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RESEARCH ARTICLE

Vermicomposting with maize increases agricultural benefits by 304 %

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Abstract Pollution of agricultural ecosystems is due to the excessive use of mineral fertilizers and mass discharge of livestock manure. Therefore, there is a need for disposing manure safely, for instance by transforming manure into valuable compost. Traditional composting is, however, time-consuming with considerable nutrient losses. Vermicomposting is an alternative method, but so far, there are few quantitative evaluations of vermicomposting. We therefore compared vermicomposting and traditional composting of cattle manure with maize. Our results show that the amount of nutrients from vermicomposting is lower than that from traditional composting. Nonetheless, vermicomposting yielded 2172.0 kg of earthworms per hectare, which provided an additional income of US$4008.1 to farmers. Moreover, vermicomposting increased aboveground biomass by 7.7 % and maize grain yield by 18.3 %. The global output of vermicomposting was thus higher by 304 % due to higher grain yield and earthworm income.

Keywords Cattle manure · Vermicompost · Traditional compost · Maize · Economic benefits

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1 Introduction

Traditional agriculture is currently characterized by excessive inputs of chemical fertilizers, pesticides, and herbicides, while the insufficient application of organic fertilizers (Li et al. 2007; Gill and Garg. 2014). The excess use of chemical fertilizers and pesticides has resulted in numerous negative effects on the environment, including water, soil (Ju et al. 2009), and food pollution (Li et al. 2007), degradation of soil quality (Ju et al. 2009), and losses of agricultural biodiversity (Minuto et al. 2006; Gill and Garg. 2014). To solve such problems, more sustainable agricultural practices are urgently required. Compared with chemical agriculture, organic farming has been thoroughly proven as beneficial in maintaining both biodiversity and environmental sustainability (Ahmad et al. 2007; Leite et al. 2010). Organic farming has been gradually adopted by agriculturalists, particularly in developed countries (Rigby et al. 2001; Lobley et al. 2009), because of its higher economic and ecological benefits.

The production of livestock manure has extensively increased with increasing human populations, industrialization, and intensive agriculture (Tripathi and Bhardwaj 2004). The mass discharge of livestock manure has also caused many environmental problems, such as offensive odors and the contamination of groundwater and soil (Edwards and Bater 1992; Garg et al. 2006). The conversion of a waste into a beneficial material could play an important role in resource recycling and environmental cleaning (Tripathi and Bhardwaj 2004; Yadav and Garg 2011).

Although various methods of livestock manure disposal are currently in use, including physical, chemical, and microbiological techniques, these methods are time-consuming and labor intensive (Garg et al. 2006). For example, traditional compost was usually carried out by the windrow system: The manure was windrowed and stirred several times by labor or special machine, with the period being 1–3 months (Wei et al. 1999; Li et al. 2000). Traditional composting is simple and cheap but does not make full use of livestock manure, with considerable nutrient losses (Wei et al. 1999; Eklind and Kirchmann 2000; Li et al. 2000). Vermicomposting has been reported to be a cost-effective, viable, and rapid technique for the efficient management of livestock manure (Fig. 1) (Garg et al. 2006). Earthworm activity not only accelerates the decomposition of organic matter (Atiyeh et al. 2001; Lv et al. 2013) but also makes nutrients available for plant growth (Tripathi and Bhardwaj 2004; Garg et al. 2006). Therefore, the composting of livestock manure could help reduce the environmental pollution caused by this waste while providing a healthier alternative from chemical fertilizer to organic farming (Atiyeh et al. 2002).

From the aforementioned facts, this paper hypothesized that the digestion of cattle manure by earthworms would lead to the fuller use of the nutrients in this waste, with plentiful earthworms being obtained. However, it remained uncertain whether applying this remainder compost product to fields would generate equal or greater yields and more economic benefits than applying traditional compost in agricultural system. Therefore, this paper conducted a study about the same cattle manure treated by vermicomposting and traditional composting, and their remainder valuable compost products were applied into the fields, respectively. The aims of the investigation were as follows: (1) to investigate effects of vermicomposting and traditional composting on nutrients of the cattle manure; (2) to investigate maize yield in plots fertilized with cattle manure vermicompost and traditional compost, respectively; and (3) to compare the inputs and outputs of the two different systems (cattle manure-vermicompost-maize system, cattle manure-traditional compost-maize system) comprehensively, and determine if the field application of cattle manure digested by earthworms generated greater economic benefits.

Fig. 1 Vermicomposting: the cattle manure is being digested by earthworms

2 Materials and methods

2.1 Experimental site

The experimental site is located at the Eco-farming Research Station of Shandong Agricultural University, based in Jiang Jiazhuang Village, Pingyi County, Shandong Province, Eastern China (35° 26′ 21″ N, 117° 50′ 11″ E). The area experiences a typical temperate and monsoonal climate, with a mean annual rainfall of 770.2 mm and average annual temperature of 13.2 °C. The soil type is brown. Before the application of fertilizer, the experimental soil (0–20 cm) contained organic matter, 1.22 %; total nitrogen, 0.08 %; available P, 14.93 mg kg^{-1}; and available K, 144.96 mg kg^{-1}.

2.2 Collection of cattle manure and earthworms

Both cattle manure and earthworms (*Eisenia fetida*) were obtained from Hongyi Organic Farm in Jiang Jiazhuang Village. Before composting, the experimental cattle manure contained organic matter, 54.14 %; total nitrogen, 1.87 %; available P, 0.24 %; and available K, 0.52 %, and had a pH of 8.63.

2.3 Experimental design

This study was conducted in two different systems, cattle manure-vermicompost-maize system (VC system) and cattle manure-traditional compost-maize system (TC system).

In the VC system, cattle manure (30 t, dry weight) was shaped into cuboids with width 1.5 m and height 0.2 m. A total of 309 kg earthworms was added into the cattle manure (Guo 2012). Water was sprinkled daily onto the manure using a sprayer to maintain a moisture level of 55–65 %. After 60 days, the earthworms were separated from the cattle manure, the remainder cattle manure vermicompost was applied into the field 1 (1 ha) before tillage.

In the TC system, cattle manure (30 t, dry weight) was shaped into cuboids with width 1.5 m, height 0.5 m, and moisture 60–70 % and then covered with plastic film, stirred, and mixed every 20 days. After 60 days, the remainder cattle manure traditional compost was applied into the field 2 (1 ha) before tillage.

Three completely randomized experimental plots were selected in each field; each plot was 2.4 × 5 m. The experimental crop was the ordinary high-yield maize Zhengdan 958. The maize was sown on June 21, 2011 and harvested on September 30, 2011. The distance between rows was 0.6 m, and the distance between plants was 0.27 m.

2.4 Sampling and chemical analysis

After 60-day composting, cattle manure vermicompost and traditional compost samples were drawn by using an auger with the bore of 6 cm. Five random sites in the same compost plot were selected and the samples were taken from top to bottom; the five random subsamples were pooled together and air-dried for nutrients analysis. Determination of pH was done by a digital pH meter (PB-10, Sartorius, Germany). Nutrient estimations involved Walkle and Black (1934) method for organic matter, macro-kjeldahl method for total N, sodium bicarbonate extractable method (Olsen et al. 1954) for available P, and ammonium acetate extractable method (Simard 1993) for available K. All the determinations were carried out in triplicate.

Dry matter of total aboveground biomass was measured two times during the growing season, at flowering and at harvest stage. The aboveground biomass included corn stem, leaves, corncob, and kernels. The whole maize plant was cut on the bottom close to the ground and was transported to the laboratory to segment and then dried at 105 °C for 30 min and at 75 °C until reaching a constant weight.

At maize harvest, three replicates of 10 consecutive plants in the same row were selected. The grain and fresh straw yields were measured for each replicate.

2.5 Statistical analysis

Data regarding economic benefits were scaled to 1 ha based on historic data collected from Hongyi Organic Farm and the present experiment. Input refers to the costs for purchasing seeds, fertilizers, plastic films, sprayers, and earthworms; cultivating, irrigation seeding, and crop harvesting; and applying fertilizer and controlling pests and weeds. Output includes the sales of earthworms, maize grain, and fresh straw.

All data were analyzed using one-way analysis of variance (ANOVA) and nonparametric tests with SPSS 17.0 at the 0.05 level. Differences between treatments were considered significant if $P \leq 0.05$. Analyses were performed in Sigma Plot 10.0 (Aspire Software Intl. Ashburn, VA, USA).

3 Results and discussion

3.1 Changes of nutrient contents and pH in cattle manure

We found that the nutrient contents, total quantities of nutrients, and pH of cattle manure were greatly changed after traditional composting and vermicomposting. Composting, particularly vermicomposting, significantly decreased pH ($P \leq 0.05$). The total quantities of organic matter and N have significantly ($P \leq 0.05$) decreased after composting, due to decomposition of organic matter and N losses (Shi et al. 2010). Organic matter and total N content were also decreased; however, the available P and K content increased, except for available K in vermicompost (Table 1). These results are in support of previous research that composting can make nutrients more

Table 1 Changes of organic matter, total N, available P, available K, and pH of cattle manure composted by traditional composting and vermicomposting

Cattle manure type	Content (%)				Total quantities (t ha^{-1})				pH
	Organic matter	Total N	Avialable P	Avialable K	Organic matter	Total N	Avialable P	Avialable K	
Before compost	54.14±0.35 a	1.87±0.01 a	0.240±0.005 a	0.523±0.007 b	16.24±0.10 a	0.56±0.003 a	0.072±0.001 a	0.157±0.002 a	8.63±0.02 a
Traditional compost	43.48±0.64 b	1.75±0.02 b	0.245±0.005 a	0.567±0.001 a	12.22±0.18 b	0.49±0.005 b	0.069±0.001 a	0.159±0.000 a	8.18±0.02 b
Vermicompost	42.76±0.11 b	1.63±0.04 c	0.248±0.003 a	0.503±0.018 b	9.05±0.03 c	0.34±0.010 c	0.052±0.001 b	0.106±0.004 b	8.03±0.06 c

Values are mean±SE ($n=3$). The different letters in the same column indicate significant differences at $P \leq 0.05$

Table 2 Comprehensive economic benefits of the two different systems

	Parameters	The amount of material		Price (USD kg^{-1})	Cost (USD)	
		Traditional compost (kg)	Vermicompost (kg)		Traditional compost	Vermicompost
Inputs	Maize seed	37.5	37.5	2.05	76.9	76.9
	Fertilizers	3.0×10^{4}	3.0×10^{4}	1.577×10^{-2}	473.1	473.1
	Plastic film	25	0	1.89	47.3	0
	Sprayer	0	2.5	4.74	0	11.9
	Introduced earthworms	0	309.0	3.15	0	973.4
	Water	0	3.75×10^{5}	4.7×10^{-4}	0	176.3
		Traditional compost (ha)	Vermicompost (ha)	Price (USD ha^{-1})		
	Harvesting earthworms	0	0.06	19716.1	0	1183.0
	Cultivation	1	1	212.9	212.9	212.9
	Seeding	1	1	189.3	189.3	189.3
	Irrigation	1	1	236.6	236.6	236.6
	Harvesting	1	1	236.6	236.6	236.6
	Fertilizer application	1	1	157.7	157.7	157.7
	Pest control	1	1	153.8	153.8	153.8
	Weed control	1	1	165.6	165.6	165.6
		Traditional compost (kg)	Vermicompost (kg)	Price (USD kg^{-1})		
Outputs	Earthworms	0	2172.0	2.21	0	4800.1
	Maize grain	8362.9	9889.6	0.32	2676.1	3164.7
	Fresh straw	22969.8	21667.4	0.011	252.7	238.3
Net output					979.0	3956.0
The ratio of output/input					1.5:1	1.9:1

Traditional compost: cattle manure-traditional compost-maize system; Vermicompost: cattle manure-vermicompost- maize system. Data were upscaled to 1 ha based on the data collected from Hongyi Organic Farm and this experiment. The income for all products was calculated based on the local market price in 2011. US$1.0=6.34 Chinese Yuan

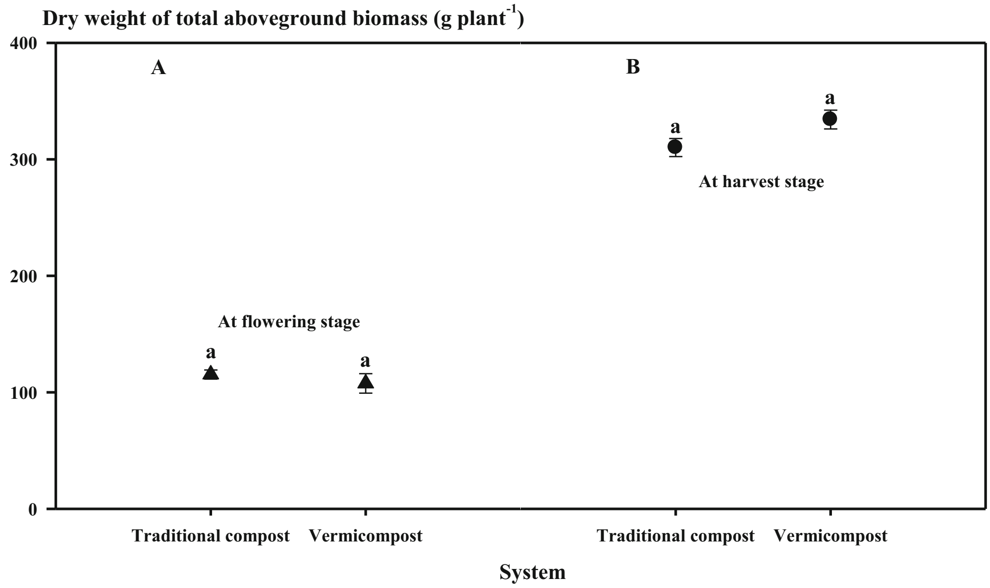

Fig. 2 Dry weight of total aboveground biomass per maize plant was lower at flowering stage, but higher at harvest stage in the vermicompost system. Values are mean±SE (n=3). The different *letters* in the same figure indicate significant differences at P≤0.05. Traditional compost: cattle manure-traditional compost-maize system; vermicompost: cattle manure-vermicompost-maize system

available (Tripathi and Bhardwaj 2004; Garg et al. 2006) while vermicomposting results in lower pH (Yang, et al. 2014). The total N and available K content were more significant in traditional compost than that in vermicompost (P≤ 0.05). Organic matter content was also higher in traditional compost than that in vermicompost, but the difference was not significant (P≥0.05). The total quantities of organic matter and N, and available P and K were significantly higher in traditional compost than those in vermicompost (P≤0.05, Table 1). This might be because earthworms and microbes require carbon as energy source and nitrogen to build proteins (Ahmad et al. 2007). Although carbon and nitrogen were consumed, plentiful additional earthworms were obtained (Table 2); simultaneously, the activities of earthworms convert the cattle manure into a finely divided, peat-like vermicompost, with higher porosity, aeration, drainage, water-holding capacity, and microbial activity being achieved (Edwards and Burrows 1988; Atiyeh et al. 2001). The results indicated that vermicomposting might fully use nutrients of the cattle manure and convert the wasteful cattle manure into valuable organic fertilizer that is friendly to the environment.

3.2 Dry weight of total aboveground biomass

Dry weight of total aboveground biomass was influenced by cattle manure vermicompost and traditional compost application (Fig. 2). At the flowering stage, the dry weight of total aboveground biomass in the plots fertilized with traditional compost was 7.1 % higher than that in the plots fertilized with cattle manure vermicompost (Fig. 2A). That might be because the main nutrients in traditional compost were higher at the beginning (Table 1). However, at the harvest stage, the dry weight of total aboveground biomass was 7.7 % higher in the plots fertilized with vermicompost (Fig. 2B). Although

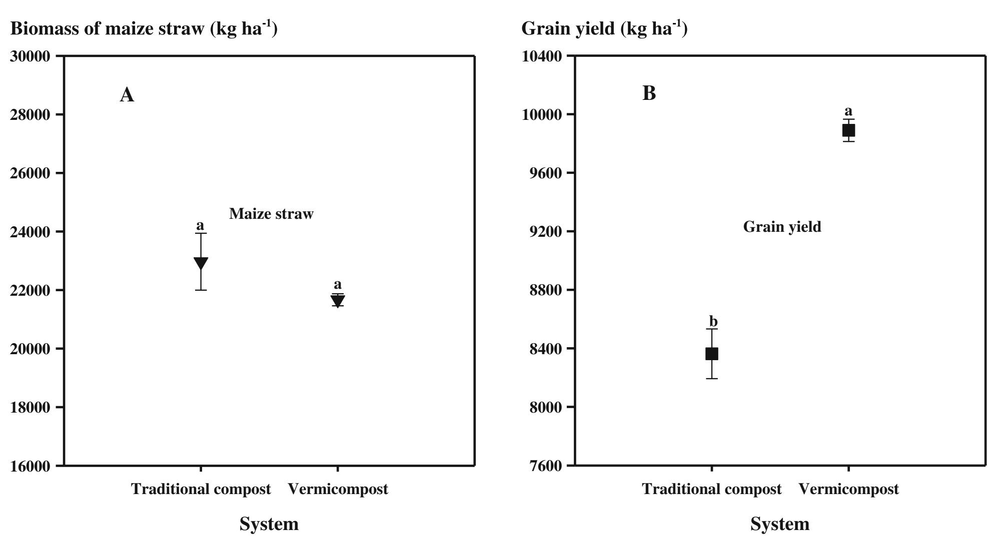

Fig. 3 The biomass of maize straw and maize grain yield in the different systems. The grain yield was significant higher in the vermicompost system. Values are mean±SE (n=3). The different *letters* in the same figure indicate significant differences at P≤0.05. Traditional compost: cattle manure-traditional compost-maize system; vermicompost: cattle manure-vermicompost-maize system

both vermicompost and traditional compost are considered to be slow-release fertilizers, the former differed from the latter in being a product of the biodegradation and stabilization of organic materials through the interaction between earthworms and microorganisms (Chaoui et al. 2003; Arancon et al. 2005; Singh et al. 2008).

Vermicompost contains plant-growth-regulating materials, such as humic acids (Senesi et al. 1992; Masciandaro et al. 1997; Atiyeh et al. 2002), auxins, gibberellins, and cytokinins (Krishnamoorthy and Vajrabhiah 1986; Tomati et al. 1988, 1990; Singh et al. 2008). These regulators are produced through the action of earthworms and microbes such as fungi and actinomycetous bacteria, which increase the plant growth and yield of many crops (Tomati et al. 1988; Atiyeh et al. 2002). Traditional compost can also provide nutrients for plant to grow, but its salinity, N immobilization, and pathogen levels may be problematic (Sims 1990; O'Brien and Barker 1996; Chaoui et al. 2003). Previous researchers have compared the effects of composting and vermicomposting and reported that vermicompost possesses a lower C/N ratio, higher protein/organic C ratio, and greater levels of N (Vinceslas-Akpa and Loquet 1997). Others have reported that vermicomposts are efficient sources of plant nutrients and that they are less likely to produce salinity stress in containers as compared to compost and synthetic fertilizers (Chaoui et al. 2003). So the plants fertilized with cattle manure vermicompost grown better than those nourished with traditional compost in the later stage.

3.3 Maize yield

Maize yield was also influenced by cattle manure vermicompost and traditional compost application (Fig. 3). The grain yield in plots fertilized with cattle manure vermicompost was significantly greater than that fertilized with traditional compost at the harvest stage ($P \leq 0.05$, Fig. 3B). Although the biomass of maize straw in plots fertilized with cattle manure vermicompost was lesser than that fertilized with traditional compost, the difference was not significant ($P > 0.05$, Fig. 3A).

Because vermicompost differed from the traditional compost, application of cattle manure vermicompost provided more plant regulator to promote plant absorbing more nutrients which further promoted the dry matter transferring to maize grain. As the nutrients in vermicompost were lesser than those in traditional compost, the higher yield performance indicated that vermicomposting facilitates more complete use of these nutrients in comparison with traditional composting.

3.4 Economic benefits

The grain yield is not the single factor considered by farmers; actually, the economic benefits are of greater importance. We found that the net output was higher (US$3956) in the VC system, increased by 304.1 % compared with the TC system. Although the inputs for vermicomposting were higher than those for traditional composting, plentiful earthworms were obtained from the former treatment, and application of cattle manure vermicompost harvested greater grain yield which led to a higher output. In the end, the ratio of output/input (1.9:1) was higher in the VC system than that (1.5:1) in the TC system (Table 2). The above mentioned results powerfully proved that cattle manure treated by vermicomposting and its application generated more economic benefits.

4 Conclusions

The digestion of cattle manure by earthworms converts the wasteful cattle manure into more valuable organic fertilizer that is friendly to the environment. Some nutrients are used by earthworms, and plentiful earthworms have been obtained. The activities of earthworms made the remainder compost product contain some plant growth regulators which led to the plant to fully use the agronomic nutrients to generate greater aboveground biomass and higher grain yield. Thanks to the harvest of earthworms and increased grain yield, both net output and ratio of output/input in the VC system were higher, even its input was simultaneously elevated. Our findings may help to sustainably increase food supply by improving soil conditions, protecting environments, and maintaining crop yields through vermicompost application.

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