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Nutrient Cycling and Safety-net Mechanism in the Tropical Homegardens

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Abstract: Nutrient cycling and safety-net mechanism of tropical homegardens are reviewed here in relation to the same processes reported mainly in alley cropping and other multistrata systems, where comparable. This is because literatures on the nutrient cycling of the homegardens are scarce. Those processes are discussed in view of biodiversity and management practices of the homegardens. Some suggestions are also put forward to better design and management of the homegardens for a higher productivity and sustenance. There are some methodological limitations of using conventional tracer techniques in scrutinizing nutrient flow in the homegardens, which warrants the search of more advanced techniques. It is frequently reported that the biodiversity or species diversity of plants is an important factor for the sustenance of soil fertility in any agroecosystem. Nevertheless, it was noticed in the present review that it is not just the biodiversity, but plant structural diversity that determines efficient nutrient cycling in the homegardens. In general, there is a less diverse faunal community in the homegardens than their original ecosystems, because of the invasion of predatory fauna and changes in the microclimate and food resources. However, the biomass is often higher owing to the colonization by mainly different earthworm species with the favourable soil moisture and increased organic matter turnover. There is a limited adaptability of the alley cropping system in the water-limited tropical agroecosystems, because of the limited scope for spatial differentiation in rooting between trees and crops (i.e., spatial complementarity). In multistrata agroforestry systems like homegardens, it is apparent that there is a signaling system of the root systems for balancing the nutrient uptake through the spatial complementarity and the safety-net mechanism, which seems to depend up on the management practices and possibly climatic factors that modify the resources availability and root activity. This allows extensive applicability of the homegardens in tropics. Tree pruning adversely affects the safety-net role of the hedgerow trees of the alley cropping. However in the homegardens, the pruning of selected trees may not influence the safety-net role due to presence of multistrata root systems of unpruned trees, which constitute multiple safety-nets. In the forested area of the homegardens with a relatively high tree density, below-ground root activities, high litterfall and relatively low nutrient export contribute to a nutrient conservation. In contrast, farming area of the homegardens with a high organic matter turnover and a relatively low tree density does not seem to support to an efficient nutrient cycling. Therefore, plant density should be increased in the farming area with suitable trees having deep and distant root activities for a better safety-net role. In addition, cover crops should be

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grown in appropriate areas of the homegardens for reducing topsoil nutrient leaching. These additional plantings will providefodder to the livestock as well as enhance carbon sequestration in the system. Soil surface litter layer should not be disturbed, if an improved nutrient cycling is to be maintained. Agronomic practices such as root pruning, fertilizer and manure applications etc. should be optimized for an enhanced productivity with a least depletion of the system.

Introduction

Tropical homegardens can be defined as 'land use systems involv ing deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual houses, the whole tree-crop animal unit being intensively managed by family labour'(Fernandes and Nair, 1986). They are a commen form of land use in south and southeast asia and south america. These gardens exemplyfy polyculture and conserve tree and crop genetic diversity and heirloom plants that are not found in monocultures. The homegardens are complex systems with plant diversity conserved through their use (Das and Das, 2005) and contain characteristics which make them an interesting model for research and the design of sustainable agroecosystems, including efficient nutrient cycling, high biodiversity, low use of external inputs and soil conservation potential (Torquebiau, 1992; Jose and Shanmugaratnam, 1993). Understanding carbon, water and nutrient flux in the homegardens provides a foundation for better design and management of the system to permit efficient use of resources, to avoid loss of energy and to increase production (Benjamin *et al.*, 2001).

It is generally believed that nutrient cycling is more efficient in multistrata agroforestry systems than in monoculture plantations (Nair *et al.*, 1999), because of the complementarity of nutrient uptake. Trees may reduce nutrient leaching by forming a 'safety net' under the root zone of the annual crops (Van Noordwijk *et al.* ,1996). This would lead to a higher use efficiency of native and applied nutrients. However even under tree crops with perennial root systems of some instances, large losses of fertilizer N from the topsoil were observed which accumulated as adsorbed nitrate in the subsoil (Schroth *et al.*, 1999). Thus, the agroforestry systems may have enhanced nutrient cycling compared to monocultures (Schroth, 1995), but experimental evidence still needs to be gathered, because below-ground nutrient fluxes and interactions between trees and crops have not been sufficiently addressed up to now. Tracer techniques can help identify and also quantify spatial and temporal patterns of nutrient uptake (Kumar *et al.*, 1999), but they have rarely been used in multistrata agroforestry systems (Lehmann *et al.*, 2001a). The use of tracers in agroforestry research has been principally limited to alley cropping systems (Rowe *et al.*, 1999), because nutrient interactions between trees in mixed cropping systems are difficult to determine due to their complex geometries. Even in some examples of alley cropping, biological N_2 fixation and N transfer estimates clearly demonstrated the limitations of ^{15}N enrichment techniques in field experiments showing even higher transfer than actually fixed N (Lehmann *et al.*, 2002). Therefore, N transfer in the hedgerow intercropping system could not be determined by the ^{15}N dilution methodology. The ^{15}N balance approach, however, yielded reliable results even 1.5 years after ^{15}N application. Assessment of the root distribution can give valuable information about the architecture of the belowground biomass, but often fails to quantify short-term dynamics of nutrient uptake (Dinkelmeyer *et al.*, 2003).

Nutrient Cycling

Impact of Biodiversity

Biodiversity is simply the number and variety of organisms found within a specified geographic region. The biodiversity in an agroforestry system like a homegarden is referred to as agrobiodiversity. It is a result of the deliberate interaction between man and natural ecosystems; the flora, fauna and microbes they contain, often leading to major modifications or transformations. The biodiversity of a homegarden is the product, therefore, of not just the physical elements of the environment and biological resources but vary according to the cultural and management systems to which they are subjected (Heywood, 1995). That includes a series of social, cultural, ethical and spiritual variables that are determined by *sensu lato* local farmers at the local community level. The biodiversity consists mainly of various trees and crops, sometimes in association with domestic animals, around the household. In general, food and fruit producing species dominate near the living quarter and working areas of the homegarden and small plots of annual vegetable crops separate this part of the garden from the more distant parts favored for timber species (Kumar and Nair, 2004). Medicinal and ornamental species are typically cultivated in small areas or in pots surrounding the household and vegetables in areas adjacent to the kitchen. Multipurpose tree and shrub species used as live fences are usually planted on farm boundaries, regardless of holding size. Trees also may be scattered throughout the homestead or at specific points to provide or avoid shade, necessary or harmful to different plants, besides providing support for climbers. In this part of the review, the effects of floristic and faunal biodiversities on the nutrient cycling of tropical homegardens are described.

Floristic Biodiversity

It is a conventional idea that the biodiversity of plants is an important factor for the sustenance of soil fertility in agroecosystems. However, ancient, humid agroecosystems in tropics demonstrate that for maintenance of long-term soil fertility, high species richness may not be as important as individual species traits that influence nutrient cycling (Russell, 2002). Rate and magnitude of nutrient return to a soil are determined by litterfall and litter quality that are specific to the plant species (Mwangi *et al.*, 2004). This has been proved for P and S dynamics in the soil (Lehmann *et al.*, 2001b). For example on infertile soils, it has been shown that tree species with rapid above-ground nutrient cycling and high quality litter should constitute the majority of crops in agroforestry systems to ensure adequate medium to long-term availability of P and S. Structurally diverse trees of homegardens have been shown to help maintain a higher content of organic and inorganic P than dual-cultures (Solomon and Lehmann, 2000). In general, the structural diversity of the homegardens is critical to their sustainability, allowing efficient use and transfer of not only nutrients, but also carbon and water (Benjamin *et al.*, 2001). Thus it is not just the biodiversity, but plant structural diversity, which determines efficient nutrient cycling in the homegardens. It helps for a maximized nutrient capturing and cycling through the establishment of multistrata root systems of different plants and trees. These constitute a safety-net mechanism with multiple safety-nets for the nutrient capturing; efficient absorption of nutrients leaching through the soil by means of spatially distributed root systems. In agroecosystems, this can be achieved by multistrata plantation establishment. That will improve the nutrient cycling and in turn sustain soil fertility through maximum complementarity of resource use in space and time; that is synchronizing the growth cycles and root activity distribution of the tree crops, each other (Fig. 1 and 2). Lack of the synchrony may result in the depletion of soil fertility in the long run. The safety-net mechanism will also optimize soil biological processes (Schroth *et al.*, 2001a).
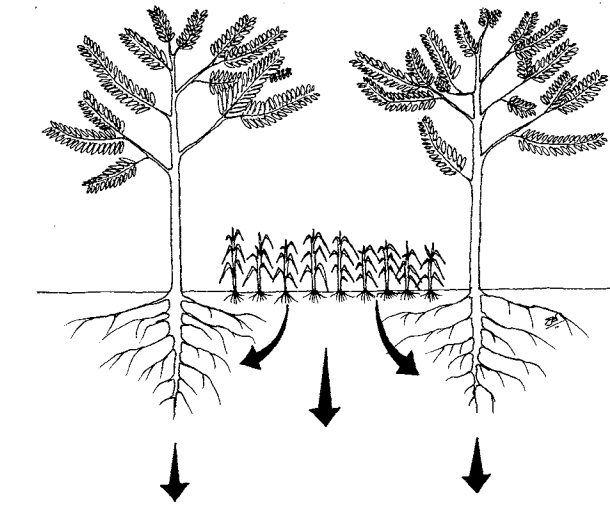
(a)

(b)

Fig. 1: A diagrammatic comparison of safety-net roles of the (a) alley cropping and (b) multistrata systems. The alley cropping establishes only one safety-net in the soil whereas the multistrata systems are characterized by multiple safety-nets. A deep root system itself of a tall tree in the multistrata system may constitute several safety-nets in the subsoil, and may take up nutrients released by its owned upper safety-nets. Size of the arrows represents the magnitude of nutrient leaching
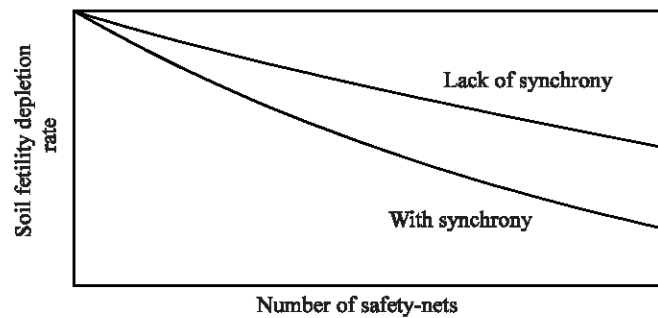
Fig. 2: Conceptual relationship between soil fertility depletion rate and safety-net role with or lack of synchrony. Soil fertility depletion rate is higher when there is a lack of safety-nets as well as synchrony between nutrient release and leaching from the topsoil and its demand by subsoil safety-nets

Faunal Biodiversity

The fauna existing on and in the soil are the major faunal contributors to the nutrient cycling in any terrestrial ecosystem. Soil faunal communities show a variety of reactions to changes induced by land management. Their abundance and diversity are indicators of the quality of soils and they influence soil organic matter dynamics, nutrient contents and physical parameters such as bulk density, porosity and water availability. Organic matter decomposition is generally dominated by drilosphere systems formed by associations between earthworms and soil bacteria, where soil moisture regimes are favorable, like in homegardens and termitosphere systems with increasing dryness (Lavelle *et al.*, 1993). Soil faunal components fragmenting litter include collembola, centipedes, millipedes and arachnids. Earthworms utilize the fragmented litter for humus formation. Termites can fragment as well as transform the litter into soil humus. Generally, these faunal activities increase nutrient availability and hence cycling and plant growth (Setala and Huhta, 1991). Earthworms facilitate P transfer downward increasing a P patchy distribution in the soil and significantly change the biogeochemical status of P in certain hot spots such as casts and burrow-linings (Le Bayon and Binet, 2005). Fragmentation of the lignified litter fractions by the soil fauna helps immensely in cycling of nutrients contained in them, which are otherwise stored in the soil, underutilized. The degradation of the ecosystems frequently results in a depletion of the faunal communities (Lavell *et al.*, 1994). That may cause to nutrient deficiencies in plants in the long run. The fragmented litter in the soil controls availability and cycling of especially limiting micronutrients in natural and managed tropical ecosystems. Under certain circumstances, litter incorporation to the soil may reduce nutrient cycling and plant growth (i.e., C sequestration), depending on the soil and litter chemical properties (Seneviratne, 2002). Once the incorporated litter was encapsulated forming humus, it contributes to increased C sequestration in the soil (Seneviratne, 2003), but impedes nutrient cycling due to its limited accessibility to microbes. Perennial cropping systems like tropical homegardens have less diverse faunal communities than their original ecosystems, because of the invasion of predatory fauna and changes in the microclimate and food resources (Tabu *et al.*, 2004). However, the biomass is often higher owing to the colonization by mainly different earthworm species with the increased organic matter turnover, in addition to native species (Lavell *et al.*, 1994).

Impact of Alley Cropping Agroforestry System

The alley cropping results in a spatial separation of the root systems of trees and crops between the hedgerows, the crop having more roots in the topsoil and the tree having more roots in the subsoil under alley cropping than in monoculture (Lehmann *et al.*, 1998). Lehmann *et al.* (1999a) reported an increase of N under Acacia hedgerows of the sole cropped trees. Unused soil N was present at the topsoil in the alleys as well as in the subsoil of Sorghum monoculture. Under light soil and high rainfall conditions, it was examined that there was an inherent problem in managing N originating from mineralization of organic materials as it accumulated at the beginning of the season, well ahead of peak demand by crops and was susceptible to leaching before the crop root system develops (Chikowo *et al.*, 2003). The N use efficiency of the tree-crop combination was higher than the sole cropped trees or crops. This was reflected in foliar N content of the crop, which was higher in the agroforestry combination than in monoculture, corresponding to the higher soil N. Resource utilization and C and N inputs to the soil are highest with a combination of annual and perennial crops (Lehmann and Zech, 1998). Therefore, the combination provided a higher internal nutrient cycling than the monocultures (Lehmann *et al.*, 1999b). In line with this, grain yield of alley cropped Sorghum was similar to or slightly higher than in monoculture and did not decrease near the tree-crop interface. At the hedgerow however, the root systems of trees and crop overlapped and more roots were found than the sum of roots of sole cropped trees and the crop (Lehmann *et al.*, 1998). Under the experimental conditions, the root systems of the alley cropped Acacia and Sorghum exploited a larger soil volume utilizing soil resources more efficiently than the respective monocultures. Recent reviews on root research however indicate that there appears to be limited scope for spatial differentiation in rooting between trees and crops (i.e., spatial complementarity) in water-limited environments, unless ground-water is accessible to tree roots (Ong *et al.*, 2002). Further, incorporating a leguminous tree into a fertilized sorghum cropping system had no effect on total leaching and total uptake of applied ^{15}N in above-ground biomass (Lehmann *et al.*, 2002). As such, planting arbitrarily selected trees in annual cropping systems does not seem to always support an efficient safety-net role. This shows the limited adaptability of the alley cropping in the tropical agroecosystems.

Impact of Other Multistrata Agroforestry Systems

In multistrata agroforestry systems with especially microaggregated tropical soils, rapid water flow through the topsoil tends to high N losses and a large nitrate accumulation in the deep soil to a depth of at least 5 m (Renck and Lehmann, 2004). However, some trees in these systems [e.g., pecan (*Carya illinoensis*)] show potential for efficient N cycling by root intercepting and absorbing N from deeper soil layers, the safety-net mechanism and returning to soil surface via litterfall. Also in temperate agroforestry systems, tree roots have been observed to play a significant role in alleviating groundwater nitrate leaching through their safety-net role (Allen *et al.*, 2004). In the multistrata systems, plants tend to avoid excessive root competition both at the root system level and at the single-root level by spatial segregation (Schroth, 1998). As a consequence, associated plant species develop vertically stratified root systems under certain conditions, leading to complementarity in the use of soil resources. In tree-based cropping systems like homegardens, tree crops can have shallow or very deep root activity (Lehmann, 2003). For cacao in Ghana, most (i.e., 75%) of the root activity was observed to confine to the top 10 cm, whereas for mango in India it reached as deep as 216 cm. For some tree crops (e.g., guava) more than 90% of the cumulative root activity was below 10 cm depth and 40-60% even below 1 m depth. Such deep root activity is important for resource acquisition.

Only few trees in homegardens show root activity reaching similarly deep. Regional and temporal variations of subsoil root activity of the same tree species have been observed to be significant and generally larger than differences between species (Lehmann, 2003). This shows the ecological complexity of the homegardens in terms of nutrient cycling. In the homegardens, deepest root activity is generally found for fruit trees such as citrus, guava and mango (Lehmann, 2003). Shaded crops such as coffee and cacao tend to have shallower root activity than fruit trees. Monocots including oil palm, coconut or banana have root activity that can be both deep and shallow. In an Amazonian agroforest, very little N was recovered by peach palm (*Bactris gasipaes*), more by cupuassu (*Theobroma grandiflorum*) and annatto (*Bixa orellana*) and most by Brazil nut (*Bertholletia excelsa*) (Dinkelmeyer *et al.*, 2003). It remained constant in cupuassu and peach palm and increased in Brazil nut during the plant growth. Most of the N uptake occurred during the first two weeks. Brazil nut showed an extensive root activity and took up more fertilizer N applied to neighboring trees than from the one applied under its own canopy in contrast to the other tree crops (Dinkelmeyer *et al.*, 2003). During the dry season, topsoil root activity measured with ^{15}N was around 80% for the all species above with the exception of the palm tree, which had a higher uptake from 0.6 m (50%) than from 0.1 m (30%). The subsoil (1.5 m) root activity was higher, when the palm tree was not regularly cut for heart of palm harvest but grown for fruit production. Despite the significant subsoil root activity there was little evidence that large amounts of nutrients below 1 m depth can be recycled by the investigated tree species. More important may be a rapid recycling of nutrients from 0-1 m depth (Lehmann *et al.*, 2001a). Pueraria, a legume cover crop proved to be very important for the N cycling in a mixed tree cropping system recovering most (31%) of the applied ^{15}N in plant and soil in comparison to cupuaçu (20%) and peach palm (21%) (Lehmann *et al.*, 2000). Further, relative subsoil root activity of cupuassu increased and topsoil root activity of both palm and cupuassu decreased when intercropped in comparison to the monoculture (Lehmann *et al.*, 2001a). The trees did not benefit from biologically fixed N_2 of the cover crop due to their low lateral root activity and the high available soil N contents largely being an effect of the amount and placement of mineral fertilizer. Management practices such as pruning, liming and irrigation are also shown to significantly affect subsoil root activity of trees (Lehmann, 2003). Thus, it is apparent that there may be a signaling system in the spatial complementarity and the safety-net mechanism of the root systems for balancing the nutrient uptake, which seems to depend up on the management practices and possibly climatic factors that modify the resources availability and root activity. This allows extensive applicability of the homegardens in tropics. This needs systematic studies to fully understand its effects and potentials.

Biological N_2 fixation and mycorrhizal associations of plants are important in the homegardens, but little quantitative information seems to exist in this respect. In particular, behavior of N_2-fixing trees that are abundant in these systems, information on the quantities of N_2 fixed and its further utilization by associated crops are not well documented.

In the homegardens where tree components are closely integrated, there is a substantial potential for capturing the leaching nutrients through the safety-net role. On-site nutrient conservation also may be accomplished through the interlocking root systems (root grafts and/or mycorrhizal connections), which essentially act as multipliers of the 'root systems' reach. In addition, horizontal transfer/sharing of nutrient ions between the rhizospheres of the neighboring plants is probable. That is, the tree roots may release, leach out and/or exude mineral and organic materials into the rhizosphere of neighboring plants, provided they interact with one another (Kumar *et al.*, 1999). Gajaseni and Gajaseni (1999)

stated that the average litter in a standing crop of a homegarden was even higher than that of a typical tropical forest. Stocking levels of plants, species attributes and management, which are variable, determine the quantity and periodicity of litterfall (George and Kumar, 1998). Further, the homegardens are characterized by low export of nutrients, because there is no complete harvesting from them. These factors also contribute to the nutrient conservation in the homegardens.

Impact of Management Practices

Tree pruning is a common management practice in the tropical homegardens mainly to remove light interception to other crops and plants and to apply the prunings as a soil-surface mulch in order to improve plant growth. This practice has been adopted in agroforestry systems like alley cropping to reduce below-ground competition between the annual crop and tree, in addition. The below-ground effects of the pruning, which are poorly understood, may also influence the soil fertility. In the alley cropping, the effects of below-ground biomass on soil fertility have been reported to be even higher than those of the mulch application (Haggar *et al.*, 1993). Allen *et al.* (2005) observed a higher net N mineralization in the soil when there was a below-ground interaction of the tree-crop system. Pruning has been observed to diminish the root length density at all depths and positions in plots with sole Acacia hedgerows (Peter and Lehmann, 2000). The highest root length density was found when the pruned trees of Acacia were intercropped with Sorghum (Lehmann *et al.*, 1998). If the trees were not pruned, combining trees and crops did not increase root length density. Of the sole Acacia plots, the relative vertical distribution of total roots did not differ between trees with or without pruning, but live root abundance in the subsoil was comparatively lower when trees were pruned than without pruning (Peter and Lehmann, 2000). In the dry season, the proportion of dead roots of pruned Acacias was higher than of unpruned ones, while the fine roots of unpruned trees contained more glucose than those of pruned trees. Pruning effectively reduced root development and may decrease potential below-ground competition with intercropped plants, but the reduction in subsoil roots also increased the danger of nutrient losses by leaching, due to a hampered safety-net role. The reduced size of the root system of pruned Acacia negatively affected its P and Mn nutrition and also the function of the tree roots as a safety-net against the leaching of nutrients such as NO_3 and Mn (Peter and Lehmann, 2000). If nutrient capture is an important aim of an agroforestry system, the concept of alley cropping with pruning should be revised for a more efficient nutrient recycling. Leaching losses of such mobile nutrients as NO_3 were likely to occur especially in the alley between pruned hedgerows and tended to be higher after pruning. After pruning, trees themselves also show a lag phase in the N uptake from the deeper soil (Rowe *et al.*, 2001). For example, total accumulation of applied ^{15}N in the above-ground biomass of annatto decreased throughout the year due to the tree pruning (Dinkelmeyer *et al.*, 2003). Pruning to reduce belowground competition for the benefit of associated annual crops can be recommended only in the light of the temporary reduction of root density in the crop rooting zone and consequently the increase in crop production (Bayala *et al.*, 2004). However in the tropical homegardens, the pruning of selected trees may not adversely affect the safety-net role due to presence of multistrata root systems of unpruned trees, which constitute multiple safety-nets.

Lehmann *et al.* (1999b) showed that nutrient (i.e., N and K) export with the crop harvest could effectively be reduced by a nutrient return with the mulch application in alley cropping. A nutrient return by mulching crop residues and prunings of the hedgerow tree was essential for a positive nutrient balance in the system. In addition to the nutrient return, the mulches conserve nutrients under especially high soil pH and leaching conditions (Lehmann *et al.*, 1999c). Decomposition and N release

of a litter mulch are basically governed by the litter moisture regime (Seneviratne *et al.*, 1998) and critical concentrations of C and plant nutrients that limit enzyme kinetics of microbial decomposers (Seneviratne, 2000). Plant polyphenolics modify the N release under limited N concentrations in the litter. The N release of fragmented and soil-incorporated litter is affected by the properties of soils to which they are incorporated (Seneviratne *et al.*, 1999). In the tropical homegardens, the soil mulch layer consists of a mixture of litter, both low- and high-quality in terms of their chemical composition and nutrient release. These mixtures contribute to prolong nutrient availability, reduce leaching losses and synchronize nutrient release with crop demands (Myers *et al.*, 1994), through a transfer of N from the high- to the low-quality litter for a temporary immobilization (Schwendener *et al.*, 2005). Total N release of such mixtures behaves as a calculated sum of individual release patterns. In some homegardens (e.g., Maya homegardens), the litter layer is customarily swept and burnt mainly to reduce insects on the garden floor and maintain the cleanliness (Benjamin *et al.*, 2001). These activities possibly contribute to energy being lost from the system through carbon liberation, while disruption of the decomposition process affects nutrient cycling. The mulch application may also reduce soil N_2O emissions by converting it to N_2 through physical and microbial processes (Seneviratne and Somapala, 2003), which contributes to N cycling as well as reducing global warming.

Land of the tropical homegardens can be divided into two parts depending on the extent of organic matter turnover; a forested area with a relatively low organic matter turnover and a cropping and livestock rearing area (farming area) with a high organic matter management in the proximity of the household. Soil faunal activities are enhanced in the latter due to high levels of organic matter turnover, unlike the forested area. The increased organic matter turnover with different management practices (e.g., composting, compost application etc.) supports to the earthworm colonization (Mwangi *et al.*, 2004). Live fences and other re-coppicing trees of the homegardens are pruned frequently and loppings and residues collected after clearing the land are often applied along the fence and/or as a soil mulch. This creates favourable temperature and moisture conditions, which may harbor a high density of earthworms and possibly other fauna improving soil physical and chemical properties, as was shown in the alley cropping (Hauser and Kang, 1993). Thus, those management practices improve organic matter turnover in, especially cropping area and replenish stable soil organic matter depleted during continuous cultivation (Solomon *et al.*, 2000). However, the farming area does not seem to support an efficient nutrient cycling through the safety-net mechanism, due to relatively low tree density. In contrast, a better safety-net role exists in the forested area with relatively low organic matter turnover, due to multistrata root distribution of shrubs and multipurpose trees. As such, the forested areas of the homegardens are comparable to natural forests in respect of their nutrient cycling processes.

Improved Nutrient Cycling for a Better Productivity

The greatest opportunity of the homegardening is that the landscape where resources are currently under-utilised can be planted by trees and crops to fill niches. In this way, it can mimic the large-scale patch dynamics and successional progression of a natural ecosystem (Ong and Leakey, 1999). Thus, the farming area can be planted with additional trees having thin crowns and high deep root activity, especially fruit trees (e.g., guava) for the improved safety-net mechanism. They can be planted in corners of plots with annual crops. In addition, tree species like Brazil nut may effectively decrease N leaching through the safety-net mechanism when planted in the farming area, because it has

a distant root activity (Dinkelmeyer *et al.,* 2003). Cover crops can be grown on the border of livestock rearing area in order to reduce nutrient leaching from the topsoil. They can also be cultivated in the forested area as undergrowth. That will also provide fodder for livestock of the homegarden. These practices will also contribute to enhanced C sequestration in the system. Soil surface litter layer should not be swept and burnt. It should be left as it is for improved nutrient cycling.

In homegardens with a high tree density, it is more worthwhile to manage below-ground competition by shoot and root-pruning. Pruning of lateral roots could redirect root function and be a powerful tool for improving spatial complementarity, provided that there are adequate resources at depth (Ong *et al.*, 2002). Thus, root activity patterns of tree crops appear to be sufficiently flexible to allow for subsoil resource use (Lehmann, 2003). However, the downward displacement of functional tree roots following root-pruning must not be allowed to affect their safety-net role in the interception of nutrients leaching from the zone of crop rooting and the long-term hydrological implications must not be ignored when attempting to meet demand for trees and their products (Ong *et al.*, 2002).

Strategies have been proposed for reducing the applied N losses from the cropping systems with trees, including the development of site- and species-specific fertilizer recommendations, closer tree spacing and the encouragement of lateral and vertical tree root development (Schroth *et al.*, 1999). A similar principle applies to mineralized soil N in the topsoil, which also shows leaching to the subsoil. Schroth *et al.* (2001b) reported that exploration of the soil volume by crop roots should be maximized, if the uptake of the mineralized N by the crops is to be increased and thereby nitrate leaching is to be reduced.

Simulations with the WaNuLCAS model to explore the concepts of a 'safety-net' for mobile nutrients by deep rooted plants suggested a limited but real opportunity to intercept nutrients on their way out of the system and thus increase nutrient use-efficiency at the system level (Van Noordwijk and Cadisch, 2002). The impacts of rhizosphere modification to mobilize nutrients in mixed-species systems were shown to depend on the degree of synlocation of roots of the various plant components, as well as on the long-term replenishment of the nutrient resources accessed. The concepts and tools to help farmers navigate between the access and excess problems in plant nutrition certainly exist, but their use requires an appreciation of the site-specific interactions and various levels of internal regulation, rather than a reliance alone on genetic modification of plants aimed at transferring specific mechanisms out of context.

Conclusions

Studying the nutrient cycling of tropical homegardens certainly helps improve their products and services rendered to the inhabitants while sustaining the system. It is apparent that advanced tracer techniques should be explored to study more precisely the nutrient cycling of the homegardens. In designing homegardens, for example on degraded lands, it is important to maintain plant structural diversity for an efficient nutrient cycling. Plant density should be increased in the farming area of the homegardens with suitable trees having deep and distant root activities for a better safety-net role and nutrient cycling. In addition, cover crops should be grown in appropriate areas of the homegardens for reducing topsoil nutrient leaching. Soil surface litter layer should not be disturbed, if an improved nutrient cycling is to be maintained. Agronomic practices such as root pruning, fertilizer and manure applications etc. should be optimized for an enhanced productivity with a least depletion of the system. The knowledge gained through the studies conducted in the tropical homegardens can be applied to improve the functioning and productivity of other agroforestry systems.

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