World Academy of Science, Engineering and Technology
International Journal of Agricultural and Biosystems Engineering
Vol:16, No:4, 2022

Production and Application of Organic Waste Compost for Urban Agriculture in Emerging Cities

Alemayehu Agizew Woldeamanuel, Mekonnen Maschal Tarekegn, Raj Mohan Balakrishina

Abstract**—**Composting is one of the conventional techniques adopted for organic waste management but the practice is very limited in emerging cities despite that most of the waste generated is organic. This paper aims to examine the viability of composting for organic waste management in the emerging city of Addis Ababa, Ethiopia by addressing the composting practice, quality of compost and application of compost in urban agriculture. The study collects data using compost laboratory testing and urban farm households' survey and uses descriptive analysis on the state of compost production and application, physicochemical analysis of the compost samples, and regression analysis on the urban farmer's willingness to pay for compost. The findings of the study indicated that there is composting practice at a small scale, most of the producers use unsorted feedstock materials, aerobic composting is dominantly used and the maturation period ranged from four to 10 weeks. The carbon content of the compost ranges from 30.8 to 277.1 due to the type of feedstock applied and this surpasses the ideal proportions for C:N ratio. The total nitrogen, pH, organic matter and moisture content are relatively optimal. The levels of heavy metals measured for Mn, Cu, Pb, Cd and Cr^{6+} in the compost samples are also insignificant. In the urban agriculture sector, chemical fertilizer is the dominant type of soil input in crop productions but vegetable producers use a combination of both fertilizer and other organic inputs including compost. The willingness to pay for compost depends on income, household size, gender, type of soil inputs, monitoring soil fertility, the main product of the farm, farming method and farm ownership. Finally, this study recommends the need for collaboration among stakeholders along the value chain of waste, awareness creation on the benefits of composting and addressing challenges faced by both compost producers and users.

Keywords**—**Composting, emerging city, organic waste management, urban agriculture.

I. Introduction

WASTE can be a useful resource if managed in a proper way. However, poor handling of municipal waste can hinder the achievement of a city's sustainable development [1]. The challenge is immense, especially in emerging cities where the amount and type of solid waste generated are increasing [2]. The rapid rate of urbanization, population and economic growth in low and middle-income countries are the major contributing factors to the growth in the extent of waste generated in urban areas [3].

Despite the rapid growth of cities in low and middle-income countries, the proportion of organic waste is still very high compared to high-income countries [4]. A report on a global review of solid waste management showed that the highest proportion of solid waste is easily biodegradable organic waste. These include yard (leaves, grass, brush) waste, process residues, food scraps, wood and others. Organic waste composition in the middle and lower-income countries ranges from 40% to 85% of the total municipal solid waste generation [5]. Similarly, according to the International Panel on Climate Change (IPCC), the Eastern Africa regional default value for the composition of municipal solid waste shows that food waste covers 53.9%; paper/cardboard, 7.7%; wood, 7.0%; textiles, 1.7%; rubber/leather, 1.1%; plastic, 5.5%; metal, 1.8%; glass, 2.3%; and others, 11.6% [6].

Different techniques, including incineration and landfilling, can manage solid waste. However, biological processing such as composting or biogas processing is an ideal option for organic waste management for households and municipalities in both developing and developed countries [7]-[9]. Adoption of these biological methods reduces the anthropogenic greenhouse gas emission from the waste stream, the expense of transportation and landfill operations of municipalities. The processing of organic waste through composting is relatively low cost, but the scale, quality, price, heavy metal contaminations and the costly waste collection and segregation affect the profitability [4]. This is particularly the problem with organic waste management in low and middle-income countries [10]. There are also many technical and financial hindrances to implement composting as a method for urban organic waste management or input in urban agriculture [11], [12]. In urban areas that do not practice segregation at the source, the solid waste generated may contain heavy metals that leads to polluting the compost product. Hence, composting can be a viable option for organic waste management by introducing a sustainable compost market and improving the quality and quantity of compost production. To better understand the adaptability of better compost technologies and sustainable compost markets in low and middle countries, there is a need for more evidence from case studies and field research, as these countries are underrepresented in the literature [13]. Therefore, this study examines the quality, quantity and market potential of compost produced in Addis Ababa, Ethiopia. The specific aims are to (i) assess the composting practice and production capacity in the city, (ii) analyze the nature and quality of compost produced, and (iii) explore the application of organic waste compost in urban agriculture.

A. A. Woldeamanuel and M. M Tarekegn are with Department of Environment and Climate Change, Ethiopian Civil Service University, Addis Ababa, Ethiopia (e-mail: alemwoldeam@gmail.com, maschalm12@gmail.com)

R. M. Balakrishina is with Department of Chemical Engineering, National Institute of Technology Karnataka, Mangalore, India (e-mail: rajmohanbala@gmail.com).

II. Materials and Methods

A. Study Area

The study area for this research is Addis Ababa, which is the capital and largest city in Ethiopia. The city has 10 administrative units or sub-cities. It is located relatively at the center of the country with 8046'0" N–9011'30" N latitude and 38035'30" E–38057'30" E longitude. The city covers an area of around 520 km^2 and is at a height ranging from 2015 to 3125 meters above sea level. The city enjoys a mild climate, having an average mean yearly temperature of 17 °C and mean annual rainfall of 1255 mm [14].

Addis Ababa's economy is growing annually by 14% and the city alone contributed about 50% of the national GDP, which shows its importance within the overall economic development of the country [15]. Addis Ababa hosts about 3.3 million people, constituting a 17% share of Ethiopia's total urban population and they estimate the population to reach 4.7 million inhabitants by 2030. The city is experiencing an annual growth rate of 3.8% and a high level of migration from rural areas [16]. According to the Ethiopian Development Research Institute (EDRI) and Global Green Growth Initiative (GGGI), Addis Ababa continues to grow into a dynamic, multi-functional and cosmopolitan megacity. It is an international city and an attractive place to do business and delivers all the national political and administrative functions [17].

Solid waste composition studies are a rare phenomenon in the city, but the Addis Ababa City Government and the French Development Agency produced a comprehensive document in 2013 that characterizes the waste generated in the city. Based on the document, the household is the major waste generator with the amount varies from 0.21 to 0.59 kg/cap/day for low and high income, respectively. Compositions of the waste generated show that households contribute 76% of the total waste, of which 57.1% are organics. Commercial centers and institutions are the second contributors with a share of 9% and the proportion of organic waste is also very high (63.4% the organic waste is from cafes, bars, restaurants and hotels, 8.4% from shops and stores, and 12.7% from institutions). The third source of waste is street weeping with a 6% contribution (45.5% is organic). Industries contribute 5% (with 7% organics) whereas the share of hospitals is only 1% (with 29% organics) and the other sources contribute the remaining 3% of the waste [18].

The city's urban agriculture office data on compost preparation show that there is a minimal amount of compost produced from the waste generated in each sub-city. As shown in Table I, the amount of waste collected and compost produced presents a marked difference in the city. Akaki-Kality sub-city produces one-third of the compost followed by Kolfe that produces about one-fifth of the compost in the city. These compost productions are an attribution of the presence of urban farmers, agricultural land and compost producers in the city. However, the proportion of the land covered by urban agriculture and the number of farmers practicing urban agriculture are declining from time to time because of the expansion of the city and preferences given to other types of land uses [14], [19].

TABLE I
Solid Waste Collection and Compost Production in Addis Ababa

Sub-city	Total area of sub-city (in ha)[a]	Agriculture Area (in ha) [b]	Number of Urban Farmers [b]	Solid Waste collected (in m^3) [c]	Compost produced (in m^3) [b]
Addis-Ketema	863.86	8.33	120	160504	40.76
Akaki-Kality	12400.71	2224	1138	108008	327
Arada	949.85	0.5	40	110593	71
Bole	11849.49	1085.76	668	135977	45.5
Gulele	3119.10	4	711	102172	119.6
Kirkos	1464.76	0.4	14	144091	72.9
Kolfe-Keranyo	6348.09	391.5	848	180069	176
Lideta	918.28	3	110	99450	-
Nifas Silk-Lafto	5821.64	670	897	194152	70
Yeka	8213.11	303.5	440	107622	67
Total	51948.89	4690.99	4986	1342638	989.76

[a]Addis Ababa City Planning Project Office, 2017 [42]
[b]Addis Ababa City Urban Agriculture Office, 2017 [43]
[c]Addis Ababa City Cleansing Management Agency, 2013 [18]

B. Data

Data collection took place in March 2017 from institutions and compost producers using structured interviews, archival records and documentation. Primary data collection uses a survey questionnaire, interview questions, site observations and laboratory analysis. The survey questionnaire contains questions related to composting activities like the existing trends of fertilizer use, knowledge of composting and perception of their land quality in terms of productivity. Finally, farmers expressed their willingness to pay for compost.

Snowball sampling was used to identify six major compost producers in the city that practice a certain level of composting. It is the compost samples taken from the producers that are used for laboratory analysis. Multi-stage sampling is used to select existing and potential compost users or urban farmers. Because of higher urban agriculture activity in peri-urban areas, four peripheral sub-cities of Addis Ababa were selected and they are Akaki-Kality, Bole, Kolfe-Keranyo and Nifas Silk-Lafto. Finally, a simple random sampling method is used to select the urban farmers from these four sub-cities.

Urban farmers in the four sample sub-cities are the sampling frame of the study. There is 3551 total number of urban farmers in the four sample sub-cities. The sample size determined uses a 95% confidence level and 0.05 precision using the formula developed by [20]. Finally, 360 sample respondents were selected and distributed to the four sub-cities proportionally: Akaki-Kality (32%), Bole (19%), Kolfe-Karanyo (24%) and Nifas Silk-Lafto (25%).

C. Method

This study combines the analysis of production and utilization of organic waste compost using the framework in

Fig. 1. Policies and institutions are the major controlling elements for both compost production and utilization. Availability and quality of feedstock materials influence compost production. The study examines this phenomenon by studying the compost production activity in the city and analyzing the physicochemical characteristics of the compost produced. Inputs used in urban agriculture as a soil improver also influence the utilization of compost. The study investigated this issue by assessing the perception and the practice of farmers. The binary logit model is used to analyze urban farmer's willingness to pay (WTP) for compost and the factors affecting it. Assessment of both the supply and demand side of compost can help to evaluate the viability of composing for organic waste management in the city.

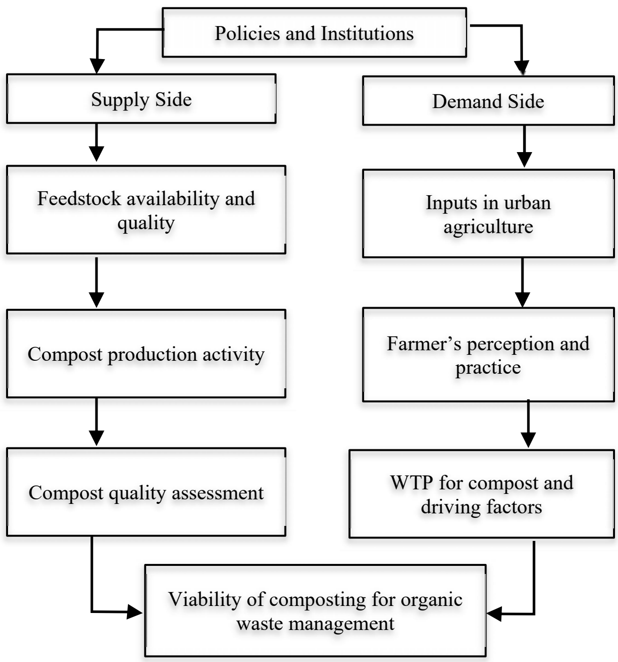

Fig. 1 Analytical framework of the study

Physicochemical analysis and heavy metals test: Various types of physical and chemical characteristics including pH, % Moisture Content, % Total Nitrogen (Kjeldahl), % Organic Matter, C: N ratio, Mn, Cu, Pb, Cd and Cr of the compost samples are studied using laboratory analysis. The study compares the laboratory result with standards set by different international organizations. The compost samples were processed in the Addis Ababa Environmental Protection (AAEPA) laboratory. First, the collected samples dried to remove the moisture and then the dried part was grounded. Second, about 5 g of dry powder from each sample was weighed by electronic monopan balance (Dhona 200D) and digested with sulfuric acid (H_2SO_4), nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) (2:6:6). Then, it was dried in a digested at a temperature of 105 °C for 1 hour and centrifuged at a speed of 10,000 rpm for 30 minutes. Finally, the supernatant was analyzed to know the heavy metals (Mn, Cu, Pb, Cr and Cd) concentrations.

Moisture content: The compost samples were carefully dried in a laboratory oven at 105 ºC +/-1 ºC for 24 hours and reweighed; then put back into the oven and checked again at hourly intervals until no loss of weight was observed; then the moisture content was calculated using (1):

$$Moisture\ content = \frac{Initial\ weight - Final\ Weight}{Initial\ Weight} \times 100\% \quad (1)$$

Nitrogen determination: The Kjeldahl procedure was employed to determine the total nitrogen content of the compost. 2 g of a dried sample of each compost sample was placed in a digestion tube with 15 ml of concentrated sulfuric acid. Then, 7 g of potassium sulphate and copper were added. The digestion tube was placed into a digestion block where it was heated to 37 °C. Sodium hydroxide solution was added to change ammonium ion to ammonia in the digestant and the nitrogen separated by distilling the ammonia and collecting the distillate in 0.1 N sulfuric acid solutions. Titration of the ammonia determines the amount of nitrogen on the condensate flask with a standard solution of 0.1 N sodium hydroxide in the presence of methyl red as an indicator and 0.1 N sulfuric acid solutions. Then, the amount of nitrogen was calculated using (2):

$$N = \frac{(14.01 \times (ml\ titrant - ml\ blank) - (N\ of\ titrant))}{Sample\ Wt \times 1000} \times 100\% \quad (2)$$

where N: Normal concentration.

Carbon to Nitrogen (C: N) ratio: Once the % of organic matter and total nitrogen is calculated, the carbon to nitrogen ratio is estimated by (3):

$$\frac{C}{N} = \frac{\%OC}{\%N} \quad (3)$$

Regression analysis: Descriptive analysis was performed on the use of inputs and other characteristics of the urban farmers before using contingent valuation methods (CVM) to evaluate the WTP for compost. The CVM analysis uses linear probability models. Farmers' WTP for compost analyzed based on the binary logistic regression model assumed that the urban farmer's WTP or not for compost depends on a vector of Xk independent variables. The logistic regression model manages the mix of continuous and categorical variables, as described in Table II.

The logistic model for K independent variables x_1, x_2, $x_3 ... x_k$) is determined by (4):

$$\log \frac{P}{1-P} = a + b_1 x_1 + b_2 x_2 + \cdots + b_k x_k \quad (4)$$

where: $\log \frac{P}{1-P}$ represents the odds ratio for the urban farmer WTP for compost to not being willing to pay, b_k represents the regression coefficient, x_k represents the independent variables and a is the constant.

Interpreting the regression analysis was performed based on the values of the constant (a), the values of the explanatory variables (b), the odds ratio (Exp (B)) and the level of significance for the t-statistics. The sign for the explanatory variables also tells us that urban farmers possessing certain characteristics are more willing to pay for compost. For instance, if the value of the explanatory variable for applying compost is positive, it means that those applying compost are more willing to pay than those not applying. If the value of this explanatory variable is negative it means that the farmers who are not applying compost are more willing to pay for it than those already applying it.

TABLE II
SUMMARY OF THE EXPLANATORY VARIABLES USED IN THE REGRESSION MODEL

Explanatory Variables	Description of variables
Age (Ag)	Age of the farmer in years
Education (Ed)	Educational status of the farmer (Illiterate = 0 Literate = 1)
Farm Location (FL)	Farm location (Peri-urban/river corridor = 0 Urban open spaces = 1)
Farm Ownership (FO	Ownership status of the farm (Not-private = 0 Yes = Private)
Farm Size (FS)	Size/area of the farm in ha
Farming Method (FM)	Farming method (Organic and Integrated = 0 Conventional = 1)
Gender (Ge)	Gender of the farmer (Female = 0 Male =1)
Household Size (HS)	Number of permanent household members
Annual Income (AI)	The annual income of the farm household
Product Type (PT)	Main product of the farm (Field Crops = 0 Vegetables = 1)
Soil fertility monitoring (SM)	Farmers monitor soil fertility (No = 0 Yes = 1)
Soil Inputs (SI)	Soil improver on the farm (Compost and other natural inputs = 0 Chemical fertilizer = 1)

III. RESULTS AND DISCUSSIONS

A. Basic Characteristics of Compost Production

Feedstock materials: The compost producers use municipal solid waste with diverse compositions such as leaves, grass, brush and branches, food waste, pulp and paper products, and floral waste and trimmings/plants as feedstock materials. For instance, compost sites (E) and (F) in Table III use manures, sewage sludge and biogas slurry as feedstock materials whereas compost site (D) uses fruit and vegetable residues collected from shops and juice making houses. The composition of the substrate for compost determines the nutrient level and other quality of the product [21]-[23]. The feedstock materials used for composting help to maintain the C: N ratio within a range of 27-30%, the standard moisture content between 79-80% and promote air for microbial degradation [24], [25]. However, almost all compost sites that operate in Addis Ababa are not considering the selection of substrates for the production of their compost properly.

Quality and accessibility of substrates: Besides getting feedstock materials that contain better nutrients, segregation contributes to the production of free heavy metals compost. This is because unsorted or non-source segregated biodegradable organic waste might be a cause of heavy metals contaminations and indirectly injure the health of the environment and human beings [26], [27]. This study identified that there is a very limited practice of using source segregated compost substrate, and the community has no habit of solid waste segregation at home. A majority of the compost producers collect, transport and sort the non-segregated solid waste from the source, before using it as a substrate for their composting. The remaining producers use mixed unsorted solid waste. Similarly, lack of source segregation was observed in other emerging cities in Africa and Asia [2], [28], [29].

Accessibility of feedstock materials is another challenge of compositing, as most of the compost producers reported. For instance, the Addis Ababa Environmental Protection Authority that manages two compost sites expressed the challenges in accessing the biodegradable waste from the sources because of the existing waste management system. The system operates by outsourcing household solid waste collection and transportation services to small and micro-enterprises. The enterprises do not give any solid waste from their zone without their payment that is merited from the Addis Ababa city waste management agency. As a result, compost producers have to pay for the waste-collecting small and micro enterprises to get feedstock materials.

TABLE III
CHARACTERISTICS OF SIX COMPOST PRODUCERS IN ADDIS ABABA, 2017

Site [i]	Feedstock materials	Quality of substrates [ii]	Accessibility of substrates	Composting method	Quality Monitoring [iii]
A	a,b,c,d,e,i	Source segregated	Difficult	Aerobic	4,6
B	a,b,c,d,e,i	Mixed/ unsorted	Moderate	Semi-aerobic	4,6
C	a,b,c,d,e,i	Sorted on site	Very difficult	Aerobic	1,2,3,4,6,8,9
D	a,b,c,d,e,g,i	Sorted on site	Difficult	Aerobic	3, 4, 6
E	a,b,c,e,f,h,i,j	Sorted on site	Easy/own source	Semi-aerobic	4,6
F	a,b,c,d,e,h,i	Mixed /unsorted	Moderate	Anaerobic	2,3,4,6

[i] Sites A, B, C and D are small scale whereas E and F are medium-scale compost producers. Sites A, D and F are government-owned; C and E are owned by non-government organizations and site B is a private producer.

[ii] Type of Feedstock Materials: a-Leaves; b-Grass; c-Brush & Branches; d-Food waste; e-Pulp & Paper; f-Floral & Trimmings; g-Fruits & Vegetables; h-Manures; i-Mixed Household Waste; j-Biogas Slurry; and k-Sewage sludge

[iii] Quality characteristics monitored: 1-C:N ratio; 2-Total Nitrogen (%); 3-pH; 4-Color; 5-Texture; 6-Odor; 7-Weight (density in kg/m^3); 8-Biological features (Total coliform, Fecal Coliform); 9-Heavy metals (Cd, Pb, Hg, Zn, Cr, etc. in mg/L)

Composting process and methods: Most of the composting facilities in Addis Ababa use the aerobic composting process where air continuously supplied to the piles facilitates microbial degradation. Some composting sites such as (B) and (E) used hybrid techniques, including both aerobic and anaerobic methods of composting. They pile the solid waste on the surface open to natural aeration but it is not continuously mixed and open to get air percolation. As a result, the anaerobic degradation process is taking place inside the pile where there is no reach of free oxygen. At site (F), they bury the selected and treated feedstock materials underground and open them after six months for further treatment. However, studies [44]-[46] showed that the anaerobic process to degrade organic waste is not as efficient as the aerobic process applied in composting. According to [30], bacteria need free oxygen in the compost pile to derive energy from the breakdown of waste materials to heat the system and facilitate degradation.

Due to lower oxygen availability, the rooting time of anaerobic degradation is slow. In this study, the aerobic composters reported a shorter compost maturation time (4-10 weeks) as compared to anaerobic composters whose maturation time is longer (24-52 weeks). Some 12% of the sites produce compost in four weeks but much of the aerobic compost production takes about 10 weeks. Composters use leachate recycling and effective microorganism to reduce maturation time. This is because compost production takes time to stabilize pH, temperature, moisture and important minerals that are called maturation dynamics [31], [32]. Factors such as temperature, moisture content and other pH maturation indicator become constant 8-10 weeks after the start time of composting. As a result, the selection and application of selected biodegradable waste reduce the compost rooting time as feedstock materials that have higher moisture content increase degradation and the thermophilic bacterial activity of the system.

Compost quality monitoring: Different physicochemical parameters including but not limited to total organic carbon availability, total nitrogen, carbon to nitrogen ratio (C: N), moisture content, pH, color, bulk density, odor, texture, macro and micronutrients, cleanness of pathogens and heavy metals can help monitor the quality of compost. This study found that most facilities do not practice compost quality monitoring. However, as given in Table III, compost sites (A), (C) and (D) use a few of the quality parameters like moisture content, odor, color and temperature for compost rooting progress monitoring. The compost quality of sites (A) and (C) was tested only one time in 2011. This shows that limited information is available on the quality of compost in the city.

B. Quality of Compost Produced

Physicochemical characteristics of compost: Compost contains a range of macro and micronutrients that determine the fertilizer value of the compost and are characterized in various types and quantities [31]. Table IV summarizes the physicochemical characteristics of compost under this study.

Site E has the highest Kjeldahl nitrogen content (1.2%) and the lowest in Site F (0.09%). In particular, Site E compost contains the highest nitrogen content because of using nitrogen-rich feedstock materials such as poultry and cattle manures so that its compost product has higher nitrogen. Site F uses manures but most of the nitrogen is gasified and released in gas forms. On the other side, the pH of compost produced from Site D showed lower pH because of its fruit and vegetable substrates. The compost product on this site has shown higher carbon content, lower nitrogen and resulted in higher carbon to nitrogen ratio. Similarly, in Site F, organic nitrogen gasified and vented from the product and yielded a product containing higher carbon to nitrogen ratio. Also, analysis of a sample from Site A showed total nitrogen (TN), total phosphorus (TP) and total potassium (TK) of 1.35%, 4.7 mg/kg and 13,193 mg/kg, respectively. The compost product showed lower nutrient content as compared to the chemical fertilizer such as di-ammonium phosphate with nutrient contents 21.3% P and 28% N; additional chemical nutrients required as supplementary or selection of feedstock materials that can balance the nutrient deficiency while compositing [34]. A report of Food and Agriculture Organizations (FAO) on Latin America experience showed composting as a selective soil conditioner if properly produced by considering the selection of feedstock with source segregation practices [35].

TABLE IV
PHYSICOCHEMICAL CHARACTERIZATION OF COMPOST IN ADDIS ABABA

Condition	Site A	Site B	Site C	Site D	Site E	Site F
C:1N ratio	215	58.33	42.02	130.22	30.83	277.11
Total Nitrogen (%)	0.20	0.60	0.69	0.46	1.20	0.09
pH	7.86	7.65	8.85	5.95	9.31	7.53
T^0	AMB	AMB	AMB	AMB	AMB	AMB
Density (kg/m^3)	295	330	305	380	230	270
Organic Matter (%)	43	35	29	60	37	25
Moisture Content (%)	70	25	32	49	14	47

The Ambient (AMB) Temperature (T^0) considered for all sites and the FAO Standard or Reference (RE) taken from [33]. The reference for C: 1N ratio (10:1-15:1); %Total Nitrogen (~1%); pH (6.5-8.5); T^0 (AMB); Density in kg/m^3 (< 700); %Organic Matter (> 20%); and %Moisture Content (40-60%).

Heavy metals content of the compost: In this study, heavy metals (Mn, Cu, Pb, Cd and Cr) concentration levels are very small despite most of the producers used non-segregated waste materials (see Table V). This could be attributed to lower contamination of feedstock materials at the sources in emerging cities. However, compost produced from non-segregated municipal waste may contain heavy metals, whereas source segregated feedstock materials usually contain very few or no contaminants, including heavy metals [27]. According to [36], the heavy metals in wastes and composts added to the soil might enter the food chain and food web after it is being applied as a soil conditioner.

TABLE V
HEAVY METAL CONCENTRATION OF COMPOST UNDER STUDY (MG/KG)

Heavy Metals	Site A	Site B	Site C	Site D	Site E	Site F
Mn	0.20	1.8	0.30	0.40	0.26	0.60
Cu	0.40	0.20	0.38	0.40	0.30	0.60
Pb	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0
Cd	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
Cr^{6+}	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

The EU standard is considered as a reference (RE) for evaluating the heavy metal concentrations of the compost. The reference for Mn, Cu, Pb, Cd and $Cr^{6+}$is 4, 70, 45 0.7 and 0 respectively

Raw materials used as a feedstock, water used and materials applied for compost handling can contaminate the compost with heavy metals. As a result, the heavy metal contamination level of compost results from solid waste generated in the community, which indirectly correlates with the income and the nature of goods consumed. The solid waste generated from a higher income society has a higher probability of heavy metals contamination as compared to the lower-income group. Source segregation of biodegradable solid waste from metals, glass and electronic waste components reduces the heavy metals contamination level of compost [37].

C. Urban Farmers' Application of Compost

The type of soil improver widely applicable by the farmers can influence the marketing environment for compost in the city. Table VI shows that chemical fertilizer is the dominant form of soil improver accounting for 78.6% of the input implying that over three-fourths of the farmers apply fertilizer with the remaining one-fourth of the farmers applying other soil improvement methods. Using compost is relatively the second most important form of soil improver (with 7.5%). The remaining soil-improving mechanisms include crop rotation (5.3%), manure (3.6%), fertile soil (1.7%) and crop residues (1.4%).

TABLE VI
THE TYPE OF SOIL IMPROVER BY MAIN PRODUCT OF THE FARM

Soil Improver	Vegetable producers	Crop producers	Total
Chemical Fertilizer	98 (27.2%)	185 (51.4%)	283 (78.6%)
Compost	27 (7.5%)	-	27 (7.5%)
Crop rotation	17 (4.7%)	2 (0.6%)	19 (5.3%)
Off-farm manure	13 (3.6%)	-	13 (3.6%)
On-farm manure	7 (1.9%)	-	7 (1.9%)
None (fertile soil)	4 (1.1%)	2 (0.6%)	6 (1.7%)
Crop residues	5 (1.4%)	-	5 (1.4%)
Total	171 (47.5%)	189 (52.5%)	360 (100.0%)

Since fertilizer application is the dominant type of soil improver both in the field crop and vegetable producers, it is important to see the type and cost of fertilizer applied. Table VII shows the fertilizer application as calculated in kg per square meter and the cost in Ethiopian Birr per kg. Most vegetable producers have a small portion of land and the cost incurred per kg for both types of producers is almost identical. Fertilizer application is higher in vegetable producers because of the demand for high productivity using a small portion of land. Similarly, the cost incurred by the vegetable producers for the purchase of fertilizer is relatively higher than crop producers. There is also a higher deviation from the mean for vegetable producers.

TABLE VII
APPLICATION OF CHEMICAL FERTILIZER AND ASSOCIATED COSTS IN THE FARMS

Farm product	Urea in Kg/ha		DAP in Kg/ha		Fertilizer Cost in Birr	
	Mean	SD	Mean	SD	Mean	SD
Crops	113.3	77.7	98.2	81.0	14.54	8.07
Vegetables	67.1	50.4	80.8	64.5	13.94	12.78
Total	80.4	62.9	84.5	68.5	14.13	11.50

The average exchange rate for March in 2017 was 1USD = 22.62 Ethiopian Birr.

Farmers' WTP for compost may reveal the availability of a market for compost and Table VIII shows 70% of the farmers' WTP for compost. A similar result was reported in Ghana, where the expense of chemical fertilizer increased and farmers started looking for other options such as compost as their soil conditioner [38], [39]. However, compared to chemical fertilizers the price of farmers WTP is very low.

TABLE VIII
URBAN FARMERS WTP FOR COMPOST

Farm product	WTP for compost		Amount WTP for 1 kg of compost in Birr	
	No	Yes	Mean	SD
Crops	28 (7.8%)	143 (39.7%)	3.0	2.0
Vegetables	80 (22.2%)	109 (30.3%)	3.0	2.0
Total	108 (30.0%)	252 (70.0%)	2.61	2.18

Farmers have their reason for not using or showing a lower WTP for compost. Urban farmers responded to the question: which compost characteristics need improvement and they show their reply in Fig. 2. Almost one-third of the urban farmers do not know the characteristics that need improvement but one-fourth of the farmers showed accessibility and followed by easier handling of the compost. This shows that WTP is a more flexible concept, as it partly depends on priorities, perceptions and appreciation for a product [40], [41].

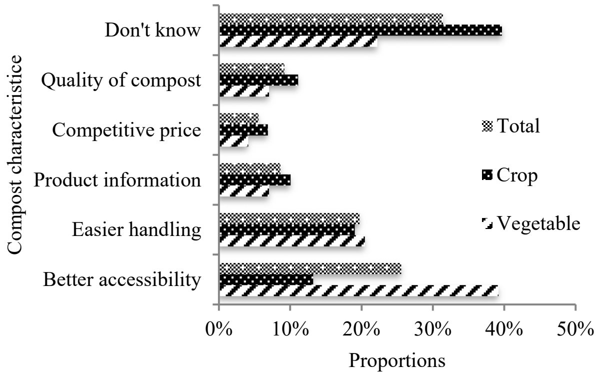

Fig. 2 Urban farmer's perception about compost characteristics

The evaluation of WTP for various prices has implications for producers mainly for pricing decisions. WTP is a more flexible concept, as it partly depends on priorities and perceptions. It reflects the appreciation for a product rather than an actual market price. WTP can increase through awareness creation but be damaged by a poor reputation. There is a need to understand and tackle through marketing quality concerns, competition with other products and stigmatization of waste-derived compost as they affect people's willingness to purchase compost [40].

D. Factors Affecting Urban Farmer's WTP for Compost

The factors that affect urban farmer's WTP for compost was analyzed using the logistic regression model. The regression analysis assumed that farmer's WTP for compost is the function of gender, household size, income, compost application, monitoring of soil fertility, fertilizer application, farming method and the principal product of the farm. Similar research applied such variables for assessing urban farmers'

WTP for compost [39]. But another study followed a choice experiment for assessing farmers' WTP for compost [41]. Table IX provides the coefficient statistics and the level of significance for these explanatory variables in terms of t-statistics. The model is used to predict the farmers characterized by the above explanatory variables based on their WTP for compost.

The regression equation is given by (5):

$$\frac{\log P}{1-P} = 2.566 - 0.150HS + 0.000AI + 1.316Ge - 1.621SI - 2.256SM - 1.011PT + 1.435FM + 1.271FO \quad (5)$$

where HS = Household Size; AI = Annual Income; Ge = Gender; SI = Soil Inputs; SM = Soil fertility Monitoring; PT = Product Type of the farm; FM = Farming method; and FO = Farm Ownership.

TABLE IX
FACTORS AFFECTING URBAN FARMERS WTP FOR COMPOST IN ADDIS ABABA

Variables	B	S.E.	Wald	Sig.	Exp(B)
Constant	2.566	0.967	7.045***	0.008	13.014
Household size	-0.150	0.078	3.642*	0.056	0.861
Age	-0.020	0.017	1.494	0.222	0.980
Annual income	0.000	0.000	7.610***	0.006	1.000
Gender	1.316	0.556	5.597**	0.018	3.728
Education	0.049	0.440	0.012	0.912	1.050
Farm size	-0.035	0.124	0.078	0.779	0.966
Soil inputs	-1.621	0.561	8.334***	0.004	0.198
Soil fertility monitoring	-2.256	0.442	26.076***	0.000	0.105
Main farm product	-1.011	0.611	2.735*	0.098	0.364
Farm location	-0.187	0.374	0.252	0.616	0.829
Farming method	1.435	0.532	7.270***	0.007	4.198
Farm ownership	1.271	0.738	2.964*	0.085	3.565

Hosmer-Lemeshow goodness of fit test: $x^2 = 3.513$, 8 degrees of freedom, and $P = 0.898$
Nagelkerke R Square value: 0.393;
*, **, *** denote the level of significance at 10%, 5% and 1% respectively.

The prediction is given by $ODDS = e^{a+bx}$. Depending on the type of inputs applied by the farmer, the $ODDS = e^{2.566-1.621(1)} = 2.57$. This means that those who are applying chemical fertilizer are only 2.57 more likely to pay for compost. The odds for farmers who are applying other inputs such as compost is $ODDS = e^{2.566-1.621(0)} = 13.01$ Farmers who are applying other inputs are 13.01 more likely to pay for compost. These odds values can be converted into probability as follows $p = \frac{odds}{1+odds} = \frac{2.57}{3.57} = .72$. That is only 72% of the farmers who are applying chemical fertilizer are WTP for compost. However, the farmers who are applying other inputs are more WTP for compost by 93%, as $p = \frac{odds}{1+odds} = \frac{13.01}{14.01} = .93$. The exponent $e^b = e^{-1.621} = 0.198$ *or* $\frac{2.57}{13.01} = 0.198$ calculates the Exp (B), known as the odds ratio predicted by the model. This implies that the model predicts that the odds of WTP for compost are 0.198 higher for those who are applying other inputs than farmers applying chemical fertilizer.

The same procedure is followed to interpret the remaining figures. The positive signs show that male farmers, higher-income farmers, private owners and farmers that apply conventional methods are more willing to pay for compost. The negative signs show that smaller household size, farmers producing crops, not monitoring soil fertility and applying other inputs are more WTP for compost. A similar study conducted in two cities of Ghana also found that income, compost experience and soil input are determinant factors for farmers' WTP for compost [38], [39].

IV. CONCLUSION

The practice of composting municipal solid waste in Addis Ababa is at a small scale and few producers existed in the city. There is a tremendous challenge on the accessibility of feedstock materials to produce compost and the accessible feedstock material also lack segregation at the source for quality compost production. The time required to produce compost is also higher compared to the standard especially for anaerobic producers that extends up to ten weeks. There is a lack of adequate technical knowledge and skills by the producers to improve the quality of their compost product as limited quality monitoring is used during compost preparation.

The quality of compost is optimal for the measured parameters including TN, pH, organic matter and moisture content. However, the concentration of carbon is very high in the compost compared to the standard due to the type of feedstock materials used that has high carbon content. The heavy metal concentrations of the compost measured for Mn, Cu, Pb, Cd and Cr^{6+} are also insignificant since the type of waste generated at the source is mainly organic. On the other hand, there is no formal market for compost products, most facilities produce compost for their consumption and only a few compost facilities sell their products in the market. The mean price farmers are willing to pay for compost is five times lower than the price of chemical fertilizer. The factors that affect urban farmer's WTP for compost include income, household size, gender, ownership, soil fertility monitoring, input type, farming method and major product of the farm.

This study implicates that marketing the environmental benefits of applying compost in the farm either through self-preparation or availing it in the market can be an ideal option for organic waste management in emerging cities where the proportion of the organic waste generated is very high. A practical experiment can support compost application and preparation to show the benefits of compost on the farm and the mechanism of preparing it. Compost should also be available in the market by considering the farmer's willingness and ability to pay for it. Finally, there is an urgent need to create a value chain that links compost feedstock materials, compost preparation, marketing strategy and compost application so that composting can be a sustainable practice for managing organic waste in urban areas of emerging cities.

ACKNOWLEDGMENT

Alemayehu A. Woldeamanuel and Mekonnen M. Tarekegn thank the Ethiopian Civil Service University for the financial support received during this research undertaking. The authors would also like to acknowledge the compost producers for providing their compost samples and the urban farmers for responding to the survey questionnaire.

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