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Mineralisation Patterns of Selected Organic Materials

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Abstract

Thirty-two standard organic materials were mixed with a sandy soil (at 40% field capacity) at a rate equivalent to 5 t ha^{-1} and incubated aerobically under controlled conditions at 25°C for 28 days. Sampling for mineral N determination and CO_2 evolution was conducted at 3, 7, 14 and 28 days. Released CO_2 was related to resource quality, with those materials high in N, low in lignin and low in polyphenol concentrations releasing higher percentages of their initial C. In vitro dry matter digestibility (IVDMD) was linearly correlated with carbon breakdown, with correlation coefficients of 0.91, 0.92, 0.92 and 0.84 for sampling times of 3, 7, 14 and 28 days, respectively. Initial N concentration was significantly positively correlated with C breakdown at all sampling times. Nitrogen mineralisation was influenced mainly by initial N concentration of the materials, with materials having at least 2.3% N releasing N throughout the 28-day period.

Organic materials constitute a major soil input in many agricultural systems in the tropics. The effect of these materials on crop production is mainly through their contribution to soil available nutrients, improvement in soil moisture status, especially in relatively dry areas, contribution to organic matter build-up in the soil and enhancement in soil microbial populations that improve nutrient release and availability to plants. Most soils in the tropics are deficient in major plant nutrients such as nitrogen, phosphorus and potassium. The contribution of these materials to soil nutrient availability is subject to nutrient release during the process of decomposition. This process is influenced by several factors, among them quality of the material (Swift et al. 1979). Among the major quality parameters influencing nutrient release, are nitrogen (N), lignin and soluble polyphenol concentrations. Materials rich in N, and low in soluble polyphenols and lignin, generally readily release nutrients once incorporated into the soil, subject to favourable environmental conditions. Materials low in nitrogen and high in lignin and polyphenol concentrations are likely to immobilise nitrogen during decomposition.

A study was carried out to determine nutrient release patterns of organic materials collected from different parts of Kenya. These materials comprised 30 plant materials (different parts), one cattle manure and one sample of sawdust.

Materials and Methods

Thirty-two organic materials were collected from different parts of Kenya, oven dried at 30–35°C and ground to pass though a 1 mm sieve (Gachengo et al. 2004). Fifty grams of oven-dry soil (78% sand, 4% clay, 8% silt, pH (in water) 5.4, total carbon 0.48%, total N 0.04%) was used. The soil was brought to 40% of field capacity and kept at room temperature

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for 2 weeks. The organic materials were thoroughly mixed with the soil at a rate of 5 t ha^{-1} dry weight basis in 60 mL bottles. These were placed in 250 mL incubation jars containing 10 mL of distilled water to maintain moisture levels during the incubation.

A vial containing sodium hydroxide (10 mL of 0.5 N) was placed in each incubation jar to trap CO_2 released during decomposition of the materials. The jars were tightly sealed with masking tape to avoid leakage of CO_2 produced by the respiring soil and kept in a temperature controlled room at 25° C. Each treatment was replicated three times in a completely randomised design.

Sampling for CO_2 and mineral N determination (nitrate plus ammonium) was done at 3, 7, 14 and 28 days. Determination of mineral N was also done at the beginning of the experiment (time 0). N mineralisation was calculated as net N mineralisation, where the sum of nitrate and ammonium N for each treatment was corrected by subtraction of the control.

Carbon dioxide trapped in the sodium hydroxide solution was determined by titration with 0.5 N hydrochloric acid. Ammonium and nitrate-nitrogen in the soil were determined by extraction using 100 mL of 2 N KCl (Dorich and Nelson 1984).

The amount of carbon released was calculated as:

$$CEVOL = (BLNKTIT - SAMTIT) \times 6 \times N_{HCL}$$

where CEVOL = evolved C (mg C)
       BLNKTIT = volume of standard HCl used to titrate the NaOH in containers from positive controls (mL)
       SAMTIT = volume of standard HCl used to titrate the NaOH in containers exposed to the soil atmosphere (mL)
       N_{HCL} = normality of standard HCl.

Results and Discussion

Carbon breakdown

The 32 organic materials analysed have been grouped into 6 quality classes depending on their N, lignin and polyphenol contents as described in Gachengo et al. (2004). During the incubation experiment, the high-quality materials (Class I) released the highest amounts of their initial C (Figure 1 (a)). By the end of 28 days, materials high in N, high in lignin and high in polyphenols (Figure 1(b)) had released the least amount of their initial C. It appears that there may be interaction between polyphenols and lignin in their influence on carbon breakdown. Materials high in either lignin or polyphenols alone but high in N (Figure 1(c) and (d)) released more of their initial carbon than those high in both lignin and polyphenols (Figure 1(b)). However, polyphenols appear to play a bigger role in limiting C breakdown than lignin. Materials low in both N and lignin (Figure 1(e)) released more of their initial carbon than those low in N and high in lignin (Figure 1(f)).

Carbon breakdown correlated well (Table 1) with most chemical constituents of the materials (Gachengo et al. 2004). Carbon released at 14 days by various materials linearly correlates well with in vitro dry matter digestibility (data reported by Barrios et al. (2004)). Correlation between the two parameters resulted in four clusters of materials (Figure 2). Cluster 1 represents materials with initial N > 2.5%, lignin and soluble polyphenol contents <15 and < 4%, respectively (quality class I). Cluster 2 comprise materials both low and high in N, lignin and polyphenols (classes I, II, III), while cluster 3 consists of materials with N <2.5% and low lignin or polyphenol contents (class III). Custer 4 is primarily made up of materials of low quality with N < 2.5% and lignin > 15% (class IV). Sawdust would be expected to fall within this cluster, but it lies on its own, probably due to its very high lignin content (29%) and low initial N (0.14%).

Significant positive linear correlation was also found between C released and N concentration. Lignin concentration showed significant negative correlation, while polyphenol concentration had no significant correlation with carbon release. However, on leaving out polyphenol data for stems, manure and stover materials (these are usually very low in polyphenols and nutrients, but high in lignin (Palm et al. 2001), there was a high negative correlation ($r = -0.86$) between carbon release and polyphenol concentration for leaf materials (Figure 3). The same applies to protein-binding capacity.

Multiple linear regression to determine the contribution of N, lignin and polyphenols resulted in the equation with an R^2 value of 0.6598:

$$C28 = 49.69 + 1.687N - 1.406PP - 1.144Lignin$$

where C28 = percentage of initial carbon evolved by 28 days
      N = per cent N in material
      Lignin = per cent lignin in material
      PP = per cent polyphenol in material.

Table 1. Simple linear correlation coefficients for mineralisation of N and C.

	%N	%P	%K	%Ca	%Mg	% total soluble polyphenols	% lignin	% soluble carbon	C:N	% in vitro dry matter digestibility	Protein-binding capacity BSA mg/g plant material
Nitrogen											
Day 3	0.826**	0.445*	0.297	0.510**	0.593**	-0.005	-0.181	0.524**	-0.393	0.414*	-0.038
Day 7	0.836**	0.450*	0.299	0.526**	0.579**	0.022	-0.183	0.563**	-0.407*	0.429*	-0.026
Day 14	0.896**	0.506**	0.351*	0.581**	0.615**	0.065	-0.334	0.651**	-0.589**	0.554**	-0.021
Day 28	0.915**	0.526**	0.352*	0.570**	0.648**	0.109	-0.415*	0.690**	-0.636**	0.621**	0.001
Carbon											
Day 3	0.709**	0.271	0.214	0.681**	0.435*	-0.233	-0.626**	0.662**	-0.449**	0.910**	-0.365*
Day 7	0.656**	0.328	0.290	0.631**	0.408*	-0.310	-0.673**	0.588***	-0.451**	0.925**	-0.432*
Day 14	0.639**	0.279	0.267	0.579**	0.395*	-0.362*	-0.706**	0.523**	-0.458***	0.923**	-0.454**
Day 28	0.418*	0.147	0.205	0.502**	0.225	-0.471**	-0.651**	0.409*	-0.423*	0.848**	-0.538**

* and ** refer to significance at 5 and 1% levels, respectively.

(a) High N, low lignin and polyphenols (Class I)

Croton megalorapus ◆ *Senna spectabilis* ■
Ctotalaria ochroleuca ▲ *Crotalaria grahamiana* ●
Gliricidia sepium ■ *Senna spectabilis* ●
Senna spectabilis ■ *Sesbania sesban* —

(b) High N, high lignin and polyphenols (Class II)

Flemingia congesta ◆
Calliandra calothyrsus ■
Calliandra calothyrsus ▲

(c) High N, low lignin and high polyphenols (Class II)

Lantana camara ◆ *Calliandra calothyrsus* ■
senna siamea ▲ *Tithonia diversifolia* ■
Calliandra calothyrsus ■ *Calliandra calothyrsus* ●
Calliandra calothyrsus ■ *Calliandra calothyrsus* —
Lantana camara — *Tithonia diversifolia* ◆

(d) High N, high lignin and low polyphenols (Class II)

Gliricidia sepium ◆
Cattle manure ■
Gliricidia sepium ▲

(e) Low N, low lignin (Class III)

Zea mays ◆
Senna siamea ■
Saccharum officinarum ▲

(f) Low N, High Lignin (Class IV)

Lantana camara ◆
Gliricidia sepium ■
Sesbania sesban ▲
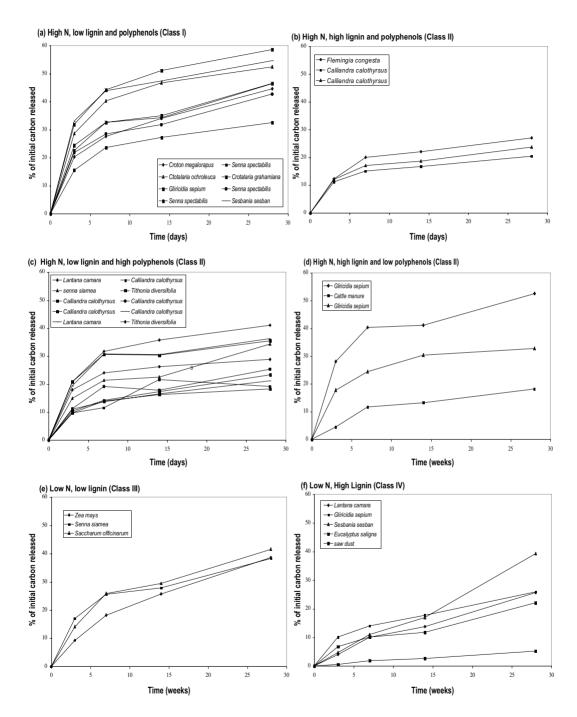*Eucalyptus saligna* ■
saw dust ■

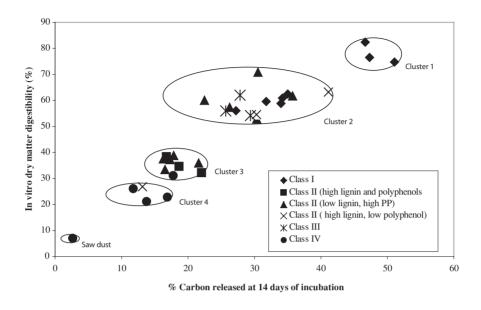**Figure 1.** Carbon mineralisation patterns of different quality classes.

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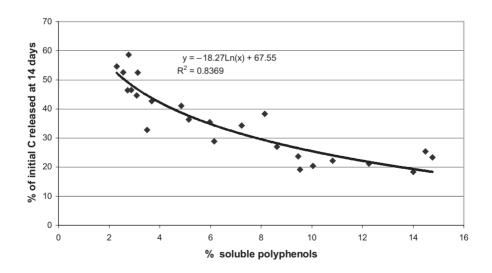**Figure 2.** Relationship between in vitro dry matter digestibility and carbon release.

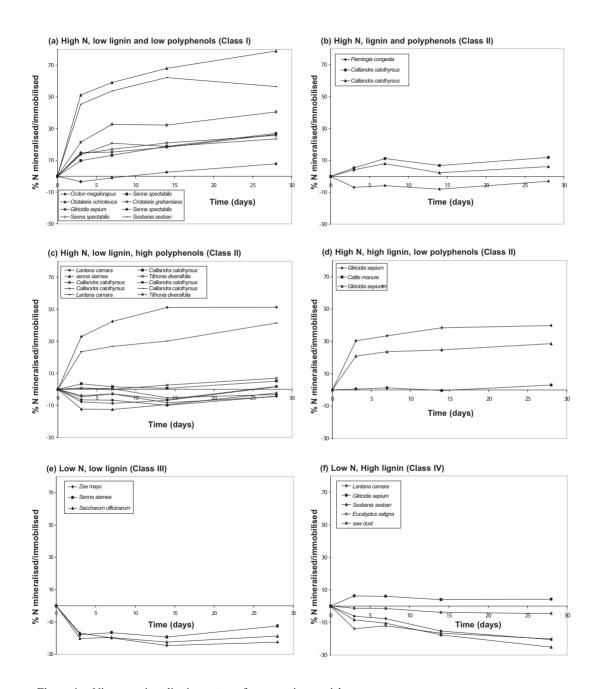**Figure 3.** Effect of soluble polyphenols on carbon release of organic materials.

(a) High N, low lignin and low polyphenols (Class I)

(b) High N, lignin and polyphenols (Class II)

(c) High N, low lignin, high polyphenols (Class II)

(d) High N, high lignin, low polyphenols (Class II)

(e) Low N, low lignin (Class III)

(f) Low N, High lignin (Class IV)

Figure 4. Nitrogen mineralisation patterns from organic materials.

Figure 5. Effect of initial N content on N mineralisation.

Thus, about 66% of variation in carbon mineralised by 28 days was accounted for by N, lignin and polyphenols contents of the materials.

Nitrogen mineralisation

Organic materials in Class I released N through the 28-day period except for one material that immobilised N during the first 7 days of incubation (Figure 4 (a)). This may be explained by its polyphenol content (3.81%), which was very close to the critical level (4%) required for net N mineralisation to occur. Most materials high in both N and polyphenol (but low in lignin) (Figure 4(c)) immobilised N for some time or throughout the 28 days, while those high in N and lignin (but low in polyphenols) (Figure 4(d)) mineralised N throughout the study period. Thus, polyphenols had a higher influence in limiting N mineralisation than lignin. Materials in class III immobilised N throughout the 28 days due to their low initial N content. However, there was a reduction in immobilisation after 14 days of incubation. Materials in class IV immobilised N, increasingly with time. The trend does not show any indication of net mineralisation taking place in the near future (Figure 4(f)).

The most significant positive correlation for nitrogen release at 28 days was with the N concentration of the materials (Table 1). Most materials whose nitrogen concentration was at least 2.3% released nitrogen (Figure 5). Materials with %N above 2.3% but soluble polyphenol above 4% immobilised N. *Gliricidia sepium* stems, though low in N (1.64%) and high in lignin (20.44%), did not immobilise N probably due to their low polyphenol concentration (1.3%). This suggests that N mineralisation of the materials was controlled mainly by their N and polyphenols contents.

Multiple regression analysis showed N mineralisation was mainly influenced by N concentration in the materials (Table 1), the following equation having an R^2 value of 0.846:

$$N28 = -97.81 - 0.00021PP + 28.85N + 0.698Lignin$$

where N28 = percentage of initial N mineralised by 28 days.

Conclusion

Mineralisation is a complex process that is governed by several factors, among them quality of the material. During the early stages of decomposition, it appears that N and polyphenol contents are the main quality parameters that determine mineralisation of nitrogen. For net N mineralisation to take place during the early stages of decomposition, a combination of low polyphenol and high nitrogen concentrations is required. Carbon breakdown was also influenced by the presence of lignin, with materials high in both lignin and polyphenols releasing less C. However, lignin did not appear to influence N mineralisation significantly, at least during the first 28 days of decomposition.

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