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The Potential of Using Agroforestry as a Win-Win Solution to Climate Change Mitigation and Adaptation and Meeting Food Security Challenges in Southern Africa

[1]Stephen Syampungani, [2]Paxie W. Chirwa, [3]Festus K. Akinnifesi and [3]Oluyede C. Ajayi
[1]School of Natural Resources, Copperbelt University, P.O. Box 21692, Kitwe, Zambia
[2]Department of Forest and Wood Science, Stellenbosch University, Stellenbosch 7602, South Africa
[3]World Agroforestry Centre (ICRAF), Southern Africa Regional Programme,
Chitedze Agricultural Research Station, P.O. Box 30798, Lilongwe 3, Malawi

Abstract: Some of the most profound and direct impacts of climate change in southern Africa over years have been droughts, fluctuations in annual rainfall, extreme temperatures and floods. These have resulted in low and unstable food production, especially maize which is the staple food in most Southern African countries. Furthermore, research suggests that 30% of threatened plant species will be critically endangered or extinct due to drought, thus further worsening food availability, accessibility and stability in the region. Therefore is assumed to be the major obstacle to the achievement of food security in Southern Africa. Agroforestry is emerging as the promising option to sustain agricultural productivity and livelihoods of farmers. We discussed the need for further selection and releasing new tree germplasm with superior capacity to adapt to the changing climatic and ecological conditions in the region. Innovative mechanisms to further enhance the contribution of agroforestry to climate change mitigation and adaptation are examined.

Key words: Trees on farm, carbon sequestration, carbon trade, sustainable production, conservation agriculture

INTRODUCTION

Deforestation, forestland degradation, agricultural activities and the combustion of fossil fuels and other industrial activities have increased atmospheric carbon dioxide and other greenhouse gases (Marland *et al*., 2003; IPCC, 2000), thereby having a profound impact on climate and leading to extreme weather conditions. The most profound and direct impact of climate change are on agriculture and food systems (Brown and Funk, 2008).

Increasing temperatures and unpredictable rainfall in both amount and timing, frequent extreme weather and higher severity of pests and diseases are among the more drastic changes that would impact agriculture and food systems negatively (Lobell *et al*., 2008). The risk of climate change varies tremendously from one region to the other with the poorest regions being the most at risk (Diaz *et al*., 2006). The smallholder farmers in developing regions like southern Africa will experience more severe consequences of climate change (Cotter and Tirado, 2008) and this will further increase poverty level for > 80% rural people in southern Africa (Makonda and Gillah, 2007). This is because the economies of the regions are largely dependent on agriculture through subsistence farming (World Bank, 1994). Agriculture is a very important sector in southern Africa in terms of food security contribution to Gross Domestic Product (35%), employment (70-80% of the total labour) and foreign exchange earnings (30%) (Abalu and Hassan, 1998). There has been a decline in agricultural productivity in the region and cereal crop yields have stagnated at about 1 ton ha^{-1} during the past 50 years (Van Rooyen and Sigwele, 1998; Kandji *et al*., 2006). This trend has been been attributed to declining soil fertility, soil erosion and changes in rainfall patterns (Sanchez, 2002).

In addition, the rapid increase in population has also led to heavy deforestation resulting from forest and woodland land clearing for agriculture and to also meet the requirements of fuelwood, tree products and building materials (Geist, 1999). Dependence on agriculture and subsistence utilization of natural resources, besides depleting the resources in the miombo ecoregion has been ineffective in improving the living standards of local communities (Syampungani, 2008). Additionally, deforestation has contributed to species extinction as well as the climate change through deforestation in the region (FAO, 2000).

There is therefore an urgent need to address these negative impacts in order to ensure sustainable rural livelihood of the region. Agroforestry has the potential to

Corresponding Author: Stephen Syampungani, School of Natural Resources, Copperbelt University, P.O. Box 21692, Kitwe, Zambia

mitigate climate change through carbon sequestration, improvement of biodiversity and optimizing crop yields on the same piece of land (Akinnifesi *et al*., 2008a, b). This review study highlights some of these innovative measures and presents opportunities for agroforestry to effectively contribute towards food security and climate change mitigation and adaptation in the region.

EVIDENCE OF CLIMATE CHANGE IN SOUTHERN AFRICA

Most of the southern African climate is influenced by the El Niño-Southern Oscillation macro-level (Collier *et al*., 2008). However, how this interacts or is affected by climate change is poorly understood. Notwithstanding, it is well known that global warming affects the outcomes of El Niño-Southern Oscillation (ENSO) through increased incidence and severity of drought, flood and other extreme weather events (Collier *et al*., 2008). The risk of drought in southern Africa has been associated with the occurrence of El Niño phenomenon has been associated with the risk of drought in southern Africa. Several researchers (Cane *et al*., 1994; Glantz *et al*., 1997; Phillips *et al*., 1998) have clearly linked the rainfall pattern in southern Africa to El Niño events in the Pacific.

Climate change or ENSO events will have negative consequences on people and the economies of not only the southern African region but Africa as a whole as this will have a direct impact on the agricultural sector, the largest single economic activity of the continent (Collier *et al*., 2008). According to Kandji *et al*. (2006), ENSO events have already been associated with death of livestock and reduction in crop production in the region. This is because such events tend to lead to water logging of soils, leaching of nutrients and the proliferation of agricultural pests and diseases. Higher temperatures and humidity result in an increased pressure from insects and fungal diseases.

The reduction in crop production and loss of livestock has been reported to have resulted in widespread food shortage in the region. For example, Harsch (1992) observed that the low regional cereal production as a result of drought in the 1991/92 season put an estimated 30 million people on the brink of starvation in the region, while Kandji *et al*. (2006) observed that the El Niño related drought resulted in a deficit of regional cereal requirement of 7.6 million tonnes. In 2001/02 season, 1.2 million tonnes of cereal deficit was reported in Lesotho, Malawi, Swaziland, Zambia and Zimbabwe (SADC, 2002). Furthermore, Kandji *et al*. (2006) reported food deficit as a result of drought to be at 3.3 million tonnoes which called for need to provide relief food to >14 million people in the region. Climate change in southern Africa has also been associated with other natural (other than ENSO events) and anthropogenic processes such as fallowland burning, clearing of land for slash and burn agriculture and cultivation of wetlands (Desanker *et al*., 1997). Land use changes have been reported to release between 1.6 and 1.7 Gt carbon annually (IPCC, 2000). Charcoal production and woody fuel consumption amount to 48 Tg annually, thus releasing about 22 Tg carbon (Desanker *et al*., 1997). If agricultural productivity is to be sustained and miombo woodland conserved, alternative land use strategies are needed.

CARBON SEQUESTRATION AND TRADING

C sequestration is the natural process of removing excess Carbon dioxide (CO_2) from the atmosphere and storing it in long-lived pools of C by fixing it or locking it up from being released back to the atmosphere. Such pools include the above-ground plant biomass below-ground biomass such as roots, soil microorganisms and the relatively stable forms of organic and inorganic C in soils and deeper subsurface environments and the durable products derived from biomass (e.g., timber, wood) and can contribute substantially in climate change mitigation (Nair *et al*., 2009). When substances with high carbon (e.g., fossil fuels) are burned, CO_2 is detonated to the atmosphere and mixed with other gases known as Greenhouse Gas (GHG).

The concept of carbon trading is based on the ability to store carbon and preventing it from being released to the atmosphere. The Kyoto Protocol has three mechanisms to ensure compliance with the reduced commitments, including Joint Implementation (JI), Clean Development Mechanism (CDM) and Emissions Trading (ET). These mechanisms enables developed economies to meet their greenhouse gas emission requirement under the CDM by purchasing GHG emission reduction credits from financial exchanges or from initiatives or projects that reduce emissions in developing nations. According to the Financial Times, carbon trading is the fastest growing commodity market in the world today and one that has the potential to generate trillions of dollars annually over the next half decade (Garrity and Verchot, 2008).

The International Panel on Climate Change (IPCC) and the Kyoto protocol, both recognize agroforestry as a potential terrestrial C sink (IPCC, 2000), through a series of mechanisms mediated by the tree component (FAO, 2000). Farmers are known to be efficient producers of sequestered carbon stored in trees grown on farms, such as for fruit trees, timber and other tree products. Through using agroforestry as a vehicle of creating C sinks on farms, these emerging conventional and voluntary carbon markets can provide significant incomes for smallholder farmers in addition to increasing farm productivity, providing diversified tree products and reducing labour for women and creating long-term farm assets. Nair *et al.* (2009) estimate that the area currently under agroforestry worldwide is 1,023 million ha and that in additionally, substantial extent of areas of unproductive crop, grass and forest lands as well as degraded lands could be brought under agroforestry.

Agroforestry and climate amelioration: The recent recognition of agroforestry as a greenhouse gas mitigation strategy under the Kyoto Protocol has earned it added attention as a strategy for biological Carbon (C) sequestration (Nair *et al.*, 2009). The forest-based systems are known to have the largest potential to mitigate climate change through conservation of existing carbon pools, expansion of carbon sinks (e.g., agroforestry) and substitution of fossil fuels for wood products (Schlamadinger *et al.*, 2007). The expansion of carbon sinks through agroforestry provides unique opportunities for mitigating Greenhouse Gas (GHGs) emissions, while addressing other more pertinent livelihood concern of the rural dwellers in southern Africa.

They can be reduced by managing the terrestrial and subterranean carbon and nitrogen pools more efficiently in agroforestry ecosystems (Bouman, 2001) by converting low-biomass land use systems (e.g., grasslands and agricultural landscapes) to tree based C-rich systems. The integration of trees in agroforestry land use has the potential to increase Soil Organic Matter (SOM) and store significant amounts of carbon in the woody biomass (Unruh *et al.*, 1993). Carbon can be sequestered from the atmosphere and stored in soils or vegetation in agroforestry systems (Albrecht and Kandji, 2003; Makumba *et al.*, 2006). For smallholder agroforestry systems in the tropics, potential C sequestration rates ranges from 1.5-3.5 ton C ha^{-1} $year^{-1}$ (Montagnini and Nair, 2004).

Two-year rotations of non-coppicing agroforestry species in Eastern Zambia sequestered 26-78 Mg ha^{-1} carbon in the soil, while four year rotations sequestered 120 Mg ha^{-1}. Similarly, Gliricidia in southern Malawi sequestered between 123 and 149 Mg ha^{-1} in the 0-200 cm (Makumba *et al.*, 2006). Both studies detected large amounts of C pools at the sub-soil (0-200 cm). This is why Roshetko and Lasco (2008) recommends the conversion of low biomass land use into agroforestry systems that maintain high tree density, contain species with long maximum age manage the system for long rotation and manage the soil to avoid a loss of baseline carbon. In southern Africa, these systems have been developed for more than two decades by the World Agroforestry Centre and its partners in the region (Akinnifesi *et al.*, 2008a, b). Albrecht and Kandji (2003) observed that about 1100-2200 Tg C could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale. This makes agroforestry to occupy a special role in mitigation of the accumulation of GHGs in the atmosphere.

Hence, agroforestry systems have the capacity to reduce the carbon emissions from the atmosphere through carbon storage in trees and soil through accumulation in living tree biomass, wood products and Soil Organic Matter (SOM) and through protection of the existing forests. Sileshi *et al.* (2007) estimated carbon storage capacity of 3-60 ton ha^{-1} (for live biomass), 1-100 ton ha^{-1} (for wood products), 10-50 ton ha^{-1} (for SOM) and up to 1000 ton ha^{-1} (existing forests), offsetting of greenhouse gas emissions through energy and material substitution and reduction of fertilizer C foot print. Crops and residues from agroforestry systems can be used as a source of fuel to displace fossil fuel combustion, either directly or after conversion to fuels such as ethanol or diesel (Cannell, 2003).

Of all the land uses analyzed in the International Panel on Climate Change (IPCC) Land Use, Land-Use Change and Forest reports, agroforestry was reported to offer the highest potential for carbon sequestration in non-Annex 1 countries (Verchot *et al.*, 2007). Agroforestry, therefore has such a high potential in southern Africa because there is such a large area that is susceptible to degradation through either slash and burn agriculture, charcoal production or other activities (FAO, 2005) and agricultural lands are mostly carbon-deficient.

The large tracts of susceptible area provide an opportunity for the deployment of agroforestry systems in southern Africa to sustainably manage such areas. Agroforestry, as an alternative to shifting cultivation or woodland degradation for fuelwood would provide tremendous carbon sequestration potential (Palm *et al.*, 2004) in southern Africa. However, the extent of C sequestered in any agroforestry system will depend on a number of site-specific biological, climatic, soil and management factors (Nair *et al.*, 2009). In general it has been estimated that about 45-50% of tree wood biomass and 30% of foliage consist of carbon.

AGROFORESTRY AND FOOD SECURITY POTENTIAL IN SOUTHERN AFRICA

Biodiversity improvement: The food security quest often relies on expansion of agricultural land at the expense of the forest, while agriculture has a low C storage potential and remains the biggest threat to biodiversity. One of the major threats to soil biodiversity in Africa is habitat loss resulting from deforestation, land degradation (Sileshi *et al*., 2007) and use of fire associated with agriculture (Sileshi *et al*., 2008a). The extinction of species may disrupt vital ecosystem processes and services and reductions in species abundance and richness are also likely to have far-reaching consequences including the loss of agricultural pest control and the spread of disease (Sileshi *et al*., 2007).

Agroforestry is often considered as an alternative land use strategy that offers solutions to land and forest degradation and to the loss of biodiversity (Oke and Odebiyi, 2007) through diversification and therefore food security. Agroforestry systems are believed to have a higher potential to sequester C than pastures or field crops (Sanchez, 2002; Palm *et al*., 2004; Verchot *et al*., 2007). According to Nair *et al*. (2009), this assertion is based on the fact that tree incorporation in croplands and pastures would result in greater net above-ground as well as below-ground C sequestration. Agroforestry systems can be integrated into biodiversity corridors for a variety of uses such as timber and non-timber forest products, thereby minimizing the exploitation of protected areas. In areas where the forest has been lost, indigenous fruit and timber trees are grown as companion species to provide environmental services.

Huang *et al*. (2002) found a significant positive impact of agroforestry on the biodiversity conservation of nature reserves in Tanzania. Such system that enhances biodiversity is important for achieving sustainable food security in changing climates like that of southern Africa. In fact, scientists in many parts of the world have demonstrated that diversified farming provides a natural insurance against major ecosystem changes be it in the wild or in agriculture (Chapin *et al*., 2000; Diaz *et al*., 2006). Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimal use of available land, labour and capital (Arnold and Dewees, 1997).

Modern agriculture is currently one of the greatest threats to biodiversity and therefore agroforestry holds the key to conservation of the biodiversity in southern Africa (Chirwa *et al*., 2008). The high abundance of diversity of plant and animal species in agroforestry systems has an important role to play in the adaptation to changing environment. Diversity management can constitute a central part of the livelihood management strategies of farmers (particularly pastoralists) and communities in different production systems throughout Africa (Rege *et al*., 2003). The higher the number of different species or varieties present in a field or in an agroecosystem, the greater the probability that at least some of them can cope with changing environment. According to Chapin *et al*. (2000), species diversity also reduces the probability of pests and diseases by diluting the availability of their hosts. Chirwa *et al*. (2008) indicated that the use of non-timber forest products as a livelihood strategy in agroforestry, particularly for food, nutrition, medicine and safety net during lean periods has been one of the drivers of biodiversity conservation. Crop diversity within a field, therefore provides a buffer against losses caused by environmental change, pests and diseases (Cotter and Tirado, 2008).

This is confirmed by Frazer (2007)'s analysis of past environment changes that resulted in famines (e.g., Ireland's potato famine and the Ethiopian famine in 1965-1997) in which specialized monocultures exhibited high levels of vulnerability. Diversity farming through agroforestry in addition to enhancing food security and climate resilience will also provide for prevention of desertification and soil erosion (Hajjar *et al*., 2008). It also provides for increased soil organic matter which in turn contributes to improved slope stabilization thereby reducing soil erosion.

Fruit species management: More than 80% of rural people in Southern Africa are poor and traditionally rely on existing non-wood goods and services (FAO, 1999). One of the non-wood products from the forests is fruits. Indigenous fruits from the miombo woodlands are central to the livelihoods of both the rural and urban dwellers in southern Africa, especially during periods of famine and food scarcity (Akinnifesi *et al*., 2008a; Syampungani, 2008; Kalaba *et al*., 2009). The miombo woodlands contain over 200 indigenous fruit species (Mithofer and Waibel, 2003) which bear edible fruits in different seasons and even in drought years (Mateke *et al*., 1995).

This makes indigenous fruits contribute significantly to household income and well being in the tropics (Akinnifesi *et al*., 2006). Mithofer *et al*. (2006) reported a reduction of 30% in probability of falling below the poverty line for households near indigenous fruit tree forests in Zimbabwe. In Zambia, Malawi and Mozambique, 26-50% of rural dwellers depended on wild fruits, especially during the period of famine (Akinnifesi *et al*., 2006).

Several researchers have acknowledged the importance of indigenous fruits as a source of income for the rural people in the miombo ecoregion (Ramadhani, 2002; Kalaba *et al*., 2009; Akinnifesi *et al*., 2008b). Unfortunately, >90% of the marketed fruit tree products in the Southern Africa still come from the wild stands (Akinnifesi *et al*., 2008a, b). This implies that very few indigenous fruit species have been domesticated in the region. This is due to limited of knowledge appropriate propagation techniques and management by smallholder farmers (Akinnifesi *et al*., 2006). Increased domestication of indigenous fruit trees through managing the species and their genetic diversity for provision of products and services to meet livelihood needs would be an important contribution of agroforestry in addressing food security in southern Africa. Furthermore, domestication of Indigenous Fruit Trees (IFTs) and maintenance of species diversity due to conservation will also result in carbon storage, thereby contributing to climate mitigation.

The IFTs also provides an alternative source of income (to other destructive activities like charcoal production) to rural communities which if well managed may provide for reduced deforestation in the region. Several studies (Leakey *et al*., 2005; Akinnifesi *et al*., 2006, 2008a, b) have demonstrated that domestication of indigenous fruits is possible in Africa. The development of superior cultivars of indigenous fruits with high productivity and harvest index, superior fruit attributes and food value are needed in agroforestry technologies that aim at addressing food security, income and nutrition needs of the communities. This will in turn contribute towards climate change through carbon storage and reduced charcoal production.

Improved crop yield from agroforestry technologies: Agroforestry studies (Akinnifesi *et al*., 2006) have focused on increasing crop yields to meet the needs for human subsistence. According to Sileshi *et al.* (2007), this has concentrated on maximizing the soil fertility improvement. Various agroforestry systems have been employed to enhance crop yield and therefore, food security in southern Africa. According to Akinnifesi *et al.* (2008b), the most common agroforestry technologies for improving crop yield in southern Africa include: traditional tree-crop and parkland systems such as the *Faidherbia albida* based system; improved fertilizers tree systems e.g., coppicing tree fallow e.g., *Gliricidia sepium* and *Lerucaena* sp., improved fallow with short duration species such as *Sesbania* sp., *Tephrosia* sp., *Cajanus cajan*, etc. in rotational fallow system and annual relay fallow using *Sesbania* sp., *Tephrosia* sp., *Cajanus cajan*.

A recent meta-analysis from 94 studies published in sub-Saharan Africa concluded that these fertilizer tree systems could double and even triple the yield of maize (Sileshi *et al*., 2008b). In East Africa, Kenya in particular, the increase in crop yield stood at 53% for *Leucaena leucocephala* and 42% for *Gliricidia sepium* (Akinnifesi *et al*., 2006). The benefits of these soil enriching technologies are not only limited to soil replenishment but also extend to the provision of fuelwood and other wood requirements for rural community households (Akinnifesi *et al*., 2008a). Kwesiga *et al.* (1999) confirmed the provision of fuelwood from *Sesbania sesban* fallows. This in turn tends to reduce the need for exploiting the communal woodlands and forests fuelwood and other wood requirements thus contributing towards reduced deforestation. Research on firewood consumption by selected agroforestry in Zambia revealed that 11% of firewood consumed by rural households comes from improved fallow fields (Govere, 2002). Ajayi *et al.* (2007a) observed that there is a potential that this proportion would substantially increase if more small scale farmers adopted agroforestry. The foregoing support the view that agroforestry technologies to contribute towards reduced deforestation and therefore mitigate climate change through storage of carbon stocks in natural woodlands.

The traditional tree crop and parkland system has widely been reported to positively enhance the crop yield of smallholdings. Several studies on traditional tree crop and parkland system (Saka *et al*., 1994; Rhoades, 1995; Akinnifesi *et al*., 2006) have reported an increased crop yield ranging from 37-200% in many parts of Africa. Different researchers have attributed the increased yield to a number of factors namely;

- Increased nutrient inputs including biological N fixation (Kang and Akinnifesi, 2000)
- Increased nutrient availability through enhanced soil biological activity and rates of nutrient turnover (Akinnifesi *et al*., 2006)
- Improved micro-climate and soil physic-chemical properties (Buresh and Tian, 1997)

Fertilizer tree systems have also demonstrated their ability to increase crop yield over an area in the miombo ecoregion. In Zambia, *Sesbania sesban* fallow was reported to have increased the maize yield by 500% (Chirwa *et al*., 2003), while in Tanzania, the improved fallow with *Tephrosia vogelii* and *S. Sesban* increased the maize yield to 40 and 68%, respectively (Gama *et al*., 2004). In Malawi, an increase of 415% was reported among farmers using Sesbania sesban in improved fallow with land holdings of 1.75 ha on average (Haule *et al*., 2003). The fallow systems have also been reported to reduce insect pests such as termites and also weed problems (Sileshi and Mafongoya, 2006; Sileshi *et al*., 2006). However, the great opportunities that agroforestry offer are sometimes constrained by some challenges that smallholder land users face. The adoption of agroforestry technologies by farmers is strongly influenced by policy and institutional context within which technologies are disseminated to potential users (Ajayi *et al*., 2007b).

Currently, although the ratification of the Kyoto Protocol on climate change and its coming into force has given rise to new opportunities to highlight issues on carbon trading and incentives to reward multi-output land use systems like agroforestry (Ajayi *et al*., 2007a; Nair *et al*., 2009), the mechanisms of how this would benefit small scale farmers is not clear.

On the other hand, taking land completely for afforestation for many years to produce only trees for environmental goods and climate change may not be attractive to smallholder farmers because of the high tradeoff in terms of food production (Ajayi *et al*., 2007a), so integrating agroforestry is one of the most promising win-win opportunities for smallholder farmers in the region. Additionally, although agroforestry technologies tend to be profitable over time, their break-even point only occurs somewhere between 2-3 years of establishment of fallow plots (Ajayi *et al*., 2007a). This means that farmers absorb net losses before the break-even point is attained. This where the initial payment to farmers for future carbon becomes an incentive that could trigger massive adoption of agroforestry in the region.

CONCLUSION

Agroforestry holds great potential for mitigating climate change by addressing food security and livelihood needs of smallholder farmers in southern Africa. Because it boosts the copying mechanisms of vulnerable people climate change adaptation in a sense, it serves as a two-prong approach to combating food and environmental challenges. In this study, we highlighted how agroforestry provides smallholder farmers options for improving agricultural productivity and at the same time contributing to climate change mitigation and adaptation. However, if the contribution and adoption of agroforestry is to be accelerated, there is need to work out incentive mechanisms for farmers during the initial establishment of fallow plots before they attain the break-event point. The trees also create farm assets for making both tangible tree products and incomes from intangible services to the society. Additionally, clear policies relating to international agreements under the Kyoto Protocol and how carbon sequestration projects may financially benefit small scale farmers in the region should be further explored.

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