Impact of the Tree Component on N Cycling in Agroforestry Systems under Subhumid Tropical Conditions

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Abstract

The tree component of agroforestry systems may interfere with N cycling in several ways. In alley cropping systems, first of all, the prunings added during the different activities have a certain biochemical quality and subsequent N release characteristics. Secondly, the quality of the complete organic matter pool or part of it and associated N release characteristics may be related to the quality of the added materials. Thirdly, the tree itself may recover part of the nutrients released from the added prunings. In this report, the impact of the tree component on the fate of freshly applied residue N and the relation between the demand for and supply of the residue N, or the degree of synchrony, are discussed. After application of the labeled residues, residue N incorporated in the particulate organic matter (POM) (the soil organic matter fractions larger than 0.053 mm), was shown to have the highest turnover rate. Crop uptake of applied residue N was low and especially limited to the first maize crop after residue addition. Substantial differences in hedgerow recovery of applied residue N were found between the *Leucaena* and *Dactyladenia* hedges. Though the *Leucaena* hedge recovered a significant proportion of the applied *Leucaena* residues, substantial amounts of added residue N remained in the soil profile in a bare microplot, during the first 7 weeks after residue addition. In the cropped microplot, maize removed all residue-derived mineral N from the soil profile in the *Dactyladenia* treatment and lowered the residue derived mineral N in the *Leucaena* treatment. Large discrepancies were observed between N release from the *Leucaena* surface litter and N uptake by the maize crop. However, after inclusion of the POM pool at the N supply side and hedgerow recovery and immobilization in the stable SOM at the N demand side, N supply seems to be relatively well balanced by N demand. Some possible research directions related to N cycling and synchrony in agroforestry systems and other improved cropping systems are highlighted.

Introduction

Integrated Soil Fertility Management aims at maximal utilization of available plant nutrients and consequent minimal reliance on external inputs to sustain crop yield (Dudal and Roy, 1995; Vanlauwe *et al.*, 2002). The development of such systems is essential for large regions in the tropics where soil intensification is needed and where mineral fertilizers are costly or not available at all. In alley cropping systems, food crops are grown between hedges of preferably N_2-fixing trees which are cut back regularly to minimize tree–crop competition for light, water, and nutrients. Tree canopy nutrients that are derived from sources not accessible to crop roots may contribute to crop nutrition after being added to the soil surface and, therefore, reduce the need for external inputs.

In alley cropping systems, various sources and sinks of plant available N may be distinguished. The soil organic matter pool acts as both a sink and a source of N. Mineral N is released from freshly added prunings through microbiological and faunal mediation, but in the process of N-mineralization, part of the N is immobilized in forms that are relatively easily available and in more stabilized organic matter. During the last decade, several attempts have been made to physically separate the total soil organic matter pool in fractions with different N release characteristics (Stevenson and Elliot, 1989; Woomer *et al.*, 1994). N incorporated in the more stable fractions may contribute to the long-term soil fertility status. Additional sinks for N obviously consist of the food crops and the hedgerow trees.

The term "synchrony" is often used to describe the concurrence in space and time of the availability of plant nutrients (source-side of the N cycle) and the demand for those nutrients by the growing plants (sink-side of the N cycle) (Myers *et al.*, 1994). In alley cropping systems, lack of synchrony between the N released from decomposing prunings, as measured with the litterbag technique, and uptake by a maize crop has been reported (Mulongoy and Van der Meersch, 1988; Van der Meersch *et al.*, 1993; Yamoah *et al.*, 1986). However, this lack of synchrony does not necessarily indicate inefficient N use. After all, N released from litterbags may not be available as such, but may be incorporated in the soil organic matter pool (Vanlauwe *et al.*, 1997a). Moreover, sinks for mineral N include not only the crop but also the hedgerow. For a proper quantification of synchrony in alley cropping systems, all sinks and sources of N need to be included in the sampling scheme.

The tree component of the alley cropping systems may interfere with the relationships between release and demand in several ways. First of all, the prunings added during the different activities have a certain biochemical quality, defined by Swift (1985) as the factors, which affect the residue decomposition rate. Residue quality has attracted a lot of attention during the last decade, because it has been shown to modify the decomposition and N release dynamics of plant residues (Cadisch and Giller, 1996). The ability to manage N release dynamics of plant residues–and consequently the N supply side of the synchrony concept–through manipulation of residue quality is one of the major reasons why synchrony has been adapted as one of the major research themes of the Tropical Biology and Fertility Programme (Swift, 1985). Low quality residues are residues which delay N release and are normally characterized by a low N and a high lignin and soluble polyphenol content. High quality residues easily release N and are characterized by a high N and a low lignin and soluble polyphenol content. Secondly, the quality of the complete soil organic matter pool or part of it and associated N release characteristics may be related to the quality of the added materials.

Thirdly, the tree itself may recover part of the nutrients released from the added prunings. One of the basic, but yet unproven, hypotheses related to alley cropping systems is that trees will recover nutrients from soil layers beyond the reach of crop roots or from the total soil profile in the absence of a significant demand for nutrients by the growing crop. The biomass accumulation rate and the tree rooting pattern will both determine the ability of the hedgerow to recycle nutrients released from its own canopy.

In this report, the impact of the tree component on the different pathways of the N cycle in alley cropping systems is discussed. Specific objectives were to: (1) discuss relations among residue quality, decomposition/N release, and the turnover of particle size classes of soil organic matter, (2) discuss the recovery of applied residue N by the crop and tree component, and (3) relate the pattern of N release with N demand in the complete

system. In a final section, we will glance at some possible research directions related to synchrony in agroforestry and other improved cropping systems. Most of the discussed data were obtained from a microplot field experiment with ^{15}N labeled high quality *Leucaena leucocephala* and low quality *Dactyladenia barteri* leaf residues, installed in the respective alley cropping systems (Vanlauwe *et al.,* 1998a; 1998b; 1998c). Recovery of applied residue N was followed in various components of the alley cropping system (crops, hedgerow, soil organic matter, mineral N) during a period of 2.5 years.

Sources of plant available N in alley cropping systems: residue quality, decomposition, and soil organic matter

The quality of the hedgerow canopy depends on the age of the canopy regrowth and on its plant part composition (e.g., leaf-to-twig ratio). Vanlauwe *et al.* (1997b) showed that 6-week old *Leucaena* leaves contained more N and less lignin than leaves of 29 weeks. Xu *et al.* (1993) showed that the petioles of *Leucaena* leaves contained more lignin and less N than the leaflets. Residue quality, measured as the (lignin + soluble polyphenol)-to-N ratio appeared to be well correlated with the N release pattern for four different prunings of the high quality *Leucaena* and medium quality *Senna* trees (Vanlauwe *et al.,* 1997b). During pruning activities, tree roots may also die off and release nutrients. Although root litter was shown to have a lower quality than leaf litter, both residues seemed to observe similar quality–decomposition relationships (Vanlauwe *et al.,* 1996).

Several techniques exist for assessing residue N release, with varying levels of experimental control on the decomposition process. Laboratory incubations under controlled conditions as well as the litterbag technique, which estimates N release from a known quantity of residues confined in bags with varying mesh sizes, may

be used when trying to develop residue quality–decomposition relationships. However, for quantification of N release under realistic field conditions, all factors modifying the decomposition process imposed by the experimental technique should be avoided. Release of residue N from the surface litter under unconfined conditions in a microplot experiment was shown to be much faster than measurements made with the litterbag technique for both *Leucaena* and *Dactyladenia* residues (Fig. 1). Especially in the case of the low quality *Dactyladenia* residues, soil fauna (mainly termites) interacted significantly with the decomposition process (Vanlauwe *et al.,* 1998b).

N removed from the litterbags or lost from the surface litter is not necessarily available but may be incorporated in the soil organic matter pool. In the earlier mentioned microplot experiment with ^{15}N labeled *Leucaena* and *Dactyladenia* leaf residues, residue N incorporated in the particulate organic matter (POM) (the soil organic matter fractions larger than 0.053 mm), was shown to have the highest turnover rate (Vanlauwe *et al.,* 1998b). A highly significant relationship between residue N incorporated in the POM and residue N uptake by 3-week-old maize plants was observed (Fig. 2). The relationship with residue N incorporated in soil organic matter with smaller particle size was much weaker, indicating a lower availability (Fig. 2). Because a significant amount of residue-derived N released from the surface litter is incorporated in the readily available POM pool, N release in the system is seriously overestimated when only the surface litter is considered, especially in the *Leucaena* (Fig. 3a) but also in the *Dactyladenia* microplots (Fig. 3b). Again, in the *Dactyladenia* treatment, part of the surface litter was removed from the microplots through faunal activity, thus hampering incorporation of part of the surface litter N in the POM (Vanlauwe *et al.,* 1998b).
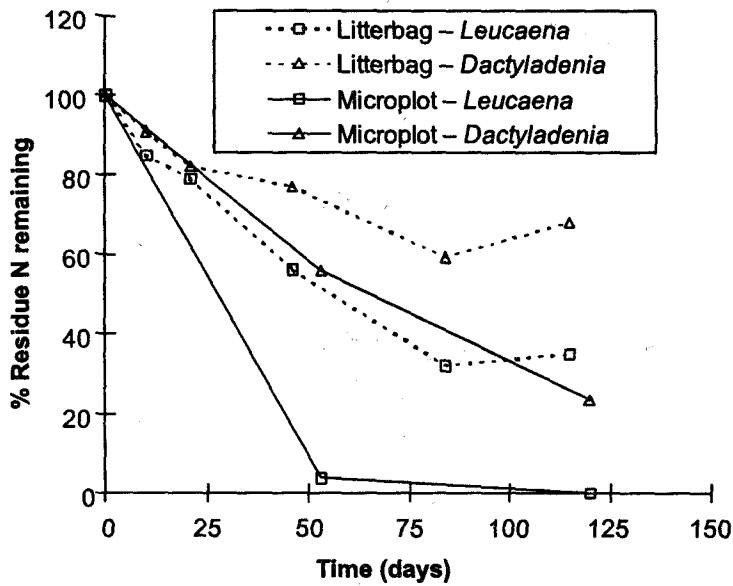
Figure 1: N release from *Leucaena* and *Dactyladenia* leaf residues as measured with the litterbag technique (mesh size 1.4 mm) (adapted from Vanlauwe *et al.*, 1995) and as remaining in the surface litter of a microplot experiment with ^{15}N labeled residues (adapted from Vanlauwe *et al.*, 1998a).
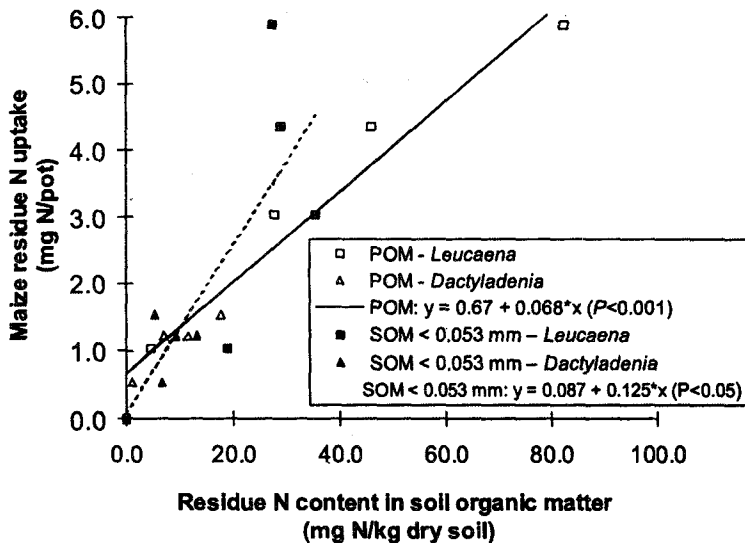

Figure. 2: Relationships between residue-derived N in the particulate organic matter (POM) and in the soil organic matter (SOM) smaller than 0.053 mm and residue N uptake by 3-week-old maize plants (adapted from Vanlauwe *et al.*, 1998b). Samples were taken from a microplot experiment with ^{15}N labeled *Leucaena* and *Dactyladenia* leaf residues 53, 120, 471, and 858 days after residue addition.

Sinks of N in alley cropping systems: crop and tree uptake vs N leaching

In the microplot experiment with ^{15}N labeled *Leucaena* and *Dactyladenia* leaf residues, crop uptake of applied residue N was low in both the treatments and especially limited to the first maize crop after residue addition (120 days after residue application) (Fig. 4). This confirms earlier reports showing recoveries ranging from 6.3 to 17.6% (Mulongoy and Van der Meersch, 1988; Van der Meersch *et al.*, 1993; Akinnifesi, 1996). The latter reports did not estimate the recycling ability of the hedgerow trees. Palm (1995) stated that the biggest and perhaps the most important unknown factor in agroforestry systems is the amount of nutrients released from added plant material that is taken up by the hedgerow. Smucker *et al.* (1995) concluded that isotopes are essential to determine how much of the aboveground tree residue N is recycled within each species and exchanged among species within the alley cropping system.

In the same microplot experiment, substantial differences in the hedgerow recovery of applied residue N were found between the *Leucaena* and *Dactyladenia* hedges (Fig. 4). During the first two prunings, the *Leucaena* hedge recovered 25% of the applied residue N compared to 1% for the *Dactyladenia* treatment. Though the *Leucaena* hedge recovered a significant proportion of the applied *Leucaena* residues, substantial amounts of added residue N remained in the soil profile in a part of the microplot kept free of crops during the first 7 weeks after residue addition (Fig. 5). This may not be such a surprise, as shortly after pruning, high amounts of mineral N may be released in the soil solution through decomposition of the added prunings, and at the same time, the tree may be unable to recover available N due to the complete removal of its canopy and minimal transpiration. Although the amount

of tree roots was rather similar for the *Leucaena* and *Dactyladenia* hedges (Fig. 6), the recovery potential of residue-derived N from the profile was very different and governed mainly by the ability of the trees to regenerate their canopy, rather than by contrasting rooting patterns. Presence of tree roots is not a proof of the withdrawal of nutrients by those roots at the time of root observation.

In the cropped microplot, maize removed all residue-derived mineral N from the soil profile in the *Dactyladenia* treatment and lowered the residue-derived mineral N in the *Leucaena* treatment. The period with the highest risk for mineral N losses seems to be between residue application and the moment where maize shows a sufficiently high demand for N. The latter period usually occurs about 6 weeks after planting for the variety used under the prevailing environmental conditions.

Synchronization between N release and demand of the alley cropping system

Large discrepancies were observed between N release from the *Leucaena* surface litter and N uptake by the maize crop (Fig. 3a), which appears to confirm earlier reports on N use in alley cropping (Mulongoy and Van der Meersch, 1988; Akinnifesi, 1996). However, after inclusion of the POM pool at the N supply side and hedgerow recovery and immobilization in the stable SOM at the N demand side, N supply seems to be relatively well balanced by N demand (Fig. 3a). At maize harvest, only about 20% of the added *Leucaena* residue N was not recovered in the measured pools and may be immobilized below 5 cm or lost through leaching or other loss mechanisms. Based on the complete system, we could conclude that for the *Leucaena* treatment, a high degree of synchrony exists and all N kept in the system and not recovered by the first crop following residue addition may benefit future
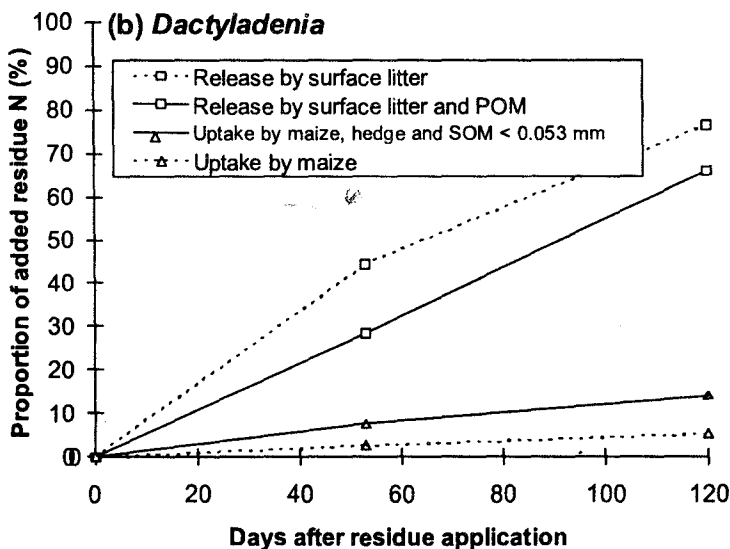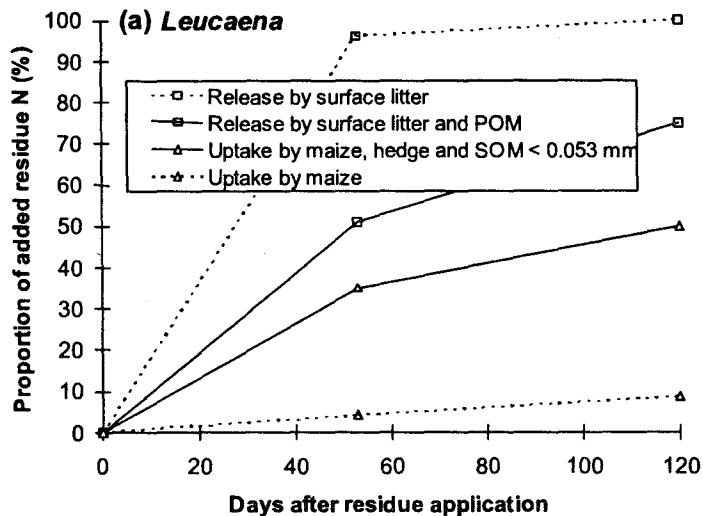
(a) Leucaena

Legend:
- ···□··· Release by surface litter
- —⊟— Release by surface litter and POM
- —△— Uptake by maize, hedge and SOM < 0.053 mm
- ···☆··· Uptake by maize

X-axis: **Days after residue application**
Y-axis: **Proportion of added residue N (%)**

(b) Dactyladenia

Legend:
- ···□··· Release by surface litter
- —□— Release by surface litter and POM
- —△— Uptake by maize, hedge and SOM < 0.053 mm
- ···☆··· Uptake by maize

X-axis: **Days after residue application**
Y-axis: **Proportion of added residue N (%)**

Figure 3: Relationships between N release and N recovery by the alley cropping system for the *Leucaena* (a) and *Dactyladenia* (b) treatments, as measured in a microplot field experiment with ^{15}N labeled leaf residues (adapted from Vanlauwe *et al.*, 1998a and 1998b). The first maize season after residue addition is considered.
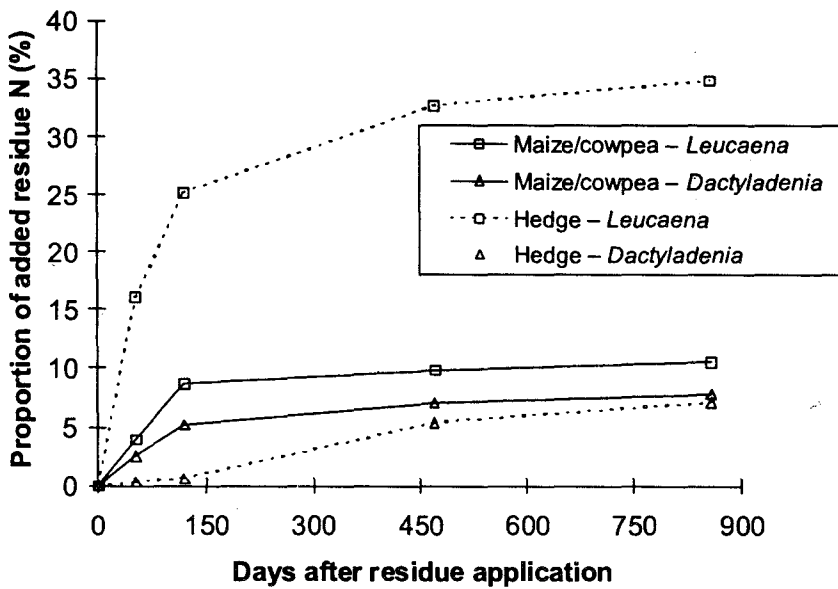
Figure 4: Uptake of applied ^{15}N labeled *Leucaena* and *Dactyladenia* residue N by three maize and two cowpea crops and by the respective hedgerows during the first ten (*Leucaena*) and five (*Dactyladenia*) pruning activities after residue application (adapted from Vanlauwe *et al.*, 1998a).

crops. Haggar *et al.* (1993) stated that the buildup of a favorable potentially mineralizable soil N pool might be more beneficial to crop productivity than the immediate effects of the large quantity of applied⋅N through mulches. Release of residue N diverged more strongly from the system demand for N in the low quality *Dactyladenia* treatment, but this could be attributed to the earlier mentioned removal of part of the applied residue N by faunal activity (Fig. 3b).

The tree component seems to play a significant role in matching N supply with N demand. The high quality *Leucaena* residues release a substantial amount of N in a very short time, but at the same time, the *Leucaena* hedgerows seem able to recover a lot of the applied residue N. The opposite could be said for the *Dactyladenia* treatment: residue N release is relatively slow (even more

so in the absence of a drastic faunal impact on decomposition) and the ability of the hedgerow to recover residue N is low. It looks as if the trees aim at maximal N recovery, as trees producing high quality residues with a rapid N release appear to have the ability to recover a large amount of mineral N and vice versa. Of course, whether this is beneficial to the crop productivity of the system depends on the degree of competition for water, nutrients, and light that exists between the hedgerow trees and the companion food crops.

A glance at possible future research directions

In above experiments, the fate of N derived from a single residue application was followed. In alley cropping systems, however, different residues enter the decomposition subsystem
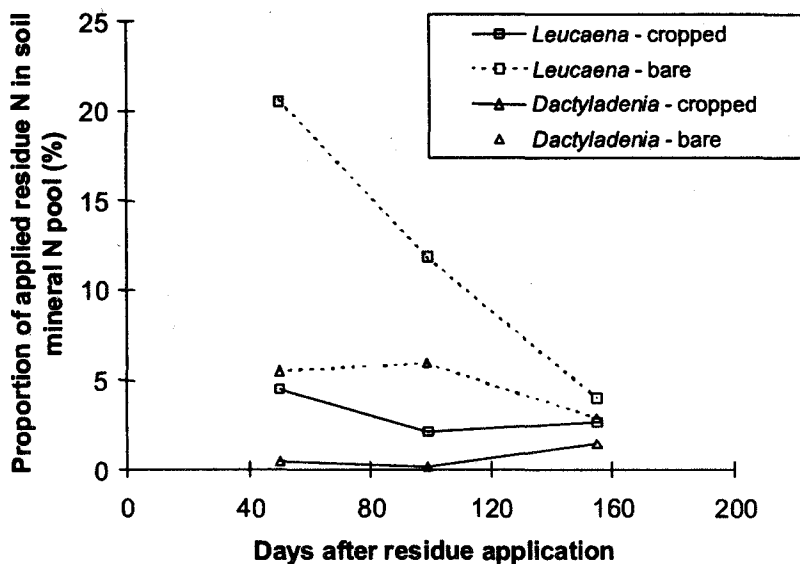
Figure 5: Proportion of added residue N (a) and total mineral N content (b) in the 0–100 cm soil profile during the first maize and cowpea crop after addition of ^{15}N labeled *Leucaena* and *Dactyladenia* leaf residues in a cropped and bare microplot, installed in the respective alley cropping systems (adapted from Vanlauwe *et al.*, 1998c). Tree roots could enter in both cropped and bare microplots, while crop roots were allowed to enter only the cropped microplots. After residue addition, maize was grown between 0 and 120 days and cowpea between 144 and 221days.

simultaneously, such as pruning leaves, pruning twigs, weed biomass, and tree roots at the different pruning activities, or prunings and crop residues before the second growing season. Establishment of relationships quantifying the different interactions between N release processes from residues decomposing simultaneously is needed.

A low recovery of applied residue N by a maize crop indicates that a large proportion of the total N incorporated in the maize biomass is derived from the soil organic matter pool. Relationships between the amount and quality of the added residues and the N supply capacity of the easily available soil organic matter fractions (soil organic matter quality) have not been established. Efforts to do so are complicated by the earlier mentioned simultaneous inputs of resources of varying qualities.

Although it was shown that trees may recover a substantial part of the applied residue N, it is not clear yet whether they extract mineral N from the same soil volume as the companion food crops. Although, due to the contrasting root patterns of the tree and crop, it is unlikely that both species exploit the same soil volume with the same efficiency, it remains necessary to determine unequivocally the source of N incorporated in the tree canopy. This would also allow the hypothesis to be tested that trees are acting as nutrient pumps by withdrawing nutrients from soil layers beyond the reach of crop roots. The trees also appear to leave a substantial amount of mineral N in the soil, especially at the start of the first growing season. Tree management options should be developed which could increase
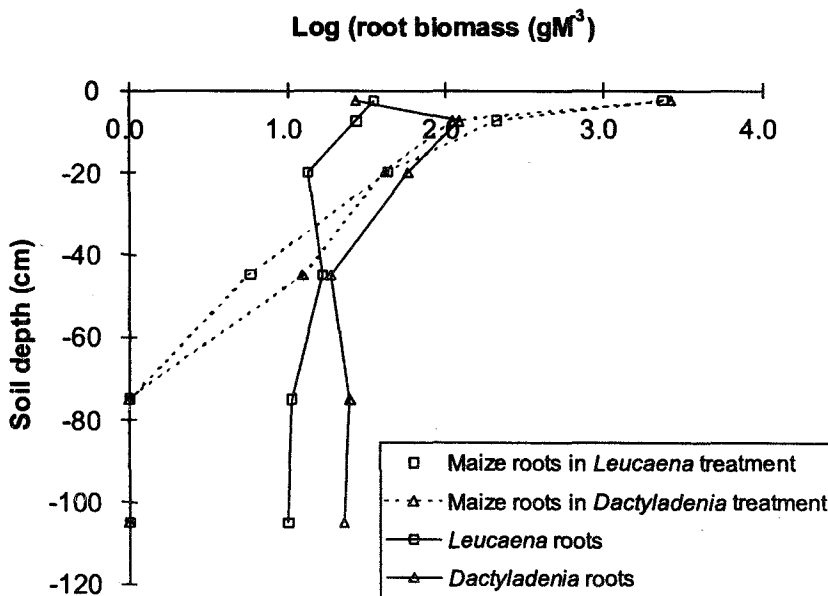
Figure 6: Maize and tree root biomass at different depths in *Leucaena* and *Dactyladenia* microplots, 80 cm away from the hedgerow trees (adapted from Vanlauwe *et al.*, 1998c).

the ability of the trees to recover mineral N, especially during the first 6 weeks of maize growth, which was shown to be a period with high risks for N losses through leaching.

Recently, a lot of attention is given to leguminous cover crops to counteract soil fertility decline and to suppress obnoxious weeds (Versteeg and Koudokpon, 1990; Sanginga *et al.*, 1996). As for agroforestry systems, a similar research approach needs to be followed in order to assess unequivocally the use of N_2 fixed through biological nitrogen fixation.

Acknowledgements

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