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Comparison of Environmental Performance of Municipal Solid Waste Compost and Chemical Fertilizer

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Abstract: Addis Ababa city is undergoing rapid urbanization and industrialization where solid waste generation is also increasing at the same pace. It would be difficult to continue with the current landfilling waste disposal in the city. The objectives of this study were to (i) evaluate the positive environmental effect of municipal solid waste (MSW) composting and its environmental effect over the synthetic nitrogen (N) fertilizer; (ii) compare the environmental performance of MSW compost and synthetic nitrogen fertilizer. We investigated the application of MSW effects on selected soil properties, wheat yield and yield components and leachate chemistry. Application of MSW composts to the soil also increased soil total nitrogen (Nt), organic C, available P, pH, and other micronutrients. Similarly, the application of both MSW compost and N-fertilizer produced higher concentrations of NO_3-N fluxes in the collected leachate that clearly showed fertilization during application poses serious threat to water quality in the absence of growing plants. In general, both MSW compost and N-fertilizer applications had positively responded in improving wheat yield and yield components. The results of the present study revealed that using MSW as a soil amendment after appropriate composting techniques and soil management not only improve soil fertility and reduce the investment on chemical fertilizers but also can alleviate the contribution of MSW to environmental pollution.

Keywords: Greenhouse Gas, Leachate Chemistry, Nitrogen Fertilizer, Soil Properties, Wheat Yield

1. Introduction

Urbanization and industrialization result in increasing volumes and varieties of both solid and liquid wastes. The amount of municipal solid waste that goes daily to the final disposal sites in Addis Ababa is about 400 t day^{-1}. This could be expected to double in a few years due to urbanization, industrialization, economic development and population growth. About 60% of the MSW are identified to be biodegradable in Ethiopia [1]. With such increasing rate of urbanization and industrialization, the landfilling disposal method could not be effective and efficient to handle 12,000 t MSW generated monthly in Addis Ababa. If it is simply dumped, it can emit the potent greenhouse gas, methane (CH_4). The CH_4 emission was estimated to be about 18% from open-dump of MSW of Addis Ababa city [2]. This calls for the integrated municipal solid waste management (ISWM). However; lack of information on the inherent value of waste and methods for processing prompted to discard MSW for a sanitary reason rather than extracting valuable resources in Ethiopia.

"The organic share of MSW can be used for agricultural soil amendment through composting or can be hydrolyzed either chemically or enzymatically to produce a sugar, and the sugar can be used as a substrate for ethanol fermentation or for single-cell protein production [3]". In Ethiopian, the soil degradation is severe and the agriculture receives low external input because of socioeconomic situations of the smallholder farmers. Thus, using MSW for soil amendment seems to be easily accessible, economically feasible and environmentally sound that does not need special skills and facilities as compared to producing sugar, ethanol, and energy. In order to make the nutrient and carbon more accessible for plants, the waste can be composted. Composting ranges from the composting carried out by individual homeowners to that undertaken by municipalities [4]. The application of the compost as a soil amendment increases the soil organic matter contents and adds nutrients such nitrogen, phosphorous and sulfur, etc., and one of the sustainable waste management strategies [5]. Thus, MSW composting can serve as one of the mitigation potentials of climate change by reducing greenhouse gas emissions from non-engineered sanitary landfills and sequestrate carbon in the soil and yet improving the soil quality [6].

In Ethiopia, there is a growing tendency of using compost as a substitute and/or supplement to chemical fertilizer due to sudden increase in fertilizer prices, which caused a serious problem for poor farmers to achieve food security and sustainable agricultural output. The farm that used compost shows improvement in the productive [7]. Compost slowly released nutrients for plant growth which has more advantageous than chemical fertilizer [8]. Moreover, chemical fertilizer production is very energy intensive technology and it is responsible for approximately 1.2% of the total greenhouse gas emissions [9]. This implies substituting chemical fertilizers with compost can reduce green gas emission. Therefore, the objectives of the study were to (i) evaluate the positive environmental effect of MSW composting and the negative impact of synthetic nitrogen fertilizer on soil fertility and wheat yield (ii) compare the environmental performance of municipal solid waste compost and nitrogen fertilizer.

2. Materials and Methods

2.1. Study and Sampling Sites

The study was conducted at Bishoftu Agricultural Research Center that located about 50 km Southeast of Addis Ababa at 38°58´E, 08°44´N and 1900 masl with annual rainfall and average temperature of 850 mm and 17°C, respectively, [10]. The Andosol and Nitisol samples were collected from Bishoftu and Holetta Agricultural Research fields, respectively. We collected ten subsamples for each soil type to get a composite sample, whereas the MSW compost was sampled from 'Gerji' composting site that's located in Addis Ababa.

2.2. Soil and Compost Analysis

The selected chemical properties of soil and compost samples were analyzed with the procedure described by James and Wells [11]. Accordingly, the pH was measured potentiometrically in supernatant suspension of a 1:2.5 soil: liquid ratio using a pH meter. The exchangeable bases (Na, K, Ca, and Mg) were extracted with 1 N ammonium acetate at neutral pH and the exchangeable Ca and Mg was measured by atomic absorption spectroscopy (AAS), whereas the exchangeable K and Na by flame photometer. Organic carbon was determined by the procedure described by Walkley and Black [12] while total nitrogen with Kjeldahl procedure [13]. The available P was determined by Olsen method, whereas the available micronutrients (Cu, Fe, Mn, and Zn) were extracted with DTPA and measured by AAS.

2.3. Experimental Setups

2.3.1. Incubations Experiment

Incubation experiment was conducted under greenhouse conditions to investigate the environmental performance of MSW compost on selected soil properties of Nitisol. The treatments of the experiments were [(i) Control (without any amendments) (ii) 5-t compost (iii) 10-t compost (iv) 15-t compost (v) 20-t compost (vi) 60-kg N (vii) 120-kgN (viii) 180-kg N] ha^{-1}. The treatments were laid out in a completely randomized design with three replications. The amounts of MSW compost and urea fertilizer was calculated based on their total N (Nt) content that was applied to 100 g soil for each treatment. The soil moisture was adjusted to 60% field capacity by weighing regularly. The vessels in which the incubation carried out were placed in the greenhouse at an average temperature of 30°C and relative humidity of 60% for 90 days. Thirty gram of incubated soil samples was sampled in the first, second and third months of incubation period to detect changes observed due to MSW compost and urea fertilizer. Soil organic carbon, ammonium, nitrate, exchangeable bases and available micronutrients concentrations were determined following the procedures described in section 2.2.

2.3.2. Leachate Collection and Analysis

This experiment was designed to compare the concentration of nitrate-nitrogen (NO_3-N) in the leachate collected from high application rate of urea and MSW compost to compare the soil amendments either urea or MSW compost contributed nitrate to surface and/or groundwater pollution on Nitisol). The five treatments used in this experiment were [(i) control (without any amendment) (ii) 5-t compost (iii) 10-t compost (iv) 15-t compost (v) 200-kg urea] ha^{-1}. The treatments were laid out in a completely randomized design with three replications. The amount of soil sample used for each treatment was 250 g per pot that was thoroughly mixed with the amendments and placed in a greenhouse for two months at 25°C temp and 60% relative humidity. The soil sample amended with compost and urea fertilizer was leached with 0.5 L distilled water and the leachate was collected every 20 days interval. The nitrate concentration in the leachate was analyzed with Kjeldahl procedures as described for total nitrogen in section 2.2.

2.3.3. Compost Amendment

A pot experiment was conducted under greenhouse conditions to compare the effectiveness of MSW compost and urea fertilizer in improving the growth, yield component and nitrogen uptake of wheat on Andosol. The treatments of the experiment were [(i) control (without amendment) (ii) 2.50 t compost + 30.00 kg N (iii) 1.67 t +40 kg N (iv) 3.33 t compost + 20.-kg N (v) 5 t compost (vi) 60-kgN (vii) 10 t compost (viii) 120-kg N] ha^{-1}. The treatments were laid out in completely randomized design with six replications using wheat as a test crop. The pots were filled with < 2 mm sieved soil (3 kg pot^{-1}). The MSW compost was mixed with the soil sample a week before wheat planting while the urea was applied at the tillering stage. All treatments including the control received the recommended rate of P for wheat production on Andosol in the form of triple superphosphate. The amount of MSW compost and urea fertilizer was calculated from the recommended rate of nitrogen. The number of seeds placed in each pot was 20 and thinned to 14 after an emergency. Distilled water was used for irrigating wheat throughout the experimental period and yield and yield components such as plant height, biomass, and grain and nitrogen uptake were recorded. The three replications were harvested at the flowering stage while the remaining three treatments allowed growing until maturity.

2.4. Statistical Analysis

Data subjected to analysis of variance (ANOVA) using SAS version 9 statistical software and mean comparison had been done with least significant difference (LSD) for the significantly differed means among the treatments at 5% probability level.

3. Results and Discussions

3.1. Selected Chemical Properties of Soil and MSW Compost

Nitisol was strongly acidic with very low concentration of organic matter and total nitrogen (Table 1). Furthermore, the soil had low concentration of available phosphorus and micronutrients. The concentrations of exchangeable bases in Nitisol were low as compared to Andosol. In general, the Nitisol was very poor in fertility status that was confirmed by very poor wheat growth regardless of compost and urea fertilizer applications. Similarly, the Andosol also characterized by low organic carbon, total nitrogen and micronutrient concentration but neutral in pH.

Table 1. *Selected chemical properties of soils and compost used for this study.*

Samples	1: 2.5	%		ppm					Exchangeable bases (cmol$_c$ kg^{-1})				
	pH	OM	TN	AVP	Cu	Fe	Mn	Zn	Ca	Mg	K	Na	CEC
Nitisol	5.25	0.93	0.03	8.15	0.34	0.63	6.73	0.56	7.14	1.66	5.83	0.08	32.9
Andosol	7.4	1.35	0.06	7.00	0.04	0.40	0.14	1.39	32.3	7.56	2.61	2.78	43.0
Compost	6.46	13.8	1.21	13.38	0.03	0.02	0.03	0.08					

Where, OM, TN, AVP are organic matter, total nitrogen, and available phosphorus respectively.

The MSW compost was near neutral in pH with a higher concentration of available phosphorus, OM, total N than the two soil types used in the present study (Table 1). However, the OM concentration in the compost was low by 20 to 55% of similar materials reported elsewhere [14, 15]. The low concentration of OM in the MSW compost of Addis Ababa could be attributed to the compost had been mixed with sand, soils, and other inert materials. Nevertheless, the MSW compost had 40 and 20 times greater total nitrogen than in that of Nitisol and Andosol. This showed MSW could be potential sources of N fertilizer source for crop production. The C: N of compost was within acceptable range (12 to 15%) that can play a crucial role in nitrogen transformation in soils since N is limiting elements for plant growth [16, 17].

3.2. Effects of Compost Amendment on Soil Properties

The soil samples amended with MSW compost and urea responded in a similar fashion in the three consecutive months of the incubation period (Table 2). However, the effects of compost amendment were revealed after three months of incubation. Both MSW compost and urea application positively affected the total N content, although the differences were not as high as the rate of compost and urea applied to the soil samples. An increment of 14.3 and 54% of total N was observed with the application of 5 and 20 t compost ha^{-1}, respectively, over the control (Table 2). The present study was in agreement with other works that suggested elevated doses of MSW compost increased total nitrogen and also supply nutrients during the initial growing season and could meet subsequent plant demand [18]. A lower application rate could also affect nutrient availability, plant development, and soil restoration. The increment of total nitrogen was higher with the application of urea than with MSW compost application over the control. For instance, the application of urea at the rate of 60 kg N ha^{-1} increased total nitrogen by 50% over the control which was slightly less than the increment of total N with the application of 20 t compost ha^{-1} where the total N was increased by 54% (Table 2). However, nitrate and ammonium showed continuous increment with the MSW compost and urea application. The highest MSW compost (20 t ha^{-1}) application resulted in higher organic C than all other treatments which was increased by 69% over the control. The present finding agreed with the results of similar studies that stated MSW compost application significantly increased soil organic C than NP and NPK fertilizers application [19]. In general, the study demonstrated that soil amended with MSW compost increased soil carbon sequestration capacity far better than soil amended with nitrogenous chemical fertilizer. Therefore, using MSW compost not only increases C-sequestering and improving soil fertility but also one of the safest strategies of MSW disposal methods to reduce their contribution to environmental pollution.

The concentration of available P showed an increasing trend along with the rate of MSW compost application (Table 2). However, the application of urea fertilizer slightly increased available P that agreed with the findings of similar studies [20]. The MSW compost application also positively affected soil pH. In the first thirty days of the incubation period, both MSW compost and urea had slightly lowered the soil pH that could due to increasing in hydrogen ion concentration by nitrification of urea and the release of labile organic acids from MSW compost. However, after two months of the incubation period, there was an increment in soil pH in all treatments of MSW compost application over the control. This was in agreement with results obtained by other researchers [19]. This indicated that MSW compost can be used as soil acidity amendment, however; further long-term studies are required to confirm the present finding.

Table 2. *Effects of MSW compost and urea application on selected soil chemical properties after three months of incubation period on Nitisol (average value).*

parameters	Treatments ha^{-1}							
	control	5-ton comp	10-toncomp	15-ton comp	20-ton comp	60-kgN	120-kgN	180-kgN
pH (1:2.5)	6.93	7.26	4.82	7.68	7.78	7.57	7.58	7.86
NH_4-N(μg-N)	16.45	23.45	32.9	35.35	24.45	34.15	42.35	59.15
NO_3-N(μg-N)	11.75	25.55	32.7	39.00	41.7	17.95	28.8	25.55
OC (%)	1.08	2.13	2.21	2.43	3.47	1.31	1.52	1.98
TN (%)	0.06	0.07	0.08	0.11	0.13	0.12	0.14	0.19
AVP (ppm)	21.8	22.2	22.4	24.0	25.0	22.4	22.5	23.1
Na(cmol$_c$kg^{-1}	0.16	0.17	0.19	0.19	0.23	0.12	0.15	0.13
K(cmol$_c$kg^{-1}	0.6	0.83	1.06	1.30	1.57	0.64	0.62	0.60
Cacmol$_c$kg^{-1}	9.9	15.4	22.1	26.05	29.45	9.8	9.24	9.33
Mgcmol$_c$kg^{-1}	4.25	4.85	3.34	5.03	5.08	4.58	4.51	4.1
Cucmol$_c$kg^{-1}	0.05	0.06	0.08	0.1	0.1	0.06	0.06	0.07
Fecmol$_c$kg^{-1}	1.34	1.14	1.32	1.37	1.50	1.10	1.11	1.25
Mncmol$_c$kg^{-1}	4.44	3.56	2.80	2.23	2.14	3.32	3.15	2.98
Zncmol$_c$kg^{-1}	0.15	1.34	2.11	3.55	4.51	0.46	0.39	0.43

3.3. Nitrate Concentration in the Leachate

Nitrate (NO_3-N) concentration in leachate showed progressive increments with increasing rate of the applied MSW compost (5 t to 15 t ha^{-1}) for the first twenty days, whereas urea application increased NO_3-N concentration in the leachate particularly with the application of 92 kg N ha^{-1} (Table 3 and 4). However, the concentration of NO_3-N decreased sharply with time regardless of N sources and amount of N applications. The highest volume of leachate was also observed in the treatment where urea was over applied. The result agreed with the findings of the similar study [21].

In general, the findings showed that over fertilization of both chemical fertilizer and MSW compost produced a higher NO_3-N concentration in the soil solution that could contribute to surface and groundwater pollution under high rainfall or irrigation conditions. Moreover, the NO_3-N concentrations in chemical fertilizer applied at a medium rate (less than 92 kg N ha^{-1}) were by far greater than MSW compost applied at the highest rate. Some scientists estimate that approximately 20 percent of the nitrogen in fertilizer leached to surface or ground water with extreme levels reaching as high as 80 percent for row crops in sandy soils [22]. Thus, the levels of nitrate concentration in this study could affect water quality and aquatic organisms. For instance 0.1 mg L^{-1} NO_3-N levels can cause Eutrophication that suggested the use of aquatic toxicities for a better indicator of water quality problem than human based maximum contaminant level [23, 24].

Table 3. *Effect of MSW compost and urea amendment on nitrate concentration in the leachate of Nitisol.*

	20 days after amendment					40 days after amendment				
Treatment		dsm^{-1}	ppm		mL		Ds L^{-1}		ppm	mL
ha^{-1}	pH	EC	NO_3-N	K	Outflow	pH	EC	NO_3-N	K	Outflow
Control	6.84	0.11	17.5	0.02	420	5.66	0.16	11.2	0.05	400
5-t compost	6.16	0.10	20.3	0.03	403	5.74	0.10	25.1	0.08	397
10-t compost	6.21	0.11	30.25	0.03	397	5.67	0.25	37.1	0.10	382
15-t compost	5.8	0.11	95.2	0.03	397	6.04	0.13	42.2	0.05	358
200-kg urea	7.35	0.21	245.7	0.04	406	5.54	0.39	111.3	0.16	390

Table 4. *Effect of MSW compost and urea amendment on nitrate concentration in leachate of Nitisol (60 days after amendment).*

Treatment ha^{-1}	pH	EC $ds^{-1}m$	NO_3-N ppm	K ppm	Outflow ml
Control	6.7	0.64	12.6	0.077	280
5-t compost	6.32	1.22	14.00	0.131	270
10-t compost	7.01	0.74	15.4	0.171	267
15-t compost	6.82	0.50	15.4	0.071	268
92-kgN	6.21	0.02	52.5	0.280	271

3.4. Wheat Response to MSW Compost and Urea Application

Application of MSW compost alone or in combination with N-fertilizer increased the height of wheat as compared to the control treatment (Table 5). The lowest value of wheat height was recorded from the control treatment, whereas the highest with the application of 60-kg N ha^{-1}. The application of N fertilizer above 60kg N ha^{-1} on the soil used in the present study did not improve wheat yield and yield component.

***Table 5.** Effect of MSW compost and urea fertilizer application on growth and yield component of wheat.*

Treatment (ha^{-1})	Plant height(cm)	Spike length (cm)	Fresh weight (kg ha^{-1})	oven-dry weight (kg ha^{-1})	Grain yield (kg ha^{-1})
Control	26.21 b	2.55 d	6040 d	1460 d	459.33 b
2.5 t compost + 30 kg N	32.77 ab	4.22 ba	9670 cb	2310 bcd	1213.33 a
1.667 t compost + 40 kg N	30.44 ab	4.44 a	8650 Cbd	2400 bc	1226.33 a
3.333 t compost + 20-kg N	35.22 a	4.11 bac	8110 cbd	2490 bc	1386.67 a
5 t compost	32.67 ab	3.33 bdc	7150 cd	2110 cd	1083.67 ba
60 kg N	37.22 a	4.77 a	11000 b	2990 ab	1369.33 a
10 t compost	30.22 ab	3.22 dc	7360 d	2110 cd	996.67 ba
120 kg N	36.56 ab	4.65 a	16360 a	3610 a	953.33 ba
Cv%	7.88	14.15	19.2	20.58	35.2
$LSD_{5\%}$	6.511	0.9592	6.97	2.0028	1.528

Means followed by the same letters within a column are not significantly different ($p<0.05$) probability level.

Total dry weight of wheat increased significantly over the control with the application of MSW compost and N-fertilizer. The minimum dry weight was recorded in the control while the maximum was with the application of 120 kg N ha^{-1}. Similarly, the highest wheat grain yield was 1280 kg ha^{-1} followed by 1266.8-kg ha^{-1} with the application of 3.3 t compost + 20 kg N and 60 kg N ha^{-1}, respectively, which was 66 to 62% more grain yield than the control treatment. The result of the present study indicated that the application of N-fertilizer in conjunction with MSW compost can give a better result than either with the sole application of N fertilizer or MSW compost. Similar results were also reported with the integrated N and P fertilizers either with farmyard manure or compost on wheat grain yield [24]. In general, the present results clearly indicated that MSW compost is one of the potential fertilizer sources that can improve crop yield.

3.5. Nutrient Uptake of the Wheat Plant

Either MSW compost addition alone or in conjunction with urea, enhanced the nutrients uptake of plants (Table 6). Accordingly, the concentration of nitrogen in wheat straw was substantially increased with the application of MSW compost alone or in conjunction with N-fertilizer. The lowest percentage of total nitrogen was determined from plants grown on control treatments, whereas the highest was observed in plants grown with the application of 120 kg N ha^{-1}. Similarly, the application of MSW compost and chemical fertilizer combination increased phosphorus concentration in wheat straw. Similar to total nitrogen, the lowest concentration of P observed in the control treatment, whereas the highest P was with the application of MSW compost at the rate of 2.50-t ha^{-1}+ 30 kg N ha^{-1}. The status of potassium uptake improved in wheat straw with the application of either MSW compost or combination with N-fertilizer. The highest potassium concentration was observed with application of 120-kg N ha^{-1}, followed by (60-kg N ha^{-1}. application. The results of this study realized that MSW compost and N-fertilizer best works for growth and yield attributes of wheat when applied in combination.

***Table 6.** Effects of MSW compost and urea on plant nutrient status.*

Treatment ha^{-1}	TN %	Phosphorus(P) %	Potassium K %
Control	0.91	0.23	9.49
2.5-t compost + 30- kg N	1.16	0.29	14.68
1.667- t compost + 40- kgN	1.14	0.22	9.68
3.333- t compost + 20-kgN	1.17	0.22	11.84
5 -t compost	1.00	0.28	11.54
60- kg N	1.21	0.28	16.01
10 -t compost	1.06	0.19	9.99
120 –kgN	1.26	0.27	19.52

4. Conclusions and Recommendations

The addition of MSW compost at different levels to Nitisol significantly increased the total nitrogen, organic carbon, available P, pH and other microelements. This has important implication because all things being equal, soil with higher organic carbon become more productive than those with lower organic carbon. The addition of MSW compost had also positively responded on yield and yield component of wheat. The study demonstrated that the integrated use of MSW compost at 2.5-t compost ha^{-1} with 30-kg N ha^{-1} or 3.33-t compost with 20-kg N ha^{-1} could be feasible to evaluate under field condition. The finding of the research also realized that high dose of N-fertilizer or MSW compost applications may not economically feasible and environmentally sound. In general, the present study revealed that the application of both MSW compost and N-fertilizer increased the concentrations of NO_3-N fluxes in the collected leachate that clearly indicated fertilization during establishment poses serious threat to water quality in the absence of plant growth and appropriate soil management. The situation was further aggravated with the highest dose of N regardless of the source of fertilizer. Therefore, optimum application of either organic fertilizer can improve water-holding capacity of the soil and reduces the contamination of surface and ground water by NO_3-N. Furthermore, composting should be considered as part of integrated solid waste management strategy with appropriate processing technologies selected based on market opportunities, economic feasibility, and social acceptance. To enhance MSW composting integration of with agricultural and horticultural activities are important research area in Ethiopia.

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