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Physico-chemical aspects during the composting of municipal solid wastes and sewage sludge in a semi-industrial composting plant

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This study investigated at first the main physico-chemical and biochemical parameters during the co-composting process of municipal solid waste and sewage sludge under Tunisian pedo-climatic conditions, and secondly to assess potential toxic elements (PTEs) content of the finished compost and to evaluate its biological stability and maturity. Results show that the temperature revealed three classical steps, the mesophilic phase during the first 25 days, the thermophilic phase between 30 and 130 days and the cooling phase began after the 14th week in the two windrows W1 (100% of municipal solid wastes) and W2 (60% of municipal solid wastes and 40% of dried sewage sludge). Potential toxic heavy metal content appeared generally more important in W2 than W1, and both finished products of compost obtained in this study appeared to satisfy the most part of the recommended norm of agronomical use. The presence or absence of nitrifying activity allowed determining that the compost W1 is more matured than the compost W2.

Key words: Compost, temperature, C/N ratio, potential toxic elements, compost maturity.

INTRODUCTION

Biological treatment and valorization of various solid wastes can lead to some diversified important materials such as compost, biogaz, enzymes, various interesting industrial and sanitary metabolites, remarkable microbes, etc (Mokni et al., 2011; Venkata et al., 2011). All these various products may generate income. Several other biological processes were used for remediation of hazardous waste materials (Cheikh et al., 2010; Borin et al., 2006; Wang et al., 2012).

Composting of solid waste is one of the main technology of valorization of urban organic residues and it is a useful method of producing a stabilized product that can be used as a source of nutrients and soil conditioner in the field. The composted product has the advantage of improving soil structure, increasing soil organic matter,

suppressing soil-borne plant pathogens and enhancing plant growth. Immature composts may contain more growth inhibiting substances than mature composts. Some of these growth inhibiting compounds include salts, free ammonia, phenolic substances, heavy metals, and organic acids.

For optimum aerobic composting, moisture is necessary to support the metabolic processes of micro-organisms. Composting materials should be maintained within a range of 40 to 65% moisture. A higher percentage will increase anaerobic decomposition, while lower moisture content will slow down the composting process as micro-organisms die or become dormant.

However, the presence of heavy metal in the raw material is one of the most serious problems in order to use its final product in agriculture. Metals appear in the municipal solid waste stream from a variety of sources. Batteries, consumer electronics, ceramics, light bulbs, house dust and paint chips, lead foils such as wine bottle

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closures, used motor oils, plastics and some inks and glass can all introduce metal contaminants into the solid waste stream (Whittle and Dyson, 2002).

Composts made from recycled organic material will inevitably contain potential toxic elements (PTEs) (Ahmed et al., 2007a). In small amounts, many of these elements may be essential for plant growth; however, in higher concentrations they are likely to have a detrimental effect upon plant growth.

Carbon and nitrogen are the two fundamental elements in composting. The bacteria and fungi in compost digest or oxidize carbon as an energy source and ingest nitrogen for protein synthesis. Carbon can be considered the food and nitrogen the digestive enzymes. If the windrow has too little nitrogen, not enough N is available for the growth of micro-organisms and the composting process slows dramatically (Ben Ayed et al., 2007).

The numerous chemical and biological parameters used to evaluate compost stability and maturity, the most widely accepted are the microbial respiration test based on O_2 uptake or CO_2 progress (Wu et al., 2000; Wu and Ma, 2001).

During the composting process, compost stability is the results of microbial activity. The chemical composition and organic matter decomposition status of compost will play an important role in determining microbial activity (Wu and Ma, 2001; Iqbal et al., 2010).

The N of the waste undergoes a number of transformations. As a result of microbial activity, nitrogen (org-N, NO_3-N, NO_2-N, NH_4-N) gets progressively included into humic substances with aromatic structures. At the same time, the NH_4-N content, after an initial increase, starts to decline as a consequence of its eventual volatilization and oxidation into NO_3-N, NO_2-N (Hassen et al., 1998). The loss of nitrogen from the compost piles also depends on the diffusion of NH_3 through the windrow into the atmosphere and frequent turning of the windrow facilitates this NH_3-volatilization (De Bertoldi et al., 1982).

The aim of this study was to investigate the main physical-chemical and biochemical parameters during the co-composting process of municipal solid wastes and sewage sludge under Tunisian pedo-climatic conditions, to assess potential toxic elements (PTEs) content of the finished compost and to evaluate its biological stability and maturity.

MATERIALS AND METHODS

Preparation of windrows

The study was conducted between April and September 2004 corresponding to the two hot seasons in Tunisia (average ambient temperature of 30°C), and was performed in the composting plant of Beja located 100 km from the north of Tunis, using two types of windrows: (i) the first windrow W1 constituted 100% of municipal solid wastes, and (ii) the second windrow W2 composed of weight of 60% of municipal solid wastes and 40% of dried sewage sludge.

Municipal solid wastes from the Erriadh city of Beja were pre-selected at source (household pre-selection with average physical-chemical characteristics, humidity = 60%, organic matter = 30% dry weight and C/N = 32) and subjected to an accurately manual sorting in the plant, weighted and put on the composting platform, in the form of windrows of 7.5 x 3 x 1.5 m (length x width x height, respectively). Stabilized sewage sludge from anaerobic digestion of the urban wastewater treatment plant of Beja was integrated in the process at the dry state (with average physical-chemical characteristics, humidity = 30%, organic matter = 65% dry weight and C/N = 12.5) and primarily for the cover of windrow W2.

Temperature and humidity were controlled daily. When the mean temperature recorded in the different depths (depths 20, 40 and 60 cm) of the pile averaged 55°C (using a thermocouple iron-constantan type J), the windrow was turned and watered. These operations of turning and watering with tap water were performed almost twice monthly in considering ambient temperature.

Physico-chemical parameter determination

Electrical conductivity and pH were measured in 1:5 (deionised water: dry compost) extracts using a standard pH-meter (LPH 230T, Tacussel Electronique, France) and a standard conductivity-meter (Orion research, model 150, USA). Organic matter was determined by aching at 550°C for 2 h in a muffle furnace. The humidity was performed using 500 g of fresh solid waste according to the differential weight of fresh and dry waste at 105°C.

Total nitrogen was measured by the Kjeldahl digestion method involving two steps as recommended by Bremner and Mulvaney (1982) : i) digestion of the sample of the waste (2 to 5 g of waste) to convert organic and inorganic forms of N to ammonium-N and ii) determination of ammonium-N in the digest. Total organic carbon by the wet dichromate oxidation method according to the method of Nelson and Sommers (1982): the destruction of organic matter present in the waste (0.5 to 1 g) was performed chemically by potassium dichromate ($K_2Cr_2O_2$) and concentrated H_2SO_4 at elevated temperatures, 450°C for 3 h. The addition of H_3PO_4 to the digestive mix after the sample had cooled has been used to help eliminate interferences from the ferric (Fe^{3+}) iron that may be present in the sample; therefore a manual titrimetric quantitation was performed in the presence of an indicator solution ortho-phenanthroline ferrous complex ("Ferroin"). The excess $Cr_2O_7^{2-}$ is titrated with ferrous sulfate ($FeSO_4$) until color change occurs in the sample.

The dehydrogenase activity expressed as triphenylformazan unit was measured according to the method of Tabatabai (1982).

Solid waste microbial C and N biomasses were evaluated using the fumigation extraction method (Sparling and West, 1988). Duplicate samples (10 g) of the treated composts and control were fumigated with ethanol-free $CHCl_3$. Fumigated and non-fumigated compost samples were extracted with 0.5 M K_2SO_4 and organic C quantified by oxidation with 0.0667 M $K_2Cr_2O_7$ and subsequent back-titration of the unreduced dichromate. Microbial biomass C content was estimated as follows: $B_C = 2.64 \times E_C$, where E_C is the difference between the organic C extracted from the fumigated and non-fumigated treatments (Vance et al., 1987). Total N in the extracts was determined according to the Kjeldahl method as described by Brookes et al. (1985). Biomass N (B_N) was calculated from the relationship $B_N = 0.68 \times E_N$, where E_N is the difference between N extracted from the fumigated and non-fumigated samples. Amounts of microbial biomass C or N are expressed (mg C or N/kg dry weight) and represent the average of three determinations.

Total heavy metal contents were measured by atomic absorption spectrophotometry (Perkin-Elmer, Model 560) after digestion of the samples in concentrated HNO_3-$HClO_4$ (2:1) according to the
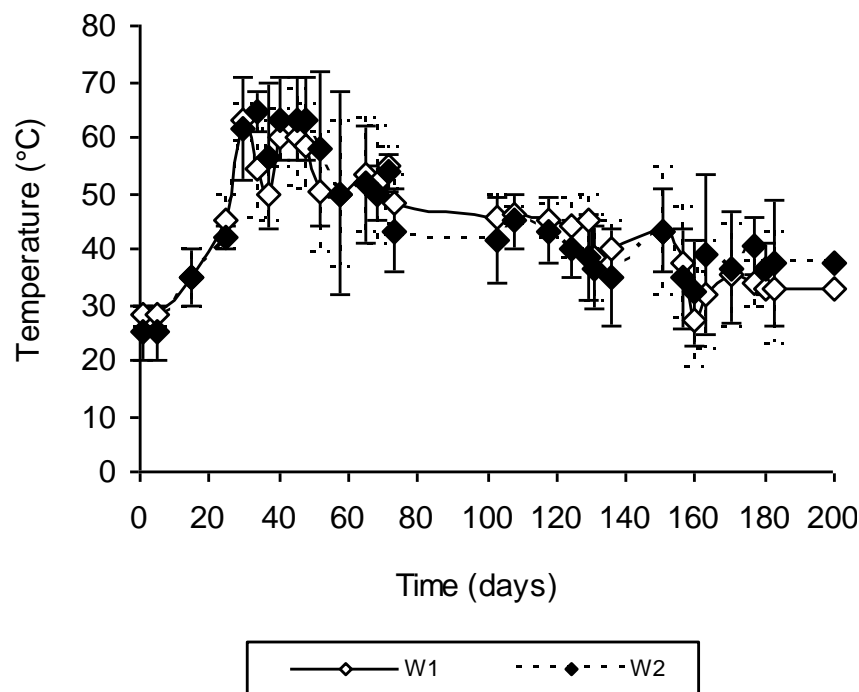
Figure 1. Progress of temperature over time in windrows W1 and W2. ± : Standard deviation, n = 3.

method of Hassen et al. (1998).

Carbon and nitrogen mineralization measurement

Carbon and Nitrogen mineralization/immobilization behavior was measured by controlled-environment aerobic incubation using 5:10 (Compost: Coarse sterile sand dry weight) and moisture maintained to 70% in a 0.5-L vessel. CO_2 progress rate was determined according to the procedure of Lannotti et al. (1994). The method used alkali trapping, followed by an acid-base titration for remaining OH from CO_3^{2-} formation. This product is formed when the CO_2-laden gas contacts an alkali absorber. The amount of CO_3 was measured by a titrimetric method using 0.1M HCl (Yusran et al., 2002). The released CO_2 was captured by 0.5 M NaOH solution and measured titrimetrically at regular intervals of 1, 3, 7, 10, 14, 21 and 28 days.

The change in mineral N (N_{min}: NH_4-N + NO_2-N + NO_3-N) concentration was measured in 2N KCl extracts at regular intervals of 0, 7, 14 and 28 days in a 1 M KCl extract by steam distillation (Hassen et al., 1998), in the presence of MgO (NH_4-N) or Devarda alloy (NO_2-N + NO_3-N). All analyses were carried out with three replicates per treatment.

RESULTS AND DISCUSSION

Temperature profiles

The fluctuation of temperature recorded in the two windrows during the composting process showed the three classic steps (Figure 1):

Mesophilic phase

Mesophilic microorganisms in waste windrows tended to increase during the first 25 days of the composting process, while the temperature increased gradually to reach 25-45°C as a consequence of biodegradation of organic compounds.

Thermophilic phase

This important step occurred between 30 and 130 days in the composting process, during which the temperature exceeds the tolerance limit of mesophilic microorganisms (≤ 45°C). The passage to the thermophilic phase for the two piles could be attributed to higher numbers of indigenous microorganisms which attack rapidly the soluble, the readily degradable compounds, the high content of available nutrients and the relatively small size of organic fraction particles. As the temperature rises above about 40°C, the mesophilic microorganisms become less competitive and are replaced by others that are thermophilic.

Cooling phase

The temperature began to decrease after the 19th week. This decrease resulted from a beginning depletion of
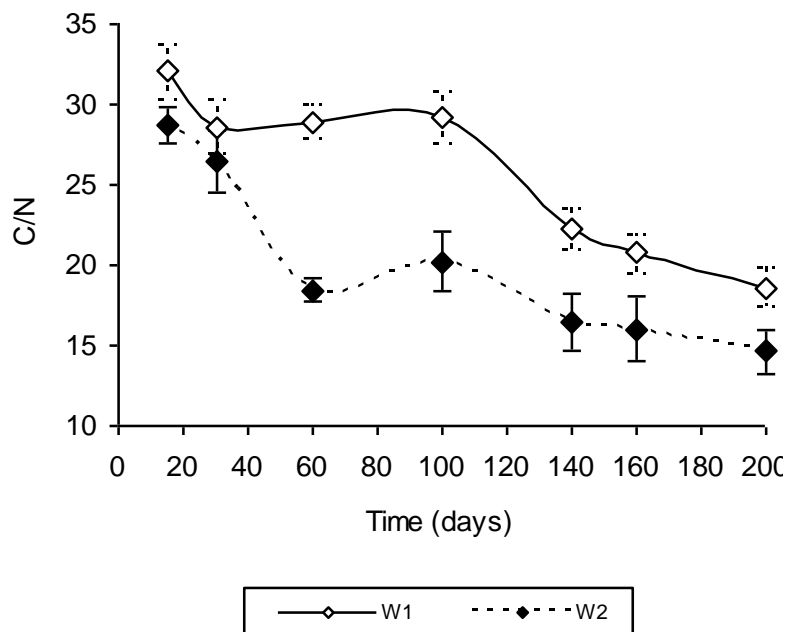
Figure 2. Progress of C/N ratio over time in windrows W1 and W2.

organic matters. During this phase, the C/N ratio in the two windrows tended to stabilize (Figure 2). By the end of the fifth month of composting, average temperatures inside the two windrows marked a real decrease with values of approximately 33°C. The temperature remained no change in spite of watering and turning of the windrows.

The rapid passage to thermophilic phase for the two windrows could be attributed to higher numbers of indigenous micro-organisms which attack rapidly the easily decomposable organic matter, the high content of available nutrients and the relatively small size of organic fraction particles (Jimenez and Garcia, 1991). The continuous decrease of temperature during the cooling and the maturing phase could be resulted from the exhaustion of available substrate and the replacement of the thermophilic microflora by a mesophilic one, which continues the partial degradation of bio-resistant compounds, fundamentally cellulose and in the lesser degree lining (El-Hussein et al., 2002).

Physico-chemical characteristics

Acidity

Ideally, the pH should be in the range of 6-8, to allow the highest rates of decomposition. If the pH is outside this range, microbial activity will be compromised and decomposition will be slowed or even stopped.

The pH values for windrow W1 showed a gradual decrease (pH 7.1 to 6.6) from the beginning until the 4th week of the composting process, this decrease produces

a slight acidic compost matrix, after that the pH starts to increase until the value (8.6) corresponding to the end of the composting process (Table 1). The pH of windrow W2 showed a notable increase from pH 6.6 to pH 8.3 at the end of the composting process. The decrease of pH resulted from the degradation of easily decomposable polysaccharides and the production and release of organic acids during the biooxidation step. The subsequent increase of pH may be referred to the metabolic degradation of these organic acids or their loss by volatilization and furthermore, due to the intensive proteolysis liberating ammonia compound (Faure and Deschamps, 1990).

To sum up, a consistent trend in pH was evident. The two windrows began the composting period at or below pH 7.0, and rose steadily until pH neared or exceeded 8.0.

Electrical conductivity

The change in value of electrical conductivity for the two windrows may be due to the characteristics and the amounts of the materials used for constructing the heap of wastes. The electrical conductivity showed gradual increases for the two windrows (Table 1). The relative fluctuation observed at the end of the composting process could be attributed to the nutrient ions release and fixation through the changes in proliferation of the aerobic microbial populations (El-Housseini et al., 2002).

Electrical conductivity might vary widely among waste sources, reflecting differences in windrow management, evaporative potential at each heap, and salt content of

Table 1. Progress of the main physical-chemical parameters over time in the two windrows W1 and W2.

Windrow	Time (days)	pH (water)	EC (ms/m)	OM (g/g WDW)	H (%)
W1	15	7.07 ± 0.31	62.08 ± 66.83	13.49 ± 1.02	61.92 ± 5.07
	30	6.64 ± 0.18	52.25 ± 39.14	17.34 ± 4.27	53.93 ± 8.12
	60	6.79 ± 0.02	36.61 ± 41.94	14.77 ± 1.53	56.91 ± 7.12
	100	6.61 ± 0.10	75.30 ± 101.78	13.63 ± 2.06	22.46 ± 3.13
	140	6.66 ± 0.08	70.41 ± 84.70	20.93 ± 1.60	11.26 ± 0.80
	160	7.22 ± 0.2	75.24 ± 96.54	10.81 ± 0.80	28.85 ± 0.19
	200	8.58 ± 0.01	68.57 ± 90.55	12.24 ± 0.82	22.34 ± 0.59
W2	15	6.56 ± 0.12	58.01 ± 74.44	20.44 ± 1.85	32.89 ± 3.30
	30	6.69 ± 0.06	64.97 ± 83.24	17.13 ± 0.65	23.19 ± 2.83
	60	6.93 ± 0.16	70.83 ± 90.37	14.37 ± 1.46	6.32 ± 0.91
	100	6.91 ± 0.05	74.78 ± 77.24	13.78 ± 0.51	27.45 ± 7.58
	140	7.11 ± 0.12	71.14 ± 81.26	13.65 ± 1.66	10.70 ± 0.99
	160	7.21 ± 0.09	73.39 ± 95.85	11.40 ± 0.14	22.77 ± 0.32
	200	8.34 ± 0.01	68.84 ± 75.37	11.45 ± 0.78	26.83 ± 0.31

n = 3, ± : Standard deviation, EC: Electrical conductivity, OM: Organic matter, H: Humidity.

the original composting materials (particularly evident with the inclusion of sewage sludge to windrow W2).

Organic matter

The organic matter and organic carbon concentration in the two windrows W1 and W2 decreased notably over time during composting (Table 1), pointing to degradation of the organic materials during the process. This organic matter degradation led to an increase of electrical conductivity and so the production of inorganic compounds. The total nitrogen also increased because of the concentration effect caused by the strong degradation of the labile organic carbon compounds, which reduced the weight of the composting mass. The concentration of total nitrogen usually increases during composting when volatile solids (organic matter) loss is greater than the loss of NH_3 (Witter and Lopez-Real, 1987).

C/N ratio

The carbon to nitrogen (C/N) ratio of the composting material is always considered as an indication of nitrogen availability in the process of biological degradation. The C/N ratio is the ratio of total organic carbon to total nitrogen. Total organic carbon is the carbon fraction of organic matter. Total nitrogen includes organic and inorganic nitrogen. The inorganic nitrogen fraction is dominated by ammonia nitrogen NH_4^+-N and nitrate nitrogen NO_3^--N.

The micro-organisms which decompose the wastes require a supply of nutrients, mainly carbon and nitrogen. The wastes itself supply these nutrients, but they must be

present in the correct balance for the process to proceed efficiently. If the C/N ratio is above or below the optimum range (25-20), composting proceeds slowly and the excess carbon is converted to CO_2 or the excess nitrogen is converted to ammonia, until the correct balance is restored. High levels of ammonia are undesirable because it may be toxic in the waste heap and is a net loss of nitrogen if released as a gas.

At the beginning of the composting process, the C/N ratio was generally higher in the windrow freer of sludge (W1) than in the one with sewage sludge (W2) and its value is 32 and 28.5, respectively (Figure 2). A net decrease was observed subsequently to reach at the end of the process the values of 18.6 in windrow W1 and about 14.6 in windrow W2, respectively. This result is certainly due to the special composition of sewage sludge used in the windrow W2. Many authors reported that a C/N ratio below 20 is indicative of an acceptable maturity (Jimenez and Garcia, 1991; Iqbal et al., 2010).

The substrate is therefore loaded with degradable carbon. Compost must lead to a very steady and slowly biodegradable compound (low C/N). During fermentation, nitrogen accumulated by the first group of micro-organisms will serve to the next microbial groups. Thus, amino acids resulting from proteolyses of protein reactions will be used for the new protein synthesis and the loss of nitrogen is generally limited. Monosaccharides are easiest to degrade. At the start, degradation of monosaccharide causes a net decrease of carbon content and contributes to the rising of temperature. The remaining carbon is incorporated into difficultly biodegradable substances, humic substances.

At the end of the composting process, the C/N ratio is equal to 18.6 in windrow W1 and to 14.6 in windrow W2, which is near to the 12 normally accepted as indicating a
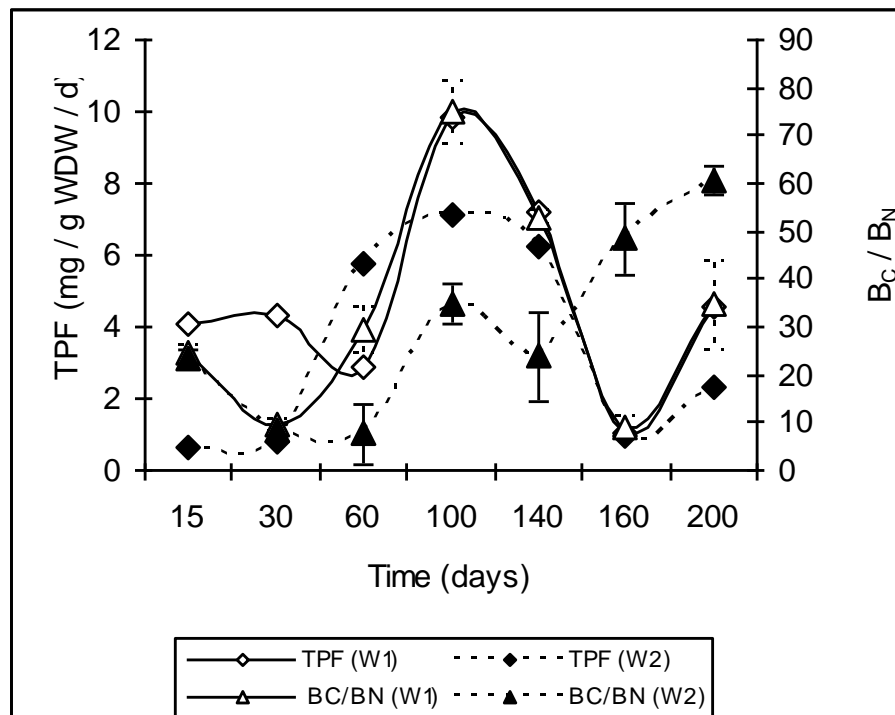
Figure 3. Progress of dehydrogenase activity and BC/BN ratio over time in windrows W1 and W2.

good degree of composting maturity (Jimenez and Garcia, 1992; Bernal et al., 1998).

To summarize total N concentration was highly variable during composting, but an overall pattern was evident. Extracts of mixed sewage sludge and municipal solid waste showed high total N concentration during the early stages of composting. As composting proceeded, NH_4-N levels generally declined, with NO_3-N increasing substantially in a few late samples. The degree of N immobilization generally decreased over time, even after more than 200 days of composting.

Dehydrogenase activity

The dehydrogenase activity generally showed an appreciable increase during the period extending between 50 and 140 days and corresponding to the thermophilic phase of the composting process. The registered values of the dehydrogenase activity during this phase were an average of 8 and 7 mg (triphenylformazan) TPF / g waste dry weights (WDW) / day (d) for windrows W1 and W2, respectively (Figure 3). This activity was very weak during the mesophilic and the cooling phase, and was generally below 4 mg TPF / g WDW / d for the two windrows. On the other hand, this activity was slightly higher in the windrow freer of sludge than in the one with sludge.

On the other side, biological oxidation of different organic substances is generally a dehydrogenation process and there are many enzymes catalyzing dehydrogenation. The dehydrogenase enzyme systems, that are an integral part of the microorganisms, apparently fulfil a significant role in the oxidation of organic compounds as they transfer H from substrates to acceptors. Several different specific dehydrogenase systems are involved in the dehydrogenase of soils for example. The dehydrogenase activity is proposed as an indicator of the maturity of compost and a net decrease of this activity is synonymous of a good stability of biodegradable substances (Forster et al., 1993). Our result shows that the dehydrogenase activity generally showed an appreciable increase during the period extending between 50 and 140 days and corresponding to the thermophilic active phase of the composting process. The dehydrogenase activity registered in composts W1 and W2 is superior to the threshold of 0.83 mg TPF / g WDW / d proposed by Forster et al. (1993). Serra-Wittling et al. (1995) reported a value of 2.3 mg TPF / g WDW / d, in solid waste compost of three months of maturity. As mentioned by Skujins (1976), the apparent dehydrogenase activity showed the average activity of the dynamic microbial population and depends on the total metabolic activity of microorganisms. Frankenberger and Dick (1983) reported that dehydrogenase activity often is correlated with microbial respiration when

exogenous C sources are added to soils. In addition, some substances may seriously affect the activity of dehydrogenase in composts, mainly volatile compounds frequently found in solid wastes such as $CHCl_3$, benzene and toluene. These latter strongly inhibit the activity of dehydrogenase. Ladd (1978) reported that some alternate electron acceptors seemed to stimulate (Fe_2O_3, MnO_2, SO_4^{2-}, PO_4^{3-}) or to inhibit the apparent dehydrogenase activity in the soil (NO_3^-, NO_2^-).

B_C/B_N ratio

The B_C/B_N ratio represents the biological activity balance of the compost and a high B_C/B_N ratio is equivalent to a high microbial heterogeneity, diversity and synonym of an important biological activity (Miller, 1991; Belete et al., 2001; Jedidi et al., 2004; Bouzaiane et al., 2007). According to Figure 3, this ratio showed a real increase during the thermophilic phase in the two windrows. A minimal value corresponding to the beginning of the cooling phase is recorded and followed by a clear increase of this B_C/B_N ratio during the maturation phase.
The microbial biomass is generally defined as the part of the organic matter in the soil or sediment that is formed by living microorganisms smaller than 5-10 μm^3. It is an estimate of the amount of solid-phase C or N tied up in living (B_C, B_N) and dead soil microbes and is essentially an estimate of bacteria and fungi. According to Figure 3, this B_C/B_N ratio increases appreciably during the thermophilic phase in the two windrows and this increase corresponds to a high microbial diversity and equivalent to an important activity.

Heavy metals

Compost is often contaminated by potentially toxic heavy elements (PTEs) due to inadequate separation of biodegradable fractions from non-degradable or inert materials. Organic matter absorbs these elements when exposed during the refuse collection, sorting and composting processes. As a consequence, potential utilization of compost might be restricted. Therefore, it is essential to monitor the magnitude of heavy metal element contamination in soils, which requires detailed chemical analysis of the soil.

During the composting, some chemical reactions are of the origin of the compost contamination by heavy metals according to the increase of temperature and the loss of matter. On the other side, heterogeneity of the waste materials contributes to complicate the total heavy metal determination and the dispersion and the large variability of the result found.

Total heavy metal registered in this study appeared more important in the compost of windrow W2 than in the one of windrow W1 (Table 2). Wastes of the windrows

W1 and W2 presented an important quantity of Zn, and showed a very weak quantity of seed. This important content of Zn in the wastes could be explained by the abundance of this element in the crude waste and by the nature and the fate of this element in the organic matrix since it will be more associated with the more soluble fractions of organic matter, such as non humic fractions of solid wastes compost. This characteristic facilitated its removal during the different steps of composting by leaching. The opposite effect was shown for Cu known to have a high relative chemical affinity towards humic substances (Sanchez-Monedero et al., 2004).

Consequently, the concentration of copper showed in general a net increase during the different periods of sampling for the two windrows (from 24.54 to 73.25 mg kg^{-1} WDW) for W1 and (from 42.32   to 77.39 mg kg^{-1} WDW) for W2, respectively. Since in general, humic materials will be abundant in the earlier stages of the composting process, so this home materials will be rich and loaded of copper. Unlike zinc that will be removed in a leachiate fraction during the earlier stages of the composting process, copper associated to hard humic fraction accumulated during the later and advanced stages of the process.

The concentration of cadmium appeared to increase from 4.80 to 9.81 mg kg^{-1} WDW for windrow W2. The only possible explanation for detecting an increase in metal concentration could be that the cadmium is all but retained within the organic fraction whilst the mass density of the composting material increases. Thus, an apparent increase in concentration is observed.

The concentration of chromium decreased from 93.3 to 16.7 mg kg^{-1} WDW for windrow W1 and from 30.2 to 2.3 mg kg^{-1} WDW for windrow W2. Chromium is classed as a "hard" metal and as such, these metals are generally less mobile. However, the results obtained from this investigation show that chromium was steadily released from the solid fraction. The fate of chromium is very much dependent upon the form in which it exists within the material. In its metallic form it is quite stable, resisting attack from environmental processes. However, in either the trivalent or hexavalent form chromium exhibits much more chemical activity as well as solubility and hence potential mobility and subsequent removal from the solid fraction.

The concentration of lead decreased from 99.5 to 41 mg kg^{-1} WDW for windrow W1 and from 112.5 to 99.5 mg kg^{-1} WDW for windrow W2. This would tend to indicate that lead is more mobile during the latter stages of the decomposition process (Whittle and Dyson, 2002). It might be possible to infer from this that either the decomposition process favors the formation of the more soluble lead species (the hydrated oxide and nitrate), or an insoluble species are removed via leaching liquors, in suspension. To substantiate the former, it is known that lead oxides will hydrolyze as the pH is raised, thereby forming the soluble hydrous derivative.

Table 2. Variation of heavy metals over time in the two windrows W1 and W2.

Windrow	Metal	Time (days)						
		15	30	60	100	140	160	200
W1	Cu	24.54 ± 5.18*	27.17 ± 5.78	17.18 ± 3.43	42.83 ± 7.37	28.06 ± 9.73	55.49 ± 3.63	73.25 ± 2.66
	Cd	4.97 ± 9.28	0.75 ± 1.50	1.99 ± 3.98	0.75 ± 1.50	2.78 ± 3.8	5.02 ± 7.10	0.86 ± 0.15
	Cr	93.26 ± 144.73	47.85 ± 55.04	16.68 ± 1.44	24.15 ± 5.76	17.41 ± 3.05	28 ± 7.54	16.68 ± 1.44
	Pb	99.47 ± 47.82	73.78 ± 53.10	59.31 ± 16.42	66.19 ± 25.54	80.01 ± 56.94	40.99 ± 9.53	102.97 ± 1.43
	Zn	95.60 ± 4.15	264.23 ± 53.90	131.24 ± 3.69	177.82 ± 19.68	100.30 ± 30.65	173.50 ± 4.15	81.40 ± 11.41
	Ni	84.34 ± 90.37	55.50 ± 52.65	20.66 ± 7.62	45.81 ± 4.69	27.47 ± 11.55	51.48 ± 26.65	0.10 ± 0.10
W2	Cu	42.32 ± 9.60*	37.37 ± 8.47	79.75 ± 6.38	76.31 ± 4.52	71 ± 12.54	68.33 ± 0.96	77.39 ± 7.5
	Cd	4.80 ± 4.78	4.73 ± 4.83	8.47 ± 7.70	4.98 ± 5.08	3.04 ± 6.08	9.81 ± 8.29	0.07 ± 0.11
	Cr	30.15 ± 7.97	21.18 ± 9.05	26.67 ± 7.51	31.92 ± 5.82	26.73 ± 11.69	31.53 ± 12.39	2.32 ± 2.07
	Pb	112.53 ± 88.46	52.75 ± 35.11	75.05 ± 40.07	122.20 ± 17.42	64.28 ± 54.37	99.45 ± 29.90	82.16 ± 7.75
	Zn	141.90 ± 23.69	150.70 ± 11.59	200.88 ± 12.56	191.29 ± 12.12	213.08 ± 17.77	190.17 ± 11.42	89.15 ± 6.51
	Ni	44.91 ± 10.11	42.61 ± 8.65	48.61 ± 14.42	62.85 ± 16.56	60.80 ± 20.55	61.34 ± 19.90	0.40 ± 0.10

* mg / Kg WDW, n = 3, ± : Standard deviation, Cu: Copper, Cd: Cadmium, Cr: Chromium, Pb: Lead, Zn: Zinc, Ni: Nickel.

The concentration of zinc decreased from 95.6 to 81.4 mg kg^{-1} WDW for windrow W1 and from 141.9 to 89.2 mg kg^{-1} WDW for windrow W2. This decrease was not seemed to be significant, hence it is assumed that there was just a modest release of zinc, with much remaining immobile and held within the solid fraction (Ahmed et al., 2007b). The results of this study may at first be somewhat surprising considering the amphoteric characteristics of zinc and its compounds and their relative high solubility across a wide pH range. It could, therefore, be assumed the zinc was correspondingly mobile and hence liable to leaching. The implication of this being that leaching of the zinc is prevented, either chemically or physically, promoting retention within the solid fraction (Ahmed et al., 2007b). In considering this, there appears to be little evidence to suggest that stable inorganic or organic-zinc compounds are formed which enable the zinc to be retained within the solid fraction.

The concentration of nickel decreased from 84.3 to 51.5 mg kg^{-1} WDW for windrow W1 and from 61.3 to 44.9 mg kg^{-1} WDW for windrow W2. Nickel in organic waste materials was mostly associated with the oxidisable and the residual phases. Such high availability of nickel has not previously been observed in organic waste materials (Tisdell and Breslin, 1995; Qiao and Ho, 1997; Pérez-Cid et al., 1999). Nickel was generally reported to be largely associated with the oxidisable and the residual phases, which was explained by the high stability of nickel complexes with organic ligands (Qiao and Ho, 1997).

Since compost is designated to be used in the agricultural and horticultural sectors, there is considerable concern over possible PTEs contamination (Zhao et al., 2012). So both finished products of compost obtained in this study appear to satisfy the most part of the norm of agronomical use recommended in various countries as Canada (CAN / BNQ 0413-200/1997). These Canadian norms point out for instance the following values in mg kg^{-1} WDW for different commonly available metals in waste: Zn = 500, Cd=3, Cr =210, Pb =150 and Ni = 62

Compost maturity

Compost maturity is the degree or level of completeness of composting. In mature compost, raw starting materials have been sufficiently decomposed under controlled moisture and aeration conditions, resulting in a stable organic amendment product. "Stability" refers to a specific stage of decomposition or a state of organic matter during composting. However, the term stability is often used interchangeably with maturity. They are not really equivalent; stability

and maturity are terms often used to characterize compost, yet compost specialists have varying opinions about what these terms mean (*Maturity*: biological activity has slowed, as most remaining molecules are difficult to break down any further; *Stability*: biological activity has slowed, but this may be due to a variety of factors, the material may be matured, or it may lack adequate nitrogen or water for the process to continue. In this case, if the missing factors are added, biological activity will resume at active levels).

The successful use of compost depends on its degree of maturity and stability, since the application of an immature product can induce anaerobic conditions (Mathur et al., 1993) or produce phytotoxic effects. As above mentioned, compost maturity refers to the decomposition of phytotoxic compounds produced in the earlier phases of the composting process (Wu et al., 2000) and the production of stable humus formed as a consequence of the modification of organic matter (Robin, 1997). Both parameters are influenced by the nature of the refuse, its structure and composition and its biodegradability.

Several indicators have been elaborated to evaluate this maturity of which several rest on the compost microflora and its activity. The presence of nitrates is only observed in the mature compost; active nitrifying microflora in compost is therefore synonymous of maturity. The biodegradability of the organic matter of compost (release of CO_2-C) decreases with the increase of compost maturity (Nicolardot et al., 1986; Lannotti et al., 1994).

In this study, composts of different ages, sampled after 15, 30, 60, 100, 140, 160 and 200 days of the process of composting, are used and compost C (CO_2-C) and N (NO_3-N and NH_4-N) transformations were evaluated during an aerobic incubation of 28 days in a sandy loam soil (Compost was applied at 500 g total kg^{-1} soil).

Carbon dioxide progress during incubation

Figure 4 shows compost C transformations during 28 days in aerobic incubation and in a sandy loam soil indicated mainly two biological phases: The first phase characterized by an intense activity that starts some hours after the beginning of incubation of solid waste samples and continues until the tenth days; this increase corresponded to the rapid biodegradation of easily degradable organic substrates. The second phase appeared later throughout the 10th to the 28th days of incubation and showed a slowing biological activity marked by a net decrease in the CO_2-C production. This period corresponded to the depletion and lack of easily degradable substances. So, organic carbon mineralization decreased in parallel to the progress of the composting process. Therefore at the start of the composting process, the CO_2-C showed the highest rate

of production because the fresh organic wastes have a high proportion of easily degradable organic matter.

Nitrifying activity during incubation

Nitrates are formed as a consequence of microbial oxidation of ammonia by nitrifier microorganisms of which the presence and the activity are indicators of the compost maturity. The comparison of the NH_4^+-N decrease and the NO_3^--N increase during incubation permits to evaluate the potential activity of compost nitrification.

During the first 16 days of the composting process, the windrow W1 presents a slow NH_4^+-N concentration. At the end of composting, the NO_3^--N concentration is superior to the NH_4^+-N concentration (Figure 5).

The NH_4^+-N concentration decreased during the composting process for the windrow W2. Parallel to this fall in the NH_4^+-N concentration, the NO_3^--N levels increased due to nitrification (Figure 6). During the 28 days of incubation, the speed of NO_3^--N appearance is slower than the NH_4^+-N disappearance. A part of NH_4^+-N is probably immobilized.

This criterion for the presence or absence of nitrifying activity allowed determining that the compost of windrow W1 is more matured than the compost of windrow W2.

The initial NH_4^+-N concentration was high and increased during the thermophilic phase as a result of organic-N mineralization, which also caused a rise of pH. After this phase, the NH_4^+-N concentration decreased. Parallel to this decrease of the NH_4^+-N concentration, the NO_3^--N levels increased due to nitrification, while the pH value decreased, due to the protons released by this process. There was hardly any nitrification during the thermophilic phase, because temperatures greater than 40°C inhibit the activity and growth of nitrifiers (Bernal et al., 1998).

The experiment could be divided in two parts, mainly conditioned by the ammonium ions progress. During the first period, the ammonium concentration remained high, providing sufficient materials for nitrifying bacteria. During the second period, a nitrate concentration increase was observed. This appearance of nitrate, differed with the time, could be attributed to a more or less rapid synthesis dynamic of this ion, according to the environmental conditions.

The continuous decrease in the total nitrogen content (Table 1) during the bio-oxidation period could be attributed to its volatilization as ammonia and by leaching as nitrate after moistening the windrows (El-Housseini et al., 2002). The little increases in nitrogen during the later stage (maturation phase) may be referred to the non-symbiotic nitrogen fixation activities. As composting proceeded, NH_4-N levels generally declined, with NO_3-N increasing substantially in a few late samples. Air-drying samples before extraction yielded quite different values,
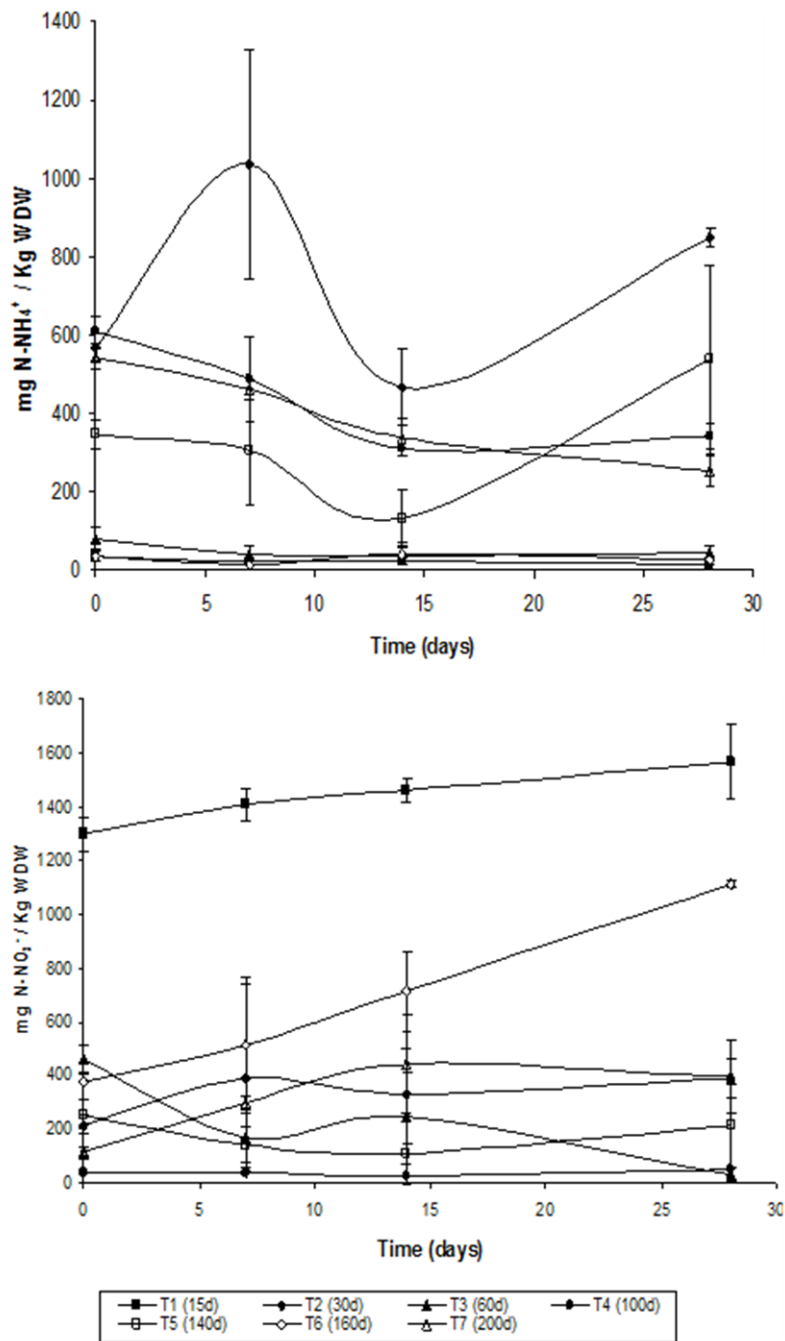
Figure 4. Carbon dioxide release from samples of compost incubated at 70% soil moisture content and 28°C for the two windrows W1 and W2.

with NH_4-N decreasing dramatically and NO_3-N generally increasing.

To conclude since compost maturity is not described by a single property, maturity is best-assessed by measuring two or more parameters. The maturity index uses widely used and commonly accepted laboratory methods. Compost stability is evaluated based on respirometry (the measurement of carbon dioxide evolved or oxygen consumed by microorganisms within the material), which provides an estimate of potential biological activity. Higher rates of carbon dioxide release or oxygen consumption will reflect less stable composts. Compost may then be rated as very mature, mature, and immature. The finished compost described later in this study have also been classed as mature (W1) or less mature (W2), based both on the presence of NO_3-N and NH_3-N in the sample and CO_2-C release. Subsequently a stable to the very stable finished product will prevent
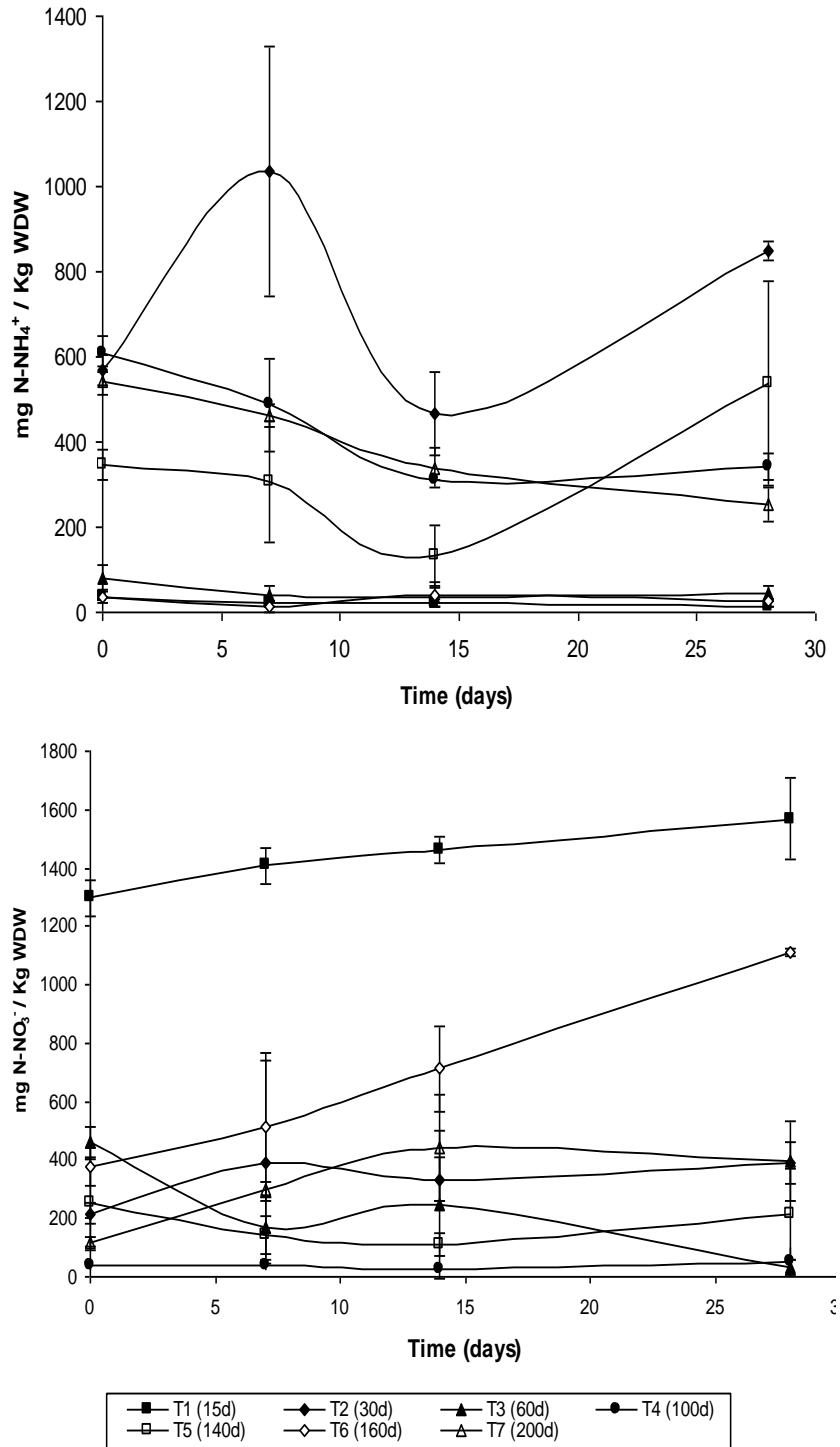
Figure 5. Nitrifying activity release from samples of compost incubated at 70% soil moisture content and 28°C for the windrow W1.

nutrient tie-up and maintain or enhance oxygen availability in soil or growth media. Immature composts may contain high amounts of free NH_3-N, certain organic acids, or other water-soluble compounds that can limit seed germination and root development.

Conclusion

In conclusion composting corresponds to the implementation of a very pointed technology. If at the heart, this phenomenon is simple (action of microorganisms
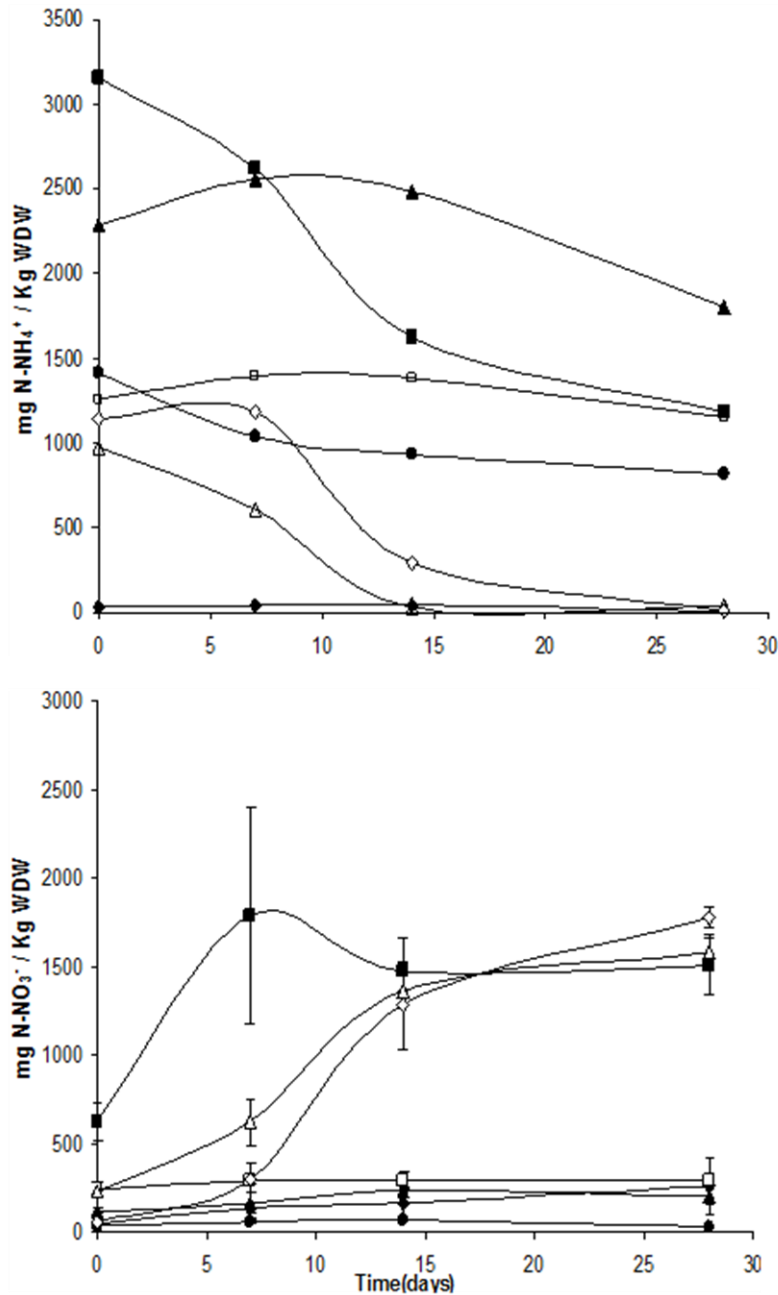
Figure 6. Nitrifying activity release from samples of compost incubated at 70% soil moisture content and 28°C for the windrow W2.

in an unprompted manner on organic matter), it requires in fact a big know-how since this basic reaction will be directed by the control of certain parameters (temperature, oxygen, humidity). It is not only a question of making degrade organic matter at the disposal by microorganisms but also degrading it "efficiently" in order to be able to obtain a product - the compost - with certain internal qualities which go allow to promote it. The application of this technique, ancestral in its principle and its use, was newly "rediscovered" under the pressure of a policy anti-wasting and was translated into practice by the installation of platforms of composting. Distributed on the whole world territory, they have as objective to treat organic waste produced as well by household as industries (wood, food processing industries) or agrarian farms. Even if every unit has its own characteristics according to the type of treated waste, they remain not less based on the same schema of organization, itself directly resulting from the technology of composting. Consequently, composting is a complex dynamic

process in which organic matter is converted to CO_2, water, biomass and humus by microbial action. Indeed, the change of the main physic-chemical characteristics indicates the great stability and maturity of the finished product.

Mature compost devoid of major potentially toxic elements when added to the soil directly may affect more and less, almost all of these following factors such as pH, supply of mineral nutrient elements, organic matter and water content, composition of soil atmosphere and biotic factors (Huttl and Fussy, 2001). In many areas of the world, the major benefits derived from compost result from improved soil physical properties.

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