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Nutrient Availability and Changes in Microbial Biomass Of Organic Amendments During Field Incubation

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Field evaluation of release and availability of nutrients and potentially toxic elements from composts is necessary to estimate their nutrient contribution to crops, potential effect on soil and environmental quality. A biosolids (BSD), a yard waste (YW), and a West Palm Beach cocompost (WPCC) were incubated under field conditions in a citrus grove on an Oldsmar fine sandy soil (sandy, siliceous, hyperthermic Alfic Arenic Haplaquods). The incubation columns and the soil underneath each column were sampled on 0, 240, and 360 days after incubation and analyzed for KCl extractable NH_4-N and NO_3-N, 0.5 M $NaHCO_3$ extractable P, and Mehlich 3 extractable K, Fe, Mn, Zn, Cu, and microbial biomass. The total concentration and extractable proportion of each element greatly varied among the three organic amendments. Approximately 34-73% of K, 1-14% of Fe, 7-68% of Zn, 7-47% of Mn, and 2-34% of Cu in the three organic amendments were extractable by the Mehlich 3 reagent at the beginning of incubation. Incubation of these amendments under field conditions for a period of 1 yr increased the availability of N, P, K, and several micronutrients including Fe, Cu, Zn, and Mn. Microbial biomass-C and -P were markedly increased during the field incubation. However, the BSD, containing high total C and other nutrients, produced less microbial biomass-C than the two composts. The rapid increase in concentrations of available metals including Cu, Zn, and Mn in the BSD during the incubation may have adverse effects on microbial biomass growth and proliferation in this compost. A combination of BSD and YW improved conditions for the microbial biomass growth as evidenced by the increase in microbial biomass C and P of this combination during the course of incubation.

Introduction

Compost use is increasing among growers and nursery producers. In Florida, surface application of compost has been used to a limited extent in citrus groves and vegetable fields to control weeds, conserve soil moisture, reduce plant disease incidence, and improve soil fertility (McSorley and Gallaher 1996; Roe *et al.* 1997a; 1997b; Stoffella *et al.* 1998).

A concern about amending agricultural soils with municipal solid waste composts is the addition of potential toxic elements, especially heavy metals in excess quantities and the subsequent effects on the quality of soil, environment, and plant products (Chaney 1993). Organic amendments vary considerably in concentrations of nutritional and toxicant (Genevini *et al.* 1997). Metals such as Cu and Zn are plant nutrients at low concentrations, but are toxic to plants and soil microorganisms at high concentrations. Controlling the input of toxicant is crucial for sustainable agriculture and therefore, a critical evaluation of concentrations and bioavailability of nutrients and potential toxicant in organic amendments is needed. Bioavailability of metals is more closely related to the amount of soluble forms than to the total concentration in the amendments (Warman *et al.* 1995). The changes in soluble forms of macro- and microelements in organic amendments during decomposition following soil application could be a useful indicator of bioavailability and contamination potential of these elements.

Microbial biomass is an important indicator of soil quality (Elliott *et al.* 1996). The application of organic amendments containing heavy metals can have various effects on soil quality. The organic carbon present in the composts can enhance the growth of microorganisms, thus increasing the microbial biomass, whereas heavy metals in excess concentrations can be harmful to soil microorganisms, thus decreasing microbial biomass or causing soil degradation (Yao *et al.* 1998). In Florida, many soils are extremely sandy with very low adsorption capacity for ions and, therefore, soil microbial biomass can be very sensitive to external sources of heavy metals, such as from compost application.

The objective of this investigation was twofold: i) to examine the changes in concentrations of available N, P, K, Mn, Zn, Fe, and Cu in the organic amendments during field incubation, and ii) to evaluate effects of increased availability of these elements on microbial biomass-C, and -P in surface-applied organic amendments and in the soil beneath each amendment.

Materials and Methods

The organic amendments evaluated in this study included a biosolids (BSD, derived from sewage sludge), a yard waste (YW) , and a West Palm Beach cocompost (WPCC) of biosolids and yard wastes.The BSD is a uniformly pelletized commercial product that contains high concentration of total N and low C/N ratio, and thus is frequently used as N source for crop production in agriculture. The YW, consisting of composted grass clippings and wood chips, has a high C/N ratio and low concentration of organic N, whereas the WPCC was intermediate between the BSD and the YW with respect to N properties. However, the BSD and YW used for composting the WPCC were from different sources. Therefore, the WPCC had properties different from those of the BSD or YW used in this study (Table 1). These organic amendments were selected because of their potential utilization as a soil amendment. Each compost or biosolids was thoroughly mixed, passed through a 5 mm sieve, and stored at 4°C in a polyethylene bags. Subsamples were analyzed for pH, EC, and concentrations of total elements (Table 1).

TABLE 1.
Chemical properties of the organic amendments[a]

Properties	BSD	WPCC	YW
pH (H_2O)	6.01	7.01	7.64
EC (dS cm^{-1})	17.58	6.25	1.44
	g kg^{-1}		
Total C	282.8	288.8	110.3
Total N	49	18.8	2.9
P	22.6	7.5	0.4
C:N ratio	5.8	15.4	38
C:P ratio	12.5	38.5	276
Ca	21.3	62.8	23.1
Mg	2.3	2.8	0.7
K	1.7	6.3	1
Fe	99.3	6.7	1.3
	mg kg^{-1}		
Zn	583	199	30
Cu	401	107	8
Mn	660	78	21
Cd	12	1	0
Pb	106	24	12
Ni	35	35	1

[a]BSD = biosolids; WPCC = West Palm Beach cocompost; YW = yard waste

Field Incubation

Samples of compost or biosolids were loosely packed in PVC columns (5 cm in diameter and 8 cm in height), and to simulate surface field use of organic amendments, the columns were vertically placed 8 cm deep into raised citrus beds in an Oldsmar sand (sandy, silicious, hyperthermic Alfic Arenic Haplaquods) in St. Lucie County, Florida. The dry weight of amendment in each packed column was 100, 50, and 25 g, which are equivalent to 50, 25, and 12.5 Mg ha^{-1} (oven-dry basis), respectively for the BSD, YW, and WPCC, provided that field application coverage accounts for 10% of the total area. The choice of the application rate was based on the same volume of compost on the soil surface. The moisture contents of the amendments were adjusted to their field water holding capacity, respectively before being packed into the column. No water was added after the composts or biosolids were incubated in the field. The moisture equilibrium between the sample inside the column and field soil was attained through the bottom end and four side holes (7 mm diameter) evenly spaced around the middle of the column. The bottom end of each column was covered with a piece of nylon cloth (400 mesh) to separate the sample from the contacting soil. The top of each column was capped to minimize leaching and volatilization loss of N, for NO_3 leached down into deep layers of the soil subject to denitrification and gas loss of N is difficult to quantify. A column packed with soil from the experimental site was incubated to measure mineralization of soil organic matter during field incubation. There were four replications of each compost with each replication consisting of 12 randomly arranged columns in the field. The field incubation began in mid-December, 1996. Four columns (one from each replication) of each amendment were sampled on 0, 240, and 360 days after incubation. The organic amendment was removed from the column and thoroughly mixed. Subsamples were analyzed for moisture content, KCl-extractable NH_4-N and NO_3-N, Mehlich 3 extractable P, K, Zn, Fe, Mn, and Cu, and microbial biomass-C and -P. A Mehlich 3 reagent was used to estimate bioavailability of these macro- and microelements (Alva 1993). On each sampling date, a soil core (20 cm in depth and 6 cm in diameter) was also sampled directly underneath the compost column, and analyzed for the above nutrients and microbial biomass as described for the organic amendments. Any increase in the concentration of elements in the soil below the column was considered to be a result of leaching from the amendment. At the end of a 1 yr incubation period (December 1997), total C and N in the residual amendments were determined to calculate the net N mineralization.

Chemical Analyses

Subsamples of organic amendments were ground to pass a 0.5 mm sieve and concentrations of total C and N were measured using a CNS Analyzer (NA 1500, Fisons Instruments Inc., Dearborn, MI). The pH and electrical conductivity (EC) of the organic amendments were measured in water suspension (1:1) using an Orion pH-Conductivity meter. Total concentrations of macro- and microelements in the amendment were analyzed using EPA method 3050 (U.S. EPA 1987). Subsamples of the composts were air-dried and ground using a zirconia grinding mill (5mm). These compost or biosolids samples (2.0 g) were digested in HNO_3 and H_2O_2 and the concentrations of P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, Cd, and Ni were analyzed using an Inductively Coupled Plasma Atomic Emission Spectrometer (ICPAES; Plasma 40, Perkin Elmer Company). Extractable NH_4-N and NO_3-N in both organic amendments and soil samples were determined by shaking a 2.5 g sample (oven-dry basis) in 25 mL 1 M KCl for 1 h, and concentrations of NH_4-N and NO_3-N in the filtrate were analyzed with a Cadmium Reduction-Auto-analyzer (Alpkem 1989). For determining the concentrations of extractable elements 2.5 g of compost or soil was extracted with 25 mL Mehlich 3 reagent (Mehlich 1984) for 5 min and the concentrations of P, K, Ca, Mg, Fe, Mn, Zn, and Cu were analyzed in the filtrate by the ICPAES.

Microbial biomass-C and -P in the organic amendment and soil were measured by a fumigation-extraction method (Brookes *et al.* 1982; He *et al.* 1997). Briefly, subsamples of fresh moist compost and soil (5.0 g for biomass-C and 3.0 g for biomass-P, oven-dry basis) were weighed into 50 mL glass beakers and fumigated with $CHCl_3$ in a vacuum desiccator for 24 h. The samples were then transferred to another clean vacuum desiccator and the residual $CHCl_3$ was removed by repeatedly evacuating the desiccator 2-3 times (each for 10 min). The samples were then extracted with 30 ml 0.5 M K_2SO_4 for 30 min for biomass-C or with 30 ml 0.5 M $NaHCO_3$ (pH 8.5) for 30 min for biomass-P measurement. The concentration of dissolved C in the K_2SO_4 extract was determined using Total Organic Carbon Analyzer (TOC-Analyzer Model 5000 A, Shimadzu Inc., Japan). Phosphorus concentration in the $NaHCO_3$ extract was determined by the ascorbic acid-blue colorimetric method (Olsen and Sommers 1982). Microbial biomass-C (MBC) and -P (MBP) were calculated with the following equations:

MBC (mg C kg^{-1}) = (K_2SO_4 extractable organic carbon in fumigated soil - K_2SO_4 extractable organic carbon in the unfumigated soil)/0.45 .... (1)

MBP (mg P kg^{-1}) = ($NaHCO_3$ extractable ortho-P in fumigated soil - $NaHCO_3$ extractable ortho-P in the unfumigated soil)/0.40 .... (2)

Statistical Analyses

Statistical differences in extractable macro- and microelements and microbial biomass-C and -P in organic amendment and soil among the three samples were analyzed with the SAS linear regression model (SAS Institute 1996).

Results and Discussion

Characterization of the Organic Amendments

The three organic amendments differed in total elemental composition, pH and EC (Table 1). The BSD had higher concentrations of N, P, Fe, Zn, Cu, Mn, Cd, and Pb and greater C/N and C/P ratios than the WPCC and YW, but lower concentrations of Ca, Mg, and K than the WPCC (Table 1). The high nutrient concentrations, especially N, make the BSD a desirable fertilizer source. However, the concentrations of Zn, Cu and Cd in the BSD (Table 1) are greater than the UK maximum permissible concentrations for these elements (200 to 450 mg kg^{-1} for Zn, 80 to 200 mg kg^{-1} for Cu, and 3 mg kg^{-1} for Cd) in soil treated with sewage sludge (Smith 1991). Therefore, caution needs to be taken when the BSD is applied as fertilizer for crops. The concentrations of potentially toxic elements such as Zn, Cu, Cd, Pb, and Ni in the WPCC and YW were generally below maximum permissi-

TABLE 2.
Extractable nutrients in the organic amendments[a]

	BSD[b]		WPCC		YW	
Properties	mg kg^{-1}	% of total	mg kg^{-1}	% of total	mg kg^{-1}	% of total
Mineral N (NH_4+NO_3)	2861	5.8	94.9	0.5	31	1.1
K	658	38.7	2134	33.9	734	73.4
P	34	0.2	247	3.3	15	3.7
Fe	717	0.7	452	6.8	177	13.6
Zn	41	7	117	59	20	67.7
Cu	8	1.9	14	13.3	3	33.8
Mn	45	6.9	19	24.5	10	47.1

[a]N in 2M KCl; P in $NaHCO_3$; K, Fe, Zn, Cu, and Mn in Mehlich 3.
[b]BSD = biosolids; WPCC = West Palm Beach co-compost; YW = yard waste

ble concentrations for these elements in soil, which makes these two organic amendments safe for use in agriculture.

Total elemental concentration may indicate the status of nutrient or potentially toxic elements in the composts or biosolids. However, the extractable concentrations of the macro- and microelements are more related to their bioavailability. The extractable portion of the total nutrient concentration varied greatly among different amendments and nutrients (Table 2). KCl extractable N (NH_4-N+ NO_3-N) accounted for 0.5 to 5.8% of the total N in the samples before incubation. The BSD had a greater percentage of mineral N than either WPCC or YW, suggesting that N in the former might be more readily available than that in the latter. The portion of total P extractable by $NaHCO_3$ was greater in the YW and WPCC than that in the BSD. The lower extractability of P in the BSD could be attributed to its high concentration of Fe, which may fix P, thus rendering P less available. The amount of Mehlich 3 extractable K accounted for 34 to 74% of the total K concentration. Thus K in the organic amendments appears to be highly bioavailable. The Mehlich 3 extractable Fe, Mn, Zn, and Cu accounted for 0.7 to 13.6%, 6.9 to 47.1%, 7 to 67.7%, and 1.9 to 33.8% of the respective total metal concentrations. The relative availability of these microelements appeared to be greater in the WPCC and YW than in the BSD, as evidenced by the greater extractable percentages of the total concentrations (Table 2). The WPCC contained higher extractable concentrations of Zn and Cu though having lower total concentrations of these two elements. The proportion of the microelements extractable by the Mehlich 3 in the organic amendments decreased in the order: Zn>Mn>Cu>Fe.

Effects on N, P, and K

During the course of incubation under field conditions, mineral N concentration increased significantly in the organic amendments, especially in the BSD (Figure 1). The initial mineral N concentration was relatively high in the BSD, and the transformation of organic N into mineral N was quite rapid during the incubation as evidenced by

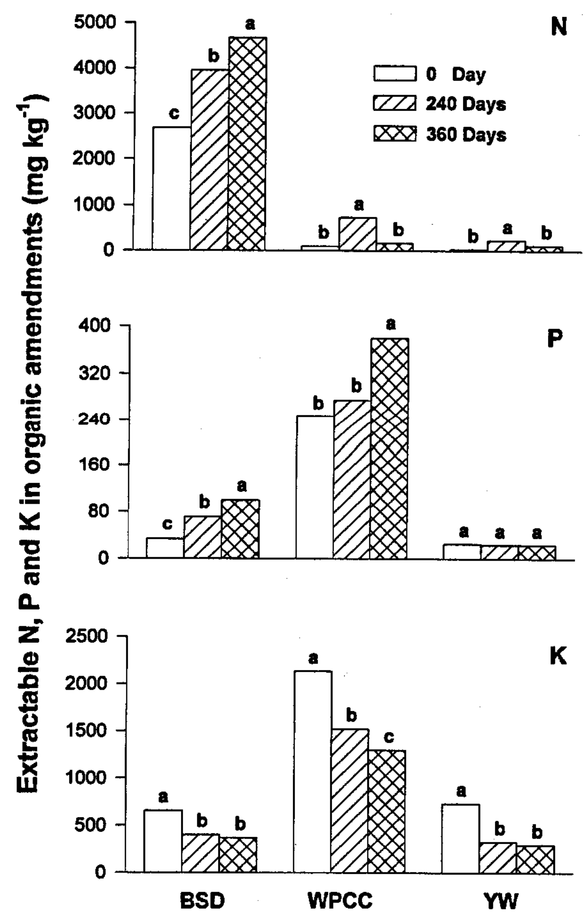

Figure 1. Concentrations of extractable N (1M KCl), P ($NaHCO_3$), and K (Mehlich 3) in biosolids (BSD), West Palm Beach co-compost (WPCC), and yard waste (YW) during the course of 1 yr incubation in field conditions. Means followed by the similar letter within each compost for each nutrient are not significantly different at 5% probability level.

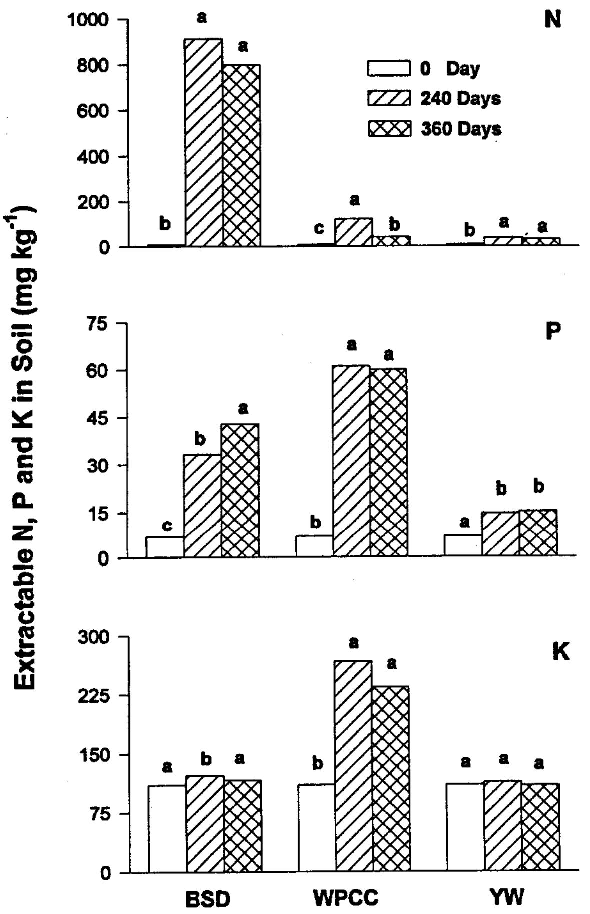

Figure 2. Concentrations of extractable N (2M KCl), P ($NaHCO_3$), and K (Mehlich 3) in soil beneath incubation columns containing either biosolids (BSD), West Palm Beach co-compost (WPCC), or yard waste (YW). Means followed by the similar letter within each compost for each nutrient are not significantly different at 5% probability level.

the marked increase in KCl extractable N in 240 and 360 days. The decrease in mineral N concentration in the WPCC and YW between 240 to 360 days was probably due to a greater loss of the mineral N from the incubation column into the underlying soil because of their greater porosity in nature, as compared to the BSD (Figure 1). The significant increase in extractable N in the soil samples underneath the incubation columns (Figure 2) confirmed leaching of mineral N from the organic amendments. A larger amount of N leaching from the BSD than the other two composts may be due to the its higher N concentration and application rate. Theoretically, leaching loss should be minimal since the column was capped. However, during the rainy season (July to October, in Florida) heavy rain might have soaked the whole soil profile and the organic samples and thus the mineralized N mainly in the form of NO_3^- could be transported downward with soil gravity water (He *et al.* 2000).

Mineralization of phosphorus was somewhat different from that of nitrogen (Figure 1). Olsen-P increased significantly during the course of the incubation for both the BSD and the WPCC. However, there was no change in the Olsen-P concentration in the YW compost for the entire period of incubation. The WPCC released much more Olsen-P than the BSD during the incubation, although it contained much less total P than the latter, indicating that P availability was greater for the WPCC than for the BSD. Olsen-P in the soil underneath the compost columns also increased significantly during the incubation period for all three amendments (Figure 2).

The WPCC contained much more extractable K than the BSD or the YW because of its high total K concentration (Figure 1). The high proportion of the total K extractable by Mehlich 3 (Table 2) suggests that the plant available fraction of total K is quite high in the WPCC. Mehlich 3 extractable K in the soil directly underneath the WPCC column also increased on 240 and 360 days sampling as compared to that on day zero (Figure 2). This again suggests that a portion of available K was leached from the compost into the soil during the incubation period.

Effects on Fe, Mn, Cu, and Zn

The concentrations of Mehlich 3 extractable Fe were in excess of 450 mg kg^{-1} in the BSD and WPCC (Table 2). Therefore, these amendments can be a good source of available Fe. Extractable Fe increased by 20 to 40% in the WPCC and about 10% in the YW, but decreased by 30 to 45% in the BSD during the course of incubation (Figure 3). The decrease in extractable Fe in the BSD during the incubation was probably due to Fe oxidation, as most of Fe in the BSD was in the inorganic form. The concentrations of Mehlich 3 extractable Mn increased during the incubation for all the organic amendments tested (Figure 3).

Extractable Cu increased during the incubation of all the three amendments (Figure 3). Copper is generally chelated to organic molecules in composts and tends to release after the organic matter is decomposed. Although excessive Cu availability is undesirable, Cu amendment at low doses is required for citrus trees, particularly for new planting on virgin soils (Smith 1966).

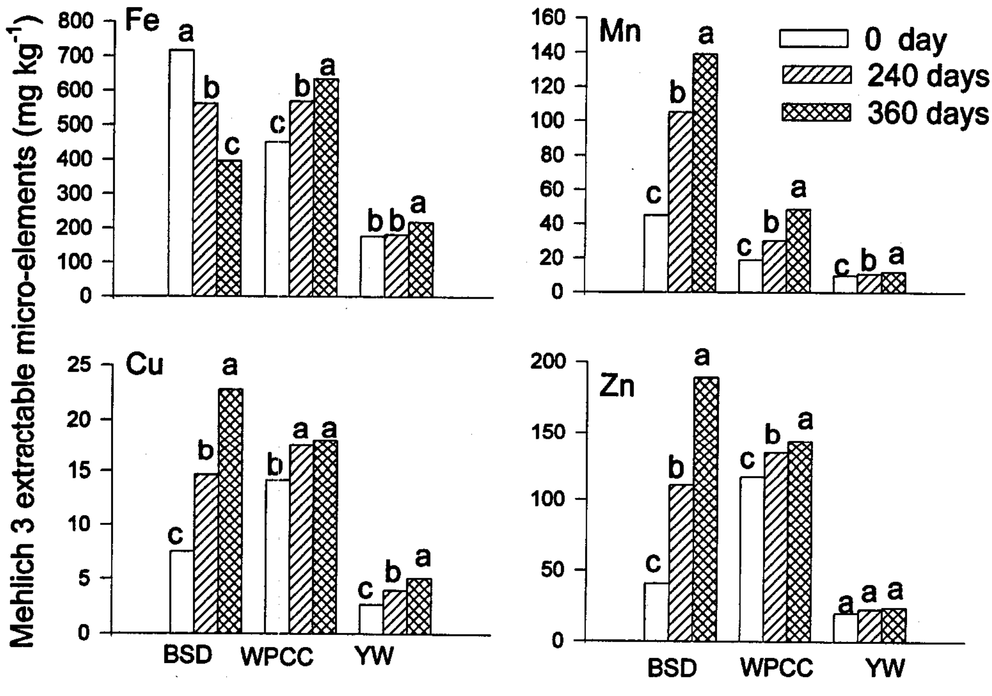

Figure 3. Concentration of Mehlich 3 extractable Fe, Mn, Cu, and Zn in biosolids (BSD), West Palm Beach co-compost (WPCC), and yard waste (YW) during the course of 1 yr incubation in field conditions. Means followed by the similar letter within each compost for each metal are not significantly different at 5% probability level.

All of the organic amendments evaluated in this study contained much higher concentrations of extractable Zn than Cu. Extractable Zn concentrations significantly increased during the incubation for the BSD and the WPCC but not for the YW (Figure 3). The increase in extractable Zn and Cu during mineralization appeared to be related to total concentrations in the amendments. Composts or biosolids with higher concentrations of total Zn or Cu tended to have greater amounts of extractable Zn or Cu after 1 yr incubation (Table 1 and Figure 3).

Effects on Microbial Biomass-C and -P

Microbial biomass has been used as an indicator of soil quality, as it responds rapidly to changes in the soil environment that can result from soil contamination. The nutrients in microbial biomass are potentially available to plants (Chander *et al.* 1995; Smith and Paul 1991). Under favorable conditions, microbial biomass is positively correlated to organic matter, and N and P contained in the biomass is positively related to N, P, and C availability (He *et al.* 1997). After 1 yr incubation, microbial biomass-C increased significantly in all three organic amendments (Figure 4). There was a great variation in the microbial biomass-C content among the three amendments. The WPCC contained 4- and 2.5-fold greater microbial biomass-C than the BSD and YW, respectively (Figure 4). Both the BSD and the WPCC contained similar total C contents which were greater than that in the YW (Table 1). Similarly, the microbial biomass-P was also greater in the WPCC than in the BSD or YW.

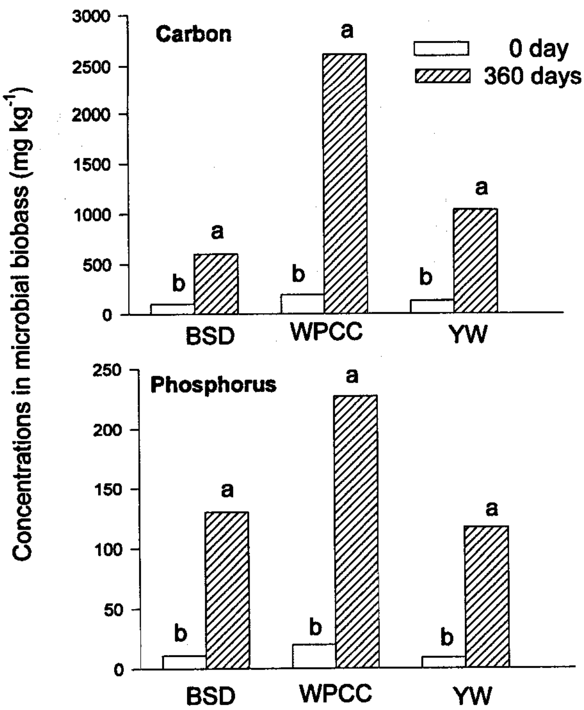

Figure 4. Changes in the concentration of microbial biomass-C and -P in biosolids (BSD), West Palm Beach co-compost (WPCC), and yard waste (YW) during the course of 1 yr incubation in field conditions. Means followed by the similar letter within each compost are not significantly different at 5% probability level.

Microorganisms are sensitive to Cu and Zn even at low concentrations (Collins and Stotzky 1989). Application of metal-enriched sludge or composts has been reported to cause significant inhibition of microbial growth at concentrations of metals below those likely to decrease the growth of sensitive crop species (Khan and Huang 1999). The ratio of microbial biomass carbon to total organic carbon in metal-polluted soils has been proposed as an indicator of the toxicity of metals on soil microflora (Khan and Huang 1999). The ratios of microbial C to total organic C were 0.0024, 0.0111, and 0.0107, respectively for the BSD, WPCC, and YW. The much lower microbial C/total organic C ratio of the BSD as compared with the WPCC or YW may indicate that microorganisms did grow in the BSD but higher extractable concentrations of Cu and Zn might have slowed its growth at the late stage of incubation (360 days), as compared with the WPCC or YW. Therefore, a combination of BSD and YW might provide more favorable conditions for microbial growth because of lower concentration of available heavy metals and improved nutrient supply as compared to either the BSD or YW by itself.

Conclusions

The mineralization of organic amendments under field conditions released a significant amount of mineral N and increased the bioavailability of Fe, Mn, Cu, and Zn contained in the amendments. The increased availability of Fe, Mn, Cu, and Zn in organic amendments could be beneficial to crops in soils deficient in these nutrients. However, excessive application of composts or biosolids, especially those with high concentrations of heavy metals, may have adverse effects on soil quality because of the increased availability of heavy metals after compost mineralization. The change in the ratio of microbial biomass carbon to total organic carbon during mineralization of a compost or biosolids may serve as an indicator of potential contamination of heavy metals from the organic amendment.

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