. *Urban For Urban Green* 12:537–545

Mahmud M, R Abdullah, JS Yaacob (2018). Effect of vermicompost amendment on nutritional status of sandy loam soil, growth performance, and yield of pineapple (A*nanas comosus var. MD2*) under field conditions. *Agronomy* 8:1–17

Mengesha WK, SM Powell, KJ Evans, KM Barry (2017). Diverse microbial communities in non-aerated compost teas suppress bacterial wilt. *World J Microb Biotechnol* 33:49

Monamodi EL (2013). Analysis of fruit yield and its components in determinate tomato (*Lycopersicon lycopersci*) using correlation and path coefficient. *Botsw J Agric Appl Sci* 9:11–18

Nair P, N Laxman, S Prabha, M Jagannath, RD Kale (2009). Comparison of soil enzyme activities as biochemical fingerprints of soil health: effect of vermicompost on gold mine tailings. *Dyn Soil Dyn Plant* 3:48–54

Patil NM (2010). Biofertilizer effect on growth, protein and carbohydrate content in *Stevia rebaudiana var Bertoni*. *Recent Res Sci Technol* 2:42–44

Raza W, N Ling, R Zhang, Q Huang, Y Xu, Q Shen (2016). Success evaluation of the biological control of Fusarium wilts of cucumber, banana, and tomato since 2000 and future research strategies. *Crit Rev Biotechnol* 37:202–212

Selvaraj A, (2011). Effect of vermicompost tea on the growth and yield of tomato plants and suppression of root knot nematode in the soil. *Doctoral Dissertation* University of California, Riverside, USA

Sharmila D, LJ Lebecca (2019). A Study on The influence of vermicompost on the growth parameters of *Arachis hypogaea*. *Res J Pharm Technol* 12:2895–2901

Shetinina E, A Shetinina, I Potshova (2019). Efficiency of vermicompost production and use in agriculture. *In: E3S Web Conferences*, Vol 91, pp: 1–9. EDP Sciences, Les Ulis, France

Singh PP, YC Shin, CS Park, YR Chung (1999). Biological control of fusarium wilt of cucumber by chitinolytic bacteria. *Phytopathology* 89:92–99

Singh SK, VR Reddy DH Fleisher, DJ Timlin (2017). Relationship between photosynthetic pigments and chlorophyll fluorescence in soybean under varying phosphorus nutrition at ambient and elevated CO_2. *Photosynthetica* 55:421–433

Srilakshmi A, GNK Sravani, G Narasimha, DVR Saigopal (2011). Effect of vermicompost on soil microbial and enzyme activities. *Asian J Microbiol Biotechnol Environ Sci* 13:459–464

Suthar S (2009). Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium stivum* L.) field crop. *Intl. J. Plant Prod.,* 3: 27–38

Tognetti C, F Laos, M Mazzarino, T Hernández (2013). Composting *vs*. vermicomposting: A comparison of end product quality. *Compost Sci Util* 13:6–13

Trandel MA, A Vigardt, SA Walters, M Lefticariu, M Kinsel (2018). Nitrogen isotope composition, nitrogen amount, and fruit yield of tomato plants affected by the soil-fertilizer types. *ACS Omega* 3:6419–6426

Verdenelli RA, AL Lamarque, JM Meriles (2012). Short-term effects of combined iprodione and vermicompost applications on soil microbial community structure. *Sci Total Environ* 414:210–219

Wang DH, Q Shi, XF Wang, M Wei, JY Hu, J Liu, FJ Yang (2010). Influence of cow manure vermicompost on the growth, metabolite contents, and antioxidant activities of Chinese cabbage (*Brassica campestris sspp. chinensis*). *Biol Fert Soils* 46:689–696

Zaller JG (2007). Vermicompost as a substitute for peat in potting media: Effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. *Sci Hortic* 112:191–199

Zhang W, J Li, K Liu, K Lin (2015). The behavior and toxicological effects of decabromodiphenyl ether (BDE209) in a soil-earthworm system. *Sci Total Environ* 537:377–384

Zhang ZL, WQ Qu, XF Li (2009). *Experimental Guide of Plant Physiology*. Higher Education Press, Beijing, China

Zhou HM, AJ Mao, LR Zhang, F Zhang, YJ Wang, WC Yang (2010). Research on inoculation method and the inheritance of resistance to *Fusarium oxysporum* f. spp. *cucumerinum* on cucumber. *Acta Agric Bor Sin* 25:186–190

Zimny L, R Wacławowicz, D Malak (2009). Formation of selected physical properties of the soil as affected by vermicompost application at cultivation of the sugar beets. *Prob Inzyn Roln* 14:14–19

Zou CL, LM Sang, ZJ Gai, YB Wang, CF Li (2018). Morphological and physiological responses of sugar beet to alkaline stress. *Sugar Technol* 20:202–211