Session 22
Nutrient cycling and biological dinitrogen fixation in agroforestry systems
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Introduction

Improved nutrient cycling is one of the most frequently mentioned benefits from including trees in agricultural systems. Further, tree species capable of forming symbiosis with dinitrogen-fixing bacteria are included in agroforestry systems in order to enhance N nutrition of the crop. However, reports from different agroforestry systems indicate quite varying tree benefits on crop nutrition, though mostly positive. There are important knowledge gaps for developing these systems towards optimum yield and environmental service benefits. Some of these concern the functioning of soil fauna and microbes in agroforestry systems, selection of suitable plant-microbe combinations and systems analysis of the nutrient cycle. In light of the current knowledge gaps, organizing a session in the 2nd World Congress of Agroforestry for presenting new studies on carbon and nutrient cycling seemed highly desirable. The session comprised 5 oral and 11 poster presentations. The session was attended by approximately 50 congress participants.

Key messages and new insights from the session

Agroforestry affects the structure, the physico-chemical and biological properties of soils when compared with uncultivated secondary forests. These effects of land use on soils may be direct or indirect, e.g. through their impacts on soil fauna. Earthworms, in particular, may affect soil carbon and nutrient dynamics and act as indicators of soil degradation, as suggested by two studies presented in the session. Fonte et al.[1] found that in systems where residues are present on soil surface, earthworms improve soil structure independent of residue quality. They stabilize soil microaggregates within the macroaggregates and protect soil carbon from decay. They also increase uptake of nitrogen fertilizer by crops. The motivation of the study was to compare the effects of slash-and-burn agriculture with a slash-and-mulch agroforestry practice called Quesungual in Honduras. The Quesungual practice improves moisture and nutrient retention in soil, enhances soil biota and reduces erosion in comparison to slash-and-burn agriculture. The results demonstrate the role of earthworms in mulch-containing agroforestry systems.

Boniao et al.[2] suggested that earthworm populations and soil organic matter content serve as indicators of soil degradation. These soil properties were the ones most affected by land use practices when agroforestry systems and secondary forests were compared. Both organic matter and earthworm populations were lower in the soils under agroforestry than under secondary forests. Species diversity of earthworm populations also changed with land-use practices. Soils in the study area are strongly acidic, prone to erosion and easily degraded by land-use changes. Planning of conservation strategies has been restricted by the lack of information on the effects of land uses on soil properties.

Soil carbon dynamics are especially important in arid agroecosystems, which are under high land-use pressure and extremely vulnerable to soil degradation. Applicability of agroforestry in such areas is restricted by the slow growth of trees and the competition between trees and crops for the scarce water and nutrient resources. In contrast, native shrub species already occurring on farmers'

[1] Fonte et al. Management and earthworm influences on soil organic matter and N dynamics in hill-slope agriculture of western Honduras.
[2] Boniao et al. Forest landuse and the physico-chemical and biological properties of soils in Mt Diwata Range, Agusan del Sur, Philippines.

fields significantly improve soil quality by providing high amounts of organic matter and by promoting soil microbial diversity and microbial processes also in the dry season, as demonstrated by Dick et al.[3] Furthermore, the shrubs contribute to surface-soil moisture by performing hydraulic lift and do not, therefore, compete with crops but instead stimulate yields. Clearing shrubs from the study areas drastically reduced crop yields from second year onwards. These beneficial shrubs are still commonly seen as weeds, and farmers are encouraged to coppice and burn them before crop planting, thus reducing organic carbon inputs to the soils.

Biological dinitrogen fixation is of high potential importance for nutrient balance and soil improvement in agroforestry systems. Its role has, however, often been underestimated because of methodological constraints and restrictive management practices, as demonstrated by Nygren et al.[4]. Nitrogen in below-ground plant biomass has often been ignored when estimating N_2 fixation, and short-term studies have not captured the full potential of perennial legumes. Estimation of N_2 fixation has been impaired by the difficulty of finding suitable reference plants when using natural N isotope ratios, or achieving uniform labeling of plants in ^{15}N enrichment studies. Moreover, legume trees are surprisingly often subjected to management practices which impede N_2 fixation, such as too frequent pruning. In order to fully harness the potential of N_2 fixation, selection of optimal combinations of trees and N_2-fixing bacteria, and studying the interlinked cycles of carbon, nitrogen and phosphorus in the symbioses of trees, N_2-fixing bacteria and mycorrhizal fungi should receive more attention.

A recent example of the importance of symbiotic aspects for N_2 fixation is the research on *Calliandra calothyrsus* provenances and different *Rhizobium* sp. strains by Lesueur & Odee[5]. The effect of *Rhizobium* inoculation on the growth and nodulation of *C. calothyrsus* varied between *Rhizobium* strains. Moreover, when tested on three different soil types of varying structure and carbon and nutrient content, the selection of *Rhizobium* strains alone and in different combinations with the tree provenances resulted in varying nodule mass and total N content of *C. calothyrsus* shoots.

Action points for research and policy

The presentations demonstrated the importance of soil fauna when assessing land management practices. Soil fauna and the other components of the agroecosystems should be managed in an integrated manner. Further studies are needed to determine and quantify the usefulness of earthworms and nematodes as indicators of soil degradation.

Management practices of native shrubs in arid agroecosystems should be revised in the light of the demonstrated importance of these shrubs, and their non-thermal management should be encouraged. The role of the shrubs could be further strengthened by active management, and optimum densities for the shrubs should be defined as a first step. Furthermore, their interactions with soil microbial populations deserve to be studied.

Research focus in N_2 fixation studies should shift from legume trees to symbiotic interactions. In addition, methods for reducing N losses from the systems should be investigated. These may include tree management for a more even N release from mulch, e.g. by promoting partial instead of complete tree pruning and by combining different legume species with different mulch quality on the same land. The performance of legume trees and the ability to form N_2-fixing symbioses under climate change should be specifically studied, as they cannot be anticipated based on studies on herbaceous legumes.

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[3] Dick et al. Native shrubs *Piliostigma reticulatum* and *Guiera senegalensis*: the unrecognized potential to remediate soils and optimize productivity of Sahelian agroecosystems.

[4] Nygren et al. Biological dinitrogen fixation: an underestimated resource in agroforestry systems?

[5] Lesueur & Odee. *Calliandra calothyrsus*: the potential for optimizing the BNF by selecting effective provenance × Rhizobium combinations.