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Multipurpose tree prunings as a source of nitrogen to maize under semiarid conditions in Zimbabwe*

3. Interactions of pruning quality and time and method of application on nitrogen recovery by maize in two soil types

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Abstract. Decomposition- and N-mineralization rates of multipurpose tree prunings applied as a source of N to annual crops in agroforestry systems are affected by the chemical composition and method and time of application of the prunings and the soil type. In a greenhouse study undertaken on two contrasting Zimbabwean soils, there was a significant interaction of pruning quality with time and method of pruning application on nitrogen recovery by maize and residual effects on a subsequent maize crop on both soil types. Incorporating prunings in the soil at planting gave higher nitrogen recovery compared to surface application at two or four weeks after planting for all three MPT species used. *Flemingia macrophylla* showed prolonged N immobilization on an Alfisol (sandy clay loam) but not on the Psamment (sandy soil). Nitrogen recovery by the second maize crop (residual effect) was influenced by pruning quality, time of application, and soil type. Low-quality prunings such as *Flemingia macrophylla* and *Acacia angustissima* applied four weeks after planting gave higher residual effect on N recovery on the Alfisol than on the Psamment (3% vs. 6%).

Introduction

There are three main types of factors that affect N mineralization from organic residues: chemical composition of the residues, cultural practices (i.e., method and rate of application of the residues), and soil properties. The environment or microclimate (temperature and moisture) may over-ride all these factors. Once the physical environment is not limiting, the resource quality plays an important role in regulating decomposition rates. These factors act in a hierarchial manner (Swift et al., 1991). Most of the studies conducted so far on organic-residue decomposition in agroforestry systems have been single-location experiments (Mugendi et al., 1994; Jama et al., 1995). Furthermore, most of the studies have been done on high base-status Alfisols (Nair et al., 1994), whereas sandy textured soils which are low in soil organic matter dominate the tropical semiarid agroecological zones. There is a need for infor-

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mation on N mineralization from prunings of leguminous trees in different soil types and different climatic zones.

Several studies have reported that organic residues decompose more slowly in soils with higher clay content (Sorensen, 1975; Xhu and Jiang, 1984). However, from the results of 12 field experiments conducted in the semiarid climate in Australia, Amato et al. (1987) found no influence of soil physical and chemical properties on the amount of ^{15}N released from leguminous residues. Thus, there appear to be conflicting and incomplete results on the effect of soil type on N mineralization from plant residues.

Most of the studies that report low nitrogen recovery (NIR) of prunings when used as a source of N to crops have not examined the residual effect of pruning application on crop yields (Xu et al., 1993; Kang et al., 1981). The N contribution from plant residues applied to a previous crop has been reported to be 1–4% of the N content of the material originally applied (Ladd et al., 1983; Janzen et al., 1990). Mulongoy and Sanginga (1990) found that the current maize crop recovered 15% of the N in leucaena (*Leucaena leucocephala*) prunings with 23% of the N found in soil organic N pool. It can be hypothesized that fast-decomposing prunings of high quality will mineralize N quickly and contribute more N to the current crop with low contributions to subsequent crops and soil organic matter (SOM) buildup. Low-quality prunings which decompose slowly may, on the other hand, have a greater residual effect. This effect may also depend on soil type and time and method of pruning application. This study was designed to test this hypothesis and determine how the interactions of pruning quality with time and method of pruning application and soil type affect N recovery and the residual effects on maize N uptake and nitrogen recovery.

Materials and methods

Experimental details

Two greenhouse pot experiments were conducted with maize as a test crop at the Harare Research Centre, Zimbabwe, from January to May 1994. Two soil types, a sandy clay loam (Alfisol) from Domboshava Agroforestry Experiment Station, and a sandy soil (Psamments) from Makoholi Experiment Station, both in Zimbabwe, were used. The treatments were a combination of three factors, namely:

Factor A: Prunings of three MPT species: *Acacia angustissima* (acacia), *Flemingia macrophylla* (flemingia), and *Cajanus cajan* (cajanus).

Factor B: Two methods of pruning application: surface mulching vs. incorporation in the top 15 cm of soil in the pot.

Factor C: Three dates of pruning application, at planting of maize, 2 weeks after planting (WAP) and 4 WAP.

The total number of treatment combinations was 19 per soil type including a control with no application of prunings. Two separate experiments were conducted at the same time, one with each soil type. The experiments were arranged in a randomized complete block design, replicated three times. One hundred seventy-one pots were used in each experiment to allow three destructive maize harvests at 6, 9, and 12 WAP. The pots which were harvested at 12 WAP were replanted with maize two days after harvest. Maize was allowed to grow for six weeks before harvest to assess residual effects on growth. The sampling date for this will be referred to as 18 WAP.

Soil and pot management

The soils used were collected from the top 20 cm layer from Domboshava and the Makoholi stations. The chemical and physical properties of the two soils are shown in Table 1. The soil was sun-dried and sieved through a 4-mm mesh. Asbestos pots of 30 cm diameter and 30 cm height were used. Each pot was filled with 7.8 kg soil. Plant materials (prunings) were applied, 70 g dry weight pot^{-1}, to give an application rate equivalent to 5 Mg ha^{-1}. This was calculated using the area of the pot.

After pruning application, four seeds of maize hybrid cultivar R215 were planted to each pot. Fertilizers were added at 280 mg of P per pot to give a rate equivalent to 40 kg P ha^{-1} as single superphosphate and 420 mg of K per pot to give a rate of 60 kg K ha^{-1} as muriate of potash to all treatments. No inorganic N fertilizer was applied to any pot. Maize plants were thinned to 2 plants pot^{-1} one week after emergence.

Prunings used

Prunings, consisting mainly of leaves, of the three woody leguminous species were used in the study. The prunings were gathered (cut) from trees grown as fodder banks at Domboshava Research Station; they were sun-dried for

Table 1. C characteristics of the two Zimbabwean soils at the beginning of the experiment.

Soil characteristics	Makoholi (psamments)	Domboshava (alfisols)
Texture	coarse sandy	medium sandy clay loam
Clay %	5.0	21.0
Silt %	3.0	4.0
Sand %	92.0	75.0
pH ($CaCl_2$)	3.9	4.8
Total exchange bases (cmol/kg)	0.8	0.9
CEC (cmol/kg)	0.8	1.6
Organic carbon (%)	0.3	0.6
Resin extractable P (ppm)	7.0	10.0
Available N after incubation (ppm)	20.0	29.0

three days at an average maximum daily temperature of 25 °C. Samples were oven-dried at 65 °C for 48 h for dry matter (DM) determination, and analyzed for initial N, lignin, soluble polyphenols, and protein binding capacity using methods described by Mafongoya and Nair (1997).

Plant harvesting and chemical analysis

Each treatment was destructively harvested at 6, 9, 12, and 18 WAP for estimating residual effects of pruning application. Maize tops were cut at soil level. The oven-dried samples were ground to pass a 2-mm mesh and analyzed for N concentration. Maize N uptake was calculated as shoot dry weight multiplied by % N concentration. Nitrogen recovery by maize was calculated as follows (Mafongoya and Nair, 1996):

$$NIR = \frac{N_{(Treat)} - N_{(Control)}}{N_{(Applied)}} \times 100$$

where
NIR = nitrogen recovery, %
$N_{(Treat)}$ = N uptake from the pruning-applied pot
$N_{(Control)}$ = N uptake from the control pot
$N_{(Applied)}$ = The amount of N in the applied pruning

Statistical analysis

The data were subjected to ANOVA (SAS, 1982). Treatment means were tested by LSD, $P < 0.05$.

Results

The prunings used in this study varied in chemical quality (Table 2). Their N concentrations were in the following order; acacia > cajanus > flemingia. Lignin concentration ranged from 8.76% to 22.80%. Considering low polyphenol contents and protein binding capacity as indicators of high pruning

Table 2. Chemical composition of the prunings used at Harare, Zimbabwe.

MPT species	Chemical composition (% of dry matter)			
	N	Lignin	Soluble polyphenols	Protein binding capacity (μg/g)
Acacia angustissima	4.38	8.76	3.35	3.92
Flemingia macrophylla	2.32	22.80	3.31	5.90
Cajanus cajan	3.95	12.56	1.19	2.56

quality, the species were ranked in terms of quality as: cajanus > acacia > flemingia.

Method of application and MPT species interaction on maize shoot dry weight (SHDW)

In general, the Makoholi soil gave lower SHDW and N uptake than Domboshava soil at all sampling dates. Incorporation of prunings produced more SHDW than surface application (Figure 1) at all sampling dates except

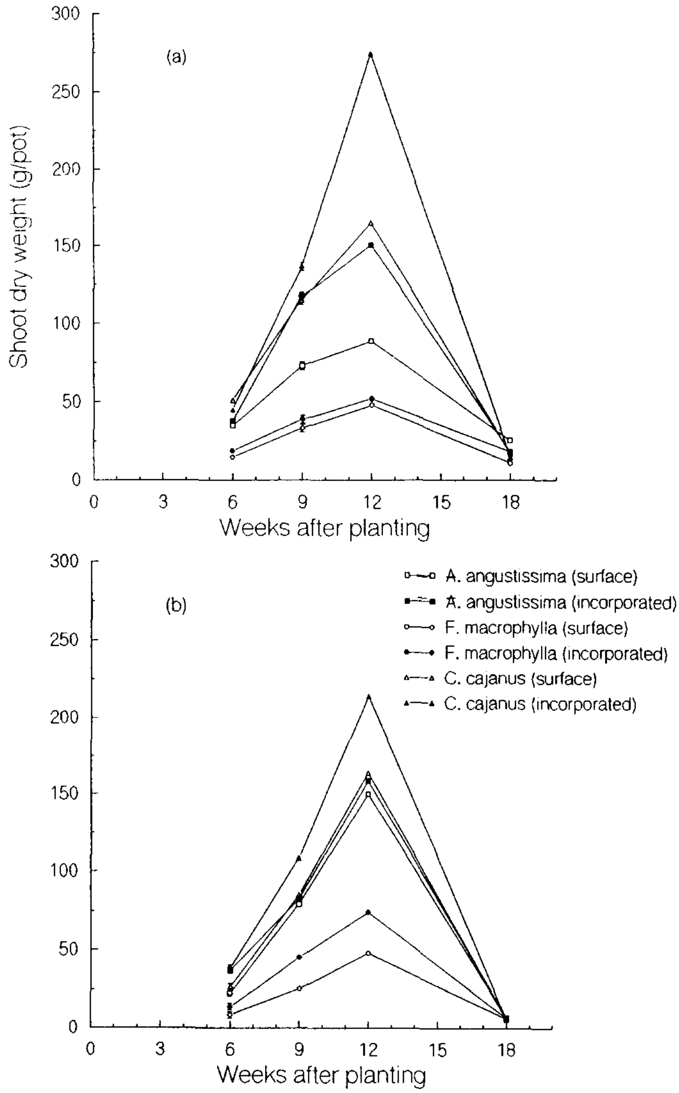

Figure 1. Shoot dry weight of maize as affected by the source (MPT species) of prunings and method of their application on (a) Domboshava soil and (b) Makaholi soil, Zimbabwe.

9 WAP. The exception was with flemingia where the method of pruning application had no effect on SHDW at 9 WAP. Across application methods, SHDW was of the order: cajanus > acacia > flemingia at most sampling dates except at 18 WAP. Data on control treatment will not be shown for all parameters to be reported since it was significantly lower than the other treatments at all sampling dates.

MPT species and time of application interaction on SHDW

Across application times, SHDW was in the following order: cajanus > acacia > flemingia at each application time with both soil types (data not presented). For each species, the effect of time of pruning application on SHDW was in the order, at planting > 2 WAP > 4 WAP. However, there were a few exceptions to this trend with Domboshava soil: at 6 WAP, pruning application time had no significant effect on SHDW with flemingia, and applying flemingia prunings at 2 WAP gave similar SHDW to applying prunings at 4 WAP when sampled at 12 WAP.

Method of pruning application and MPT species interaction on N uptake

Incorporation of prunings resulted in higher N uptake than surface application with both soil types (Figure 2) at all sampling dates. Across application methods, there was more N uptake from pots supplied with cajanus prunings than from those with acacia. N uptake from 'flemingia pots' was the least. With Domboshava soil, surface application of flemingia prunings immobilized N at 6 WAP and 9 WAP, compared to the control treatment (data not shown) whereas no N immobilization was observed with Makoholi soil. For acacia and flemingia on the Domboshava soil, and cajanus and flemingia on the Makoholi soil, incorporation of prunings gave significantly higher N uptake than surface application at 18 WAP. Surface application gave higher residual N uptake with cajanus on Domboshava soil and with acacia on Makoholi soil. When prunings were surface-applied, N uptake by the second crop was in the order acacia > cajanus > flemingia with Domboshava soil, and there was no significant effect of species with Makoholi soil.

Time of application and MPT species interaction on N uptake

At all application times, cajanus prunings gave the highest N uptake followed by acacia and flemingia on both soil types (Figure 3). Across species, application of prunings at planting gave significantly higher N uptake, followed by application at 2 WAP and 4 WAP. However, there was an exception: with flemingia, N was immobilized in Domboshava soil when applied at planting; furthermore, application time had no effect on N uptake with flemingia. With cajanus, applying prunings at planting had no significant effect on N uptake compared to applying at 2 WAP. The same effect was observed with acacia on Makoholi soil at 9 WAP.

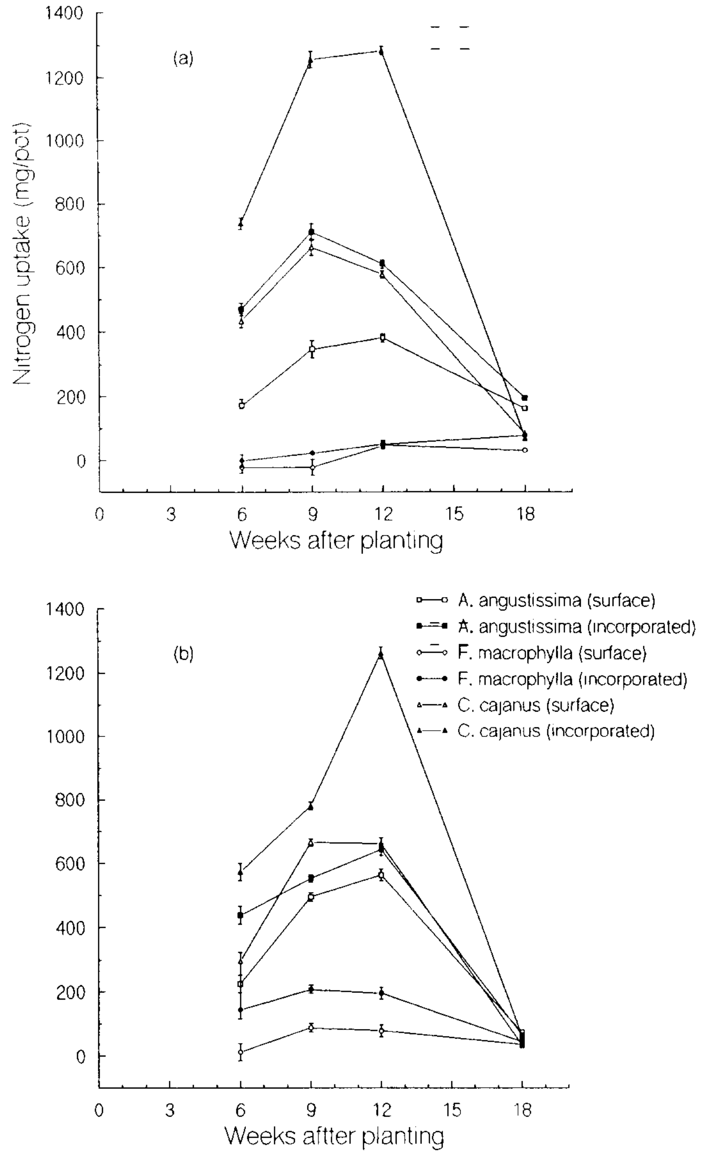

Figure 2. Nitrogen uptake by maize as affected by the source (MPT species) of prunings and method of their application on (a) Domboshava soil and (b) Makaholi soil, Zimbabwe.

Method of application and MPT species interaction on nitrogen recovery (NIR)

Incorporation of prunings gave significantly higher NIR than surface application for all species on both soil types at all sampling dates; the data for 18 WAP are presented in Figure 4. Across application methods, cajanus

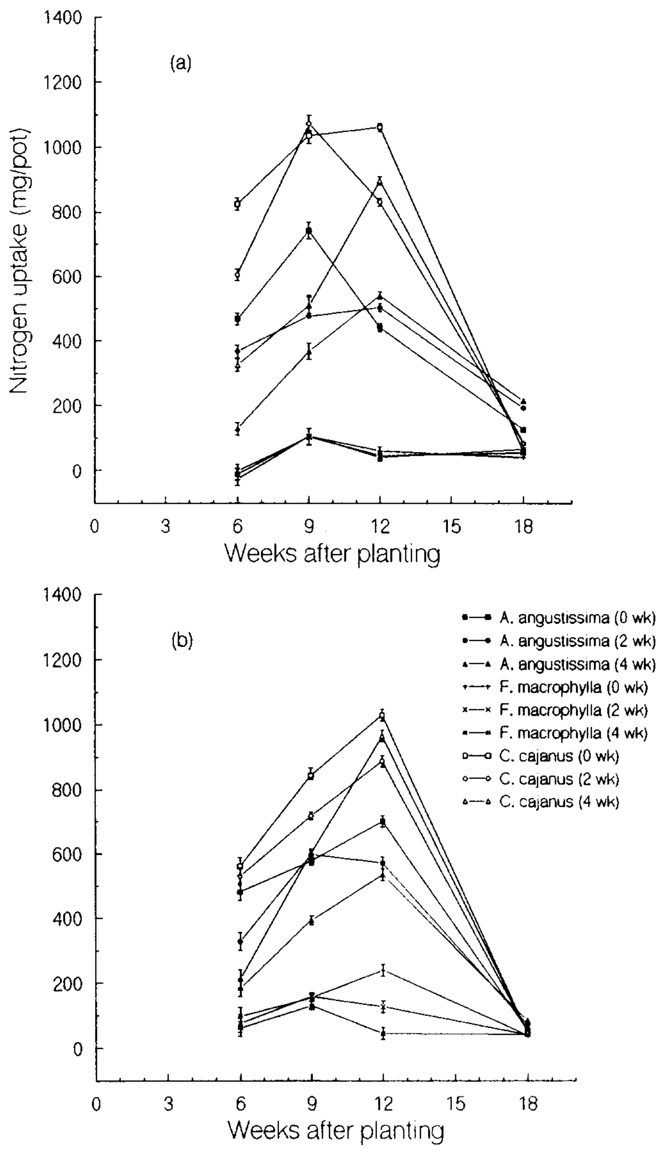

Figure 3. Nitrogen uptake by maize as affected by the source (MPT species) of prunings and time of their application on (a) Domboshava soil and (b) Makaholi soil, Zimbabwe.

gave the highest NIR followed by acacia and flemingia which gave the least.

Time of application and MPT species interaction on nitrogen recovery

At each application time, the same trend was observed on species with regard to NIR; the data for 18 WAP are presented as Figure 5. For each species,

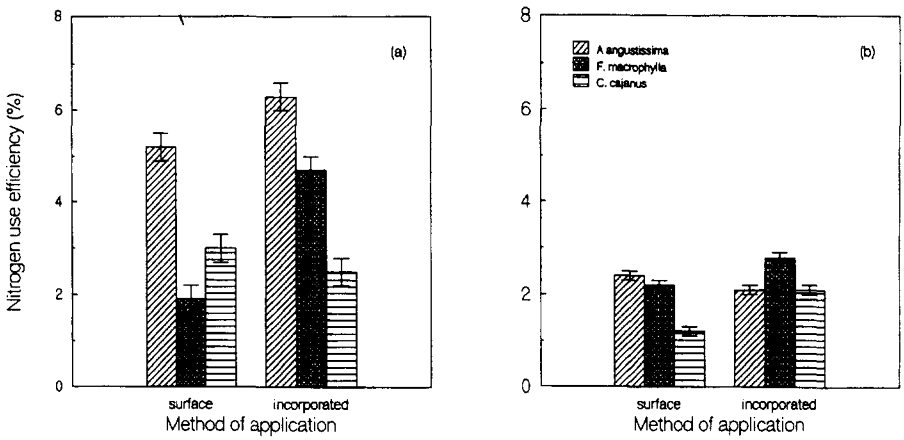

Figure 4. Percent nitrogen recovery by maize 18 weeks after planting as affected by the source (MPT species) of prunings and method of their application on (a) Domboshava soil and (b) Makaholi soil, Zimbabwe.

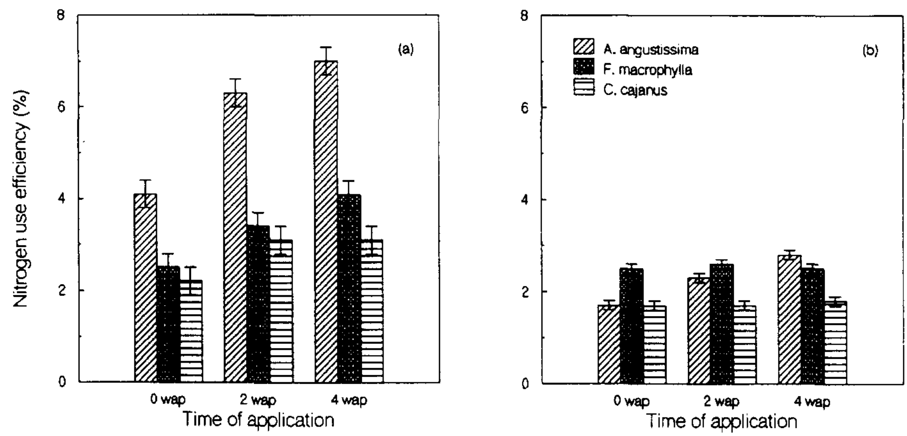

Figure 5. Percent nitrogen recovery by maize 18 weeks after planting as affected by the source (MPT species) of prunings and time of their application on (a) Domboshava soil and (b) Makaholi soil, Zimbabwe.

NIR in relation to pruning-application time was in the order, at planting > 2 WAP > 4 WAP with few exceptions. For flemingia and acacia on Makoholi soil, applying prunings at planting and 2 WAP were not different in NIR when sampled at 9 WAP.

Incorporation of acacia and flemingia on Domboshava soil, and cajanus and flemingia on Makoholi soil, gave significantly greater NIR with the second crop. However, for cajanus on Domboshava soil, method of application had no significant effect on NIR whereas, on Makaholi soil, acacia gave higher NIR on Makoholi soil when surface-applied than incorporated.

Incorporation of prunings into soil generally gave higher NIR than surface application at all application times. Within application methods, applying prunings at 4 WAP gave higher NIR, followed by application at 2 WAP and at planting, in the second maize crop (Figure 5). Among the MPT species, in general, acacia gave the highest NIR followed by flemingia and cajanus. With Domboshava soil, across pruning application times, the order of response was: acacia > flemingia > cajanus. However with Makoholi soil, the order differed with each application time; at planting it was: flemingia > acacia and cajanus; when prunings were applied at 2 WAP, the order was: flemingia > acacia > cajanus.

Discussion

There was an interaction among MPT species, time of pruning application, and method of pruning application on maize shoot growth, N uptake, and NIR. Incorporation of prunings gave higher N uptake and NIR than surface application. This could be attributed to greater rates of decomposition and N mineralization of incorporated prunings compared to those of surface-applied prunings. Similar results were also obtained under field conditions, where prunings of acacia and cajanus had higher decomposition and N-release constants when they were incorporated than when surface-applied (Mafongoya and Nair, 1997). When prunings are surface applied, the effect of – often harsh – physical environment may override the effect of resource quality as reported by Swift et al. (1991). Greenhouse studies done by Kaufusi and Asghar (1990) and Ezenwa and Alasiri (1991) using the same species also found that N uptake by maize was higher prunings were incorporated than surface applied. The low N uptake and NIR from surface-applied prunings could be due also to N volatilization as ammonia, as suggested by Costa et al. (1990) and Janzen and McGinn (1991) and Glasener and Palm (1995).

Across application methods, different MPT prunings caused differences in N uptake, NIR, and shoot dry weight of maize. Cajanus gave the highest N uptake, NIR, and shoot dry weight, followed by acacia and flemingia. This could be explained by the differences in pruning quality as shown in Table 2. Flemingia immobilized N in the Domboshava soil but not in the Makoholi soil. The low NIR from flemingia prunings could be associated with slow decomposition due to high contents of lignin and soluble polyphenols and low content of N in the prunings (Table 2). Flemingia had also a high protein binding capacity which could have reduced the rate of N mineralization as reported by Handayanto et al. (1995).

The differences in N release patterns between the two soil types could be explained by inherent low soil fertility of Makoholi (sandy) soil compared to Domboshava (sandy loam) soil. Christensen (1985) also found no N immobilization in a sandy soil compared to a sandy loam with wheat straw. It may be that the relatively higher organic C content of Domboshava sandy loam soil than in the sandy Makoholi soil (Table 1) caused high microbial activity and high N immobilization rates; the clay particles (higher in Domboshava soil) also would have protected decomposition products from microbial attack and reduced N mineralization rates as found by Sorensen (1975).

Time of pruning application affected NIR. Across MPT species, applying prunings at planting led to more efficient use of pruning N. Applying prunings at 2 or 4 WAP led to lower N uptake, NIR and shoot dry weight. Maize growth and N uptake are slow from emergence to six weeks after emergence; then the crop enters a period of rapid growth and N uptake until tasselling and silking (Karlen et al., 1987, 1988). Prunings applied at planting may have released most of their N prior to peak N demand by maize from 6 WAP to 9 WAP, resulting in more available N to the crop during this period. Applying prunings at 2 WAP or 4 WAP may result in less N release before peak N uptake, hence lower maize N uptake and NIR. Results from several field experiments (Mulongoy et al., 1993; Mulongoy, 1987; Kang and Mulongoy, 1987) also confirm that prunings applied at 2 or 4 WAP resulted in significantly lower NIR than those applied at planting.

The residual effects of pruning application on maize shoot dry weight, N uptake and NIR were influenced by MPT species and time and method of pruning application. Across application methods, species and time of application had significant effects. In general, incorporation of prunings gave higher N uptake and NIR for cajanus, acacia and flemingia in that order.

Applying prunings at 4 WAP produced the highest residual effect on NIR, followed by application at 2 WAP and at planting. Prunings applied at 4 WAP would have decomposed for eight weeks at final harvest, i.e. when maize plants were sampled at 12 WAP. This could have created an asynchrony between N supply from the prunings and peak N demand by the current season's maize crop. However, the N that was not used up by the current season's crop will have contributed to the higher residual effect. The nitrogen recovery of the second maize crop was low in the range from 1.5–6.0%, possibly due to differences in pruning quality and time and method of pruning application. The other reason could be that the N released would be tied up in soil organic pools, which do not mineralize N rapidly for the subsequent crop.

The advantage of applying prunings of low quality would be to build up soil organic matter pools which release N slowly over time. However, application of high quality prunings such as those of cajanus would immediately benefit the current crop rather than the subsequent crop or build up soil organic matter pools (Jensen, 1994; Janzen et al., 1990; Harris and Hesterman, 1990). The fate of N released could be more accurately assessed if ^{15}N is used to determine the relative amounts of N assimilated in microbial biomass from surface-applied and soil-incorporated prunings. The different ^{15}N proportions entering the soil microbial pool, soil mineral pool and organic N pools need to be measured under field conditions.

It must be borne in mind that these experiments were carried out in pots in the greenhouse, under ideal moisture conditions atypical of field conditions. N dynamics are restricted in pot environments and may not be comparable to field conditions. These results may be useful in initial screening of MPT prunings for important management factors in order to improve nitrogen recovery. Such greenhouse studies need to be confirmed by field studies before field-scale recommendations can be made.

General summary and conclusions

The overall thrust of this study and the earlier two parts of this series of papers (Mafongoya and Nair, 1997; Mafongoya et al., 1997) was on management of MPT prunings for supporting crop (maize) production in semiarid conditions. The source of mulch (MPT species, pruning quality (chemical composition of prunings), method of pruning application (soil-surface application versus soil incorporation), application of varying quantities of prunings at different times in relation to the crop's growth stages, and desirability of mixing different types of prunings were investigated in a combination of field- and greenhouse conditions. Rates of nitrogen recovery from the applied prunings at various stages, N uptake by the current and a succeeding crop, and various crop-growth parameters were measured as indicators of the effects. In general, the results of the study support the hypotheses and expectations, and provide suggestions on pruning-management strategies. Important among these are the following:

1. Nitrogen recovery rates from the prunings are higher when the prunings are incorporated into the soil than when applied as mulch on soil surface.
2. Incorporating adequate quantities of high-quality prunings such as those of *Cajanus cajan* and *Leucaena leucocephala* into the soil demonstrates closer synchrony between availability and demand than in the lower quality prunings such as *Flemingia macrophylla*.
3. Application of prunings at maize planting, rather than four weeks after planting, is better in terms of N recovery, N uptake by maize, and maize grain yield.
4. Applying a mixture of prunings of *Leucaena leucocephala* and *Calliandra calothyrsus* has no special effect on N uptake by maize. Mixtures did not behave as simple additions of two species but showed more complex interactions.
5. Low-quality (slower-decomposing) prunings such as those of *Flemingia macrophylla* and *Acacia angustissima* have greater residual effects and could be better sources for building up soil organic matter in the long run, whereas high-quality (faster-decomposing) prunings such as those of *Leucaena leucocephala* and *Cajanus cajan* are better sources to provide N to the current crop.

6. Incorporation of prunings at planting gave a higher maize grain yield and N recovery than surface-applied prunings. This practice may require more labor at planting and farmers may adopt surface application due to its lower labor demands. There is a need to do on-farm research trials on these technological options to determine their economic viability and adoption by farmers.

Although several questions remain unanswered, these studies suggest some management options and their underlying principles for maximizing the potential benefits of MPT prunings as a source of N to maize. These options need to be carefully considered in deciding the strategies for crop production in N-starved farming systems in semiarid regions where fertilizer N-inputs are inadequate and/or infeasible.

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References

Amato M, Ladd JN, Ellington A and Walsgot P (1987) Decomposition of plant material in Australian soil: IV. Decomposition in site of ^{13}C and ^{15}Nlabelled legume and wheat materials in a range of Australian soils. Aust J Soil Res 25: 95–105

Christensen BT (1985) Wheat and barley straw decomposition under feed conditions: effect of soil type and plant cover on weight loss, nitrogen and potassium content. Soil Biol Biochem 17: 691–697

Costa FJSA, Bouldin DR and Suhet AR (1990) Evaluation of N recovery from mucuna placed on the surface or incorporated in a Brazilian Oxisol. Plant and Soil 124: 91–96

Ezenwa IV and Alasin KO (1991) Use of leguminous tree leaves as a nutrient source for maize in a lateritic soil. Nitrogen Fixing Tree Res Rep 8: 93–84

Glasener KM and Palm CA (1995) Ammonia volatilization from tropical legume mulches and green manures and unlimed and limed soil. Plant and Soil 177: 33–41

Handayanto E, Cadisch G and Giller KE (1995) Manipulation of quality and mineralization of tropical legume tree prunings by varying nitrogen supply. Plant and Soil 176: 149–160

Harris GH and Hesterman OB (1990) Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen-15. Agron J 82: 129–134

Jama BA, Nair PKR and Rao MR (in press) Productivity of hedgerow shrubs and maize under alleycropping and block planting systems in semi-arid Kenya. Agrofor Syst 31: 257–274

Janzen HH and McGinn SM (1991) Volatile loss of nitrogen during decomposition of legume green manure. Soil Biol Biochem 23: 291–297

Janzen HH, Bole JB, Biederbeck VO and Slinkard AE (1990) Fate of N applied as green manure or ammonium fertilizer to soil subsequently cropped with spring wheat at three sites in Western Canada. Can J Soil Sci 70: 313–323

Jensen ES (1994) Availability of nitrogen in ^{15}N-labelled mature pea residue to substitute for nitrogen fertilizer in lowland rice. Leucaena Res Rep 10: 24–25

Kang BT and Mulongoy K (1987) *Gliricidia sepium* as source of green manure in alley cropping system. In: NFTA *Gliricidia sepium* Management and Improvement, pp 44–58. Nitrogen Fixing Tree Association Special Publication 87-01. NFTA, Waimanalo, HI, USA

Kang BT, Wilson GF and Sipkens L (1981) Alley cropping maize (*Zea mays* L.) and leucaena (*Leucaena leucocephala* Lam.) in Southern Nigeria. Plant and Soil 63: 165–179

Karlen DL, Flannery RL and Sadler EF (1987) Nutrient and dry matter accumulation rates for high yielding maize. J Plant Nutrition 10: 1409–1417

Karlen DL, Flannery RL and Sadler EJ (1988) Aerial accumulation and partitioning of nutrients by corn. Agron J 80: 232–242

Kaufusi P and Asghar M (1990) Effects of incorporating plant materials on corn growth. Nitrogen Fixing Tree Res Rep 8: 81–82

Ladd JN, Amato M, Jackson RB and Butler JHA (1983) Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. Soil Biol and Biochem 15: 231–238

Mafongoya PL and Nair PKR (1997) Multipurpose tree prunings as a source of nitrogen to maize (*Zea mays* L.) under semiarid conditions in Zimbabwe. 1. Nitrogen recovery rates in relation to pruning quality and method of application. Agrofor Syst 35: 31–46

Mafongoya PL, Nair PKR and Dzowela BH (1997) Multipurpose tree prunings as a source of nitrogen to maize (*Zea mays* L.) under semiarid conditions in Zimbabwe. 2. Nitrogen recovery rates and crop growth as influenced by mixtures of prunings. Agrofor Syst 35: 47–56

Mugendi DN, Mochoge BO, Coulson CL, Stigter CJ and Sang FK (1994) Decomposition of *Cassia siamea* loppings in semiarid Machakos, Kenya. Arid Soil Res Rehabil 8: 363–372

Mulongoy K (1987) Relative nitrogen contribution of prunings in alley cropping with cassia, gliricidia and leucaena. In: IITA Resource and Crop Management Program, Annual Report 1987, pp 36–37. IITA, Ibadan, Nigeria

Mulongoy K and Sanginga MK (1990) Nitrogen contribution by leucaena in alley cropping system. IITA Res 1: 14–17

Mulongoy K, Ibewono BE, Oseni O, Kulumba N, Opara-Nadi AO and Osobuni O (1993) Effect of management practices on alley cropped maize utilization of nitrogen derived from prunings on a degraded alfisol in southwest Nigeria. In: Mulongoy K and Merckx R (eds) Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture, pp 223–230. John Wiley & Sons Ltd, Chichester, UK

Nair PKR, Rao MR and Fernandes ECM (1994) Tree-crop interactions in sustainable agroforestry systems. In: Virmani SM and Sekhon GS (eds) Soil Technology for Sustainable Agriculture, pp 110–137. Symposium Vla, XV World Soils Congress, Acapulco, Mexico

SAS (1982) SAS User's Guide. SAS Institute, Cary, NC, USA

Sorensen LH (1975) The influence of clay on the rate of decay of amino acid metabolites synthesized in soil during decomposition of cellulose. Soil Biol Biochem 171–177

Swift, MJ, Kang BT, Mulongoy K and Woomer P (1991) Organic-matter management for sustainable soil fertility in tropical croppings systems. In: Dumanski J, Pushparajah E, Latham M and Myers R (eds) Evaluation for Sustainable Land Management in the Developing World 2, Technical Papers, IBSRAM Proceedings No. 12(2), pp 307–326. Bangkok, Thailand

Xhu Z, Liu C and Jiang B (1984) Mineralization of organic nitrogen in some paddy soils of China. In: Organic Matter and Rice, pp 259–272. IRRI. Los Baños, The Philippines

Xu ZH, Saffigna PG, Myers RJK and Chapman AL (1993) Nitrogen cycling in leucaena (*Leucaena leucocephala*) alley cropping in semi-arid tropics. I. Mineralization of nitrogen from leucaena residues. Plant and Soil 148: 63–72