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Olfat D. El-Sebaie,* Ahmed H. Hussein,* Magda M. Abdel-Aty,*
Mohamed H. Ramadan,* Helaly A. Helaly**

* Department of Environmental Health, High Institute of Public Health, University of Alexandria

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ABSTRACT

There are two wastewater primary treatment plants in Alexandria (west and east). The produced primary sludge is mechanically dewatered and transported to sludge disposal site 9N where composting is carried out. However, prior to 1970, composting played a very minor role in sludge or solid wastes treatment because of greatly unfavorable balance between its economics and those of the principal competing option, namely landfill disposal. This study aims at monitoring and evaluating the composting process of demitted sludge produced from Alexandria wastewater treatment plants. Ten batches of sludge were composted. During the composting process the batches were been investigated and followed up to 3 months. Representative samples

(10 for each batch) were taken from these batches at the start of windrowing and after each turning (4-15days) and were analyzed for physical; chemical; bacteriological; and parasitological characteristics, heavy metals, and plant nutrients. Results revealed that C/N ratio of the final compost product comply with the decree of the Minister of Agriculture No. 100 /1967, while moisture, C%, and TKN did not. Heavy metals, faecal coliforms, and helminthes complied with the decree No. 222/2002 for the Minister of Housing, Utilities, and Urban Communities. Moisture had positive correlation with both C and VS and negative correlation with pH. Temperature had negative correlation with TKN. Both total and faecal coliforms had negative correlation with temperature and positive correlation with C, N, and VS. It is recommended to optimize the quality of the produced sludge compost by use bulking agent rich in carbon and nitrogen as Hay or Rice straw, instead of the matured sludge compost.

Key Words: Alexandria, composting, sludge, C/N ratio, faecal coliforms, helminthes eggs, legislation.

INTRODUCTION

Alexandria has two wastewater treatment plants; west and east primary treatment plants. The produced primary sludge is mechanically dewatered to reduce its volume and to render it easy to handle. Sludge production in Alexandria is currently about 450 m^3/d but this will increase to112000 tons dry solids/y by 2010 (Water research center, 1999).

Currently, the dewatered raw sludge is transported by trucks to the sludge disposal site 9N which is far from Alexandria city by more than 30 Kilometers, where composting is carried out (Wastewater consulting group,1981). Usually, composting lasts about 3 months.

The composting area is 30 ha which contains 60 windrows of 250m length surrounded by some trees in order to reduce odor, dust, and inconvenient view during operation. Sludge has important constituents: nitrogen and phosphorous which act as major macronutrients for plants, heavy metals as a micronutrient, and organic matter as a substrate for microorganisms. Also, it contains hazardous constituents. The raw sludge contains pathogenic microorganisms and parasites which pose a risk to human health via direct contact with sludge. The main risk is from the contamination of foods grown on sludge-treated land which are eaten uncooked (Bache, 1986).

Composting is a biological treatment in which aerobic thermophilic microorganisms decompose organic matter and produce CO_2, H_2O, and stabilized end product, compost, (Giusquiani et al., 1995).

Sludge composting is a treatment process, which has the advantages of requiring few equipment and lower operating outlay, having fewer unfavorable impacts upon the quality of the environment, increasing landfill capacity, and decreasing land needed for direct application (Robert et al., 1991). However, prior to 1970, composting played a very minor role in sludge or waste treatment because of greatly unfavorable balance between its economics and those of the principal competing option, namely landfill disposal (Metcalf & Eddy, 1991).

This study aims at monitoring and evaluating the composting process of demitted sludge produced from Alexandria wastewater treatment plants.

MATERIAL AND METHODS

Ten batches of sludge were composted and during the composting process the batches were been investigated and followed up to 3 months over nine stages. Each compost batch was composed of dewatered sludge and bulking agent (dried old mature composted sludge). Their ratio was adjusted to give optimum moisture (40-60%). Representative samples were taken from these batches at the start of windrowing and after each turning (4-15 days). Samples were analyzed physically (temperature, moisture, and pH.), and chemically (TOC, TKN, C/N ratio, NH_3, NO_3, TDS, VS, and NaCl). In addition, plant nutrients (P, K, Ca, and Mg.), and heavy metals (Zn, Cu, Ni, Cd, Cr, and Pb) were analyzed. All the previous parameters were analyzed according to the methods of analysis of sludge and compost of the World Health Organization, 1978. Also, the collected samples were analyzed bacteriologically (MPN of total and faecal coliforms) according to standard methods, 1992. Parasitological examination and counting of parasitic cysts, eggs, and larvae were carried out using a modification of the centrifugal flotation technique (Saad and Hussein, 1993). Comparison with the related legislations was made.

RESULTS AND DISCUSSION

1- Physical characteristics:

1-1. Moisture:

Results showed that the moisture, of the sludge during composting process, ranged between 14.4-55%. Raw sludge had a high moisture content (72.5%) as presented in table 1 and shown in figure 1. The optimum moisture for composting is between 40-60% because too wet condition inhibits airflow due to that water fills the pore space while too dry condition decreases microbial action (Gray et al., 1971 part two). This high moisture content of raw sludge can be reduced by blending the sludge with a dry bulking material (Willson, 1977). Later on, it decreased during the different stages with time until it reached to the lowest value (14.4%) after 3 months. It is evident, at 30^{th} day and later, that the moisture was lower than the minimum 40% needed for optimum composting. This condition should have been corrected by adding water to the windrows. This moisture shortage was aggravated at the end of the second month when it reached 25.3%. This shortcoming was reflected on the VS being almost constant throughout the composting process, denoting that the latter was retarded. Nevertheless, the deçree of the Minister of Agriculture No. 100/1967 stated that the final sludge compost should have moisture less than 8%±0.2%.

It was found that moisture was statistically very significantly correlated (at $p<1\%$) with each of pH, VS, and carbon content. Moisture and pH had negative correlation. This may be due to that when water is accumulated faster than it is eliminated via either aeration or evaporation, the oxygen flow is impeded and anaerobic decomposition starts resulting in acidic conditions (Gray et al., 1971 part one). On the other hand, the correlation between moisture and both VS and C was positive correlation and this is in agreement with Boutillot's results (1999). This may be due to that when moisture content increases, the activity of aerobic microorganisms in decomposing of organic matter slows down resulting in accumulation of high content of VS and C (JICA, 1980).

1-2. Temperature:

Temperature has frequently been used as a measure of composting efficiency and degree of stabilization (Jeris et al., 1973). Results revealed that the temperature increased from 48.2°C at the beginning of composting until it reached to its maximum value of 64.9°C after 1 month which lasted at least 7 days , then it decreased slightly until it reached to 59.6°C after 3 months as presented in table 1 and shown in figure 1. This was in compliance with EPA standards which indicated that the suggested time-temperature requirement for windrow composting was 15 days at or above 55°C and a minimum of five turnings during this period (Anid, 1986). The too high temperature causes microbes die-off, while the too low one slowed down microbe activity (Robert et al., 1991). The most effective temperature is between 45 and 59°C, when temperature is less than 20°C, the microbes do not proliferate and decomposition slows down while at temperature greater than 59°C, some microorganisms are inhibited or killed and diversity of organisms is reduced which results in lower rates of decomposition (Storm, 1985; Richard, 1992).

It was found that there was a strong very significantly negative correlation (at P<1%) between temperature and TKN. When temperature rises, the stabilization of organic content is perfect and hence the nitrogen content decreases (EPA, 1995).

1-3. pH:

It has been found that the pH of raw sludge and that of bulking agent were the same (5.7). With time, the changes in pH were very small until it reached to its maximum value after 3 months (6.1) as presented in table (1) and shown in figure 1. These values of pH indicated that the sludge was acidic due to the formation of organic acids during the start of the composting process. It remains at this state until the end of composting process without shifts toward neutrality. This could be an indication that the compost product was not matured or cured (Gray, 1971; Willson et al., 1980). Low sludge pH (<6.5) promotes leaching of heavy metals, while higher sewage sludge pH (>11) kills many bacteria and encourages the conversion of NH_4-N to NH_3, resulting in a N-loss to the atmosphere (EPA, 1995). It is said that the optimum pH range for proper composting is 6-9 (Metcalf & Eddy, 1991).

2- Chemical characteristics:

2-1. Organic carbon (C):

The carbon ranged between (29-32.7%) along the composting stages of different batches with the mean of 30.2%. Carbon % showed a decreasing trend from 32.7% at the start of composting to 29% at the end of 3 months as presented in table 1 and shown in figure 2. This result indicated that the C% values were lower than the limits of Egyptian decree No. 100/1967, which stated that C% must not be less than 40%±2%. This was due to that the ratio of bulking agent/sludge was not adjusted properly and consequently the carbon content was not sufficient because the bulking agent is considered as a source of carbon (Shuval, 1977). That is to say, from the start, the C% was too low to carry out efficient composting. Carbon was significantly positively correlated with nitrogen at P<1%. This was due to that composting accomplishes greater stabilization of organic compounds. The slower the rate of decomposition of carbon compounds and the lower are the amounts of organic nitrogen (EPA, 1995). This indicates that C and N increase or decrease with each other, i.e., directly correlated.

2-2. Nitrogen (TKN%):

The follow up of the batches indicated that the TKN% decreased during the composting stages of different batches with very small changes which ranged between 1.51-1.71% and its mean was 1.57% as presented in table 1 and shown in figure 2. However, TKN should have increased throughout the composting stages rather than decreased (Stentiford et al., 1996). These results do not agree with the decree of Egyptian Minister of Agriculture No. 100/1967, which stated that the final nitrogen content should not be less than 2%±0.1%. This may be due to the low nitrogen content of added bulking agent (1.52). In addition, the composting process results in a significant Nitrogen reduction within the wastewater sludge, which differs from those for composting refuse (USA, 1978). Therefore, using of bulking agent rich in nitrogen, e.g., hay (2.5-4% TKN) or rice straw, is very important to adjust the nitrogen content of the final compost.

2-3.Carbon to Nitrogen ratio (C/N ratio):

Results indicated that C/N ratio mean was 19.3 and ranged between 18.8-19.9 with small differences between the different stages of different batches, table 1 and figure 2. The C/N ratio of the final compost complied with the decree of Egyptian Minister of Agriculture No. 100/1967 which stated that the C/N ratio should be ranged between 18.1-22.1 and with Kaloash (1994) who reported that C/N ratio of final compost was 17-18. Generally, the present study indicated that C/N ratio decreased during composting. It started at 19.9 after first turning and finally it attained 18.8 at the end of 3 months.

Sewage sludge usually has C/N ratio of less than 15:1 so the addition of bulking agent is important to adjust the C/N ratio (Willson et al., 1980). However, the C/N ratio of the mixture at the start of composting was too low to allow proper composting. The minimum C/N ratio is about 30 (Sathianathan, 1975). Therefore, the decrease of C/N ratio during the composting stages was incidental and was not due to actual composting activity. This indicated that the composting process was not optimum. This may be due to many factors (Metcalf & Eddy, 1991). First, the moisture % was too low after the 4th turning (30 days). Second, the acidic pH (5.7-5.9) was lower than the recommended minimum pH (6) (Metcalf and Eddy, 1991). Third, the available C was less than the actual C% (30.2%) (Sathianathan, 1975). Fourth, the nitrogen content was low. All these factors would hinder the microbiological action responsible for aerobic composting. Therefore, these factors should be taken into consideration. The most important may be the adjustment of C/N ratio which was low (19.4) at the start. Carbonaceous materials have to be added to increase the C/N ratio up to 30. In addition, the low TKN (1.71%) has to be increased so that at the end of the composting process, TKN must not be less than the 2%±0.1% dictated by the said decree No. 100/1967. Amendment could be done by adding hay (TKN = 2.5-4%) or rice straw, which would also supply the C. To supply the nitrogen, rich-nitrogenous materials, e.g., manure, or better, slaughterhouse wastes, have to be included. Stentiford et al. (1996) described the progress of good composting as follows: Moisture was sustained at >40%, pH and TKN were increased, C/N ratio dropped to its third initial value, and VS has decreased to half its original value.

2-4. Ammonia (NH_3) and Nitrate (NO_3):

It was found that NH_3 ranged between 0-0.55 mg/g with a mean of 0.33 mg/g while NO_3 ranged between 0-0.09 mg/g with mean value of 0.06 mg/g, table 1 and figure 2. Ammonia is usually higher during the first weeks but it is converted to NO_3 at the end of maturation (Monedero, 2001). As presented in table 1, NH_3 was greater than NO_3 throughout the composting processes and this may pose a risk from the Ammonium ion toxicity (Reed, 1988). Also, it indicated that the composting process was inefficient and hence the batches were immature. This condition is a function of the unsuitable conditions, e.g., moisture, pH, C, N, and C/N ratio.

2-5. Total dissolved solids (TDS) and Volatile solids (VS%):

Both the TDS and VS exhibited minimal changes throughout the composting process, table 1 and figure 2. This behavior, especially that of VS, emphasized the previously said statement that the composting process was not properly controlled. The VS dropped from 62.9% to 55.7%, i.e., 7.2% increment. Therefore, the breakdown of organic matter was not maintained, and hence the retardation of the composting process. Efficient composting usually achieved about 45% decrease of VS (Stentiford, 1996). A study by Levi-Minize et al. (1992) reported that VS of garbage compost at the beginning was 79% and decreased to 63%. As expected, the present results of VS did not agree with Mario et al. (1984) who reported that VS must be reduced to below 40%. So the composting process is completed and the compost material is then stable enough.

It was found that there was perfect significantly positive correlation (at $P<0.1\%$) between VS and Carbon. VS is usually used as a measurement of organic content and composting is used as a treatment process to reduce VS content and break down organic waste (EPA, 1995), i.e., VS decreases indicate that organic waste breaks down. As carbon is a constant element in these organic, carbon decreases with reduction of VS.

Another positive correlation was found between VS and TKN at $P<1\%$. This correlation should have been a negative one as during composting, VS decreases and TKN increases. Actually, in good composting process, the observed increase of TKN is a reflection of the loss in VS and not an increase in the TKN in the windrows (Stentiford, 1996).

3- Plant nutrients:

Plant nutrients are classified into two categories; primary (Phosphorous, P, and Potassium, K) and secondary (Calcium, Ca, and Magnesium, Mg) (Brady, 1988). Table (1) indicated that P ranged between 4.3-6.2 mg/g with a mean of 5.2 and K ranged between 2250-2630 mg/kg with a mean of 2519 mg/kg. Ca ranged between 30225-34033 mg/kg with a mean of 32287 mg/kg and Mg recorded mean value of 4241 mg/kg and ranged between 4014-4580 mg/kg. The values of Ca and Mg were higher than that of another study carried out on composting of agriculture residues (El-Sebaie et al., 2000). Although, sodium chloride (NaCl) is not regarded as a plant nutrient, it is regulated by the decree No. 100/1967 not to be more than 5%±0.5%. Some plants are sensitive to excessive amount absorbed through the plant roots (Soil Improvement Committee, 1985). The NaCl content of the sludge compost did not exceed 0.5% throughout the composting stages.

4- Heavy metals:

As represented in table 2, all the heavy metals concentrations, except that of Lead (Pb), were below the limit values stated by decree No. 222/2002 of the Minister of Housing, Utilities, and Urban Communities. Owing to the combined nature of Alexandria wastewater, sewage sludge was believed to contain high concentrations of heavy metals (Abdel-Qawy, 1985). However, from the heavy metals point of view, sludge compost of site 9N is safe to apply to agricultural soil.

5- Bacteriological characteristics:

Results presented in table 3 and shown in figure 3 indicated that the MPN of total coliforms ranged between 50 and 1368230/gm with a mean value of 184238/gm. MPN of faecal coliforms ranged between 10 and 58213/gm with a mean value of 7664/gm. Faecal coliforms decreased with time and reached its minimum value (10/gm) after 3 months. These results agree with the decree No. 222/2002 for Minister of Housing, Utilities, and

Urban Communities, which stated that faecal coliforms must be less than 1000 cells/gm of final product. The die-off of faecal coliforms was due to the high temperature recorded during the composting process.

Results proved that total and faecal coliforms were significantly negatively correlated with temperature and positive with C, N, and VS. The negative correlation between temperature and both total and faecal coliforms indicates that the high temperature is sufficient to destroy any pathogen and ensure safe handling of compost. Sludge composting by windrows method, with a minimum 5 turnings, maintained at 55°C or higher for 15 days or longer guarantees to reduce pathogen (EPA, 1995). A temperature in the range of (55-65°C) is enough to ensure destruction of pathogenic organisms (EPA, 1993).

C, N, and VS were positively correlated with total and faecal coliforms. When C, N, and VS were high, the stabilization of organic matter was very poor and so faecal and total coliforms were high. The stabilization of organic compounds during composting processes indicates the destruction of pathogens (EPA, 1995).

6-Parasitological characteristics:

It was noticed that, eggs, worms, and larvae were not detected during the composting processes although Ascaris eggs and Strongyloides larvae were detected in raw sludge as presented in table 3 and shown in figure 3. This was due to the high temperature that reached, during composting, to 64.6°C and lasted one week. The temperature needed for helminthes egg destruction is 51°C (Farrell et al., 1996). These results agree with the decree No. 222/2002 for Minister of Housing, Utilities, and Urban Communities and WHO limits which stated that the treated sludge should contain no more than one helminthes egg/100 ml and the number of the eggs present should not exceed more than three genera of helminthes eggs.

CONCLUSION

1- Moisture, pH, VS, C, TKN, and C/N ratio were not properly adjusted to start and maintain good quality composting.

2- Consequently, the final compost was not fit for agricultural application as the VS was high and the TKN was low. This would lead to nitrogen robbing as the immature compost would continue to decompose in the soil. This would adversely affect the crops grown on such soil.

3- The heavy metals content and biological properties of the compost were in agreement with the decree No. 222/2002.

4- The final product characteristics did not comply with the decree No. 100/1967 regarding moisture, C, and N, but it was in compliance regarding C/N ratio.

5- From the public health point of view, the sludge compost was safe as regards heavy metals, bacterial quality, and parasitological properties.

RECOMMENDATIONS

1- Using bulking agent rich in carbon and nitrogen contents, as rice straw, hay and manure.

2- The characteristics of the mixture of the bulking agent and dewatered sludge must be adjusted to start and support composting and give end product in compliance with the Egyptian standards.

3- Maintaining the moisture at least 40% throughout the composting stages.

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Table 1: Means of physico-chemical parameters along composting stages of different batches, Site 9N, Alexandria, Egypt, 2000

	Raw sludge	Bulking agent	After mixing	1st turng.	2nd turng.	After 1 month	3rd turng.	4th turng.	5th turng.	After 2 mnths	After 3 mnths	STATISTICS OF COMPOSTING STAGES (1-9)			
STAGE			1	2	3	4	5	6	7	8	9	X	SD	MIN	MAX
Days	0	0	0	4	16	30	37	46	63	60	90				
Moist, (%)	72.5	6.4	55.0	50.1	46.1	38.9	37.8	31.0	30.8	25.3	14.4	36.6	12.8	14.4	55.0
Temp,C	37.1	34.3	48.2	54.2	61.1	64.9	63.7	64.6	62.8	61.4	59.6	60.1	5.5	48.2	64.9
pH	5.7	5.7	5.7	5.8	5.8	5.9	5.8	5.9	5.8	5.9	6.1	5.8	0.1	5.7	6.1
Car (%)	38.1	28.1	32.7	31.0	31.0	30.2	29.6	29.3	29.9	29.0	29.0	30.2	1.2	29.0	32.7
TKN (%)	2.15	1.52	1.71	1.57	1.57	1.56	1.57	1.51	1.57	1.54	1.54	1.57	0.06	1.51	1.71
C/N	18.1	18.6	19.4	19.9	19.9	19.4	18.9	19.5	19.1	18.8	18.8	19.3	0.4	18.8	19.9
NH_3 (mg g^{-1})	0.34	0.10	0.29	0.34	0.30	0.47	0.41	0.00	0.55	0.20	0.40	0.33	0.16	0.00	0.55
NO_3 (mg g^{-1})	0.05	0.08	0.09	0.06	0.06	0.07	0.09	0.00	0.07	0.07	0.07	0.06	0.03	0.00	0.09
TDS (mg g^{-1})	44.5	70.6	56.7	53.2	56.2	51.8	54.4	60.5	54.3	53.7	54.6	55.0	2.5	51.8	60.5
VS (%)	73.3	54.0	62.9	59.5	59.6	58.1	56.9	56.4	57.5	55.7	55.7	58.0	2.3	55.7	62.9
P (mg g^{-1})	5.4	5.9	4.8	5.1	4.9	4.5	6.0	8.2	5.0	4.3	5.8	5.2	0.7	4.3	6.2
K (mg kg^{-1})	2300	2760	2250	2375	2625	2580	2630	2488	2594	2541	2589	2519	129	2250	2630
Ca (mg kg^{-1})	28730	33630	33130	32100	34010	30550	31230	32200	30225	33109	34033	32287	1407	30225	34033
Mg (mg kg^{-1})	3362	4404	4480	4014	4580	4084	4130	4063	4103	4155	4578	4241	234	4014	4580
NaCl (%)	0.44	0.48	0.43	0.45	0.49	0.44	0.49	0.48	0.48	0.49	0.51	0.47	0.27	0.43	0.51

Table 2: Means of heavy metals along composting stages of different batches, Site 9N, Alexandria, Egypt, 2000

	Raw sludge	Bulking agent	After mixing	1st turng.	2nd turng.	After 1 month	3rd turng.	4th turng.	5th turng.	After 2 mnths	After 3 mnths	STATISTICS OF COMPOSTING STAGES (1-9)			
STAGE			1	2	3	4	5	6	7	8	9				
Days	0	0	0	4	16	30	37	46	53	60	90	X	SD	MIN	MAX
Cd (mg kg^{-1})	1.41	2.06	1.30	1.00	1.81	1.07	1.54	1.25	1.84	1.14	0.72	1.30	0.37	0.72	1.84
Co (mg kg^{-1})	10.43	10.21	11.01	13.95	13.48	12.02	10.51	10.88	11.68	10.61	13.83	12.00	1.41	10.51	13.95
Cr (mg kg^{-1})	39.82	40.85	32.62	34.67	42.17	40.23	39.99	40.49	41.34	37.77	41.67	38.99	3.32	32.62	42.17
Cu (mg kg^{-1})	215.56	281.21	200.26	242.55	239.91	246.07	250.35	204.54	241.76	229.32	251.57	234.04	19.10	200.26	251.57
Mn (mg kg^{-1})	406.5	329.6	285.7	382.5	359.8	353.3	374.1	381.1	291.2	346.6	321.8	344.0	36.7	285.7	382.5
Ni (mg kg^{-1})	30.49	39.57	30.51	35.93	43.33	36.6	36.52	40.06	39.64	36.55	31.53	36.74	4.02	30.51	43.33
Pb (mg kg^{-1})	235.06	269.7	212.56	263.75	255.63	241.31	258.67	267.24	347.55	261.16	270.14	264.22	35.87	212.56	347.55
Zn (mg kg^{-1})	382	371	334	385	423	422	467	474	476	443	458	431	47	334	476

Table 3: Means of biological parameters along composting stages of different batches, Site 9N, Alexandria, Egypt, 2000

	Raw sludge	Bulking agent	After mixing	1st turng.	2nd turng.	After 1 month	3rd turng.	4th turng.	5th turng.	After 2 mnths	After 3 mnths	STATISTICS OF COMPOSTING STAGES (1-9)			
STAGE			1	2	3	4	5	6	7	8	9	X	SD	MIN	MAX
Days	0	0	0	4	16	30	37	46	63	80	90				
T.Coli (g^{-1})	14572000	105	1368230	259943	25709	1495	2190	376	84	50	61	184238	4.5E+05	49.87272727	1368230
F.Coli (g^{-1})	444510	8.53	58213	8544	1666	230	180	61	28	43	10	7664	19157	10.36666667	58213
Ascaris (g^{-1})	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strong (g^{-1})	4.1	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0.4

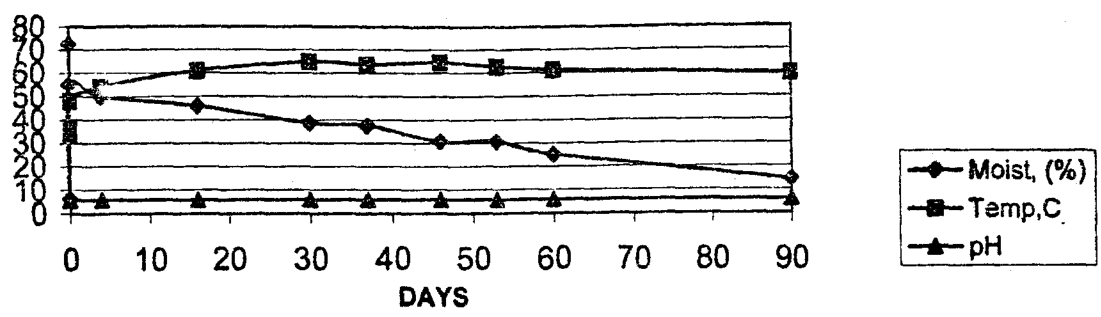

Fig. 1: Composting progress, physical parameters

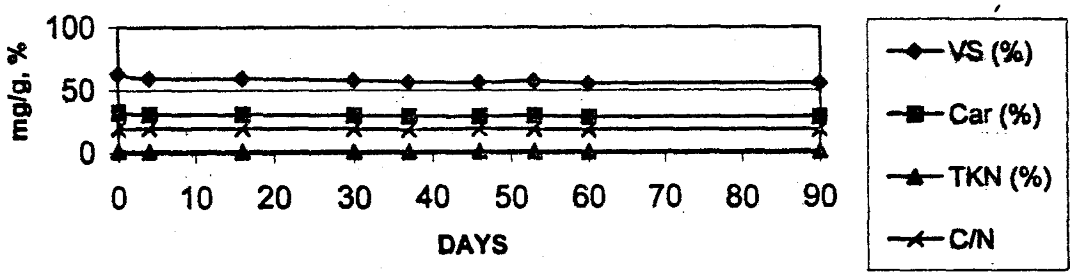

Fig. 2: Composting progress, chemical parameters

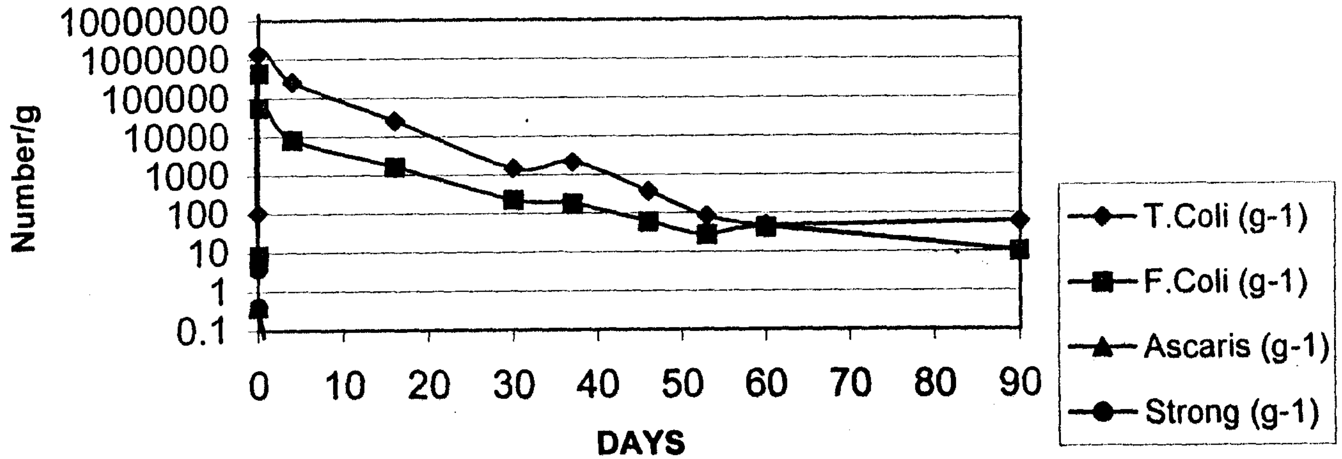

Fig. 3: Composting Progress, biological parameters