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Nitrogen Mineralization Kinetics and Nutrient Availability in Soil Amended with Composted Tea Leaves, Coffee Waste and Kitchen Garbage

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Abstract: An incubation study was conducted to assess the effect of composted tea leaves, coffee waste and kitchen garbage on the kinetics of net nitrogen mineralization and P, K, Ca and Mg availability. $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, Bray II P, the exchangeable cations, EC and pH were determined after 0, 7, 14, 21, 42 and 63 day. Inorganic N concentration in the amended soils was analyzed by a first-order model. The pH of the soil increased after 14-21 day of incubation and gradually decreased thereafter. EC values showed the following trend: composted tea leaves > kitchen garbage > coffee waste. The composts were highly variable in their N mineralization characteristics, but the peaks for mineralized N content were observed at early incubation times in all the composts, i.e., after 14-21 day because the composts had undergone maturation. Potential respective mineralizable N (N_0) content of the composted tea leaves, coffee waste and kitchen garbage was 18.8, 6.30 and 22.4 mg kg^{-1} dry soil and the respective rate constant (k) was 0.101, 0.199 and 0.255 day^{-1} . Rate of N mineralization for the composted tea leaves, coffee waste and kitchen garbage was 5.25, 9.10 and 38.6%, respectively, of the total N content. Composted kitchen garbage displayed the highest value for N release rate. P, K and Ca showed the following trend: composted tea leaves > kitchen garbage > coffee waste and Mg was composted tea leaves > coffee waste > kitchen garbage.

Key words: By-product, compost, N mineralization, phosphate, potassium

INTRODUCTION

In Japan, organic matter wastes have become a major issue for the land, air and water environments. According to the Ministry of the Environment, Government of Japan (2006), the total amount of food wastes from kitchen garbage and the food industries has shown a continuous increase and it was 19.7 Tg in 2003. The rate of waste recycle has also increased, but only 21% of the total waste was used as organic fertilizer or animal feed; the remaining 79% was incinerated and land-filled.

By-products from the food industry have often been used as organic composts. This improves the fertility of arable soils by increasing the soil organic matter content, enhancing the microbial activity and nutrient supply to the soil and eventually the nutrients can be recycled through the soil-plant system. Composted tea leaves and coffee waste are by-products of the beverage industry and recently, the waste amount of these has increased due to an increase in consumption.

However, the major concern in the continuous or abundant application of compost is the behavior of organic nitrogen that penetrates the soil; on eventual decomposition, the available N and excess NO_3 is leached into the ground water and contaminates it or is released into the air. To minimize these

effects, the amount of compost used should be fine-tuned in accordance with its ability to release the available nitrogen. For compost application to fulfill the nutrient requirements of a crop, information on the amount of nutrients mineralized following application is considered necessary. Hence, an accurate prediction of the amount of inorganic nitrogen that would be released from the soil on amendment with composted by-products is essential in the development of farming practices for maximizing N-use efficiency, minimizing negative effects of N on the environment, improving crop quality and increasing crop production.

There are many studies on N mineralization kinetics in soil amended with plant residues such as sugar beat leaf, wheat straw (Nordmeyer and Richter, 1985), wheat, lentil, rape (Janzen and Kucey, 1988), barley, ryegrass, white and red clovers, white cabbage, kale and haulm of oilseed rape, pea and potato and (Henriksen and Breland, 1999), corn, soybean, wheat (Kaboneka *et al.*, 1997) and grasses (Bloemhof and Berendse, 1995). In contrast, studies on those in soil amended with composts are relatively limited; these composts included olive mill sludge (Cabrera *et al.*, 2005), bio-waste (Nendel *et al.*, 2004), sewage sludge-cotton waste (Bernal *et al.*, 1998) and spent mushroom compost (Stewart *et al.*, 1998a) but not animal manures (Sørensen and Jensen, 1995). However, information on the N mineralization kinetics of composted kitchen garbage, tea leaves and coffee waste is limited and few studies have reported on the amount of P (Sinaj *et al.*, 2002), K, Ca and Mg released from the composts (Stewart *et al.*, 1998b). Previous studies on composted coffee bean waste investigated the composting process (Takemoto and Fujiwara, 1996) and disease suppression (Matsubara *et al.*, 2002; Hamanaka *et al.*, 2005) and those on composted tea leaves investigated the composting process (Sakai *et al.*, 2004) and effects on rice growth (Shu, 2005).

The objectives of this study were as follows: (I) to determine and compare the amount of N released from different by-product of composts such as tea leaves, coffee waste and kitchen garbage, (ii) to apply this data to a kinetic model of net nitrogen mineralization and (iii) to determine the amount of other inorganic nutrients that are released into the soils amended with the composts under controlled laboratory conditions.

MATERIALS AND METHODS

Soil and Composts

This study was conducted with upland soil [low fertile, Brown Forest Soils, Dystric Regosol (FAO/ UNESCO classification system), Typic Udorthents (USDA)], pH (H₂O) 6.30, that had the following properties (based on dry soil measurements): Electrical Conductivity (EC), 0.37 dS m⁻¹; total C content, 1120 mg kg⁻¹; total N content, 110 mg kg⁻¹; available P content, 1897 mg kg⁻¹; exchangeable K content, 624 mg kg⁻¹; exchangeable Ca content, 1449 mg kg⁻¹; exchangeable Mg content, 341 mg kg⁻¹; NH₄-N content, 2.00 mg kg⁻¹; NO₃-N content, 0 mg kg⁻¹ and cation exchange capacity (CEC), 16.4 cmol (+) kg⁻¹. The soil was obtained from the University Farm, Ehime University, Matsuyama Ehime, southwest Japan. The soil samples were sieved through a 2 mm mesh. Composted tea leaves and coffee waste were prepared from the by-products of beverage industries and the composted kitchen garbage was prepared by the Nagai Rainbow Plan Compost Center, Nagai-city, Yamagata Pref., Japan. Some chemical properties of the composts used are presented in Table 1.

Analytical Methods

Incubation and the Determination of N, P and K Content

Nitrogen mineralization of the composts was investigated in a laboratory by incubation under aerobic conditions. First, 20 g of air-dried soil was mixed with 2.0 g fresh composts (wt/wt) in a 50 mL plastic centrifuge tube (Polypropylene, Corning Inc., NY). Soil controls were run without any amendment. Subsequently, distilled water that amounted to 60% of the water-holding capacity of the

Table 1: Chemical properties of composts used

Properties	Composts		
	Tealeaf	Coffee	Kitchen
pH ¹	8.90	7.70	8.40
EC ¹ (dS m ⁻¹)	26.2	3.80	22.1
Total C (%)	32.4	42.2	17.1
Total N (%)	5.50	2.01	0.90
Avail. P ^t (%)	5.30	0.17	0.60
Exch. K (%)	2.70	0.44	1.60
Dry matter (% w/w)	62.0	51.0	53.0
C/N	5.90	21.0	19.0

¹The pH and EC were measured in the compost suspension [1:2.5 (w/v) and 1:5 (w/v), respectively, fresh weight basis].

^tDetermined by Bray II method.

soil was added and the samples were incubated in the dark at 30°C. The moisture content was periodically checked by measuring the weight and was maintained by adding distilled water when required. At the beginning of the incubation and at 7, 14, 21, 42 and 63 day, NH₄-N and NO₃-N were extracted with 2 M KCl and their amounts were determined by steam distillation (Bremner, 1965). Total N content was calculated by adding the amount of NH₄-N, NO₂-N and NO₃-N. Exchangeable cations, i.e., Ca, K and Mg, were extracted with ammonium acetate-strontium chloride solution (Chapman, 1965); the available P content (Bray and Kurtz, 1945), the EC and pH of the soil samples were also measured. All the treatments were carried out in 4 replicates.

Mineralization Models and Data Analysis

Nitrogen mineralization data were analyzed by a first-order model according to Jones (1984).

$$N_m = N_0(1 - e^{-kt}) + N_i \quad (1)$$

where N_m (mg kg⁻¹) is the amount of N mineralized at time t (d); N_0 , the initial mineralizable N content (mg kg⁻¹); k , the first-order rate constant (d⁻¹) and N_i (mg kg⁻¹), the zero-order constant (mg kg⁻¹), i.e., N mineralized at time 0. Using the nonlinear least-square technique, N mineralization data was fitted to the kinetic model by means of the data processing software KyPlot (KyensLab Inc., Tokyo, Japan).

RESULTS AND DISCUSSION

Soil pH and Electrical Conductivity

The pH of the composted by-products is crucial because it can alter the availability of nutrients to the plant, thereby affecting the activity of the roots and microbes. The pH of the composts used in almost all cases in this study was weakly alkaline (7.70-8.90). Figure 1 shows the effect of compost application on the soil pH during the incubation period. Our experiment indicated that the composts tended to increase the soil pH for the first 21 day of incubation after which it decreased slightly. The broad peaks obtained can be mainly attributed to the intense microbial activity and organic matter decomposition that followed the formation of NH₃ as a result of organic nitrogen ammonification. The high ammonia solubility led to the formation of ammonium ions and an increase in the pH values, particularly in the composted tea leaves that displayed a maximal value of 8.6. After 21 day of incubation, the pH tended to decrease due to the lower rate of organic matter decomposition and modest ammonia formation. However, on initiation of nitrification, the pH tended to decrease in all the composted mixtures. The pH of the composted tea leaves was higher than the pH values of the composted coffee waste and kitchen garbage, thereby confirming the belief that the pH of the

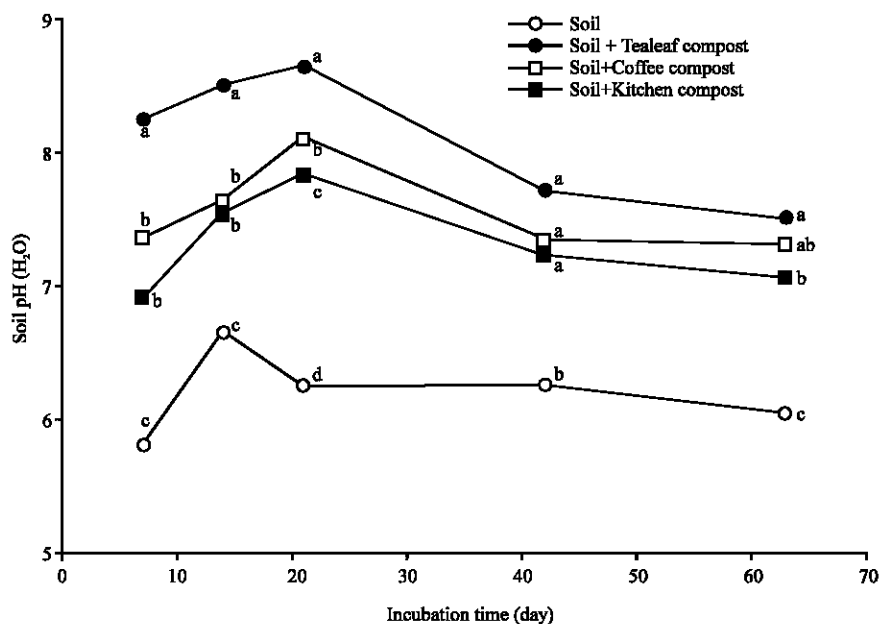


Fig. 1: Changes in pH of the soils applied with or without tealeaf, coffee and kitchen compost. Symbols with the same letter in each time are not significantly different ($p < 0.05$)

composted mixtures was directly related to nitrification. This trend was observed throughout the incubation period. Stanford and Smith (1972) reported only a small or no change in pH during the incubation experiment. The soil used in this study might have a lower ability to stabilize soil pH, i.e., CEC or organic matter content.

During the decomposition of the various by-products, changes in the EC of the soil/compost mixture were observed. Figure 2 shows the effect of compost application on the EC. The soil EC in composted tea leaves and kitchen garbage displayed high fluctuations, i.e., between 3.69 and 5.63 and between 3.31 and 3.41 dS m^{-1} , respectively. However, the EC of the composted coffee waste was as low as that of the soil control. These results possibly reflect the concentration of the mineralized nutrients (NO_3 , available P, K, Ca, Mg, etc.) and certain water-soluble compounds (organic acids or low-molecular weight organic compounds) in the soil.

Net Nitrogen Mineralization

The concentration of the inorganic forms of nitrogen, ammonia ($\text{NH}_4\text{-N}$) and nitrate ($\text{NO}_3\text{-N}$) in the compost was determined by subtracting the concentration of these forms in the soil control from those in soil/compost mixture. Figure 3 shows the time course for the accumulation of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and total N content produced from the composted by-products during the incubation period.

Concentration of $\text{NH}_4\text{-N}$ in the samples varied amongst the amended composts and certain significant ($p < 0.05$) differences were obtained in the concentration of $\text{NH}_4\text{-N}$ among the composts. A large variation was observed in the chemical composition of the composted by-products, i.e., total-N content varied from 0.90 to 5.50% and the C/N ratio ranged from 5.90 to 21.0 (Table 1). Generally, the highest concentration of NH_4 was observed during the first 21 day of incubation. This was mainly due to the fact that during this period, the intense organic matter degradation assisted NH_4 production via the mineralization of organic nitrogen; subsequently, NH_4 levels gradually decreased. After 42 day of incubation, a reduction in $\text{NH}_4\text{-N}$ concentration was observed in all the composted mixtures. These

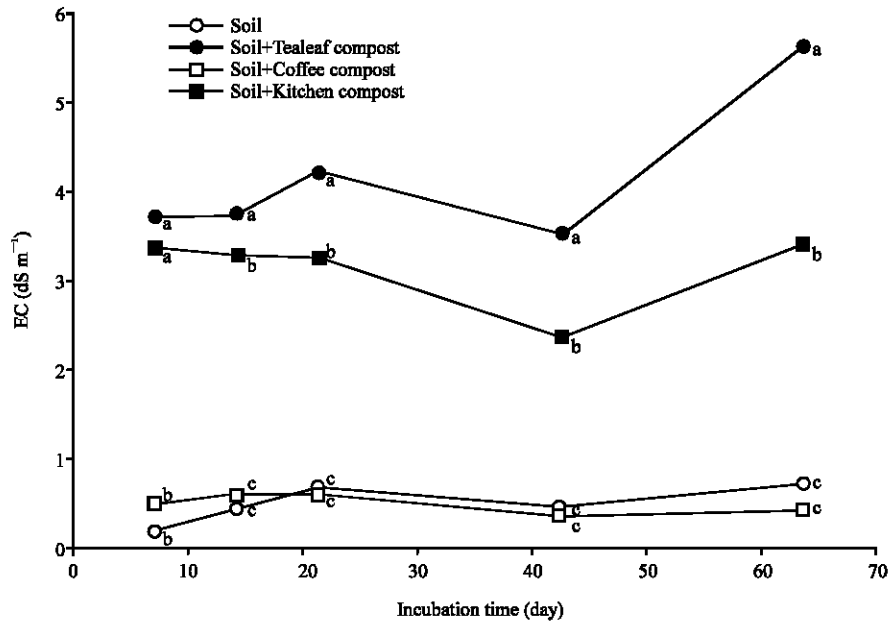


Fig. 2: Changes in Electric Conductivity (EC) of the soils applied with or without tealeaf, coffee and kitchen compost

results indicate that the soil microorganisms may have already decomposed the soluble nitrogenous organic matter. The highest $\text{NH}_4\text{-N}$ concentration ($19.5 \text{ mg N kg}^{-1}$, dry soil basis) was observed in composted tea leaves at 21 day of incubation. The lowest $\text{NH}_4\text{-N}$ concentrations were observed in the composted kitchen garbage. These low concentrations may have resulted from the lower intensity of organic matter degradation and the nitrogen source used. This implies that the microorganisms had less organic matter available for use from the outset; i.e., the most labile fraction of the compost had been already decomposed. The smaller peak observed for $\text{NH}_4\text{-N}$ accumulation (3.02 mg kg^{-1}) in the soil control at 7 day was probably caused by its low concentration of T-N, hence suggesting low fertility.

During incubation, concentration of NO_3 in the composted kitchen garbage sharply increased by 7 day and was significantly high ($p < 0.05$) in all the mixtures. However after a 7 day incubation period, it remained steady till the end of the incubation period. On the other hand, certain significant ($p < 0.05$) differences among composted soil, tea leaves and coffee waste were observed, but they increased in a similar manner as time lapsed. Ammonium was released immediately from the composted tea leaves and coffee waste; however, the formation of nitrate by nitrification was sluggish after 21 day. On the contrary, in kitchen garbage compost, the nitrate concentration showed a marked increase compared to that in NH_4 , which suggests that the composted kitchen garbage had already matured with cessation of most of its biological activity and it was relatively stable. This compost contained significantly ($p < 0.05$) higher amount of nitrate than ammonium during the incubation period. In composted kitchen garbage, the inherent nitrifying bacteria were presumably reactivated when mixed with the soil and having on attaining adequate environmental requirements such as moisture, temperature and oxygen partial pressure.

The total amount of mineralized N among the composted by-products differed considerably. The highest peak was observed in composted kitchen garbage at 21 day (33.8 mg kg^{-1}), this was followed by that of composted tea leaves at 21 day (25.3 mg kg^{-1}), composted coffee waste at 14 day (16.4 mg kg^{-1}) and soil control at 42 (9.7 mg kg^{-1}). The mineralized N content in all the composts

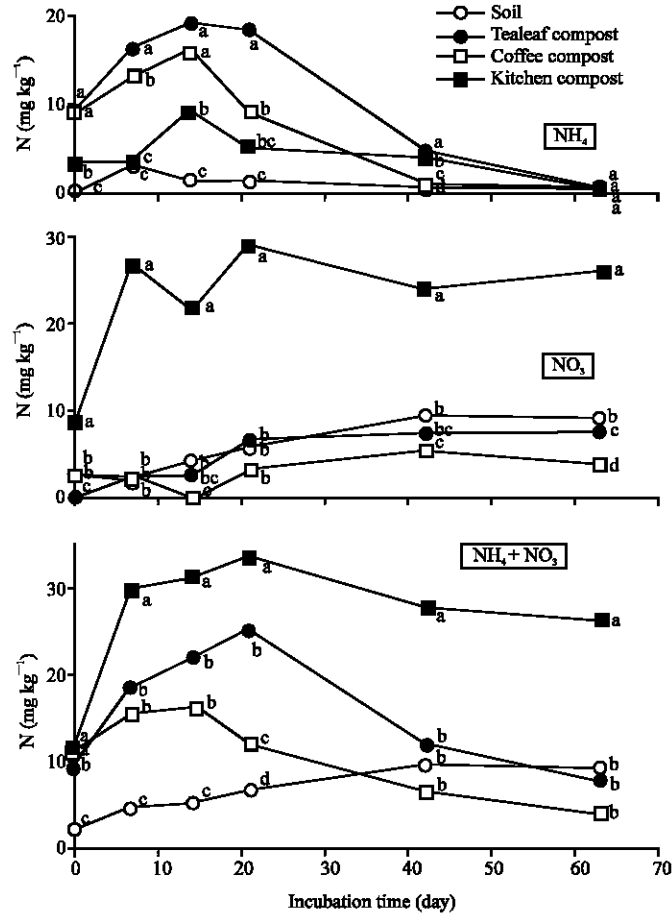


Fig. 3: Changes in concentrations of NH₄-N, NO₃-N and NH₄-N + NO₃-N of the soils applied with or without tealeaf, coffee and kitchen compost

increased rapidly by 14 or 21 day of incubation as compared to the gradual increase observed in the soil control; this rapid increase may be attributed to the almost complete maturation in all the composts prior to incubation. Based on the different stages of the composting process, Bernal *et al.* (1998) reported that the degree of maturity of composted sewage sludge-cotton waste was crucial in determining changes in the concentration of NH₄ in the soil mixture; further, in agreement with the present study, the mature compost demonstrated a greater mineralization flush at an early stage and a subsequent gradual increase.

Some papers have also reported that the amount of N mineralized correlates with the total N content (Fox *et al.*, 1990; Constantinides and Fownes, 1994; Aulakh *et al.*, 2000), the C/N ratio (Aulakh *et al.*, 2000; Trinsoutrot *et al.*, 2000) and microbial N content (Marion *et al.*, 1981; Antonopoulos, 1999). However, in this study, the total N content of the compost was not necessarily a direct factor in determining the amount of N that was mineralized from the compost. With regard to N mineralization, composts may demonstrate a fairly different behavior compared to plant residues. In fact, a noteworthy observation in this study is that the amount of N released was independent of the total N content of the compost (Table 1). It has also been mentioned that N mineralization correlates linearly or non-linearly with the C/N ratio (Janssen, 1996). The present study also showed

that the composted coffee waste that had the highest C/N ratio (21.0) also had the lowest N mineralization degree among all the composts. But the mineralized N content in composted kitchen garbage was the highest among all the composts despite the relatively high C/N ratio (19.0). To clarify the phenomena, further chemical fractionation to allow modification from labile to calcitrant N compounds in the compost would be required.

Mineralization Kinetic Models and Mineralization Rates

The data for net nitrogen mineralization in the composted by-products observed from 0 to 21 day (soil and composted tea leaves and kitchen garbage) or 0 to 14 day (composted coffee waste) displayed the best fit with the first-order model equation (Eq. 1) than with the simple first-order kinetic model (Eq. 2) advocated by Stanford and Smith (1972) or the two components first-order model (Eq. 3) proposed by Inubushi *et al.* (1985).

$$N_m = N_0(1 - e^{-kt}) \quad (2)$$

$$N_m = N_{0q}(1 - e^{-k_q t}) + N_{0s}(1 - e^{-k_s t}) \quad (3)$$

where N_{0q} is the active mineralizable N content (mg kg^{-1}); N_{0s} the resistant mineralizable N content (mg kg^{-1}); k_q and k_s , zero-order rate constants (day^{-1}) and the other parameters, the same properties as those in Eq. 1. Lower determination coefficients were obtained by fitting the data with Eq. 2 and 3 (data not shown) than with Eq. 1 because a certain amount of mineralized N was present at $t = 0$ and the curves were unfitted with the data (data not shown).

The kinetic parameters for N mineralization that were calculated using Eq. 1 are shown in Table 2. The N_0 value is interpreted as an estimate of the N content that will mineralize in an infinite time period under optimal conditions of temperature and moisture (Stanford and Epstein, 1974). The results obtained show that the estimated N_0 values were lower in the composted coffee waste (6.30 mg kg^{-1}) and soil control (6.55 mg kg^{-1}) than in the composted tea leaves (18.8 mg kg^{-1}) and kitchen garbage (22.4 mg kg^{-1}). However, it is important to understand that the obtained N_0 values represent not only the quantity but also the quality of the composts and their interface with the soil matrix, including the effects of texture, cations and biological properties.

The mineralization rate constant (k) of the composts displayed a wide range from 0.101 to 0.255 day^{-1} and this may be attributed to the differences in the composted materials. The highest k was obtained for composted kitchen garbage (0.255 day^{-1}) followed by composted tea leaves (0.199 day^{-1}), composted coffee waste (0.101 day^{-1}) and soil control (0.0531 day^{-1}). Composts with a high k indicate early N mineralization. Previous studies on composted by-products describe a wide range of k -values as follows: spent mushroom compost (0.0629 or 0.143 day^{-1}) by Stewart *et al.* (1998a and b) and municipal solid waste compost ($0.000923 \text{ day}^{-1}$) and olive mill wastewater sludge compost (0.0034 or 0.0029 day^{-1}) by Cabrera *et al.* (2005). It seems that composted kitchen garbage and tea leaves appear to demonstrate rather high k values. Frankenberger and Abdelmagid (1985)

Table 2: Parameters of N mineralization in the soil and composts during incubation, nitrogen mineralization potential (N_0), rate constant (k), constant (N_i) and statistical results calculated from the first-order model

Soil/ compost	N_0 (mg kg^{-1})	k (day^{-1})	$N_0 \cdot k$ ($\text{mg kg}^{-1} \text{ day}^{-1}$)	N_i (mg kg^{-1})	$(N_0 + N_i)/\text{T-N}$ (%)	R ²	n
Soil	6.55*	0.0531	0.348	2.48***	8.21	0.871	16
Tealeaf	18.8***	0.101	1.90	10.1***	5.25	0.804	16
Coffee	6.30	0.199	1.25	12.0***	9.10	0.455	12
Kitchen	22.4***	0.255**	5.71	12.3***	38.6	0.943	16

The model equation: $N_m = N_0(1 - e^{-kt}) + N_i$; N_m is mineralizable N at time = t , * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

reported comparatively lower k -values for leguminous crops such as alfalfa (0.013 day^{-1}), clover (0.026 day^{-1}), cowpea (0.0064 day^{-1}) and soybean (0.029 day^{-1}). Kinetic study on composts with varying levels of maturity demonstrated that the first-order rate constant decreased with maturity; the k -values of the initial mixture, sample at the end of the active phase and the mature compost were 0.185 , 0.161 and 0.083 day^{-1} , respectively (Bernal *et al.*, 1998). Since the composts used in the present study were entirely matured, the differences in the k values may be due to the differences in the composted materials.

The initial N mineralization rates of these composts ($N_0 \cdot k$) at $t = 0$ has been used as an index signifying N availability (Cabrera *et al.*, 2005; Serna and Pomares, 1992). Griffin and Laine (1983) found that the yield and N uptake correlated well with the parameter $N_0 \cdot k$. Campbell *et al.* (1991) reported that the instantaneous mineralization rates were more accurate in predicting the effects on soil organic matter quality than N_0 , k , or total-N content. Cabrera *et al.* (2005) discovered that the $N_0 \cdot k$ -value was greater in finer-textured soil. The $N_0 \cdot k$ -values observed in the present study, i.e., $1.90 \text{ mg kg}^{-1} \text{ day}^{-1}$ (tea leaves), $1.25 \text{ mg kg}^{-1} \text{ day}^{-1}$ (coffee waste) and $5.71 \text{ mg kg}^{-1} \text{ day}^{-1}$ (kitchen garbage), were moderate compared to those observed in earlier studies, such as $0.434 \text{ mg kg}^{-1} \text{ day}^{-1}$ (olive mill sludge compost) by Cabrera *et al.* (2005), $1.27 \text{ mg kg}^{-1} \text{ day}^{-1}$ (cowpea), $1.51 \text{ mg kg}^{-1} \text{ day}^{-1}$ (alfalfa), $4.58 \text{ mg kg}^{-1} \text{ day}^{-1}$ (soybean) and $4.65 \text{ mg kg}^{-1} \text{ day}^{-1}$ (clover) by Frankenberger and Abdelmagid (1985).

The ratios of $N_0 + N_t$ to the total N content showed a wide range, i.e., for composted tea leaves, 5.25%; for coffee waste, 9.10% and for kitchen garbage, 38.6%. Bernal *et al.* (1998) reported that the N mineralization ratio for sewage sludge compost was 9.12%. Other studies discovered rather high mineralizable N content (%) after the incubation period when using different materials such as blood meal, 51-61%; alfalfa pellets, 41-52%; partially composted chicken manure, 37-45% after 12 week (Agehara and Warncke, 2005); biosolids, 23.3%; yard waste, 23.5% and West Palm Beach co-compost, 48.4% after a 1 year incubation period (He *et al.*, 2000). The composted tea leaves and coffee waste may be characterized by their slow decomposability and this may be associated with the polyphenol content (Fox *et al.*, 1990; Constantinides and Fownes, 1994) or the lignin/N ratio (Constantinides and Fownes, 1994; Kumar and Goh, 2003).

Availability of P, K, Ca and Mg

The concentration of P, K, Ca and Mg in the compost was calculated by subtracting the concentrations of these observed in soil control from those in the soil/compost mixture. Changes in the concentrations of available P and exchangeable K content released from the composts are shown in Fig. 4 and 5, respectively. With regard to both P and K content, composted tea leaves demonstrated the highest concentration during the incubation period and it had moderately significant differences with the other composted materials. In addition, these concentrations in composted tea leaves increased with time, although only a slight increase was observed in the other composts and soil. The concentrations of Ca and Mg changed according to a pattern similar to that of the P content; during the incubation period, Ca and Mg peaks (mg kg^{-1}) were observed at 1984 and 336 for composted tea leaves, 727 and 310 for composted coffee waste, 1010 and 75 for composted kitchen garbage and 2038 and 460 for the soil control. In this study, identical release patterns for P, K, Mg and Ca could not be obtained in all the composts, but the wide variation in the changes in concentration may be related to immobilization by soil microbes and compost materials. Stewart *et al.* (1998) noted an occurrence of extreme immobilization of S, K, Ca and Mg during incubation when the compost was amended with an N fertilizer. They also conducted a kinetic study on the release of S, P, Ca and Mg from spent mushroom compost and found that the amount of all the elements released increase with time and they fitted certain kinetic models with high correlation coefficients ($r^2 \geq 0.965$). The discrepancies between these results and those obtained in our study may be attributed to the differences in the extraction methods and solutions used.

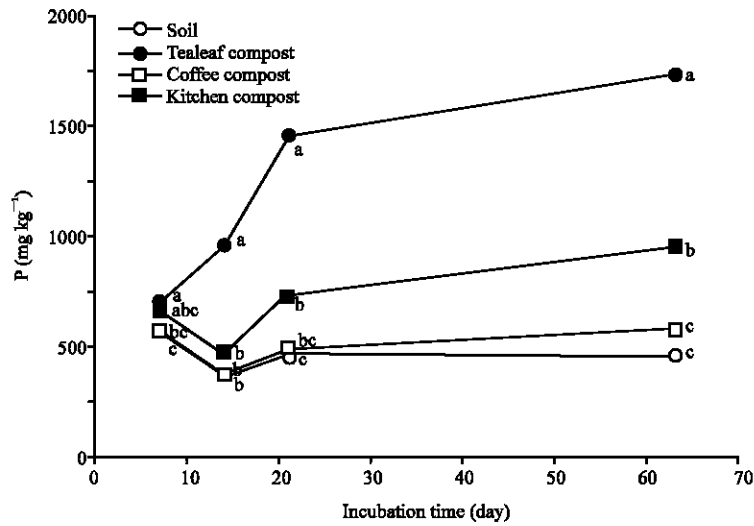


Fig. 4: Changes in concentrations of available phosphate of the soils applied with or without tealeaf, coffee and kitchen compost

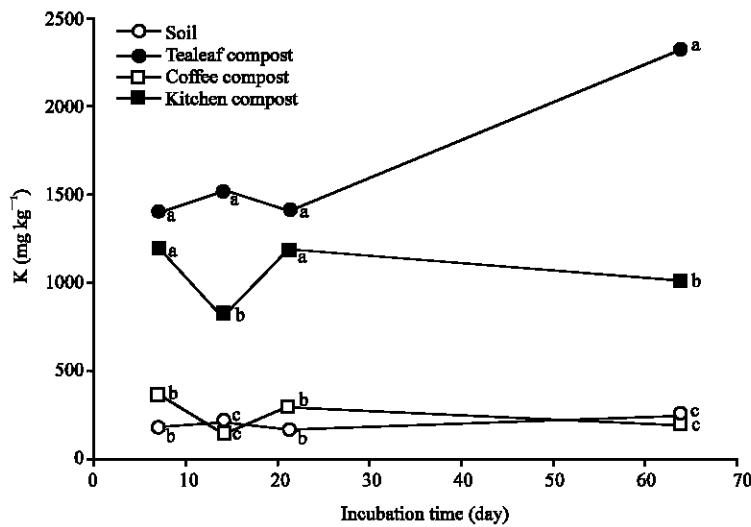


Fig. 5: Changes in concentrations of potassium of the soil applied with or without tealeaf, coffee and kitchen compost

In conclusion, composted tea leaves, coffee waste and kitchen garbage were useful sources of N, P, K, Ca and Mg for plant growth. However, during application of the compost, factors such as release rate and the amount of nutrients actually required by the plant and soil (Cassman and Munns, 1980) and the application temperature (Agehara and Warncke, 2005; Antonopoulos, 1999) should be considered because the release pattern of the nutrients varied widely across the composts used. However, further studies are necessary to clarify the plant nutrient uptake and the nutrient dynamics in the soils amended with the composts.

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