"Science Stays True Here"
Advances in Ecological and Environmental Research, 69-89 | Science Signpost Publishing

Production of Compost and Organic Fertilizer from Sugarcane Residues

Dalia A. Nakhla[1], Y.I. Mahmoud[2], Salah El Haggar[3]

1, Environmental Management Consultant, 40 Mohi El Din Abu ElEzz, Dokki, Giza, Egypt.

2, Soil, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt.

3, Mechanical Engineering Department, School of Sciences and Engineering, American University in Cairo, Egypt.

Received: September 17, 2016 / Accepted: November 10, 2016 / Published: February 25, 2017

Abstract: The main residues generated from the sugarcane industry, in Egypt, are green tops and dry leaves from the harvesting process as well as bagasse, filter cake/mud and furnace ash from the cane milling process. The green tops are directly fed to the farmers' livestock in its raw form during the sugar harvesting season which is from January to April. As for the dry leaves, it represents a burden due to its large volume and fire hazard and so it is daily burnt in the fields causing considerable air pollution. Bagasse, on the other hand, is currently used in Egyptian sugar mills as fuel to generate the mill's steam and electricity or as fiber to make fiberboard and paper. However, as natural gas is replacing bagasse as fuel, bagasse will be available in large quantities in the factories that are not currently utilizing it for fiber. In addition, filter cake/mud and furnace ash are currently applied directly on reclaimed lands to act as soil additive. However, direct incorporation of raw agro-industrial waste into the soil may cause undesirable outcomes as phytotoxicity and soil nitrogen immobilization. The objective of this research was to test for the possibility and feasibility of producing compost/organic fertilizer from the waste streams generated from the agricultural and industrial phases of sugarcane manufacture, as an environmentally friendly reuse alternative to produce organic fertilizer that is more safe than chemical or artificial fertilizers. The pilot experiment has demonstrated that a variety of compost types and organic fertilizers can be produced from a combination of the residues generated from the sugarcane residues according to their chemical and biological properties.

Key words: Baggase, Compost, Filter Mud, Sugarcane Residues

Corresponding author: Dalia A. Nakhla, Environmental Management Consultant, Dokki, Giza, Egypt.

1. Introduction

Sugarcane industry in Egypt goes back to the year 710 AD [1]. Cane plantations are concentrated in the area of Upper Egypt. The total amount of cane cultivated in Upper Egypt is about 16 million tons per year [2]. There are eight sugarcane producing mills located in five of Upper Egypt Governorates: El Menia, Sohag, Qena, Luxor and Aswan. The location, areas, capacities, inputs and outputs of the factories of Upper Egypt are shown in Table 1.

Table 1. Areas, capacities, inputs and outputs of the sugarcane mills [2]

Location	Factory	Area (Hectare)	Factory Design Capacity (tons)	Cane Processed in the Mill (tons)	Sugar Produced in the Mill (tons)	Percentage Contribution to Sugar
El Menia	Abou Korkas	4163	700,000	408,085	45,868	4.5
Sohag	Gerga	5188	900,000	531,633	60,107	5.9
Qena	Nagaa Hamadi	14280	1,700,000	1,435,137	166,296	16.4
	Deshna	8132	1,000,000	811,497	90,741	9.0
	Kous	16003	1,600,000	1,496,836	165,175	16.3
Luxor	Armant	13288	1,300,000	1,320,602	148,568	14.7
Aswan	Edfu	14054	1,100,000	1,199,351	136,775	13.5
	Komombo	19048	1,800,000	1,821,253	199,955	19.7
Total			10,100,000	9,024,394	1,013,485	100

The sugarcane industry in Egypt can be currently defined as an open industrial system that consumes material and energy and creates products and wastes. The two main stages of sugarcane production are the agricultural stage and the industrial stage. The agricultural stage involves cane cultivation which involves the use of fertilizers, water and fuel for irrigation, and cane harvesting which results in the production of two main residues which are cane tops and dry leaves. The cane tops are collected and used by the farmers to feed their livestock. The dry leaves, on the other hand, are openly burnt resulting in pollution of the ambient air.

The cane is transported from the fields to the mills mainly by the sugarcane train. In the mill, the production process involves the consumption of chemicals, water and fuel to produce a number of by- products in addition to the main two products: raw sugar and molasses. The main residues or by- products are filter mud residing from the juice clarification process, bagasse from the cane squeezing and furnace ash in case the bagasse is burnt in the power house to provide steam and electricity for the mill. The filter mud and furnace ash are used in their raw form as soil additive due to their nutritional value. The bagasse, on the other hand, is either burnt in the mill power house to provide steam and electricity to the mill, or is directed to auxiliary factories to produce paper or fiberboard.

The percentage of by-products and co-products generated during the sugar production process are 30% bagasse, 3.5% filter mud/cake and 0.4% furnace ash [3]. Based on these estimates and the amount of cane detailed in Table 1, the amounts of residues produced from the sugar cane factories of Upper Egypt are shown in Table 2.

Table 2. Amount of waste generated during sugarcane manufacturing process

Governorate	**Factory**	**Cane Processed in the Factory (tons)**	**Amount of Bagasse (tons)**	**Amount of Molasses (tons)**	**Amount of Filter mud/cake (tons)**	**Amount of Furnace Ash[1] (tons)**
El Menia	Abou Korkas	408,085				
Sohag	Gerga	531,633	164,806	21,797	18,607	2,127
Qena	Nagaa Hamadi	1,435,137				
	Deshna	811,497	251,564	33,271	28,402	3,246
	Kous	1,496,836	464,019	61,370	52,389	5,987
Luxor	Armant	1,320,602	409,387	54,145	46,221	5,282
Aswan	Edfu	1,199,351	371,799	49,173	41,977	4,797
	Komombo	1,821,253	564,588	74,671	63,744	7,285
Total		9,024,394	2,797,562	370,000	315,854	3,6098

The main aspects that have contributed to the research motivation are the current mismanagement of the considerable amounts of residues generated during sugarcane harvest and its associated negative environmental impacts as well as lack of low cost sustainable waste management options for sugar cane industry to achieve environmental balance. Therefore, the research proposes alternative environmental friendly practices for reuse of residues which is composting.

Composting is one of the most recommended methods for recycling of organic waste, as it closes the natural cycle and returns back to soil its nutrients. It is considered the “highest form of recycling” [4]. Composting can improve soil conditions and plant growth, reduce potential for erosion and runoff and can add humus to the soil, if properly produced. Production of composted fertilizer from lignocellulosic residues of by-products of sugar industries maintains the health of plant and soil properties and protects the plant from soil borne diseases [5].

[1] In case the bagasse used as fuel in the sugar mill for generation of steam and electricity

2, Materials and Methods

A pilot scale experimental setup for experimental production of silage and compost was set up within the facility of the Research Institute for a Sustainable Environment (RISE) in the American University in Cairo (AUC) New Cairo Campus. Residues of the sugarcane harvesting, including dry leaves, generated in one of the agricultural fields of El Menia Governorate were collected, baled and transported to the AUC New Cairo Campus for processing. The dry leaves were shredded in the fields to reduce its size to allow its baling. As for the bagasse, filter mud and furnace ash, which are residues of the sugarcane milling process, they were purchased from Abou Korkas sugarcane mill also located in El Menia Governorate. Samples of raw materials were taken and analyzed in the laboratories of the Soil, Water and Environment Research Institute of the Agricultural Research Center, Ministry of Agriculture and Land Reclamation. The physical, chemical and microbiological characteristics of these materials are presented in Table 3.

Table 3. Characteristics of sugarcane residues generated during harvesting and milling

Parameters	Additive	Harvest Residues	Milling Residues		
	Cow dung	**Dry Leaves**	**Bagasse**	**Filter Mud**	**Furnace Ash**
Density (kg/m^3)	750	110	112	650	195
Moisture content (%)	60	18	53	76	41
pH (1:10)	7.35	-	5.46	5	8.39
EC (1:10) (ds/m^2)	4.40	-	2.13	1.9	1.46
Total nitrogen (%)	1.38	0.54	0.35	1.84	0.42
Ammoniacal Nitrogen (ppm)	44	-	-	53	Nil
Nitrate Nitrogen (ppm)	12	-	-	28	Nil
Organic matter (%)	74.72	89.47	98	67.74	46.22
Organic carbon (%)	43.34	51.90	56.84	39.29	26.81
Ash (%)	25.28	10.53	2.00	32.26	53.76
C/N ratio	31.4:1	96:1	162:1	21.4:1	63:1
Total phosphorus (P_2O_5) (%)	0.61	0.06	0.04	1.98	1.00
Total potassium (K_2O) (%)	0.88	0.54	0.1	0.28	0.99
Calcium (mg/kg)	-	9270	906.8	47961	17047
Magnesium (mg/kg)	-	1881	397.8	2296	6850
Iron (mg/kg)	-	809.7	471.2	5627	5774
Manganese (mg/kg)	-	50	17.2	177.3	143.9
Copper (mg/kg)	-	11.3	7.7	44.8	40.4
Zinc (mg/kg)	-	47.2	7.7	52.7	40.6
Total Coliform Bacteria (Cfu/g)	8×10^5	Nd	Nd	40×10^4	Nd
Fecal Coliform Bacteria(Cfu/g)	3×10^4	Nd	Nd	20×10^4	Nd
Salmonella & Shigella Bacteria (Cfu/g)	12	Nd	Nd	3×10^3	Nd

All the analysis is done on oven dry basis except density and moisture content

Nd: Not detected Cfu: Colony forming unit

Composting was carried out using two methods: in vessel composting and windrow composting. In vessel composting was carried out for five mixtures and windrow composting for two mixtures. Composting was also carried out in a 1 m^3 bag for a mixture due to the availability of its raw material in limited quantities.

Five wooden boxes of 4.5 m^3 capacity were constructed specifically for this research. The box was partially opened from three sides and closed from the fourth side to act as a gate. The material mixes were proportioned based on weight, which was measured using a portable scale. The percentages of mixtures of the different raw material were chosen based on assumed scenarios as follows:

1, Dry leaves produced in the field has high C/N ratio (96:1) as shown in Table 3 and it was thus proposed to add animal dung, which is usually available in Egyptian agriculture lands (in limited amount), to act as a starter to the digestion process. The ratio 5:1 was calculated based on weight of leaves produced per feddan of land in proportion to assumed amount of dung generated from farmers' livestock.

2, Dry leaves were also mixed with filter mud generated from the cane mills so accomplish a good starting C/N ratio that is less than 40:1.

3, Bagasse, the main residue of sugar milling, also having a high C/N ratio was mixed with animal dung which was also intended to act as a starter to the digestion process and to test the feasibility of the composting mix.

4, Bagasse was mixed with filter mud with the same ratio as that produced from the sugar mill which is about 8:1, since as bagasse is generated with an amount of 30% of cane weight and filter mud as 3.5%.

5, Bagasse was mixed at a ratio of 1:1 with filter mud, assuming that 90% of the amount of bagasse is used for other uses such fiberboard or paper and only 10% are available for composting.

6, Bagasse was mixed with filter mud at a ratio of 1:2 to mimic the situation when most of the bagasse is burnt for power and so a limited quantity is available to be mixed with the filter mud.

7, Filter mud was composted alone to test for its properties and quality with and without being composted, as it was expected to give very high quality fertilizer after it is digested.

8, Filter mud was mixed with furnace ash at a ratio of 9:1 as this is the actual ratio of their production from the sugar mill if bagasse is burnt for power.

Table 4. Composition of the raw material mixtures used in compost production

Composition	**Treatments**							
	Dry Leave: Cattle Dung	Dry Leaves :Filter Mud 1:6	Bagasse :Cattle Dung 5:1	Bagasse : Filter Mud 8:1	Bagasse: Filter Mud 1:1	Bagasse :Filter Mud 1:2	Filter Mud	Filter Mud: Ash 9:1
Abbreviation	L:D 5:1	L:M 1:6	B:D 5:1	B:M 8:1	B:M 1:1	B:M 1:2	M	M:A 9:1
Treatment method	Vessel	Windrow	Vessel	Vessel	Windrow	Vessel	Vessel	Bag
Initial Total Weight (kg)	336	4200	600	630	4000	1170	2500	500
Initial Volume (m^3)	3.375	15	3.04	3.4875	13.5	3.375	3.15	0.85

Composting using aerobic decomposition is a process that consumes oxygen, and releases carbon dioxide, water vapor and heat. The main factors that affect the composting process are moisture content and oxygen (aeration). The ideal moisture content is 60% and if it decreases below 40%, microbial activity slows down, while above 60% anaerobic conditions may develop [7]. Aeration, on the other hand, is needed to recharge the oxygen supply for the micro-organisms. Therefore every week, the compost was discharged from of the box to be manually turned and watered and then packed again in the wooden box or bag. The windrows were also watered and turned using a loader. Reduction in the volume of the compost was noted after the maturation period.

Temperature is also an important factor of composting, as it is an indicator of the microbial activity. The ideal temperature range is from 32°C to 60°C, within which activity of microorganisms is ideal. The increase in temperature during composting kills weeds, nematode and plant pathogenic organisms.

Composting undergoes two stages: intensive decomposition and curing. The intensive decomposition has two stages; the mesophilic stage (<45°C) and the thermophilic stage (>45°C). In the active or decomposition phase, easily decomposable and putrescible compounds are broken down and pathogens are eliminated. During curing, the compounds that are less susceptible to carbon mineralization are broken down along with fatty acids [4]. The temperatures of the compost treatments were recorded on weekly basis to monitor the performance of the composting process using a thermo-couple thermometer.

Based on the analysis of the main raw material, the physical characteristics of the different compost treatments are presented in Table 5. The methods of analysis of the parameters are as follows [6,8]:

- Bulk density was determined using the core method [9].
- The pH values of compost were determined in 1:10 compost-water suspension using a glass electrode of

Orion Expandable ion analyzer EA920 [10].

- Electrical Conductivity (EC) measurements were run in (1:10) compost: water extract [11], using EC meter ICM model 71150.
- Organic Matter (OM) content of compost materials was determined by glowing the compost dried samples at 550 ºC to a constant weight [12].
- Organic Carbon (OC) in both raw organic materials and compost samples was determined according to Page et al. [12].
- Total Nitrogen (TN) was determined in compost materials using Kjeldahl digestion method [13].
- Soluble nitrogen (ammonium and nitrate-nitrogen) forms in compost i.e. NH4+, NO2-, and NO3- were determined according to the methods outlined by Page et al. [12].
- Total Phosphorus (TP) was determined using acid solution of the digested compost samples as a reluctant [12].
- Total Potassium (TK) was determined from digested solutions of compost by flame photometrically [14].

Table 5. Characteristics of the compost treatments at the start of the experiment

Parameters	Treatments							
	Dry Leaves : Dung	**Dry Leaves: Mud 1:6**	**Bagasse :Dung 5:1**	**Bagasse :Filter Mud 8:1**	**Bagasse :Filter Mud 1:1**	**Bagasse :Filter Mud**	**Filter Mud**	**Filter Mud: Ash 9:1**
Abbreviation	L:D 5:1	L:M 1:6	B:D 5:1	B:M 8:1	B:M 1:1	B:M 1:2	M	M:A 9:1
Density (kg/m^3)	100	280	197	181	296	347	794	588
Moisture content (%)	57	63	61	63	60	69	76	72
pH (1:10)	7.39	7.15	7.65	5.12	5.8	5.45	5	5.52
EC (1:10) (ds/m^2)	2.20	1.4	0.83	0.66	0.2	0.9	1.9	1.93
Total nitrogen (%)	0.58	1.37	0.47	0.44	0.85	1.10	1.84	1.54
Ammoniacal Nitrogen (ppm)	112	357	119	63	378	441	53	25
Nitrate Nitrogen (ppm)	21	Nil	28	Nil	Nil	35	28	Nil
Organic matter (%)	79.58	75.62	80.45	96.18	87.77	82.71	67.74	63.12
Organic carbon (%)	46.16	43.87	46.66	55.76	50.91	47.97	39.26	36.61
Ash (%)	20.42	24.38	19.55	3.82	12.23	17.29	32.26	36.88
C/N ratio	79:1	32:1	100:1	127:1	60:1	43:1	21:1	24:1
Total phosphorus (P_2O_5) (%)	0.09	1.28	0.08	0.16	0.7	1.02	1.98	1.77
Total potassium (K_2O) (%)	0.67	0.37	0.41	0.11	0.16	0.19	0.28	0.43
Calcium (mg/kg)	9220	33923	2914	3730	16812	24682	47961	41329
Magnesium (mg/kg)	2415	2145	1599	512	1039	1357	2296	3273
Iron (mg/kg)	1343	3879	1388	781	2214	3076	5627	5659
Manganese (mg/kg)	56	131	34	27	71	98	177	170
Copper (mg/kg)	12	33	10	10	20	26	45	44

Zinc (mg/kg)	47	51	17	10	23	30	53	50
Free Nematode (Larve/200g)	Nd	Nd	80	20	Nd	20	Nd	Nd
Pathogenic Nematode (Larve/200g)	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total Coliform Bacteria (Cfu/g)	$5x10^4$	$180x10^4$	$8x10^4$	$15x10^5$	$295x10^4$	$12x10^5$	$40x10^4$	$14x10^5$
Fecal Coliform Bacteria (Cfu/g)	$3x10^4$	$80x10^4$	$6x10^4$	$3x10^4$	$50x10^4$	$4x10^4$	$20x10^4$	$2x10^4$
Salmonella & Shigella Bacteria (Cfu/g)	15	$25x10^3$	14	$13x10^3$	$15x10^3$	$19x10^3$	$3x10^3$	$11x10^3$

All the analysis is done on oven dry basis except density and moisture content

Nd: Not detected Cfu: Colony forming unit

3. Results and Discussion

After 20 weeks of watering, mixing of the compost and based on monitoring of temperature of the compost treatments and observation of the physical appearance of the compost, the composting process was terminated.

Results of temperature monitoring showed that all treatments passed through the mesophilic and thermophilic stages and were in the curing stage which results in stable and mature compost as shown in Figures 1 to 8. In all composting mixtures, the temperature increased to over 600C during the first month of composting, and then gradually decreased down to 45-60 0C. The temperature of mixtures thereafter, fluctuated within a range from 25-34 0C till the end of composting period.

The final volume of the treatments was taken and reductions in volume, density, and fresh weight were calculated as shown in the Table 6. Analysis of the compost produced after about 20 weeks are included in table 7.

Table 6. Change in the characteristics of compost mixtures

Composition	Treatments							
	Dry Leave: Cattle Dung	**Dry Leaves: Filter Mud 1:6**	**Bagasse : Cattle Dung 5:1**	**Bagasse : Filter Mud 8:1**	**Bagasse : Filter Mud 1:1**	**Bagasse: Filter Mud 1:2**	**Filter Mud**	**Filter Mud: Ash 9:1**
Abbreviation	L:D 5:1	L:M 1:6	B:D 5:1	B:M 8:1	B:M 1:1	B:M 1:2	M	M:A 9:1
Treatment method	Vessel	Windrow	Vessel	Vessel	Windrow	Vessel	Vessel	Bag
INITIAL TREATMENT								
Initial Weight (kg)	336	4200	600	630	4000	1170	2500	500
Initial Volume (m^3)	3.375	15	3.04	3.4875	13.5	3.375	3.15	0.85
Initial Density (kg/m^3)	100	280	197	181	296	347	794	588
Initial Dry Matter (kg)	273.28	1356	313	280	1420	370.5	600	137.5
FINAL PRODUCT								
Final Weight (kg)	288	1008	279	360	1213	401	536	114
Final Volume (m^3)	0.9	1.6	0.9	0.9	2.5	0.9	0.9	0.3

Final Density (kg/m^3)	320	630	310	400	485	445	595	380
Final Dry Matter (kg)	150	585	134	259	497	204	273	86
PERCENTAGE CHANGE IN THE BATCH CHARACTERISTICS								
Decrease in Volume	73%	89%	70%	74%	81%	73%	71%	65%
Increase in Density	221%	125%	57%	121%	64%	28%	-25%	-35%
Decrease in Dry Mass	45%	57%	57%	7%	65%	45%	54%	38%

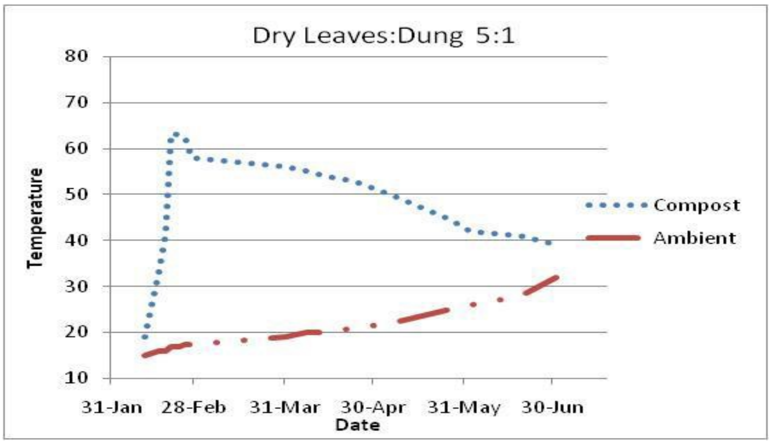

Figure 1. Temperature monitoring for L:D (5:1)

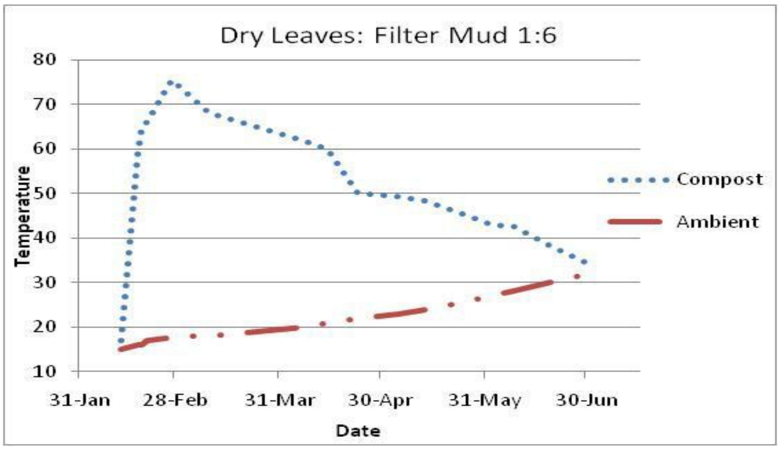

Figure 2. Temperature monitoring for L:M (1:6)

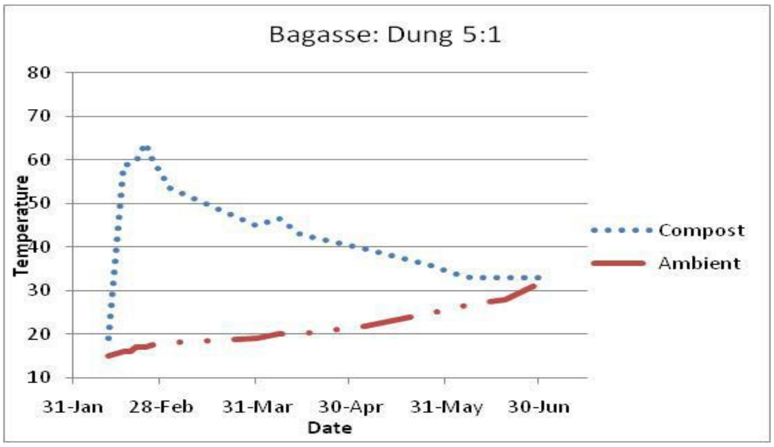

Figure 3. Temperature monitoring for B:D (5:1)

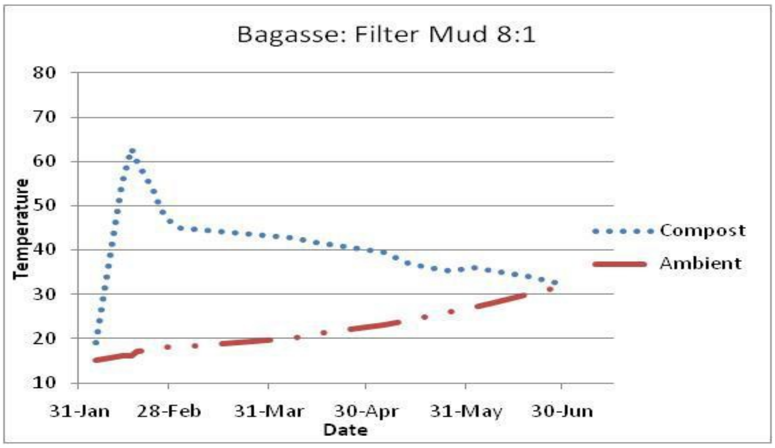

Figure 4. Temperature monitoring for B:M (8:1)

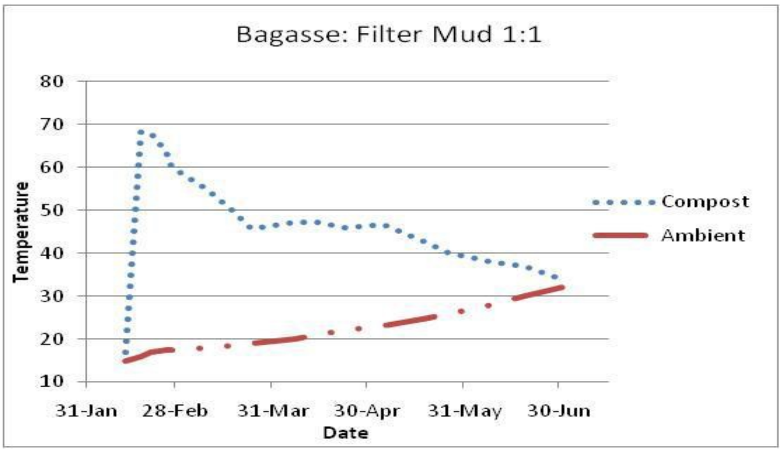

Figure 5. Temperature monitoring for B:M (1:1)

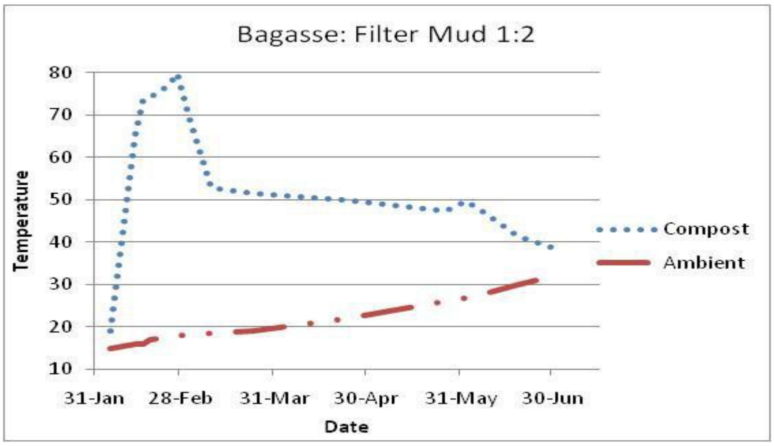

Figure 6. Temperature monitoring for B:M(1:2)

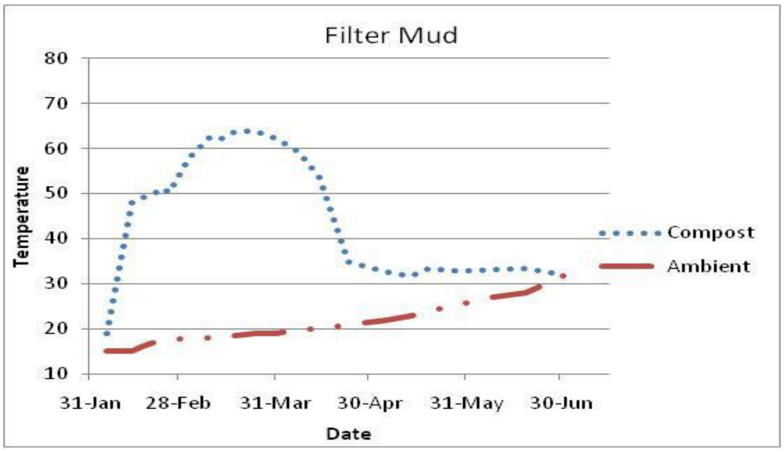

Figure 7. Temperature monitoring for M

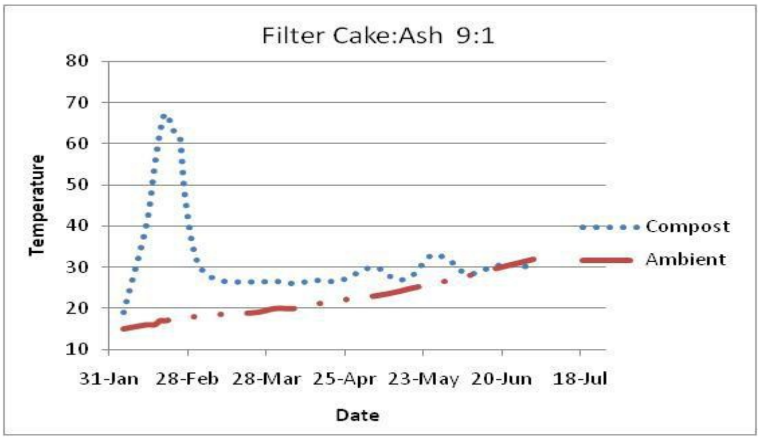

Figure 8. Temperature monitoring for M:A 9:1

Table 7. Characteristics of the compost treatments at the end of 20 weeks

Parameters	Treatments							
	Dry Leaves: Dung	**Dry Leaves: Mud 1:6**	**Bagasse :Dung 5:1**	**Bagasse :Filter Mud 8:1**	**Bagasse :Filter Mud 1:1**	**Bagasse :Filter Mud 1:2**	**Filter Mud**	**Filter Mud: Ash 9:1**
Abbreviation	L:D 5:1	L:M 1:6	B:D 5:1	B:M 8:1	B:M 1:1	B:M 1:2	M	M:A 9:1
Density (kg/m^3)	320	630	310	400	485	445	595	380
Moisture content (%)	48	42	52	28	59	49	49	25
pH (1:10)	7.01	7.34	7.46	7.11	6.88	6.9	6.56	6.47
EC (1:10) (ds/m^2)	3.66	1.72	1.67	0.45	0.58	2.48	3.91	4.98
Total nitrogen (%)	1.03	1.6	1.08	0.78	1.4	1.44	1.55	1.24
Ammoniacal Nitrogen (ppm)	67	57	57	38	47	47	76	105
Nitrate Nitrogen (ppm)	47	143	38	Nil	Nil	152	143	152
Organic matter (%)	53.07	29.67	63.92	42.4	50.58	57.08	45.46	42.42
Organic carbon (%)	30.78	17.21	37.07	24.59	29.34	33.11	26.37	24.61
Ash (%)	46.93	70.33	36.08	57.60	49.42	42.92	54.54	57.58
C/N ratio	30:1	11:1	34:1	32:1	21:1	23:1	17:1	20:1
Total phosphorus (P_2O_5) (%)	0.64	2.32	0.88	0.79	2.04	2.7	3.87	2.74
Total potassium (K_2O) (%)	1.14	0.31	0.82	0.27	0.12	0.33	0.36	0.56
Calcium (mg/kg)	44235	66740	22485	15895	51210	47420	75145	73670
Magnesium (mg/kg)	9445	9010	4400	1875	3465	4850	8065	7235
Iron (mg/kg)	8340	20430	5070	3005	8420	9565	18370	13890
Manganese (mg/kg)	178.5	747.7	106.8	50.7	288.9	261.5	443.7	501.9
Copper (mg/kg)	25.8	122.8	22.1	18.7	66.6	56.8	146.9	115.6
Zinc (mg/kg)	41.7	406.5	49	21.8	147	129.6	169.2	147.8
Free Nematode (Larve/200g)	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Pathogenic Nematode (Larve/200g)	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total Coliform Bacteria (Cfu/g)	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Fecal Coliform Bacteria (Cfu/g)	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Salmonella & Shigella Bacteria (Cfu/g)	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd

All the analysis is done on oven dry basis except density and moisture content

Nd: Not detected Cfu: Colony forming unit

The **bulk density** for all treatments except the filter mud (M) and filter mud ash mixture (M:A 9:1) increased with composting by amounts ranging from 221% to 28%, as demonstrated in Figure 9. The change in bulk density depends on the physical characteristics of the mixture. The higher the fiber content of the mixture, the more it increases in density with time. The fiber structure breaks with time and the particle size decreases causing the porosity of the mixture to decrease. The opposite effect was observed with treatments composed of filter mud as the bulk density decreased by 25% and 35%. The filter mud produced from the mill is heavy due to its high moisture content but as the moisture content decreases and the material is aerated; it becomes more porous and light.

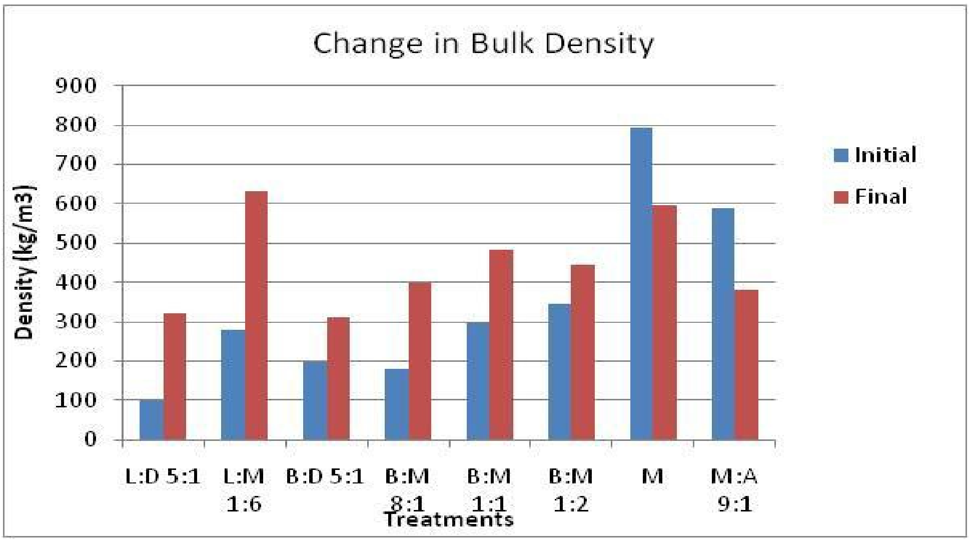

Figure 9. Change in bulk density of different compost treatments

The **pH** of mature compost typically approaches neutral, which is the case in all treatments as shown in Figure 10. The treatments composed with filter mud started off with low pH and so did some of the treatments composed of filter mud and bagasse. However, the ones mixed with animal dung or filter ash started the experiment with higher pH due to their alkali nature.

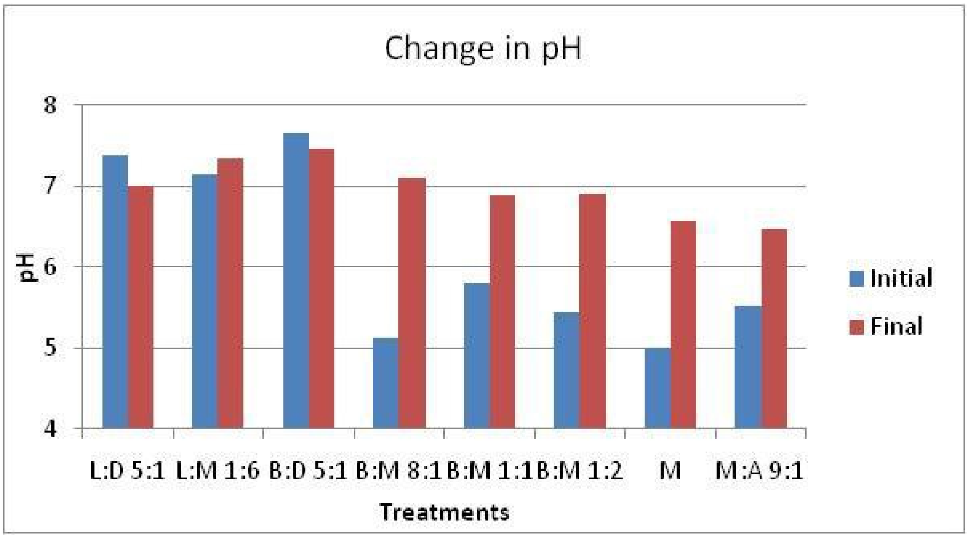

Figure 10. Change in pH of different compost treatments

The electrical conductivity **(EC)** increased in all treatments except for the B:M 8:1, which witness a decrease in electrical conductivity, as shown in Figure 11. The increase in conductivity could be attributed to the high concentration of nutrient ions released during the mineralization of organic matter.

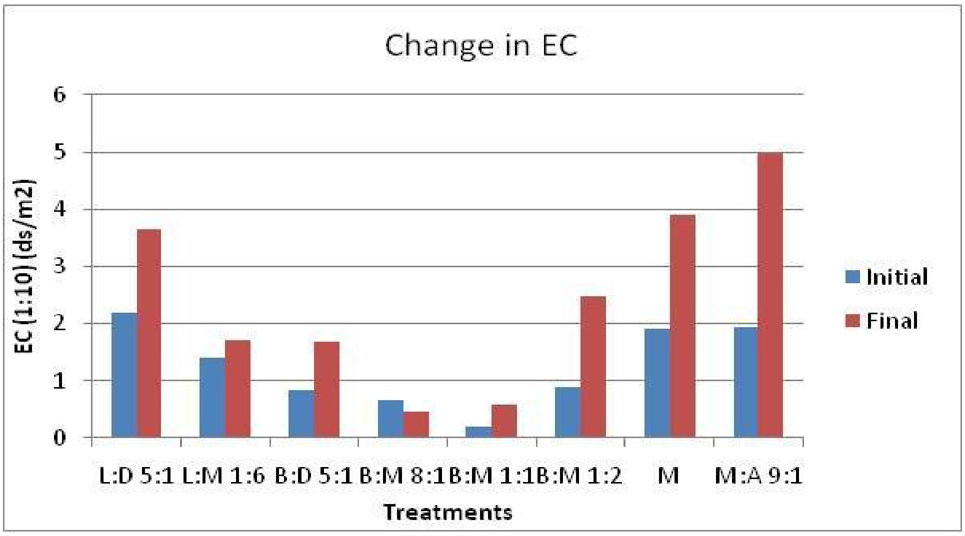

Figure 11. Change in electric conductivity of different compost treatments

The percentage as well as mass of **organic content** and **organic carbon** decreased resulting from the loss of carbon dioxide during composting as shown in Figure 12. The percentage ash content thus increased.

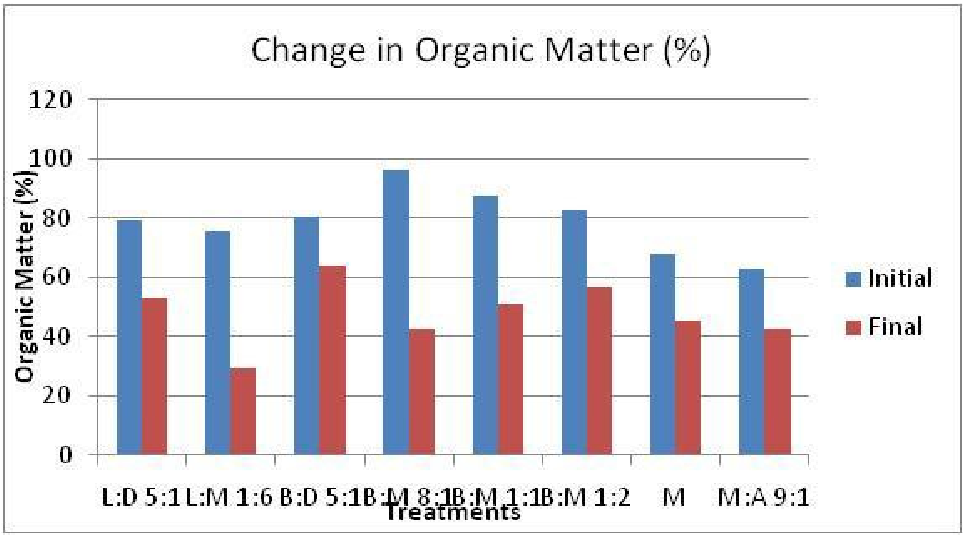

Figure 12. Change in percentage of organic matter in different compost treatments

The **nitrogen content,** as percentage of dry matter, increased for the treatments containing dry leaves or bagasse as they contained cellulosic material but decreased in the treatments containing mainly filter mud as shown in Figure 13. However, the nitrogen content in terms of mass decreased for all treatments except for the one that had the highest bagasse content mixed with the lowest amount of filter mud which is B:M 8:1 as presented in Figure 14. The significant drop in the nitrogen content in kg of nitrogen in L:M 1:6 could be attributed to excessive watering of the windrow which lead to leaching of the nutrients.

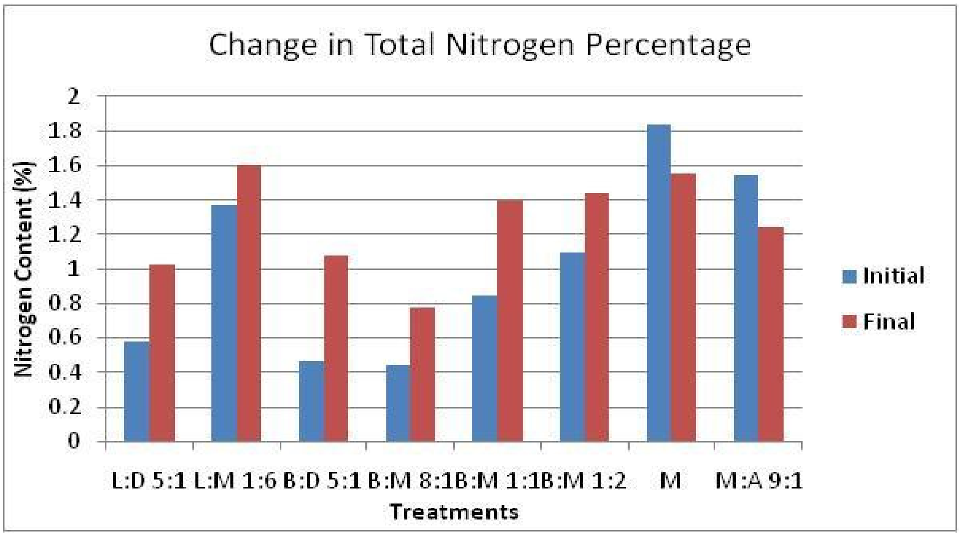

Figure 13. Change in the mass of total nitrogen in different compost treatments

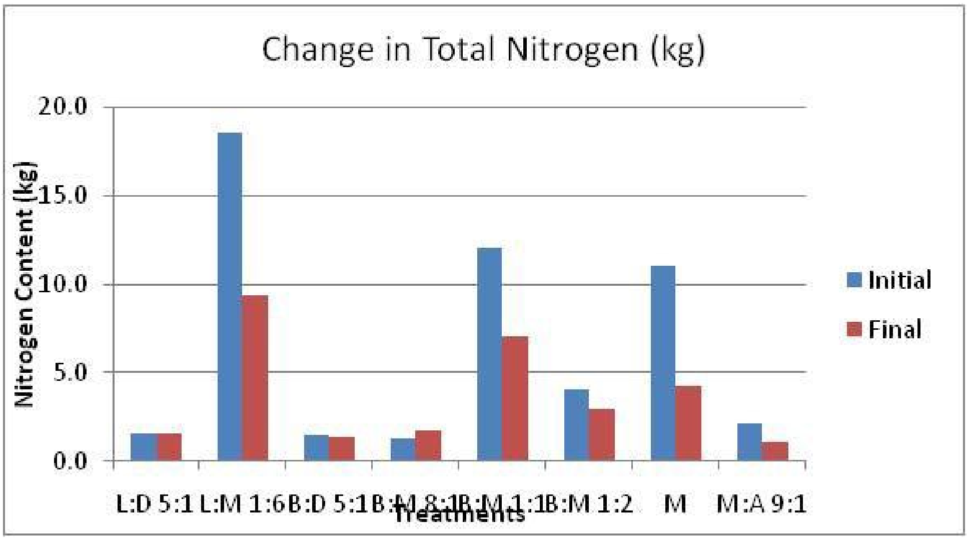

Figure 14. Change in the mass of total nitrogen in different compost treatments

The large decrease in **ammoniacal nitrogen** and increase in **nitrate nitrogen** during composting was related to the nitrogen transformation that occurred during composting. In treatments L:D 5:1, L:M 1:6 and B:D 5:1, the ammoniacal nitrogen decreased and the nitrate nitrogen increased but the ammoniacal nitrogen remained higher than the nitrate nitrogen. The same occurred with treatment B:M 1:2, however, the nitrate nitrogen reached higher values that the ammonium nitrogen. In treatments M and M:A 9:1both the ammoniacal and nitrate nitrogen increased. Treatments B:M 8:1 and B:M 1:1 had no nitrate nitrogen before and after composting and its ammoniacal nitrogen decreased during composting. Figures 15 and 16 show these trends.

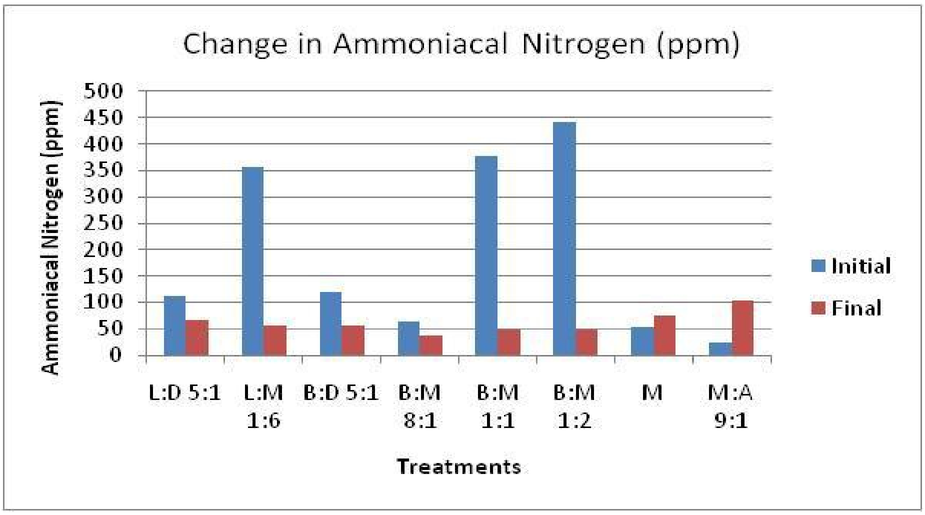

Figure 15. Change in ammoniacal nitrogen of different compost treatments

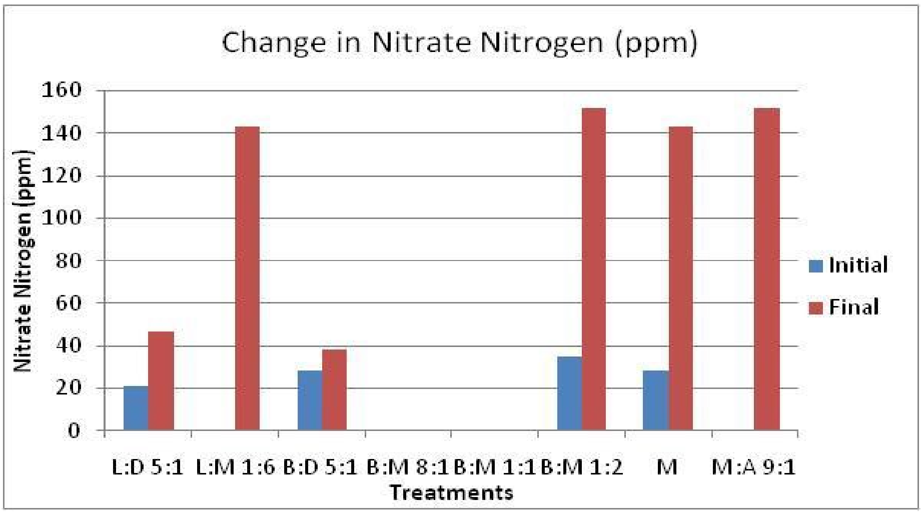

Figure 16. Change in nitrate nitrogen of different compost treatments

The treatments that were high in fiber content started with very high **C/N ratio** such as with treatments L:D 5:1, B:D 5:1, B:M 8:1 and L:M 1:6, which had C/N ratios of 79:1, 100:1, 127:1 and 60:1 respectively. These were followed by B:M 1:2 and L:M 1:6 having C/N ratios of 43:1 and 32:1, respectively, as they had lower fiber and more filter mud. The treatments with no fiber at all, started off with low C/N ratio of 21:1 and 24:1 which were M and M:A 9:1. However, by the end of the composting procedure, the C/N of all treatments dropped. The ones high in fiber dropped to a range of 34:1 to 30:1. These will be suitable to be used as soil conditioner, which includes treatments L:D 5:1, B:D 5:1 and B:M 8:1. However, treatments containing filter mud which are L:M 1:6, B:M 1:1, B:M 1:2, M and M:A 9:1. had a C/N ration ranging from 23:1 to 11:1, which make them suitable to be used as organic fertilizer. Changes in the C/N are shown in Figure 17.

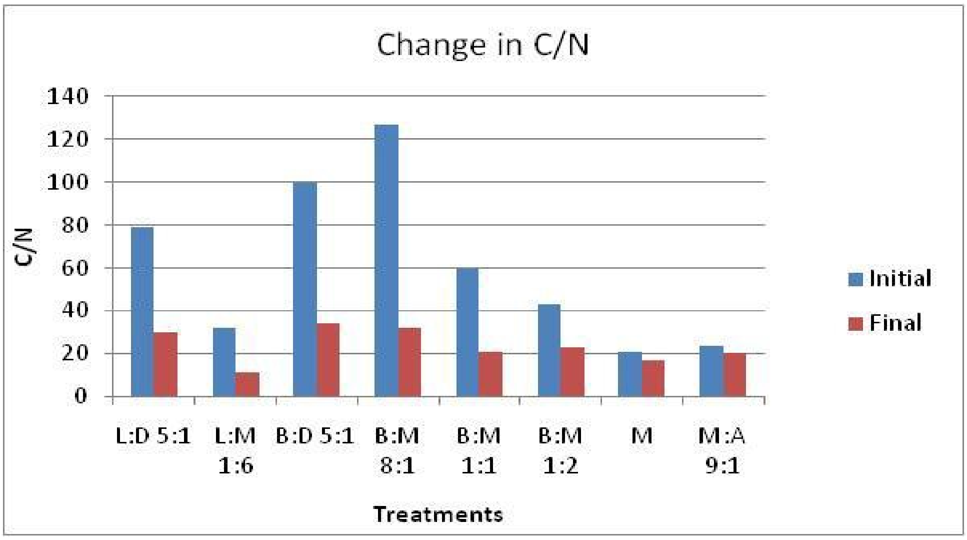

Figure 17. Change in C/N of different compost treatments

As for **phosphorus**, it increased with composting as a percentage for all treatments, but with decreasing rate as the amount of filter mud is increased, as shown in Figure 18. As for the change in phosphorus mass, it showed as increase for treatments numbers L:D 5:1,B:D 5:1, B:M 8:1 and small increase in B:M 1:2, but showed nearly no significant change in the remaining treatments L:M 1:6,B:M 1:1,M and M:A 9:1, as illustrated in Figure 19.

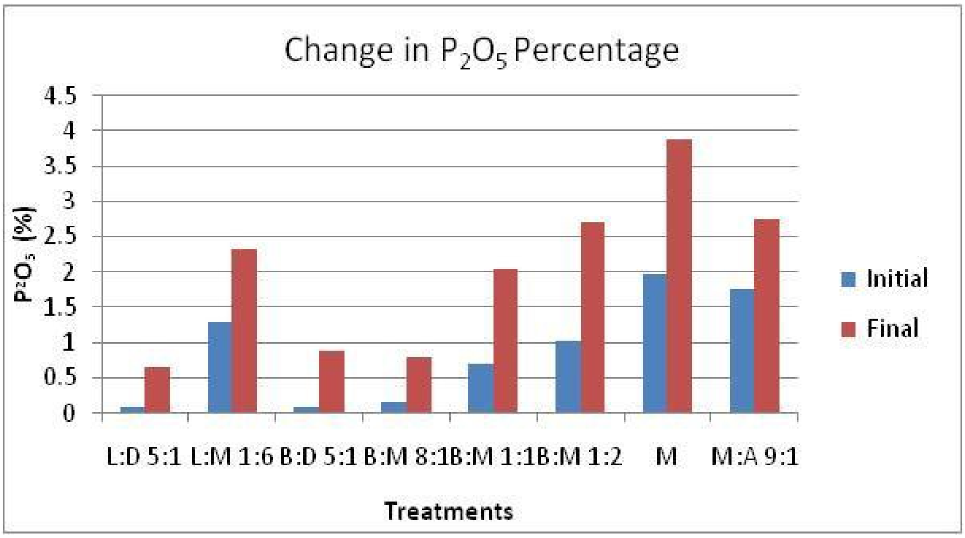

Figure 18. Change in percentage of phosphorus in different compost treatments

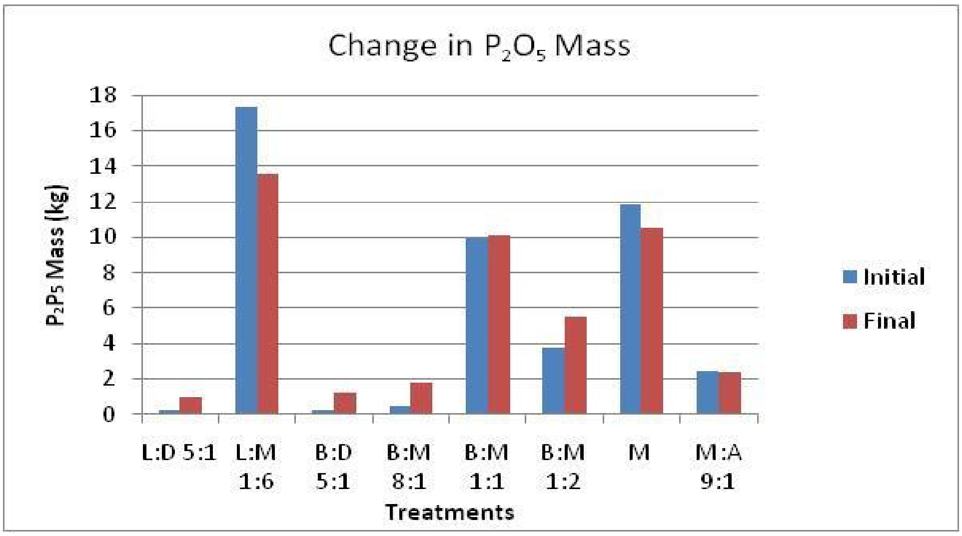

Figure 19. Change in mass of phosphorus in different compost treatments

With regards to **potassium**, treatments number L:D 5:1, B:D 5:1, B:M 8:1, B:M 1:2, M and M:A 9:1 witnessed an increase in the percentage of potassium with composting and a slight decrease for numbers L:M 1:6 and B:M 1:1. However, all treatments with the exception of treatment B:M 8:1, showed a decrease in the potassium mass content with composting. These relations are shown in Figures 20 and 21.

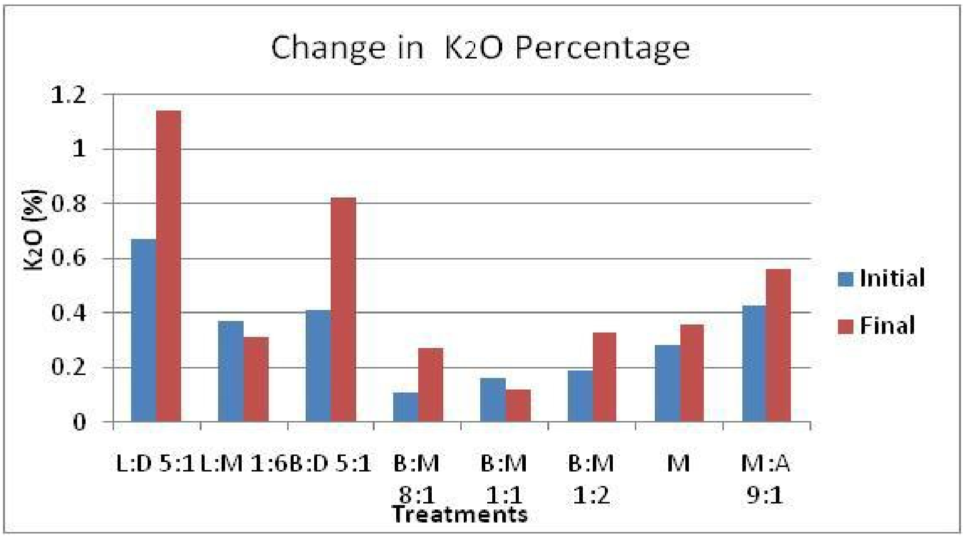

Figure 20. Change in percentage of potassium of different compost treatments

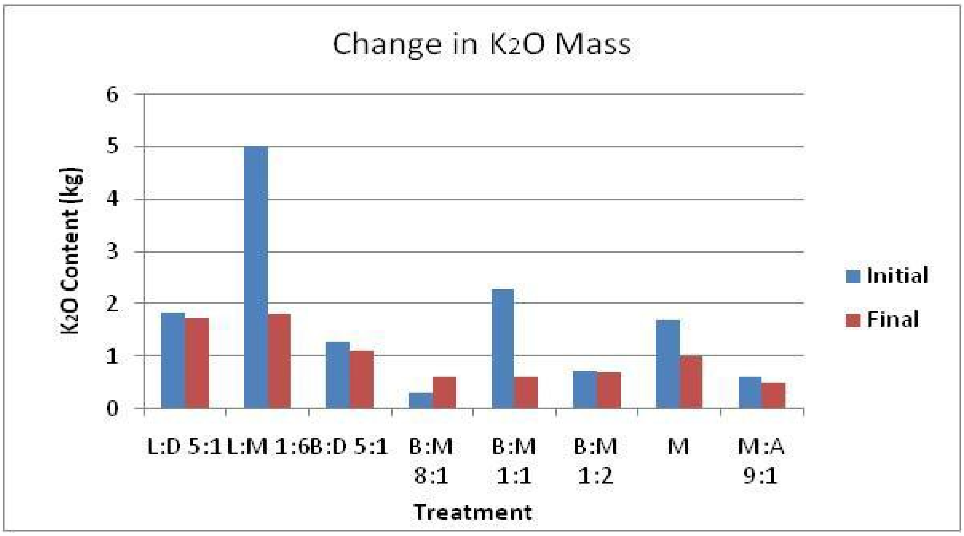

Figure 21. Change in mass of potassium of different compost treatments

Regarding the **micro nutrients** including calcium, magnesium, iron, manganese, copper and zinc, they all increased in concentration due to composting.

It can be also concluded from results of the analyses that at the start of the experiment, all treatments suffered from coliform bacteria (total and fecal) including salmonella and shigella bacteria and some had free nematode. However, **all bacteria and nematode** were destroyed during the composting process due to the high temperature reached during the thermophilic stages.

Moreover, all treatments after composting had a high water holding capacity (**WHC**) percentage as shown in Table 7. This is a favorable characteristic of composted material used as soil conditioner or organic fertilizer. Treatments with high fiber content had higher WHC.

Table7. Measured water holding capacity of compost mixtures

Treatment	L: D 5:1	L: M 1:6	B:D 5:1	B:M 8:1	B:M 1:1	B:M 1:2	M	M:A 9:1
WHC (%)	434	212	448	771	492	689	303	331

4. Conclusion

Based on results of the pilot experiment, it can be recommended that the farmers shred the dry leaves left behind the cane harvest and mix them with dung produced by their livestock to make compost out of the mixture to be used as soil conditioner. Based on the quantities of dry leaves generated per one hectare (10,000 m2) of land, the compost piles or windrows will only require less than 100 m2 of the hectare (less that 1% of land area). Each hectare would generate about 5 tons of compost replacing about 10.4% of the amount of fertilizers used per hectare.

The pilot experiment has also demonstrated that a variety of compost/organic fertilizers can be produced from a combination of the residues generated from the sugar mills which are bagasse, filter mud and furnace ash. It depends on the amounts available in each sugar mill from each type residue. The author recommends two proposed scenarios. The first scenario assumes that due to a deficiency or unavailability of natural gas, bagasse will be used to generated steam and electricity for the mill and hence the only residues generated from sugar mill are filter mud and furnace ash. In this case, every hectare of agriculture land will generate 3.5 tons of filter mud and 400 kg of furnace ash which if composted will give 1 ton of organic fertilizer. If this compost is returned to the sugarcane agricultural fields, it could replace 45 kg of the total amount of inorganic fertilizer currently used per hectare of land (about 6%). The composting area in the sugar mill will only occupy less than 0.1% of the mill land area.

The second scenario is that the bagasse is not used for steam and electricity generation in the sugar mill nor is it used for the production of paper or fiberboard. In that case, all the bagasse will be mixed with the filter mud to produce compost in the mill. One hectare of cane would generate 31 tons of bagasse and 3.5 tons of filter mud. If these are composted, they will result in 15.3 tons of compost with a NPK content that could replace 194 kg of the total amount of fertilizers used per hectare of cane (about 26%). The area required in this case for composting is about 2.5% of the sugar mill land area.

References

[1] Hassan, S.F. & Nasr, M.I., 2008. Sugar Industry in Egypt. *Sugar Tech*, 10(3): 204-209.

[2] Hamada, Y.M., 2011. Water Resources Reallocation in Upper and Middle Egypt. *EWRA European Water, EW Publications*, 33: 33-44.

[3] El Haggar, S.M. & El Gowini, M.M., 2005. Comparative Analysis of Alternative Fuels for Sugarcane Industry in Egypt, *1st Ain Shams International Conference on Environmental Engineering*, 9-11/4/2005, Cairo, Egypt.

[4] Epstein, E., 1997. *The Science of Composting*, United States: Technomic Publishing Co.

[5] Sardar, S., Ilyas, S.U., Malik, S.R., & Javaid, K., 2012. Compost Fertilizer Production from Sugar Press Mud (SPM), *International Journal of Chemical and Environmental Engineering*, 3(1): 39 – 43.

[6] Nakhla, D. A., Achieving Environmental Sustainability of Sugarcane Industry in Egypt: An Application of Life Cycle Assessment. PhD Thesis, The American University in Cairo. Dept. of Construction and Architectural Engineering, 2015. http://dar.aucegypt.edu/handle/10526/4231

[7] El Haggar, S.E., 2007. *Sustainable Industrial Design and Waste Management: Cradle-to-Cradle for Sustainable Development*, United States: Elsevier Academic Press.

[8] El Haggar, S.E., Mahmoud, Y.I. and Nakhla D.A., 2015. Chemical and Microbiological Evaluation of Compost from Sugarcane Wastes. *Middle East Journal of Applied Sciences*, 5(4): 879-892.

[9] Vomocil, J.A. Porosity. In: Blake, C.A., Ed. Methods Of Soil analysis. Madison, American Society of Agronomy, 1965. P.299-314.

[10] Jodice, F., 1982. The soil plant environment. In: Plant Nematology. (Eds. Southey, J. F.), Her Majesty Stationary Office, London.

[11] Richards, L. A., 1954. Diagnosis and improvement of saline and alkaline soil. The pollination system of meliotus species. Ecology Plant, 12: 383-394.

[12] Page, A. L., R. H. Miller and D. R. Keeney, 1982. Methods of Soil Analysis Part 2. American Soc. of Agronomy, Madison, Wisconsin, USA.

[13] Jakson, M. L., 1973. Soil Chemical Analysis. Second edition. Prentice-Hall, Englewood Califfs, New Jersey.

[14] Chapman, H. D. and F. P. Pratt, 1961. Methods of Analysis for Soils. Plants and Waters. Univ. of California, Division of Agriculture Science, Riverside, California, USA.