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Review

Soil Improvement by Trees and Crop Production under Tropical Agroforestry Systems: A Review

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Abstract

The expansion and intensification of the world's agricultural lands poses the challenge on how to produce enough food without jeopardizing the state of the natural environment. This is especially true in tropical regions, where population growth rates are the highest in the world. At the same time, soils which are less suitable for agricultural production are relatively more abundant and the chemical inputs needed for high productivity are often in scarce supply in remote areas and beyond the economic grasp of smallholder farmers. To address the mentioned problems or challenges different options exists among which agroforestry; agriculture with tree is one. Trees can potentially improve soils through numerous processes including maintenance or increase of SOM, biological N_2 fixation, uptake of nutrients from below the reach of crop roots, increased water infiltration and storage, reduced loss of nutrients by erosion and leaching, improved soil physical properties, reduced soil acidity and improved soil biological activity. Thus the purpose of this paper is to discuss on how trees improve the physico-chemical and biological soil conditions and the resulting site amelioration effect on crop productions of the tropics focusing on empirical researches conducted.

Keywords: Agroforestry, Biological N fixation, Fertilizer trees, inorganic fertilizers, Land Equivalent Ratio (LER), Soil Organic Mater, Soil properties

INTRODUCTION

With a projected human population growth of 50 percent by the year 2050 the world food demand is expected to be more than doubled (Green *et al*., 2005). Increasing world population requires that agricultural production increase so as to keep up with basic food needs. This indicates that the demand from agricultural areas will increase enormously over the coming years (Tilman *et al.,* 2002). The expansion and intensification of the world's agricultural lands poses the challenge on how to produce enough food without jeopardizing the state of the natural environment. This is especially true in tropical regions, where population growth rates are the highest in the world. At the same time, soils which are less suitable for agricultural production are relatively more abundant in tropical regions compared to the temperate zone, while the chemical inputs needed for high productivity are often in scarce supply in remote areas and beyond the economic grasp of smallholder farmers (Smithson and Giller, 2002). But to address the mentioned problems or challenges different options exists among which agroforestry, agriculture with tree is one.

Agroforestry as alternative land management system addresses many of the global challenges, including deforestation, unsustainable cropping practices, loss of biodiversity, increased risk of climate change, as well as rising hunger, poverty and malnutrition, which have been highlighted by the United Nations Millennium Development Goals (MDGs)(Garrity, 2004).

For this reason, various agroforestry practices are finding enormous application in many tropical regions and are lifting many out of poverty and mitigating declining agricultural productivity and natural resources. Notable examples are: fertilizer trees that when integrated with inorganic fertilizers can double or triple crops yields in degraded lands, fodder trees that can be used in smallholder zero-grazing systems in ways that supplement or substitute commercial feeds, improved varieties of temperate and tropical fruits that can be used to supplement household incomes and nutrition, medicinal trees that are utilized on farm and conserved in-situ, and fast-growing timber and fuel wood trees that can be grown in various niches within the farm and in commercial woodlots and plantations (Bashir Jama *et al*., 2006).

Applying chemical or inorganic fertilizers on depleted lands may be one of the quickest ways of restoring or maintaining productivity. However, it is difficult to use this approach in the case of marginal upland farms (Gholz, 1987). First, there is a need to replace not only the nutrients but also the soil lost through erosion. Inorganic fertilizers can add nutrients but cannot contribute to soil formation, unlike fallow vegetation or scattered trees on farmlands, for example, which can accumulate organic matter from litter by as much as 5 to 7 tons per year (Sharma, 2005). Second, as mentioned above, the high cost of chemical fertilizers, relative to the farmers' 2eager income, is prohibitive. Since most farmers have little or no cash incomes, this type of input is out of question for most (Gholz, 1987). For these reasons, the greatest hope for regaining or maintaining productive capacity rests upon low cost biological approaches such as the use of forest fallows or introducing nitrogen fixing trees (Sharma, 2005). Trees can potentially improve soils through numerous processes including maintenance or increase of SOM, biological N_2 fixation, uptake of nutrients from below the reach of crop roots, increased water infiltration and storage, reduced loss of nutrients by erosion and leaching, improved soil physical properties, reduced soil acidity and improved soil biological activity (Young, 1997)

Most importantly, trees can influence both the supply and availability of nutrients in the soil. Trees increase the supply of nutrients within the rooting zone of crops through: input of N by biological N_2 fixation, retrieval of nutrients from below the rooting zone of crops and reduction in nutrient losses from processes such as leaching and erosion. Trees can increase the availability of nutrients through increased release of nutrients from soil organic matter (SOM) and recycled organic residues (Buresh and Tian 1998). However, some agroforestry trees have the potential to provide N in quantities sufficient to support moderate crop yields through N inputs from biological N_2 fixation and retrieval of nitrate from deep soil layers and cycling of N from plant residues and manures. The cycling of P from organic materials is normally insufficient to meet the P requirements of crops. Hence, sustained crop production with agroforestry on P-deficient soils will typically require external P inputs (Buresh and Tian 1998).

Agroforestry, as productive system, combines nutrient and soil conserving trees and soil forming as well as soil improving perennials with food crops, and therefore possesses the potential for achieving the desired sustainability in managed areas of the tropics (Gholz, 1987). Hence, the aim of this paper is to discuss on how trees improve the physico-chemical and biological soil conditions and the resulting site amelioration effect on crop productions of the tropics focusing on empirical researches conducted all over the tropics.

Soil improvement by Trees

Trees affect soil properties through several pathways (Buresh and Tian 1998; Rhoades, 1997). Trees alter inputs to the soil system by increasing capture of wet fall and dry fall and by adding to soil N via N_2 fixation. They affect the morphology and chemical conditions of the soil as a result of the characteristics of above and belowground litter inputs. The chemical and physical nature of leaf, bark, branch and roots alter decomposition and nutrient availability via controls on soil water and the soil fauna involved in litter breakdown. Extensive lateral root systems scavenge soil nutrients and redistribute them beneath tree canopies. In general, trees represent both conduits through which nutrients cycle and sites for the accumulation of nutrients within a landscape (Rhoades, 1997). Hence, the next sections focus on empirical researches conducted all over the world on how the soil physico-chemical and biological condition is modified due to the presence of trees.

Soil Physico-chemical Properties

Hailu *et al.* (2000) carried a research on the impact of *Millettia ferruginea* on soil fertility in southern Ethiopia. The authors found that significantly higher ($P < 0.000$ to $P < 0.015$) level of surface soil P, organic C, exchangeable base forming cations and cation exchange capacity under the trees than in the open field. They also found nutrient levels that declined with depth and increasing distances from the tree trunk. However, soil pH values did not show significant horizontal or vertical variations. Similar results were also found for *F. albida, karate, Gliricida and B. eagyptica*. Poschen (1986) found enhanced fertility status of the soil and improved physical conditions under *F. albida* while Hadgu *et al.* (2009) found increased soil fertility when field locations were closer to a *F. albida* trunk in *F. albida* alone and *F. albida* + livestock land use systems. Besides, Boffa *et al.* (2000) observed richer top soils (0–20 cm) in terms of organic carbon and potassium around karité crowns than in open control field. Reyes *et al.* (2009) also observed improved soil nitrogen and organic matter content under *Gliricidia sepium* over the levels found in natural forest. In another study, Hailemariam Kassa *et al.*, (2010) investigated soil properties on farm fields (at Limat, Goblel and Korbebite and Endakeshe), where *B. aegyptiaca* are traditionally retained. Their results of the Limat site indicated that percent clay and available P were significantly higher ($p < 0.05$) under the canopy than further away from the canopy while there was significantly lower ($p < 0.05$) % silt at under the canopy than away from the canopy. While their pH result at Goblel and Korbebite sites was significantly lower ($p < 0.05$) under the canopy and near the tree than away from the canopy, exchangeable Ca, exchangeable K, organic carbon, cation exchange capacity (CEC) and electrical conductivity (EC) were non-significant among the three zones at the sites. Whereas mean moisture levels of all sites under the canopy (14.36%) were significantly ($p < 0.05$) lower than away from the canopy (16.32%).

Kamara and Haque(1992) studied *F. albida* and its effects on Ethiopian highland Vertisols. From their studies on the lateral and vertical influence of the tree canopy on some physical and chemical properties of the soil, they found apparent higher organic matter on the West side of the tree than the East due to accumulated windblown litter by prevalent wind direction, and organic matter, N, P and K levels were higher under the tree canopy than outside for all directions and depths studied. However, soil pH, exchangeable Na, Ca and Mg under the canopy and outside were similar, available water capacity was 1.5 to 2 times more under than outside the tree. Besides, noticeable increases in the silt fraction under the tree were recorded which they discussed in relation to soil condition improvement and plant growth.

In line Pandey *et al*., (2000) studied the influence of three tree canopy positions, viz. mid canopy, canopy edge and canopy gap, of *Acacia nilotica* (≥ 12 years) on texture, organic C, total and mineral N and P, and soil pH, in 0 to 10, 10 to 20 and 20 to 30 cm depth of the soil at ten sites in a traditional agroforestry system. The authors results showed that sand particles declined by 10% and 9% whereas clay particles increased by 14% and 10% under mid canopy and canopy edge, respectively, compared to that under canopy gap. Clay particles did not decline significantly with soil depth under all canopy positions and proportion of silt particles was not influenced by the canopy position. Besides, soil organic C, total N, total P, mineral N (NO_3 –N and NH_4 + N) and P were greater under mid canopy and canopy edge positions compared to canopy gap. They found maximum Soil organic C and N pool sizes in 0 to 10 cm and declined with the depth of soil. However, total and mineral P contents were nearly uniform across the depths, C/N ratio tended to increase with the soil depth whereas C/P ratio declined.

In similar but another study Aweto and Dikinya (2003) evaluated the effects of two tree species, *Combretum apiculatum* and *Peltophorum africanum*, on the soil under their canopies in semi-arid traditional grazing land in south eastern Botswana. The authors found lower bulk density and higher total porosity in the 0–10 cm layer of soil under the tree canopies than in the open savanna. Similarly, soil organic carbon, exchangeable potassium, calcium and magnesium and cation exchange capacity were higher in soil under the tree canopies, mainly due to the effects of litter accumulation under the tree canopies. Mean organic carbon levels under the canopies of *Peltophorum* and *Combretum* were 47% and 55% higher than in the open grassland. Exchangeable K, Mg, Ca and CEC were 66%–106% higher than their respective levels in the open grassland. The effects of the two tree species on soil nutrients were similar. From their results they inferred that it is ecologically unwise to completely eliminate trees from rangeland ecosystems, as they help to maintain soil fertility and the long-term sustainability of traditional rangeland ecosystems, which do not depend on the input of fertilizers, would seem ultimately to depend on the retention of trees.

A similar study conducted by Jiregna Gindaba *et al.* (2005) investigated leaf nutrient content, root biomass and the contribution of trees on farms to soil fertility parameters in Badessa area, eastern Ethiopia. Their results showed that leaves of *C. macrostachyus* had 20% higher P and 25% lower K contents than those of *C. africana* while having comparable leaf N content. Both species did not affect soil organic C, pH and cation exchange capacity. Surface and subsurface soils under tree canopies had 22–26 and 12–17% higher N, respectively, than the corresponding soils away from tree canopies. Surface soil available P under tree canopies was 34–50% higher than the corresponding soil away from canopies. Available P content of subsurface soil was improved only under *C. africana* canopy. The available P of surface soil under *C. macrostachyus* canopy was more than double that for *C. africana*. Trees of both species increased underneath surface and subsurface exchangeable K by 18–46% compared with the corresponding controls. From the results they come to a conclusion that *C. macrostachyus* and *C. africana* trees on farms keep soil nutrient high via protection against leaching, translocation of nutrients from deeper to the surface layer and accumulation of litter, which create a temporary nutrient pool in the surface soils under their canopies. Similar results were also established under alley cropping agroforestry systems.

Similarly, Fadl and El sheikh (2010) conducted two field trials under rain fed conditions at El-Obeid Research Farm and Eldemokeya Forest Reserve North Kordofan State, Sudan. The amount of sand and silt was higher under intercropping in both Eldemokeya and El-Obeid sites. Nitrogen, phosphorus and organic carbon were higher under *A. Senegal* agroforestry system at Eldemokeya trial. The effect of intercropping on soil N, P and pH was not significantly different at El-Obeid. In general, their results indicate that soil properties were higher under agroforestry systems compared to the sole cropping systems. The levels of all of the chemical properties in both sites except K and soil pH were slightly higher under the intercropping systems in the uppermost soil layer (0–0.02 m). The soil water contents at the different depths were significantly affected by the cropping system at both sites. The highest soil water content (18.6 mm) in the different soil layers in El-Obeid trial sites was found under sole cropping system, while the lowest soil water content (9.3 mm) was found under the intercropping system. Generally, soil water content increased by 50% with increase in soil depth. The higher sand and silt contents under the intercropping systems could be attributed to the dense tree cover and the shelter they provided to soil from wind erosion. Nitrogen and phosphorus were higher under the intercropping systems of groundnut, sesame and roselle with *A. senegal.* The higher soil nitrogen content under the intercropping systems could be attributed to a direct N input from tree to soil due to litter mineralization. There were slightly higher OC levels in intercropping system at El-Obeid, while the level of P, OC and N were higher under intercropping at the Eldemokeya trial site. This could be attributed to their dense vegetation cover. Conversely, the lower OC content under the sole cropping systems may be attributed to scant vegetation and continuous cropping with subsequent removal of plant residues. In another intercropping, Chamshama *et al.* (1998) examined the effect of *Leucaena leucocephala* and *F. albida* on soil nitrogen status. The authors observed higher total N and inorganic N (NO_3-N plus NH4+–N) under *F. albida* and lowest *under L. leucocephala*. Similarly, higher foliar N concentration in maize plots intercropped with *F. albida* and least in *L. leucocephala* intercropping. Inline, Fadl (2010) investigated soil physical and chemical properties under *A. senegal* agroforestry system in comparison with sole cropping system in western Sudan at El-Obeid Research Farm and El-demokeya Forest Reserve, North Kordofan State. The author obtained significant differences (P 0.05) for sand and silt content on both sites, while clay content was not significantly different on both sites. The nitrogen (N) and organic carbon were significantly (P 0.05) higher in the intercropping system in Eldemokeya Forest Reserve compared with sole cropping. However, soil organic carbon, N and pH were not significant on El-Obeid site, the level of organic carbon, N, P and pH was higher in the intercropping system. While from their assessment on soil fertility in intercropping of maize with *A. albida* for 5 years Jama and Amare Getahun (1991) found Soil fertility levels remained unchanged during the experimental period relative to the initial status, and differences between the intercropped *A. albida* plots and the tree or crop only control appeared not to be significant.

From their study on farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia, Zebene Asfaw and Agren (2007) found high concentration of Na in the topsoil, and significant variations in the analysed soil nutrients between the tree species in different sites. Zebene Asfaw and Agren (2007) observed significantly higher concentration of P under Millettia and Cordia than under Red gum in one site while at another site, concentrations of available P under Cordia were nearly two-fold, and four and half-fold greater than under Millettia and Red gum, respectively. At one site, total N under Red gum was 14% and 24% lower than under Cordia and Millettia, respectively. In contrast, organic C content under Red gum was 11.6% greater than under Millettia and 23.8% greater than under Cordia. The pH under Millettia and Cordia were significantly higher than concentrations under Red gum at one site. Topsoil under Millettia and Cordia also had significantly higher levels of exchangeable Ca and Mg than Red gum

Raddad *et al.* (2006) investigated nutrient cycling in young *A. senegal* farming systems over a period of 4 years on Vertisol in the Blue Nile region, Sudan. Their results showed that soil organic carbon, N, P and K contents were not increased by agroforestry as compared to the initial levels. Besides, soil OC was not increased by agroforestry as compared to sole cropping. In addition there was no evidence that P increased in the topsoil as the agroforestry plantations aged. At a stocking density of 400 trees ha^{-1} (5 m *5 m spacing), *A. senegal* accumulated in its biomass a total of 18.0 kg ha^{-1} of N, 1.21 kg ha^{-1} of P, 7.8 kg ha^{-1} of K and 972 kg ha^{-1} OC. Hence they inferred that agroforestry contributed ca. 217 and 1500 kg ha–1 of K and OC, respectively, to the top 25-cm of soil during the first four years of intercropping. Similarly, Budiadi *et al.* (2006) studied Biomass cycling and soil properties in an agroforestry based plantation system and found with increasing stand age, soil organic matter (SOM) accumulated in soil indicating that returned biomass was decomposing slowly while their content of primary nutrients did not change with stand age.

Bhojvaiw *et al.* (1996) conducted a green house pot trial to assess the impact of Prosopis afforestation on the productivity and fertility of degraded sodic soils in Haryana. The afforestation improved physical and chemical properties of surface soils by decreasing pH, electrical conductivity and exchangeable Na levels, and increasing infiltration capacity, organic C, total N, available P, and exchangeable Ca, Mg, and, K levels. The amelioration effect of the trees on top soil increased with duration of tree occupancy. Soil nutrient status under the 30-year-old plantation was higher than that of the non sodic farm soil. The reduced soil sodicity and improved fertility contributed to higher germination, survival, growth, and grain yield of wheat plants grown on the Prosopis chronosequence soils, even surpassing the yield attained on the farm soil in the case of 30 year-old plantation soil. Sodium accumulation in the crop declined while N, P, K, Ca, and Mg uptake increased with soil plantation age reflecting the changing nutrient status of the rooting zone due to afforestation. Results confirmed that successful tree plantation may restore the productivity and fertility of highly degraded sodic soils.

Kasongo *et al.* (2009) surveyed as well as compared a 17 year chronosequence of *Acacia auriculiformis* fallows on Arenosols of the Bateke Plateau (D.R. Congo) with virgin savannah soils to assess chemical soil fertility changes induced by these N-fixing trees. Significant increases in organic C content, total nitrogen content, cation exchange capacity and sum of base cations were found after relatively short fallow periods of only 4 years and did not only affect the forest floor, but extended to at least 50 cm depth. The Acacia act as a major source of organic matter (OM), hence increasing organic carbon and nitrogen content and decreasing the C/N ratio. The increased OM content suggests that humification processes are the main cause of the significant decrease in pH. Total exchangeable cations initially increased slowly but doubled (topsoil 0–25 cm) and tripled (subsoil 25–50 cm) after 10 years. The point of zero net proton charge was systematically lower than soil pH and decreased with increasing OM content, thereby increasing the cation exchange capacity, although concurrent acidification retarded a significant beneficial impact at field pH on Acacia fallows of 10 years and older. However, the chemical soil fertility improves steadily with time, after 8 years of Acacia fallow the absolute amounts of available nutrients are still small and they recommended slash and burn practices to liberate the nutrients stored in the remaining biomass and litter before each new cropping period.

Solomon *et al.* (2002) evaluated soil organic carbon (SOC) dynamics following deforestation and subsequent cultivation in the sub humid Ethiopia highlands. Total SOC declined by 55% (32.0 Mg ha^{-1}) at Wushwush and by 63% (40.2 Mg ha^{-1}) at Munesa following cultivation, while losses of N amounted to 52% (2.8 Mg ha^{-1}) and 60% (3.1 Mg ha^{-1}) at the two sites, respectively. 13C values of bulk soils of natural forests at Wushwush (24.3‰) and Munesa (23.4‰) were significantly lower than those from the corresponding cultivated fields (19.9‰, Wush-wush and15.5‰, Munesa).Deforestation and continuous cultivation at Wushwush and Munesa resulted in depletion of 80 and 96% of the initial forest-derived SOC in sand, while 73 and 85% of C3 SOC was lost from silt fraction of the two sites, respectively. These results suggest that SOC in sand was a very labile component of SOM and is a more sensitive indicator to changes in soil C storage in response to land use changes. However, the substantial amount of forest-derived SOC lost from silt indicates that SOM associated with silt was also quite susceptible to management changes, and that at least in the soils under study represents a moderately labile SOM pool, which is generally not the case in temperate soils. Forest-derived SOC in clay declined by 48 and 61% at Wushwush and Munesa, respectively, suggesting that clay retained C3 derived SOC more effectively and that SOM bound to clay was more stable than SOM associated with sand and silt fractions.

Bukhari (1998) studied tree-root influence on soil physical conditions at under three sites; a forest, a-two-year-old logged-over area and a-one-year-old abandoned farm. His results showed higher soil bulk density at the 60 to 90 cm layer in forest, low in logged over and intermediate in farm while soil moisture content varied in the reverse order. He also found the ameliorated soil texture, structure and fertility following tree felling.

Soil Biological Properties

Soil microbial biomass comprises about 1–5% of total organic carbon in soil. It acts as a source and sinks for the plant nutrients playing a crucial role in nutrient cycling and soil organic matter dynamics. It is the prime agent involved in plant residue decomposition, nutrient conservation and cycling processes in the soil (Smith and Paul 1990; Yadav *et al.* 2010). The microbial biomass has therefore been used as an index of soil fertility, which depends on nutrient fluxes (Hassink et al., 1991). An increase in the size of the soil microbial biomass is considered essential for the improvement of soil fertility. Plant cover through its effect on quantity and quality of organic matter inputs influences microbial biomass (Wardle 1992; Yadav *et al.* 2010). The biomass itself constitutes the part of soil organic matter and served its most dynamic pool (Yadav *et al.* 2010). Studies also show that enzyme activities are greater in agroforestry alley cropping practices due to differences in litter quantity and quality and, root exudates (Mungai *et al.* 2005). The organic matter subjected to microbial decay in soils comes from several sources. The fast growing woody perennials in agroforestry provide an almost permanent litter cover; the decomposing organic matter in the form of litter being replenished by freshly falling material.

Yadav *et al.* (2010) investigated the effect of traditionally grown trees (*P. cineraria, D.sissoo, A.leucophloea* and *A.nilotica*) on soil biological characteristics. Their results revealed significant and substantial improvement in soil biological activity in terms of microbial biomass C, N and P, dehydrogenase and alkaline phosphatase activity under different tree based agroforestry systems as compared to a no tree control (cropping alone). Soil microbial biomass C, N and P under agroforestry varied between 262–320, 32.1–42.4 and 11.6–15.6 µg g^{-1} soil, respectively, with corresponding microbial biomass C, N and P of 186, 23.2 and 8.4 µg g^{-1}soils under a no tree control. Fluxes of C, N and P through microbial biomass were also significantly higher in *P. cineraria* based land use system followed by *D. sissoo*, *A. leucophloea* and *A. nilotica* in comparison to a no tree control. The higher amount of microbial biomass C, N and P under *P. cineraria* might be due to greater microfungal biomass than under other multipurpose trees. From the calculated flux of C, N and P through microbial, they suggested that soil microorganisms are prime source of plant nutrients in the agroforestry systems. Similarly, from a study on seasonal variation of soil microorganisms underneath and outside the canopy of *Adesmia bedwellii* (Papilionaceae), Aguilera *et al*. (1999), found higher magnitude of Bacteria and fungi underneath shrub canopies in mid spring as compared to mid fall. Microorganism abundances were positively correlated with nitrogen levels and soil moisture.

From a studies on the effects of growing trees in combination with field crops on soil organic matter, microbial biomass C, basal respiration and dehydrogenase and alkaline phosphatase activities, Chander (1998) also observed higher organic C and total N, microbial biomass C, basal soil respiration and activities of dehydrogenase and alkaline phosphatase in treatments with tree-crop combination than in the treatment without trees. The results indicate that adoption of the agroforestry practices led to an improved organic matter status of the soil, which is also reflected in the increased nutrient pool and microbial activities necessary for long-term productivity of the soil.

In monthly monitoring of the population dynamics of soil fauna, Adejuyigbe *et al*. (1993) found higher earthworm and microarthropod populations under planted woody fallows than under continuous cropping with a maize/cassava intercrop. The relatively low earthworm population under *L. leucocephala* can be attributed to relatively lower soil water content under *L. leucocephala*. Microarthropod populations were positively correlated with lignin content of the leaf litter in the natural fallow and planted fallow plots (Adejuyigbe *et al*., 1998; Buresh and Tian, 1998).

Tian *et al.* (1993) found that tree residues applied as soil mulch increased earthworm, termite and ant populations. Earthworm populations were inversely correlated with the lignin-to-N ratio of plant residues, and ant populations were positively related to N content of residues. Tian *et al.* (1993) integrated the C-to-N ratio, lignin content and polyphenol content of plant residues into a quality index. Ant density and decomposition of the residues correlated positively to the plant quality index, whereas termite population correlated negatively to the plant quality index.

In monoculture plots of four agroforestry tree species, *G. sepium, L. leucocephala, D. barteri and T. africana*, Badejo and Tian (1999) reported very low mite populations in all plots during the dry season (500 to 3000 m^{-2}), compared to those during the wet season (10, 000 to 30, 000 m^{-2}). Besides, Badejo and Tian (1999) observed highest mite population in Gliricidia plots (3 044 m^{-2}) for the dry season and Leucaena plots (30 240 m^{-2}) for the wet season. There were more taxonomic groups of mites under Leucaena than in the other agroforestry plots. Based on the density, diversity and complexity of the mite communities, they considered Leucaena to be better than other agroforestry species in encouraging the growth of mite populations.

In hedgerow intercropping, Kang *et al*. (1990) reported a higher number of earthworm casts with *Dactyladenia barteri, Alchornea cordifolia, G. sepium* and *L. leucocephala* than in the control with no trees. Hauser (1993) found that mean dry matter of earthworm casts was 117 Mg ha^{-1} yr^{-1} under a *L. leucocephala* hedgerow as compared to 28 Mg ha^{-1} yr^{-1} in control plots without trees. Increased microbial biomass was also found with hedgerow intercropping in southwest Nigeria (van der Meersch *et al*., 1993).

Araujo and López-Hernández (1999) examined earthworm communities in a natural savanna (NS) and in an AFS supplied with organic fertilizers. Their results revealed organic matter management of the savanna soils has strongly modified the earthworm populations in the studied AFS as compared with the original savanna soil. Earthworm density was found to be 1.6–4.8 times higher in the AFS than in the original savanna. The correlations among earthworm populations and soil parameters suggested that earthworms in AFS can be limited by the amounts of food (organic matter) present in the soil. Moisture, in turn, affects other parameters that are important for earthworm distribution. And their results emphasized the importance of appropriate organic matter management and the relevance of earthworms in such agroecosystems.

Crop Production under Agroforestry systems

The influence of canopy trees and shrubs on under storey plants is complex and context-dependent. Canopy plants can exert positive, negative or neutral effects on production, composition and diversity of under storey plant communities, depending on local environmental conditions and position in the landscape (Schade *et al*., 2003).

Bayala *et al.* (2002) tested millet production under pruned tree crowns of *Vitellaria paradoxa* (karité) and *Parkia biglobosa* (néré) in a parkland system in Burkina Faso. The results showed that tree crown pruning had significant effect on millet production with the highest millet grain yield (507 ± 49 kg ha^{-1} year $^{-1}$) and total dry matter (2033 ± 236 ha^{-1} year $^{-1}$). Bargali et al. (2009) also found similar results. After the removal of 10% of basal tree branches (in 12–28-yr-old trees) that ultimately resulted in the reduction of crown diameter of trees (0.81 to 3.77%), Bargali *et al.* (2009) found increased plant density (0.05 to 1%), effective tillers (1.19 to 5.8%) and grain yield (1.52 to 2.92%). Besides they also found decreased plant height (0.09 to 1.32%) over the unmanaged (without cutting the tree branches) condition.

In line Boffa *et al.* (2000) found higher sorghum grain production in karate parklands with trees of mean crown radii of 225 to 275 cm, average densities of 12 and 31 trees per ha than in areas without trees.

Reyes *et al.* (2009) conducted a study to find out how cardamom (*Elettaria cardamomum*) and black pepper (*Piper nigrum*), will produce under natural forest, *Grevillea robusta* and *Gliricidia sepium*. Results showed that cardamom produced better (5.5 times) with grevillea than in natural forest. In addition their Land Equivalent Ratios results for black pepper and cardamom showed that pepper intercropped with grevillea produced 3.9 times more than in monoculture whereas cardamom intercropped with grevillea and pepper produced 2.3 times more than in monoculture. Besides, Anthofer *et al.* (1998) from their investigation on the response of wheat (*Triticum aestivum*) to application of leaf prunings of nine agroforestry tree species both in a field trial and a pot trial found highest grain yield (248 g/m^2)of wheat treated with Gliricidia. Similar results were also evident from parkland systems. For instance, Poschen (1986) investigated the effects of the *A. albida* on farmlands on the yield of maize (*Zea mays*) and sorghum (*Sorghum bicolor*). A statistically significant increase in crops yields by 56% (76% for maize and 36% for sorghum) on average was found for the crops under the tree canopies compared to those away. Similar results were found on barley under *A. albida* based land use systems and Millettia trees. Hadgu *et al.* (2009) studied implications of changes in traditional *Faidherbia albida* based land use systems on productivity of barley in northern Ethiopia and found increased barley yield when field locations were closer to a *F. albida* trunk in *F. albida* alone and *F. albida* + livestock land use systems while Hailu *et al.* (2000) also found significantly better growth responses and higher dry matter yield of maize plants grown on soils collected from underneath Millettia as compared to the control ($P < 0.001$).

Fadl (2010) conducted a field experiment under rain fed conditions in western Sudan at El-Obeid Research Farm and El-demokeya Forest Reserve with main objective of investigating yield of groundnut (*Arachis hypogea*), sesame (*Sesamum indicum*) and roselle (*Hibiscus sabdariffa*) of an *Acacia senegal* agroforestry system in comparison with the sole cropping system. He found a significantly different and highest fresh weight in the intercropping system on both sites. Besides, he got significantly different dry weights for sesame and roselle on both sites, while groundnut was not significantly different. In line Gaafar *et al.* (2006) found increased gum production per unit area when sorghum was intercropped with trees in low or high density while Raddad *et al* (2006) observed significant positive relationship between second gum picking and the total gum yield. Moreover, Jama and Amare Getahun (1991) from their assessment of growth performance (height and diameter at breast height, DBH) of *A. albida* rotationally intercropped with maize (*Zea mays*) and green gram (*Phaseolus aureus*), for a 5 year period found higher mean height (140%) and DBH (24%) of intercropped *Acacia albida* than tree only controls by the fifth year. Similar results were also evident from Dhyani and Tripathi (1999). Dhyani and Tripathi (1999) analyzed tree growth, survival and crop yield under agrisilvicultural practices over a seven-year period on acid alfisol under rain fed conditions in India. The authors observed a positive effect of intercropping on height and diameter growth, crown width and timber volume in alder, albizia and cherry but no appreciable differences for these parameters were observed in mandarin between the two situations. Alder and albizia attained maximum growth and woody biomass followed by cherry and the minimum growth was recorded by mandarin. The better growth and timber volume in the ‘tree + crop’ situation was mainly due to the application of fertilizers and weeding.

Similarly, Mutanal *et al.* (2009) initiated a field experiment to know the effect of multipurpose tree species on soybean and safflower in black clayey soils under rain fed conditions at Dharwad. Field crop yield decreased as the trees advances in age. Soybean yields were significantly higher with *P. cineraria* and *A. indica* as compared to other tree species. Similar trends were observed in rabi yield of safflower. Growth of tree species was higher in *T. bellerica, C. pentandra, E. tereticornis* and *C. equisetifolia* as compared with other tree species. Economic analysis indicated that benefit cost ratio, net returns and internal rate of return were higher in Field crop + *P .cineraria* (2.27:1.00; Rs.5041.3/ha/yr; 124% respectively) as compared to other tree species.

Muthuri *et al.* (2005) conducted a study to test the hypothesis that deciduous (*Paulownia fortunei*) and semi deciduous (*Alnus acuminata*) trees are less competitive with crops than evergreen species (*Grevillea robusta*) due to their differing leafing phenology. From their results, the presence of trees affected maize growth and yield 2.5 years after planting to an extent which depended on tree species and location. A positive interaction between *A. acuminata* and maize was apparent at Thika, but growth was suppressed in the first two crop rows at Naro Moru. *G. robusta* reduced maize yield by 36% close to the tree rows at Thika, whereas yield reductions were negligible adjacent to *P. fortunei*. These findings suggest there is some complementarity of resource use between *A. acuminata* and maize at Thika, and neutral or competitive interactions between trees and crops in all other treatments.

Similarly, from their investigation of tree and crop growth, gum and crop yields, Raddad *et al* (2006) observed statistically non significant differences in sorghum and sesame yields between the intercropping and control treatments with mean values of 1.54 and 1.54 t ha^{-1} for sorghum grain and 0.36 and 0.42 t ha^{-1} for sesame seed in the mixed and monocrop plots, respectively. In another study Chamshama (1998) examined the effect of alley cropping of *Leucopenia leucocephala* and *Faidherbia albida* on wood biomass and maize grain yield. His results revealed, however, mulch biomass averaged 6.18 t ha^{-1} for *L. leucocephala* and 0.97 t ha^{-1} *F. albida* with corresponding wood production of 1.71 and 1.11 t ha^{-1}, there was no gain in maize grain yield due to the presence of *L. leucocephala* and *F. albida*. From his results Chamshama (1998) suggest that alley cropping in Gario is justified for wood production but not for increasing maize grain yield. Similarly, from field and pot experiment Hailemariam Kassa *et al.* (2010) found no significant sorghum yield improvement under *Balanites aegyptiaca* as compared to open area.

Semwal *et al.* (2002) evaluated crop productivity under differently lopped canopies of multipurpose trees in Central Himalaya, India. Wheat (*Triticum aestivum*), mustard (*Brassica campestris*) and lentil (*Lens esculenta*) were intercropped during winter season, and rice (*Oryza sativa*), foxtail millet (*Setaria italica*) and barnyard millet (*Echinochloa frumentacea*) during warm rainy season following traditional practices. There were no significant differences in grain and by product yields between no lopping and 25% lopping and between 75% and full lopping treatments in all crops, except lentil. For winter crops, grain yields in no lopping treatments were only 16 to 21% of the yields in full lopping treatments compared to 3 to 5% in rainy season crops. By product yields from winter crops in no lopping treatments were 29 to 32% of the full lopping treatments compared to 6 to 8% in rainy season crops. Their study showed that loss of crop yields may not be significant if 25% of branches are retained.

Ludwig *et al.* (2004) studied East African savanna herbaceous layer productivity and species composition around *Acacia tortilis* trees of three different age classes, as well as around dead trees and in open grassland patches. Species composition of the herbaceous layer under Acacia trees was completely different from the vegetation in open grassland. Also the vegetation under bushes of *A. tortilis* was different from both open grassland and the understorey of large trees. The main factor causing differences in species composition was probably nutrient availability because species compositions were similar for stands of similar soil nutrient concentrations even when light and water availability was different. Changes in species composition did not result in differences in aboveground biomass, which was remarkably similar under different sized trees and in open grassland. The only exception was around dead trees where herbaceous plant production was 60% higher than under living trees. The results suggest that herbaceous layer productivity did not increase under trees by a higher soil nutrient availability, probably because grass production was limited by competition for water. This was consistent with the high plant production around dead trees because when trees die, water competition disappears but the high soil nutrient availability remains. Hence, in addition to tree soil nutrient enrichment, belowground competition for water appears to be an important process regulating tree-grass interactions in semi-arid savanna. Besides, from a different study conducted by Bukhari (1998) on seedling establishment and natural thinning of *Acacia seyal* on clays of Central Sudan found low soil moisture content and high soil bulk density that reduced under canopy seedling survival. From the findings he suggest that canopy shading did not seem to affect seedling survival as tree seedlings and agricultural crops are not able to compete with the *A. seyal* trees for soil resources.

Bargali, *et al.* (2009) evaluated the effects of an age series (6–28 years old) of *Acacia nilotica* based traditional agroforestry system on different rice (*Oryza sativa*) crop parameters. They found that the maximum impact of the tree on the crop at 1 m distance from the tree trunk and an increase (4%) in grain yield under 6-yr-old tree. However, with increase in tree age, crown diameter and diameter at breast height (DBH), rice productivity reduced from 4.7% (under 9yr-old tree) to 28.8% (under 28-yr-old tree). Similarly, with increase in tree canopy size the plant density and effective tillers also reduced. Percent yield reduction showed significant positive correlation with tree age, crown diameter and DBH.

To investigate the effect of *A. senegal* on the performance and yield of groundnut (*Arachis hypogea*), sesame (*Sesamum indicum*) and roselle (*Hibiscus sabdariffa*) in an agroforestry system, Fadl and El Sheikh (2010) conducted two field trials under rain fed conditions at different sites. Using Land equivalent ratios (LER) and simple financial analyses of gross surpluses evaluate the productivity of the different treatments, Fadl and El Sheikh (2010) found significantly different ($P < 0.005$) fresh weight of groundnut, sesame and roselle. Higher fresh weights were found under the intercropping system than the sole cropping system. Dry weights were significantly greater for sesame and roselle in both sites, while that of groundnuts was not significantly different. In both sites, intercropping reduced the yield of sesame by 6 and 11% in the first season and 37 and 39% in the second season. The reduction in roselle yield was 19 and 28% in the first season and 15 and 8% in the second season. Yield reduction in groundnut was 35 and 17% in the first season and 35 and 11% in the second season. The combined analysis indicated that intercropping reduced groundnut yield by 26%, sesame by 21% and roselle by 20%. All the treatments gave LER of more than one: indicating the superiority of growing the field crops in intercropping over the sole cropping systems. The highest LER of (1.71) was obtained when roselle was intercropped with *A. senegal*, while the lowest LER (1.48) was obtained when groundnuts were inter-cropped with *A. senegal*. All the treatments gave positive net revenues, the highest being for intercropped roselle

(438 SDG/ha). The intercropping of sesame gave the second highest net revenue (387 SDG/ha), while the sole roselle gave the lowest net revenue (97 SDG/ha).

Selamyihun Kidanu *et al.* (2005) conducted an on-farm trial on Pellic Vertisol at Ginchi to determine the production potential of eucalypt boundaries and their effect on the productivity of adjacent crops of tef (*Eragrostis tef*) and wheat *Triticum sp*. They found significant depression of tef and wheat yields occurred over the first 12 m from the tree line: the reduction was 20 to 73% for tef and 20 to 51% for wheat, equivalent to yield losses of 4.4 to 26% and 4.5 to 10% per hectare respectively. Similarly, Hadgu et al (2009) observed a decreasing trend in barley yield as distance from a *F. albida* trunk decreased in *F. albida* + *Eucalyptus camaldulensis* land use system while Anthofer, Hanson and Jutzi (1998) reported adverse effects *of G. robusta, A. polyacantha, A. nilotica and E. abyssinica* on wheat seedlings with increased pruning loads probably due to immobilization processes or allelopathic effects. Similarly, Boffa et al (2000) studied field scale influence of karité (*Vitellaria paradoxa*) on sorghum production in the Sudan zone of Burkina Faso. Under tree crowns, plant height and grain yield were significantly lower, by a factor of 16% for grain yield, than elsewhere in transects. In addition, mean plant height, and mean biomass and grain production per area as well as per plant were higher at the outside edge of tree crowns than in the middle of the field. In line Gaafar *et al.* (2006) found similar results from of karkadeh (*Hibiscus sabdariffa*) and sorghum intercropped with *A.Senegal.* Yields of sorghum and karkadeh planted within trees of high density diminished by 44 and 55% compared to sole crops, respectively. Karkadeh appears to be more appropriate for intercropping with *A. senegal* than sorghum and particularly recommendable in combination with low tree density (Gaafar *et al*., 2006). In line Jama and Amare Getahun (1991) found declined crop yields and weed biomass under higher tree densities due to unexpected shade.

Pandey *et al.* (2001) studied relative influence of above and belowground competition on the growth and productivity of *Linum usitatissimum* in a *Leucaena leucocephala* based alley cropping system at a sub humid site in central India. Growth rate in Leucaena shrub, across the alley sizes, ranged from 5.6 to 11.8 g m^{-2} day^{-1}. Aboveground biomass and grain yield of the crop were reduced by 9 to 37% and 17 to 26%, respectively in crop + hedge treatment and 64 to 98% and 89 to 96%, respectively in crop + shrub treatment compared to that of sole crop. Comparing the two competition treatments (crop + hedge and crop + shrub neighbour) they observed that above-ground biomass was reduced to the maximum by 55 to 60%, growth rate by 42 to 55% and crop yield by 71 to 72% due to aboveground competition. Belowground competition was 3.6 times greater in 4 m compared to that in 8 m alley.

Intensity of competition ranged, across the alley sizes, from 0.10 to 0.37 in crop + hedge and from 0.64 to 0.77 in crop + shrub neighbour competition treatment.

Kessler (1992) investigated the influence of karitè (*Vitellaria paradoxa*) and nèrè (*Parkia biglobosa*) trees on sorghum production in Burkina Faso. According to his findings Sorghum grain yields under the karitè and the nèrè are reduced by an average of 50% and 70% respectively, in comparison with yields in the open field. And he speculated reduced light intensity, to a minimum of 20% under the nèrè canopy, is probably largely responsible for low sorghum production under the tree canopies. Similarly, Schade *etal* (2003) studied the influence of *Prosopis velutina* (mesquite) on understorey vegetation along a topographic gradient in the Sonoran Desert. Biomass of understorey vegetation was highest and species richness was lowest in the riparian zone. Canopies had a positive effect on biomass in both desert and terrace, and a negative effect on species richness in the terrace. Individual species distributions suggested interspecific variation in response to water vs. N availability; they strongly influence species composition at both patch and landscape position levels. Dhyani and Tripathi (1999) also observed crop yield reduction was with alder, mandarin and cherry as the distance from tree decreased, However, in albizia the proximity of tree did not reduce crop yield. Fadl (2010) also reported reduced groundnut, sesame and roselle yields by 26.3, 12 and 20.2%, respectively on two sites of intercropping systems. The reduction in yield in intercropping plots could be attributed to high tree density, which resulted in water and light competition between trees and the associated crops.

CONCLUSION

Agroforestry as alternative land management system addresses many of the global challenges. Hence, agroforestry practices are finding enormous application in many tropical regions and are lifting many out of poverty and mitigating declining agricultural productivity and natural resources. Trees can influence both the supply and availability of nutrients in the soil. Trees represent both conduits through which nutrients cycle and sites for the accumulation of nutrients. Trees improve soil chemical, physical and biological properties in terms of improved soil N and OM, percent clay, available P, higher total N and inorganic N (NO_3-N plus NH_4+–N), soil pH, OC, CEC and EC, mean moisture content, exchangeable K Na, Ca and Mg, available water capacity, declined sand particles, increased clay particles, SOC, total N, total P and mineral N (NO_3 – -N and NH4 + -N). The point of zero net proton, Soil organic C and N pool, total and mineral P, C/N, C/P, lower bulk density, higher total porosity and increasing infiltration capacity. Likewise, soil microbial biomass acts as a source and sinks for the plant nutrients playing a crucial role in nutrient cycling and SOM dynamics. It is the prime agent involved in plant residue decomposition, nutrient conservation and cycling processes in the soil. An increase in the size of the soil microbial biomass in terms of C, N and P, dehydrogenase, microbial biomass C, basal respiration and dehydrogenase and alkaline phosphatase activities, higher organic C and total N, basal soil respiration and activities of dehydrogenase and alkaline phosphatase activity, root exudates is considered essential for the improvement of soil fertility. Therefore, increased nutrient pool and microbial activities are necessary for long term productivity of the soil. Trees can exert positive, negative or neutral effects on production, composition and diversity of understorey plant communities, depending on local environmental conditions and position in the landscape. The amelioration effect of the trees on top soil increases with duration of tree occupancy. Hence, integration of trees in to farms is highly recommended.

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