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Bioconversion of rice straw and certain agro-industrial wastes to amendments for organic farming systems: 1. Composting, quality, stability and maturity indices

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ABSTRACT

The microbiological and physicochemical parameters were monitored for 12 weeks during composting of five piles ($1.5 \times 1.0 \times 0.80\ m^3$) containing mainly rice straw, soybean residue and enriched with rock phosphate. Two treatments were inoculated with buffalo's manure or composite inoculum, two were supplemented with vinasse and inoculated with either the composite inoculum or with both, the last one was served as a control. Four typical phases of composting were observed during the bioprocess: short initial mesophilic phase followed by, thermophilic, cooling and maturation phases. Physicochemical changes confirmed the succession of microbial populations depending on the temperature of each phase in all treatments. Intense microbial activities led to organic matter mineralization and simultaneously narrow C/N ratios. Inoculation of composting mixtures enhanced the biodegradation of recalcitrant substances. The duration of exposure to a temperature above 55 °C for at least 16 consecutive days was quite enough to sanitize the produced composts. After 84 days, all composts reached maturity as indicated by various parameters.

1. Introduction

Organic wastes from animal production, agricultural and by-products of agricultural and food processing industries have become major sources of environmental and social problems throughout the world in both developed and developing countries. In Egypt, rice straw is considered one of the main agricultural wastes which represent about 4 million tons annually produced every autumn. It is traditionally disposed of, by burning in situ, causing real harmful environmental implications through producing huge black clouds of smoke that affect all the adjacent municipalities. The problems are varied and even affect human health. Furthermore, the production of CO_2 during burning has been linked to global warming as green house gases.

Vinasse, as another main by-product waste in Egypt, is the dark brown aqueous generated from the distillation of ethanol following fermentation of carbohydrates in volume more than $2000\ m^3\ day^{-1}$ from Sugar and Integrated Industries Company in Hawamdia. It creates serious environmental problems when throw out into either water bodies and/or land (Diaz et al., 2002).

Okara, or soy pulp, a rich protein by-product, is another pollution problem added during the manufacturing of soymilk and tofu (Wang and Cavins, 1989).

Manures also represent a serious pollution problem resulting from the huge accumulation of such material. These animal wastes are known to be heavily contaminated with pathogenic bacteria and parasites causing a direct health risk (Hanajima et al., 2006).

The increase in the production of wastes in a society can be diminished or even ceased to be a problem if an added value was attributed to them. Composting is one of the natural bioprocesses capable of treating organic wastes through the microbial activity. However, rice straw among certain organic materials are resistant to microbial attack because of the wide C/N ratio and the high content of ligno-cellulose (Zhu, 2007). Therefore, co-composting of rice straw with the aforementioned wastes is likely to provide better results than rice straw alone. Composting can destroy pathogens; converts nitrogen from unstable ammonia to stable inorganic forms, reduces the volume of waste, and satisfies the needs of fertilizer for agricultural use seasonally (USEPA, 1993; Zhu, 2007).

Because of phosphorous is the second limiting nutrient after nitrogen in majority of soils for crop production, many attempts had been made by some workers to produce compost from rice straw enriched with RP to increase the availability of P. The direct application of rock phosphate (RP) is not reasonably suitable for direct use in neutral to alkaline soils such as in Egyptian ones (Zayed and Abdel-Motaal, 2005; Biswas and Narayanasamy, 2006).

The most important factors affecting the composting include temperature, moisture content, C/N ratio, degree of aeration, pH level, and the physical structure of the waste material.

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Furthermore, compost maturity and stability are the key factors of the bioprocess. Several authors have concluded that using a single parameter as a maturity index is insufficient and that amalgamation of several parameters is usually needed. Various physical, biological and chemical parameters that have been used to monitor the quality and maturity of compost include C/N ratio, NH_4/NH_3, CO_2 evolution, pH, electrical conductivity, cation exchange capacity, water-soluble carbon, Dewar flask self-heating capacity, oxygen uptake rate and production of humic substances in the finished product as well as germination index to measure the phytotoxicity as a reliable indirect quantification of compost maturity (Zucconi et al., 1981; Aparna et al., 2007; Gomez-Brandon et al., 2008).

The objectives of this study were: to evaluate the efficiency of co-composting of enriched rice straw with rock phosphate and some agro-industrial by-products wastes in order to produce quality composting products for organic farming; to monitor the microbiological and physicochemical changes that may occur during composting of rice straw with other additives; to investigate the effect of composting process on reduction of health related pathogenic organisms and to assess the maturity and stability of the end product according to the selected parameters.

2. Methods

The experiment for bioconversion of agricultural and industrial wastes into compost was carried out in the Agricultural Experimental Station, Faculty of Agriculture, Cairo University, Giza. The experiment was started in August 2007 and extended for 12 weeks.

2.1. Composting of raw materials

Air-dried rice straw used in this study was obtained from the Faculty farm chopped into small pieces 3–6 cm using shredding machine. Air-dried okara, a heated (90 °C) by-product of soymilk and tofu-making processes, was obtained from the Soy Technology Center, Agricultural Research Center (ARC), Giza. Vinasse was obtained from the ethyl alcohol production plant located at the area of Sugar and Distillery industry, Sugar and Integrated Industries Company, Hawamdia, Giza. Fresh buffalo's manure was collected from the farms of the Agriculture Experimental Station. The selected physicochemical properties of the raw composting materials were measured prior to starting the experiment and C/N ratio of each material was calculated (Table 1). Grounded rock phosphate was kindly obtained from El-Ahram Company for Mining and Natural Fertilizers, Giza. For each pile, rock phosphate was added with 10% (Zayed and Abdel-Motaal, 2005).

Table 1
Selected physicochemical properties of raw composting materials.

Parameters	Materials			
	Rice straw	Okara	Vinasse	Buffalo manure
Moisture content (%)	5.60	5.0	49.20	73.49
OM (%)[a]	82.85	95.76	90.90	76.60
TC (%)[b]	48.05	55.54	52.72	44.42
TN (%)[c]	0.63	4.96	1.65	2.06
C/N	76.27	11.19	31.95	21.56
pH	7.1	6.7	5.2	7.5
EC ($dS\ m^{-1}$)[d]	2.76	2.27	5.46	1.32

All analysis was reported on a dry weight (d.w.) basis.
TC = OM (%) × 0.58.
[a] OM, organic matter.
[b] TC, total carbon.
[c] TN, total nitrogen.
[d] EC, electrical conductivity.

2.2. Microorganisms

Cellulose degrading fungi: *Trichoderma reesei* (NRRL 11236) and *Phanerochaete chrysosporium* (NRRL 6361) were obtained from Department of Microbiology, Faculty of Agriculture, Cairo University. While, *Trichoderma viride* (EMCC 107) was obtained from the culture collection of Cairo "MIRCEN", Faculty of Agriculture, Ain-Shams University. The cultures were grown and maintained on potato dextrose agar (PDA) slants.

2.3. EM solution

It consists of different types of microorganisms including bacteria, yeasts, actinomycetes and fungi as a mixture of effective microorganisms (EM) locally produced by Afforestation and Environment Administration, Ministry of Agriculture, Egypt, in association with EMRO Organization Okinawa, Japan.

2.4. Composite inoculum

Due to the low number of fungi in EM solution (4×10^3 cfu/ml), a mixture of spore suspension of cellulose degrading fungi were added to the EM solution, to form what is called composite inoculum. The spore suspension was prepared from the 15 days cultures using distilled water by mixing them in equal portions. The suspended cultures were filtrated through the cheesecloth, only the filtrates were used (spore suspension). The total plate count was performed on Rose Bengal agar base medium to encounter the number of spore in the spore suspension (7.8×10^8 cfu/ml). This inoculum was composed of EM solution 2:1 fungal spores suspension (v/v), and added to compostable materials at concentration of 10% (v/w).

2.5. Composting process

Composting piles were constructed by laying several layers of shred rice straw, okara and rock phosphate one over another and inoculated with buffalo's manure and/or composite inoculum (Table 2) in proportions based on the dry weight. During piling the heap, each layer was watered to keep about 70% moisture and mixed with proper amounts of other additives. The dimensions of each pile at the beginning were about 1.5 m length × 1.0 m width × 0.80 m height. Moisture was maintained at 50–60%. The fermentation was allowed to continue for 12 weeks. The piles were turned for aeration once a week and three replicate samples were taken from different spots in each pile at 0 time, 1st, 2nd week and at 15 day intervals for subsequent microbiological and physicochemical analyses, whereas temperature degrees were recorded every 4 days at early morning at the depth height of 40 cm from the surface.

2.6. Microbiological determinations

An initial suspension of 10 g of composing mixtures was made following the technique of Vargas-Garcia et al. (2005). The suspension was serially diluted, and then one ml of each dilution was transferred aseptically to inoculate appropriate media in triplicate using the pour plate or MPN method. The microbial numbers were estimated as colony forming unit/g or cells/g. Total count of mesophilic bacteria was determined on tryptone glucose extract agar medium at 30 °C for 3 days. Thermophilic bacterial count was determined on the same medium after incubation at 50 °C for 2 days; total mesophilic and thermophilic fungi on Rose Bengal agar base medium at 30 and 50 °C for 5–7 days, respectively; actinomycetes on Jensen's medium at 30 °C for 2 weeks. Phosphate dissolving bacteria (PDB) and phosphate dissolving fungi (PDF) were estimated using the methodology of Zayed and Abdel-Motaal (2005) at 30 °C for 3 and 7 days, respectively. Aerobic cellulose

Table 2
The composition of composting piles.

Treatments	Proportion (w/w)				Percentage		C/N ratio
	Rice straw	Okara	Vinasse	Buffalo manure	Rock phosphate (w/w)	Composite inoculum (v/w)	
T1	4	1	–	–	10	–	33.41
T2	4	1	–	1	10	–	32.54
T3	4	1	–	–	10	10	32.63
T4	4	1	1	–	10	10	33.18
T5	4	1	1	1	10	10	32.73

decomposers were determined using Dubo's liquid medium by MPN technique. Inoculated tubes were incubated at 30 °C for 30 days. Carboxymethyl cellulase (CMCase) activity was determined according to the method of Takao et al. (1985). Total coliforms count on MacConkey broth medium, by Most Probable Number (MPN/g) technique at 37 °C for 24 h, and fecal coliform on the same medium at 44.5 °C for 24 h. *Salmonella* detection was conducted by inoculating a bottle of selenite cystine broth medium with 10–25 g of the sample (at the beginning and at the end of composing process) and incubated at 37 °C for 24 h. Full loop from this bottle was streaked onto plates of Xylose Lysine Desoxycholate (XLD) agar medium, then plates were incubated at 37 °C for 24–48 h.

2.7. Physicochemical analyses

Temperature degrees at the center of each pile as well as environmental temperature were recorded manually by a thermometer every 4 days. pH and electrical conductivity (EC) values were measured by using a pH digital meter (3020, Jenway, UK) and an EC meter (ESD, 76, USA) in aqueous extract (Rhoades, 1996). Moisture content of raw materials and composting mixtures was determined by drying the samples at 105 °C for 24 h (Tiquia and Tam, 1998). Ash was determined in a muffle furnace at 550 °C for 5 h, and the organic matter (OM) was calculated as the difference between ash and dry weight as a percentage (Tiquia and Tam, 1998). From values of OM, the percentage of organic carbon (OC) was calculated by multiplying of OM by 0.58. Biodegradability coefficient (K_b) was calculated using the equation:

$$K_b = \frac{(OM_i - OM_f)100}{OM_i(100 - OM_f)}$$

where OM_f is the OM content at the end of the process; OM_i is the organic matter content at the beginning of the process (Haug, 1993). Total nitrogen (TN) in dry compost was determined by micro-Kjeldahl method as recommended by Cottenie et al. (1982), while C/N was calculated using values of the OC and TN. Ammonical and nitrate nitrogen, the available forms of nitrogen, were calculated according to the methods described by Page et al. (1982).

The produced composts were analyzed for: total and available phosphorus using the methods described by David (1966) and Olsen et al. (1954), respectively; total and available potassium using a flame photometric method outlined by APHA (1989) and Chapman and Pratt (1961), respectively; humic substances according to the method outlined by Francou (2004); the Phytotoxicity test (Germination Index, GI) using the radish seed (*Raphanus sativus* L.) germination and the root length test, according to Zucconi et al. (1981).

2.8. Statistical analysis

Data of microbiological and chemical analyses were statistically analyzed using general linear model (GLM) according to (SAS, 2002) and differences between means were analyzed using the least significant difference test (LSD) at $p < 0.05$.

3. Results

3.1. Changes in physicochemical parameters during composting

Four typical phases of composting temperature were evidently observed during the bioprocess: (i) a short initial mesophilic phase in which the temperature rose rapidly to reach 48 °C in buffalo inoculated piles during the first 7 days; (ii) a thermophilic phase, during which the temperature attained a maximum peak at the 16th day and surpassed 60 °C for all inoculated piles (Fig. 1a). Except for un-inoculated control pile (T1), thermophilic phase was sustained until the 40th day then; (iii) a cooling phase started from about the 36th day in T1 and the 45th day in almost all inoculated ones, through which, the temperature of all compost treatments regularly dropped off to equal the ambient level and remained constant during the maturation phase (v).

Regarding the pH and EC, the initial values found to vary depending mainly on the feeding materials of composting piles. The relatively low starting pH values as well as higher EC were recorded in piles received vinasse (T4 and T5). During the first two weeks of composting, the pH values of all treatments were increased to attain the maximum peaks, then gradually declined to reach the lowest values at the end (Fig. 1b). However, the EC values were decreased steadily from the beginning of the process until the 12th week (Fig. 1c). The final EC values of different composts ranged between 0.79 and 1.04 dS m^{-1}.

Fig. 2a and b shows the changes of organic matter and total nitrogen during the fermentation course. The OM content decreased in all composting mixtures (Fig. 2a) and the decrease was more marked during the first stage of the bioprocess. Losses of 23.82, 23.60, 19.53, 17.10 and 13.64% for T5, T4, T2, T3, T1, correspondingly were recorded after 84 days of composting. The biodegradability coefficient (*Kb*) values were 0.59, 0.55, 0.51, 0.42 and 0.37 in that order. As the vinasse and buffalo's manure inoculum added, higher losses in OM were observed. The produced composts found to contain OM over the range of 56–63%. Conversely, total N increased gradually to reach the highest value at the end. T4 and T5 achieved the maximum content of total nitrogen 2.08% and 1.94%, respectively (Fig. 2b). The changes in concentrations of the two inorganic forms of nitrogen, NH_4^+–N and NO_3^-–N followed the typical trends in all treatments with composting time (Fig. 3a and b). As ammoniacal nitrogen, NH_4^+–N, increased, the nitrate nitrogen, NO_3^-–N, decreased and vice versa. The maximum significant content of NH_4^+–N was recorded after two weeks at the thermophilic phase and then decreased. However, NO_3^-–N was in increasing order, the utmost levels of NO_3^-–N (321.66 and 227.0 ppm) were observed in treatments T4 and T3, respectively which have the highest values of NH_4^+-N as a result of nitrification ($P = 0.0001$).

3.2. Changes in microbial populations

Changes in the densities of the microbial population throughout bioprocessing in different pre-composting mixtures are illustrated in (Figs. 4–6). The mesophilic bacteria markedly increased in all

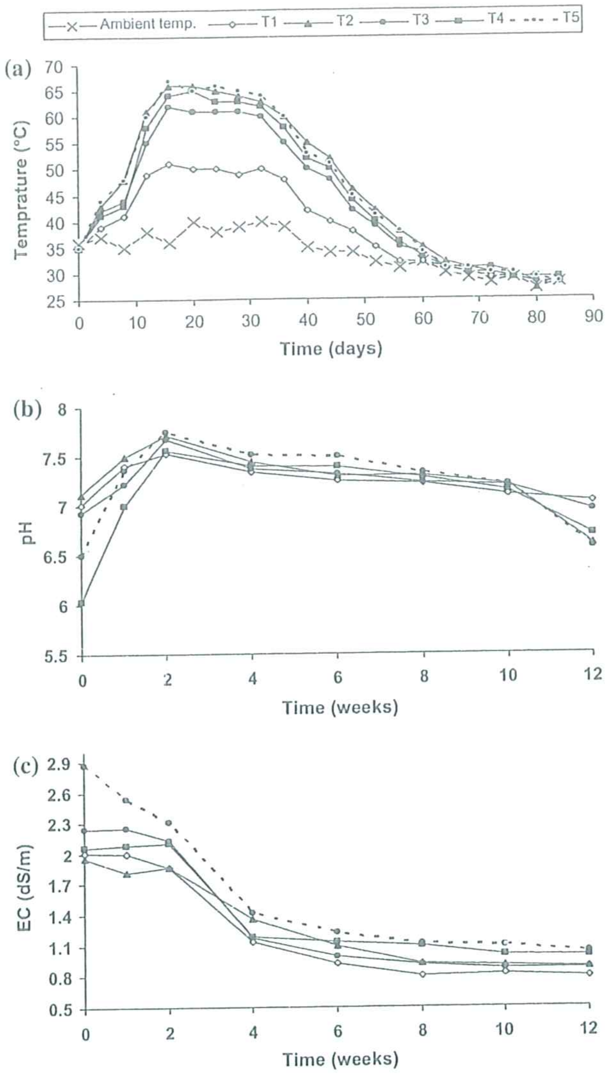

Fig. 1. Changes in temperature (a), pH (b) and EC (c) during co-composting of rice straw.

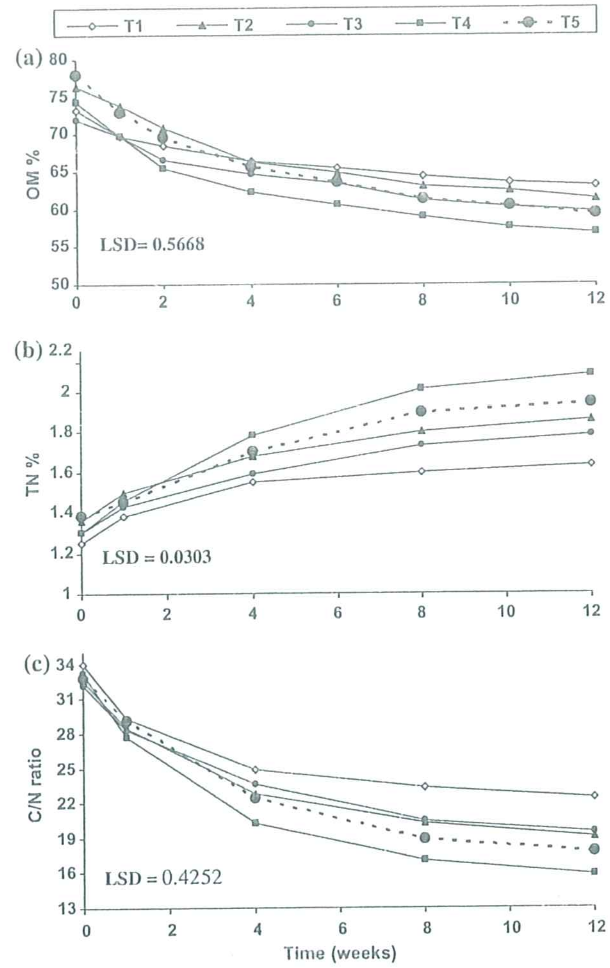

Fig. 2. Changes in the contents of OM (a), TN (b) and C/N ratio (c) during co-composting of rice straw.

treatments during the initial stage of composting to reach the maximum at the end of the 1st week (Fig. 4a). T4 recorded the highest significant number 2.3×10^{11} cfu/g (LSD = 6.8×10^9, $P = 0.0001$), however, T1 (un-inoculated control) recorded the lowest one of 7.0×10^9 cfu/g. Subsequently, mesophiles decreased temporarily during the thermophilic phase while thermophiles increased (Fig. 4b), T4 and T5 varied significantly with other treatments (LSD = 8.01×10^7, $P = 0.0001$). As the temperature dropped during the cooling phase, thermophiles decreased and mesophiles reincreased slightly but never reached the counts recorded initially.

Although, actinomycetes exhibited slow growth throughout the composting course, they withstood the adverse conditions during the thermophilic phase, and increased lately as the composting period progressed (Fig. 4c). T5 which inoculated with composite inoculum plus buffalo's manure had the highest actinomycetal number (LSD = 4.53×10^6).

The highest initial mesophilic fungal counts were found in piles T3, T4 and T5 which received composite inoculum. Nevertheless the densities of thermophilic fungi during the initial period of composting were very low or even not detected in some treatments (Fig. 5a and b). Mesophilic fungal population were serotinous augmented and reached their maximal peak at the 10th week for all treatments, T4 and T3 that received composite inoculum varied significantly with other treatments(LSD = 3.35×10^6). However, a steep increase in the thermophilic populations was noticed as the temperature rose throughout the composting process but never reach 10^6 cfu/g dw (Fig. 5b). Thenceforth, their figures decreased gradually parallel with the reduction of temperatures and reached their minimal values at the 12th week but still insignificantly higher than those recorded at the initial time of composting (LSD = 1.03×10^4).

Concerning the aerobic cellulose decomposers, treatments inoculated with buffalo's manure found to contain the highest significant numbers of cellulose decomposers (LSD = 1.39×10^4, Fig. 5c) and the highest cellulase activity (Table 3). The utmost of cellulase activity was achieved in T5 that received manure, composite inoculum and vinasse (279.6 mg reducing sugar/g dry matter/h, $P = 0.0001$) followed by T2 which received manure only. Although the cellulase activity was in decreasing order, its activity in all treatments at the end was still higher than at the start of composting process (3–5-fold).

The phosphate dissolving bacteria (PDB) in both control and inoculated piles were present in relatively convergent numbers ($3–7.5 \times 10^5$ cfu/g dw) at the beginning of composting (Fig. 6a). However the densities of phosphate dissolving fungi (PDF) were varied initially among composting mixtures between 2.8 and

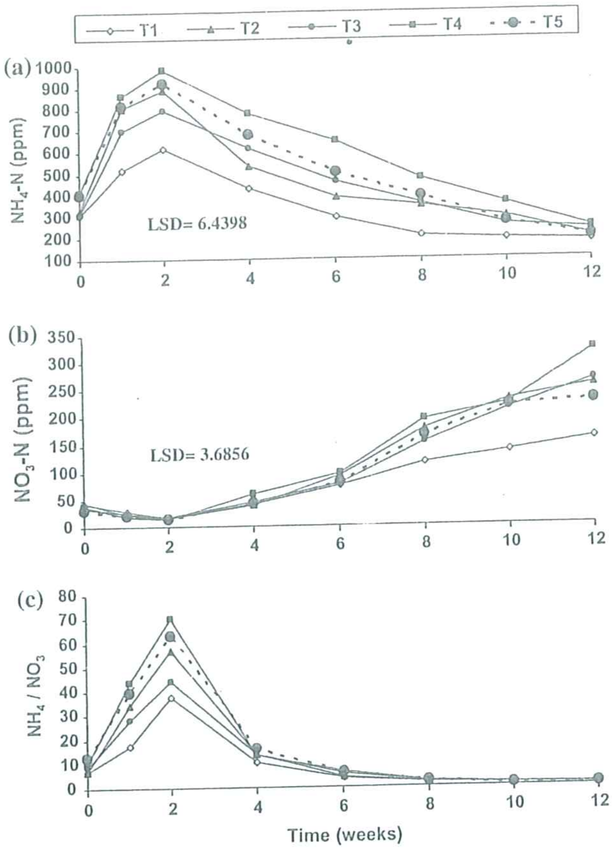

Fig. 3. Changes of inorganic forms of nitrogen (a) NH_4–N, (b) NHO_3–N (ppm) and (c) nitrification index (NH_4/NO_3) during co-composting of rice straw.

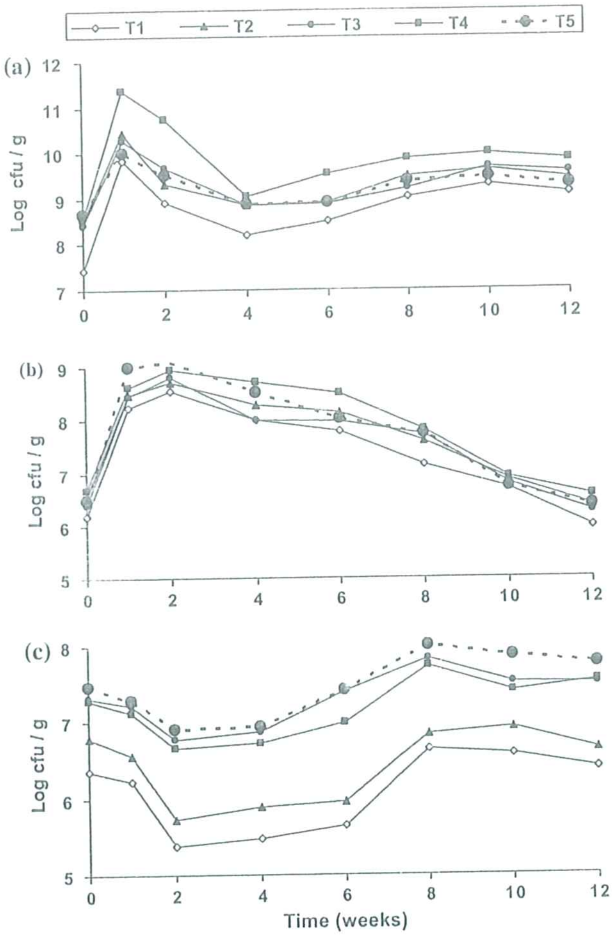

Fig. 4. Changes in counts of mesophilic (a), thermophilic bacteria (b) and actinomycetes (c) during co-composting of rice straw.

43×10^3 cfu/g dw (Fig. 6b). The pile received both buffalo's manure and composite inoculum had the highest significant counts of PDB (LSD = 2.03×10^6) and the piles received composite inoculum only harbored the significant uppermost counts of PDF (LSD = 1.91×10^5, $P = 0.0001$). PDF behaved similarly to PDB whereas their counts remained nearly stable through the first 4 weeks, followed by a gradual increase.

Pertaining to the sanitarian indicators, piles contained buffalo's manure had higher counts either total and/or fecal coliform than other piles. The numbers of total coliform of all treatments slightly increased during the 1st week of composting recording a range between 1.6 and 140×10^6 MPN/g dw. When the composting proceeded, a steady decline was noticed until they became undetectable in piles 2, 4 and 5, however, they were detected at very low numbers in piles 1 and 3 at end of composting, (14.3 and 23.3 MPN/g dw, respectively). Correspondingly, fecal coliform followed the same pattern of total coliform bacteria, but they completely disappeared as early as the 6th and 8th week from the all treatments T2, T4, T5 and T1, T3, respectively. *Salmonella* sp. was detected at the beginning of composting process only in all samples taken from piles received buffalo's manure. After 12 weeks of bioprocessing, all treatments were totally free of *Salmonella*.

3.3. Quality and stability of the produced composts

3.3.1. Phosphorus (P) and potassium (K) amounts in produced composts

As shown in Table 4, it is evident that both the total and available phosphorus contents in composts were increased on decomposition in all treatments. Although, the resident microbiota in composting mixture of control pile were not effective in solubilizing phosphate when compared to the inoculated piles either with manure and/or composite inoculum. Overall, the highest significant amount of total and solubilized P and K were achieved in composts received vinasse, ($P = 0.0001$).

3.3.2. Nitrification index (NH_4/NO_3)

The ratio between the inorganic forms of nitrogen has been used as decisive factor for evaluating the ripeness of compost. Highest significant values were obtained during the thermophilic phase followed by a significant continuous decrease during the cooling and maturation phases (Fig. 3c). The resulted ratio of NH_4/NO_3 was <1 at the end of the process in all obtained composts (0.75–0.87) produced only from inoculated piles which indicated that the final composts had reached maturity.

3.3.3. Changes in C/N ratio

As illustrated in Fig. 2c, The C/N ratio of all treatments lessened piecemeal during composting process and reached the final values at the end. It is worthy mention that the narrowest C/N ratios were achieved in treatments received vinasse. T4 showed the narrowest C/N ratio which differed significantly than other treatments ($P = 0.0001$).

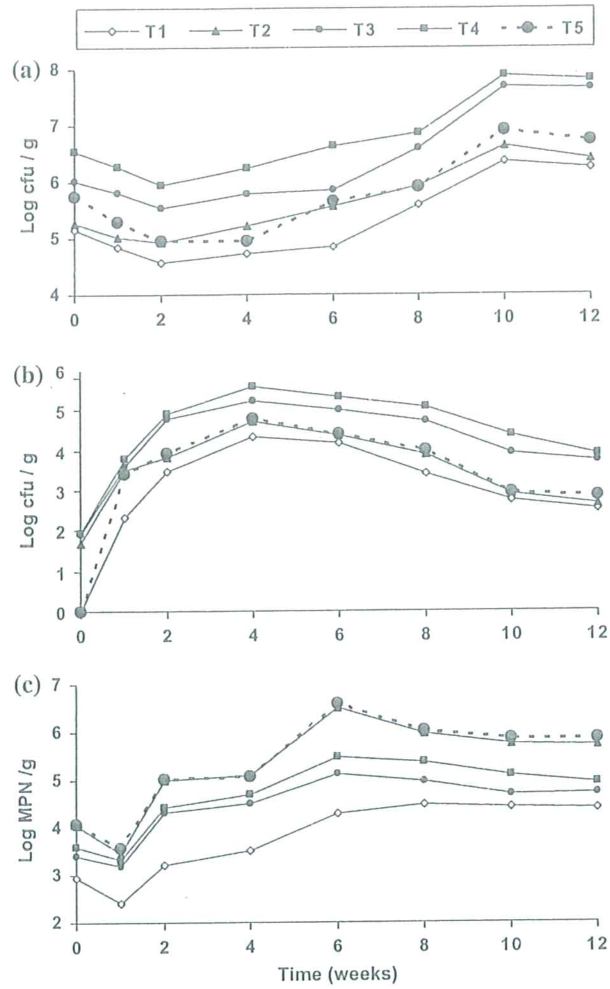

Fig. 5. Changes in counts of mesophilic fungi (a) thermophilic fungi (b) and cellulose decomposers (c) during co-composting of rice straw.

Table 3
Cellulase activity during co-composting of rice straw (mg reducing sugars/g dw/h).

Treatments	Time (weeks)							
	0	1	2	4	6	8	10	12
T1	13.0	27.6	65.3	81.0	74.6	63.3	45.3	40.6
T2	25.0	71.0	117.6	249.3	184.3	161.6	131.0	101.0
T3	15.3	35.6	80.0	180.3	126.6	119.0	93.3	70.0
T4	17.0	41.6	102.3	220.0	160.6	133.6	117.6	87.6
T5	32.3	81.3	134.6	279.6	193.3	182.3	156.0	116.0
LSD	4.2092							

3.3.4. Humic substances and humification index

As composting progresses, the percentage of humic substances is expected to increase, in relative to total organic matter. Highly significant amounts of humic substances (humic and fulvic acids) were produced in composts of T4 and T5 (12.77% and 12.25%, respectively) comparing to other treatments. The humification index, the ratio of the humic acid to the fulvic acid (HA/FA), was used to evaluate the maturity of the composts (Table 5). In all the five treatments, the humification index recorded was greater than 1 (1.71–1.88), consequently, 12-week-old composts could be considered mature.

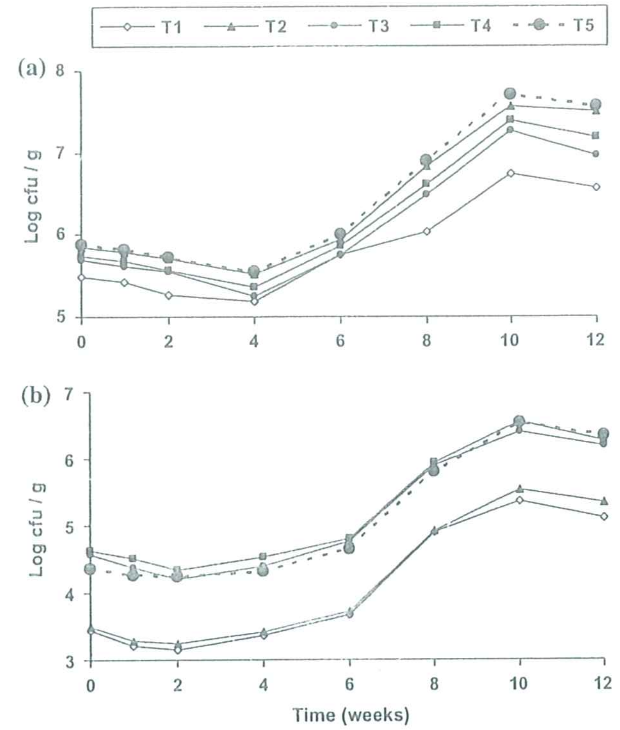

Fig. 6. Changes in counts of PDB (a) and PDF (b) during co-composting of rice straw.

3.3.5. Germination index (GI)

The GI values obtained ranged between 71.77% and 83.38% which indicating phytotoxic free composts without any significant differences between treatments Table 6.

4. Discussion

Co-composting of enriched rice straw with 10% rock phosphate and some agro-industrial by-products such as soybean residue (okara) and vinasse was confirmed to be a good alternative method for agric wastes management, generating safe and stable composts could be used for organic farming and/or as soil amendments. Monitoring the composting conditions during the bioprocess; and the changes in the physicochemical characteristics confirmed the succession of microbial population depending on the temperature of each phase in all the five composting treatments. Four typical phases of composting were evidently observed during the bioprocess: short initial mesophilic phase, thermophilic phase, cooling phase and maturation phase. In early stage of composting, bacteria were thrived as the major fast growers responsible for the initial decomposition of organic matter and the generation of heat, but actinomycetes and fungi exhibited dilatory progress and thence, weak competitors. While tardily, they keep growing because of their unique capability of decomposing complex materials in the later stage of composting process when temperature dropped to mesophilic condition (Saludes et al., 2008).

Although, it was necessary, as reported by Saludes et al. (2008), to control the process temperature particularly during the cooling phase in order to maximize the effectiveness of fungi and other main decomposers in breaking down the lignocellulosic components. An early study of Waksman et al. (1939) exhibited that the highest degradation occurred at 50 °C, while the degradation was to some extent lower at 28 and 65 °C. Later on, in (1995) Tomati and his co-workers confirmed that, 70% of lignin was degraded

Table 4
Initial (*I*) and final (*F*) values of total and available forms of phosphorous (P_2O_5) and potassium (K_2O) in the produced composts.

Treatments	Phosphorous (P)				Potassium (K)			
	Total (%)		Available (ppm)		Total (%)		Available (ppm)	
	I	*F*	*I*	*F*	*I*	*F*	*I*	*F*
T1	1.23	1.47	418.33	725.66	0.652	0.821	228.66	323.0
T2	1.27	1.76	425.33	858.0	0.632	0.925	238.0	398.66
T3	1.21	1.62	430.33	808.0	0.706	0.914	227.33	377.33
T4	1.38	2.01	432.66	987.33	0.720	0.966	246.33	433.33
T5	1.41	1.95	419.0	965.0	0.726	0.953	240.33	436.33
LSD	0.963		29.951		0.031		17.538	

Table 5
Humification parameters of the produced composts.

Treatments	Humic acid (HA) (%)	Fulvic acid (FA) (%)	Humification index HA/FA	Humic carbon (%) (HA + FA)	HC/OC (%)
T1	5.17	2.77	1.86	7.94	21.67
T2	7.07	6.90	1.81	10.97	30.83
T3	6.03	3.51	1.71	9.54	27.54
T4	8.20	4.57	1.79	12.77	38.76
T5	8.0	4.25	1.88	12.25	35.61
LSD	0.775	1.1971			

Table 6
Effect of different compost extracts on germination of radish seeds.

Treatments	Parameters				
	Average no. of geminated seeds	Growth index *G* (%)	Average root length (cm)	Root length index *L* (%)	Germination index (GI %)
Control (distilled water)	20.0	–	9.0	–	–
T1	17.0	85.0	7.6	84.44	71.77
T2	18.66	93.33	8.0	88.88	82.95
T3	17.66	88.33	7.5	83.33	73.60
T4	19.00	95.0	7.9	87.77	83.38
T5	18.33	91.66	7.8	86.66	79.43
LSD	4.278		1.0946		12.596

during 35 days when the temperature of the compost was kept at 50 °C, whereas only negligible degradation occurred later during compost maturation. According to these studies, it seems probable that sufficient duration of the thermophilic phase is an important factor in the compost environment.

Intense microbial activity led to organic matter mineralization and water loss resulting in a decrease in the piles size or composting mixtures, and simultaneously the C/N ratio; inoculation of composting mixtures enhanced the biodegradation of recalcitrant substances. The maximum cellulose decomposers coincided with cellulase activity, OM losses, an increase in the amounts of total and available P and K were recorded for pile received both manure and composite inoculum and supplemented with vinasse. It had been reported that most of the solubilized P was immobilized in the microbial cells which resulted in an increase in organic P content of the compost. This microbial (organic) P acts a slow release fertilizer and provides available P to the plants for a longer period instead of fixation and/or precipitation in soil minerals as in case of conventional water-soluble P-fertilizers (Zayed and Abdel-Motaal, 2005; Biswas and Narayanasamy, 2006).

The continuous decrease in the EC values from the starting of composting process might be attributed to the reduction of water-soluble substances and the volatilization of ammonia as well as precipitation of mineral salts during the bioprocess. The ultimate EC values of the obtained composts were less than 1.5 dS ml^{-1} which made the produced composts acceptable as soil amendments (Watson, 2003).

Numerous studies have already shown the relationship between pH changes and nitrogen transformation (Aparna et al., 2007; Saludes et al., 2008). In the present work, highest pH values coincided with highest content of NH_4^+–N and lowest NO_3^-–N were observed during the peak of thermophilic phase at the time of the most intense degradation and mineralization of organic nitrogen. The final NH_4^+–N contents of all produced composts were less than 250 ppm, below the maximum limit of 400 ppm recommended for mature compost (Zucconi and de Bertoldi, 1987). Moreover, the final values of nitrification ratios (NH_4/NO_3) were in accordance with those proposed by some authors (Gomez-Brandon et al., 2008).

In reality, the increase of pH values and ammonia levels during the degradation of proteins by ammonification and; the duration of exposure to a temperature above 55 °C for at least 16 consecutive days in inoculated piles were quite enough for sanitizing the produced composts from the sanitarian indicators, fecal coliform and salmonellae. The higher temperature may be due to introducing more active microorganisms through inoculation which increased the rate of organic matter decomposition. The obtained results are generally in agreement with those obtained previously (USEPA, 1993; Tiquia and Tam, 1998; Hanajima et al., 2006).

Maturity and stability are expressions often used in description of high quality compost. However, they are not easy to define and cannot be described in a single parameter. The degree of completion of the composting process can be evaluated by measuring various changes in the chemical, physical and biological properties of the substrate. Considering the key roles of microorganisms in the composting process, the microbiological properties as stability and maturity indicators are used. One problem associated with immature compost is continued decomposition in soil which can induce anaerobic conditions as the microbial biomass utilizes oxygen present in soil pores. This in turn can deprive plant roots of oxygen, lead to generation of H_2S and NO_2^- (Mathur et al., 1993). Further overturning or moisturizing did not result in any temperature rise, instead, remained at the ambient level indicating the depletion of degradable materials and subsequently maturation (Saludes et al., 2008).

The changes in the carbon-to-nitrogen proportion reflect the organic matter decomposition and the stabilization during composting. The C/N ratio is often used as an index of compost maturity. The ratio should be 15–25 (Watson, 2003). Consequently, the eventual C/N ratios of the present study showed that all produced composts are mature. However, in some cases C–N ratio may not be a good indicator of compost because it can level off before the compost stabilizes (Zmora-Nahum et al., 2005).

In the present work, the narrowest C/N ratios were achieved in treatments received vinasse and inoculated with composite inoculum including cellulolytic fungi (*Trichoderma* and *Phanerochate*) or buffalo's manure + composite inoculum which accelerated the decomposition of organic matter as corroborated by biodegradability coefficients (K_b). In this concern, the initial C/N ratio of co-composting mixtures was adjusted to about 30/1, the ideal value to accelerate the microbial decomposition of organic matter as recommended by Hansen et al. (1990). What's more, specific microbial strains or combinations to enhance the degradation of relatively recalcitrant materials were used. It had been documented (Diaz et al., 2002) that vinasse containing carbon and nitrogen in highly biodegradable forms which helping in the proliferation of microbial population and would be the best compromise to optimize the composting process and obtain a high quality product only when added in a moderate amount (10–20%). Beside, its acidic nature can minimize NH_3 losses due to the immobilization of NH_4^+ in the composting material (Whitely and Pettit, 1994). In addition, total nitrogen can also be increased by the activities of nitrogen-fixing bacteria at the end of the composting process (Bishop and Godfrey, 1983).

The germination index (GI) is a factor of relative seed germination and relative root elongation. It had been proven to be one of the more sensitive parameters, which is able to account for both low toxicity affecting root growth and high toxicity affecting germination and finally the degree of compost maturity. In general, the decrease of phytotoxicity during composting is resulted from the degradation of phytotoxic substances by microorganisms (Aparna et al., 2007). It had been proposed (Aggelis et al., 2002) that: if the GI < 25 then, the substrate is characterized as very phytotoxic, if 26 < GI < 65 then the substrate is characterized as phytotoxic, if 66 < GI < 100 then the substrate is characterized as non-phytotoxic; stable and can be used in agricultural purpose, and if GI >101 the substrate is characterized as phytonutrient–phytostimulant and can be used in agricultural purposes as fertilizer. According to that proposal, the produced composts are satisfied as phytotoxin-free, (GI values in the range of 71.77% and 83.38%), and safe for soil application. In a further trial (unpublished data), application of composts contained inoculum and vinasse to sandy soil, under green house conditions, at 5% (w/w) proved to be highly efficient in proliferating the growth of snap bean and surpassed the recommended dose of NPK.

With regard to humic substances as one of the maturity parameters, it is well established that increasing level of humic acids during the composting process represents the humification and maturity of compost (Francou, 2004; Aparna et al., 2007). Humification index reflects the degree of condensation of the aromatic nucleus of humus, indicating its maturity.

Finally, the produced composts showed a higher fertilizer value according to the characters proposed by the Council of Agriculture (2004), Executive Yuan (Taiwan). High quality composts were obtained from piles received vinasse and inoculated with composite inoculum or both composite inoculum plus buffalo's manure.

5. Conclusion

Monitoring the composting conditions during the bioprocess and the changes in the physicochemical characters confirmed that satisfactory composting occurred after 12 weeks. Although high quality products were obtained from inoculated piles supplemented with vinasse, it is palpable that buffalo's manure inoculation was the most potent, so it is recommended to accelerate the bioprocess. Moreover, inoculated composting piles enhanced P availability in the final product; thus, it met the growing interest in manipulating RP by biological methods in order to enhance its agronomic effectiveness for long period and offering a cheaper source of P-fertilizer which increase the feasibility of the produced compost.

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