Vol. 13(40), pp. 2154-2162, 4 October, 2018
DOI: 10.5897/AJAR2018.13283
Article Number: FCEF26158725
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Sandy soil fertility restoration and crops yields after conversion of long term *Acacia senegal* planted fallows in North Cameroon

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Received 1 June, 2018; Accepted 3 September, 2018

Tree planted fallow is an agroforestry system that may restore degraded soils and protect them from erosion. In this study, sandy soils properties of *Acacia senegal* planted fallows (AF) were assessed and compared to those from the continuous cropped system (CC) in 3 sites from Northern Cameroon in order to determine its suitability to restore soil fertility and sustain crop productivity. Soil samples were collected from the topsoil (0 to 20 cm) and the subsoil (20 to 40 cm) and subjected to physicochemical analyses. The trials were established for 2 consecutive years, respectively with sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*). Results confirmed the sandy (more than 80% of sand) and acidic (4.42 ≤ pH ≤ 6.59) soil characters. In every site, topsoil from AF was relatively more fertile than from CC. Globally, nutrients content were influenced by tree density and fallow duration. The more improved elements were organic matter, nitrogen and pH. Sorghum and cowpea yields were quite variable depending on fallow duration, tree density and conversion form. The highest crop yields (3.4 tha^{-1} for sorghum and 2.4 tha^{-1} for cowpea) were obtained in 19 years old AF converted by partial clear-felling. The intercropping process by partial clear-felling of trees was the best conversion form. Overall findings indicated that fallowing with *A. senegal* can reduce soil acidity, restore nutrients and therefore it constitutes a suitable agroforestry system that may sustain annual crops productivity. However, researches have to determine the best tree density for intercropping and the tools for their sustainable management.

Key words: *Acacia senegal* fallow, agroforestry, sandy soils, continuous cropping, North Cameroon.

INTRODUCTION

Soils in sub-Saharan Africa are characterized by nutrients depletion along with time. In cultivated savannas, natural fallows became unable to restore their fertility and sustain productivity. Hence, the potential solutions to restore

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degraded soils reside in the planting of legume tree and the incorporation of woody perennials into cropping systems (Palm, 1995; El Tahir et al., 2009; Mubarak et al., 2011; Partey et al., 2011; Githae et al., 2013). Therefore, a concept of improved fallows was introduced and agroforestry is known as a common system of improved fallows observed in many parts of African countries (Rao et al., 1998). The almost used trees were *Faidherbia albida, Acacia auculiformis, Acacia nilotica* and *Acacia senegal* (El Tahir et al., 2009; Hadgu et al., 2009; Partey et al., 2011; Harmand et al., 2012; Omar and Muhammad, 2015).

Recent studies show how to arrange and measure of chlorophylls and effect of plants (Cetin, 2016). They also show that the plants have bioactive compounds. They explain how to cause inhibition of root growth, as well as reduced water absorption. Also, they research how on how to cause morphological, biochemical and physiological changes in plants of different species (Ibrahima et al., 2008; Cetin, 2016; Turkyilmaz et al., 2018). Recent studies show that medicinal plants are an important source of new chemical substances with potential materials. They research on both physical, chemical and biological and found that they are very valuable and effective medical plants (Cetin, 2017; Yigit et al., 2016).

When the recent work was being done, it affects the life of the city to spread the leaf of the leafy trees. Although the leaves can absorb CO_2, environmental pollution comes to the forefront when they are poured. Recent studies demonstrate how they affect human health with the air quality through PM_{10} (coarse particles) and CO_2 (Cetin et al., 2017; Sevik et al., 2018). Several studies on air pollution exposure showed that the problems about human health are associated to fine particulate organic matter concentration (Cetin et al., 2017).

Climatic factors are affected by temperature, wind, rain, and drought that people feel comfortable or not comfortable in the area because the planning and management are not well done. Some of these studies show that there is a range of bioclimatic comfort zone which people feel comfortable (Rao et al., 1998; Cetin, 2015; Sevik et al., 2018). Drought evaluation is very important as well as climatic ranges. Drought assessments give people an active scenario in the city to protect the damaging socioeconomic and politic problems. Recent studies with drought stress show monitoring of drought stress through various tools (Dawson, 1996; Yigit et al., 2016; Cetin et al., 2018).

A. senegal is a typical tree adapted to deep sandy soils which is widely observed in arid and semi-arid zones of Africa and is planted for gum arabic, wood production and animal nutrition (Isaac et al., 2011; Harmand et al., 2012). An integration of this tree in agroforestry system as a means of restoring the soil fertility and promoting gum arabic production was observed and has been widely published (Fadl, 2010; Palou Madi et al., 2010; Kissi, 2011). It was recognized and considered as one of the most successful forms of natural forests management in tropical dry lands. Also, the traditional *A. senegal* based agroforestry was observed as sustainable in terms of its environmental, social and economic benefits (Deans et al., 1999; Nasreldin, 2004; Kissi, 2011; Isaac et al., 2011).

In Northern Cameroon, between 1990 and 2006, rural development agencies such as Rural Development and Land Management (DPGT) and ESA/SODECOTON have encouraged smallholders to establish and manage *A. senegal* plantations (Mallet et al., 2002; Palou Madi et al., 2010; Kissi, 2011). These established plantations were extended between 2007 and 2011 through *Acacia* gum project financed by the European Union (Palou Madi et al., 2010). The introduction of this tree in agricultural farms was also to restore soil fertility and diversify sources of income for farmers through the production of gum arabic (Mallet et al., 2002; Palou Madi et al., 2010; Kissi, 2011). So, farmers planted this tree on marginal soils mainly sandy red soils which has been strongly depleted particularly in sudano sahelian zone in order to restore their fertility. After 15 years, gum production was reduced and was not beneficial. The plantations were then converted by farmers to different land resources management. Usually, their cropping by different management systems such as total clear-felling of trees or intercropping was observed (Kissi, 2011).

Sandy soils do not have the capacity to hold enough water and nutrients. The constraints to their cropping reside in their high permeability, their low organic matter content and their low fertility level which are responsible for water and nutrients stresses observed in crops (Basga and Nguetnkam, 2015). Cropping these soils consisted in increasing the organic matter content, nitrogen, nutrients levels and limits their degradation via erosion. Improved tree fallow is one of the possible approaches (Muthuri et al., 2005; Kissi, 2011). In semi-arid sub-Saharan, planting *A. senegal* seemed to be more adapted because of its high adaptation potential to drought and fodder generation for animal as well as wood and gum arabic (Nasreldin, 2004; Palou Madi et al., 2010; Abib et al., 2013). It can also stabilize sandy soils and restore their fertility, protecting them from erosion (Mallet et al., 2002; Harmand et al., 2012).

The effect of *A. senegal* tree on sandy soil fertility has been widely published all over the world mainly in arid environment such as Sudan, Ethiopia and Kenya (Gaafar, 2005; El Tahir et al., 2009; Fadl, 2010; Mubarak et al., 2011; Githae et al., 2013; Berhe and Retta, 2015). Unlike in many countries, an integration of this tree in Cameroon agroforestry systems was neither significant nor documented. Former studies always focused on improving gum arabic production or commercialization (Mallet et al., 2002; Palou Madi et al., 2010; Harmand et al., 2012; Mujawamariya et al., 2013; Abib et al., 2013). Little works had concerned soil fertility restoration at the

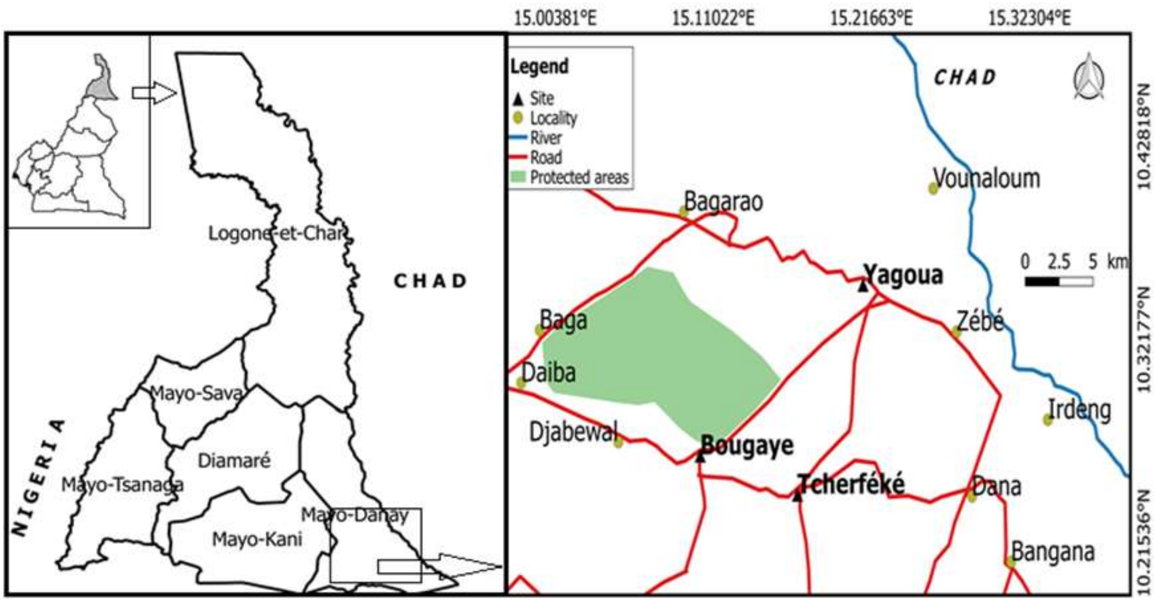

Figure 1. Location of the studied area.

lowest possible cost through their integration in agroforestry systems (Abib et al., 2013; Mujawamariya et al., 2013). So, studies on the conversion of these plantations or cropping these plantations were scarcely approached as well as assessment of soil fertility improvement potentiality (Kissi, 2011). This paper (1) determines the influence of *A. senegal* fallow duration on soil properties; (2) determines the effect of conversion form on sorghum and cowpea production and (3) assesses and compares sorghum and cowpea production of fallowed land to continuous cropping without *A. senegal*.

MATERIALS AND METHODS

Study area

The study was conducted in Northern Cameroon especially in Mayo Danay Division. The experiment was carried out in *A. senegal* plantations located in three sites, Yagoua, Bougaye and Tcherfeke (Figure 1). The main soil groups in studied sites are sandy deep soil developed on dunes sands classified as ferruginous and isolated lowland vertisols (Brabant and Gavaud, 1985; Raunet, 2003). They are acid and display a low content in organic matter and clay which is globally less than 10% (Raunet, 2003). The climate which is tropical made of two contrasting seasons: a humid season which occurs mainly from June to September and a dry season from October to May (L'Hote, 2000). The mean annual rainfall is 800 mm and the mean annual temperature is 28°C. The natural vegetation is savannah dominated by *Guieira senegalensis*, associated to *Balanites aegyptiaca, Faidherbia albida, Tamarindus indica, Zizifus mauritiana, Annona senegalensis* and *Acacia sieberiana* (Letouzey, 1985). Besides the natural vegetation, some *A. senegal* plantations were observed. These trees were tapered at the beginning of the dry season notably around November with regard to defoliation patterns for gum production. It is a source of income for many stakeholders (Harmand et al., 2012; Abib et al., 2013). The relief is smooth with some gentle sand dunes slopes. Geological formations are sedimentary rocks represented by sand dunes deposits. Agriculture, fishing and cattle breeding are the mains activities of populations. The most cultivated crops are millet, sorghum, rice and cowpea. The populations are poor and cannot supply external inputs (fertilizers, manure) to crops cultivated in depleted sandy soils.

Experimental design

A field trial was made during 2014-2015 and 2015-2016 growing seasons. Four *A. senegal* plantations of the farmers with different ages and plant density were selected in 3 sites (Yagoua, Bougaye and Tcherfeke). In Yagoua, *A. senegal* plantation was 16 years old and planted in a 4×4 m with 4 m spacing between the trees on the planting rows. Tcherfeké plantations were 18 and 19 years old and were planted, respectively in a 5×3 m and 5×5 m densities. Bougaye plantation was 15 years old. The overall characteristics of the different plantations are shown in Table 1.

The experimental design consisted of a 2 duplicated complete block design constituted by three treatments each one with 2 replications:

(1) A continuous cropping system without *A. senegal* tree (CC),
(2) *A. senegal* plantation after clear-felling and total removing of trees (AsCb),
(3) *A. senegal* plantation after clear-felling and total removing of one row over three (AsEc).

Each block was divided into 6 plots representing the 3 treatments with replication. Each plot size was 100 m² (10×10 m). AsEc had an average 6 trees per plot, while AsCb and control had no *A. senegal* tree.

Soil sampling and analytical procedure

Soils were sampled at different points of the trials plots mainly at

Table 1. Characteristics of the studied *A. senegal* plantations.

Site	Longitude and latitude	Altitude (m)	Soil type	Textural class	Plantation age (years)	Tree density (m)
Bougaye	10° 14’ 941’’ N; 15° 06’ 661’’ E	327	Ferruginous	Sandy	15	5×5
Yagoua	10° 19’ 584’’ N ; 15° 12' 994’’ E	336	Ferruginous	Sandy	16	4×4
Tcherfeké	10° 14’ 527’’ N; 15° 11’ 045’’ E	342	Ferruginous	Sandy	18	5×3
					19	5×5

topsoil (0 to 20 cm) and subsoil (20 to 40 cm) before tillage. In every site, a composite soil sample was obtained by mixing and quartered all samples collected at plots from *A. senegal* plantation. The same procedure was applied to the continuous cropped soils (control). Samples were air-dried and passed through a 2 mm sieve before analyses at the Institute of Agricultural Research for Development (IRAD) soils and plant laboratory at Yaoundé. Particle size distribution was determined by the pipette method following dispersion with sodium hexametaphosphate. Soil pH was measured in water and in KCl with pH meter equipped with a glass electrode in 1:2.5 soil-water suspensions. The soil organic carbon (OC) was measured by the wet oxidation method (Walkley and Black, 1934). The percentage of organic matter was calculated by multiplying the organic carbon values by the factor 1.72 in cropped soil and by the factor 2 in fallow soil. Total nitrogen was measured by the Kjeldahl method. Available phosphorus was determined by Bray II method. Exchangeable cations (Ca^{++}, Mg^{++}, K^+ and Na^+) were determined by Atomic Absorption Spectroscopy after extraction by ammonium acetate (CH_3COONH_4) using percolation method at pH 7 and cation exchange capacity (CEC) was determined using the sodium saturation method.

Plant materials and data recording

Plant materials were rainfed sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*) which are among the most important cereals and leguminous cultivated in North Cameroon and are considered as the main foods crop. Sorghum seed (*Zouaye* variety) and cowpea seed (*Lori* variety) were obtained at IRAD and sown at the spacing of 80 × 40 cm as recommended for the agro ecological zone. The seeds rates were 5 in each hole and plants were thinned to 2 plants 2 weeks later. A micro dose (4 g) of fertilizer (NPK, 20 10 10) was added in each hole of plant of replicated treatments. Data were collected only from the central rows of each plot, discarding the four marginal rows. Sorghum was grown for the first year (2015) of conversion and replaced by the cowpea in the second growing season (2016). Sorghum recorded data include stem height at 15, 35 and 75 days after sorghum lift (DAL) and yield by hectare for each treatment. Concerning cowpea, plants height, collar diameter, the number of ramifications and the number of matured pods mainly at the flowering and harvest stages were collected. During the trial, farmers which had *A. senegal* plantations or practice tree tapping were invited in every site to compare and appreciate growth and yield crops at different treatments especially at flowering and harvest time. Farmers were also called to appreciate soil restoration in the fallowed plantations.

RESULTS AND DISCUSSION

Soils physicochemical properties

Results showed that the studied soils have high proportion in sand (up to 88.55%) and a slight amount of fines elements which were globally less than 10% in topsoil (Table 2). This revealed a sandy texture grade of studied soils at surface horizon as mentioned by many researchers (Brabant and Gavaud, 1985; Raunet, 2003). It is also noted an increase of clay content from the topsoil to subsoil while an opposite trend was observed with sand content. This suggests that topsoil was eroded and reflects vertical washing. In the three sites, clay contents were similar between continuous cropping and *A. senegal* fallow. Soils from continuous cropping and from *A. senegal* fallow were not too different. This means that fallowing with *A. senegal* had little effect on soil texture. However, intercropping was recognized to protect soil from erosion and in this order, soils under this system may be more clayey than those under pure annual crop (El Tahir et al., 2009). This is because fine particles (clay and silt) are more susceptible to erosion and especially when cropped.

Soil chemical properties varied widely in different soils samples (Table 3). As noted in Table 3, pH H_2O was higher than pH KCl in all samples. According to Kasongo et al. (2009), a net negative charge is suggested. A decrease of pH values with depth was noted in all studied soils samples. Based to the pH values (H_2O and KCl) which were totally less than 6, these soils are strongly acidic. In *A. senegal* plantations, pH was relatively higher than in continuous cropping. Similarly to pH pattern, H^+ amount decreases according to depth with null values in topsoil from fallowed lands. This highlights a contribution of *A. senegal* tree in soils acidity reduction. This result is different from those published by Kasongo et al. (2009) which stated that the *Acacia auriculiformis* tree induces a clear acidification of topsoil. However, trees globally have potentiality to reduce soil acidity (Berhe and Retta, 2015).

Available phosphorus ranged between 0.207 and 13.746 $mgkg^{-1}$ and almost concentrated in topsoil while in subsoil, it was less than 1 $mgkg^{-1}$. Higher values were observed in *A. senegal* fallows (13.746 $mgkg^{-1}$ in Yagoua, 20.74 $mgkg^{-1}$ in Bougaye and 8.173 $mgkg^{-1}$ in Tcherfeke). The oldest fallow was not characterized by the highest amount of available phosphorus. This suggests that fallow duration did not influence phosphorus accumulation in soils under *A. senegal.* Palm (1995) reported that the pruning of trees species provides sufficient nutrients to meet crop demand except phosphorus. Soil organic

Table 2. Particles size distribution of sampled soils.

Soil depth	Topsoil (0-20cm)						Subsoil (20-40cm)					
	CCB	CCY	CCT	AF15	AF16	AF18	CCB	CCY	CCT	AF15	AF16	AF18
Clay	9.6	10.02	6.98	10.4	9.81	6.82	13.5	13.77	9.71	13.5	17.60	4.54
Fine silt	1.7	2.43	2.88	1.5	1.11	2.43	2.7	2.64	1.67	2.2	1.62	2.77
Coarse silt	9.1	2.73	6.24	6.6	3.10	5.74	7.9	3.19	4.76	5.9	3.49	5.80
Fine sand	61.6	68.81	72.30	56	73.01	73.01	56.3	65.36	70.19	53.4	66.89	74.19
Coarse sand	18	15.61	11.17	25.5	15.54	11.87	19.62	14.86	13.52	25	10.30	12.48

CCB: Continuous cropping system (control) in Bougaye; CCY: continuous cropping system in Yagoua; CCT: continuous cropping system in Tcherfeke; AF15: 15 years old *A. senegal* plantation; AF16: 16 years old *A. senegal* plantation; AF18: 18 years old *A. senegal* plantation.

Table 3. Soils chemical properties.

Parameter	Topsoil (0-20cm)						Subsoil (20-40cm)					
	Bougaye		Yagoua		Tcherfeké		Bougaye		Yagoua		Tcherfeké	
	CC	AF15	CC	AF16	CC	AF18	CC	AF15	CC	AF16	CC	AF18
pH H_2O	6.190	6.590	4.570	4.960	4.420	4.800	5.640	5.890	4.700	4.720	4.530	4.650
pH KCl	4.570	5.520	4.040	4.150	3.970	4.370	3.820	4.400	3.910	3.950	3.940	3.920
H^+	-	-	0.500	-	0.600	-	-	-	1.210	0.100	0.900	0.900
Pav $mgkg^{-1}$	9.066	20.740	3.311	8.173	3.927	13.746	5.150	7.398	0.207	0.518	0.310	2.687
OM gkg^{-1}	2.574	15.466	8.779	15.770	8.530	14.504	1.436	3.342	8.555	8.968	10.385	8.624
N tot gkg^{-1}	0.491	0.802	0.749	1.006	0.701	0.926	0.233	0.432	0.574	0.632	0.597	0.570
Ca^{++} $cmolkg^{-1}$	1.138	2.657	0.103	1.978	-	1.539	2.008	1.994	0.351	0.056	-	0.054
Mg^{++} $cmolkg^{-1}$	0.487	0.785	0.032	0.546	-	0.209	0.705	0.701	-	0.001	-	-
K^+ $cmolkg^{-1}$	1.856	3.420	0.155	0.517	0.066	0.221	1.928	2.152	0.113	0.178	0.012	0.078
Na^+ $cmolkg^{-1}$	1.369	-	0.027	0.018	0.011	0.012	-	1.018	0.026	0.027	0.006	0.018
CEC $cmolkg^{-1}$	1.247	2.825	7.682	6.628	6.120	7.087	2.993	3.514	5.734	8.959	7.655	4.018

CC: Continuous cropping system; AF15: 15 years old *A. senegal* plantation; AF16: 16 years old *A. senegal* plantation; AF18: 18 years old *A. senegal* plantation.

matter (SOM) varied between 8.530 and 15.770 $mgkg^{-1}$ with higher values in topsoil of fallowed plots. In continuous cropping soils, SOM was situated around 8 $mgkg^{-1}$ while in *A. senegal* fallow, these values reached 15 $mgkg^{-1}$ showing a positive effect of *A. senegal* tree on SOM content. The total nitrogen (N tot) which ranged between 0.570 and 1.006 $mgkg^{-1}$ follows similar trend as SOM. In subsoil, there were no significant differences. A significant and steady increase in SOM and N during *Acacia* species tree fallow were widely published (Deans et al., 1999; Kasongo et al., 2009; El Tahir et al., 2009; Mubarak et al., 2011; Berhe and Retta, 2015). The higher content in nitrogen could be linked to a direct N input from tree to soil as a consequence of leaf litter mineralization (Palm, 1995; Gaafar, 2005; Ibrahima et al., 2008; Fadl, 2010). *A.*

senegal is well known as a deciduous tree which shed their leaves during dry season (Gaafar, 2005; Harmand et al., 2012; Abib et al., 2013). The decomposition of leaf litter supplies N and organic carbon in soil inducing an increase of their levels within the soils (Gaafar, 2005; Kasongo et al., 2009; Mubarak et al., 2011; Fadl, 2010; Omar and Muhammad, 2015). Partey et al. (2011) emphasized that an addition of plant residues component to the soil plays an important role by improving soil structure, microbial activities, and nutrient status by recycling of plant nutrients. Its regulation plays an important role in poor soil in savannah from Northern Cameroon (Ibrahima et al., 2008). As all others leguminous species, *A. senegal* is recognized as a N_2-fixing tree and its ability to fix atmospheric nitrogen through their root system symbiosis with rhizobium was well documented (Isaac et al., 2011; El Atta et al., 2013; Githae et al., 2013). Furthermore, N fixed by *Acacia* is released into the soil through litter fall and root decay (El Atta et al., 2013). As expected, CEC was globally low in studied soils (less than 9 cmolkg^{-1}). This overall low CEC is in agreement with the sandy texture grade and the mineralogy dominated by kaolinite. Exchangeable bases were low and mainly dominated by Ca^{++}. The highest values of Ca^{++} (2.657 cmolkg^{-1}) and Mg^{++} (0.785 cmolkg^{-1}) were observed at the *A. senegal* topsoil while the lowest obtained in continuous cropping. In subsoil from these continuous cropped lands, Ca^{++} and Mg^{++} values were not detectable. The high values of Ca^{++} and Mg^{++} in topsoil might be due to the decomposition of fallen leaves which supply exchangeable bases in soil (Palm, 1995; Kasongo et al., 2009; Hadgu et al., 2009; Partey et al., 2011).

Yield and yield components

Sorghum height at 15, 35 and 75 days after lift (DAL) according to treatments are as shown in Figure 2. The higher values were recorded in AsCb while the lesser were obtained in CC (control). At 15 days after lift, sorghum height was not too different between AsEc and AsCb although it was relatively higher in AsCb (Figure 2).

Measured cowpea growth parameters are shown in Table 4. The higher growth data were observed on *A. senegal* fallowed plots. In these plots, AsEc treatment recorded the highest cowpea performance growth. This finding means that the partial clear-felling represents the best conversion form of old plantation than the total clear-felling.

Sorghum grain and cowpea yields in hectare according to the plantation age and the conversion form are presented in Figure 3. The continuous cropping system without tree (control) recorded the less crops yields which are globally less than 1 tha^{-1} and 1.5 tha^{-1}, respectively for sorghum and cowpea. The age of the plantation and the conversion form were highly influencing the crops yield. In fact, the old plantation (19 years) recorded the higher yields while the young (15 years) recorded the less. *A. senegal* fixes nitrogen in the soil and accumulates it during the fallowing period as well as organic carbon, improving soil fertility and leading to higher yields (Mallet et al., 2002; Isaac et al., 2011). The partial tree clear-felling seemed to be a better form of conversion because it recorded the higher sorghum (3.59 tha^{-1}) and cowpea (2.4 tha^{-1}) yields (Figure 3). Commonly, intercropping annual crops with tree species reduces crops yields because of the competition between trees and associated crops caused by tree density and size (Rao et al., 1998; Muthuri et al., 2005; Gaafar et al., 2006; Hadgu et al., 2009; Fadl, 2010). Furthermore, trees use the water in the topsoil where annual crops are grown rather than the water below (Raddad and Luukkanen, 2007). Obtained findings implied that no competition existed between sorghum and cowpea with *A. senegal* tree for water, light and nutrients leading to yield reduction. Furthermore, it shows that *A. senegal* trees in intercropping with sorghum or cowpea enhance their productivity. Several studies reported that the yields of intercrops in combination with pruned trees were not significantly different with their yields when grown alone (Ong et al., 2000; Droppelmann et al., 2000; Hadgu et al., 2009). This was made possible because *A. senegal* leaves area are low. This is in agreement with Dawson (1996) which stated that water use by trees is positively correlated to their leaf area. Also, the decomposition of fallen leaves and nutrient release rates of different agroforestry species are related to the quality of leaf material (Ibrahima et al., 2008; Partey et al., 2011). Muthuri et al. (2005) remarked that tree leafing phenology was also an important parameter promoting annual crops growth and yield in intercropping agroforestry system in Kenya. The high difference in yields observed between crops in fallowed plots (AsEc and AsCb) and in continuous cropped (CC) could be due in one hand to soil fertility improvement through trees litter fall and on the other hand to the microclimate created which were favorable to crops growth. In fact, *A. senegal* remaining tree (in the density of 5×10 m or 4×8 m according to studied sites) created a microclimate condition limiting water evaporation loss and fertility decline through erosion. Former studies obtained similar results (Raddad and Luukkanen, 2007). Research results concerning benefits effect of intercropping annual crops with *A. senegal* abound in literature (Nasreldin, 2004; Raddad and Luukkanen, 2007; Kissi, 2011). Further, N-deficient soils have high potential response to tree fallow (Palm, 1995; Kasongo et al., 2009; El Tahir et al., 2009). The differences observed about yields of sorghum and cowpea between AsCb and AsEc may be related to the fact that the remaining *A. senegal* trees continue to supply nutrients within the soil through litter fall without competing with associated crops. In addition, conversion of old plantations is associated with nutrients content

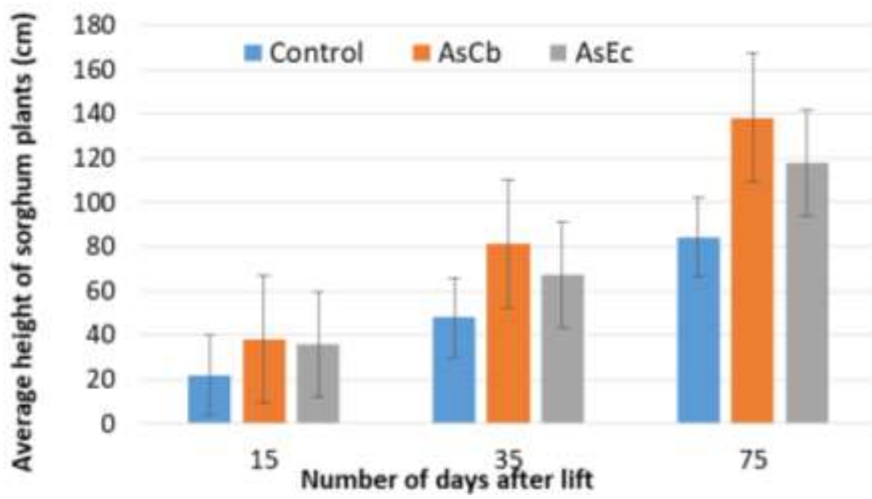

Figure 2. Average height of sorghum according treatments.

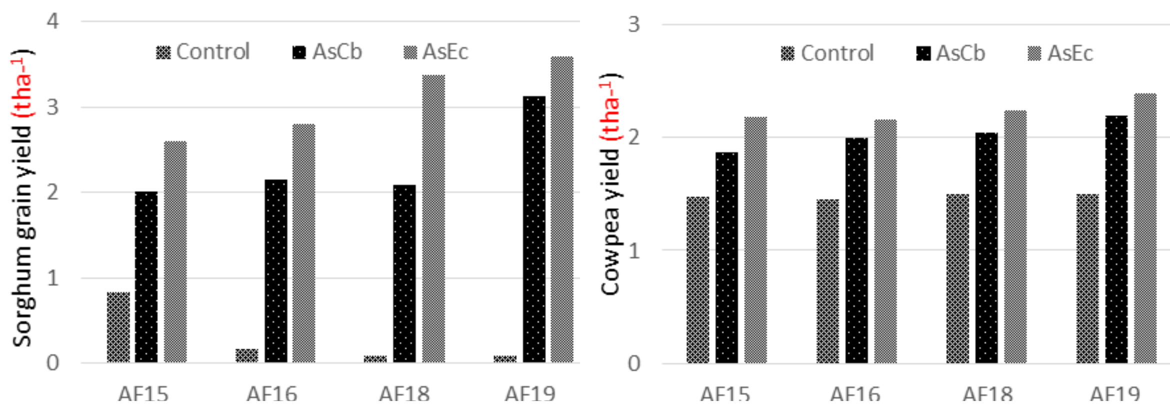

Figure 3. Sorghum grain (a) and cowpea (b) yields according to plantation age.

decrease (El Tahir et al., 2009). These findings were benefit to farmers because intercropping sorghum with *A. senegal* enhances gum arabic production (Gaafar et al., 2006).

Comparing differences between yields of sorghum and cowpea from fallowed lands to continuous cropped systems, it was remarked that the difference was not higher with cowpea. This suggests that cowpea was not significantly affected by N-soil deficiency and less sensitive to soil poverty. Cowpea is also a leguminous capable like *A. senegal* to fix and recycle atmospheric N into the soil via their active root noodles. This is why no fertilizers were provided to this crop by farmers in North Cameroon.

Farmer's perception of the conversion approaches and soil restoration

In Northern Cameroon savannas, farmers easily distinguish fertile soils from degraded one through indigenous knowledge (Ibrahima et al., 2007). The *Massa* people (dominant ethnic group of the studied area) globally refer to physical and biological indicators (Kossoumna Liba'a, 2007). During field visits, they easily identified the difference between crops growth between fallowed and continuous cropping plots. Another aspect that retained the attention of the visitors was the soil colors in surface horizons. For instance, the relative dark color of fallowed lands as compared to continuous cropping was interpreted by farmers as a sign of fertility recovery and abundance of organic matter. The soil black color and the presence of earthworms were considered as best indicators of soil fertility (Kossoumna Liba'a, 2007; Ibrahima et al., 2007). The farmers nourished an intention to adopt the partial clear-felling process during plantation conversion in cropping fields. Furthermore, they considered wood collected after cutting down or pruned trees as another benefits in this part of the country where *A. senegal* plantations were important sources of firewood. The fruits and leaves constitute a

Table 4. Effect of the *A. senegal* plantation conversion form on cowpea growth parameters (means + standard deviation) at flowering (FS) and harvest (HS) stages.

Treatment	Leaves number at FS	Leaves number at HS	Plants height at FS (cm)	Plants height at HS (cm)	Collar diameter at FS (cm)	Collar diameter at HS (cm)	Plants ramification number at HS	Number of pods by plant
CC	28.155±9.555	14.077±4.777	32.575±13.245	30.77±5.570	6.83±1.505	7.22±1.225	3.04±1.370	10.07±3.845
AsEc	31.080±12.935	27.525±12.650	39.745±13.580	37.36±8.095	7.85±1.610	7.66±1.665	3.93±1.395	10.40±4.810
AsCb	29.545±11.840	26.840±12.085	36.645±13.065	35.65±6.055	7.51±1.380	6.81±1.570	3.06±1.250	10.24±4.735

fodder appreciated by animals. However, the problem of less gum production and the lack of a formal market were considered as major constraints to promote new plantations. The lack of appropriate equipment for gum collection and tree management (pruning) was another constraint to be considered. Similar results were observed in Central and West Africa (Palou Madi et al., 2010; Mujawamariya et al., 2013). The application of ethephon in semi-arid North Cameroon when tapping trees is a way for enhancing gum production (Abib et al., 2013). It was also reported that the time of tapping as well as it intensity and tapping methods strongly influence gum yield by plant (Adam et al., 2009; Harmand et al., 2012; Abib et al., 2013). The needs of farmer's training about this new technology and the organization of the sector were real in order to sustain existed plantations and promote the new implementations. In North Cameroon, tapping is generally manual and traditional while gum collection is made mainly by women and children (Palou Madi et al., 2010; Abib et al., 2013). The rural development agencies have to redefine the speech when vulgarizing *A. senegal* plantations.

Conclusion

This study was focused on the conversion of old *A. senegal* plantation in order to determine their suitability, to restore degraded sandy soils and sustain crop productivity. Obtained results can be summarized as:

(1) *A. senegal* planting fallow restores sandy soil fertility and sustain crop productivity;
(2) The higher is the fallowing period, the more soil fertility is improved and the higher is the crops yields;
(3) The best form of old plantation conversion is the partial clear-felling of trees because it recorded higher sorghum and cowpea yields;
(4) The total clear felling process has to be forbidden, but the partial clear-felling is recommended.

The global findings indicated that fallowing with *A. senegal* can restore sandy degraded soils and therefore constitutes a suitable agroforestry system that may sustain annual crops. Further studies have to be done in order to determine the real tree density to be left when converting and intercropping with annual crops.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Agence Française de Developpement (AFD) through the project 10 of their program C2D/PAR. They are also grateful to the farmers of the studied sites for their whole involvement in the project and the information they provided about plantations and indigenous knowledge concerning soil fertility. Dr. Nanche Billa Robert of the University of Maroua is gratefully acknowledged for English editing. The comments of anonymous reviewers were highly appreciated.

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