15. Soil fertility improvement and maize yields following woodlots of three different tree species in Shinyanga, Tanzania

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Key words: Indigenous trees, Intercropping, Nitrogen mineralization, Soil fertility, Tree fallows, Woodlots

Abstract

Soil fertility decline and fuelwood scarcity are among the major constraints affecting livelihoods of resource-poor farmers in Tanzania. An agroforestry option that can address these twin problems is rotational woodlot technology, which involves rotating arable crops with planted tree-fallows. A study was conducted in Shinyanga region, Tanzania to evaluate woodlots of three tree species (*Leucaena leucocephala*, *Acacia polyacantha* and *Acacia nilotica*) for their effects on soil fertility improvement and subsequent maize yields compared with natural grass fallow (control). The trees were intercropped with maize during the first three years of their growth and then left as tree-fallow for another three years. Following six years of growth, strong differences were noted among tree species in terms of pre-season nitrogen accumulated and maize yields. *Leucaena* and *A. polyacantha* woodlots yielded 71 and 89 t ha⁻¹ of wood, respectively. *Leucaena* fallow was superior to others in terms of nitrogen mineralized (87 kg N ha⁻¹) in the first cropping year, followed closely by *A. polyacantha* (82 kg N ha⁻¹). In terms of crop yield, maize rotated with *A. polyacantha* woodlot gave the highest yield of 3.2 t ha⁻¹, followed closely by *L. leucocephala* with 2.8 t ha⁻¹. Maize yields after *L. leucocephala* and *A. polyacantha* fallows relative to those after natural grass fallow were greater by over 30%. *Acacia nilotica* was inferior to others in all the parameters measured. Maize grain yields were positively correlated ($r^2 = 0.871, P < 0.001$) with accumulation and release of inorganic nitrogen, particularly in the first post-fallow cropping year. *Leucaena leucocephala* and *A. polyacantha* are, therefore, suitable species for rotational woodlots for soil fertility improvement in addition to wood production.

Introduction

Soil fertility depletion has been cited as the fundamental biophysical root cause for declining food production in sub-Saharan Africa (Sanchez et al. 1997). Nitrogen and phosphorus are the most severely depleted nutrients in many soils in southern Africa (Sanchez et al. 1997). Similar observations have also been reported in Tanzania (Otsyina et al. 1995; Shem 1996). In the Sukuma agropastoral system, nutrients are removed from the system through the harvested crop, livestock grazing (including crop residues), soil erosion and leaching, resulting in a net nutrient loss. At the same time, inputs into croplands and rangelands in the form of manure and fertilizers are negligible. These problems are partly a result of increasing pressure on land for both cultivation and grazing. These are associated with poor husbandry techniques of smallholders. On the other hand, the high demand for food and cash crops, meat and milk by the rapidly increasing population and expanding agro-industries have led to overexploitation of the existing resources. The traditional shifting cultivation systems are no longer capable of supporting the human population. The fallow periods have reduced from 8–15 years in the past to about 2–5 years at present. Consequently, crop yields have been declining and many families have been experiencing food insecurity, low income and poor nutrition. Improvement of agricultural production therefore relies on introduction of low cost technologies such as ‘rotational woodlots’, which can be adopted easily and integrated in the current farming systems. This technology involves alternating arable crops with improved tree fallow on the same piece of land over time (Otsyina et al. 1998). The practice is intended to simulate the effects of shifting cultivation systems but with carefully selected tree species for their fast growth, high wood yields, and soil enrichment capacity (Young 1989).

Wood fuel accounts for 91% of energy in Tanzania (Kaale 1985). In Shinyanga, women have to travel 1 to 30 km to collect fuelwood (Otsyina 1993). In some parts of Shinyanga, cow dung and crop residues are used as a source of domestic energy because of the
scarcity of fuelwood (Siima 1997), thereby removing soil nutrients from the system. Rotational woodlots are expected to provide wood for various domestics use (firewood, poles, and timber). This system involves mainly three phases: tree establishment phase, fallow phase and finally the post-fallow phase (Chidumayo 1988; Otsyina et al. 1994). Many studies have indicated that herbaceous as well as woody legumes have the ability to fix nitrogen. Studies have also revealed that trees have the potential of capturing nutrients leached beyond the crop rooting zone and bringing them up to the soil surface (Mekonnen et al. 1997; Jama et al. 1998). Nitrogen fixing trees have the potential to replenish soil nitrogen in farmlands as well as providing fodder and wood for various uses (Chidumayo 1988; Otsyina et al. 1994). A study was therefore initiated in 1992 to evaluate the effects of indigenous as well as introduced multipurpose trees in rotational woodlots for wood production and soil fertility improvement.

Materials and methods

The study was conducted on-station at Lubaga (03°40’S, 033°28’ E, altitude 1120 m) in Shinyanga District of northern Tanzania. Rainfall in this region is erratic and poorly distributed with high variability within and between seasons. Mean annual rainfall is 700 mm. Monthly mean temperatures range from 30.2°C (maximum) to 18.3°C (minimum). The soils are moderately well drained and clay loams on over lacustrine deposits at 70 to 100 cm depths. They are classified as vertic Luvisols (FAO 1988) or Ibushi (local). The chemical properties of the soil at the experimental site were: pH (1:2.5 soil : water ratio) = 7.6, organic C = 1.9%, total N = 0.14%, available P (Olsen) = 4 ppm, exchangeable K = 0.38 cmol_2 kg^-1, Ca = 12.3 cmol_2 kg^-1, Mg = 4.28 cmol_2 kg^-1 and CEC = 21.3 cmol_2 kg^-1.

The trial was established in December 1991. The treatments were woodlots of Acacia polyacantha, Acacia nilotica, Leucaena leucocephala, and natural fallow (control). The trees were established using 4-month-old seedlings at the onset of rains, at a spacing of 3 x 4 m in 20 x 30 m plots. The trial was conducted in a randomized complete block design with three replications. Maize (Zea mays) var. Kilima was grown intercropped with trees and in the control plots at the recommended spacing of 0.6 x 0.7 m during the first three years of the woodlots. Maize grain and stover yields were recorded during these three seasons. The woodlot plots were then left as tree-fallowed for another three years. Leaves from the tree fallows and natural fallow were sampled for chemical analysis.

At the start of the 1998-99 growing season, the trees were felled and wood yield from each tree species was measured. Soil samples were collected from each plot at 0–15 and 15–30 cm depths to determine soil fertility improvement during the fallow period. The cleared land was cultivated using hand hoes and maize var. Kilima was sown in all the plots. One or two robust and healthy coppices of the trees were left to grow into trees. Cropping continued during the 1999-2000 and 2000-01 seasons. During this period any tree re-sprouts apart from the selected coppices were removed. Soil samples were taken again during the cropping seasons before planting (Bp), at planting (Ap), four weeks after planting (4 wap), eight weeks after planting (8 wap), and eight weeks after harvesting (8 w) to monitor nitrogen mineralisation from decomposition of litter and roots. Maize grain and stover yields were measured. Soil samples collected during the fallow period (1991-1997) were analyzed for inorganic N. Data on wood, maize grain yield and soil were subjected to the analysis of variance and treatments compared using LSD at 5%.

Results and discussion

Wood production

Farmers in Tanzania rely heavily on wood for various domestic uses such as fuel, poles, and timber. Tree species significantly (P < 0.05) differed in wood yields (Table 1). Leucaena leucocephala produced the highest wood yield (89 t ha^-1) followed closely by A. polyacantha (71 t ha^-1), while A. nilotica produced the lowest wood yield. Leucaena leucocephala is a fast-growing and high wood producing tree species. Wood volume of 4-year old L. leucocephala grown at Mafiga, Morogoro ranged from 25 to 52 m^3 ha^-1 (Lulandala 1987). Between the indigenous tree species, A. polyacantha was superior to A. nilotica in terms

<table>
<thead>
<tr>
<th>Fallow type</th>
<th>Wood yield (t ha^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia nilotica</td>
<td>8.4</td>
</tr>
<tr>
<td>Acacia polyacantha</td>
<td>70.9</td>
</tr>
<tr>
<td>Leucaena leucocephala</td>
<td>88.9</td>
</tr>
<tr>
<td>Natural fallow</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. Wood yields from 6-year old woodlots (or tree fallows) of three different tree species at Lubaga in Tanzania.

SED 33
after *A. ployacantha* and *L. leucocephala* fallows relative to that after natural fallow. This suggests that the residual effects of these tree fallows on subsequent crop yields could last for three cropping seasons. The amount of soil inorganic N accumulated under *A. ployacantha* and *L. leucocephala* plots was more than the recommended rate of nitrogen fertilizer for maize (50 kg N ha⁻¹) in this region (Mowo et al. 1993). Rotational woodlot technology using these tree species can therefore be an effective way of minimizing the use of mineral fertilizers, which are expensive and out of reach of small-scale farmers.

**Relation between pre-season soil inorganic N and maize yield**

Maize grain yields correlated positively with pre-season soil inorganic N for all three seasons. When data of the three cropping seasons were combined, maize yields were significantly correlated (r²=0.871**) to soil inorganic N. Similar relationships were reported elsewhere in tree legume–maize rotations (Barrios et al. 1998). Pre-season soil inorganic N (NO₃ + NH₄) was highly correlated with maize yield compared with pre-season nitrate (NO₃) alone in tropical soils with pronounced dry seasons (Barrios et al. 1998).

**Conclusion**

This study clearly indicated that tree species such as *Leucaena leucocephala* and *Acacia polyacantha* are best suited for rotational woodlot technology to improve soil fertility and subsequent crop yields as a secondary service in addition to serving the primary function of wood production. Furthermore, carefully selected indigenous trees have equally good potential as exotic trees in increasing the productivity of rotational woodlots.

**Acknowledgements**

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**References**


Maize yields

*Acacia polyacantha* fallow plots had resulted in the highest maize yield followed closely by *L. leucocephala* plots, while natural fallow had resulted in the lowest yield (Table 4). Maize yields following these two tree fallows were significantly \( P < 0.05 \) higher than after natural fallow. However, the two tree fallows between them did not differ significantly. This further indicates that maize yields were related to the amount of nitrogen accumulated by the different fallow types. Fallows enriched with leguminous vegetation generally increase crop yields compared to natural falls (Szott et al. 1999).

In the third crop following fallows, although soil inorganic N and maize yields were low across all the treatments, they were significantly \( P < 0.05 \) high

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**Figure 2. Nitrate nitrogen in the 0–30 cm soil depth during the 1999–2000. **BP = before planting, AP = at planting, 4wap = 4 weeks after planting, 8wap = 8 weeks after planting and 8wah = 8 weeks after harvesting.

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**Figure 3. Variation in soil inorganic nitrogen with soil depth under different fallow systems during the 1999–2000 cropping season.**

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**Table 4. Maize grain yields during the post-fallow period over three consecutive seasons in Tanzania.**

<table>
<thead>
<tr>
<th>Fallow type</th>
<th>1998-99</th>
<th>1999-00</th>
<th>2000-01</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia polyacantha</em></td>
<td>3.2</td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>2.8</td>
<td>2.2</td>
<td>1.6</td>
</tr>
<tr>
<td><em>Acacia nilotica</em></td>
<td>2.5</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Natural fallow</td>
<td>2.0</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>SED</strong></td>
<td>0.20</td>
<td>0.24</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Table 3. Chemical composition of leafy biomass of three woodlots and natural fallow in Tanzania.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nitrogen (%)</th>
<th>Phosphorus (%)</th>
<th>Potassium (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia nilotica</em></td>
<td>2.1</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td><em>Acacia polyacantha</em></td>
<td>3.0</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>4.0</td>
<td>0.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Natural fallow</td>
<td>1.4</td>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Nitrogen release**

Figures 1 and 2 present nitrogen released at 0–30 cm soil depth under the fallow types during the 1999–2000 cropping season. Soils collected before planting (Bp) indicated strong evidence ($P < 0.02$) of difference between treatments in the amount of ammonium-nitrogen ($\text{NH}_4$-$\text{N}$)(Figure 1). Ammonium N was higher relative to nitrate-nitrogen (NO$_3$-$\text{N}$) under all treatments. The difference in the amount of ammonium N between treatments could be due to variation in leafy biomass production, root mass and nitrogen fixing ability of the fallow species.

At crop planting (Ap), there was a significant ($P < 0.05$) increase in nitrate N and a corresponding decrease in ammonium N under all species. At 4 weeks after planting (wap), nitrate nitrogen tended to decrease but was still significantly ($P < 0.05$) higher than ammonium N. At 8 weeks after planting (8wap), ammonium N was still low while nitrate N decreased to near depletion. There were no significant ($P > 0.05$) differences among treatments in both forms of nitrogen. The decrease in nitrate-N under all species at 4 and 8 weeks after planting indicates probable uptake by maize, as the demand for nitrogen at this stage is high (Figure 2). Both forms of nitrogen were low across treatments at 8 weeks after harvesting. This could be due to reduced mineralisation as a result of low soil organic matter and low water content as this period coincided with the beginning of the dry season.

Nitrogen released under *Leucaena leucocephala* was highest followed closely by *A. polyacantha* and lowest under the natural fallow throughout the cropping season. While *Leucaena leucocephala* and *A. polyacantha* fallows did not differ significantly in the amount of nitrogen released, they differed significantly from natural fallow (control). Soil water availability is one among many factors that determine nitrogen release pattern. Ammonification is less limited by water deficit because most of the microorganisms responsible in this process (actinomycetes, fungi) remain active even at lower water potentials unlike nitrifying bacteria that are more limited by water deficit (Wetselaar 1968; Ikerra et al. 1999). This could be the reason for accumulation of ammonium relative to nitrate nitrogen during the dry season. The on-set of rains activate nitrification resulting in net N mineralisation, commonly referred to as the nitrogen flush (Birch 1960). This is the soluble form of nitrogen taken up by most plants. The higher amount of nitrogen released under *L. leucocephala* compared to that under other fallows might be due to its relatively low lignin+polyphenol):N ratio (Buresh and Tian 1998; Mafongoya et al. 1998).

**Variation in inorganic N with soil depth**

Soil inorganic nitrogen tended to decrease with soil depth under all fallow types (Figure 3). There was clear evidence ($P < 0.001$) of depth effect on soil inorganic nitrogen across treatments. Higher inorganic nitrogen in the topsoil (0–15 cm) was observed under *L. leucocephala* while the natural fallow plots had

![Figure 1. Ammonium nitrogen in the 0–30 cm soil depth during the 1999–2000; AP = at planting, Bp = before planting, 4Wap = 4 and 8 weeks after planting respectively, 8 wah = 8 weeks after harvest.](image-url)
of growth and wood production. Otsyina et al. (1996) reported similar results from the studies based at Lubaga. The low wood production by *A. nilotica* could be attributed to its slow growth and small tree structure (Mbuya et al. 1994).

**Pre-season soil inorganic nitrogen**

Soil samples taken before sowing the first crop after tree fallows indicated evidence ($P < 0.02$) of differences between treatments for pre-season soil inorganic nitrogen (Table 2). Soil inorganic nitrogen ranged from 51 to 87 kg N ha$^{-1}$. All the three tree fallows had resulted in significantly ($P < 0.05$) greater soil inorganic nitrogen than natural fallow. However, there was no significant difference between *L. leucocephala* and *A. polyacantha* fallows. In the second cropping season after fallow, soil inorganic nitrogen was again significantly ($P < 0.05$) greater under all tree falls compared to natural fallow. *Leucaena leucocephala* fallow plots had the highest inorganic nitrogen followed closely by *A. polyacantha*, while the natural fallow plot had the lowest soil N.

In the third cropping season, although there was a substantial decrease in soil inorganic nitrogen under all treatments, *A. polyacantha* and *L. leucocephala* fallows still recorded significantly ($P < 0.05$) higher N than *A. nilotica* and natural fallows. While there was less evidence ($P > 0.02$) for significant difference between *L. leucocephala* and *A. polyacantha* throughout the three cropping seasons, these two treatments differed significantly ($P < 0.05$) from natural fallow. *Acacia nilotica* plots recorded intermediate levels of inorganic N, which were higher but not significantly different from natural fallow.

The amount of nitrogen added to the soil by plants is determined by such factors as amount and quality of biomass, density of roots and nitrogen fixing ability (Young 1997). *Leucaena leucocephala* has the ability to fix 100 to 500 kg N ha$^{-1}$ yr$^{-1}$ while some *Acacia* species can fix 20 to 200 kg N ha$^{-1}$ year$^{-1}$ (Young 1997). The high soil inorganic nitrogen that accumulated under *L. leucocephala* and *A. polyacantha* (Table 2) could be attributed to their good quality litter, high leaf biomass, and N-fixing ability. Leaves of *L. leucocephala* were reported to be superior in N content (and therefore high quality litter) compared to leaves of *A. angustissima* (Mafongoya et al. 1998b). The natural fallow predominantly composed of grasses such as *Hyperenia* sp., *Cenchrus ciliaris* and *Pennisetum* species and its biomass was of low quality because of relatively higher carbon:nitrogen ratio of these species. This could be the reason for low soil inorganic nitrogen accumulated under natural fallow. The substantial decrease in soil inorganic nitrogen leading to less variability across treatments in the third crop after fallow indicates that most of the organic nitrogen accumulated during the fallows had already been mineralized. This implies that under the climatic conditions of Shinyanga three years could be the optimum cropping period/cycle before the plots have to be left under fallows again.

**Chemical composition of leafy biomass of fallows**

The foliage of *L. leucocephala* had the highest N concentration (4.0% N) and that of natural fallow the lowest (0.5%) (Table 3). The pre-season nitrogen status in the soil under different fallow systems closely corresponded with the N concentration in the foliage of fallow systems. The N concentration of leaves is one of the determinants of quality and therefore decomposition rate of organic material. Organic material having high N and low lignin + polyphenol concentrations decompose and release inorganic N faster than the materials having low N and high lignin + polyphenols concentrations. This could be the reason for greater pre-season N accumulation observed under the tree fallows relative to natural fallow.

### Table 2. Pre-season soil inorganic N in the 0–30 cm soil depth during three consecutive cropping seasons after tree fallow phase at Lubaga in Tanzania.

<table>
<thead>
<tr>
<th>Fallow type</th>
<th>1998-99</th>
<th>1999-00</th>
<th>2000-01</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia polyacantha</em></td>
<td>82</td>
<td>48</td>
<td>35</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>87</td>
<td>57</td>
<td>32</td>
</tr>
<tr>
<td><em>Acacia nilotica</em></td>
<td>73</td>
<td>47</td>
<td>28</td>
</tr>
<tr>
<td>Natural fallow</td>
<td>51</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td><strong>SED</strong></td>
<td>3.6</td>
<td>3.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>


Siima B. 1997. Adoption rate and effect of improved stoves on forests in Shinyanga. BSc Forestry Special Project. Sokoine University of Agriculture, Morogoro, Tanzania.


