Vol. 14(7), pp. 379-388, 14 February, 2019
DOI: 10.5897/AJAR2018.12972
Article Number: A03945F60236
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Review*

# Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in Sub-Saharan Africa

**Nyong P. Awazi and Martin N. Tchamba***

Department of Forestry, Faculty of Agronomy and Agricultural Sciences, University of Dschang, Dschang, Cameroon.

Received 3 January, 2018; Accepted 2 March, 2018

**Fighting climate change and its nefarious effects is at the forefront of the United Nations' SDGs, agenda 2030. This comes at a time when the global climate is changing rapidly owing to increasing concentration of carbon dioxide ($CO_2$) and other greenhouse gases (GHGs) in the atmosphere resulting principally from fossil fuel combustion and agricultural lands taking the place of tropical forests. Climate change threatens human existence in general and the livelihood of smallholder farmers in particular in the 21st century. Research shows that the developing world has about 500 million small-scale farms, with almost two billion people implicated, a majority of them in Asia and sub-Saharan Africa where small-scale farms produce about 80% of the food consumed. Hence, smallholder farmers will bear the greatest brunt of predicted changes in climatic patterns owing to their limited adaptive capacity. Small-scale farmers being appallingly vulnerable, easily succumb to climate-induced extreme weather events, thus threatening food security. It is therefore within this backdrop that the necessity to document and promote climate-smart, sustainable, productive and low cost agricultural practices becomes incumbent. Agroforestry is one of the few existing practices that contribute simultaneously to agricultural sustainability enhancement as well as improved farm productivity owing to its ability to provide many ecosystem services. There are currently very few existing agricultural practices where sustainable agricultural goals can be attained through simultaneous enhancement of agro-ecosystem diversity and farm productivity as in agroforestry systems. Today, few studies have looked into the contribution of agroforestry to beefing up agricultural sustainability and productivity in the context of climate change. This review paper therefore sought to research on what has been done so far as well as look into the way forward with focus on sub-Saharan Africa.**

**Key words:** Climate change, agroforestry practices, agricultural sustainability, agricultural productivity, sub-Saharan Africa

## BACKGROUND

Climate change is a key existential threats facing humanity in the 21st century, which explains why combating climate change and it nefarious effects features prominently amongst the seventeen (17) United

Nations Sustainable Development Goals (SDGs), agenda 2030 (FAO, 2016). Scientists have discovered that the major causes of this scourge are anthropogenic activities such as too much fossil fuel combustion and the transformation of tropical forest cover into agricultural lands. These human activities increase the concentration of greenhouse gases (GHGs) in the atmosphere especially carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) which has largely led to global warming and hence variability and changes in climate (IPCC, 2007). The impacts of climate change are wide ranging with one of the most significant being a shift of ecological zones: desertification of the Sahel, sahelization of the Savanna and savannization of the forests. Mankind has only two possibilities to get around the climate change scourge: adaptation and/or mitigation (UNFCCC, 2006; Sanz et al., 2017).

Sub-Saharan Africa which is the most tropical region in the world is already experiencing and is predicted to further face the full wrath of climate change (IPCC, 2001). Amongst those who are already suffering and are expected to suffer the most from exponential changes in climate, are smallholder farmers who depend almost completely on rain-fed agriculture coupled with the deeply entrenched poverty amongst this population strata (Bishaw et al., 2013; World Bank, 2013). This therefore leaves smallholder farmers appallingly vulnerable to the whims and caprices of a variable and changing climate. With the continuous wholesale neglect of rain-fed agriculture by policy makers in sub-Saharan Africa and failure to make adequate investment in inputs such as improved seeds, fertilizer and irrigation, smallholder farmers who are the principal actors involved in rain-fed agriculture increasingly find themselves on the back foot as far as keeping pace with the changing climate conditions is concerned (Cooper, 2004). The prevalent punitive environmental conditions have pushed smallholder farmers to indulge in unsustainable and less productive agricultural practices in their drive to counter the unpredictable climate conditions.

Increasingly, some relatively rich smallholder farmers in sub-Saharan Africa are taking to very intensive agricultural practices as adaptive measures to counter soil fertility loss caused by climate change and other drivers (Mboh et al., 2013a; Tondoh et al., 2015). These adaptive measures include application of mineral fertilizers, pesticides, insecticides and herbicides at rates that are far from being environmentally benign, all in a bid to increase agricultural productivity. Though these practices enhance agricultural productivity in the short run, in the long run, productivity reduces tremendously owing to the unsustainable nature of such intensive agricultural practices (Tondoh et al., 2015). Meanwhile the very poor smallholder farmers in sub-Saharan Africa (who constitute the bulk of the smallholder farmers' population) resort to practices such as clearing their farm plots by setting them on fire, shifting cultivation, and piling of cleared grasses within mounds of soil and burning them (a practice called "Ankara" in the North-West Region of Cameroon). All these practices lead to increased productivity in the short run but in the long run, crop productivity drastically reduces owing to the non-durability of such practices. Shifting cultivation in particular has been identified by various studies as being the main cause of deforestation in sub-Saharan Africa (Alao and Shuaibu, 2013; Vaast and Somarriba, 2014). With smallholder farming systems in sub-Saharan Africa facing sustainability and productivity crises especially under the current changing climate conditions, it therefore becomes incumbent to identify, document and promote sustainable, productive, pro-poor and climate-smart practices that can help smallholder farmers attain the twin goals of agricultural sustainability and productivity.

Factoring in the foregoing, agroforestry practices therefore come in handy as a partial panacea to remedy the deplorable situation of smallholder farmers in sub-Saharan Africa. This is because agroforestry is a dynamic, ecologically based, natural resources management system where in, trees are integrated in farms and in the landscape, thereby diversifying and sustaining production leading to increased social, economic and environmental benefits for land users at all levels (Leakey, 1996). Agroforestry practices constitute one of the most conspicuous farming systems across many parts of sub-Saharan Africa (Mbow et al., 2013a; Kabir et al., 2015; Lasco et al., 2015; CGIAR, 2017; Catacutan et al., 2017). Though very conspicuous, few studies have actually investigated the potential of this practice to enhance agricultural sustainability and productivity in sub-Saharan Africa. This review paper therefore seeks to unearth the potential contributions of agroforestry practices to agricultural sustainability and productivity enhancement in sub-Saharan Africa, in the context of climate change.

## Categorization of major agroforestry practices in sub-Saharan Africa

Agroforestry practices can be classified under three (03) major systems (Table 1); agro-silvicultural systems, silvi-pastoral systems and agro-silvi-pastoral systems (Torquebiau, 2000; Garrity et al., 2006; Schoene et al., 2007; Rao et al., 2007). Agro-silvicultural systems are the

*Corresponding author. E-mail: mtchamba@yahoo.fr.

**Table 1.** Agroforestry systems and practices in sub-Saharan Africa.

| Systems | Practices | Combination | Components |
|---|---|---|---|
| Agro-silvicultural Systems | 1. Improved fallows | trees planted during non-forest phase if land not expected to revert to forest | t: fast growing<br>h: agricultural crop |
| | 2. Taungya | crops during tree seedling stage | w: plantation species<br>h: agricultural crops |
| | 3. Alley cropping | trees in hedges, crops in alleys | w: coppice trees<br>h: crops |
| | 4. Tree gardens | Multi-species, dense, Mixed | w: vertical structure, fruit trees<br>h: shade tolerant |
| | 5. Multipurpose trees on cropland | trees scattered, boundaries | w: multipurpose trees<br>h: crops |
| | 6. Estate crop Combinations | | w: coffee, coconut, fruit trees<br>h: shade tolerant |
| | 7. Homegardens | multistorey combinations around homes | w: fruit trees<br>h: crops |
| | 8. Trees in soil conservation, reclamation | | w: multipurpose fruit trees<br>h:crops |
| | 9. Shelterbelts, windbreaks, live hedges | around farmland plots | w: trees<br>h:crops |
| | 10. Fuelwood Production | firewood species around cropland plots | w: firewood species<br>h: crops |
| Silvi-pastoral Systems | 11.Trees on rangelands | scattered trees | w: multipurpose, fodder<br>f: present, a: present |
| | 12. Fodder banks | trees for protein-rich cut fodder | w: leguminous trees<br>h: present, a: present |
| | 13. Estate crops with Pasture | For example cattle under coconut palms | w: estate crops<br>f: present, a: present |
| Agro-silvi-pastoral Systems | 14. Homegardens with Animals | around homes | w: fruit trees<br>a : present |
| | 15.Multipurpose woody hedgerows | trees for browse, mulch, soil protection | w: coppicing fodder trees<br>a, h: present |
| | 16. Aquaforestry | trees lining ponds | w: leaves forage for fish |

Source: Schoene et al. (2007) in Rao et al. (2007) w: woody species, a: animals, h: herbaceous (crop) species.

most ubiquitous agroforestry systems found across landscapes in sub-Saharan Africa with about ten (10) practices scattered across different agro-ecological zones of the region. There are few silvi-pastoral and agro-silvi-pastoral practices in sub-Saharan Africa when compared to agro-silvicultural practices. This may be due to the simplicity and ease to manage agro-silvicultural practices when compared to the complexities associated with especially the agro-silvi-pastoral system. The multifarious agroforestry practices in sub-Saharan Africa portray the importance of these practices to smallholder farmers especially in the context of an increasingly variable and changing climate.

## Agroforestry and agricultural sustainability enhancement in the context of climate change

Following Pretty (2007), the concept of agricultural sustainability today revolves around developing agricultural techniques and practices that have positive effects on the environment, easily available and effective to farmers, improves food productivity and positively impacts environmental goods and services. Sustainability in agricultural systems therefore embodies many concepts like resilience and sustenance, as well as other broader economic, social and environmental issues. The four (04) key principles of agricultural sustainability according to Pretty (2007) are; to integrate into food production processes, biological and ecological processes such as competition, parasitism, nutrient cycling, predation, nitrogen fixation, soil regeneration and allelopathy; to ensure that non-renewable inputs that are a menace to the environment or to the health of farmers and consumers are minimized; to make proper use of human capital by beefing up self-reliance and substituting costly external inputs through the putting into use of farmers' indigenous knowledge; and to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest and credit management by making productive use of people's collective capacities to work together.

Catacutan et al. (2017) concludes that agroforestry practices fit perfectly within these principles of agricultural sustainability because they contribute immensely to addressing several sustainability issues through the provision of ecosystem services like biological diversity conservation, provision of wood and non-timber products, maintenance of ecosystem integrity, soil and water quality improvement, terrestrial carbon storage and multifarious socio-economic benefits. According to the World Bank (2004), about 1.2 billion rural persons around the world currently practice agroforestry on their farms and in their communities, and depend upon its products, and most of these people are smallholder farmers living in village communities in sub-Saharan Africa.

Climate change in particular and other drivers in general have led to a steady decrease in soil fertility thereby seriously destabilizing the practice of sustainable agriculture in sub-Saharan Africa (Young, 1989; Garrity et al., 2006; Oke and Odebiyi, 2007). Soil degradation especially topsoil erosion has worsened in recent years and is probably to be further worsened by prolong removal of crop residues and surface litter (Muchena et al., 2005). Discussions on food security in sub-Saharan Africa today have been tilted towards sustainable agroforestry practices owing to the shortage of mineral fertilizers, the inability of smallholder farmers to purchase the available mineral fertilizers and the poor performance of existing agricultural policies (Mbow et al., 2013a).

Agroforestry has enormous potentials to enhance the fertility of the soil (Catacutan et al., 2017). This is basically due to the fact that the leguminous trees integrated in agroforestry-based farming systems contribute to biological nitrogen fixation and an amelioration of soil organic matter. The role of green mulch from leguminous trees to the enhancement of soil fertility for associated crops in agroforestry systems in the tropics has been evaluated by many studies (Garnett et al., 2013). These studies have found in most cases that the integration of trees on farms enrich the soil with nutrients and organic matter and facilitate tighter nutrient cycling, as well as enhancing soil structural properties than monoculture systems (Mbow et al., 2013b). Waliyar et al. (2003) and Garrity et al. (2010) found that the integration of trees in farmlands helps with the recovery of nutrients, the conservation of soil moisture and the improvement of soil organic matter through the tapping of water from deeper soil horizons and preventing the leaching of nutrients.

Bayala et al. (2008) on their part found that trees integrated in croplands improved the structural stability of the soil, enhanced water infiltration through tree roots and increased the number of soil pores which improved water storage. Lott et al. (2009) demonstrated that, macro pores in the soil channel excess surface water flow and allow air and moisture to move into the soil speedily thereby reducing the risk of soil erosion; meanwhile tree roots and trunks reduce surface flow of water and sediment by acting as physical barriers. Mueller et al. (2012) found that, trees in croplands greatly influenced the addition of nutrients associated crops through the interception of rainfall, by way of throughfall (rainwater falling through tree canopies) and stemflow (rainwater falling down branches and stems). Molua (2006) stated in clear terms that agroforestry has huge potentials to reduce the yield gap, but this is largely dependent on the biophysical and human context under which it is practiced, hence he proposes a slate of improved agroforestry techniques such as soil improving trees, trees that grow very fast for fuel wood, indigenous fruit trees that provide added nutrition and income, and trees that provide medicinal plant products. This explains why Rice (2008); and Oke and Odebiyi (2007) emphasized on the absolute necessity to differentiate between simple agroforestry practices (like alley cropping, intercropping, life fences, and hedgerows) and complex agroforestry practices that function more or less like natural forest ecosystems but are still integrated into agricultural management systems (like multipurpose hedgerows and Aquaforestry).

Dosskey (2001) conducted a study which demonstrated that it is possible to reduce pollution from crops and grazed pastures through agroforestry. Following this study, tree strips located close to rivers, streams or lakes reduces water pollution from farmlands in five major ways: reducing surface runoff from fields; filtering surface runoff; filtering groundwater runoff; reducing bank erosion; and filtering stream water. According to Lott et al. (2009), trees in croplands have deeper roots which captures leached out nutrients from the crop rooting zone, reducing pollution and enhancing the efficiency of nutrient use. Lott et al. (2009) demonstrate that a permanent tree component helps to capture nutrients and store for use during the next planting season which is not the case with monocultures where the soil remains bare after harvest. According to Borin et al. (2009), buffer strips greatly reduce pollution from run-off, with reductions of between 70 to 90% for suspended solids, 60 to 98% for phosphorus and 70 to 95% for nitrogen. Borin et al. (2009) equally demonstrate that runoff can be reduced and infiltration increased if riparian buffers and other agroforestry practices are implemented by smallholder farmers.

Following a study conducted by Jose (2009), agroforestry practices contribute to the preservation of biodiversity owing to their naturally higher diversity of components than monocultures of crops and livestock which usually have a single component (crops only, livestock only or trees only). Jose (2009), further demonstrates that biodiversity can be preserved through agroforestry in five major ways: preserving the germplasm of threatened species; reducing the rates of transformation of natural habitat and reduce resource use pressure; habitat for species that can tolerate some degree of perturbation; providing connectivity through corridors created between habitat remnants and the conservation of threatened floral and faunal species; conserving biodiversity by providing ecosystem services like water recharge and erosion control, preventing the degradation and loss of habitats.

Schoeneberger and Ruark (2003), Du-Toit et al. (2004), McNeely and Schroth (2006), Harvey and Gonzalez-Villalobos (2007) and Bhagwat et al. (2008) have all demonstrated that, agroforestry plays a major role in conserving biodiversity. These studies show that agroforestry based farming systems integrate plant and animal species that are (in some cases) as rich and diverse as natural forests, but composed of mostly non-forest species.

Lal (2004), Verchot et al. (2007), Schoeneberger (2009), Nair et al. (2009), Catacutan et al. (2017), CGIAR (2017) and Sanz et al*. (*2017) have found that agroforestry practices in smallholder farming systems contribute to climate change mitigation and adaptation. Following Jose (2009), there has been an increase in research over the last two decades looking at the potential of agroforestry as a practice to tackle the nefarious effects of climate change. Research shows that agroforestry owing to the incorporation of trees and shrubs, increases the quantity of carbon sequestered compared to monocultures of crops or animals (Sanz et al., 2017). Following Schroeder (1994), a great amount of carbon is stored by woody perennials in above ground biomass as well as contributing to belowground carbon sequestration in soils. Nair et al. (2009) found that agroforestry systems store an estimated average of 21 and 50 Mg C $ha^{-1}$ of carbon in sub-humid and humid zones, respectively. According to Dixon (1995), over fifty (50) years, agroforestry systems can contribute to sequester 1.9 Pg of carbon, following a worldwide estimate of 1023 million ha of agroforestry. Watson et al. (2000) on their part found that 585 to 1274 x $10^6$ ha of suitable land could be used for the establishment of agroforestry systems at the global scale contributing to storing 12 to 228 Mg C $ha^{-1}$. Thus, it is estimated that 630 million ha of unproductive croplands and grasslands could potentially sequester 586,000 Mg C $yr^{-1}$ by 2040 should agroforestry systems take the place of these unproductive croplands and grasslands.

According to Oke and Odebiyi (2007), agroforestry systems constitute the third largest carbon sink in Africa after primary forests and long term fallows. Compared to monoculture systems, agroforestry systems contribute to greater abatement of greenhouse gases especially $CO_2$, $N_2O$ and $CH_4$ (Mutuo et al., 2005). Albrecht and Kandji (2003) found that $N_2O$ emissions are reduced drastically in agroforestry systems owing to a reduction in the application of supplementary nitrogen as inorganic nitrogen recycled from leaf litter and made available to associated crops. Thevathasan and Gordon (2004) ran models demonstrated that, the release of nitrates is reduced by an estimated 50% when compared to a monoculture based system. Models estimate that nitrates leaving a tree-based intercropping system can be reduced by 50% compared to a monoculture system. Agroforestry is therefore a multifunctional land-use system that contributes to climate change mitigation and adaptation simultaneously. There are few existing options that can do this, thus there is need to document, promote and encourage the adoption and implementation of sustainable agroforestry practices especially amongst smallholder farmers.

Studies have equally demonstrated that agroforestry-based farming systems provide various socio-economic benefits which go a long way to aid in adaptation to climate change and enhance the sustainability of smallholder farming systems (Smith, 2010). In the economic sphere, agroforestry practices enhance financial benefits through the diversity of local products and services they provide; advance the skills of the rural population and increases employment opportunities; and reduces reliance on fossil fuels for energy. Socially, agroforestry practices play cultural, aesthetic and recreational roles. Though the social aspect of agroforestry is often overlooked, its importance to the local population and the public cannot be underrated (Smith, 2010).

The World Agroforestry Centre (ICRAF) has conducted studies which show that agroforestry systems can contribute to the attainment of between six to seven Sustainable Development Goals (SDGs) (especially in the case of the rural poor and smallholder farmers in sub-Saharan Africa) which are: combating hunger, poverty, disease, illiteracy, environmental degradation, climate change and discrimination against women. ICRAF has demonstrated that agroforestry can contribute to the eradication of hunger through its ability to improve soil fertility and enhance the regeneration of land, thereby improving crop productivity and food security. Agroforestry can further contribute to poverty alleviation through the marketing of the numerous products and services obtained from agroforestry systems which improves the incomes of smallholder farmers.

Agroforestry can equally improve the health and nutrition of the rural poor through the utilization of medicinal plants, food crops, fruits and animal products found in agroforestry based systems. Agroforestry also contributes to reduce environmental degradation through the conservation of biodiversity *ex-situ* and the protection of watersheds. Combating climate change and its nefarious effects is also possible through agroforestry as it contributes to climate change mitigation through carbon sequestration especially by the tree component in the system.

Lastly, agroforestry contributes to the empowering of women thereby fostering gender parity. This is because agroforestry is mostly practiced by women in rural areas which give them the possibility to make income and be independent. With the "food-fuel-biodiversity" palaver continuing to be a thorn in the flesh of many development stakeholders, agro-ecosystem based farming systems like agroforestry become a necessity (Mbow et al., 2012; Fobissie et al., 2014). Little wonder, Leakey (2010) calls for the uptake of multifunctional landuse systems (like agroforestry) which simultaneously meet fuel, food, environmental and biodiversity protection needs as well as resilience enhancement to climate change. Smith (2010) conducted a study, which showed that there is a great desire by the research community and policy makers to find and promote agricultural systems that proffer environmental and ecosystem services, with agroforestry identified as one of the few existing practices today.

It was within this framework that, this study sought to look at the place of agroforestry in enhancing agricultural sustainability under changing climate conditions, especially its role in climate change mitigation and resilience enhancement in smallholder farming systems.

## Agroforestry and agricultural productivity improvement under changing climate conditions

Agricultural productivity is generally seen as a measure of the amount of agricultural output produced for a given amount of input. Under changing climate conditions especially in the case of sub-Saharan Africa, the productivity benefits accruing from agroforestry-based farming systems are quite marveling. In studies conducted on agroforestry systems by Garity et al. (2006), Jackson et al. (2000) and Catacutan et al. (2017), there is general unanimity that a higher level of productivity occurs in agroforestry systems than in monoculture systems owing to the complementary relationship that exists between trees and crops, as the deep tap roots of trees capture and supply nutrients to crops that crops on their own would not capture. This fits squarely with the ecological theory of niche differentiation according to which resources are captured from different parts of the environment by different species. In a study carried out by Smith (2010), it was observed that crops are unable to absorb soil nutrients, water and leached nutrients from deep underground soil horizons hence the tree component on croplands helps to capture these nutrients and water, making it available at the level of the crop's rhizosphere. Garrity et al. *(*2006) found that, the complementarity that exists between trees and crops in an agroforestry system increase nutrient capture as well as crop yields compared to monoculture systems, owing to better nutrient cycling through leaf fall and fine root decay in the agroforestry system. A study conducted by Leakey (2010) found that agroforestry systems are endowed with a wide array of products and services such as food, fuelwood, timber, gums and resins, thatching and hedging materials, gardening materials, medicinal products, crafts products and recreation. Mead and Willey (1980) came up with a ratio for comparing productivity in agroforestry and monoculture systems, known as the Land Equivalent Ratio (LER). Following Mead and Willey (1980), "the LER is calculated as the ratio of the area needed under monoculture to the area of agroforestry at the same management level to obtain a particular yield". As stated by Dupraz and Newman (1997), "an LER of 1 indicates that there is no yield advantage of agroforestry compared to monoculture, while an LER of 1.1 indicates a 10% yield advantage that is under monocultures, 10% more land would be needed to match yields from agroforestry". Dupraz and Newman (1997), however found that the LER has a drawback which is the fact that, it does not take into consideration the services that agroforestry systems provide like air quality regulation, climate buffering, flood control, water quality regulation, and pest and disease control. This goes to show that, should all these services be taken into consideration when computing for the LER, agroforestry's productivity will far exceed that of monocultures.

A study conducted by Jose et al. (2004) demonstrated that agroforestry systems play a key role in microclimate buffering, especially its tree component. Following this study, trees on croplands play a positive role in inducing crop growth and animal welfare owing to their ability to buffer microclimatic elements like temperature, wind speed, and water vapour present in the atmosphere. Tamang et al*.* (2010) found that trees on croplands helped to reduce wind speed by up to 30 times the height of the trees on the leeward side, preventing crop destruction and increasing crop productivity. Tamang et al*.* (2010) further demonstrate that wind speed reduction by the tree component in agroforestry systems helps crops to grow faster, protects crops from windblown soil, controls soil moisture content and protects the soil from erosion, thereby leading to an increase in productivity. Brandle et al. (2004) conducted a study which demonstrated that higher air and soil temperature on the leeward side of trees found in agroforestry systems, helps to extend the growing season, as crops germinate earlier and grow faster at the start of the season. They equally discovered that, agroforestry systems bolster animal welfare as the multifunctional role of trees provides animals with resources like shelter from the rain and wind, shade from the sun, different foraging materials, and hideouts from predators. The trees can also benefit from the interaction with animals in a silvi-pastoral agroforestry system, as the excrements of the animals contribute to fertilize the trees and thus enhancing growth compared to a treeless rangeland (Ponder et al., 2005). This mutually beneficial relationship contributes to enhance the productivity of the system.

According to Schroth et al. (2000), agroforestry systems contribute to a reduction in pest problems owing the higher level of diversity and complexity present in agroforestry systems compared to monoculture systems. An earlier study had been conducted by Vandermeer (1989), showing that pest problems are attenuated in an agroforestry system due to several factors: pests find it difficult to discover plants due to a variable distribution of host plants; some associated economically valuable species are protected from attack because a plant species which is very attractive to pests can act as “trap-crop”; some plant species are repellant to pests which helps to deter the pests from attacking other palatable plant species in the vicinity; the spread of pests is limited owing to increased inter-specific competition between pest and non-pest species. Following Young (1989), Stamps and Linit (1998) and Schmidt and Tscharntke (2005), agroforestry systems if well managed enhances pest control owing to its ability to provide sources of adult parasitoid food like flowers and sites for oviposition, resting and mating as well as more structural and microclimatic diversity, more biomass, diverse pollen sources, nectar, and stable refuge for pests.

Wilkins (2008) conducted a study which showed that agroforestry systems help smallholder farmers to reduce the use of inorganic inputs. Following this study, it was found that the tree-crop interaction in agroforestry systems increases ecosystem efficiency through improved nutrient recycling thereby reducing the necessity for external inputs. The study further stated that a landuse system is ecologically efficient if, there is a greater efficiency and sustainability of the resources used in agricultural production. This efficiency is attained when a higher level of agricultural production is obtained using fewer resources while ensuring environmental protection. According to BCPC (2004), agroforestry possesses five key attributes which make it an ecologically efficient farming system: efficient use of resources especially renewable resources; no pollution both internally and externally; foreseeable output; ecological processes are aided through the conservation of biodiversity; ability to quickly respond to changes in the socio-economic and biophysical environment. The study shows that compared to monoculture systems, improved agroforestry systems can meet all five of the above mentioned criteria, thus enhancing the economic base and increasing farm profitability. Owing to the deeply entrenched poverty amongst smallholder farmers in sub-Saharan Africa, agroforestry systems are often managed conventionally with little or no additional inputs. This therefore permits agroforestry systems to realize their full potential as a sustainable and low-input system.

Young (1989) conducted a study which demonstrated that agroforestry systems favour the proliferation of soil micro and macro organisms owing to the differences in litter quality between the tree and crop components in an agroforestry system. The study further showed that soil micro and macro organisms carry out numerous soils biological processes leading to sustained productivity in agroforestry systems. Garrity et al. (2006) equally found that differences in the quality and quantity of litter in agroforestry systems leads to greater microbial diversity, increased enzyme activity and greater stability in agroforestry systems compared to monoculture systems. According to Schädler et al. (2010), Arbuscular mycorrhizal (AM) fungi present in most agroforestry systems, enhances crop yields while reducing the need for chemical fertilizer input. This is done through the facilitation of plant nutrient uptake and growth, soil aggregation and soil stability and the rate of litter decomposition. The foregoing discussion goes a long way to show that agroforestry is a good candidate for agricultural productivity enhancement under the prevailing changing climate conditions.

## Trade-offs between sustainability and crop yields in agroforestry systems

In the food-focused smallholder farming systems in sub-Saharan Africa, trade-offs emerge between agricultural sustainability and improved crop yields (Figure 1a and b). With food demand expected to double in the next 50 years owing to population explosion, food production will become an issue and natural resources will be skinned terribly unless sustainability concerns are taken into consideration (Tilman et al., 2002). Studies show that agroforestry systems through the ecosystem services provide, contribute to agricultural sustainability enhancement than their monoculture counterparts (Elmqvist et al., 2011; Vaast and Somarriba, 2014).

However, studies also demonstrate that monoculture systems improve agricultural yields at the expense of other ecosystem services owing to limited diversity and limited competition between the components on the farm compared to agroforestry systems (Gockowski and Sonwa, 2010; Tondoh et al., 2015).

Under the current changing climate conditions in sub-Saharan Africa, agroforestry practices are therefore the best option for smallholder farmers as evidenced by the numerous ecosystem services they provide, which

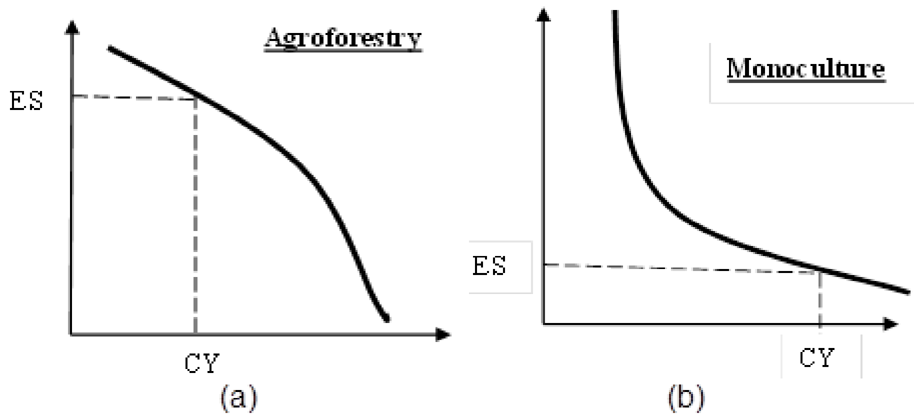


**Figure 1.** (a) Agroforestry and (b) Monoculture practices (ES = Ecosystem Services, CY = Crop Yields). Source: Adapted from Elmqvist et al. (2011).

contribute to enhance the resilience of smallholder farming systems. Monoculture systems are only able to enhance crop yields, but provide few or no ecosystem services, and under the prevailing changing climate conditions, monoculture systems are unsustainable (Tondoh et al., 2015).

## Conclusion

This review paper found that sustainable agroforestry practices could contribute to the simultaneous attainment of the twin goals of agricultural sustainability and improved agricultural productivity in the context of climate change in sub-Saharan Africa. More attention therefore needs to be tilted towards agroforestry especially during international environmental conferences and forums owing to the social, economic and ecological benefits of this practice. Promoting agroforestry into the mainstream however necessitates three key tools: research, dissemination of information, and favourable policies.

Scientific research in the domain of agroforestry is still very limited and mainly global, thus the need for more locally based research in order to better decipher the realities on the ground (for local problems imperatively need local solutions). Awareness raising on the benefits of agroforestry amongst smallholder farmers is essential to trigger intensification as well as adoption and implementation. Favourable policies equally need to be implemented in order to incentivize smallholder farmers to take up agroforestry.

Factoring in the above it is imperative that locally based scientific research on agroforestry be conducted in sub-Saharan Africa adopting the participatory approach in order to understand farmers' problems and propose proper solutions. Additionally, research on agroforestry should be conducted to assess how to quantify and assign costs to the various ecosystem services provided by agroforestry-based farming systems, in order to pave the way for payments of ecosystem services to smallholder farmers practicing agroforestry.

## ACKNOWLEDGEMENTS

We are immensely thankful for the moral and material support received from the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang, Cameroon.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

### REFERENCES

Alao JS, Shuaibu RB (2013). Agroforestry practices and concepts in sustainable land use systems in Nigeria. Journal of Horticulture and Forestry 5(10):156-159.

Albrecht A, Kandji ST (2003). Carbon sequestration in tropical agroforestry systems. Agriculture, Ecosystems and Environment 99:15-27.

Bayala J, Heng LK, Noordwijk MV, Ouedraogo SJ (2008). Hydraulic redistribution study in two native tree species of agroforestry parklands of West African dry savanna. Acta Oecologica doi:10.1016/j.actao.06.2008010.

British Crop Protection Council (BCPC) (2004). Enhancing the Eco-Efficiency of Agriculture, British Crop Protection Council: Alton, Hampshire. http://randd.defra.gov.uk/Document.aspx?Document=IS0217_2040_FRP.doc

Bhagwat SA, Willis KJ, Birks HJB, Whittaker RJ (2008). Agroforestry: a refuge for tropical biodiversity? Trends in Ecology and Evolution 23(5):261-267.

Bishaw B, Neufeldt H, Mowo J, Abdelkadir A, Muriuki J, Dalle G, Assefa T, Guillozet K, Kassa H, Dawson IK, Luedeling E, Mbow C (2013). Farmers' strategies for adapting to and mitigating climate variability and change through agroforestry in Ethiopia and Kenya, edited by Caryn M. Davis, Bryan Bernart, and Aleksandra Dmitriev. Forestry Communications Group, Oregon State University, Corvallis, Oregon.

Borin M, Passoni M, Thiene M, Tempesta T (2009). Multiple benefits of buffer strips in farming areas. European Journal of Agronomy 32:103-111.

Brandle JR, Hodges L, Zhou XH (2004). Windbreaks in North American agricultural systems. Agroforestry Systems 61:65-78.

Catacutan DC, van Noordwijk M, Nguyen TH, Öborn I, Mercado AR (2017). Agroforestry: contribution to food security and climate-change adaptation and mitigation in Southeast Asia. White Paper. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Jakarta, Indonesia: ASEAN-Swiss Partnership on Social Forestry and Climate Change.

CGIAR Research Program on Forests, Trees and Agroforestry (FTA) (2017). Climate change mitigation and adaptation. http://www.cifor.org/publications/pdf_files/brochures/6570-FTAbrochure.pdf

Cooper P (2004). Coping with Climatic Variability and adapting to Climate Change: Rural water management in dry land areas, Discussion Paper, IDRC, London.

Dixon RK (1995). Agroforestry systems: sources or sinks of greenhouse gases? Agroforestry Systems 31:99-116.

Dosskey MG (2001). Toward quantifying water pollution abatement in response to installing buffers on crop land. Environmental Management 28(5):577-598.

Dupraz C, Newman SM (1997). Temperate Agroforestry: The European Way, in Temperate Agroforestry Systems, A.M. Gordon and S.M. Newman, Editors. CAB International: Wallingford.

Du-Toit JT, Walker BH, Campbell BM (2004). Conserving tropical nature: current challenges for ecologists. Trends in Ecology and Evolution 19:12-17.

Elmqvist T, Tuvendal M, Krishnaswamy J, Hylander K (2011). Managing Trade-offs in Ecosystem Services. Ecosystem Services Economics (ESE) Working Paper Series. Division of Environmental Policy Implementation Paper Number 4.

Fobissie K, Alemagi D, Minang PA (2014). REDD+ Policy Approaches in the Congo Basin: A Comparative Analysis of Cameroon and the Democratic Republic of Congo (DRC), Forests 5:2400-2424.

Food and Agricultural Organization (FAO) (2016). Climate change and food security: risks and responses. http://www.fao.org/3/a-i5188e.pdf

Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, Hoffmann I, Smith P, Thornton PK, Toulmin C, Vermeulen SJ, Godfray HCJ (2013). Sustainable intensification in agriculture: premises and policies. Science 341(6141):33-34.

Garrity D, Okono A, Grayson M, Parrott S (2006). World Agroforestry into the Future. Nairobi: World Agroforestry Centre. http://www.worldagroforestry.org/downloads/Publications/PDFS/b14409.pdf

Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, Mowo JG, Kalinganire A, Larwanou M, Bayala J (2010). Evergreen agriculture: a robust approach to sustainable food security in Africa. Food Security 2:1970-2214.

Gockowski J, Sonwa D (2010). Cocoa Intensification Scenarios and Their Predicted Impact on $CO_2$ Emissions, Biodiversity Conservation and Rural Livelihoods in the Rainforest of West Africa, Environmental Management. https://link.springer.com/article/10.1007%2Fs00267-010-9602-3

Harvey CA, Gonzalez-Villalobos JA (2007). Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. Biodiversity and Conservation 16:2257-2292.

Intergovernmental Panel on Climate Change (IPCC) (2001). Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, NY.

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (eds), Cambridge University Press, Cambridge, United Kingdom.

Jose S (2009). Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems 76:1-10

Kabir KH, Billah MM, Sarker MA, Miah MAM (2015). Adaptation of farming practices by smallholder farmers in response to climate change. Journal of Agricultural Extension and Rural Development 7(2):33-40.

Lal R (2004). Soil carbon sequestration impacts on global climate change and food security. Science 304:1623-1627

Lasco RD, Espaldon MLO, Habito CMD (2015). Smallholder farmers' perceptions of climate change and the roles of trees and agroforestry in climate risk adaptation: evidence from Bohol, Philippines. Agroforestry Systems DOI 10.1007/s10457-015-9874-y

Leakey RRB (1996). Definition of agroforestry revisited. Agroforestry Today 8:5-7.

Leakey RRB (2010). Should we be growing more trees on farms to enhance the sustainability of agriculture and increase resilience to climate change: Special report, 2010. http://www.istf-bethesda.org/specialreports/leakey/Agroforestry-Leakey.pdf

Lott JE, Ong CK, Black CR (2009). Understorey microclimate and crop performance in a Grevillea robusta-based agroforestry system in semi-arid Kenya. Agricultural and Forest Meteorology 149:1140-1151.

McNeely JA, Schroth G (2006). Agroforestry and biodiversity conservation - traditional practices, present dynamics, and lessons for the future. Biodiversity and Conservation 15:549-554.

Mead DJ, Willey RW (1980). The concept of a 'land equivalent ratio' and advantages in yields from intercropping. Experimental Agriculture 16:217-228.

Mbow C, Skole D, Dieng M, Justice C, Kwesha D, Mane L, El-Gamri M, Von Vordzogbe V, Virji H (2012). Challenges and Prospects for REDD+ in Africa: Desk Review Of REDD+ Implementation in Africa. Copenhagen: GLP-IPO; 2012. http://www.worldagroforestry.org/downloads/Publications/PDFS/B17421.pdf

Mbow C, Smith P, Skole D, Duguma L, Bustamante M (2013a). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Current Opinion in Environmental Sustainability 6:8-14.

Mbow C, Van Noordwijk M, Luedeling E, Neufeldt H, Minang PA, Kowero G (2013b). Agroforestry solutions to address food security and climate change challenges in Africa. Current Opinion in Environmental Sustainability 6:61-67.

Molua EL (2006). The economics of tropical agroforestry systems: the case of agroforestry farms in Cameroon. Forest Policy and Economics 7:199-211.

Muchena FN, Onduru DD, Gachini GN, Jager DA (2005). Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. Land Use Policy 22:23-31.

Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012). Closing yield gaps through nutrient and water management. Nature 490:254-257.

Mutuo PK, Cadisch G, Albrecht Palm CA, Verchot L (2005). Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. Nutrient Cycling in Agroecosystems 71:43-54.

Nair PKR, Kumar BM, Nair VD (2009). Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science 172(1):10-23.

Oke DO, Odebiyi KA (2007). Traditional cocoa-based agroforestry and forest species conservation in Ondo State, Nigeria. Agriculture, Ecosystems and Environment 122:305-311.

Ponder F, Jones JE, Mueller R (2005). Using poultry litter in black walnut management. Journal of Plant Nutrition 28:1355-1364.

Pretty J (2007). Agricultural sustainability: concepts, principles and evidence. Philosophical Transactions of the Royal Society B: Biological Sciences 363:447-465.

Rice RA (2008). Agricultural intensification within agroforestry: the case of coffee and wood products. Agriculture, Ecosystems and Environment 128:212-218.

Sanz MJ, de Vente J, Chotte JL, Bernoux M, Kust G, Ruiz I, Almagro M, Alloza JA, Vallejo R, Castillo V, Hebel A, Akhtar-Schuster M (2017). Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany. http://www2.unccd.int/sites/default/files/documents/2017-09/UNCCD_Report_SLM.pdf

Schädler M, Brandl R, Kempel A (2010). "Afterlife" effects of mycorrhisation on the decomposition of plant residues. Soil Biology and Biochemistry 42:521-523

Schmidt M, Tscharntke T (2005). The role of perennial habitats for Central European farmland spiders. Agriculture, Ecosystems and Environment 105(1-2):235-242.

Schoene D, Killmann W, Von Lupke H, Loychewilkie M (2007). Definitional issues related to reducing emissions from deforestation in developing countries. Forests and Climate Change Working Paper No. 5, FAO, Rome, Italy; in Rao, K.P.C., Verchot, L.V., Laarman, J. (2007). Adaptation to climate change through sustainable management and development of agroforestry systems, SAT 4:1. ejournal/ejournal.icrisat.org

Schoeneberger MM (2009). Agroforestry: working trees for sequestering carbon on agricultural lands. Agrofor. Syst. 75:27-37.

Schoeneberger MM, Ruark GA (2003). Agroforestry – Helping to achieve sustainable forest management, report delivered at the UNFF intersessional experts meeting on the role of planted forests in sustainable forest management, 24-30 March 2003, New Zealand

Schroeder P (1994). Carbon storage benefits of agroforestry systems. Agroforestry Systems 27: 89-97

Smith J (2010). Agroforestry: Reconciling Productivity with Protection of the Environment. A synopsis of research literature; The Organic Research Centre. http://orgprints.org/18172/1/Agroforestry_synopsis.pdf

Stamps WT, Linit MJ (1998). Plant diversity and arthropod communities: Implications for temperate Agroforestry. Agroforestry Systems 39:73-89.

Tamang B, Andreu MG, Rockwood DL (2010). Microclimate patterns on the leeside of single-row tree windbreaks during different weather conditions in Florida farms: Implications for improved crop production. Agroforestry Systems 79(1):111-122.

Thevathasan NV, Gordon AM (2004). Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada. Agroforestry Systems 61:257-268.

Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S (2002). Agricultural sustainability and intensive production practices. Nature P. 418.

Tondoh JE, Kouamé FN, Guéi AM, Sey B, Koné AW, Gnessougoud N (2015). Ecological changes induced by full-sun cocoa farming in Côte d'Ivoire. Glob. Ecol. Conserv. 3:575-595.

Torquebiau EF (2000). A renewed perspective on agroforestry concepts and classification. Comptes Rendus de l'Académie des Sciences 323:1009-1017.

United Nations Framework Convention for Climate Change (UNFCCC) (2006). United Nations Framework Convention on Climate Change: Handbook. UNFCCC Secretariat. Bonn, Germany.

Vaast P, Somarriba E (2014). Trade-offs between crop intensification and ecosystem services: the role of agroforestry in cocoa cultivation. Agroforestry Systems 88:947-956.

Vandermeer J (1989). The Ecology of Intercropping, Cambridge: Cambridge University Press.

Verchot LV, Noordwijk MV, Kandji S, Tomich T, Ong C, Albrecht A, Mackensen J, Bantilan C, Anupama KV, Palm C (2007). Climate change: linking adaptation and mitigation through Agroforestry. Mitigation and Adaptation Strategies for Global Change 12:901-918.

Waliyar F, Collette L, Kenmore PE (2003). Beyond the gene horizon: sustaining agricultural productivity and enhancing livelihoods through optimization of crop and crop-associated biodiversity with emphasis on semi-arid tropical agroecosystems. Proceedings of a workshop, 23-25 September 2002, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and viale delle Terme di Caracalla, Rome 00100, Italy: Food and Agriculture Organization of the United Nations (FAO). 206 pp. ICRISAT ISBN 92-9066-457-6 Order code CPE 146.

Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (2000). Land Use, Land-use Change and Forestry. A Special Report of the IPCC. 2000, Cambridge University Press: Cambridge, UK.

Wilkins RJ (2008). Eco-efficient approaches to land management: A case for increased integration of crop and animal production systems. Philosophical Transaction of the Royal Society B. 363:517-525.

World Bank (2004). Sustaining forest: A Development Strategy. World Bank, Washington DC.

World Bank (2013). Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington, DC:World Bank. License: Creative Commons Attribution—NonCommercial–No Derivatives 3.0 Unported license (CC BY-NC-ND 3.0).

Young A (1989). Agroforestry for Soil Conservation, C.A.B International, International Council for Research in Agroforestry Division of Environmental Policy Implementation Paper N° 4.