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Review on the Mechanism of Soil Fertility Improvement as Influenced by Agroforestry Trees

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Abstract

Compiled information on the Mechanism of Soil Fertility Improvement as Influenced by Agroforestry trees in relation to soil fertility improvement through agroforestry systems, soil organic matter and organic carbon enhancement in agroforestry system, processes by which trees improve soils in agroforestry systems, agroforestry improves soil biota, role of trees root, agroforestry tree's litter quality and decomposition, agroforestry systems for Soil and Water Conservation, soil nutrient cycling in agroforestry system through availing the required information which in turn has an implication to the sustainability of the system. So, the aim of this review paper was to compile information on mechanism of soil fertility improvement as influenced by agroforestry trees. Agroforestry is considered to be more compatible with society's ecological and environmental goals than conventional agriculture. Thus, the tree based agriculture play an important role, not only in improving the productivity and overall returns from the system, but also protects the soil from further degradation and improve the quality of the soil across the profile layers. The integration of trees, agricultural crops, and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, and enhance soil biodiversity. Agroforestry trees also help in improving soil physical and biological properties. The mechanisms by which trees improve soil conditions include increased inputs (organic matter by litter and root residue decomposition, nitrogen through biological nitrogen fixation by nitrogen-fixing trees) and increased nutrient availability by nutrient uptake from below the reach of crop roots by deep-rooted trees. In order to use agroforestry systems as an important option for Socio-economic and environmental benefits; research, policy and practices will have to progress. Therefore, the governments and stakeholders should encourage agroforestry practices for improving the livelihoods of farming community and smoothly to tolerate soil degradation and the variable of climate change.

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Agroforestry, Soil biota, Soil fertility, Organic matter, Nutrient cycling, Agroforestry trees.

Introduction

The loss of soil through erosion that deteriorates soil fertility, moisture storage capacity, and soil structure contributed to reduced agricultural productivity (Bishaw, 2001). Nutrient replacement using mineral fertilizers is a limited option for many smallholder farming households. Continuous application of chemical fertilization leads to the decay of soil quality and fertility and might lead to the collection of heavy metals in plant tissues, affecting the fruit nutritional value and edibility (Farnia and Hasanpoor, 2015). Harmful effects of usage of such fertilizers include weakening of roots of plants, increase of disease incidence, soil acidification. Agroforestry which is a diversified land use systems not only help the farming community in providing assured income in the events of drought, but also protect the land from degradation and enhance the soil quality. Hence, implementing agroforestry systems in resource poor farming households is considered to mitigate soil nutrient mining (Gladwin *et al.,* 2002).

Agroforestry systems are often seen by farmers and practitioners as a way to diversify production, income and services (Abdulai *et al.,* 2018). Incorporation of trees in the croplands can help in maintaining the nutrient pool and enhance soil fertility both under sequential and simultaneous agroforestry. Tree and crop root systems play a crucial role in these interactions and are involved in most of belowground processes, which determine soil functions and, ultimately, a large set of ecosystem services. A better understanding of these processes at the interface between soil science and agroforestry, such as soil organic carbon sequestration or water infiltration (van Noordwijk *et al.,* 2018). Agroforestry has potential to improve soil fertility. This is mainly based on the increase of soil organic matter and biological nitrogen fixation by leguminous trees. Trees on farms also facilitate tighter nutrient cycling than monoculture systems, and enrich the soil with nutrients and organic matter, while improving soil structural properties (Lehmann *et al.,* 1998).

Integration of legume trees into agricultural systems, therefore, adds biologically fixed nitrogen and other agriculturally important nutrients to the soil in a way that complements the crops grown in association with the trees. These trees are also known to bring about changes in edaphic, micro-climatic, and other components of the ecosystem through bio recycling of mineral elements, environmental modifications, and changes in floral and faunal composition (Sumpam, 2009).There are numerous examples of traditional land-use practices that incorporate trees into agricultural crop fields on the same piece of land (Mosquera-Losada *et al.,* 2009). These trees have been either purposely planted or naturally grown on farmlands and left to stand to support agriculture by reducing nutrient losses from erosion and leaching, increasing nutrient inputs through nitrogen fixation, and increasing biological activities by providing biomass and suitable microclimate. Tree litter and pruning improve soil fertility not only through the release of nutrients in the soil by mineralization but by also adding soil organic matter. Further, agroforestry trees also help in improving soil physical and biological properties. Moreover, farmers revealed that these trees provide firewood, timber, medicine, bee forage, carving, and other benefits that are vital to the rural communities (Bekele-Tesemma, 2007).

Soils of semiarid tropical regions of the world are nearly exhausted of soil organic matter and fertility. This is primarily attributed to fast oxidation of organic matter, washing away of nutrient rich top soil with runoff water, poor recycling back of crop residues, continuous and intensive cultivation of crops without replenishment of nutrients through chemical fertilizers (Sharma, 2011). Among the solution recommended by scientists, practicing agroforestry system has a major role for the reduction of climate change impacts particularly total crop failure and, socioeconomic benefits, biodiversity conservation, soil fertility improvement, soil and water conservation, improving crop productivity. Duguma and Hager (2011) also explained despite superiority of agroforestry practices for livelihoods improvement, the practical limiting factors for implementation and expansion of these agroforestry practices is an essential point to be addressed. And also agroforestry system have been practiced by many farmers in different countries for many years by traditional and modern ways of cultivation. Many scholars have carried out different researches about mechanism of soil fertility improvement as influenced by agroforestry trees, even though it is not sufficient. However, very little compiled information is available to the stakeholders at different levels. So, the target of this review paper was to review and compile datum available with regards to the analysis of the mechanism of soil fertility improvement as influenced by agroforestry trees.

Definition and Classification of Agroforestry

Agroforestry has been defined in several ways due to its complexity and spatial specificity (Nair, 2007). Atangana *et al.,* (2013) defined the term as “the introduction, or deliberate retention, of trees on farms through either spatial or temporal arrangements. A definition widely used in the tropics is “Agroforestry is a farming system that integrates trees on farms to diversify and sustain production for increased social, economic, and environmental benefits” (Garrity, 2004). Specific or comprehensive definitions are necessary in order to develop a shared understanding of the term among researchers, policy makers and funding agencies. However, the absence of a universally accepted definition has not limited the development and wider acceptance of agroforestry practices (Nair, 2007).

Nair (1993) explained the characteristics of agroforestry systems at farm level as follows:

Agroforestry normally involves two or more species of plants (or plants and animals), at least one of which is a woody perennial;

An agroforestry system always has two or more outputs;

The cycle of an agroforestry system is always more than one year; and

Even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system

Beyond such definitions, it is necessary to categorize particular types of agroforestry, in order to understand the systems, and to provide a framework for synthesis and analysis (McAdam *et al.,* 2009). Agroforestry classification schemes have been developed based on several criteria such as discrete components of agroforestry (trees, crops and animals) and/or the spatial and temporal structure of system components and their functions. However, the schemes have been limited by lack of clarity and wider acceptance (Torquebiau, 2000).

Agroforestry Species: The Multipurpose Trees

The emergence of agroforestry as an important land-use activity has raised the issue of "agroforestry species," i.e., which species to use as well as what constitutes an agroforestry species (Nair, 1980). The term "agroforestry species" usually refers to woody species, and they have come to be known as "multipurpose trees" (MPTs) or "multipurpose trees and shrubs" (MPTS). Important woody perennial groups in agroforestry include fruit trees, fodder trees, timber, and fuel wood (Nair, 1993). They represent important groups of MPTs. It is incorrect, however, to assume that agroforestry species consist only of MPTs; indeed, the herbaceous species are equally important in agroforestry. Many of these species are conventional agricultural species. In the agroforestry context, multipurpose trees are understood as "those trees and shrubs which are deliberately kept and managed for more than one preferred use, product, and/or service; the retention or cultivation of these trees is usually economically but also sometimes ecologically motivated, in a multiple-output land-use system." Simply stated, the term "multipurpose" as applied to trees for agroforestry refers to their use for more than one service or production function in an agroforestry system (Wood and Burley, 1991). MPT can be said to be the most distinctive component of agroforestry, and the success of agroforestry as a viable land-use option depends on exploiting the potential of these multipurpose trees. Agroforestry trees that have received research attention and are therefore more widely known than others, as well as some lesser-known species that seem particularly promising (*Oduol et al.*, 1988).

Soil Fertility Improvement through Agroforestry Systems

The domestication of soil improving trees commonly known as multipurpose trees for enhancing soil productivity through a combination of selected trees and food crops on the same piece of a farm field is one of the reasons for practicing agroforestry (Kassa *et al.,* 2010). The roles that are considered as protective gives more emphasis to sustainability of the systems by the ecosystem services such as climate amelioration, reduction of loss of soil moisture, nitrogen fixation and soil fertility improvement, reducing wind and soil erosion, soil stabilization and conservation,, flood control, etc. (Raj and Lal, 2014). The research done by Asfaw and Agren (2007) stated that in southern Ethiopia *Cordia africana* has significantly more nutrients in the topsoil underneath its canopy, improves soil fertility, and soil and water conservation and soil quality, improves some soil properties under their canopy as compared to the adjacent open lands. Trees alter inputs to the soil system by increasing capture of wet fall and dry fall and by adding to soil N via N2 fixation. 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. (Gindaba *et al.,* 2005).

The integration of trees with crops is utilized by small farmers to improve subsistence agriculture (Bayala *et al.*, 2011). Isichei and Muoghalu, (1992) also reported that, soils under tree canopy have higher pH, organic carbon, Ca, Mg, K, total exchangeable bases and CEC than in open grassland. Kho *et al.*, (2001) found that the availability of N and P is more than 200% and 30% greater, respectively, under *A. albida* than in open areas. Shrubs and trees reduce wind velocity in semi-arid zones and increase deposition of top soil particles by trapping. The branches and leaves placed on crusted soil or hardpan areas are mixed in the top soil by termites and this improves soil structure. Tree-crop integration increases crop yields, and the presence of trees, leaves and crop residues on the soil increases soil fauna activity and nutrient cycling which in turn improves soil fertility (Schlecht *et al.*, 2006).

Both nitrogen and non-nitrogen fixing trees can also enhance soil physical, chemical and biological properties by adding significant amount of above and belowground organic matter and releasing and recycling nutrients in agroforestry systems (Jose *et al.*, 2004). Trees on farmlands have significant values for soil nutrient improvements either by preventing or mitigating soil erosion, in turn, reducing nutrient losses from the system (Bayala *et al.*, 2020) or by increasing the total content of nutrients in different studies on soil-plant-crop relation in agroforestry practices showed that selected trees and shrubs improve soil fertility which results in boosting crop yield. Nutrient storage and cycling by woody species might have a positive influence on the understory and annual crop through litter fall and decomposition, which, in turn, increases soil nutrient supply for the understory. On the other hand, (Anteneh, 2010) also indicated that the soil loss due to rill and inter-rill erosion is higher in open fields than agro-forested fields.

Availability of essential elements in agroforestry because of presence of trees is an indication of soil health and the soil's capacity for sustaining production and services (Jose *et al.*, 2004). Yengwe *et al.*, (2018) evaluated the nutritive potential of *Faidherbia albida* intercropped with maize in Zambia. They estimated that litter inputs from *F. albida* could supply more than 18 kg N ha^{-1} $year^{-1}$ and increase the microbial diversity and abundance. Litter decomposition, although being the major nutrient supply pathway, can be complemented by nutrient leaching from leaves and nutrient-enriched rainfall.

Limon *et al.*, (2018) compared nutrient leaching from leaves between three tree species, *Emblica officinalis, Sesbiana grandiflora and Moringa oleifera*. They measured higher leaching of NH4, K and PO4 from *S. grandiflora* and *M. oleifera* than from *E. officinalis*. Total soil nitrogen, soil organic carbon was influenced by the presence of *F. albida and C.africana* trees on farm field and decreased with increasing distance from the tree trunk (Abdella *et al.*, 2020). Integration of shade in coffee farming system created creditable promising in producing organic coffee as a result of organic soil improvement. Almost all the given soil parameters value increased significantly under the tree canopy than in the open area (Mohammed *et al.*, 2017).

Soil Organic Matter and Organic Carbon Enhancement in Agroforestry System

Essentially, soil organic matter consists of two parts: fully decomposed organic matter, or humus, that is already a part of the soil colloidal complex, and plant and microbial remains that are in various stages of decomposition, commonly called litter (Ford and Greenland, 1968). Since the most widely accepted estimation of soil organic matter is based on the determination of oxidizable organic carbon (Walkley-Black Method; % organic matter = % organic C * 1.724), studies on organic matter are invariably studies of organic carbon (Nair, 1993). One of the often-repeated advantages of agroforestry arises; trees and shrubs presence in the system help maintain soil organic matter through the provision of litter and root residues. As Young (1989) stated, soil organic matter is the prime mover from which stem many of the other soil improving processes. Woody perennials differ from herbaceous crops in the rate and time of addition of organic-materials, and in the nature of the materials added. Furthermore, trees provide far more woody and other lignified materials than herbaceous crops, which in turn, affects the rate of decomposition and humus formation (Nair, 1993)

Incorporation of trees in agroforestry enhances the soil OM by adding litter both above and belowground. As a result, SOC is one of the important indicators used in assessing soil health. Hoosbeek *et al.*, (2018) investigated how C, N and P stock as well as microbial respiration varied with distance from trees in silvo-pastoral systems composed of grazed open prairies with isolated trees.

They measured higher C and N stocks under the canopy and area receiving litter fall than in the open prairie. However, OM was found to be more labile under the canopy, indicating that leaf litter deposition improves soil fertility, but most likely not the long-term SOC storage in those systems. Dhaliwal *et al.*, (2018) found that the SOC levels in both aggregate types were greater under the poplar based and guava-based agroforestry systems than under the sole crop. These papers illustrate that land use type as well as agroforestry system design influence SOC storage efficiency. Carbon storage in agroforestry systems is not only an important indicator of soil health, but also a mechanism for climate change mitigation. Priano *et al.*, (2018) found that SOC was greater under systems containing trees than under pasture.

Agroforestry improves soil biota

The biota are considered critical to soil health and ecosystem sustainability because of their role in decomposition of soil OM, nutrient cycling, and thereby influencing soil chemical and physical properties, which will ultimately determine soil fertility and long-term sustainability(Dollinger, 2019). In recent years, a number of papers have examined soil biota within the context of agroforestry and the trend continues. AMF diversity can be affected by agroforestry system design, as evidenced by Shukla *et al.,* (2018), which showed the influence of shade on the efficiency of bio inoculants composed of rhizobacteria, phosphate solubilizing bacteria and AMF.

They found that the efficiency of the bio inoculants was comparable in full sun and under shade for *Glycine max, Phaseolus mungo*, and *Cicer arietinul* and more beneficial for *Vigna radiata* and *Pisum sativum*. However, they observed less successful nodulation under shade than in full sun. In addition to the effect of land use, management practices such as pesticide application can also greatly affect microbial communities and thereby nutrient turnover and speciation in agroforestry systems as revealed by Afolabi and Muoghalu (2018).

Agroforestry can sustain a rich microbial diversity that is essential to soil health and productivity. Dobo *et al.,* (2018) compared the AMF diversity and spore density between nine agroforestry systems based on either *Cordia, Millettia or Erythrina* associated with coffee or Ensete. They found a slight effect of the system design on both density and diversity of AMF, with tree-Ensete having greater AMF diversity and density than tree-coffee and multiple species cropping systems.

Microbial community dynamics are also exploited for commercial products in certain agroforestry practices like forest farming. Torres-Go´mez *et al.,* (2018) compared the diversity and production of wild edible fungi between a native oak-pine forest and a *Cupressus lusitanica* (non-ectomycorrhizal species) plantation intermingled with ectomycorrhizal trees. They concluded that inter planting with ectomycorrhizal trees could potentially improve ecosystem processes such as nutrient cycling, soil forming, and decomposition of litter in non-ectomycorrhizal plantations. In general, it is safe to say that a greater diversity of species is more favorable, as it results in a more complete occupation of space above and below the soil, and the variation in the characteristics of the litter produced can maintain a greater level of soil biodiversity, with positive effects on fertility.

Agroforestry Systems for Soil and Water Conservation

AF has a potential for erosion control through the soil cover provided by tree canopy and litter, in addition to the role of trees in relation to the runoff-barrier function (Nair, 1993). The role of trees and shrubs in erosion control could be direct or supplementary. In direct use, the trees are themselves the means of checking runoff and soil loss. In supplementary use, control is achieved primarily by other means (grass strips, ditch and-bank structures, and terraces); the trees serve to stabilize the structures and to make productive use of the land, which they occupy. (Nair, 1993) and (Young, 1989) supported that leguminous trees have shown potential of reducing soil erosion through five principal ways: interception of rainfall impact by tree canopy, surface runoff impediment by tree stems, soil surface cover by litter mulch, promotion of water infiltration, and formation of erosion resistant soil structure. Udawatta *et al.,* (2002) reported that AF and contour strip had a combined significant effect on runoff, sediment, and nutrient loss reduction as compared with non-AF treatments. Anteneh (2010) also indicated that the soil loss due to rill and inter-rill erosion is higher in open fields than agro-forested fields.

Agroforestry and other tree based systems increase soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years, maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems (Orindi and Murray, 2005). Through the reduction of wind speed through trees, wind-erosion will be decreased, which indirectly will have its beneficial impact on the farm economy (Leakey, 2010).

Moreover, the hydrology of the system is well maintained and enhanced by reduced evapo-transpiration due to its canopy structure and pumping effect of trees (Bogale, 2007). Study on Gedeo indigenous agroforestry practices demonstrated the ability of trees and shrubs, apart from optimizing the yields of diverse crop/tree species, regularly replenish soil fertility and productivity through continuous supply of organic matter and through protection from erosion and leaching (Yadessa, 2006). Although much of the landscape of Gedeo is very steeply sloped, incidences of runoff and erosion are minimal because of the intact vegetation cover (Bishaw *et al.,* 2013).

Soil Nutrient Cycling in Agroforestry System

Agroforestry and other tree-based systems are commonly credited with more efficient nutrient cycling (greater potential to improve soil fertility) than other systems because of the presence of woody perennials in the system and their suggested beneficial effects on the soil (Jordan, 1985). These woody perennials have more extensive and deeper root systems than herbaceous plants and thus have a potential to capture and recycle a larger amount of nutrients (Robertson, 2012). Golley (1986) cautioned, the ability to accumulate nutrients varies according to particular sites and soils, and this factor must be taken into account while selecting nutrient-conserving species for incorporation into agroforestry technologies. The deep root systems of trees may reach deeper soil horizons, which are not often attained by roots of common agricultural crops. The magnitude of this process, which is commonly - though erroneously - called nutrient pumping, is not known; it is believed to be a significant factor of soil fertility improvement in agroforestry systems. Gains from symbiotic N2-fixation by trees can be enhanced through tree-species selection and admixture and nitrogen addition through litter or prunings, which may result in an internal transfer within the system). Management practices that lead to improved organic matter status of the soil will lead inevitably to improved nutrient cycling and better soil productivity (Nair, 1993). In coffee and cacao plantations with shade trees, the return from litter and prunings is 100-300 kg N ha^{-1} yr^{-1}, which is much higher than the amount removed during harvest or derived from nitrogen fixation (Young, 1989).

The contribution of agroforestry trees to nutrient requirements of intercropped plants and the timing of nutrient transfer from the decomposition of the pruning residues to intercrops, uplift of deep subsoil nutrients by trees and the role of tree roots as a safety-net to reduce nutrient leaching (Tully *et al.*, 2012). Battie-Laclau *et al.*, (2020) studied the respective role of trees and herbaceous vegetation beneath trees in maintaining arbuscular mycorrhizal communities in temperate alley cropping agroforestry systems. They showed that roots of trees and associated herbaceous vegetation were extending several meters within the cropped alley in the topsoil, challenging the common view of a stratification and niche separation of tree and crop roots. Such intermingled root systems are an important feature for potential plant-plant interactions in agroforestry systems, e.g. facilitation processes through sharing common mycorrhizal communities and networks.

Such intermingled root systems are an important feature for potential plant-plant interactions in agroforestry systems, e.g. facilitation processes through sharing common mycorrhizal communities and networks. Studies on nutrient provision in agroforestry systems have mostly focused on tree litter decomposition and release of nutrients from pruning residues, in terms of amounts and use efficiency as well as on biological N2-fixation (Chikowo *et al.,* 2004). Sida *et al.,* (2020) designed an original trial to disentangle tree-crop-fertilizer interactions in several agroforestry systems in Ethiopia and Rwanda. They found that in parkland with the nitrogen-fixing tree species *Faidherbia albida* the addition of nitrogen. Moreover, the phosphorus use efficiency was doubled under the canopy of *Faidherbia albida*. The phenology of *Faidherbia albida* is unique as it sheds its leaves during the rainy season, and cattle usually graze under its canopy during the dry season, potentially bringing some nitrogen, but also phosphorus and potassium through their dejections.

Processes by which Trees Improve Soil in Agroforestry Systems

The mechanisms by which trees improve soil conditions include increased inputs (organic matter by litter and root residue decomposition, nitrogen through biological nitrogen fixation by nitrogen-fixing trees) and increased nutrient availability by nutrient uptake from below the reach of crop roots by deep-rooted trees. Furthermore, trees enhance soil quality by improving soil physical conditions, increasing soil biological activities and reducing soil fertility loss by controlling erosion and nutrient leaching (Zhu, 2020). Lee and Jose (2003) examined soils under pecan cotton alley cropping systems in Southern USA and found that soil organic matter and microbial biomass were higher in the alley cropping systems relative to monoculture cotton. Increased soil organic matter under trees plays many significant roles in soil fertility improvement including maintaining good soil physical properties such as higher water-holding capacity, permeability and aeration (Saxton and Rawls 2006). Soil organic matter also enhances soil chemical properties through protection of base cations from leaching, improvement of ion-exchange capacity and higher recycling and supply of nutrients (Jose, 2009).

Nitrogen fixation by trees and herbaceous legumes has long been a recognized way of overcoming soil nutrient depletion (Chianu *et al.,* 2011). Agroforestry systems with N fixing trees; such as intercropping and improved fallows, can add 46- 140 kg N ha $^{-1}$ y $^{-1}$ to the cropping system (Rosenstock *et al.,* 2014). Quantifying the amount of nitrogen fixed is constrained by factors including varied N_2 fixing status of different species, long and varied N assimilation pattern of trees, and logistic problems of dealing with older trees (Boddey *et al.,* 2000). Brinson *et al.,* (1980) has emphasized that the major recognized avenue for addition of organic matter to the soil from the trees standing on it was through litter fall, i.e., through dead and falling leaves, twigs branches and so on. The observations on the tendency of accumulation of organic carbon and nutrients in surface layer of soil, corroborates findings made by Sharma (2011) stating that the bulk of the organic matter and nutrients that are added or contributed by inclusion of tree species are mostly located in the top soil. The differential behavior of the land use systems in influencing the physico-chemical and biological properties and nutrient status in profile was very much evident. The above observation is in conformity with that recorded by Kellman (1979) stating that trees showed preferential enrichment of the soil below them in terms of Ca, Mg, K, Na, P and N.

The beneficial effects of trees on soil are: Additions to the soil (maintenance or increase of organic matter, Nitrogen fixation, Nutrient uptake, Atmospheric input, Exudation of growth-promoting substances into the rhizosphere), Reduction of losses from the soil(Protection from erosion, Enhanced nutrient-use efficiency), Maintenance or improvement of physical properties, Effect on chemical properties of the soil (Reduction of acidity, Reduction of salinity, Effects of shading) (Nair, 1993).The mechanisms leading to the improvement of soil fertility and overall chemical soil quality by virtue of adopting these land use systems could be i) Nutrient mining from subsurface layers and their efficient cycling, ii) Biological nitrogen fixation by tree legumes, iii) solubilization of difficultly available plant nutrients through the root exudates and acid secretions, and iv) Indirect effect of tree canopies in reducing the nutrient losses through runoff and sediments (Sharma, 2011).

Role of Trees Root

Roots of woody perennials change their own environment by accumulating dead root litter and redistributing nutrients. Roots are a component of primary productivity, although they are seldom considered in conventional plant productivity calculations (Nair, 1993). While the roots of annuals function on a seasonal basis, tree roots function all year round. Combining trees and crops increases rooting densities and reduces inter-root distances, which increases the likelihood of inter-plant competition (Young, 1989).Tree root systems are involved in some favorable effects on soils such as carbon enrichment in soil through root turnover, the interception of leached nutrients, or the physical improvement of compact soil layers. Trees have deep and spreading roots and hence are capable of taking up nutrients and water from deeper soil layers usually where herbaceous crop roots cannot reach. This process of taking up nutrients from deeper soil profile and eventually depositing on the surface layers through litter-fall and other mechanisms is referred to as 'nutrient pumping' by trees (Makumba *et al.,* 2009).

Mycorrhizal associations, that is, symbiotic associations between roots and soil fungi, are also important in soil-plant relationships. Mycorrhizae absorb carbohydrates from the host plant, and, in turn, function as an expanded root system which increases nutrient absorption.

When trees are introduced to a site for the first time, mycorrhizal inoculation, like *Rhizobium* inoculation, might be beneficial (Nair, 1993).The contribution of roots to soil organic matter, and thus to soil fertility, has not received serious attention. The ability of the root system to improve soil organic matter even where all above-ground biomass is removed, is a crucial factor in low-input agricultural systems with low productivity levels (Szott *et al.,* 1991). Ewel *et al.,* (1982), who compared root biomass with leaf biomass (not total above-ground biomass) for a range of land-use systems in Costa Rica, found that the total root biomass in agroforestry systems (cacao + *Cordea alliodora*, and coffee + *Erythrina)* was substantially higher than in sole crops of maize or sweet potato, and *Gmelina* plantation. Thus, available indications strongly suggest the potential for improvement of soil's organic matter content under agroforestry systems through root biomass.

Agroforestry Tree's Litter quality and decomposition

The term "litter quality" is commonly used in literature about organic matter decomposition to refer to nutrient content and comparative rate of decomposition of plant residues (Anderson and Swift, 1983). Plant litter that is high in nutrients, especially nitrogen, and is decomposed rapidly, is traditionally considered to be of high quality.

Table.1 Classification of agroforestry into six structural categories (adapted from Torquebiau (2000)).

Category	Characteristics
1. Crops under tree cover	scattered trees in cropland, shade trees in plantation crops, parklands, crops in orchards, plantation crops combinations
2. Agroforests	agroforestry home gardens, village forest gardens, mixed woodlots, agroforestry buffer zones
3.Agroforestry in a linear arrangement	windbreaks and shelterbelts, boundary planting, live hedges, living fences, soil conservation hedgerows, roadside planting,
4. Animal agroforestry	grazing in wooded or forested land, tree planting in rangeland, animal feeding with collected, browse, browse banks
5. Sequential agroforestry	shifting cultivation, tree-improved fallows
6.Minor agroforestry techniques	Sericulture, lac production, apiculture with trees, tree-based aquaculture

Table.2 Topsoil chemical properties on enset fields as influenced by upper storey *Cordia* and *Millettia* trees adapted from (Zebene, 2003)

Variable description	*Cordia Africana*		*Millettia ferrugenia*	
	Under canopy	Out side	Under canopy	Out side
total N%	0.34[a]	0.27[b]	0.35[a]	0.26[b]
Organic C%	3.35[a]	2.69[b]	2.67[a]	2.34[b]
pH (H2o)	7.01[a]	6.65[b]	6.55[a]	6.06b
available P PPM	15.42[a]	5.07[b]	9.03[a]	4.94[b]
CEC Meq/100gm	27.69[a]	22.78[b]	27.3[a]	23.09[a]

Fig.1 Schematic representation of nutrient relations and advantages of "ideal" agroforestry systems in comparison with common agricultural and forestry systems. Source: Nair (1984).

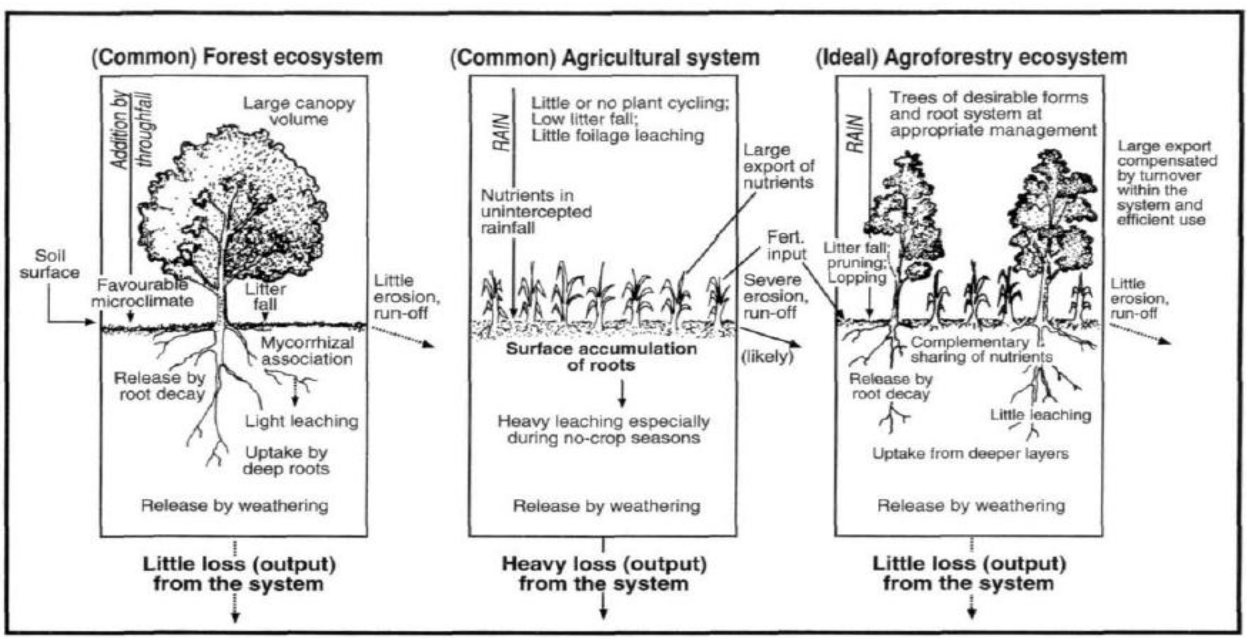
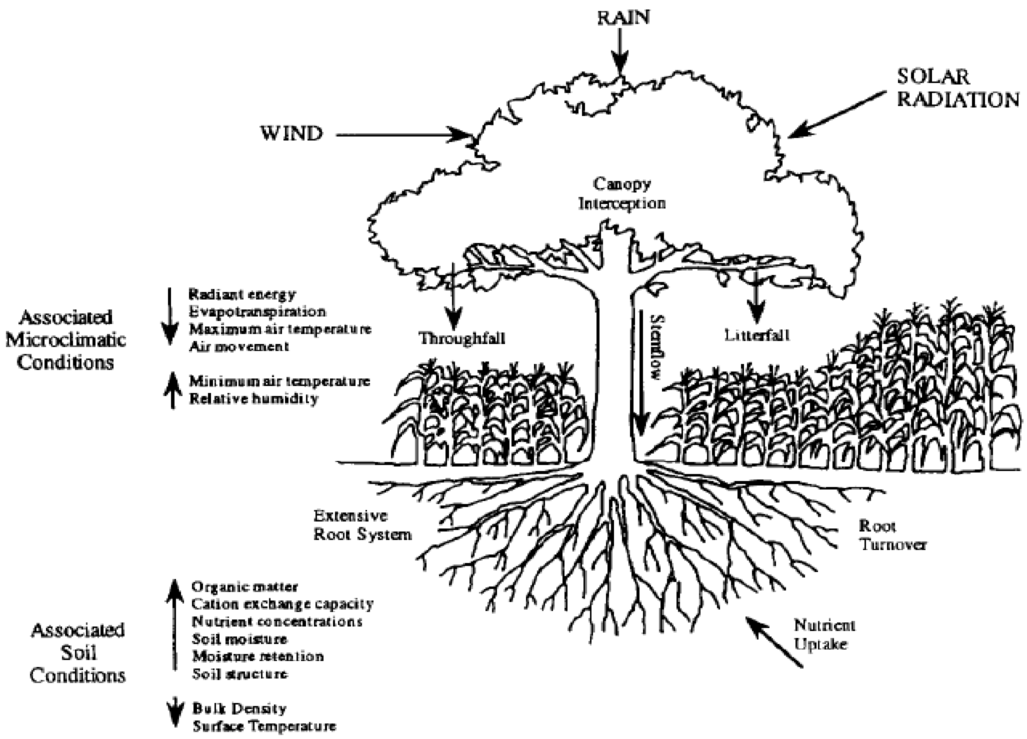


Fig.2 Factors influencing soil processes beneath single trees growing in agroforestry systems. Source: Farrell (1990)



Pruning, which consist mostly of leaf but also some woody tissues, of many of the woody perennials used in agroforestry systems, especially alley cropping, are generally high in nitrogen (Budelman, 1988). These pruning, when applied to the field, will result in increased available nitrogen levels for the associated crops. However, the rates of decomposition of the leaves vary widely. Mineralization of P, K, Ca, and Mg is faster from high-quality Erythrina leaves than from those of *Inga edulis* or *Cajanus cajan.* Approximately 40% of the initial P and Ca contents and 75% of Mg and K contents of Erythrina leaves were mineralized within four weeks (Palm and Sanchez, 1990). Mulches of species such as *Cassia siamea, Flemingia macrophylla* and *Dactyladenia* (syn. *Acioa) barteri* that are also commonly used in alley cropping are generally slow to decompose.

In some situations, providing a good ground cover for a longer period of time, for example to suppress weed growth or reduce moisture loss through evaporation from bare soil surface, may be more desirable than providing a quick supply of nitrogen. In such circumstances these slower-decomposing mulches are preferred (Young, 1989). Litter decomposition studies using the litter-bag technique are becoming a common element of investigations on soil fertility aspects of agroforestry (Nair, 1993). The information has very important management implications in deciding the schedule of hedgerow pruning. Depending on the decomposition characteristics of the plant litter, the timing of pruning can be adjusted to allow the most efficient use of the mulch (Jama, 1993). This is the concept of synchronization of nutrient release from plant residues. Thus, better synchrony and, hence nutrient use efficiency, can be accomplished through management decisions such as: selecting species with differing rates of litter decomposition; adjusting the timing of pruning to regulate the time of addition of the mulch; and modifying the method of application of the mulch (surface addition or soil incorporation) (Nair, 1993).

Recommendation

The introduction of tree and shrub nitrogen-fixing trees into cropping systems is the most straightforward approach to reduce the use of chemical fertilizers, improving the soil ecosystem and the livelihoods of smallholder farmers. Agroforestry which is a diversified land use systems not only help the farming community in providing assured income in the events of drought, but also protect the land from degradation and enhance the soil quality. The mechanisms by which trees improve soil conditions in agroforestry system include increased inputs (OM by litter and root residue decomposition, nitrogen through BNF by nitrogen-fixing trees) and increased nutrient availability by nutrient uptake from below the reach of crop roots by deep-rooted trees. AF has a potential for erosion control through the soil cover provided by tree canopy and litter, in addition to the role of trees in relation to the runoff-barrier function. Agroforestry and other tree-based systems are commonly credited with more efficient nutrient cycling (greater potential to improve soil fertility) than other systems because of the presence of woody perennials in the system and their suggested beneficial effects on the soil. Agroforestry can sustain a rich microbial diversity that is essential to soil health and productivity. A better understanding of the positive effects of trees on soils, and other benefits, is an important step towards increasing the use of trees on farms. Tree root systems are involved in some favorable effects on soils such as carbon enrichment in soil through root turnover, the interception of leached nutrients, or the physical improvement of compact soil layers.

In order to use agroforestry systems as an important option for Socio-economic and environmental benefits; research, policy and practices will have to progress towards: (i) effective communication with farmers in order to enhance the agroforestry practices with primacy to multifunctional values; (ii) maintenance of the traditional agroforestry systems and strategic creation of new systems; (iii) enhancing the size and diversity of agroforestry systems by selectively growing trees more useful for soil fertility improvement; (iii) and addressing the research needs and policy for linking knowledge to action. Generally, Agroforestry is an option for improving the livelihoods of smallholder farmers, environmental benefits and reduce the effects of soil degradation and climate related hazards associated with total crop failure.

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