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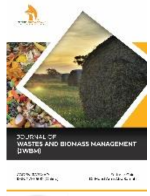

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RESEARCH ARTICLE

EFFECT OF MUNICIPAL SOLID WASTE TREATMENT TECHNIQUES ON SOIL CHEMICAL PROPERTIES IN SUDAN SAVANNAH, KANO STATE, NORTHERN NIGERIA

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ABSTRACT

The objective of this study was to determine the impact of municipal solid waste (MSW) treatment techniques on the soil Chemical properties of Sudan Savannah, Nigeria. MSW was collected from multiple metropolitan sites and mixed together. The composite sample was used to produce biochar and compost treatments. The effect of MSW treatment techniques on the qualities of soil was assessed by applying treatments and controls (untreated MSW) to soil at various rates. Soil samples were collected four weeks after treatment application, processed and analyzed in the laboratory. Results showed significant difference (*$P \leq 0.05$) in soil Mg and Zn, as well as highly significant difference at (**$P \leq 0.01$) in soil EC and K values. Biochar is recommended for acidic soil to improve soil pH, whereas compost is suggested for increasing soil organic matter and microbial activity. The use of untreated MSW is primarily advised for long-term soil deterioration solutions.

KEYWORDS

Municipal Solid Wastes (MSW), Biochar, Composting, Nigeria

1. INTRODUCTION

Small-holder farmers in Sudan savannah face substantial constraints such as declining land productivity and decreasing crop yields. Under these conditions, farmers can benefit from the use of fertilizer, both organic and inorganic. Although inorganic fertilizers give important nutrients to the soil, their long-term usage causes organic matter depletion, soil compaction, and overall soil quality degradation (Opachat, et al., 2018). According organic fertilizer improves crop quality and productivity, and its usage expanded fast at the dawn of the green revolution to (Edvan and Jesus, 2015). Other options for preserving soil fertility attainable to producers include the integration of legumes into cropping systems, the use of farmyard manures, green manuring, crop residue incorporation, and crop rotation (Giller and Wilson 1991). According to manure application is critical for the sustainability of small-holder farming in the Sudan savannah (Yusuf, 2002).

Waste management is becoming increasingly difficult in economically developing countries due to the large amount of waste generated. Minimization, recycling, composting, incineration, and sanitary land-filling are all viable waste management methods. The use of these wastes as soil amendments and organic fertilizer is an effective and efficient way of disposing of them.

Municipal Solid Waste (MSW) is generated primarily from three sources: domestic solid waste (from households and public areas), commercial solid waste (from shops, restaurants, hotels, offices, and markets), and industrial solid waste (waste from industries, excluding construction and demolition waste, chemical waste, and other special types of waste) (Chandler et al., 1997; SUTD, 2012).

The application of organic MSW has been widely acknowledged as a successful technique of enhancing soil physical and chemical qualities and as a result, crop yields (Zink and Allen, 1998). However, economic, technological, and qualified human restrictions have reduced the range of acceptable solid waste management and treatment options for use in soil. Furthermore, there is insufficient information on the utilization of municipal solid wastes as soil amendments, as well as recommended treatment methods for producing suitable soil amendments in Sudan savannah of Nigeria.

A study of the influence of MSW treatment methods on soil chemical characteristics would aid in identifying of waste disposal options as well as determining which treatment method offers the best solution for soil improvement. The purpose of this research is to evaluate the impact of municipal solid waste treatment techniques on soil chemical characteristics in the study region.

2. MATERIAL AND METHODS

2.1 The Study Area

This research was conducted in the Faculty of Agriculture, Bayero University Kano, which is located along Gwarzo Road, Ungogo Local Government Area of Kano State (11.9742ºN; 8.4684ºE, 460 m above sea level) in Northern Nigerian Savannah zone. The climate of the region is characterized by a wet season from May to September and a cold dry season from October to February. Rainfall often starts in late April to early May and peaks in August (Buba, 2009; Adamu et al., 2014). The typical yearly temperature is around 25ºC 7ºC throughout the year (Adamu et al., 2014). The rate of evaporation in the research region has been calculated to be exceptionally high, with a potential evapotranspiration rate of 1772 mm (Olofin and Tanko, 2002).

2.2 Municipal Solid Waste Sources and Treatment

Biodegradable wastes (fruits and vegetable wastes) taken from landfill sites of Yankaba and Yanlemo markets in Kano metropolis, as well as plant

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residues collected on the University campus, were employed in this study. Wastes from different sources was merged together and split into three portions, which were then exposed to various treatments such as pyrolysis, composting, and control (non-treated waste). Table 1 shows individual treatment approaches and their associated products.

Untreated waste materials were air-dried, ground, and used as raw materials for field trials, whereas collected waste materials in the pyrolysis method were placed inside a pyrolysis chamber at the Department of Soil Science and subjected to heating (300-400ºC temperature) in the absence of oxygen, as recommended by (Lehman, 2007). The product of the pyrolysis (biochar) was ground for field trial. The composting process involved subjecting the collected wastes to biological breakdown in a composting bin at the Department of Soil Science for 8 weeks, as suggested by (USDA, 2010). During the composting process, the contents in the bin were turned weekly to provide proper aeration, moisture control, and consistent decomposition. Finally, compost was created, which was air-dried and crushed for field testing.

Table 1: Treatment Methods and their Respective Products

S/N	Treatment Method	Product
1	Untreated	Raw
2	Pyrolysis	Biochar
3	Composting	Compost

2.3 Soil Treatment And Sampling

Soil samples were collected in a W-shape framework across the plot at roughly 0-20 cm depth prior to the start of the experiment. The samples were combined to form a composite soil sample of the research area in order to examine the physical and chemical parameters of the soil. To evaluate the effect of different MSW treatment products on soil chemical properties, products from the three treatment methods were applied to the soil at graded rates of 5, 10, and 15 t ha-1, with non-amended soil serving as the control, for a total of ten treatments (Table 2) that were replicated three times. Soil samples were taken from each plot using an auger at 0-20 cm depth four weeks after these treatments were applied to the soil. The soil samples were air-dried and pulverized using a pestle and mortar before being sieved through a 2 mm sieve and stored in plastic bottles for laboratory analysis.

Table 2: Municipal Solid Waste Treatment Combinations Used in the Soil

Application Rate	Description
Raw_5 t ha^{-1}	Untreated MSW applied to the soil at the rate of 5 t ha^{-1}
Raw_10 t ha^{-1}	Untreated MSW applied to the soil at the rate of 10 t ha^{-1}
Raw_15 t ha^{-1}	Untreated MSW applied to the soil at the rate of 15 t ha^{-1}
Biochar_5 t ha^{-1}	Product of pyrolysis applied to the soil at the rate of 5 t ha^{-1}
Biochar_10 t ha^{-1}	Product of pyrolysis applied to the soil at the rate of 10 t ha^{-1}
Biochar_15 t ha^{-1}	Product of pyrolysis applied to the soil at the rate of 15 t ha^{-1}
Compost_5 t ha^{-1}	Product of composting applied to the soil at the rate of 5 t ha^{-1}
Compost_10 t ha^{-1}	Product of composting applied to the soil at the rate of 10 t ha^{-1}
Compost_15 t ha^{-1}	Product of composting applied to the soil at the rate of 15 t ha^{-1}
Control	Non-amended soil, receiving no any form of MSW products

2.4 Laboratory Analyses

Soil samples taken from the experimental plots were subjected to Soil samples taken from the experimental plots were subjected to laboratory analysis. The conductivity and pH electrode meters were used to evaluate EC and pH, respectively while the Walkley-Black Wet Oxidation Method was used for determining OC (Arnold, 1978; Bower and Wilcox, 1965). The regular Macro-Kjeldahl technique was used to measure total nitrogen, whereas the Vanado-Molybdate yellow method was used to evaluate soil available P. The extraction methods for exchangeable bases, exchangeable acidity, and ECEC were ammonium acetate and KCl while micronutrients were extracted using hydrochloric acid and the quantities were estimated with an Atomic Absorption Spectrophotometer (Anderson and Ingram, 1993).

2.5 Statistical Analysis

Data obtained from the study was subjected to descriptive statistics and one-way analysis of variance (ANOVA) via GenStat Software (17th Edition). Means were separated using Students-Newman-Keuls (SNK) at 5% level of probability.

3. Results and Dicussion

3.1 Pre-planting Physical and chemical Properties of the Soil of the Study Area

3.1.1 Soil Texture

Table 3 shows the particle size distribution of the soil in the research area. The sand content was 87%, the clay fraction was 7.00%, and the silt fraction was 6.00%. It implies that the soil texture in the research area is loamy sand. In general, the sand component dominated the particle size distribution in the studied area. Approximately 90% of the soils sampled belonged to the loamy sand textural class. According to the soils of Nigerian Savannah regions are physically fragile because the topsoil has a high amount of sand, resulting in poor aggregation given the low quantity of organic matter (Adeoye and Mohammed-Saleem, 1990; Salako et al., 2002). The findings of this study agree with those who ascribed the dominance of sand contents in Northern Nigerian soils to material sorting by clay eluviation and surface wind erosion of (Nzamouhe et al., 2020; Voncir et al., 2008). As a result of the soil's high sand concentration, it has a low moisture retention capability and structural stability.

3.1.2 Soil pH

The pH value in the soil of the research area (Table 3). The average pH of the soil was 6.47.The result suggests that the soil is partially acidic. The slight acidity of the soil might be due to leaching of basic cations or to the crop's constant absorption of basic cations. The soil's slight acidity indicates that the majority of nutrients are likely to be accessible for crop usage. As a revealed that pH levels between 5.5 and 6.5 are optimal for the release of most plant nutrients (Odunze et al., 2006).

Table 3: Pre-planting Physical and chemical Properties of the Soil of the Study Area

Variable	Value
Particle size distribution	
Sand (%)	87
Clay (%)	7
Silt (%)	6
Texture	Loamy sand
Soil pH.	6.47
Electrical Conductivity (dSm^{-1})	0.22
ECEC (cmol(+) kg^{-1})	3.68
Organic Carbon (g kg^{-1})	5.6
Total Nitrogen (g kg^{-1})	1.1
Available Phosphorus (mg kg^{-1})	2.17
Exchangeable Acidity (cmol(+) kg^{-1})	0.83
Calcium (cmol(+) kg^{-1})	3.26
Magnesium (cmol(+) kg^{-1})	0.19
Potassium (cmol(+) kg^{-1})	0.13
Sodium (cmol(+) kg^{-1})	0.10

3.1.3 Total Nitrogen

The total nitrogen (TN) in the soils was found to be 0.11%, indicating that the total N of the soil in the area of study was moderate according to rating scale the (Esu,1991;Landon, 1991). However, as shown in (Table 3), the distribution of TN in soils was mostly graded poor. Given the low OC level and sandy character of the soils, the nitrogen content was not surprising. This finding is consistent with what discovered in Katagum's highland soils in the same agro-ecological zone (Umar and Pantami, 2014). The low N concentration of these soils might possibly be attributed to continuous fertilizer absorption by crops as well as constant soil tillage.

3.1.4 Organic Carbon

Soil organic carbon (OC) concentration was found to be (5.6 gkg-1) in the soils, implying that the OC carbon found fell into the exceedingly low to low fertility class (Table 3). The low organic carbon content of the soils can be attributed to the characteristics of Nigeria's Sudan Savanna agro-ecological zone, which includes low natural litter fall deposition, rapid decomposition and mineralization of organic matter, and poor management, which includes farmers burning crop residues (Lawal et al., 2012). This conclusion is similarly consistent with the findings of for Nigerian Savanna soils (Yaro et al., 2006). Going by the low OC and the high sand content of the soils, this implies that, the soils would be more prone to leaching of mobile nutrients

3.1.5 Available Phosphorus

The available P concentration in the surface soils of the research area was found to be (2.17 mgkg-1) (Table 3). According to the grading system, the available phosphorus in the field was classified as low (Esu, 1991). The low Av. P obtained in the studied soils may be connected to their intrinsic low status, such as parent materials with low weatherable mineral reserves required for nutrient recharge, and partially to the farmers in the area's total crop waste removal. This finding is consistent with the findings of in several chosen Sudan Savanna soils, as well as the work of (Umar and Pantami, 2014; Shehu et al., 2015).

3.1.6 Exchangeable Bases

Calcium was found to be between (3.26 cmolkg-1) in the exchangeable bases in (Table 3). However, the soils in the research area were classified as medium in Ca fertility (Table 3) by (Esu, 1991). Magnesium was found to be (0.19 cmolkg-1) in the soils, whereas potassium was found to be (0.13 cmolkg-1) and sodium was found to be (013 cmolkg-1). However, Mg, K, and Na content is low throughout the field (Table 3) and hence ranked poor in fertility. Has a attributes the moderate to high exchangeable base contents in the Northern Nigerian Savanna to the prevalence of these elements over other cations in the harmattan, dust materials introduced yearly, and/or parent materials with high exchangeable base contents (Dawaki et al., 2018).

4. Effective Cation Exchange Capacity (ECEC)

The effective cation exchange capacity (ECEC) in the soils was found to be 3.68 (cmol (+) kg-1) as stated in (Table 3). According to the low level of ECEC in the soils indicates that the soil is dominated by low activity clays and sesquioxides (Tan, 2000). Tan went on to explain that this is because of the low organic colloidal fractions, which result in substantial leaching of basic exchangeable cations. These studies also agreed with an earlier result of and attribute the low ECEC to the soils' low clay concentration (Lombin and Knabe, 1981).

4.1 Effect Of Municipal Solid Waste On Soil Chemical Properties

Table 4 illustrates the effects of the various MSW treatments on soil pH, EC, EA, and ECEC as assessed by an ANOVA test at the 5% level of probability. The treatment effects on soil pH, EA, and ECEC were found to be statistically insignificant. However, EC was $^{**}P \leq 0.01$, with Biochar_15 t ha-1 in the soil having the highest mean (0.32 dSm-1) and Control having the lowest (0.18 dSm-1). The mean pH value of Biochar_15 t ha-1 amended soil was found to be higher, which may be attributed to the initial pH of the biochar used on the soil. Increases in pH have been observed according to literatures as a result of biochar application in the soil (Yamato et al., 2006; Glaser et al., 2002). According to the use of biochar in acidic soil increases soil pH due to its buffering ability (Novak et al., 2009). However, a rise in soil pH owing to compost application has also been recorded in several literatures, which is associated to its liming effect due to the substantial amount of alkaline cations such as Ca, Mg, and K (Agegnehu et al., 2014; Daniel and Bruno, 2012). The found a significant increase in pH value even with moderate compost treatments (Kluge, 2006). The precipitation of exchangeable and soluble Al in the soil solution was caused by an increase in soil pH, which resulted in the precipitation of exchangeable and soluble Al (Ritchie 1994). The higher EC value of biochar-amended soil might be attributed to the biochar's high amount of nutrients such as P, K, Ca, and Mg, as well as micronutrients such as Cu, Zn, Fe, and Mn (Major et al. 2010; Lehmann and Rondon, 2006). Furthermore, the high lignin concentration and porosity of biochar may result in improved nutrient sorption capacity and consequently increased soil EC (Novak et al., 2009). Similar EC results have been published indicating that soil EC increases when different types of organic materials are added by (Sarwar et al., 2003; Niklasch and Joergensen, 2001). The discovered significant modifications in soil EC with increased rates of biochar application (Kannan et al., 2012).

According to the increased ECEC in the Compost_15 t ha-1 amended soil may be due to the high organic matter content of the compost (Amlinger et al., 2007). They claim that soil organic matter provides between 20 and 70% of the ECEC of various soils. Has a demonstrated that the application of composted organic residue in soil increased ECEC owing to the application of stabilized organic matter rich in functional groups into the soil (Agegnehu et al., 2014; Gamal, 2009; Mohammad et al., 2004). On the other hand, also observed a rise in soil ECEC with the application of biochar (Liang et al., 2006).

4.2 Effect Of Msw Treatments On Soil Oc, Total N And Available P

Table 4: Effect of MSW Treatments on Soil pH, EC, EA and ECEC

Soil treatments	pH	EC (dSm^{-1})	EA (cmol(+) kg^{-1})	ECEC (cmol(+) kg^{-1})
Control	6.53	0.18c	0.70	3.06
Raw_5t ha^{-1}	6.53	0.19c	0.72	3.07
Raw _10t ha^{-1}	6.63	0.22bc	0.61	3.07
Raw _15t ha^{-1}	6.73	0.23bc	0.5	3.20
Biochar_5t ha^{-1}	6.60	0.21bc	0.78	3.21
Biochar_10t ha^{-1}	6.73	0.25b	0.61	3.16
Biochar_15t ha^{-1}	7.00	0.32a	078	3.60
Compost_5t ha^{-1}	6.60	0.22bc	0.72	3.17
Compost_10t ha^{-1}	6.70	0.22bc	0.5	3.11
Compost_15t ha^{-1}	6.70	0.22bc	0.5	3.50
P-Value	0.192	<0.01**	0.053	0.525
SED±	0.153	1.644	0.103	0.273

** = highly significant difference, means followed by the same letter(s) in a columns are not significantly different at 5% probability level using Students-Newman-Keuls test.

4.3 Effect Of Msw Treatments On Soil Oc, Total N And Available P

Table 5 shows the effects of MSW treatments on soil organic carbon (OC), total nitrogen (TN), and available phosphorus (AVP). There were no significant differences observed on either as shown (Table 5).

Biochar can increase the activity of beneficial fungi and microorganisms in soil by raising soil pH and can absorb carbon from the atmosphere-biosphere pool and transfer it to soil (Winsley, 2007; Laird, 2008). According the application of composted garbage led in a considerable rise in OC in soil to (Bouajila and Sanaa, 2011). There are also found that applying waste compost to soil increases the quantity of organic carbon in the soil as the rate of compost treatment rises (Soheil et al., 2012). Total N in soil is a function of environmental conditions, as well as nitrogen volatility and leaching in soil. The findings correspond with those of (Dempster et al., 2012; Yao et al., 2012). However, showed that biochar and compost minimize nitrogen loss by leaching and denitrification by stabilizing soil organic matter and slowly releasing nutrients (Lehmann et al., 2003). This also showed that following soil treatment with waste biochar, the residence period of nitrogen in soil is enhanced because nitrogen is weakly adsorbed by the biochar and easily desorbed by water penetration (Clough et al., 2013). The higher available P value in Biochar_15 t ha^{-1} treated soil may be because of microbially mediated mineralization of soil organic P to form inorganic P. To observed increasing trend of available P in biochar-applied soils (Glaser et al., 2002). As a determined the effects of composted Municipal Wastes on soil chemical properties in pot experiment and found that the amount of available P concentrations in soil increased as the result of waste compost application (Soheil et al., 2012). Moreover, observed a significant increase in the P contents after using the compost as soil amendment, attributing it to increases in the enzymatic activity of phosphatases from earthworms (Devliegher and Verstraete, 1997).

Table 5: Effect of MSW Treatments on Soil OC, Total N and Available P

Soil treatments	OC (gkg^{-1})	TN (gkg^{-1})	AVP ($mgkg^{-1}$)
Control	5.0	0.7	2.81
Raw_5 t ha^{-1}	6.4	0.9	2.48
Raw _10 t ha^{-11}	7.8	1.0	1.65
Raw _15 t ha^{-1}	8.1	1.2	2.51
Biochar_5 t ha^{-1}	6.7	0.8	3.33
Biochar_10 t ha^{-1}	8.0	1.1	6.44
Biochar_15 t ha^{-1}	8.8	0.8	6.46
Compost_5 t ha^{-1}	7.5	0.9	3.64
Compost_10 t ha^{-1}	7.7	0.8	4.51
Compost_15 t ha^{-1}	8.1	0.8	2.79
P-Value	0.187	0.881	0.056
SED±	0.121	0.034	1.516

OC =organic carbon, TN = total nitrogen, AVP = available phosphorus

4.4 Effect of MSW Treatments on Soil Exchangeable Bases

The higher available P value in Biochar_15 t ha^{-1} treated soil may be due to microbially driven mineralization of organic P in the soil to create inorganic P. Observed increasing trend of available P in biochar-applied soils (Glaser et al., 2002). In a pot experiment, studied the effects of composted Municipal Wastes on soil chemical characteristics and discovered that the quantity of accessible P concentrations in soil increased as a result of waste compost application (Soheil et al., 2012). Furthermore, reported a significant increase in P levels after using compost as soil amendment, which they attributed to increases in the enzymatic activity of earthworm phosphatases (Devliegher and Verstraete, 1997).The suggest that the high nutrient content of the amendments and speculate that the findings of Mg and K may be due to the slow and gradual release of plant nutrients by compost (Aggegnehu et al., 2014; Seran et al., 2010). According to compost-amended soils had equivalent concentrations of plant available nutrients to conventionally fertilized soils (Brown and Cotton, 2011). That found similar results (Antoniadis and Alloway, 2003). Surface functional groups and porosity, which may function as nutrient retention sites, could explain the results obtained in soil for Ca and Na concentration (Glaser et al., 2002; Singh et al., 2010).

Table 6: Effect of MSW Treatments on Soil Exchangeable Bases

Soil treatments	Exchangeable bases(cmol(+)kg-1) Ca Mg Na			K
Control	1.94	0.81b	0.10	0.1d
Raw_5 t ha-1	1.92	0.19b	0.11	0.12cd
Raw _10 t ha-11	2.17	0.20b	0.10	0.19b
Raw _15 t ha-1	2.17	0.19b	0.11	0.23a
Biochar_5 t ha-1	1.98	0.19b	0.11	1.16bc
Biochar_10 t ha-1	2.07	0.19b	0.11	0.18b
Biochar_15 t ha-1	2.32	0.22b	0.10	0.18b
Compost_5 t ha-1	2.03	0.20b	0.10	0.12cd
Compost_10 t ha-1	2.17	0.21b	0.11	0.13cd
Compost_15 t ha-1	2.49	0.25a	0.11	0.16b
P-Value	0.385	0.008*	0.889	⍰0.01**
SED±	0.236	0.015	0.011	0.012

* = significant difference, ** = highly significant difference, means followed by the same letter(s) in a columns are not significantly different at 5% probability level using Students-Newman-Keuls test

4.5 Effect of MSW Treatments on Soil Micronutrients

Table 7 shows the influence of MSW treatments on the study soil micronutrients (Fe, Cu, and Zn). Compost¬_15 t ha-1 soil recorded the highest mean of 0.66 mg kg-1, whereas Biochar_10 t ha-1 and Biochar_15 t ha-1 soils recorded the lowest means of 0.29 mg kg-1 and 0.22 mg kg-1, respectively. A *P≤0.05 was observed in Zn of the soil. There were no significant difference in the Fe and Cu contents of the soil. The slow and gradual release of nutrients by compost may be the reason for the higher Zn concentration in soil supplemented with compost (Seran et al., 2010; Aggegnehu et al., 2014). The result is also in consistent with that of who also observed a significant increase in Fe and Zn in soil upon compost application (Lee et al., 2004).

Table 7: Effect of MSW Treatments on Soil Micronutrients

Soil treatments	Micronutrients (mgkg-1) Fe Cu Zn		
Control	0.42	0.37	0.31ab
Raw_5 t ha-1	0.38	0.44	0.34ab
Raw _10 t ha-1	0.45	0.49	0.40ab
Raw _15 t ha-1	0.47	0.32	0.45ab
Biochar_5 t ha-1	0.49	0.34	0.39ab
Biochar_10 t ha-1	0.45	0.42	0.29b
Biochar_15 t ha-1	0.38	0.35	0.22b
Compost_5 t ha-1	0.49	0.43	0.46ab
Compost_10 t ha-1	0.51	0..42	0.41ab
Compost_15 t ha-1	0.49	0.46	0.66a
P-Value	0.959	0.883	0.037*
SED±	0.114	0.118	1.104

* = significant difference, means followed by the same letter(s) in a columns are not significantly different at 5% probability level using Students-Newman-Keuls test

5. Conclusion

In conclusion, municipal solid waste treatment have an impact on the soil properties. Biochar application at a rate of 15 t ha-1 significantly increased soil pH, electrical conductivity, organic carbon, and available P. Compost use at a rate of 15 t ha-1 was shown to considerably improve soil organic carbon, Mg, K, and Zn. Untreated (raw) wastes are less laborious and less expensive to utilize, but have a less effect upon soil chemical characteristics.

The recommended treatment technique for municipal solid waste is determined by the overall application purpose. Pyrolysis and the usage of biochar are more recommended for improving the pH status of acidic soil, especially at higher levels. Composting is the most recommended treatment strategy for increasing soil organic matter and microbial activity. The use of untreated MSW will be suggested primarily due to to its low production cost, less tedious and time demanding treatment, and for a long-term solution to soil deterioration. It is also proposed that stakeholders participate in the composting of municipal solid wastes in order to decrease expenditures for the acquisition of inorganic fertilizer and offer a waste management solution.

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