Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization

Webster D. Sakala\textsuperscript{a,b}, George Cadisch\textsuperscript{a}, Ken E. Giller\textsuperscript{a,*}

\textsuperscript{a}Department of Biological Sciences, Wye College, University of London, Wye, Ashford, Kent TN25 5AH, UK
\textsuperscript{b}Chitedze Agricultural Research Station, P.O. 158, Lilongwe, Malawi

Received 24 March 1999; received in revised form 7 October 1999; accepted 22 October 1999

Abstract

Nitrogen mineralization patterns of maize and pigeonpea (\textit{Cajanus cajan}) residues were examined in leaching tubes, both in isolation and mixtures, in Malawian soils of varying texture. Senesced pigeonpea leaves (C-to-N ratio 24) induced a short period of nitrogen immobilization which was followed by steady net nitrogen mineralization in all of three soils. The immobilization period lasted between 14 and 28 days and was longer in soils with larger clay contents. Maize residues contained 30\% of their N in the form of water-soluble nitrate. Both the sole maize residue (C-to-N ratio 75 after adjustment for nitrate which constituted 28\% of the N) and the mixture of maize and senesced pigeonpeas leaves revealed a similar prolonged strong net N immobilization up to 130 days before the two treatments started to diverge slightly. Mixing maize with pigeonpea residues with equal amounts of N failed to substantially alleviate the N immobilization capacity of the maize residues. N immobilization in the mixture was much greater than that predicted from the mineralization patterns of the individual components. When increasing amounts (50, 100 and 150 mg N kg\textsuperscript{-1} soil) of green pigeonpea leaves, senesced pigeonpeas leaves and ammonia-N were added to 50 mg N kg\textsuperscript{-1} soil of maize residues, N released in the mixtures increased with the increasing amounts of N added to the maize residues with greater increases from residues with larger N concentrations. There was evidence that microbial degradation of maize carbon was limited by N availability. The implications of the results for management of crop residues and mineral N fertilizers in the field are discussed. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Residue quality; Litter; Decomposition; N immobilization; N mineralization; N fertilizers

1. Introduction

Intercropping of legume and cereal crops is commonly practiced by smallholder farmers throughout the tropics. One of the most successful legumes for intercropping is pigeonpea (\textit{Cajanus cajan} (L.) Millsp.) in many parts of Africa, India and the Caribbean. Due to the slow initial growth of pigeonpea there is minimal competition with an intercropped cereal (Dalal, 1974). In Malawi, where many smallholder farmers intercrop maize (\textit{Zea mays} L.) and pigeonpea, Sakala (1994) demonstrated that intercropping long-duration pigeonpea varieties without reducing the normal farmers’ maize plant population resulted in minimal yield reduction of the associated maize and the benefit of pigeonpea yield of grain and fuelwood. Pigeonpea can nodulate well and has been estimated to fix up to 90\% of its N from the atmosphere (Kumar Rao et al., 1987), with greatest biomass accumulation and N\textsubscript{2}-fixation in the long-duration varieties (Kumar Rao and Dart, 1987). During growth substantial amounts of pigeonpea leaves senesce and fall to the ground which result in additions of 28–40 kg N ha\textsuperscript{-1} to the soil from long-duration varieties (Kumar Rao et al., 1983; Kumar Rao and Dart, 1987).
The extent to which intercropped or subsequent cereal crops can benefit from this N will depend on the rate at which the leaves decompose and release N. Chemical composition or quality of organic residues has a major influence on their rates of decomposition and N release when added to the soils (Cadisch and Giller, 1997). When crops are grown in association, the residues of different crops become mixed so that residues of different quality decompose simultaneously within the same soil volume. Interactions between decomposing residues can be complex and may result in N mineralization patterns which are not readily predicted from the N mineralization of the separate components of the mixture (Handayanto et al., 1997a,b).

The decomposition and net N mineralization-immobilization patterns of individual and mixed maize and pigeonpea residues were studied in Malawian soils of varying texture. We hypothesised that mixing poor quality maize stover (with a wide C-to-N ratio) with pigeonpea residues of better quality would overcome the strong immobilization capacity of the maize stover. Interactions between decomposing maize residues and mineral N fertilizers on the immobilization/mineralization of N were also studied. Leaching tubes were used for the incubation experiments because they take into account the initial rapid loss of organic and mineral constituents during decomposition and allow periodic leaching from the same tube over time. This method has been widely used in assessing N mineralization (e.g. Stanford and Smith, 1972; Frankenberger and Abdelmagid, 1985; Handayanto et al., 1997a).

2. Materials and methods

2.1. Nitrogen mineralization and decomposition

Decomposition and N mineralization were measured in leaching tube incubations (Stanford and Smith, 1972). In the first experiment the N mineralization of three residue treatments, maize stover, senesced pigeonpea leaves, a mixture of maize and senesced pigeonpea residues were compared in three Malawian soils of different texture from Chitala, Chitedze and Lisasadzi (Table 1). An unamended soil treatment was included in each case as a control and all treatments were replicated four times. Sole maize and pigeonpea residues were added at a rate equivalent to 100 mg N of residues kg\(^{-1}\) soil (representing 1.4, 0.63 and 2.5% of total soil N, respectively, in the Chitala, Chitedze and Lisasadzi soils). The treatment which had a mixture of maize residues and senesced pigeonpea leaves received an equivalent of 50 mg N of maize residues kg\(^{-1}\) soil and 50 mg N of senesced pigeonpea leaves kg\(^{-1}\) soil.

Table 1

<table>
<thead>
<tr>
<th>Origin of soil</th>
<th>pH (H(_2)O)</th>
<th>C %</th>
<th>N %</th>
<th>C-to-N ratio</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Fine sand %</th>
<th>Coarse sand %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitala</td>
<td>5.6</td>
<td>1.07</td>
<td>0.07</td>
<td>15</td>
<td>26</td>
<td>9</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Chitedze</td>
<td>5.4</td>
<td>2.39</td>
<td>0.16</td>
<td>15</td>
<td>28</td>
<td>21</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Lisasadzi</td>
<td>5.8</td>
<td>0.59</td>
<td>0.04</td>
<td>15</td>
<td>4</td>
<td>4</td>
<td>36</td>
<td>56</td>
</tr>
</tbody>
</table>

Twelve treatments were compared in a second experiment in the Chitala soil. Green pigeonpea leaves, senesced pigeonpea leaves or mineral N (as NH\(_4\)-N) were added at three rates (50, 100 and 150 mg N kg\(^{-1}\) soil) together with 50 mg N kg\(^{-1}\) soil of maize residues. The other three treatments were an unamended control soil, green pigeonpea leaves added at a rate of 100 mg N kg\(^{-1}\) soil and sole maize residues at a rate of 50 mg N kg\(^{-1}\) soil.

The leaching tubes were made from plexiglass tubing and were 28 cm long with an internal diameter of 38 mm (total volume 318 cm\(^3\)). A plate made of polycarbonate rod with numerous holes was inserted at the base of the tube, covered with a fibre-glass filter paper and a 2 cm layer of fine sand. For both experiments samples of 75 g of soil were mixed thoroughly with 75 g of acid-washed sand and the relevant plant residue treatment and placed in the leaching tubes, filling roughly half the volume of the columns. Tubes were stepwise leached with 150 ml of a leaching solution (1 mM CaCl\(_2\); 1 mM MgSO\(_4\); 0.1 mM KH\(_2\)PO\(_4\) and 0.9 mM KCl (adapted from Cassman and Munns, 1980) in 50 ml aliquots. After each leaching, the moisture of the soil–sand mixture in the tube was brought back to approximately 70% of the water holding capacity by removing the excess water with a mild suction pump and the tubes were kept at 27°C in the dark. For those treatments receiving additional mineral N fertilizer, NH\(_4\)-N was added as (NH\(_4\))\(_2\)SO\(_4\) to leaching tubes after removal of excess moisture with a suction pump after the first leaching (day 0) to avoid fertilizer N from being leached. NH\(_4\)-N fertilizer was dissolved in 5 ml of water and added from the top of the leaching tube through a syringe. The leachates were analysed for mineral-N (NH\(_4\)-N plus NO\(_3\)-N) as described below and net N release was calculated by subtracting N released from the residue-amended treatment from the N release from the unamended soil controls. Cumulative N release was calculated by adding net N
release at each leaching. N released at the initial leaching was not included in the cumulative N release but reported separately. In the second experiment carbon dioxide evolution was measured in a parallel set of leaching tubes with 20 ml of 0.25 M NaOH placed in a suspended glass container in air-tight leaching tubes to trap CO$_2$ evolving from the soil plant mixture. Capped tubes were fitted with a soda-lime syringe inserted through a sampling port to allow oxygen diffusion but prevent carbon dioxide entering (Urquiaga et al., 1998). After removing the trap from the leaching tube excess BaCl$_2$ was added to the trap to precipitate the carbonates, indicator (phenolphthalein) was added and the OH$^-$ concentration remaining in the trap was measured by titration with HCl.

2.2. Soil and plant material characterization

Soils were sampled from the surface 20 cm layer at Chitala, Chitedze and Lisasadzi (Table 1). Soil pH was determined in water (1:2.5, soil:water ratio). The particle size analysis was performed using the pipette method. The crop residues used were maize stover (stalks and leaves), naturally-senesced pigeonpea leaves and green pigeonpea leaves (leaves and petioles) collected from the field at Chitedze. Prior to chemical analysis plant samples were oven-dried (65°C for 48 h) and ground to pass through a 2 mm sieve. Total N and C contents of soil and crop residues were determined by dry combustion using a Roboprep automatic C/N analyzer coupled to a 20–20 mass spectrometer (Europa Scientific, Crewe, UK). Total extractable mineral-N from residues was determined by mixing 100 mg of residues into 50 ml of cold water and shaking it for 1 h and NO$_3$-N and NH$_4$-N in solutions were measured colorimetrically using an SFA-2 Burkard-Scientific autoanalyzer. NO$_3$-N was reduced by a copper-hydrazine solution to NO$_2$-N and subsequently reacted with sulphanilamide and N-1-naphthylene-diamine. NH$_4$-N was measured by a modification of the ‘Berthelot reaction’ (Searle, 1984). Anthrone-reactive carbon in leachates from day 0 to 2 was determined using the method adapted from Cheshire and Mundie (1990). The acid detergent fibre (ADF) method was used for determination of lignin and cellulose contents (Anderson and Ingram, 1993). The Folin–Denis method was used for the extraction of total extractable polyphenols using tannic acid as a standard (Anderson and Ingram, 1993) after extraction in hot (80°C) 50% methanol. The protein-binding capacity of polyphenols was determined by applying these plant extracts to a chromatography paper and reacting with bovine serum albumin following the method of Dawra et al. (1988).

### Table 2

<table>
<thead>
<tr>
<th>Residue type</th>
<th>C %</th>
<th>N %</th>
<th>C-to-N ratio</th>
<th>Water soluble mineral N % of total N</th>
<th>C-to-N adjusted</th>
<th>Water soluble mineral N</th>
<th>C-to-N ratio</th>
<th>Water soluble mineral N</th>
<th>C-to-N ratio</th>
<th>Lignin %</th>
<th>TEP %</th>
<th>Lignin:N (TEP+lignin):N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize stover</td>
<td>42</td>
<td>0.70</td>
<td>60</td>
<td>28</td>
<td>75</td>
<td>5.7</td>
<td>50</td>
<td>0.5</td>
<td>8.1</td>
<td>8.9</td>
<td>37</td>
<td>4.5</td>
</tr>
<tr>
<td>Senesced pigeonpea leaves</td>
<td>44</td>
<td>1.86</td>
<td>24</td>
<td>1</td>
<td>24</td>
<td>15.7</td>
<td>37</td>
<td>1.3</td>
<td>8.3</td>
<td>9.0</td>
<td>27</td>
<td>4.0</td>
</tr>
<tr>
<td>Green pigeonpea leaves</td>
<td>44</td>
<td>3.18</td>
<td>14</td>
<td>0</td>
<td>14</td>
<td>12.8</td>
<td>27</td>
<td>1.5</td>
<td>4.0</td>
<td>5.5</td>
<td>9</td>
<td>1.2</td>
</tr>
<tr>
<td>Mixture of maize stover and senesced pigeonpea leaves</td>
<td>43</td>
<td>1.29</td>
<td>33</td>
<td>9</td>
<td>49</td>
<td>8.5</td>
<td>48</td>
<td>0.7</td>
<td>6.5</td>
<td>7.1</td>
<td>8</td>
<td>3.7</td>
</tr>
</tbody>
</table>

*a Adjusted after deduction of the water soluble mineral N.

ADF = Acid detergent fibre

TEP = total extractable polyphenols.
3. Results

3.1. Crop residue characterization

The small N content of the maize stover (0.70%N) resulted in a C-to-N ratio three times wider than that of the senesced pigeonpea leaves (Table 2). As expected the green pigeonpea leaves had a larger N content (3.2%) than senesced pigeonpea leaves (1.9%N). The lignin content of the pigeonpea leaves (12.8–15.7%) was much larger than that of the maize stover (5.7%), whereas the acid detergent fibre (ADF) of the maize stover was largest. Pigeonpeas had greater total extractable polyphenols than maize residues, but all of the residues studied here had relatively small concentration of active polyphenols and protein binding capacity (data not presented) when compared with legume tree residues (Handayanto et al., 1994).

Maize residues resulted in the greatest leached anthrone-reactive carbon content followed by the mixture of maize and pigeonpea residues (Table 3). There were only trace amounts of soluble carbohydrate in senesced pigeonpea leaves. Maize residue treatments had a surprisingly large amount of water soluble mineral N at the first leaching whereas only a small amount of mineral N was leached from the senesced pigeonpeas leaves (Table 3). When mineral N was extracted from the residues by shaking in cold water 1.98, 0.16 and 1.08 mg N g⁻¹ was extracted from maize residues, senesced pigeonpea leaves and a mixture of maize residues and senesced pigeonpea leaves, respectively (Table 1). Virtually all of the mineral N in the maize stover was present as nitrate. When the water soluble C and N removed by leaching were taken into account, the C-to-N ratio of the maize stover became much wider (75) whereas the C-to-N ratios of the pigeonpeas leaves remained the same as they contained negligible amounts of water-soluble carbon and nitrogen (Table 2).

3.2. Soil effects on N release

In the first experiment, N mineralization from the unamended Lisasadzi soil, which had a smaller total N content (0.04% N), was initially significantly slower than from the two soils with larger total N contents; Chitedze (0.16% N) and Chitala (0.07% N) (Fig. 1). After 28 days cumulative N released was 13, 19 and 24 μg N g⁻¹ for the Lisasadzi, Chitedze and Chitala soils, respectively. However, between 60 and 80 days after first leaching N release was between 4 and 6 μg N g⁻¹ in all three soils.

In all of the residue-amended treatments initial N release was reduced compared with the unamended soils indicating net N immobilization (Fig. 2). The degree of N immobilization was stronger in the Chitala (35% clay+silt) and Chitedze (49% clay+silt) soils with larger clay+silt contents than in the sandy Lisasadzi soil (8% clay+silt) with all residue treatments. After 14 days of incubation, the cumulative net N immobilization with maize stover was 20, 14 and 9 μg N g⁻¹ for the Chitala, Chitedze and Lisasadzi soils respectively. At the end of the incubation after 500 days, there was still net N immobilization of 33 and 25
mg N g soil⁻¹ in the Chitala and Lisasadzi soils amended with maize stover. There was also a shorter period of net N immobilization with senesced pigeonpea leaves which was both stronger and of longer duration (> 12 weeks) in the heavier-textured Chitala and Chitedze soils than in the sandy Lisasadzi soil (8 weeks).

3.3. Effects of litter quality on N release

All residue-amended treatments resulted in similar immobilization of N for the first 4 weeks in each of the three soils in the first experiment, although the amount of N immobilized varied between the soils as indicated above (Fig. 2). After 4 weeks re-mineralization of N was observed in the soils amended with senesced pigeonpea leaves, although there was still net N immobilization with respect to the unamended control soils. In contrast, N immobilization continued to predominate in soils amended with maize stover and the mixture of maize stover and senesced pigeonpea leaves up to 110–130 days (Fig. 2) after which re-mineralization was observed in the mixture. The actual N mineralization from the mixture was substantially less than that predicted as an average of the sole maize and sole pigeonpea treatments indicating a strong negative interaction on N release from the mixture (Fig. 2).

3.4. Effects of residue quality and NH₄-N on CO₂ evolution

In all of the residue-amended treatments there was rapid CO₂ evolution within the first 10 days (Fig. 3) with no significant differences (P ≥ 0.05) between treatments. After 8–12 days, rates of CO₂ evolution slowed in most treatments and CO₂ evolution was significantly greater where only green pigeonpea leaves were added compared with all other treatments amended with...
maize residues (Fig. 3). CO₂ evolution from the mixtures of maize stover and pigeonpea leaves largely followed what was expected from the sole residue treatments. Addition of NH₄-N as (NH₄)₂SO₄ caused an initial reduction in rates of CO₂ evolution which was stronger with the larger amounts of NH₄-N added, but after 20 days there was a significant stimulatory effect of NH₄-N on CO₂ evolution from the maize residues. After 60 days the mean cumulative CO₂ released for senesced pigeonpea leaves, green pigeonpea leaves and NH₄-N mixed with maize residues were 332, 376 and 407 mg C g⁻¹ C added, respectively, and CO₂ released from sole maize and sole green pigeonpea leaves were 255 and 519 mg C g⁻¹ C added, respectively.

3.5. Effects of different sources and N rates on N mineralization/immobilization

The patterns of N immobilization with the sole

![Graphs showing N mineralization patterns](image)

maize residue treatment and the treatment in which equal amounts of N as maize or senesced pigeonpea leaves were added were similar to that found in the first experiment with net N immobilization persisting in both cases throughout the 460 day incubation period (Fig. 4a). When larger amounts of senesced pigeonpea leaves were added with the maize stover net N mineralization was found around 300 days. Immediate, rapid net N mineralization was found with green pigeonpea leaves, but there was initial net N immobilization in all cases where they were added together with maize stover (Fig. 4b). The effect of the different rates of green pigeonpea leaves on N mineralization was proportional to the amount added: net N mineralization was achieved more rapidly and more N was mineralized when 150 µg N g⁻¹ soil⁻¹ was added as green pigeonpea leaves than with 50 or 100 µg N g⁻¹ soil⁻¹. However, similar to observations in the first experiment, there was a negative interaction in N release in the green pigeonpea–maize mixture; that is actual N release was slower than that predicted from the individual components during the initial phase of decomposition.

A short initial phase of net N immobilization was found with all rates when NH₄-N was added with maize stover; again the length and strength of this immobilization phase was shorter and smaller when larger rates of NH₄-N were added (<10 days with 150, ~12 days with 100 and >50 days with 50 µg NH₄-N g⁻¹ soil⁻¹; Fig. 4c). At the end of the experiment (460 days) the difference between the amount of N mineralization in the NH₄-N amended treatments and the amount of N immobilized with the sole maize residue was similar to the amount of NH₄-N added in each case (53, 84 and 138 µg N g⁻¹ soil⁻¹, respectively).

4. Discussion

4.1. Leaching of mineral N from the residues

A considerable amount of N (28%) in the maize residues was present as nitrate which was readily leached from the residues (Table 2), together with a substantial amount of anthrone-reactive C (Table 3). Leaching of water-soluble materials is an initial stage of the decomposition process (Swift et al., 1979; Heal et al., 1997). C and N which was removed at the first leaching (day 0) probably would have given lesser immobilization with the maize residue because of the greater availability of nitrogen in the maize residues which was leached. Between 19 and 26 mg N kg⁻¹ soil from maize residues was leached at first leaching (day 0) which represented 19–26% of total N of maize residues applied (initial application rate of 100 mg N kg⁻¹ soil). Most of the N in the maize residue was in the
form of NO₃-N, a similar result to that of Recous et al. (1995) who found 16% of the total N in maize residues to be in mineral form and mainly as nitrate. The large amounts of soluble N in the residues found here are attributed to late rains at the end of the growing season which would have stimulated soil N mineralization and uptake of mineral N by the maize crop just before it dried in the field.

4.2. N mineralization/imobilization in the different soils

Initial rates of N mineralization in the unamended soils (Fig. 1) were greater in the Chitedze and Chitala soils which had larger total N contents (0.16 and 0.07% N, respectively) than in the sandy Lisasadzi soil which had a smaller N content (0.04% N; Table 1). Although influenced by management, amounts of total C and N in African soils are strongly related to the amount of clay and silt (Feller et al., 1991; Giller et al., 1997), as observed here. After 60 d rates of N mineralization slowed and were similar in all three soils.

When the soils were amended with maize residues, immediate N immobilization was observed in all three soils. The N immobilization predicted from the mixture or maize and pigeonpea residues (Fig. 4) was based on the actual N immobilization measured rather than the potential N immobilization of the maize residues. The amount of N immobilized was directly equivalent to the amount of N mineralized from the soil (Fig. 2), which indicated that the maize residues had a capacity to induce more immobilization of N than that observed. This is supported by the similar amounts of N immobilization found with maize residues in the two experiments reported here, although twice as much maize stover was added in the first experiment (Fig. 2) compared with the second experiment (Fig. 4). Using the equation of Whitmore and Handayanto (1997):

\[
N = C_0 \left\{ \frac{1}{Z - E} \right\} Y
\]

complete decomposition of maize residue applied at a rate of 50 mg N kg⁻¹ soil (which equals an initial C content (C₀) of 3 g C kg⁻¹ soil) has an immobilization potential (N) of around 80 mg N kg⁻¹ soil (assuming a microbial efficiency (E) of 0.4 and a C-to-N ratio of the end-product of the decomposition process (Y) to be the same as the soil). After 60 days roughly 25% of the C added in the maize residues had been released as CO₂ (Fig. 3), which would suggest that 42% of the C had passed through the microbial biomass. Assuming uniform decomposability of C and N in the residues this indicates an immobilization potential of 34 mg N kg⁻¹ soil compared with the 20 mg N kg⁻¹ soil observed (Fig. 4), again indicating a stronger immobilization potential than that observed. Over longer periods of time, due to continued mineralization of soil N (Fig. 1) and microbial turnover, N mineralization predominates over immobilization (Figs. 2 and 4).

Immobilization of all available mineral N when small rates of fertilizer were added to soil with maize residues has been reported elsewhere (Recous et al., 1995). There was net immobilization with maize residues with respect to the unamended controls in all soils throughout the 500 day incubation, but the maximum extent of immobilization occurred around 240 days in the sandy Lisasadzi soil and later (ca. 300 days) in the Chitala soil (Fig. 2). The noticeably prolonged and stronger N immobilization phase induced by the senesced pigeonpea leaves in the Chitala and Chitedze soils (Fig. 2) with a heavier texture (35 and 49% clay+silt, respectively) than the Lisasadzi soil (8% clay+silt) indicated the stabilizing effect of the clay on microorganisms and microbial metabolites which leads to slower decomposition and N turnover (van Veen et al., 1985).

4.3. Effects of residue quality on N mineralization patterns

The differences in N mineralization between the three residues studied; green pigeonpea leaves, senesced pigeonpea leaves and maize stover were largely as expected from their litter quality. Green pigeonpea leaves (C-to-N ratio of 14) gave immediate net N mineralization and released almost 50% of their N during the incubation (Fig. 3). The pigeonpea leaves contained substantial amounts of lignin (13–16%) which may explain why more of the N was not released. Palm and Sanchez (1991) found pigeonpea leaves to have substantially larger polyphenol contents than those reported here, but this is probably due to the different varieties of pigeonpea studied. Pigeonpea is rarely used as green manure by smallholder farmers in the tropics although it has been studied for pruning management for forage (Cobbina, 1995) and soil amendment and fuelwood production (Chiyenda and Materechera, 1989). Although the green pigeonpea leaves released N readily, they are unlikely to be used widely in agriculture. For most smallholder farmers in Africa and India the primary reason for growing pigeonpea is for grain and fuelwood and in the unimodal climates of southern Africa most leaves have fallen by the time of harvest.

Senesced pigeonpea leaves caused a short period of N immobilization despite the fairly narrow C-to-N ratio of 24-to-1 (Fig. 2). In the field pigeonpea leaves usually start falling approximately 10 weeks after planting and may add up to 40 kg N ha⁻¹ to the soil.
(Kumar Rao et al., 1983). However, as net N mineralization from senescing pigeonpea leaves did not occur for 30–60 days after incubation (Fig. 2), little N would be made available to a companion maize crop which would normally mature after 90–120 days. Some longer-duration varieties of cereal crops such as sorghum (Sorghum bicolor (L.) Moench), which are intercropped with pigeonpea in parts of India, may derive some N benefit from fallen pigeonpea leaves. Some of the N released could also be re-utilized by the pigeonpea crop itself and will contribute substantially to the residual benefit often observed in growing maize or other cereal crops after pigeonpea (Kumar Rao et al., 1983), although these residual benefits are partly due to N inputs from decaying roots and nodules (Kumar Rao et al., 1987).

The wide C-to-N ratio of the maize residue (60-to-1) resulted in immediate immobilization of all of the N available in each soil (Fig. 2). Leaching at day 0 further increased the immobilization strength of the maize residues by widening the initial C-to-N ratio from 60 to 75 (Table 2). Immobilization continued to increase with respect to the unamended soils for 240–300 days. After this steady mineralization of N from the sole maize residues was observed in all cases (Figs. 2 and 3), though there was net N immobilization with respect to the control soils even at the end of the experiments after 500 days. The maize residues contained a large amount of cellulose (as ADF minus lignin; 44%) and a small lignin (<6%) content as well as much more anthrone-reactive C than the senesced pigeonpea leaves, indicating that much of the C was readily accessible for microbial attack.

The long phase of N immobilization induced by maize stover in both experiments indicated that incorporation of large quantities of maize residues in the field would restrict N availability for growing crops. In Malawi, some smallholder farmers incorporate maize residues into ridges of soil at the end of the rainy season when some moisture remains to allow decomposition. In other parts of Africa, cereal crop residues are fed to animals or are burned to aid tillage and assist in pest control (Giller et al., 1997).

4.4. Effects of mixing residues and mineral N on decomposition and N mineralization

Mixing maize stover with senesced pigeonpea leaves on the basis of equivalent amounts of N failed to substantially alleviate the N immobilization induced by the maize residues in the first experiment (Fig. 2). Net N immobilization in the mixture and sole maize treatments was similar for more than 110 days, and comparison of the mineralization pattern with the average of the two sole residue treatments (Fig. 2) demonstrated that this strong interaction between maize residue and senesced pigeonpea leaves persisted throughout the incubation. The interaction thus resulted from a general N limitation in the residue mixtures rather than any specific interaction between components of the residues such as that observed in some mixtures of legume tree leaves in which availability of N is decreased due to the complexation of proteins with reactive polyphenols (Handayanto et al., 1997b). The relative quantities of senesced pigeonpea leaves and maize stover added (roughly three times more maize stover than pigeonpea leaves on a weight basis) is realistic of what may be produced in a maize/pigeonpea intercrop in the field. It also suggests that adding large amounts of maize stover would override the residual benefit of senesced pigeonpea leaves in the field. Adding larger quantities of senesced pigeonpea leaves resulted in net N mineralization compared with the unamended soil only after 300 days (Fig. 4). Green pigeonpea leaves overcame the net N immobilization more quickly than the senesced pigeonpea leaves as would be expected given their rapid N mineralization, and the effect was proportional to the amount of N added as green leaves. A similar benefit of adding green bean leaves with maize residues on decomposition and N release was demonstrated by Ehaliotis et al. (1998). Stimulation of decomposition and microbial respiration during the early stages of decomposition was observed when leaves and stems of rye, wheat and oats were mixed (Quemada and Cabrera, 1995). These authors found that a large soluble C content of wheat stems resulted in a strong retardation of N release when mixed with wheat leaves of higher N content.

Even when large amounts of NH4-N (150 mg N kg−1 soil) were added with the maize residues there was a brief 10 day period during which all of the mineral N was immobilized (Fig. 4). Again the effect was largely proportional to the amounts of NH4-N added and it took over 50 days for net N mineralization to occur with 50 mg NH4-N kg−1 soil added with respect to the unamended control soil. However, at the end of the incubation less than 16% of the mineral N which had been added initially remained immobilized in the soil by the maize residue in all the three treatments (Fig. 3).

There was strong evidence that microbial respiration was limited by N availability when maize residues were added to soil. The fastest rates of CO2 evolution and the maximum amount of the C respired were found with the green pigeonpea residues (Fig. 3) whereas there were no significant differences in CO2 evolution in the sole maize residues or the maize/pigeonpea mixtures over the first 12 days. CO2 evolution from 14 days onwards was much slower with the sole maize residue than with the maize/pigeonpea mixtures indicating that N was limiting microbial respiration. Although this difference could partly have been due to
differences in C availability for microbial attack between the maize and pigeonpea residues, the larger lignin and smaller cellulose contents of the pigeonpea residues render this unlikely. The strongest direct evidence that N availability limited C decomposition came from the N fertilizer treatments although where NH$_4^+$-N was added there was an initial inhibition of respiration during the first 10 days which was proportional to the amount of NH$_4^+$-N added (Fig. 4c). This could have been due to direct toxicity of the NH$_4^+$ to the microbial biomass or to transient effects on soil pH (cf. Salonius, 1972). From 20 days onwards rates of CO$_2$ evolution were more rapid in the treatments where NH$_4^+$-N had been added, providing clear evidence that N limitation was restricting microbial respiration and decomposition of the sole maize residues. A strong positive effect of increased mineral N availability on decomposition of high C-to-N ratio maize straw was also observed by Recous et al. (1995).

Our results indicate that maize residues will act as a trap for mineral N in soil which is often available in large concentrations at the end of the dry season in the semi-arid tropics and susceptible to leaching and gaseous losses. Some of this N will be immobilized in soil for a prolonged period (>1 year). The extent to which the capacity of maize residues to immobilize and release mineral N later can be used to assist in managing N fertilizer availability and losses is unclear and requires further experimentation in the field. N fertilizers are generally added in split applications to maize by smallholder farmers in Africa, often at fairly small rates (<30 kg N ha$^{-1}$) and at different times than when maize residues are incorporated; factors not mimicked in our experiments. In the field in the semi-arid tropics, N immobilization may be further prolonged due to the long dry season, or conversely N mineralization may be stimulated during the cropping season due to periodic drying and wetting of the soil (Birch, 1958).

In conclusion, although N mineralization from fallen pigeonpea leaves can supply a large amount of N for crop growth, rates of N release are slow and likely to be of benefit only to subsequent crops. The poor quality of maize residues means that substantial amounts of N must be made available if problems of N supply for crop growth are to be avoided when they are added to soil, although large amounts of organic inputs are required for long-term maintenance of soil organic matter.

Acknowledgements

We thank the Rockefeller Foundation for financial support and Jon Fear for expert assistance with the experimental work.

References


Chiyenda, S.S., Materechera, S.A. 1989. Effect of incorporating pigeonpea leaves can supply a large amount of N for crop growth, rates of N release are slow and likely to be of benefit only to subsequent crops. The poor quality of maize residues means that substantial amounts of N must be made available if problems of N supply for crop growth are to be avoided when they are added to soil, although large amounts of organic inputs are required for long-term maintenance of soil organic matter.

Acknowledgements

We thank the Rockefeller Foundation for financial support and Jon Fear for expert assistance with the experimental work.

References


Chiyenda, S.S., Materechera, S.A. 1989. Effect of incorporating pigeonpea leaves can supply a large amount of N for crop growth, rates of N release are slow and likely to be of benefit only to subsequent crops. The poor quality of maize residues means that substantial amounts of N must be made available if problems of N supply for crop growth are to be avoided when they are added to soil, although large amounts of organic inputs are required for long-term maintenance of soil organic matter.

Acknowledgements

We thank the Rockefeller Foundation for financial support and Jon Fear for expert assistance with the experimental work.

References


Chiyenda, S.S., Materechera, S.A. 1989. Effect of incorporating pigeonpea leaves can supply a large amount of N for crop growth, rates of N release are slow and likely to be of benefit only to subsequent crops. The poor quality of maize residues means that substantial amounts of N must be made available if problems of N supply for crop growth are to be avoided when they are added to soil, although large amounts of organic inputs are required for long-term maintenance of soil organic matter.

Acknowledgements

We thank the Rockefeller Foundation for financial support and Jon Fear for expert assistance with the experimental work.

References


Chiyenda, S.S., Materechera, S.A. 1989. Effect of incorporating pigeonpea leaves can supply a large amount of N for crop growth, rates of N release are slow and likely to be of benefit only to subsequent crops. The poor quality of maize residues means that substantial amounts of N must be made available if problems of N supply for crop growth are to be avoided when they are added to soil, although large amounts of organic inputs are required for long-term maintenance of soil organic matter.

Acknowledgements

We thank the Rockefeller Foundation for financial support and Jon Fear for expert assistance with the experimental work.

References


Chiyenda, S.S., Materechera, S.A. 1989. Effect of incorporating pigeonpea leaves can supply a large amount of N for crop growth, rates of N release are slow and likely to be of benefit only to subsequent crops. The poor quality of maize residues means that substantial amounts of N must be made available if problems of N supply for crop growth are to be avoided when they are added to soil, although large amounts of organic inputs are required for long-term maintenance of soil organic matter.

Acknowledgements

We thank the Rockefeller Foundation for financial support and Jon Fear for expert assistance with the experimental work.

References


ation and nitrogen uptake in pigeonpea (Cajanus cajan (L.) Millsp.) of different maturity groups. Plant and Soil 99, 255–266.