Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.5, No.12, 2015

Influence of Municipal Solid Waste Vermicompost on Soil Organic Carbon Stock and Yield of Okra (*Abelmoschus esculentus* Moench) in a Tropical Agroecosystem

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Abstract
A three year trial was conducted in a farmers' field within the degraded Abraka Forest Farm Reserve about 5km from the Teaching and Research Farm of the Delta State University, Abraka, (latitude 5^0 46' and longitude 6^0 5') Nigeria in early cropping (March-July) and late cropping (August-December) of 2010, 2011 and 2012. The study was aimed at determining the influence of vermicompost application on soil organic carbon stock and crop yield in an okra based vegetable farm. Six treatments, namely: control (no application), 100%NPK, 100%vermicompost, 85% vermicompost + 15%NPK, 50% vermicompost + 50%NPK and 15%NPK + 85% vermicompost, were arranged in a randomized complete block design. Soil fertility attributes studied were soil bulk density, soil organic carbon and soil organic carbon stock, while pod yield was the only plant parameter. Vermicopmost application significantly reduced soil bulk density, and increased soil organic carbon (SOC) and carbon stock. Agronomic efficiency indices (AEI) of vermicompost for all the soil fertility attributes and pod yield were more efficient than NPK by values above 100%. Highest cumulative marketable fruit yield of okra over the three years was obtained with 100% VC with value of 67.04tons ha^{-1} and increased by 94.8% and 73.8% over the control and 100%NPK respectively.
Keywords: okra, soil organic carbon, agronomic efficiency index, vermicompost, solid wastes

INTRODUCTION

Growing heaps of domestic solid wastes and sludge from sewage, markets and recreational centres abound in towns and cities in Nigeria. While open dumping is practiced all over the country, attempts by the Federal Government to ensure other viable methods of hygienic disposal by legislation have not been successful. Segregation and composting are options that could be adopted. After the discovery of crude oil in the 1960s, composting which was practiced at community or individual level was abandoned. In Kano, Northern Nigeria, night soil and city refuse were composted between 1936 and 1942 and regular revenue was generated (Gilles, 1946,; Sridar, 2006). However, within the last two decades several studies have reported renewed interest in converting organic wastes to organic fertilizers at household, community level and by 1995 the interest has spread to the national level (Adeoye et al., 1993; Sridar and Adeoye, 2003; Sridar, 2006).

Global estimates indicate that current waste management methods, specifically emissions from landfill contribute significantly to climate change. Generally, 70% of solid waste is landfilled; a meagre 19% is recovered through composting or recycling while the remaining 11% is converted to energy through incineration or waste to energy technologies (Bogner *et al.* 2007).. There is a great potential for addressing methane emissions by reducing the amount of waste that ends up in a landfill, since the decomposition of organic materials in landfill produces methane. Large quantities of plant nutrients abundant in domestic wastes and agricultural byproducts are waste, sometimes usually burnt or landfilled.

Tropical agroecosystems such as crop farmlands are low in soil organic carbon (SOC). The low SOC content is attributed to reduced natural vegetation and low below and aboveground crop growth. The relatively high soil temperatures also promote rapid turnover rates of organic material and activities of soil fauna (Bationo et al., 1995). The degraded and depleted tropical soils are high with carbon sink capacity but with low rate of sequestration resulting in low soil quality causing poor crop yields (Binyam, 2014; Lal, 2004). Soil restorative farm practices are needed to mitigate soil degradation trends.

The removal of atmospheric CO_2 by plants and storage of fixed C as soil organic matter is usually termed soil carbon sequestration, a strategy aimed at increasing soil organic carbon (SOC) density in the soil which in turn stabilize the SOC within stable micro aggregates and improve the depth distribution of the SOC. These processes in turn maintain the carbon as a recalcitrant carbon with a long turnover time or protect it from microbial processes (Lal, 2004). Organic agriculture is a cost effective and environment-friendly process for improving soil carbon stock and reducing soil degradation.

Existing waste-management practices have the potential to provide effective mitigation of greenhouse gas (GHG) emissions. A host of environmentally-effective technologies are available in nature to mitigate emissions and provide public health, environmental protection, and sustainable development co-benefits (Bogner *et al.* 2007). Collectively, these technologies can directly reduce GHG emissions or significantly reduce GHG generation (through controlled composting or vermicomposting of organic waste.

As noted by Robert et al. (2009) organic-based agriculture has the potential to sequester up to the equivalent of 32% of all current man-made GHG emissions. Organic-based agriculture sustains the health of soils, ecosystems and people through increase in soil organic matter (Yagi et al., 2003) and positively changes other soil attributes that has link with soil fertility such as pH, nutrient availability, and cation exchange capacity (Alves et al., 1999). It utilises ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of chemical inputs with adverse effects. It combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (IFOAM (2009).

Vermicomposting, one of the options to reduce GHG emissions from post-consumer waste is a technology that allows aerobic biodegradation of the wastes with earthworms. The use of vermicompost in vegetable farming has the potential to sequester carbon and reduce the need for chemical fertilizers. Anikwe (2010) observed that the carbon stock of continuously cropped and conventionally tilled soils was 25% lower than the carbon stock of the soil cultivated by use of conservation tillage in southeastern Nigeria. In a related study on soil carbon stock in a rubber plantation, Wilaipron and Kruamas (2014) also observed that plant nutrients, age of rubber plantation, and latex yield effected soil carbon stock.

In a study on use of vermicompost on okra, the results as reported by Abdullah and Kumar (2010) indicated that the average yield of okra during trial showed a significantly greater response in vermiwash + vermicompost compared with the control by 64.27 %. There was also a qualitative improvement in the physical and chemical properties of the soil vermiwash +vermicompost treatment. Replacement of 25% of the nutrients applied to maize crops by vermicompost resulted significant greater increases in plant height and marketable crop yield than those produced by 100% inorganic fertilization(Lazcano and Domínguez, 2011).

The aim of this study therefore was to determine the influence of vermicompost application on soil organic carbon stock and crop yield in a okra based vegetable farm.

MATERIALS AND METHODS

The study was conducted in a farmer's field within the degraded Abraka Forest Farm Reserve about 5km from the Teaching and Research Farm of the Delta State University, Abraka, (latitude 5^0 46' and longitude 6^0 5') Nigeria in early cropping (March-July) and late cropping (August-December) of 2010, 2011 and 2012. The vermicomposts were prepared from organic wastes. Substrates for the vermicompost include mixtures of food wastes, vegetable clippings, fruit wastes, animal manures and other organic residues collected from the local food market bins. Materials were chopped into small pieces and thoroughly mixed. Earthworms (*Lumbricus terrestris* L.) were introduced two weeks later. Vermicompost (VC) incubation period was 50 days.

The field experiment consists of six treatments, namely: control (no application), 100%NPK, 100%VC, 85%VC + 15%NPK, 50%VC+ 50%NPK and 15%NPK + 85%VC. The recommended rates of 4 t ha^{-1} and 400 kg ha^{-1} were applied for 100% VC and 100% NPK respectively, while the other treatments varied with the corresponding percentages. Nutrients were applied in two equal splits (at planting and six weeks after planting). The vermicompost was broadcasted and worked into the soil by light hoeing before planting of seed at the rate of two seeds per hill and later thinned to one seedling. The experimental layout was a randomized complete block design with the six treatments replicated thrice. The test crop was *Abelmoschus esculentus* Moench (var. NHAE 47-4), planted at a spacing of 60cm by 40cm. The experiment was repeated twice during each cropping year in March –July and August-December to coincide with early and late season cropping.

Pods were harvested from okra plants on a continuous basis. Yield data were presented as cumulative pod yield in each cropping season. Plot yield was converted to tons ha^{-1}.

Composite soil samples were collected from soil surface at depth of 0-30cm. Soil parameters were determined for soil bulk density using the core sampling method (Blake, 1965) and soil organic carbon (SOC) before the experiment and at the end of the three year cropping . Soil organic carbon stock (SOC stock) was estimated with the following equation by Milne (2008):

SOC stock= (SOC content of soil x BD x A x D],

Where: SOC stock= soil organic carbon stock (tons ha^{-1}); SOC= soil organic carbon content of soil (%), BD= bulk density, Area= area of farm (m^2) and D= soil sampling depth (m).

The agronomic efficiency index (AEI) was adapted from the formula by Rajj (1991) and stated as follows:

AEI = [Yvermi-based-Ycontrol]/ [Y_{NPK}-Ycontrol] x 100;

Where Yvermi-based= yield of crop or soIl fertility attribute in vermicompost based application (alone or mixed)

Y_{NPK} = yield of crop or soIl fertility attribute in NPK alone;

Ycontrol = yield of crop or soil fertility attribute in control (without any application)

Data on pod yield was obtained at the end of each cropping. Data were subjected to analysis of variance (ANOVA). Means were separated by the least significance difference (LSD) at 5% level of probability. Correlation between soil fertility attributes and cumulative pod yield was done with SPSS version 16.0.

RESULTS AND DISCUSSION

Soil Fertility Attributes

Table 1 shows data on the soil fertility attributes over the three year period. Organic amendments with municipal solid waste based vermicopmost (MSWVC) significantly reduced soil bulk density (BD) and increased soil organic carbon (SOC). The soil bulk density decreased with increasing proportion of vermicompost as soil amendment. Soil bulk density ranged from 1.21 to 1.43gcm^{-3}, with lower values of 1.21 and 1.28gcm^{-3} in 100% and 85% vermicompost soil amendments respectively. In comparison to the soil BD status before cropping, the use of verimcompost soil amendments reduced the soil bulk density by 15.7% and 13.8% in 100% VC and 50% VC while the 100% NPK only reduced soil BD by 3.4%. Kumar et al. (2009) and Oroka (2013) also reported reduced soil bulk density with organic amendments. These results confirm earlier reports that show that in mineral soils, reduced bulk density is a significant productivity index since it promotes water percolation and root penetrability which further supports good crop growth (Devis and Freitas, 1970; Asiedu et al 1997; Asiedu et al. 2013).

SOC increased with increasing quantity of the organic amendment in form of vermicompost. Highest SOC was found in plots with 100% (2.97%) and 85% (2.83%) MSWVC. 100% and 85% vermicompost soil amendment showed significantly higher carbon stock (SOC stock) with values of 10781 and 10867.8 gC m^{-2} at the end of the three year cropping period. Relative to the control treatment, carbon stock in plots increased by 203.9%, 206.3% and 187.7% in 100%, 85% and 50% MSWVC soils. Rosales et al. (1999) and Yagi et al (2003) also observed significant increases in organic matter and carbon contents with the application of compost or vermicompost, either combined or not with mineral fertilizers. Vermicompost is an already decomposed material hence it is expected that with continuous application; the compost will incorporate more organic matter (OM) to the soil, with consequent increase in SOC stock, because of the greater OM stability in the compost. This agrees with reports of other researchers (Dalal and Chan, 2001;.Yagi et al., 2003) which notes that vermicompost is not 'naked carbon' but 'humus in making' containing labile organic matter, with stable organic compounds, macro and micronutrients and diverse microbial and other fauna population, hence is an important source of energy for the soil food web.

Agronomic efficiency indices for all the soil fertility attributes (bulk density, soil organic carbon and soil organic carbon stock were all above 100% (Table 2)., The 100%VC was more efficient by 900% , 623% 923% in reducing soil bulk density, increasing SOC and SOC stock respectively. when compared with NPK alone. However 15% VC with NPK showed 400%, 78% and 63% efficiency in reducing soil bulk density, increasing SOC and SOC stock respectively.in comparison with NPK alone. Increased AEI of OM with use of vermicompost over cattle manure was also reported by Yagi et al. (2003).

Table 1: Soil fertility attributes before cropping and at the end of 3-year cropping

	Before treatment	Control	100%NPK	100%VC	85%VC + 15%NPK	50%VC + 50%NPK	15%VC + 85%NPK
BD (%)	1.46	1.43^{a}	1.41^{ab}	1.23^{c}	1.28^{bc}	1.26^{bc}	1.37^{ab}
SOC (%)	0.65	0.85^{c}	1.08^{b}	2.97^{a}	2.83^{a}	2.70^{a}	1.26^{b}
SOC stock (tons ha^{-1})	3547.8	3545.5^{c}	4568.4^{b}	10959.3^{a}	10867.2^{a}	10206^{a}	5178.6^{b}
ΔSOC stock (%)	-	2.78	28.77	208.9	206.3	187.7	46.0

Means followed by the same letter on the same row are not significantly different at LSD (5%)

Table 2: Agronomic efficiency index (%) of soil fertility attributes as influenced by different nutrient sources

	Bulk density (BD)	SOC	SOC stock
100%VC	1000	923	1023
85%VC +15%NPK	1050	861	716
50%VC +50%NPK	850	826	651
15%VC +85%NPK	500	178	163

Okra Pod Yield

From the results in Table 3, replacement of nutrients with organic fertilization using increasing quantity of municipal solid waste based vermicompost resulted in increased pod yield. On the average, the early cropping of okra had better yield than the late cropping. Relative to other treatments with nutrient application which had increasing trend in okra yield, the control had a downward trend with continuous okra cropping. Bationo et al. (2004) also reported a similar trend of low and steady decline in crop yield in control plots (without mineral fertilizer and organic amendment). This is an indication that the potential for continuous cropping of okra on these soils without organic amendment is limited in this environment. Although the 85% vermicompost maintained higher yield relative to other nutrient treatments, the 100% VC became highest with time. Highest cumulative marketable fruit yield of okra over the three years was obtained with 100% VC with value of 67.04tons ha^{-1} and increased by 94.8% and 73.8% over the control and 100%NPK respectively. Increases in yields by vermicompost applications alone or in mix with other chemical fertilizers has been reported in similar studies in lettuce, *Amaranthus* species, okra, pepper, egg plant and cucumber (Papathanasiou et al. 2012; Ansari and Kumar Sukhraj 2010; Seethalakshmi 2011 Moraditochaee et al. 2011; Uma and Malathi 2009; Azarmi et al. 2009).

The comparison of the effect of vermicompost on okra pod yield in relation to NPK was done by the agronomic efficiency index (AEI) (Table 4). Results showed that all indices were above 100%, indicating that organic fertilization alone or mixed with NPK was more efficient than NPK alone in increasing pod yield of okra. Level of agronomic efficiency generally decreased with decreasing trend of organic fertilization in all the three years of cropping

Soil organic carbon (S0C) is an index of sustainable crop farmland management (Nandwa, 2001). The application of organic amendments to the soil would have elicited increased OM and positively changed other chemical characteristics associated with soil fertility, such as nutrient availability (Yagi et al., 2003)) and SOC stock (Bationo et al. (2006). SOC plays an important role in supplying plant nutrients, (Dudal and Deckers, 1993), hence its not only a major regulator of various processes underlying the supply of nutrients, but it also creates a favorable environment for plant growth (resulting in increased crop yield) and regulating various processes governing the creation of soil-based environmental services (Vanlauwe, 2004).

Table 3: Pod yield (tons ha^{-1}) of okra as influenced by different nutrient sources

	2011		2012		2013		Cumulative pod yield (tons ha^{-1})
	Early	Late	Early	Late	Early	Late	
Control	5.88^{b}	5.96^{b}	5.72^{d}	5.83^{d}	5.83^{c}	5.68^{c}	35.80
100%NPK	6.24^{b}	6.36^{b}	6.68^{cd}	6.52^{cd}	6.51^{c}	6.40^{c}	38.71
100%VC	9.38^{a}	9.42^{a}	10.61^{a}	11.43^{a}	12.75^{a}	13.45^{a}	67.04
85%VC +15%NPK	9.42^{a}	9.68^{a}	10.73^{a}	11.07^{a}	12.62^{a}	12.87^{a}	66.39
50%VC +50%NPK	7.86^{ab}	7.94^{ab}	8.63^{bc}	8.57^{b}	9.49^{b}	9.71^{b}	52.20
15%VC +85%NPK	6.67^{ab}	6.93^{ab}	8.30^{c}	7.16^{bc}	7.56^{bc}	7.64^{bc}	44.26
Mean	7.64	7.68	8.30	8.29	9.09	9.31	
LSD (5%)	2.84	2.65	2.24	1.86	2.51	2.82	

Means followed by the same letter on the same column are not significantly different at LSD(5%)

Table 4: Agronomic efficiency index of okra pod yield as influenced by different nutrient sources

	2011		2012		2013	
	Early	Late	Early	Late	Early	Late
100%VC	972	865	573	782	762	1020
85%VC +15%NPK	956	955	537	690	961	1868
50%VC +50%NPK	450	495	320	397	532	560
15%VC +85%NPK	219	243	284	193	252	272
Mean	649	640	429	516	627	930

Correlation

Table 5 shows the correlation matrix of the cumulative okra pod yield over the three years and the soil fertility attributes. Soil bulk density had a strong significant negative correlation with SOC, SOC stock and cumulative pod yield, while a significant positive correlation was observed between okra pod yield and SOC (r=0.943) and SOC stock (r=0.944). A decrease in bulk density is expected to contribute to increased SOC and SOC stock which will invariably result in higher okra pod yield.

Table 5: Correlation matrix of cumulative okra pod yield and soil fertility attributes as influenced by different nutrient sources

	Bulk density (BD)	SOC	SOCstock	Cumulative pod yield
Bulk density(BD)	-			
SOC	-0.982**	-		
SOC stock	-0.977**	0.999*	-	
Cumulative pod yield	-0.917*	0.943*	0.944*	-

**Significant at 0.05 level
**Significant at 0.01 level

CONCLUSION

The use of vermicompost alone or in mixture with mineral fertilizer significantly increased okra pod yield and SOC and SOCstock while reducing the soil bulk density relative to the application of only mineral fertilizer. Vermicompost application also showed better agronomic efficiency index in pod yield of okra and soil fertility attributes studied. The results of the study has shown that introduction of organic manure in form of vermicompost in vegetable farming will contribute to increasing carbon stock in farmlands, relative to using only mineral fertilizer. In addition the vermicomposting of municipal solid waste is better option than landfilling which contributes to GHG emissions.

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