

Summary

In Sub-Saharan countries soil infertility is the major problem constraining agricultural production, with N being the most limiting element. Introduction of agroforestry systems with leguminous trees has been suggested as remedy to N deficiency under low input farming systems. The leguminous trees provide high quality organic materials (prunings with high N content), that can be used as organic fertilizer for the associated crop. The trees provide also wood that can be used as firewood or for building houses. In addition, the trees may contribute to building up soil fertility in the top soil by recycling nutrients from the subsoil, and by sequestering organic carbon in the soil.

Though there are many possible benefits of simultaneous agroforestry systems with leguminous trees, there are also constraints and pitfalls. The latter arise from competition between trees and crops. The management of these systems is also knowledge-intensive, as these systems are highly complex, and all interactions between trees and crop are not fully understood yet. A major constraint of agroforestry systems is the low recovery by the crop of N released by applied organic materials. Usually not more than 20 to 30 % of N from applied organic materials is recovered by the crop, while the remainder is lost to the wider environment and/or can not be accounted for. The low recovery by the crop is a major obstacle for increasing crop yield in agroforestry systems. The low N recovery has been ascribed to (i) lack of synchrony between N release by the organic materials and N demand by the crop, and as a result high N losses via leaching, run-off and denitrification, and (2) competition for below-ground resources between the crops and the trees when they are grown simultaneously in the same field.

The work presented in this thesis aims at contributing to a better understanding of management options that may improve the N use efficiency in simultaneous agroforestry systems with leguminous trees. The specific objectives were to assess

- (1) decomposition and N mineralization rates of high and low quality organic materials, and their possible interaction when applied as mixture;
- (2) fertilizer substitution values of (mixtures of) organic materials, as function of time and method of application (split versus all at once) of organic materials;

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- (3) root distribution and root length density of mixed cropping systems with trees; carbon sequestration and nutrient recycling in agroforestry systems.

In order to achieve these aims several experiments were conducted in greenhouse, laboratory and field. The main observations and studies were made in long-term agroforestry field experiments in Malawi, in Sub-Saharan Africa. A preliminary study was carried out in a greenhouse at Wageningen University, The Netherlands. The background of the study, and the complex mixed cropping systems employed in Malawi are discussed in Chapter 1. Chapter 2 presents the main characteristics of the long-term agroforestry systems trials and of the methods used to collect the data and information discussed in the subsequent chapters.

Chapter 3 reports the findings of the preliminary experiment carried out in the greenhouse under controlled environmental conditions. Rates of N mineralization, immobilization and re-mineralization of various organic materials were examined using the double-pot technique. The low quality (maize stover) and high quality (prunings of leguminous trees) organic materials were applied either separately or as mixtures to potted sand, with maize as test crop. N mineralization, immobilization and re-mineralization were derived from the N uptake by the maize. All nutrients other than N were supplied in abundance such that only N was variable.

Initially, mixtures of maize stover and tree prunings showed to immobilize N. Later, the immobilized N was partly mineralized again. The remineralization occurred faster in the mixture with a 1:2 ratio than in the mixture with a 1:1 ratio of stover and tree prunings. The fertilizer substitution values (SVs) of the tree prunings increased with time. The SVs of gliricidia were lower than that of sesbania because of the presence of phytotoxins produced by gliricidia prunings. The mixtures with 1:1 and 1:2 ratios of stover and tree prunings were selected for further testing under field conditions, as discussed further in Chapter 5.

In Chapter, 4 we discuss the effects of time of application of tree prunings on soil mineral N in the topsoil, N recovery by maize and fertilizer substitution values. Recovery of N and fertilizer substitution values of gliricidia prunings greatly varied

with time of application. Substitution values (SVs) were highest (up to 66%) when the prunings were applied before planting and decreased when applied later in the season after planting. The rate of N mineralization itself was not affected by time of application. The low SVs of late applications (between 20 and 30%) were due to lack of synchrony between the N release by the prunings and the N demand by the crop. Split application of organic materials had shown to extend the time of availability of mineral N in the topsoil but did not increase maize yield under our rainfall condition. These results showed that high availability of mineral N early in the season was more important for high N uptake and corn yield than the availability of mineral N later in the season.

Alternatively, mineral N in the soil may be managed by mixing high and low quality organic materials. Chapter 5 discusses the decomposition and mineralization patterns of mixtures of high quality tree prunings with low quality crop residues in soil, using the results of a litterbag incubation study, an incubation study with aluminum soil cores, and field experiments with maize as test crop. Decomposition patterns of mixtures of tree prunings (*gliricidia* and *sesbania*) and crop residues (pigeon pea leaves and roots, and maize stover) were studied in litterbags. The decomposition rate constants of the mixtures were in between their individual pure components, following the general decomposition order: tree prunings > mixtures > crop residues. The organic materials with a high C : N ratio, pigeon pea roots and maize stover, immobilized up to 15% of the applied N during the wetter season but doubled during the drier season. The mixtures of prunings with pigeon pea roots or maize stover depressed maize yield under relatively dry conditions. The results suggest that remineralization was slower under relatively dry conditions than under relatively wet conditions.

In Chapter 6 we present the root distribution and root length density of maize, pigeon pea and *gliricidia*, and the effects of the trees and crops on soil mineral N and Olsen P along the soil profile. Information about the distribution of roots of trees and crops in a simultaneous agroforestry is important for predicting competition for belowground resources between the trees and crops. Recovery of N by the crop can be acutely reduced in systems where competition for N between the crops and trees is high. In the *gliricidia*-maize system, maize root density in the topsoil was much higher than

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that of the trees. However, gliricidia root length density was much larger than that of maize in the subsoil. The planting of maize on a ridge and trees in the furrows, and the application of the tree prunings within the ridge, all increased the chances of the maize to benefit more than the trees from the applied N. In maize-pigeon pea intercropping, maize had faster root and shoot development than pigeon pea during the early growth stages, giving maize more chances of benefiting from the soil resources than pigeon pea. In the complex intercropping system gliricidia-pigeon pea-maize, maize was the strongest competitor and pigeon pea was the weakest. This was attributed to the combined effects of the specific crop characteristics and the management of crops, trees and soil.

The effects of gliricidia-maize simultaneous system on soil chemical and physical properties are further discussed in Chapter 7. In this chapter we also discuss organic carbon sequestration in gliricidia-maize and sole-maize cropping systems and we make a comparison with a seven year old grass fallow. In gliricidia-maize and gliricidia-pigeon pea-maize systems, the amounts of soil mineral N and Olsen P were relatively high in the topsoil and low in the subsoil. This suggests recycling of N and P by the tree and pigeon pea roots from deeper soil layers to the topsoil via prunings and crop residues. The results indicate that gliricidia-maize sequestered more carbon in the soil and standing tree biomass than the sole-maize and grass-fallow. At the same time, gliricidia-maize released substantial more CO₂ into the atmosphere than the sole-maize and grass-fallow, because of the decomposition of large amounts of prunings and crop residues. In the gliricidia-maize simultaneous system, amounts of exchangeable cations were increased in the topsoil but declined in the subsoil. The soil water holding capacity and bulk density of the soil was improved in the Gs-Maize compared to the Sole-Maize.

In chapter 8 the simple model MINIP was applied to study rates of mineralization of N and decomposition of organic materials, as affected by time of application, weather conditions of the two seasons, availability of inorganic N, and composition of mixtures of high and low quality organic materials. From the calculations it followed that the initial period after application gave the biggest differences among various situations, especially the presence or absence of external inorganic N. The time needed to mineralize the required amounts of N for the N uptakes found in the field

was on average 51 days. Interaction between high and low quality organic materials did not have much effect on the total N mineralization of sesbania and maize, but it had a clear effect on maize decomposition. For maize stover and pigeon pea roots, immobilization period was 3 and 4 months, and maximum immobilization was 10 kg N per ton of materials. A total of 1.4 and 1.05 tons of gliricidia and sesbania prunings, respectively, were needed to neutralize this immobilization.

Chapter 9 finally summarizes and discusses the major findings of the PhD thesis research. A main result is that addition of prunings with low C:N ratio may promote the rate of decomposition of low quality (high C:N ratio) crop residues by furnishing mineralized N to the microbial biomass, when the soil solution is low in inorganic N. Another main result is that the interactions between high and low quality organic materials, if any, are marginal, and that the effects of the combined materials are almost purely additional. This was shown by both the experiments in greenhouse and field, and the modeling exercises. Our results have also shown that maize grown in a system of Gliricidia-Pigeon pea-Maize out yielded maize grown in a system of Gliricidia-Maize, despite of expected increased competition in the multiple cropping system. Evidently, maize was the stronger, and pigeon pea the weaker competitor in a Gliricidia-Pigeon pea-Maize intercropping system. Competition for nutrients between maize and trees was relatively small, because of their different rooting pattern, especially within the ridge where the prunings were applied and maize had higher root densities than trees. Our results also showed that after 7-10 years of agroforestry, Olsen extractable phosphorus (P Olsen) and exchangeable cations had increased slightly in the topsoil, but had decreased in the subsoil. Evidently, the trees in the agroforestry systems had pumped nutrients from the subsoil and recycled them via prunings into the surface soils. This has resulted in higher yields and by that also in larger outputs of nutrients. The increase of soil organic carbon in the topsoil of agroforestry fields improved bulk density, infiltration rates, permeability, water holding capacity and cation exchange capacity.

Summarizing, the system of gliricidia-maize –pigeonpea simultaneous intercropping is an efficient system as long as the subsoil has not been depleted yet. For the fields of the Makoka Agricultural Research Station it was estimated that the sub-soils would be depleted the next period of about 6 years. Once the sub-soil has been depleted, soil

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fertility is much lower than it was before the practice of agroforestry started. Hence, from the point of view of chemical soil fertility, agroforestry without any external inputs cannot be considered as a sustainable system, and cannot replace organic or inorganic fertilizers in the long run. Apart from soil fertility, agroforestry has other advantages for the farmer. It should be realized, however, that sooner or later input of nutrients from outside the agroforestry fields will become indispensable.