Vermicompost Affects Soil Properties and Spinach Growth, Physiology, and Nutritional Value

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Abstract. The use of vermicompost to improve soil fertility and enhance crop yield has gained considerable momentum due to its contribution to agroecological sustainability. Short-term (35 days after transplanting) effects of vermicompost, applied either as a soil amendment (5% and 10%, v/v) or a drench (40 mL of vermicompost extract at 0, 14, 21, and 28 days after transplanting), on soil properties and spinach plants (Spinacia oleracea L.) were evaluated in a greenhouse. After harvesting, the amendments left high residual levels of nutrients, organic matter and carbon, and increased soil cation exchange capacity (CEC) and water-holding capacity (WHC). Drench treatment of unamended soil increased soil nutrients, CEC, and WHC. All vermicompost treatments, especially amendment at 10% rate, increased leaf number, area, fresh and dry weight (FW and DW), shoot FW and DW, root DW, and water use efficiency (WUE). Vermicompost increased leaf chlorophyll content, and photochemical efficiency, yield, and electron transport rate (ETR) of mature leaves, as well as increased leaf succulence, and carotenoid, protein, and amino acid content. Vermicompost soil amendment reduced phenolics and flavonoids, leading to lower antioxidant capacity, whereas drench treatment only decreased betacyanin content. Vermicompost improved soil fertility, prompted leaf production, delayed leaf senescence, and enhanced growth of spinach. It also favorably influenced spinach quality by increasing leaf succulence and carotenoid, protein, and amino acids content, although it, as soil amendment, reduced flavonoid content leading to low antioxidant capacity.

Soil organic matter plays a key role to achieve sustainability in agricultural production, because it possesses many desirable properties such as high WHC, CEC, ability to sequester contaminants, and beneficial effects on the physical, chemical, and biological characteristics of soil (Herrick, 2000; Liu et al., 2006). In this context, the use of organic soil amendments to improve soil fertility and enhance crop yield has gained considerable momentum for agroecological sustainability (D’Hose et al., 2014; Hargreaves et al., 2008).

Vermicomposting is a bio-oxidative process that uses earthworms and microorganisms for solid organic waste reclamation. The microorganisms, both in the earthworm guts and in the feedstock, are responsible for the biochemical degradation of the organic matter, whereas the earthworms are responsible for the fragmentation of the substrate, which increases the surface area exposed to the microorganisms. The product, vermicompost, is a finely divided mature peat-like material with high porosity, aeration, drainage, WHC, and microbial activity (Srivastava et al., 2011). It can be applied as soil amendment to improve soil fertility by increasing soil organic matter, CEC, and nutrient content, and improve soil structure (Arancón et al., 2006a; Srivastava et al., 2011). Many studies indicated that vermicompost is preferable to compost to improve soil quality (Fornes et al., 2012; Tognetti et al., 2005).

There are many reports of positive effects of vermicompost, as soil amendments or leachate, on many crops, including parsley (Petroselinum crispum Mill.) (Peyvast et al., 2008b), tomato (Solanum lycopersicum L.) (Arancón et al., 2003a, 2012), bell pepper (Capsicum annuum grossum L.) (Arancón et al., 2003b), lettuce (Lactuca sativa L.) (Arancón et al., 2012), mustard (Brassica L.) (Srivastava et al., 2011), strawberry (Fragaria ananasa L.) (Arancón et al., 2003a, 2004), ryegrass (Lolium perenne L.) (Tognetti et al., 2005), sorghum (Sorghum bicolor L.) (Gutiérrez-Miceli et al., 2008), petunias (Petunia sp.) (Arancón et al., 2008), cow pea (Vigna unguiculata L.), banana (Musa acuminate L.), and cassava (Manihot esculenta L.) (Padmavathianna et al., 2008). However, literature about the effects of vermicompost on spinach (Spinacia oleracea L.), an important salad vegetable with large quantities of bioactive compounds and nutrients, is very scarce and focused on growth only (Peyvast et al., 2008a). Our objective was to assess the short-term effects of vermicompost as soil amendments or leachate on soil properties, and spinach growth, physiology, and nutritional value.

Materials and Methods

Plant materials and treatments. Two trials, each with four replications, were conducted from 30 Mar. to 14 May 2015 and 13 Apr. to 28 May 2015, in a greenhouse located in Salinas, CA (lat. 36°40′40″N, long. 121°39′20″W). The average temperature inside the greenhouse during the course of the trials ranged from 15 °C night to 34 °C day and relative humidity ranged from 20% to 80%. The greenhouse was supplemented with light of a 12-h photoperiod (Sun System 3; Sunlight Supply, Vancouver, WA).

There were four treatments in this experiment: 1) Control: field soil (sandy loam) without amendments; 2) Drench: plants were drenched with 40 mL of commercial liquid vermicompost extraction (Worm Power, Avon, NY) at 0, 14, 21, and 28 d after transplanting; 3) 5Ver: soil mixed with 5% (v/v) of commercial granular vermicompost (Worm Power, Avon, NY); 4) 10Ver: soil mixed with 10% (v/v) of granular vermicompost. Plastic pots (diameter: 15 cm; depth: 17 cm) with a single, bottom drain hole were filled with 3 kg different mixture of soil and vermicompost amendments, and watered just to field capacity 2 weeks before transplanting. Uniform-sized spinach seedlings (cv. Crocodile) were transplanted into pots 10 d after sowing in rock wool cells (Grodan Group, Roermond, Netherlands). Plants were thinned to one plant per pot 1 week after transplanting. Plants were irrigated twice weekly and irrigation volumes were determined by weighing each pot at field capacity and again just before irrigation. The weight loss per pot was assumed to equal total evapotranspiration (ET), and its equivalent amount was applied for each pot. Therefore, the water applied was very close to ET and the leached water and nutrients were negligible.

Soil and compost analysis. The untreated field soil and vermicompost samples were collected before treatments were applied, and the soil samples from different treatments were also collected using a soil sampler after harvesting. One soil core (diameter: 2.6 cm; length: 15 cm) was collected from each pot and four soil cores from each treatment were mixed together as one composite sample for determination of macro- and micronutrients, pH, electrical conductivity (EC), organic matter and carbon, CEC, and WHC.
by a commercial laboratory (Soil Control Laboratories, Watsonville, CA).

**Growth and physiology measurements.** Five weeks after transplanting in each trial, leaf maximum photochemical efficiency \( (F_v/F_m) \), photochemical yield \([Y(II)]\), and ETR were measured with a fluorometer (MINI-PAM-II fluorometer; Heinz Walz, Effeltrich, Germany) on the first, second, and third pair of leaves from the bottom of each plant. Leaf \( F_v/F_m \) was measured after leaves were adapted in darkness for 30 min. Then plants were harvested to measure leaf number, area, FW and DW, shoot FW and DW, and root DW. Sample DW was measured after drying at 65 °C for 3 d. Leaf area was measured with a leaf area meter (CI-202 laser area meter; CID Bio-Science Inc., Camas, WA). WUE was calculated as WUE = shoot FW/water used or ET.

Leaf discs were collected using a cork borer from the four largest leaves of each plant to measure relative water content (RWC), specific leaf area (SLA), succulence, chlorophyll content, and nutritional values. Specific leaf area was calculated as SLA = leaf area/DW (Evans, 1972). Leaf RWC was calculated as RWC (%) = 100 \((FW – DW)/(TM – DW)\), where TM is turgid mass after being soaked in water for 4 h at 4 °C (Barr and Weatherley, 1962). Succulence was calculated as water content per unit leaf area (Longstreth and Nobel, 1979). Leaf pigments were extracted with methanol and absorbance of the extraction was measured at 665, 652, and 470 nm \((A_{665}, A_{652}, A_{470})\) with a spectrophotometer (Spectronic Genesys; Spectronic Instruments, Rochester, NY). Chlorophyll \( a \), \( b \), and carotenoid contents \( (C_a, C_b, C_x) \) were calculated using the formula described by Lichtenthaler (1987): 

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C_a (\text{mg} \cdot \text{L}^{-1}) = 16.72A_{665} – 9.16A_{652} \\
C_b (\text{mg} \cdot \text{L}^{-1}) = 34.09A_{652} – 15.28A_{665} \\
C_x (\text{mg} \cdot \text{L}^{-1}) = (1000A_{470} – 1.63C_a – 104.96C_b)/221.
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**Phytochemical analyses.** Leaf samples were soaked in liquid nitrogen immediately after harvest and stored at –80 °C. Phytochemicals were extracted from sample material with 15 mL acidified methanol (1% HCl) using a homogenizer.

**Table 1. Physical and chemical properties of initial soil and granular vermicompost before treatment and soil from each treatment after harvesting.**

| Properties | Soil | Vermicompost | Soil | Drench<sup>3</sup> | 5Ver | 10Ver |
|-----------|------|--------------|------|----------------|------|-------|
| Total N (%) | — | 4.0 | — | — | — | — |
| Available N (mg·kg<sup>−1</sup>) | 48 | — | 6.0 | 7.0 | 6.0 | 10.0 |
| NH₃-N (mg·kg<sup>−1</sup>) | 4.6 | 17 | 4.7 | 4.7 | 4.4 | 6.6 |
| NO₃-N (mg·kg<sup>−1</sup>) | 43 | 8,000 | <2 | 2.3 | <2 | 3.2 |
| P (mg·kg<sup>−1</sup>) | 39 | 7,500 | 32 | 40 | 51 | 61 |
| K (mg·kg<sup>−1</sup>) | 79 | 34,000 | 67 | 80 | 140 | 240 |
| Ca (g·kg<sup>−1</sup>) | 1.0 | 39 | 1.0 | 1.2 | 1.1 | 1.1 |
| Mg (mg·kg<sup>−1</sup>) | 140 | 10,000 | 130 | 160 | 150 | 170 |
| SO₄ (mg·kg<sup>−1</sup>) | 32 | 6,200 | 16 | 25 | 24 | 48 |
| Cu (mg·kg<sup>−1</sup>) | 0.53 | 1,000 | 0.56 | 0.72 | 2.0 | 2.8 |
| Zn (mg·kg<sup>−1</sup>) | 2.6 | 250 | 2.9 | 3.5 | 3.4 | 3.8 |
| Fe (mg·kg<sup>−1</sup>) | 32 | 3,400 | 25 | 39 | 33 | 53 |
| Mn (mg·kg<sup>−1</sup>) | 13 | 180 | 12 | 14 | 10 | 9.6 |
| B (mg·kg<sup>−1</sup>) | 0.27 | 53 | 0.30 | 0.38 | 0.42 | 0.44 |
| Na (mg·kg<sup>−1</sup>) | 67 | 9,800 | 66 | 88 | 89 | 120 |
| Cl (mg·kg<sup>−1</sup>) | 55 | 13,000 | 28 | 55 | 50 | 95 |
| pH | 6.8 | 6.7 | 7.3 | 7.3 | 7.3 | 7.3 |
| EC<sup>y</sup> (dS·m<sup>−1</sup>) | 1.9 | 26.0 | 0.58 | 0.91 | 0.92 | 1.4 |
| Organic matter (%) | 2.3 | 72 | 2.4 | 2.5 | 2.9 | 3.4 |
| Organic carbon (%) | 1.4 | 37 | 1.4 | 1.4 | 1.7 | 2.0 |
| Bulk density (g·mL<sup>−1</sup>) | 1.22 | 0.26 | 1.17 | 1.22 | 1.18 | 1.14 |
| CEC (meq/100 g) | 6.9 | — | 6.7 | 8.0 | 7.4 | 8.1 |
| WHC (g H₂O/100 g soil) | 7.00 | — | 6.85 | 7.62 | 8.16 | 7.74 |
| C:N ratio | — | 9.3 | — | — | — | — |

<sup>3</sup>Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost.
<sup>y</sup>EC = electrical conductivity; CEC = cation exchange capacity; WHC = water-holding capacity.

**Fig. 1.** Effect of vermicompost on spinach leaf number (A), area (B), fresh (C) and dry (D) weight 35 d after transplanting. The values are means of eight replicates ±SE. Different letters on top of bars indicate significant difference at \( P \leq 0.05 \) according to Student’s t test. Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost.
(Polytron; Kinematica AG, Schweiz, Switzerland), then incubated in darkness at –20 °C overnight. After centrifuging at 9070 g for 15 min, the supernatant was collected for the analysis of nutrition values. Its A535 was measured for total betacyanin content. Results were calculated using a molar extinction coefficient of 65,000 (Schwartz and von Elbe, 1980). The antioxidant capacity was measured by the method of ferric-reducing ability of plasma (Benzie and Strain, 1996). 10 mM 2,4,6-tris-2,4,6-tripyridyl-2-triazine (TPTZ) and 20 mM ferric chloride was diluted in 300 mM sodium acetate buffer (pH 3.6) at a ratio of 1:1:10. Extracts (25 µL) were added to 2 mL TPTZ solution, and A593 was determined after 4.5 min reaction. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxyl acid) equivalent (TE) standard curve was prepared.

For total phenolics content, 0.1 mL extract was added to a mixture of 0.15 mL H2O and 0.75 mL of 1:10 diluted Folin–Ciocalteu reagent (Sigma-Aldrich, St. Louis, MO). After 6 min, 0.60 mL of 7.5% (w/v) Na2CO3 was added and vortexed, then the mixture was incubated at 45 °C in a water bath for 10 min. Samples were allowed to cool to room temperature before reading A765 (Slinkard and Singleton, 1997). A standard curve was prepared from a freshly made gallic acid equivalent (GAE) solution. For total flavonoid content, 0.20 mL extract was mixed with

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**Fig. 2.** Effect of vermicompost on spinach shoot fresh weight (A), water use efficiency (WUE; B), dry weight (C), and fresh: dry ratio (D) 35 d after transplanting. The values are means of eight replicates ±SE. Different letters on top of bars indicate significant difference at P ≤ 0.05 according to Student’s t test. Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost.

**Fig. 3.** Effect of vermicompost on spinach root dry weight (A) and shoot: root ratio (B) 35 d after transplanting. The values are means of eight replicates ±SE. Different letters on top of bars indicate significant difference at P ≤ 0.05 according to Student’s t test. Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost.
0.85 mL distilled water and 50 μL of 5% NaNO₂. After 6 min, 100 μL of 10% AlCl₃·6H₂O was added, and after another 5 min, 0.35 mL of 1 M NaOH and 0.20 mL distilled water were added, then A₅₁₀ was measured immediately (Dewanto et al., 2002). A (+)-catechin hydrate equivalents (CHE) standard curve was prepared from a freshly made solution.

**Protein and amino acid contents.** Leaf samples (about 2 g) were homogenized in 15 mL 0.2 M phosphate buffer (pH 6.6) using a homogenizer. After centrifuging at 9070 g for 15 min, the supernatant was collected to measure the content of protein and amino acid. Amino acid content was determined using the ninhydrin method (Yokoyama and Hiramatsu, 2003). A 1% w/v ninhydrin stock solution was prepared in ethanol containing 0.025% w/v ascorbic acid. A working ninhydrin solution was prepared immediately before use by adding two parts of 0.4 M sodium acetate buffer (pH 5.0) to one part of ninhydrin stock solution. Extract or standard glutamate solution (50 μL) was added to 2.9 mL ninhydrin work solution and the mixture was heated at 95 °C for 10 min. The solution was cooled and A₅₇₀ was measured. Protein content was determined according to the method of Bradford (1976) using bovine serum albumin as standard.

**Statistical analysis.** A complete randomized design was used for this experiment. Each biological replicate contained one pot and each treatment included four replicate pots for each trial. Treatment means were separated by Student’s t test at the 0.05 level of probability using the JMP program version 5 (SAS Institute Inc., Cary, NC). The interaction of the two trials was not significant, so data were pooled together.

**Results**

**Soil physical and chemical properties.** The granular vermicompost contained high levels of macro- (N, P, K, Ca, Mg, and SO₄) and micronutrients (Cu, Zn, Fe, Mn, and B), and organic matter and carbon (Table 1). However, it also had high levels of Na (9.8 g·kg⁻¹) and Cl (13 g·kg⁻¹) with high EC value (26 dS·m⁻¹). The C:N ratio of solid vermicompost was 9.3. After harvesting, the amendments left high residual levels of nutrients (P, K, SO₄, Cu, Zn, Fe, and B), organic matter and carbon, and increased soil CEC and WHC. However, the soil EC increased from 0.58 to 0.92 and 1.4 dS·m⁻¹ with 5% and 10% amendments, respectively. The drench treatment increased, to a lesser extent, soil levels of P, Mg, SO₄, Cu, Zn, Fe, and B. Drench treatment increased soil CEC and WHC, although it had negligible effects on organic matter and carbon.

**Growth and physiological responses.** Compared with the control, all vermicompost treatments (drench, 5Ver, and 10Ver) significantly increased leaf number from 14.0 to 15.3, 17.0, and 19.8 per plant (Fig. 1A); area from 155 to 252, 314, and 473 (Fig. 1B); FW from 8.7 to 14.3, 20.7, and 33 g per plant.
1.15, 1.22, and 1.16 mg (Fig. 5A), chlorophyll b content from 0.83 to 4.2, 3.5, and 3.6 mg·g⁻¹ DW, respectively (Fig. 4B). Root DW significantly increased from 10.6 to 17.5, 24.4, and 39.6 g per plant (Fig. 2A); DW from 1.8 to 3.1, 3.9, and 6.3 g per plant (Fig. 2C); and WUE from 3.4 to 5.8, 6.9, and 11.3 mg·m⁻²·s⁻¹ H₂O (Fig. 2B); by drench, 5Ver, and 10Ver treatments, respectively. Shoot FW:DW ratio was unaffected by vermicompost treatments.

Nutritional values. Leaf carotenoid content significantly increased from 1.4 to 1.9, 1.7, and 1.8 mg·g⁻¹ DW under drench, 5Ver, and 10Ver treatments, respectively (Fig. 7A). Soil amendments significantly decreased total phenolic content from 17.6 to 14.9 and 13.1 GAE mg⁻¹ DW, whereas the drench treatment had no effect (Fig. 7B). Betacyanin content significantly decreased from 62 to 51, 38, and 32 μg·g⁻¹ DW under drench, 5Ver, and 10Ver treatments, respectively (Fig. 7C).

Soil fertility. The vermicompost used in the present study had preferable C:N ratio of 9.3. A C:N ratio less than 20 indicates acceptable maturity of the product, but a ratio less than 15 is preferred (Gaur and Sadasivam, 1993; Jimenez and Garcia, 1992). Similar to previous studies (Fornes et al., 2012; Padmavathamma et al., 2008), the vermicompost has many favorable properties including high content of organic matter and carbon, and macro- and micronutrients, in spite of the high EC value due to its high contents of Na and Cl. This suggests that a high application rate as soil amendment is not recommended because of the salinity stress it might cause. Even after harvesting, soil with vermicompost amendments, especially at 10% rate, had high content of nutrients, organic matter and carbon, and high values of CEC and WHC. Also drench treatment increased soil nutrient contents, CEC, and WHC. The results indicate that vermicompost could be used to improve soil fertility as a soil amendment or drench.

Discussion

Growth and physiological responses. All vermicompost treatments, especially amendment at 10% rate, greatly stimulated spinach growth, as indicated by increased leaf number, area, FW and DW, shoot FW and DW, and root DW, and shoot growth was more favorably influenced than root growth by soil amendment. Peyvast et al. (2008a) reported that spinach plants with 10% vermicompost as soil amendment had highest leaf number, area, and FW. Numerous studies indicated that vermicompost amendment into soilless media in greenhouse resulted in increased germination, growth and flowering of ornaments, and growth and yield of vegetables even at low mix rates (Arancon et al., 2008; Atiyeh et al., 1999, 2000a, 2000b, 2001). In addition, Peyvast et al. (2008b) reported that vermicompost as soil amendments enhanced parsley leaf FW and DW, root DW, and plant height in greenhouse. Similarly, in another greenhouse study, vermicompost as soil amendments increased mustard root and shoot length, numbers of branches, leaves, flowers and pods, and plant FW and DW (Srivastava et al., 2011). Favorable effects of vermicomposts as soil amendments have been reported in field studies on the growth and yield of peppers, tomatoes, and strawberries (Arancon et al., 2003a, 2004, 2005a).

Although vermicompost contains macro- and micronutrients, its positive effects on crop growth and yield may not be mainly due to its nutrients, since in some studies, the nutrients in vermicompost were equalized in the control plots treated with inorganic fertilizers (Arancon et al., 2003a, 2003b, 2004, 2005a, 2005b, 2006a, 2006b, 2007a, 2007b, 2008a, 2008b, 2009a, 2009b, 2010a, 2010b, 2011, 2012).
addition to soil can cause significant changes in physical and chemical properties. Our results indicated that vermicompost enhanced soil organic matter, CEC, and WHC. Similarly, Ferreras et al. (2006) reported that vermicompost as soil amendment improved soil porosity and aggregate ability. Gopinath et al. (2008) observed decreases in soil bulk density and increases in soil pH and organic carbon after addition of vermicompost. These changes in soil properties improved the availability of air and water, enhancing root growth, which in turn facilitates water and nutrient absorption.

Vermicompost can enhance microbial biomass and activities due to its mucus and casts, which were responsible for better litter decomposition and mineralization and provided high amount of available forms of nutrients (Atiyeh et al., 2000b; Padmavathiamma et al., 2008; Srivastava et al., 2011; Tognetti et al., 2005). The byproducts of microbial activities, polysaccharides, can help the aggregation of soil particles. Other products of microbial activities include plant growth-regulating substances such as auxins, gibberellins, cytokinins, ethylene, and abscisic acids (Arancon et al., 2012; Frankenberger and Arshad, 1995; Tomati et al., 1987, 1988). In addition, humic materials from vermicomposts increased plant growth of carrots, tomatoes, and peppers (Arancon et al., 2003c, 2006b; Atiyeh et al., 2002b; Muscolo et al., 1999). Atiyeh et al. (2002b) and Arancon et al. (2003c, 2006b) suggested that humic acid may absorb plant hormones and/or itself has hormone ability to affect plant growth. Actually, Canellas et al. (2002) found that the identified auxin groups in humic acids from vermicompost could enhance root elongation, lateral root emergency, and plasma membrane H+ -ATPase activity. Mora et al. (2010) observed that action of humic acid on promotion of cucumber shoot growth involves nitrate-related changes associated with the root-to-shoot distribution of cytokinins, polyamines, and mineral nutrients.

In addition, some studies have shown that vermicompost can suppress a wide range of microbial disease (Edwards et al., 2006), insect pest (Arancon et al., 2005b; Ramesh, 2000; Yrdim et al., 2006), and parasitic nematodes (Arancon et al., 2003b; Swathi et al., 1998). As mentioned above, vermicompost increased soil microbial biomass and activity and changed the diversity and abundance of soil fauna, and thus a broader range of microorganisms may act as biocontrol agents through competition, antibiotic, and parasitism (Lazcano and Dominguez, 2011). Also, the induction of plant systemic resistance by vermicompost was observed by Singh et al. (2003).

All vermicompost treatments increased spinach WUE, which might at least partly result from improved soil properties, such as soil WHC. Vermicompost as soil amendments reduced SLA at 10% mix rate and increased leaf succulence, indicating the improvement of spinach quality. There are limited reports on chlorophyll content and photochemistry of photosystem II as affected by vermicompost. In this study, chlorophyll content increased under all vermicompost treatments, especially drench treatment. Vermicompost was also reported to increase chlorophyll content in marigold (Atiyeh et al., 2001) and mustard (Srivastava et al., 2011) leaves. In the present study, vermicompost treatments improved photochemistry of photosystem II, especially in mature leaves. They enhanced ETR and Y(II) of both first and second pair leaves, and Fv/Fm of all leaves. Parameters related to photochemistry of photosystem II and chlorophyll content are commonly used as indicators for leaf senescence (Adams III et al., 1990; Lima et al., 1999; Plesni et al., 1994). The result suggested that vermicompost could delay leaf senescence and extend leaf longevity. Similarly, the positive role of vermicompost in leaf production and longevity was reported.

Fig. 7. Effect of vermicompost on spinach leaf carotenoid (A), total phenolic (PHE; B), and betacyanin content (C) 35 d after transplanting. The values are means of eight replicates ± SE. Different letters on top of bars indicate significant difference at P ≤ 0.05 according to Student’s t test. Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost. GAE = gallic acid equivalents.
in strawberry, banana, and cassava (Arancon et al., 2004; Padmavathiamma et al., 2008). High number of functional leaves is essential for crop production, especially for leafy vegetable such as spinach.

**Nutritional values.** Carotenoids have long been recognized as essential nutrients and important health-beneficial compounds (Fraser and Bramley, 2004). Consistent with previous study in mustard and pak choi (Pant et al., 2009; Srivastava et al., 2011), its content increased under all vermicompost treatments, especially under drench treatment, in the present study. However, vermicompost as soil amendment, especially at 10% rate, reduced the content of other phytochemicals such as phenolics, betacyanins, and flavonoids, and drench treatment only reduced betacyanin content in the present study. Phenolics are a class of secondary metabolites that play a key role as antioxidants. The most important group of phenolics in plants is flavonoids, which have attracted considerable interest due to their broad spectrum of biological effects such as antioxidative, anti-inflammatory, vasorelaxant, antimicrobial, antiviral, and for their anticarcinogenic and antimutagenic activities (Guo et al., 2011; Maimoona et al., 2011). In the present study, only vermicompost as amendment decreased total antioxidant capacity, and the response pattern of total antioxidant capacity was very similar with that of flavonoids, suggesting that flavonoids might be the main antioxidant phytochemical in spinach leaves, at least of this cultivar. Its content might not be negatively altered by drench treatment of vermicompost. There are a few reports about vermicompost’s effects on crop phytochemical content. Previous study indicated that vermicompost tea decreased phenolic content in pak choi (Pant et al., 2009). Zaller (2006) reported that ascorbic acid content in tomato fruits decreased after foliar spraying of vermicompost extract.

Vermicompost, whether as an amendment or a drench, also favorably influenced spinach’s nutritional value in the present study by increasing protein and amino acid contents. A previous study also indicated that protein content in mustard leaves was greatly increased by vermicompost (Srivastava et al., 2011). In addition, vermicompost was reported to increase sugar content in banana (Padmavathiamma et al., 2008), mustard (Srivastava et al., 2011), spinach, and parsley (Peyvast et al., 2008a, 2008b). Foliar application of vermicompost extract did not alter the content of glucose or fructose in tomato fruit (Zaller, 2006). The information about vermicompost’s effect on mineral content was very limited and inconsistent, probably due to different application methods. Vermicompost leachate had no effects on N, P, and K concentration in sorghum leaves (Gutiérrez-Miceli et al., 2008). Foliar application of vermicompost extract did not alter mineral content of tomato fruit (Zaller, 2006), whereas soil amendment increased mineral content in spinach and parsley.

**Fig. 8.** Effect of vermicompost on spinach leaf flavonoid content (FLA; A) and total antioxidant capacity (B) 35 d after transplanting. The values are means of eight replicates ± SE. Different letters on top of bars indicate significant difference at P ≤ 0.05 according to Student’s t test. Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost. CHE = (+)-catechin hydrate equivalents; TE = trolox equivalents.

**Fig. 9.** Effect of vermicompost on spinach leaf amino acid (A) and protein content (B) 35 d after transplanting. The values are means of eight replicates ± SE. Different letters on top of bars indicate significant difference at P ≤ 0.05 according to Student’s t test. Drench: 40 mL of vermicompost extract at 0, 14, 21, and 28 d after transplanting; 5Ver or 10Ver: soil amended with 5% or 10% (v/v) vermicompost.
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(Peyvast et al., 2008a, 2008b). The effect of vermicompost on spinach sugar and mineral content was not assessed in the present study, but deserves further investigation.

In summary, vermicompost improved soil fertility, prompted leaf production, delayed leaf senescence, enhanced spinach growth and WUE. It also improved spinach quality by increasing succulence and the content of carotenoid, protein, and amino acid, although as soil amendment it reduced flavonoid content, leading to low antioxidant capacity. Vermicompost as soil amendment or drench for spinach production in the field might be an efficient strategy for water savings, and organic production, as well as recycling of organic waste materials. Further research should be conducted to investigate its long-term effect and optimize its application rates in the field.

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