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Effect of Microbial Inoculation and Mineral Amendments on Improving Compost Quality

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THE present work aimed to study the use of some bio-accelerator, namely *Trichodermaviride*, *T.harzianum*, *Serratiamarcescens*, *Pseudomonas fluorescence* and *Bacillus polymyxa*, together with mineral materials, that is dolomite, feldspar, rock phosphate, bentonite and elemental sulfur, for production of a reduced time of processing with a high-quality compost. Plant residues composting 40% rice straw +40%maize stalks + 15% fruit residues + 5% medicinal plant residues were subjected to the composting process. Four compost piles were arranged as follows Pile 1: plant residues + 10% FYM; Pile 2: plant residues + %5 FYM + mineral additions; Pile 3: plant residues + %5 FYM + microbial bioaccelerator and Pile 4: plant residues + %5 FYM + microbial bioaccelerator + mineral additions. The experiment continued under aerobic conditions up to 90 days. The piles temperature reached maximum after 15 days, and then dropped gradually to resemble the ambient one at maturity. Microbial inoculants accelerated the composting process and raised the pile temperature within three days, as compared with the other treatments. Also, the highest temperature degree, i.e. 63C° was recorded for pile 3. Furthermore, bulk density, contents of total macro and micronutrients, and humification process were increased with progressing of the composting process. While, contents of organic matter, organic carbon and C/N ratio were decreased. Pile 4 achieved higher bulk density values and lowest contents of organic carbon, organic matter and C/N ratio. Incorporation of mineral materials increased the contents of total phosphate, potassium and trace elements, especially in piles 2 and 4. It is recommended to introduce bacteria during composting in order to accelerate the composting process and shortage time for composting maturity.

Keywords: Recycling, Enrichment bioaccelators, Agriculture wastes, Manures, Decomposition.

Introduction

Egypt is 97% desert and only 5% of the land area is actually occupied with less than 4% of the land is suitable for agricultural. The agricultural activities result in "the yield", which is economic part of the crop, and less important part, which used to be called "agricultural residues". Agricultural residues annually reach to 30-35 million tons on the Egyptian national level. Type and quantity of agricultural residues in Egypt change from one village to another and from one year to another, because farmers always cultivate the most profitable crops suiting the land and environment (Abou Hussein and Sawan 2010). Composting is one of the most promising low-cost technologies that convert solid wastes into value-added biofertilizers. On the other hand, the compost is a product of humification of agricultural wastes that is considered as a nutrient-rich, organic fertilizer and soil conditioner (Zeng et al. 2007; Mtui 2009). The agronomic utilization of compost has some benefits to soil. Compost increase soil nutrients, and soil organic matter content; thus, it has a positive effect on biological, physical, and chemical properties of the soil (Glab et al. 2018).

The strategy of inoculants to improve the composting process has been a controversial subject since scientists started to devote attention

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to this question. Some works described the complete absence of effects of this kind of treatment (Lei and Vandergheynst 2000), whereas others reported the way that inoculation led to the production of compost with better properties, to achieve specific goals and /or to overcome the obstacles of production (Mirdamadian et al. 2011). Bowen (1990) and Charest et al. (2004) declared the role of bacteria, fungi and actinomycetes in composting through degrading complex organic materials such as cellulose, lignin, chitin and proteins. Their enzymes enable them to chemically breakdown tough debris such woody stems and attack organic residues producing in the last stages humus. Sadik et al. (2010) and Zeng et al. (2010) evidenced that the presence of microbial activator into composting heaps led to a higher degrading ratio for lignin than in non-inoculated ones. Also, activator stimulated the composting process with dense bacteria and enzymes, which usually occur in nature. This accelerating method provides a good quality compost product in the shortest time. Also, it is found that the inoculation of compost by thermo-tolerant actinomycetes improved cellulose activities, accelerated the degradation of cellulose, increased the content of humic substances and influenced the structure of actinomycetes community (Zhao et al. 2017). It is reported that inoculating food waste by anti-acidification microbial consortium could effectively accelerate carbohydrate process and improve composting efficiency (Song et al. 2018).

Beneficial effects of microbial inoculants have been reported to accelerate the composting process, but enrichment with natural minerals is scanty. Therefore, the present work was planned to study the conversion of some agricultural residues to compost via utilization of microbial inoculants and mineral additives as enriching and accelerating agents for the composting process.

Materials and Methods

Various plant residues (PR) chopped to sizeless than 25 mm, namely 40% rice straw, 40% maize stalks, 15 % fruit wastes (grapes, banana and orange) and 5% medicinal plant residues. Those residues were supplemented with farmyard manure (FYM) as organic amendment at a rate of 10% or 5 %, while some natural minerals, i.e. dolomite $CaMg(CO3)_2$, feldspar, rock phosphate, bentonite and elemental sulfur were thus added in a very fine form at rates of 5%, 5%, 5%, 10% and 1%, respectively. Some chemical properties of the used plant residues and supplements are given in Table 1.

TABLE 1. Some characteristics of the main raw materials used for preparing the compost.

Parameter	Rice straw	maize stalks	Farmyard manure	Rock phosphate	Feldspar	Bentonite
pH (1:10 ext.)	5.98	5.75	7.93	7.75	7.80	8.10
EC (dS/m)	4.21	4.52	3.25	3.10	0.52	6.21
Organic-C(%)	48.32	52.15	13.17	0.45	0.39	0.15
Total-N (%)	0.51	0.68	0.92	0.036	ND	0.028
C/N ratio	94.75	76.69	14.32	12.5	ND	5.36
Total-P (%)	0.11	0.33	0.55	10.2	0.035	0.41
Total-K (%)	1.30	1.38	1.79	0.38	8.72	1.43
Total soluble-N	111.8	122.6	185.7	ND	ND	ND
Total-Fe (ppm)	698.4	879.4	169.5	4500	1379.3	5932
Total-Mn (ppm)	23.5	32.5	42.5	630	64.6	1500
Total-Zn (ppm)	18.3	22.4	27.9	82	23.7	73.3

Microbial Inoculants

Lignocellulose decomposers fungi, namely *Trichodermaviride* and *Trichodermaharzianum* were used as bio-accelerators, while the plant growth promoting rhizobacteria as a consortium of*Serratia*sp., *Pseudomonas fluorescence* and *Bacilluspolymyxa* were used as enrichments. Microbial inoculants were applied ata rate of one liter per ton with microbial load 10^8cfu/ml. All strains of fungi and bacteria were provided by Agricultural Microbiology Dept., Soils, Water, Environment ResearchInstitute,AgriculturalResearch Center, Giza, Egypt.

Experimental Methods

Four piles were constructed, each pile was made from 500 kg shredded agricultural residues (AR) of main substrates and additives in successive layers to make four piles with dimensions of 2x3x1.25 m for width, length and height, respectively. Piles moisture was maintained at 60% water holding capacity along the process.

Ingredients of the four piles were as follows:

Pile 1: plant residues + 10% FYM

Pile 2: plant residues + %5 FYM + mineral additions.

Pile 3: plant residues + %5 FYM + microbial bioaccelerator

Pile 4: plant residues + %5 FYM + microbial bioaccelerator + mineral additions

The piled components were turned regularly every 15 days. After each turning, samples were taken from different sites of each pile, mixed and air dried. Three representative samples from each pile were collected for analyses, i.e. at zero, 15, 30, 45, 60, 75 and 90 days after pile build up.

Analytical Methods

- Temperature degree was recorded every day at different location and depths in a contoured pattern according toInsam and De Bertoldi (2007).
- Bulk density of air-dried sample was determined using the core method according to (Margesin and Sehinner 2005).
- Ash and total organic carbon (TOC) were calculated by loss on ignition (LOI) at 550°C in muffle furnace according to (Margesin and Sehinner 2005).
- Total nitrogen, phosphorus and potassium were determined in acid digestate of air-dried organic wastes and compost samples. Total micronutrients (Iron, manganese, and zinc) were determined using Atomic Absorption Spectrophotometer (Jackson, 1973).
- Humification Indices: The extraction and fractionation of humic substances were carried out according to Ciavatta et al. (1990).

Results and Discussion

Composting and temperature

Changes in temperature values of the compost piles were measured regularly every 15 days up to 90 days are shown in Fig. 1. Data obtained show that temperature values reached their maximum after 15 days of the composting process. Thence after the temperature had declined to reach the atmospheric ambient value at terminating the process. It is worthy to mention that the temperature degree inside any pile was always higher than the outer layers. These results are in harmony with those obtained by Yu et al. (2011), who found that the temperature reached its maximum values with progressing the composting process, thenceforce started to decline. The increase in compost temperature was due to the effect of microbial activity on decomposing the organic materials being favorable for the growth and proliferation of the heterotrophic microorganisms. This elevated temperature was certainly effective for pasteurization and inhibition of most pathogens as well as acceleration of the degradation rate and production of safe compost, (Badawi 2003).

Concerning the effect of the added microbial activators and mineral amendments on the temperature profile, data in Fig. 1 show that pile 3 recorded the highest temperature degree of 63°C as compared that of P1 (58°C). This was the reflection of the microbial amendments that accelerated the biological activity causing temperature rise. These results are in accordance with those obtained by El-Tahlawy (2013) who mentioned that composted rice straw supplied with some biofertilizers and mineral amendments recorded a slight temperature increase higher than those recorded for the unamended ones.

Also, data in Fig. 1 shows that temperature increases of the compost piles were not high enough due to their small size which caused heat loosing (Misra et al. 2003).

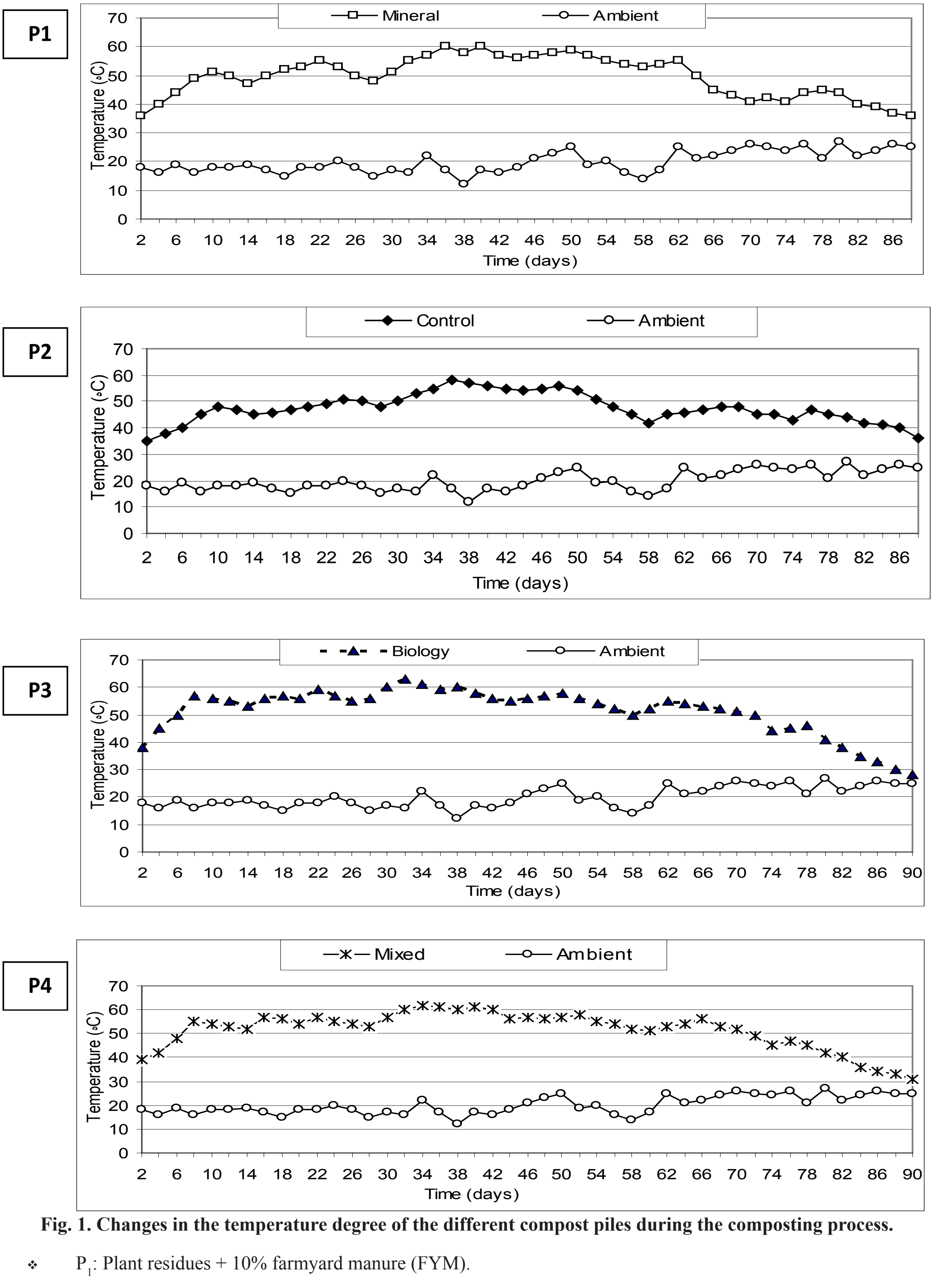

Fig. 1. Changes in the temperature degree of the different compost piles during the composting process.

- P_1: Plant residues + 10% farmyard manure (FYM).
- P_2: Plant residues, %5 farmyard manure and mineral amendments
- P_3: Plant residues, %5 farmyard manure and microbial activators.
- P_4: Mixture of agriculture residues**,** %5 farmyard manure, microbial activators and mineral amendments

Composting and Bulk Density

Changes in bulk density of the compost piles that occurred during the different intervals of composting process are shown in Fig. 2. Generally, the bulk density in all piles increased with increasing the experimental period up to 90 days. Its values increased from 0.12 to 0.27, 0.13 to 0.37, 0.11 to 0.35 and 0.12 to 0.40 g/cm^3 for piles 1, 2, 3 and 4, respectively. However, a higher progressive increase of bulk density had been observed in the amended piles during the first intervals, due to a higher decomposition rate. These results were presumably due to reduction of the raw materials contents via their breakdown. Similarly, Rynket al. (1992) and Fahmy et al. (2000) reported that composting led to a volume reduction of one-quarter to more than one-half of initial volume. Part of this volume reduction represents the loss of CO_2 and vapor to the atmosphere. In addition, amending the piles with microbial and mineral activators recorded higher bulk density values, compared to the unamended ones. Introduction of microorganisms to pile 3 led to increase the bulk density to reach 0.35 g/cm^3 at the end of composting process, while the mixed additives (mineral + microbial activators) led to increase the bulk density, which reached 0.40g/cm^3 in pile 4. Addition of mineral amendments to pile (2) led to increase the bulk density, to reached 0.37 g/cm^{3}at the end of the composting process, compared to pile (l), which recoded a bulk density of 0.27 only.

Such results are explained by the effect of the added amendments on accelerating the biological activity and thus volume reduction. These results are in agreement with those obtained by Badawi (2003), who reported that addition of mineral amendments and biofertilizers to compost piles led to accelerate the biological activity and caused volume reduction than those in the untreated piles.

As aerobic composting proceeds, the particle size of organic solid fraction decreases due to the breakdown of larger particles and, in turn, wider surface is thus provided for microbial decomposition (Ravivet al. 1987). The aerobic decomposition of organic materials increases the ash content and decreases organic fraction, e.g., volatile solids, total organic matter, as well as organic carbon content, which imply an increase in particle density and subsequently bulk density leading to increase the composting matrix along

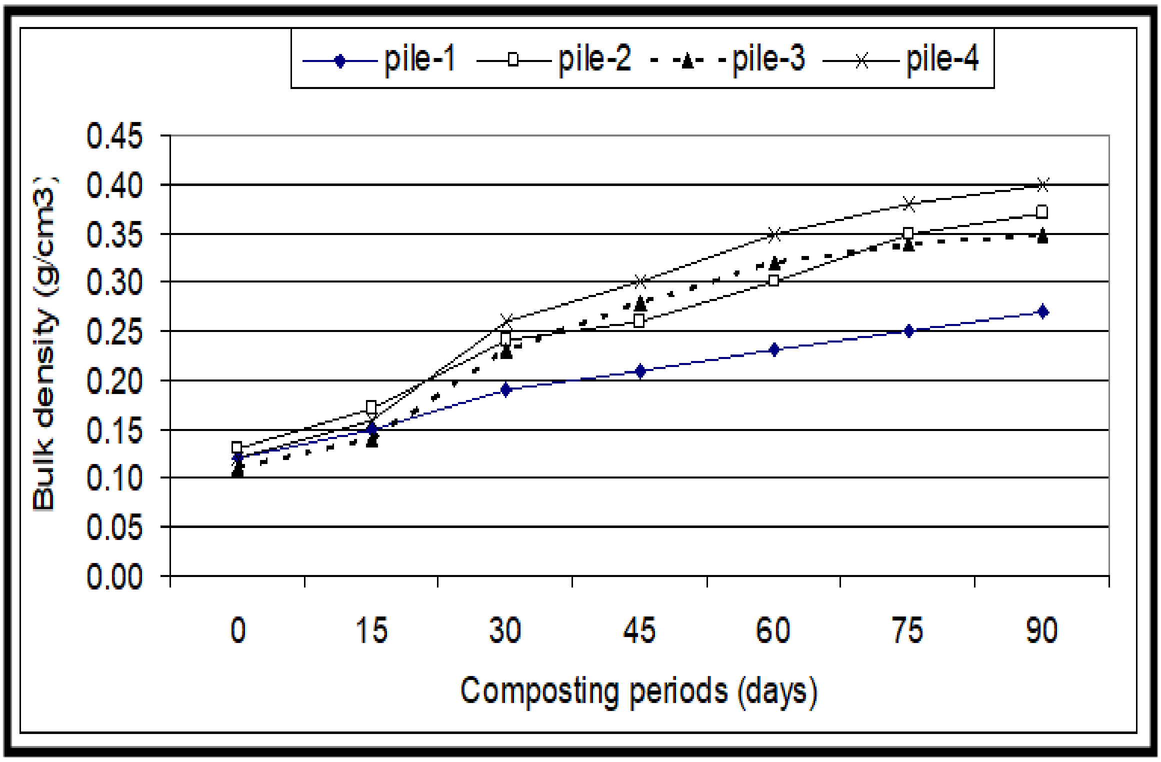

Fig. 2. Changes in Bulk density of compost piles during the experimental duration.

the composting time (Mohee et al.2008).

Composting and Organic Matter

Changes in organic matter (OM) contents, corresponding to organic carbon contents during the composting process are shown in Table 2. Data revealed that their values decreased gradually with the successive stages of composting, where the organic matter contents of the starting raw materials were 93.6, 86.4, 82.2 and 84.5% in $P_{1,}$ $P_{2,}$ P_3 and P_4, respectively. Such values had gradually decreased as the course had proceeded to reach 52.51, 46.46, 40.20 and 43.28% of piles 1, 2, 3 and pile 4, respectively, at termination of composting process (90 days). The highest diminution rats had been detected within the period of 45-57 days.

The decrease of OM during the biooxidative phase corresponded with the elevated temperature degrees and maximum microbial activities that were stimulated by inoculation with the microbial activators, where the amended piles recorded decreases in OM contents from 82.20% to 40.20% and 84.5% to 43.28% for piles 4 and 3, respectively, comparing to the unamended ones which reduced from 93.60% to 52.51% and 86.40% to 46.46% for piles 1 and 2, respectively. Loss of organic matter occurred through volatilization of CO_2 and release of

TABLE 2. Changes in some characters of organic matter during composting process.

Time (days)	Pile NO.	Organic carbon (%)	Organic matter (%)	C/N ratio	Ash (%)
0	1	52.00 a	93.6 a	70.27 a	6.40
	2	48.00 a	86.4 a	72.73 a	13.60
	3	45.67 a	84.5 a	57.81 a	15.50
	4	46.94 a	82.2 a	58.68 a	17.80
15	1	48.39 a	87.10 a	59.01 a	12.90
	2	46.19 a	83.15 a	63.28 a	16.85
	3	44.06 a	79.30 a	51.23 b	20.70
	4	41.67 a	75.00 a	56.31 ab	25.00
30	1	45.57 a	82.02 a	45.12 bc	17.98
	2	43.28 ab	77.9 ab	50.32 b	22.10
	3	37.63 b	67.74 b	37.63 d	32.26
	4	35.88 b	64.59 b	39.00 d	35.41
45	1	36.51 a	65.72 a	33.19 a	34.28
	2	33.63 a	60.53 a	37.36 da	39.47
	3	30.67 a	55.20 a	30.07 e	44.80
	4	29.24 a	52.63 a	29.24 f	47.37
60	1	32.12 a	57.81 a	28.93 f	42.19
	2	30.33 a	54.60 a	31.60 e	45.40
	3	29.22 a	52.60 a	23.76 g	47.40
	4	26.34 a	47.41 a	24.62 g	52.59
75	1	29.47 a	53.04 a	26.08 fg	46.96
	2	27.61 a	49.70 a	25.33fg	50.30
	3	25.57 a	46.02 a	20.79 h	53.98
	4	23.50 a	42.3 a	20.80 h	57.70
90	1	29.17 a	52.51 a	25.82 g	47.49
	2	25.81 ab	46.46 ab	23.05 g	53.54
	3	21.33 b	43.58 b	17.20 i	56.42
	4	23.21 b	40.2 b	20.18 h	59.80

mineral constituents (ash) and water (Desoki, 2004; El-Tahlawy, 2013).

Upon advancing the course of composting, the ash content (mineral constituents) had increased, as well as the C/N ratio had narrowed (Table 2). This is elucidated by decomposition of the compos row materials resulting in evolution of CO_2 on account of total nitrogen, on one hand, and release of minerals from the initial organic buildup. Application of the used amendments, generally, positively affected the ash content and C/N ratio of the composted piles, denoting the order noted above (Insam and Debroldi, 2007; Himanen and Hanninen 2009).

Composting and macro nutrients

Changes that had taken place for the contents of the macro elements, nitrogen, phosphorus and potassium during the composting process are shown in Table 3. Results explored gradual increases during the composting all over the experimental time. Decomposition of the initial organic substrates containing such elements was

TABLE 3. Changes in Total macro elements (N, P and K) of composted piles during different decomposition periods

Composting Time (days)	Pile No.	Total nitrogen (%)	Total phosphorus (%)	Total potassium (%)
0	1	0.74a	0.30a	1.40a
	2	0.66a	0.34a	1.28b
	3	0.79a	0.31a	1.05a
	4	0.80a	0.32a	1.21c
15	1	0.82ab	0.28b	1.05ab
	2	0.73b	0.45a	1.31b
	3	0.86a	0.33ab	1.10a
	4	0.74ab	0.40a	1.27c
30	1	1.01a	0.31b	1.07b
	2	0.86a	0.60a	1.38b
	3	1.00a	0.34a	1.25a
	4	0.92a	0.57a	1.34b
45	1	1.10a	0.32b	1.10ab
	2	0.90a	0.82a	1.52b
	3	1.02a	0.41a	1.33a
	4	1.00a	0.85a	1.50ab
60	1	1.11a	0.34c	1.19b
	2	0.96a	0.95a	1.70c
	3	1.23a	0.45b	1.38a
	4	1.07a	0.99ab	1.75ab
75	1	1.13a	0.37b	1.22b
	2	1.09a	1.03a	1.95b
	3	1.23a	0.48b	1.42a
	4	1.13a	1.08ab	1.82b
90	1	1.13a	0.38b	1.24b
	2	1.12a	1.08a	2.08b
	3	1.24a	0.49a	1.45a
	4	1.15a	1.14a	1.86b

behind the relatively increasing contents shown in the ash. Some increments in N content could be referred to some contribution of N2- fixers.

Similar findings were reported by Desoki (2004) who reported that the gradual increases in the total elements may be attributed to the decomposition of organic materials and consequently the reduction in the weight and also to the biological nitrogen fixation.Kavitha and Subramanian (2007) reported that addition of microbial inoculants increased the nitrogen content by about 36% when compared to compost material without enrichment.

Phosphorus concentration had increased in the ash, due to the addition of rock phosphate, that is the case of P2 and P4 (supplied with mineral amendments and microbial activators). Similar trend was obtained by Nishanth and Biswas (2008). Likewise, maximum T.K content (2.08%) was found in P_2 which was supplied with mineral amendments additives (dolomite, feldspar, rock phosphorus, bentonite and sulfur). Moreover, the combined addition, of the mineral amendments together with microbial activators (P_4) thus increased TK to 1.86%, as compared with P_3 and P_1.

Composting and micro nutrients

Micronutrients (Fe, Mn and Zn ppm) were determined during the different intervals of composting process and their data are listed, (Table 4). The tabulated resulted reveal that the concerned metals indicated that proportional increases were detected by increasing the time of composting. Those increases were against continuously reduced bulk quantity of the manure gained, but the absolute amounts of such nutrients were stable. Kaosol et al. (2012) mentioned that availability of Fe, Mn and Zn in compost piles showed a highly gradually increase during the deferent periods of composting process.

Order of abundance of the trace elements was: Fe >Mn> Zn, which follows the natural concentrations of such metals in the plant tissues (El-Gala and Amberger, 1982).

The compost pile 4 showed the highest total concentrations of the trace elements detected during composting. Incorporation of minerals into piles 2 and 4 led to resulted in the highest total contents of the trace elements, compared to piles 1 and 3.

Humification process

The humification course of organic matrix monitored as a fraction, quantification and humification indices (HI) is shown in Table 5. As the decomposition of the substrates had progressed, values of the extractable fractions of organic carbon were 116.18, 111.60, 104.95 and 58 mg/g in the piles 1, 2, 3 and 4, respectively, at the end of process.

Despite of slight variations of the extractable carbon, its components percentages, humic and fulvic acids notably, varied according to the different treatments. Addition of microbial activators (piles 3 and 4) rapidly stimulated the formation and highly yielded humic acids as compared with piles 1 and 2 (non- bio amended). The HA content was higher than that of FA in P_3 and P_4 compared to P_1 and P_2, where humic acid contents reached 46.75, 49.68, 53.30 and 56.10 mg/g, against the corresponding those of fulvic acid reached 69.43, 61.72, 51.62 and 41.90 mg/g For P_1, P_2, P_3 and P_4, respectively, at end of the process (Bernal et al. 2009; Elegami 2011).

Humification indices (Hi, HA/FA) appears to be the most sensitive way to monitor the humification process pathways and has been proposed by numerous authors as index of maturity (Bernal et al. 2009).

The data presented in Table 5 shows the variation in the humification ratio (HR) and the humification (HI) during composting of different treatments. The HR and HI were also determined to assess compost maturity. As expected, the HR increased over the composting to reach, 45.15, 46.52, 49.52 and 50.90% in the piles 1, 2, 3 and 4 respectively at the end of process. The HI increased over the composting to reach to18.60, 21.30, 25.10 and 28.75% in the piles 1, 2, 3 and 4 respectively at the end of process.

Conclusion

The results of the study clearly indicate that the biodegradation and recycling of agriculture residues using introduced of bacteria led to accelerate the composting process and shortage time for composting maturity. Also, addition of

TABLE 4. Changes in Total contents of micro nutrients (Fe, Mn and Zn) of the compost piles along the course of processing.

Time(days)	Pile No.	Fe (ppm)	Mn (ppm)	Zn (ppm)
0	1	1210b	75.60d	26.60d
	2	1650a	119.25b	50.50b
	3	1600a	99.98c	32.30c
	4	1760a	138.56a	58.60a
15	1	1360b	84.23c	34.70c
	2	1820a	130.23ab	59.25ab
	3	1945a	113.58b	44.50bc
	4	1930a	145.85a	65.45a
30	1	1416b	90.15c	38.20b
	2	2245a	145.45ab	73.85a
	3	2460a	123.45bc	58.80a
	4	2265a	170.85a	73.30a
45	1	1978b	92.95c	48.80b
	2	2720ab	175.57a	85.85a
	3	2873a	125.96b	71.10a
	4	3011a	193.45a	85.50a
60	1	2110c	94.56b	50.25b
	2	3225b	180.24a	93.42a
	3	2940ab	128.78b	79.90a
	4	3455a	210.78a	90.90a
75	1	2280d	95.45b	53.45b
	2	3750b	185.63a	100.00a
	3	3070c	133.25b	85.50a
	4	4932a	216.05a	92.20a
90	1	2300d	98.87d	54.50b
	2	3900b	190.85b	105.20a
	3	3165c	130.30c	90.80a
	4	4411a	221.00a	119.90a

TABLE 5. Changes in humification process of the compost piles along the course of processing.

Pile No.	NHC mg/g	HC mg/g	HA mg/g	FA mg/g	HR (%)	HI (%)
1	142.47a	116.18a	46.75c	69.34a	45.15d	18.59d
2	128.50b	111.40b	49.68b	61.72b	46.52c	20.74c
3	106.81c	104.95c	53.30b	51.62c	49.21b	24.95b
4	95.08d	98.00d	56.10a	41.90d	50.90a	28.83a

Non-HC=Non-humifed-C, HC= Alkali-exactable organic-C, HAs=Humic aids, FAs=Fulvic acids, HR=Humification rate, HI=Humification index.

mineral amendments can been rich the compost piles with mineral nutrients especially potassium and phosphorus.

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