Effect of Pit Floor Material on Compost Quality in Semiarid West Africa

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ABSTRACT

Composting improves nutrient recycling in semiarid Africa but requires labor and water inputs. We compared effects of pit floor materials (sand, mud, and straw bricks [banco], and cement) on quality of compost made of pearl millet [*Pennisetum glaucum* (L.) R. Br.] stalks and cow manure. Mean compost dry mass loss ranged from 25% in sand-floor pits to 37% in banco-floor pits. Final C contents were 0.25 g g^{-1} for cement-floor compost, 0.20 g g^{-1} for sand-floor compost, and 0.16 g g^{-1} for banco-floor compost. Final C/N ratios were 25.8 in sand-floor compost, 20.6 in banco-floor compost, and 24.9 in cement-floor compost. Compost water content increased as floor porosity decreased. Dry mass and nutrient content were much greater for plants grown with sand-floor compost, but none of the compost data taken suggested superior quality. Results suggest increased floor porosity improves compost quality. Additional study is required to improve local compost technology.

Increased population pressure in semiarid Africa has lead to unsustainable cropping practices that have reduced soil fertility and contributed to declining food security (Penning de Vries and Van Keulen, 1982; Sanchez et al., 1997; Payne, 2006). Improved soil organic matter and nutrient management is essential to reversing this trend. Composting has long been considered as an appropriate method of improving soil and nutrient management for resource-poor farmers (Adediran et al., 2004; Ouédroago et al., 2001; Diop, 2005). However, despite farmer recognition of the importance of organic matter to crop production (Quansah et al., 2001), relatively few have adopted composting. This lack of adoption has largely been due to the need for increased labor associated with turning and watering the compost pile (Quansah et al., 2001; Ouédraogo et al., 2001; Adediran et al., 2004). In rural villages, women generally are assigned the task of bringing water, often from large distances. Any method that conserves water while maintaining compost quality would potentially reduce labor requirements.

Compost piles are often placed in pits (Ouédraogo et al., 2001; Misra et al., 2003) with floors of different porosities due to soil type or floor lining material, such as cement or bricks (Rodale Institute, 1990). Porosity affects water retention, nutrient leaching, and aeration, all of which affect compost evolution and quality. Compost quality can be described in terms of age, maturity, nutrient content, and other physical, biological, and chemical properties (Mathur et al., 1993; Emino and Warman, 2004). However, all of these properties are affected by the materials, technology, and amount of time used for composting. Ideally, the value of compost to a particular agricultural system should be determined by plant growth response, but there is no standardized procedure or plant species to judge compost quality (Emino and Warman, 2004). Preferably, plant species that are relevant to specific cropping systems should be used to assess the compost's capacity to enhance crop growth.

We know of no studies on the effect of pit floor material on compost evolution and quality. Our study objectives were to compare the effects of floor material effects on (i) compost evolution in terms of dry mass, macronutrient content (C, N, P, and K), C to N ratio, and moisture content, and (ii) compost quality in terms of growth and nutrient content (N and P) of pearl millet, the staple cereal in many cropping systems of semiarid Africa.

MATERIALS AND METHODS

The experiment was conducted at the ICRISAT Center near Niamey, Niger. Soils are classified as Psammentic Kandiustalfs (sandy, siliceous, isohypothermic). Pits 1 m long by 1 m wide and 0.75-m deep were constructed with floors made with (i) sandy soil, that is, without modification; (ii) bricks made of clay mud and straw ("banco") that are traditionally used for home construction; and (iii) cement. A randomized complete block design was used with floor material as the treatment and three replications.

Compost substrate was made of cow manure and pearl millet stalks harvested during the previous growing season. Before composting, stalks were air-dried for several days, cut into ~10-cm pieces, and thoroughly mixed. Fresh cow manure was obtained from the local slaughterhouse, dried for 14 d, and mixed. Initial compost mixture was composed of 11 alternate layers of 2 kg of pearl millet stems and 1kg of manure, for a total of 22 kg of pearl millet stalks and 11 kg of manure. The initial mean water content of the dried compost mixture was 0.05 g g^{-1}.

Two times a week, 155 kg of water were added to each compost pit. At 2-wk intervals, contents of pits were emptied and weighed. The compost was then mixed to facilitate the decomposition process (Shi et al., 1999) and sampling. Each compost mixture was sampled using a 500-mL beaker, and returned to the pit. Samples were weighed and dried for 72 h at 70°C, then weighed again to obtain water content. The dried samples were then ground and analyzed for total N by a Kjeldahl procedure (Bremner and Mulvaney, 1982), total C by the dry combustion method (Nelson and Sommers, 1982), total K by flame photometry, and total P by the molybdate-blue method (Olsen and Sommers, 1982). Composting continued for 90 d.

After composting was completed, a glasshouse experiment was conducted to evaluate the effect of the three floor materials on compost quality as manifested by pearl millet growth and nutrient (N and P) content. Compost was dried, sieved through a screen with 2-cm diameter holes, and mixed thoroughly with the native Psammentic Kandiustalf soil to obtain mixtures that

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contained 0, 3, 5, and 21% compost by weight. Pearl millet (cv. Sadoré Locale, the local landrace) was planted in pots in a randomized block design with two factors (compost type and compost/soil mixture) and three replications.

Ten seeds were planted in each pot. After 2 wk, pots were thinned to two uniform plants per pot. At 45 d after sowing (i.e., during the vegetative stage), plants were harvested, and soil was washed from roots. Plants were dried and weighed to obtain total plant dry mass. Shoots were then ground and assayed for total N using a Kjeldahl method (Bremner and Mulvaney, 1982) and for total P using the molybdate-blue method (Olsen and Sommers, 1982).

RESULTS

After 30 d of composting, compost dry mass in sand-floor pits was greater than in cement- and banco-floor pits (Fig. 1A). At the end of 90 d, mean loss of dry mass ranged from 25% of the initial 33 kg in sand-floor pits to 37% in banco-floor pits. Using a number of compost mixtures, Breitenbeck and Schellinger (2004) observed that average mass reduction after 100 d of composting in windrows ranged from 12% for a 4:1 volumetric mix of wood chips and municipal biosolids, to 31% for a 2:1 volumetric mix of grass hay and spoiled corn silage. If mass loss were the only criterion considered, the smaller mass loss from sand-floor pits would suggest slower decomposition and less mature or poorer quality compost.

Carbon content (Fig. 1B) decreased from an initial mean value of 0.52 g g^{-1} to final mean values of 0.25 g g^{-1} for cement-floor compost, 0.20 g g^{-1} for sand-floor compost, and 0.16 g g^{-1} for banco-floor compost. Carbon content of cement-floor compost was significantly greater than those of sand- and banco-floor composts from 60 d onward. Carbon loss was highly correlated with dry mass loss (Fig. 1C), reflecting the fact that mass loss results primarily from microbial mineralization of organic C. The greater C content of cement-floor compost suggests that its rate of microbial mineralization was less than in the other two composts. This particularly appears to be the case from 10 to 20 d. If C content alone were used to evaluate maturity, then cement-floor compost would be considered the least mature. The linear relation between C and mass losses for our data set is similar to that obtained by Breitenbeck and Schellinger (2004), but the slope, intercept, and Pearson correlation coefficient of our regression equation (C Loss = 2.25 + 1.76 × Mass Loss; $r^2 = 0.92$) were greater than those of their equation (C Loss = 0.06 + 1.08 × Mass Loss; $r^2 = 0.72$). We speculate that our greater slope was due to smaller resistance of pearl millet stalks to microbial decomposition compared to wood chips, that the greater intercept was due to higher initial C content of our compost mixture (0.52 g g^{-1}) compared to theirs (0.15–0.45 g g^{-1}), and that the greater correlation coefficient was due to the fact that one relatively homogeneous mixture was used for our study, whereas four very different mixtures were used in their study.

Nitrogen content of all composts (Fig. 2A) decreased from an initial value of slightly more than 10 to 7 mg g^{-1} at 18 d. At 60 d, N content was greatest for cement-floor compost and least for banco-floor compost. By 90 d, mean N contents of banco- and sand-floor composts were 8 mg g^{-1}, and N content of cement-floor compost was 10 mg g^{-1}. Compost N content is determined by several complex processes mediated by exoenzymes, heterotrophic microorganisms, and nitrifiers or denitrifiers that are all influenced by such environmental factors as temperature, moisture, and aeration (Mathur et al., 1993). Nitrogen content varies with compost mixture (Shi et al., 1999; Kostov et al., 1996) and during the composting process (Mondini et al., 2003; Eghball et al., 1997) due to the physicochemical composition of the substrates and changes in immobilization-mineralization rates (Kostov et al., 1996). As a result, total N concentration after composting can substantially increase or decrease (Mondini et al., 2003; Eghball et al., 1997), or only undergo slight changes (Michel et al., 1996; Shi et al., 1999). Typical values of mature compost N content range from 6 mg g^{-1} (Kostov et al., 1996) to 43 mg g^{-1} (Mondini et al., 2003).

Mean C/N ratios increased slightly from 50.2 during the first 2 wk of composting because of a proportionally greater decrease in N content than in C content (Fig. 2).

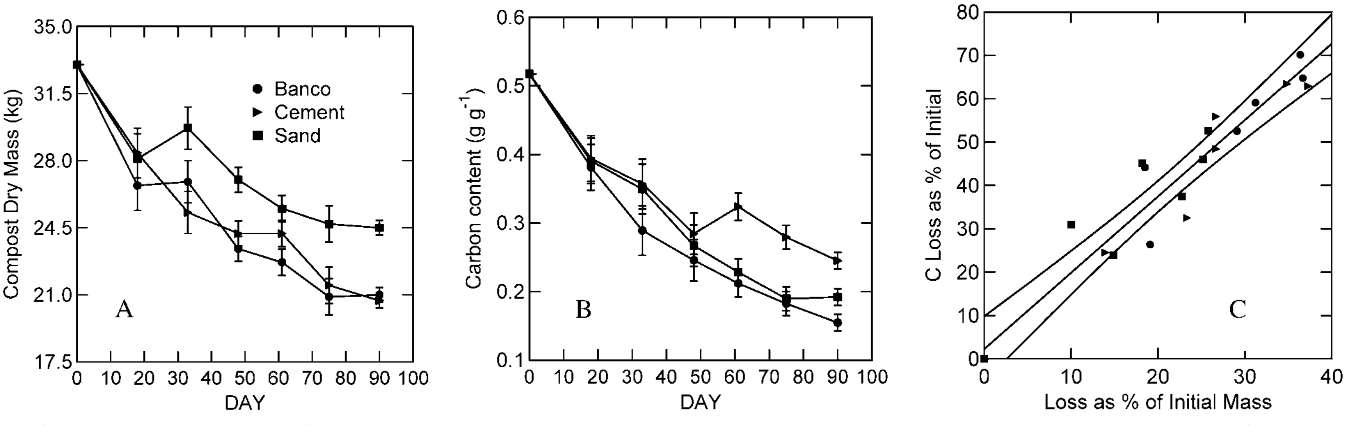

Fig. 1. Dry mass, C content, and C loss as a function of initial mass for composts made on three floor materials. Vertical lines represent ±1 standard error. The fitted linear regression equation is C Loss = 2.25 + 1.76 × Mass Loss (r^2 = 0.92). Exterior lines represent 95% confidence level for carbon loss.

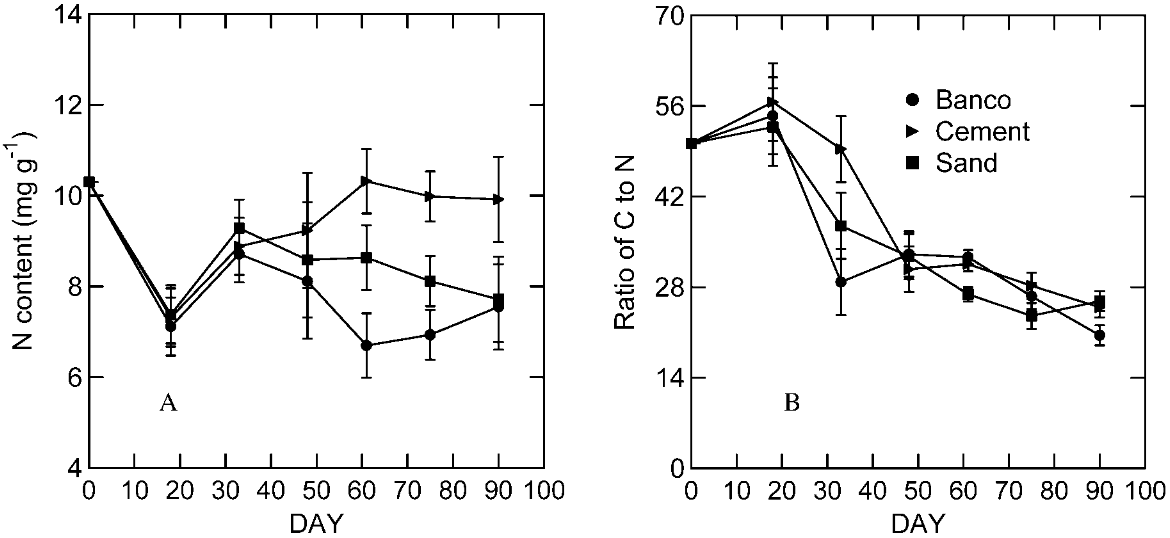

Fig. 2. Nitrogen content and C/N ratio of compost as affected by time of composting and pit floor composition in Niger, West Africa. Vertical lines represent ±1 standard error.

Ratios then gradually decreased to final values of 24.9 in cement-floor compost, 20.6 in banco-floor compost, and 25.8 for sand-floor compost. These values represent relatively high C/N ratios. The ideal C/N ratio of mature compost is about 10, which approaches that of humus (Mathur et al., 1993). However, this value is almost never achieved because of differences in bioavailability of compost mixtures. Mathur et al. (1993) state that mature composts typically have C/N ratios of up to 20, but cite reports of stable composts with C/N ratios as high as 35 when initial compost mixtures have high C/N ratios. If C/N ratio were the only criterion used to judge compost, then banco-floor compost would be considered the most mature and the highest quality.

Mean compost total P content decreased from initial values of 4.3 mg g^{-1} to final values of 2.7 mg g^{-1} in cement-floor compost, 1.6 mg g^{-1} for banco-floor compost, and 1.9 mg g^{-1} in sand-floor compost (Fig. 3A). Typical values for compost P content range from 1 to 9 mg g^{-1} (Michel et al., 1996; Eghball et al., 1997; Barker, 2001). Total P content of compost is of special interest because soil P availability has been identified as the most limiting constraint to crop production in semiarid West Africa (Payne et al., 1992; Hafner et al., 1993). The greater total P content of cement-floor compost is noteworthy, but it does not give an indication of plant P availability. Potassium content decreased from a mean value of 14 mg g^{-1} to final mean values of 1.2 mg g^{-1} in cement-floor compost, 1.6 mg g^{-1} for banco-floor compost, and 1.1 mg g^{-1} in sand-floor compost (Fig. 3B). In contrast to N, P, and C contents, values for K content were similar throughout the composting process for all the treatments.

During most of the composting period, water content was greater in cement-floor compost (Fig. 3C). Water content decreased from over 0.80 g g^{-1} to final mean values of 0.74 g g^{-1} for cement-floor compost, 0.66 g g^{-1} for banco-floor compost, and 0.65 g g^{-1} for sand-floor compost. Water content is a dominant factor affecting aerobic microbial activity in composts because it provides a medium for the metabolic and physiological activities of microorganisms (Liang et al., 2003). Low moisture reduces biological processes, giving physically stable but biologically unstable compost. On the other

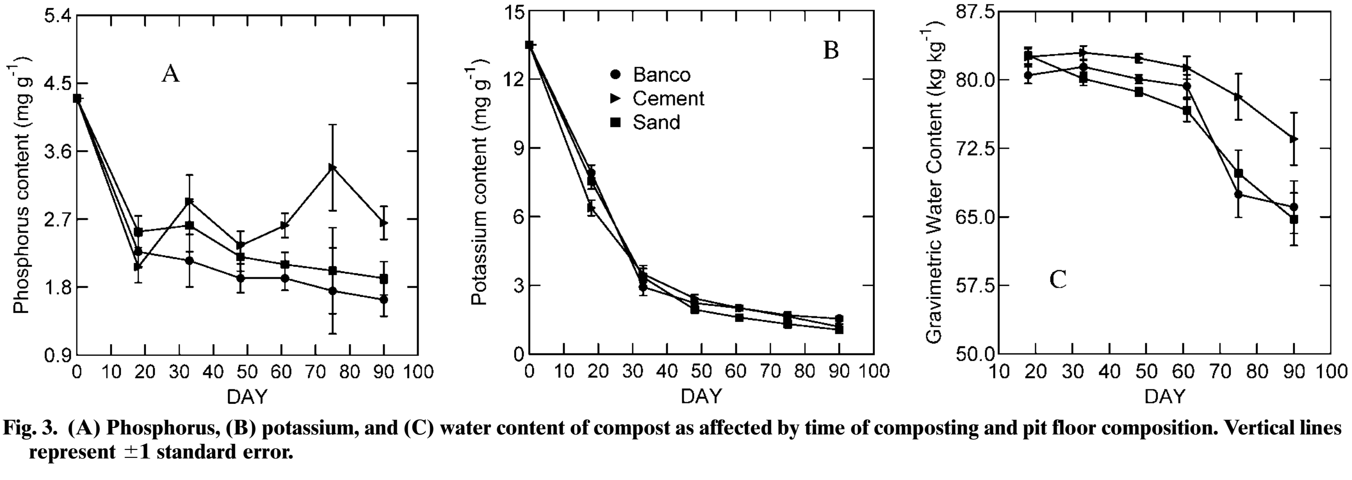

Fig. 3. (A) Phosphorus, (B) potassium, and (C) water content of compost as affected by time of composting and pit floor composition. Vertical lines represent ±1 standard error.

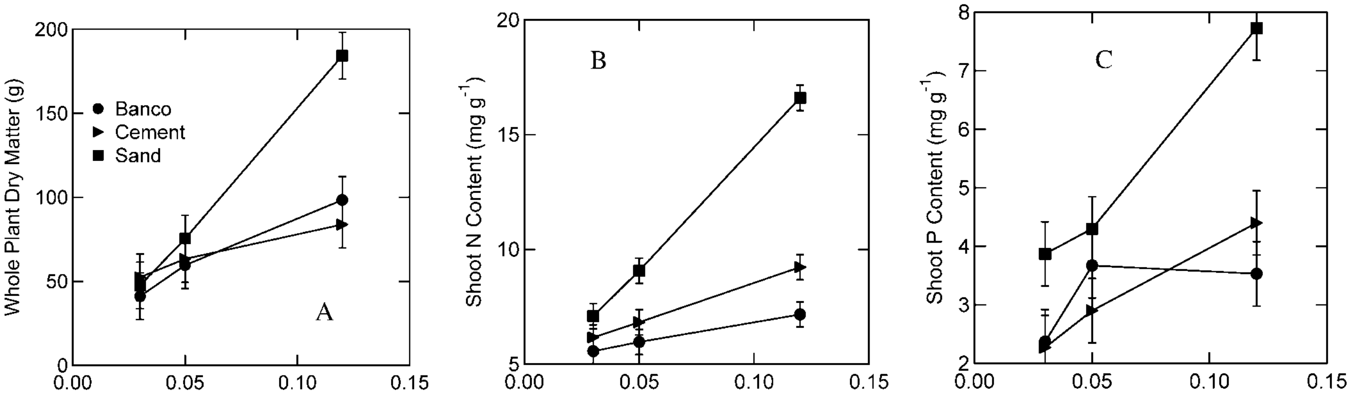

Fig. 4. Whole plant dry matter, shoot N content, and shoot P content of pearl millet as affected by compost/soil mixture using compost from pits of different floor materials. Vertical lines represent ±1 standard error.

hand, high water content can cause anaerobic conditions that inhibit biological processes. Based on respiration measurements, Liang et al. (2003) found that minimal water content for rapid increase in microbial activity was 0.50 g g^{-1}, and that optimum water content ranged from 0.60 to 0.80 g g^{-1}. They concluded that moisture content was more important to controlling microbial respiration in composting systems than temperature. On the other hand, Shi et al. (1999) concluded that aeration via turning was more important than watering for composting dairy wastes that had <0.40 g g^{-1} water content. There appears to be no universal optimal water content range for obtaining high quality compost, but after initial slightly wet conditions, water contents of all composts in our study were maintained between 0.60 and 0.80 g g^{-1}, the range found optimal by Liang et al. (2003). Decreasing porosity of pit floors conserved water to a small extent, as reflected by higher water content in the cement-floor compost. Theoretically this higher water content would have led to a higher compost rate (Liang et al., 2003) assuming anaerobic conditions did not develop. Oxygen levels were not measured, but there were no obvious H_2S odors emitted by cement-floor compost, and the frequent mixing would have discouraged anaerobic conditions.

Pearl millet growth and N and P contents were much greater for sand-floor compost than for the other two composts (Fig. 4A—C). For sand-floor compost, dry mass increased from 48 g with 3% compost by weight to 184 g with 12% compost. By contrast, dry mass increased for the same compost/soil mixtures from 41 to 98 g for banco-floor compost, and from 53 to 84 g for cement-floor compost. The fact that all composts promoted, rather than inhibited, growth suggests that none was immature (Mathur et al., 1993; Barker, 2001). There were interactions between compost source and amount. Shoot N and P content responded greater with the addition of sand-floor compost than additions of the other composts. Nitrogen content was greater from cement-floor compost than from banco-floor compost at higher compost/soil mixtures, but there were mixed results for plant dry mass and P content from banco-floor and cement-floor compost. Even though there is no universally agreed-upon procedure or species to evaluate compost quality, plant growth response is generally considered the best indicator (Emino and Warman, 2004). Therefore, sand-floor compost had the highest quality, and there was no clear distinction between qualities of banco- and cement-floor composts.

DISCUSSION

Without plant growth response data, compost data would have given conflicting indicators of quality. Banco-floor compost had the lowest C content (Fig. 1) and C/N ratio (Fig. 2), and significantly smaller mass than sand-floor compost (Fig. 1). Using these three criteria, one might have expected banco-floor compost to have had the greatest maturity and highest quality. Cement-floor compost maintained the highest water and P contents (Fig. 3), which might have been considered as indicators of high quality, but it also had highest C content, suggesting less maturity. High N content of cement-floor compost could have been interpreted as an indication of either immaturity or higher quality. None of the compost data suggested that sand-floor compost would have had dramatically greater plant dry mass and nutrient content (Fig. 4). Our results therefore support the view that plant response is a better overall indicator of compost quality than physical or chemical properties of the compost (Mathur et al., 1993; Emino and Warman, 2004).

We can only speculate about the reasons for the apparent superiority of sand-floor compost. It may have been due to better aeration associated with slightly lower water content, especially compared with cement-floor compost (Fig. 3C). However, water content of the banco-floor compost was about the same as that of sand-floor compost. Water content was always within the optimum range recommended by Liang et al. (2003), but Misra et al. (2003) state that water contents above 0.65 g g^{-1} can develop anaerobic conditions. It is also possible that direct contact of the compost with the native soil in the sand-floor compost pits promoted microbial populations that enhanced decomposition.

Our data suggest potentially large beneficial effects from more porous pit floors in terms of crop production and cycling of organic matter and nutrients, but the reasons for this are poorly understood. Compost science has made substantial gains in recent years (e.g., Mondini et al., 2003; Liang et al., 2003) but research has mostly been driven by environmental issues in developed countries rather than crop production in developing countries. Since compost quality depends on the materials and technology used, as well as the cropping conditions in which it is applied, there is a need for more compost studies that are relevant to semiarid African cropping systems.

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