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Evergreen Agriculture: Agroforestry for Food Security and Climate Change Resilience

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Abstract
This paper examines the role of agroforestry in food security and climate change resilience as a sustainable evergreen agriculture. Agroforestry technologies are ensuring food security and are lifting many out of poverty and mitigating declining agricultural productivity and natural resources. Remarkable 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 *insitu*, and fast-growing timber and fuel wood trees that can be grown in various niches within the farm and in commercial woodlots and plantations. The survey showed that about 88% of the respondents were attained food security through local purchasing from local market ranging from a month to six months depending on households. Agroforestry helped the households to attain food security as source of cash for all assessed households and as a source of food for 72% of the assessed households. Agricultural lands are believed to be a major potential sink and could absorb large quantities of C if trees are reintroduced to these systems and judiciously managed together with crops and/or animals. Thus, the importance of agroforestry as a land-use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. C storage data in some tropical agroforestry systems and to discuss the role they can play in reducing the concentration of CO_2 in the atmosphere. The C sequestration potential of agroforestry systems is estimated between 12 and 228Mgha^{-1} with a median value of 95Mgha^{-1}. Agroforestry interventions, because of their ability to provide economic and environmental benefits, are considered to be the best measures in making communities adapt and become resilient to the impacts of climate change. The important elements of agroforestry systems that can play a significant role in the adaptation to climate change include changes in the microclimate, protection through provision of permanent cover, opportunities for diversification of the agricultural systems, improving efficiency of use of soil, water and climatic resources, contribution to soil fertility improvement, reducing carbon emissions and increasing sequestration, and promoting gender equity.
Key words: agroforestry, food security, climate change, carbon sequestration, resilience, productivity

Introduction

Food insecurity, extreme poverty and environmental degradation nexus are the most challenging problems of developing countries. Land holdings and per capita food production are on the decline. Low and erratic rainfall and soil fertility depletion are fundamental biophysical limitations responsible for declining productivity. The lowest development indicators and the incidence of poverty is the highest with the majority of the population in the developing countries living below the poverty line. Droughts, conflicts, famine and food insecurity are common features of the developing countries (EARO 2000, Eyasu 2002). Promoting agroforestry is one option many perceive as a major opportunity to deal with problems related to land-use and CO_2-induced global warming. In this paper agroforestry is defined as any land-use system that involves the deliberate retention, introduction or mixture of trees or other woody perennials with agricultural crops, pastures and/or livestock to exploit the ecological and economic interactions of the different components (Lundgren, 1982; Nair, 1993; Young, 1997). Historical evidence showed that agroforestry has been widely practiced through the ages as a means of achieving agricultural sustainability and slowing the negative effects of agriculture such as soil degradation and desertification. Agroforestry as evergreen agriculture has enormous potentials to tackle food insecurity in one hand and climate change in other hand.

I. Agroforestry for food security and natural resource management

Agroforestry, defined as a land use system in which trees and shrubs are grown in association with crops or animals in the same land unit, has the potential to arrest land degradation and rural poverty in the developing country through its service and productive functions.

Service functions include soil fertility maintenance through erosion control and biological
Nitrogen fixation (BNF), watershed protection, maintains ecological stability, conservation of bio-diversity and carbon sequestration. Agroforestry has the potential to increase carbon sink capacity thereby contributing to climate change mitigation. **Productive functions**: high value fruits for income and nutrition security, supply

high quality fodder for livestock, wood for household energy, timber/poles for construction and income generation.

Indigenous agroforestry systems

In many parts of Africa, farmers traditionally practice agroforestry. Trees are planted in agricultural or silvopastoral systems to provide shade, windbreak, medicines, or to meet household energy needs. Traditional agro-forestry system takes the form of trees scattered on crop fields, woodlots, homestead tree planting and multi-storey home garden (Eyasu Elias 2002.

Trees on crop fields – parklands

Parkland is random scattering of trees in fields with crops grown understorey. The management of trees in this system requires pruning of branches and the tops to reduce shading. The trees provide valuable products such as fuelwood, charcoal, construction materials and fodder for livestock. In Ethiopia some tree species traditionally managed in this system include *Faidherbia albida, Acacia tortilis, Balanites aegyptiaca,* and *Acacia raddiana.* The service functions of trees include improving soil fertility, conserving soil moisture and improving micro-climate resulting in increased crop yields. Experiments conducted in Debre Zeit and Alemaya-Ethiopia showed that wheat and maize yields increased by over 50% under F. albida canopy (within 1.4 m radius) compared to those further away from the base of the tree (Dechasa Jiru 1989, EARO 2000).

Multi-storeyed home gardens

Tropical home gardens consist of an assemblage of multi-purpose trees and shrubs with annual and perennial crops and livestock within compounds of individual houses managed by family labour. The home gardens are characterized by high species diversity and usually 3-4 vertical canopy strata – tree layers upper storey, herbaceous layer near the ground and intermediate layers in between. The ensete-coffee-livestock tree system of southwestern Ethiopia represents a typical multistory home garden. The upper storey is dominated by broad-leaved trees (e.g., *Cordia, Croton, Millettia*) fruit crops (avocado, mango), the middle storey containing ensete, coffee and maize while vegetables, spices, herbs cover the lower canopies. This results in a continuous food production throughout the year.

Trees on soil conservation structures

Planting trees/shrubs on earth structures such as soil and stone bunds, terraces, raisers, etc combines soil conservation with production of various products such as fodder, fruit or fuelwood. This makes productive use of the land because trees would use the area along the structures where other crops cannot be grown. A wide range of species, both exotic and indigenous, are planted along terrace bunds by farmers (e.g. trees for fodder, timber or edible fruits). It is common to find *Leucaena sp, Grevillea, Faidherbia albida* and sometimes high value fruit trees (e.g. mango, citrus and papaya) planted on conservation bunds. The challenge to guard against is some of the species introduced for soil conservation are becoming weeds. An example of this is *Prosopsis juliflora* initially a very good fodder but has now become an ecological disaster in the arid and semi-arid lands of northern Kenya and Ethiopia (Sanchez and Jama 2000).

Soil conservation hedges

A contour hedge is a horizontal strip of multipurpose trees or shrubs that is used for soil erosion control on sloping lands. The hedges at the same time provide high quality fodder (e.g. *Leucaena* hedges), firewood, stakes for climbing beans and mulch material. Contour hedges control erosion by providing a physical barrier as well as through increased infiltration as a result of leaf litter layer creating good soil structure. Over the long-term, these hedges result in the formation of terraces on the upper side of each hedge. In many parts of Africa, fodder trees/shrubs (*Leucaena, Gliricidia, Calliandra*), fruit trees (mango, citrus, avocado) and timber trees (*Grevillea*) are also grown as upperstory in the contour hedges.

Woodlots

A woodlot is a small patch of land planted with trees to provide fuelwood, pole or timber products to rural communities as well as for purposes of environmental regeneration. Area closures and community woodlots are important community resources in Tigray. A study showed that nine out of ten villages have community woodlots and on average there are nine woodlots per *tabia* with average size of 8 ha (Gebremedhin et al 2002). These are established primarily for ecological regeneration than economic and managed by the community at village level.

Improved fallows

This is a process of *land resting from cultivation,* enriched with planting leguminous trees to speed up soil fertility replenishment process. Leguminous trees and shrubs such as *Sebania sesban, Tephrosia vogelii*, *Gliricidia sepium, Crotalaria grahamiana,* and *Cajanus cajan* rapidly replenish soil fertility in one or at most two growing seasons. It takes a maximum of 3 years to replenish fertility of extremely degraded soils through improved or planted fallows (Kwesiga and Chisumpa 1992). The trees and shrubs are interplanted with crops (e.g., maize) during the main rainy season and are left to grow alone during the dry season tapping subsoil water with deep roots. Right before the next rainy season, farmers harvest the fallows, removing the fuel wood and incorporating the biomass (leaves, soft stems and leaf litter) into the soil prior to planting maize. The benefits of

improved fallows are manifold:
Nitrogen production: Planted fallows can increase the amount of available nitrogen in the topsoil in the order of 100 - 200 kg N ha-1 within 0.5 – 2 years (ICRAF 2003). This is shown in Table 1 for the three most popular species for improved fallows used by farmers in Western Kenya – *Crotalaria grahamiana*, *Sesbania sesban* and *Tephrosia vogelii*. Approximately 2/3 of the nitrogen captured by the fallows comes from biological nitrogen fixation and the rest from deep nitrate capture from the subsoil. Upon subsequent mineralization, these improved fallows provide sufficient nitrogen for one to three subsequent maize crops, doubling to quadrupling maize yields at the farm scale.

Table 1. Nitrogen yield of biomass (leaves plus twigs < 2 cm diameter) of 6-month old improved fallow species in Western Kenya in a researcher managed on-farm trial near
Maseno, Kenya. Fallows were established from 2-month old seedlings (Source: Sanchez and Jama 2000)

Species	**Nitrogen yield (kg N ha-1)**
Crotalaria grahamiana	152.6
Tephrosia vogelii	121.3
Sesbania sesban	85.4
SED	11.5

Improved crop yields: In western Kenya, maize yield following improved fallows averaged 4.1 t/ha. That is much higher than maize yield from non-fertilised plots continuously planted to maize (1.7 t/ha) (Sanchez et al 1996, ICRAF 2003). Similar experiments in Malawi showed that maize yields from third year onwards were markedly increased by *Gliricidia* manuring to an average of 1800-2500 kg/ha (Bohringer and Akinnifesi 2001).
Soil and water conservation: Fallows improve soil structure, making the soil easier to till, and facilitate conservation tillage (ICRAF, 2003). Fallows increase the soil's water infiltration capacity and are capable of deep root development as much as 7 m. Fallows decrease soil erosion, by maintaining a leaf canopy during dry seasons and more vigorous crop growth during the rainy seasons. Better soil conservation results are achieved when fallows are combined with contour hedges planted to fodder species (Sanchez and Jama 2000).
Fuelwood production: Fuel wood production is in the order of 15 tonnes ha-1 in 2-year sesbania fallows in Eastern Zambia. Sanchez and Jama (2000) estimated that on average a family consumes about 0.4 tonnes of fuel wood per year. Therefore a tree fallow as small as 0.5 ha, would provide the firewood needed for the family to cook for one year, saving women's time in collecting and carrying heavy loads. In addition, fallows help prevent encroachment of communities in nearby forests and woodlands, and conserve biodiversity.
Mixed intercropping with coppicing species: Coppicing tree species used for improved fallows include *Gliricidia sepium, Calliandra calothyrsus and Leucaena trichandra*. Maize/*Gliricidia* intercropping has been widely applied in densely populated areas such as Malawi and western Kenya where sizes of land holdings preclude fallows (Sanchez and Jama 2000). The maize and *Gliricidia* are established concurrently on the same plot. Trees are managed through repeated cutting back so that they do not interfere with the crop. Large amounts of nitrogen rich tree biomass are left on the plot as green manure. The nitrogen equivalent that is added to the soil through the biomass ranges from 60 to 120 kg/ha/yr (Ikerra et al 1999).

Biomass transfers

The biomass transfer technology involves the growing of trees/shrubs along boundaries or
contours on farms or the collection of the same from off-farm niches such as roadsides and applying the leaves on field at planting time. In western Kenya, *Tithonia diversifolia* became the preferred species used by farmers to grow maize, beans or kale. *Tithonia* accumulates high concentrations of nutrients in its leafy biomass, which mineralises very rapidly when incorporated in the soil. Green leaf biomass of *Tithonia* is high in nutrients, in the order of 3.5 – 4.0% N, 0.35 – 0.38% P, 3.5 - 4.1% K, 0.59% Ca and 0.27% Mg on a dry matter basis in Western Kenya (Rutunga et al 1999). In many parts of Ethiopia farmers collect leaf litter and pollarded branches from selected trees such as *Cordia africana, Erythrina absinica, Croton macrostachyus*, etc and incorporated into crop fields to enrich soil fertility on selected sites (Eyasu Elias 2002).

Food Insecurity Coping Mechanisms and Agroforestry

Food security has different meaning to different people (Meert et al 2005). However, food availability and food accessibility are mentioned as the dimension of food security in many literatures (Schmidhuber and Tubiello 2007; Pinstrup-Andersen 2009 and Adekoya 2009). Table 2 shows household food production and food security status in southwestern Ethiopia. The result showed that 89% of the respondents gave their answer as food secured. However, only 12% of food secured respondents had food availability throughout the year. About 88% of the respondent attained food security through local purchasing from local market ranging from a month to six months depending on households. Agroforestry helped the households to attain food security as source of cash for all assessed households and as a source of food for 72% of the assessed households. This finding agrees with (Pinstrup-Andersen 2009) report from Oyo state, Nigeria indicating all households purchase one food items or another to attain food security.

Table 2: Production and household food security status

Average family size per household	6
Household food security status (%)	100
Secured	89
In-secured	11
Household food security mechanisms (%)	
Available (%)	12
Access (%)	88
Food deficient period at household (months)	
Minimum	1
Maximum	8
Contribution of Agroforestry to food security (%)	
Source of cash	100
Source of food	72

II. Agroforestry for climate change resilience

Carbon storage in a few agroforestry practices

According to recent projections, the area of the world under agroforestry will increase substantially in the near future. Undoubtedly, this will have a great impact on the flux and long-term storage of C in the terrestrial biosphere (Dixon, 1995). Agroecosystems play a central role in the global C cycle and contain approximately 12% of the world terrestrial C (Smith et al., 1993; Dixon et al., 1994; Dixon, 1995). Soil degradation as a result of land-use change has been one of the major causes of C loss and CO2 accumulation in the atmosphere. Agroforestry may involve practices that favour the emission of GHGs including shifting cultivation, pasture maintenance by burning,

Table 3. Potential C storage for agroforestry systems in different ecoregions of the world (Dixon et al., 1993; Krankina and Dixon, 1994; Schroeder, 1993; Winjum et al., 1992)

	Ecoregion	System	Mg C ha−1
Africa	Humid tropical high	Agrosilvicutural	29–53
South America	Humid tropical low	Agrosilvicutural	39–102a
	Dry lowlands		39–195
Southeast Asia	Humid tropical	Agrosilvicutural	12–228
	Dry lowlands		68–81
Australia	Humid tropical low	Silvopastoral	28–51
North America	Humid tropical high	Silvopastoral	133–154
	Humid tropical low	Silvopastoral	104–198
	Dry lowlands	Silvopastoral	90–175
Northern Asia	Humid tropical low	Silvopastoral	15–18

a Carbon storage values were standardised to 50-year rotation.

paddy cultivation, N fertilisation and animal production (Dixon, 1995; Le Mer and Roger, 2001). However, several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create C sinks (Winjum et al., 1992; Dixon et al., 1993; Krankina and Dixon, 1994; Dixon, 1995). The amount of C sequestered largely depends on the agroforestry system put in place, the structure and function of which are, to a great extent, determined by environmental and socio-economic factors. Other factors influencing carbon storage in agroforestry systems include tree species and system management. Table 3 shows the carbon storage potential of agroforestry systems in different regions of the world.

Agroforestry systems play a critical role in moderating the microclimate

The full genetic potential of many crops and varieties can only be realized when the environmental conditions are close to optimum. Any change in these conditions, especially during the reproductive stage, will have a direct impact on the production and economic viability of certain crops. While removing the extra energy accumulated and trapped by atmosphere is not feasible, agroforestry systems with appropriate shade trees offer a promising option to moderate the effects of heat stress locally. Trees on farm bring about favourable changes in the microclimatic conditions by influencing radiation flux, air temperature, wind speed, saturation deficit of understorey crops all of which will have a significant impact on modifying the rate and duration of photosynthesis and subsequent plant growth, transpiration, and soil water use (Monteith et al., 1991). Some examples where the beneficial aspects of microclimatic changes are extensively used are shade trees to protect heat sensitive crops like coffee, cacao, ginger and cardamom from high temperatures, wind breaks and shelter belts to slow down the wind speed to reduce evaporation and physical damage to crops, mulches to reduce soil temperature and various crop tree mixes to reduce erosion and maximize resource use efficiency.

In general, shade will create microclimates with lower seasonal means in ambient temperature and solar radiation as well as smaller fluctuations. Beer et al. (1998) while reviewing the literature on shade management in coffee and cacao plantations have observed that shade trees buffer high and low temperature extremes by as much as 5 °C. According to Steffan-Dewenter et al. (2007) the removal of shade trees increased soil surface temperature by about 4 0C and reduced relative air humidity at 2 m above ground by about 12%. Soil temperature under the baobab and *Acacia tortilis* trees in the semi-arid regions of Kenya at 5-10 cm depth were found to be 6 °C lower than those recorded in open areas (Belsky et al., 1993). In the Sahel, where soil temperatures often go beyond 50° to 60 °C, a major constraint to establish a good crop, *Faidherbia* trees lowered soil temperature at 2-cm depth by 5° to 10 °C depending on the movement of shade (Vandenbeldt and Williams, 1992). Shelterbelts, parallel rows of trees over the landscape, is another widely used option to improve microclimates, more specifically to reduce the velocity of the wind by increasing the surface roughness and control wind erosion and evapotranspiration. The effects of properly designed shelterbelts extend from about 10 to 25 times the height of the belt downwind with the greatest effect close to the leeward side.

While there is a general consensus on the beneficial effects of trees in moderating and ameliorating the microclimatic conditions, there is still considerable uncertainty on the productivity and economic benefits of these systems (Beer et al., 1998; Kho, 2000; Rao, et al.1998). This is partly due to the complex interactions common with agroforestry systems. The major biophysical factors influencing the performance mixed systems are crop and tree type, number and distribution of trees, age of the tree, management of crop and tree and climate during the season. Based on the response of crops to shade, Brenner (1996) has classified leafy horticultural crops (e.g., alfalfa, cliver) as the most responsive crops and cereals as moderately responsive (e.g., barley and millet) or less responsive (e.g., maize, and wheat). The net shade effect was reported to be more positive when the annual crop is a C3 plant which is normally light saturated in the open (Ong, 1996). Among the climatic regimes, higher crop yields were noted mostly in inherently fertile soils in humid and subhumid tropics where benefits from fertility improvement are much larger relative to the effects of competition (Rao et al., 1998). In the semi-arid tropics, the competition for water and nutrients severely reduced maize yields when grown with *Grevillea robusta* (Ong et al., 2000).

Agroforestry systems are highly effective in soil and water conservation through provision of permanent cover.

With nearly two thirds of the continent occupied by deserts and drylands, Africa faces the biggest threat of desertification and degradation. Since climate exerts a strong influence over various soil processes that contribute to degradation, the expected changes in climate will have the potential to alter these processes and thereby soil conditions. A recent assessment by IIASA predicted that the arid and semi-arid areas in Africa will increase by 5-8% by 2080 (Fischer et al., 2005). There are several ways by which climate change manifests soil degradation. Higher temperatures and drier conditions lead to lower organic matter accumulation in the soil resulting in poor soil structure, reduction in infiltration of rain water and increase in runoff and erosion (Rao et al., 1998) while the expected increase in the occurrence of extreme rainfall events will adversely impact on the severity, frequency, and extent of erosion (WMO, 2005). These changes will further exacerbate an already serious problem the continent is facing.

Arresting degradation and restoring the productive potential of soil calls for improvement in the physical, chemical and biological conditions. The advantage with agroforestry systems is in their ability to bring favourable changes in all the three conditions. Agroforestry systems like improved fallows, contour hedgerows and other systems involving permanent cover play an important role in arresting and reversing land degradation via their ability to provide permanent cover, improve organic carbon content improve soil structure, increase infiltration, enhance fertility, and biological activity. In western Kenya, the World Agroforestry Centre, in collaboration with the Institut de Recherche pour le Développement (IRD) and Kenyan national agricultural research services, has tested the potential of improved fallow for controlling soil erosion, using fast growing shrubs such as *Crotalaria grahamiana* and *Tephrosia spp*. These species showed great promise in reducing soil losses. Soil protection through improved fallow is a process that starts right from the fallow period when tree cover reduces soil battering by raindrops, but continues way after fallow clearance due to the improvement of soil structure and biological activity.

Very few studies have quantified soil faunal activity under planted fallows, compared with natural fallows or continuous cropping. Observations made at Muguga, Kenya under natural forest, continuously cropped maize, one-year-old sesbania fallow, and grass fallow indicated that sesbania fallows restored the soil biological activity to the same level as in natural forest and was several-fold higher than in the cropped fields or grass fallows.

In a parallel development aimed at improving the diagnosis and monitoring of soil quality, World Agroforestry Centre has made substantial progress in the application of infrared spectroscopy for rapid analysis of soils and various other organic resources (Shepherd et al. 2003). The technique not only provides a better understanding of the complexity and diversity of local soils, but also serves a tool for monitoring soil quality for environmental protection. Infrared spectroscopy allows for large numbers of geo-referenced soil samples to be rapidly characterized. It can therefore be used in conjunction with satellite imagery to interpolate ground measurements over large areas. There is potential for use of IR spectroscopy to increase efficiencies and reduce costs in both large-area applications (soil survey, watershed management, pedo-transfer functions, and soil quality indicators) and site-specific management problems (precision agriculture, farm advisory services, process studies). In particular, the ability to rapidly characterize large numbers of samples opens up new possibilities for risk-based approaches to soil evaluations that explicitly consider uncertainty in predictions and interpretations of soil properties.

Agroforestry systems offer a major pathway for sustainable diversification of agricultural systems and incomes

Diversification of agricultural enterprises is one of the oldest practices adopted by the farmers to reduce/spread the risks and capitalise on the opportunities associated with variable climate through better exploitation of potential synergies and complementarities among different farm enterprises. Diversification is an adjustment of the farm enterprise pattern in order to increase farm income or reduce income variability by reducing risk, exploiting new market opportunities and existing market niches, diversifying not only production, but also on-farm processing and other farm-based, income-generating activities (Dixon et al., 2001). At the farm level it is the adoption of multiple production activities that are complementary in economic and/or ecological dimensions involving crops, trees, livestock and post harvest processing. Integrated agroforestry systems are a suitable pathway for sustainable diversification of agricultural systems. Examples of such systems are a bound. The fast growing poplar has become a major tree component on many farms in South Asia. Across Africa, home gardens with a diverse range of vegetable and fruit yielding trees are quite popular (Mendez et al., 2001; Vogl et al., 2002; Wezel and Bender, 2003) and contribute significantly to food security by providing products year round. A global review on the contribution of home gardens to food and nutrition of households found that up to 44% of calorie and 32% of protein uptake are met by the products from home gardens (Torquebiau, 1992). Besides meeting the subsistence needs of households, the role of home gardens in generating additional cash income cannot also be overlooked (Christanty, 1990; Torquebiau, 1992; Dury et al., 1996; Mendez et al., 2001).

It is now being recognized that expanding market opportunities for smallholders particularly in niche markets and high value products is critical to the success of agroforestry innovations (Russell and Franzel, 2004). The major constraints to the growth of the small holder tree product sector in Africa are forest policies, physical and social barriers to smallholder participation in markets, the overall lack of information at all levels on markets for agroforestry products, and the challenges to outgrowing schemes and contract farming. Notwithstanding these constraints, there are promising developments including contract fuelwood schemes, small-scale nursery enterprises, charcoal policy reform, novel market information systems, facilitating and capacity building of farmer and farm forest associations, and collaboration between the private sector, research and extension (Russell and Franzel, 2004). The possibilities for integrating farms with traditional and non-traditional trees that provide fruits, nuts and other food products, medicinal plants (Rao et al., 2004), short rotation woody crops (Rockwood et al., 2004), and biomass energy plantations (Hall and House, 1993) are plenty, if suitable market structures are put in place.

Agroforestry systems have the capacity to enhance the use efficiency of rain water

Water is already a scarce resource and climate change is expected to make the situation worse. Climate change has both direct and indirect impacts on water availability. The direct impacts include changes in precipitation patterns while the indirect ones are increases in losses through runoff and evapotranspiration. Based on the results from extensive studies conducted under the Comprehensive Assessment of Water Management in Agriculture, CA warns that today's food production and environmental trends, if continued, will lead to crises in many parts of the world (CA, 2007). Hence with or without climate change, improving agricultural productivity of water is extremely important in managing the acute water shortages that the humankind is expected to face over the next 50-100 years.

There are several mechanisms whereby agroforestry may use available water more effectively than the annual crops. Firstly, unlike in annual systems where the land lies bare for extended periods, agroforestry systems with a perennial tree component can make use of the water remaining in the soil after harvest and the rainfall received outside the crop season. Secondly, agroforests increase the productivity of rain water by capturing a larger proportion of the annual rainfall by reducing the runoff and by using the water stored in deep layers. Thirdly, the changes in microclimate (lower air temperature, wind speed and saturation deficit of crops) reduce the evaporative demand and make more water available for transpiration.

Despite its importance, the knowledge and understanding of the competition for resources between the tree and crop components remains imperfect due to the complex nature of the interactions and difficulties associated with quantification. Much of the evidence is based on the interpretation of the observations made on above ground components of the system which have mostly reported negative effects of trees on crop yields. This negative effect is commonly attributed to the competition for nutrients in case of humid areas where moisture is unlimiting and to moisture in case of semi-arid tropics primarily to water. Soil water measurements made over three consecutive seasons under hedgerow intercropping with contrasting Senna species (*S. siamea* and *S. spectabilis*) and a maize–cowpea (*Vigna unguiculata*) annual crop system at Machakos, Kenya (av. rainfall 760 mm yr–1 in two rainy seasons), highlighted the importance of competition of hedgerows for water in semiarid environments (Figure 2). Soil water under both hedgerow systems was lower than in the annual crop system throughout the study period and the differences were greater in periods of water stress. Soil water depletion was greater under the fast-growing and high-biomass-producing *S. spectabilis* than under the slower growing and less-biomass-producing *S. siamea*. The soil profile was never fully recharged, even when rainfall was 547 mm (50% higher than normal) during the 'short rainy' season of 1994–95, because of severe water depletion in the previous season (Rao et al., 1998). Interception of rain by canopy can also play a significant role in reducing the amount of water reaching the soil and losses as high as 50%, depending on the tree density and the amount and distribution, of the rainfall were reported (Ong et al. 1996).

Vertical root complementarity is considered as one of the advantages of agroforestry systems. Studies on root growth indicate that all trees used in agroforestry systems do not always have deep pivotal roots, and that mixed and superficial tree root architectures are common (vanNoordwijk et al., 1996). Similarly, trees tend to develop or redirect their roots to the upper soil layers, if water recharge below the root zone is infrequent as it happens in low rainfall years and in the absence of plant available nutrients (Rao et al., 2004). Only a few species have the root systems that can reach relatively deep water tables. Consequently, there seems to be less scope for vertical root complementarity than originally thought (Sanchez, 1995; Ong and Swallow, 2004) highlighting the need for management approaches to reduce the competition. Side-pruning of trees to reduce above ground competition and periodic root pruning to reduce below ground competition were tried, although the feasibility for managing root competition is questionable on many tropical farms.

Agroforestry systems provide economically viable and environmentally friendly means to improve soil fertility

Nutrient mining from continuous cropping without adequately fertilizing or fallowing the land is often cited as the main constraint to increase in productivity in most countries across Africa. It is estimated that on average African soils have been depleted by about 22 kg nitrogen, 2.5 kg phosphorus, and 15 kg potassium per hectare of cultivated land over the past 30 years in 37 African countries – an annual loss equivalent to $4 billion worth of fertilizers (Sanchez, 2002). While fertilizers offer an easy way to replenish the soil fertility, at the current prices it is very unlikely that there will be any change in the investments made by African farmers in fertilizers. In this context, Agroforestry systems have attracted considerable attention as an attractive and sustainable pathway to improve soil fertility. World Agroforestry Center made substantial progress in the identification and promoting of agroforestry systems aimed at improving soil fertility.

According to Sanchez et al. (1997), there are four ways through which trees can contribute to the improved nutrient supply -increase nutrient inputs to the soil, enhance internal cycling, decrease nutrient losses from the soil, and provide environmental benefits. After extensive experimentation with a wide range of soil fertility replenishment practices, the World Agroforestry Center has developed a system with three components that can be used in combination or separately: (i) nitrogen-fixing leguminous tree fallows, (ii) indigenous rock phosphates in phosphorusdeficient soils, and (iii) biomass transfer of leaves of nutrient-accumulating shrubs (Sanchez, 2002). The Leguminous trees of the genera Sesbania, Tephrosia, Crotalaria, Glyricidia, and Cajanus are interplanted into a young maize crop and allowed to grow as fallows during dry seasons, accumulating 100 to 200 kg N ha–1 over the period from 6 months to 2 years in subhumid tropical regions of East and Southern Africa. The quantities of nitrogen captured are similar to those applied as fertilizers by commercial farmers to grow maize in developed countries. The other options tried include mixed intercropping with gliricidia (*Gliricida sepium*) and biomass transfer with wild sunflower (*Tithonia diversifolia*) or gliricidia (Place et al. 2002). These systems were found to provide 50 to 200 kg N ha−1 to the associated cereal crops. Yield increases are typically two to three times that with current farmers' practices. These approaches, although attractive, are not useful in all the agro-ecologies. Improved fallows have yet to prove their worth in the semiarid tropics of Africa where the much longer dry season limits their growth and nitrogen fixation potential, in shallow soils, poorly drained soils, and frost-prone areas (Sanchez, 2002).

Agroforestry systems have the potential to limit carbon emissions and sequester carbon

The greatest role of agroforestry in relation to climate change is perhaps in mitigating the emissions of CO2 by productively sequestering carbon from the atmosphere (Figure 3). The tree component of the agroforestry systems can be a significant sink for carbon in lands devoted to agriculture. The three major paths through which tree can help reduce atmospheric carbon are: conservation of existing carbon pools through practices such as avoided deforestation and alternatives to slash and burn; sequestration through improved fallows and integration with trees, and substitution through biofuel and bioenergy plantations to replace fossil fuel use (Montagnini and Nair, 2004).

A number of studies have estimated the potential of agroforestry systems to act as effective carbon sinks (IPCC, 2000; Albrecht and Kandji, 2003; Montagnini and Nair, 2004, Palm et al., 2005). Assuming mean carbon content of above ground biomass of 50%, average carbon storage by agroforestry practices has been estimated to be 9, 21, 50, and 63 Mg C ha−1 in semiarid, subhumid, humid, and temperate regions respectively (Schroeder, 1994). The quantitative importance of agroforestry as carbon sink derives from its wide applicability in existing agricultural systems. Worldwide it is estimated that 630 x 106 hectares are suitable for agroforestry. Improved fallows aimed at improving nutrient depleted soils is undoubtedly one of the most promising agroforestry technologies in the sub-humid tropics and has, in recent years, shown great potential for adoption in southern and eastern Africa. Even in drier areas such as the Sudan- Sahel zone of West Africa, recent field experiments have shown that the technology could significantly contribute to curbing land degradation and improving farm productivity. Unlike the more perennial systems in the humid tropics, improved fallows are mostly short-rotation and as such sequester much less carbon aboveground. Nevertheless, if the time-averaged aboveground carbon is considered, they store substantial quantities of carbon compared to degraded land, croplands or pastures (Albrecht and Kandji, 2003).

While the potential of agroforestry systems to store additional carbon is well established and widely recognised, possible tradeoffs between carbon storage and profitability in agroforestry systems have to be taken into account while promoting these systems (Gockowski et al., 2001). It is estimated than an increase of 1 tonne of soil carbon of degraded cropland soils may increase crop yield by 20 to 40 kg ha-1 for wheat, 10 to 20 kg ha-1 for maize, and 0.5 to 1 kg ha-1 for cowpeas. Carbon sequestration is a secondary product but it is unclear how smallholders can benefit from carbon sequestration projects and CDM (Montagnini and Nair, 2004). Better quantification of carbon sequestered is required to establish how much carbon is sequestered and how much is added to the soil carbon pool before any of this can figure in carbon audits and provide incentives to smallholder farmers. Nevertheless, the potential of agroforestry as a strategy for carbon sequestration has not yet been fully recognized, let alone exploited. A major difficulty is that empirical evidence is still lacking on most of the mechanisms that have been suggested to explain how agroforestry systems could bring about reductions in the buildup of atmospheric CO2.

Conclusion and Recommendation

It has been demonstrated that agroforestry innovations provide options for reducing poverty, improving food and income security and sustaining environmental quality. Home garden, woodlot and coffee farm were the potential agroforestry intervention area in the future. Despite less attention has been given to tree based land use option, agroforestry has played a major role in reducing household vulnerability to shocking. Smallholder farmers have already started mainstreaming tree based land use system as resilience to social needs because the poor are more exposed to change; agroforestry is one of best risk aversion option to make them move out of food insecurity.

The growing and compelling evidence about global warming and its impact on global climatic systems has firmly established that climate change is real and that its consequences will be serious especially for Africa more than any other continent. The agricultural impacts of climate change are of the greatest concern to most developing countries, particularly in the tropics, because of higher dependence on agriculture, subsistence level of operations, low adaptive capacity and limited institutional support.

Most research, to date, has focused on the impacts of climate change on major annual crops and very little on trees and perennial crop systems. The long duration of the perennials and difficulties in changing varieties over short periods pose special challenges and more research is required to address the same. A thorough understanding of how well the perennial trees overcome the impacts of climate change is an essential requirement before promoting their use.

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