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Trade-off of Tree Conservation and Crop Production on Agroforestry Parklands in Burkina Faso

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Abstract

Rapid population growth coupled with food demand make land for agriculture scarcer obliging farmers to make use of any available piece of land at their disposal for crops production. This preferential use of land for crops production may appear to be competitive with tree keeping on farm. To elucidate that, the trade-off between crop production and tree conservation on farms was assessed in Bouroum-Bourmoum, Sapouy and Ouahigouya, three municipalities of Burkina Faso. More than 3 000 individual trees which spreading was 1 154 in Bouroum-Bourom, 884 in Ouahigouya and 1 054 in Sapouy were used. The mean tree canopy cover and tree cover in the farms were calculated. The three principal crops (millet, red sorghum and white sorghum) yield were used to estimate the trade-off using the mean tree canopy cover as the potential no cropping area. The results revealed a tree canopy cover of 66.25 m^2 in Bouroum-Bourom, 59.92 m^2 in Sapouy and 42.1 m^2 in Ouahigouya. The average tree cover was 23.99% in Bouroum-Bouroum, 18.23% in Sapouy and 14.88% in Ouahigouya. This represents a loss in grain production of 109.5 kg/ha in Bouroum-Bouroum, 247.6 kg/ha in Sapouy and 252.8kg/ha in Ouahigouya. A higher tree cover implies a higher trade-off in the agroforestry parkland and suggests reduction in tree density. There is urgent need to work out the balance between smallholders' farmer continuous requirement for increase food crop production and the need to maintain tree diversity in the farm for carbon credit payment promotion.

Keywords: smallholders, trade-off, tree conservation, crop production, canopy cover

1. Introduction

In Sahelian countries, smallholder farming is widely dominated by parkland land use system, composed of scattered trees that share the space with underwood crops and livestock (Bationo *et al*., 2012). Parkland management system is based on socio-ecological knowledge of farmers in dealing with the variability of climate, to cope with climate change and to overcome the adversity of soil fertility loss and land degradation (Arbonier, 2002; Adjatin, 2006; IAASTD, 2009). In Burkina Faso, economy is essentially based on natural resources, and agriculture which keeps busy more than 80 % of the population (INSD, 2006). Agroforestry parkland is the most widely spread farming system throughout the countryside. However, beside climate variability, soil degradation continues to be the most important factor limiting crop production (Soubeiga, 2004; FAO and WWF, 2008) and tree density within farm land will reduce every year (Bayala *et al*., 2014).

Several studies have shown the importance of agroforestry parkland trees for food security (FAO, 2011; Bationo *et al*., 2012; Neufeldt *et al*., 2012) and sustainable soil management (Bationo and Buerkert, 2001; Bayala *et al*., 2008). It has been demonstrated that crop under trees were less exposed to excessive temperature, wind speed, water stress and to daily temperature variation during drought spell than in open area (Brenner, 1996; Jonsson *et al*., 1999; Schroth *et al*., 2000; Bayala *et al*., 2013). These stress adaptation indicators are good signs of crop productivity improvement and system resilience to climate variability. Hansson (2006) and Sanou (2010) reported higher soil porosity under tree compared to adjacent open area in the Sahel zones where water scarcity is the most limiting factor of productivity. Moreover, soil under trees has shown higher water infiltration and increased soil nutrient exchange capacity, which is a good sign for improved crop production. According to Sanou (2010), modification of soil properties and microclimate in agroforestry parklands can be due to the morphological characteristics of tree species in term of height, density, crown and shape.

Though there is positive impact of trees on crop productivity, it has been widely reported that trees and crops compete for above-ground growth resources such as light, heat, air relative humidity, and rain interception (Parkouda *et al*., 2007, Sanou *et al*., 2012). Below-ground, the competition is for water and nutrients, although it is generally expected that the roots of trees and crops occupy different soil layers, at least to some extent (Van Noordwijk and Ong, 1999; Cannell *et al*., 1999).

Based on the above, it appears that there are different schools of thought regarding the impacts of trees in farm lands. While one group of researchers appreciate and encourage parklands promotion, a second put much more emphasis on the negative effects of parkland trees in smallholders farming system. Therefore, there is a need to get a better insight into these apparent contradictory positions. The few studies carried out on trade-off between trees keeping and crop production were mainly in research stations and covered limited agroforestry species (Rodríguez *et al*., 2006; Bationo *et al*., 2012). Moreover, most of these studies failed to quantify the trade-off between crop production and the benefits gained from tree keeping (Balmford *et al*., 2002; MEA, 2005; Rodríguez *et al*., 2006).

In the current study an attempt has been made to estimate crop production under tree canopy in case of no-presence of trees in farms. This production was assimilated to the trade-off of tree conservation on farm, the assumption being that tree presence humpers crop production under their canopy. More specifically, the trade-off between parkland trees conservation and crop production was investigated, trough (i) tree canopy cover assessment within farms, (ii) evaluation of trees cover in farms and (iii) estimation of trade-off between crop production and tree conservation.

The results represented in this paper are synthesis of data collected across three climatic zones in Burkina Faso.

2. Material and Method

2.1 Study Sites

The study was carried out in Bouroum-Bouroum (10° 32′ N, 3° 14′ W), Sapouy (11° 33′ N, 1° 46′ W) and Ouahigouya (13° 35′ 00″ N, 2° 25′ 00″ W), municipalities located in three different climatic zones of Burkina Faso (Figure 1).

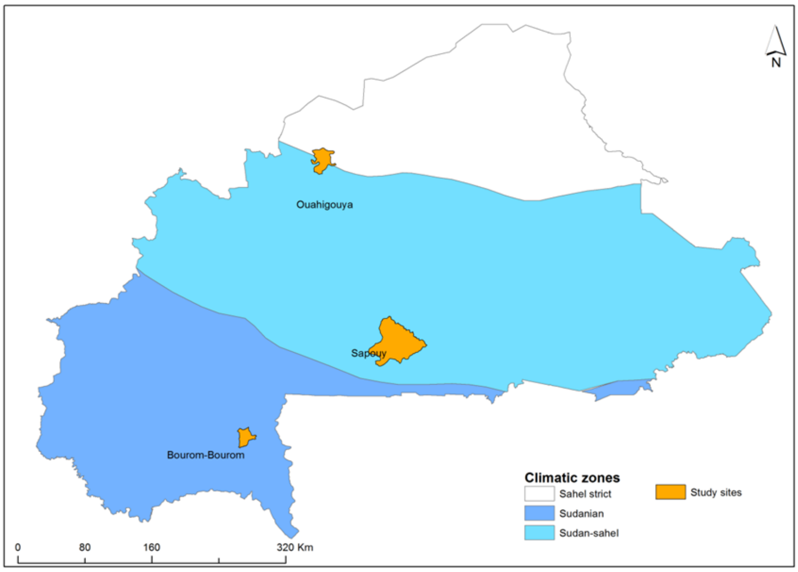

Figure 1. Location of the three study sites namely Ouahigouya (Sahel strict), Sapouy (Sudan -Sahel) and Bouroum-Bouroum (Sudanian)

Regarding climate characteristics, the average annual temperature in Bouroum-Bouroum is 27.7 ℃ and the amount of annual precipitation is estimated to be 1 000 mm (Figure 2a). Sapouy climate is characterised by an average annual rainfall of 884 mm and 27.6 ℃ as average temperature (Figure 2b). Finally, for Ouahigouya, located in the dryer climatic zone, the annual amount of precipitation average is 599 mm with an average annual temperature of 28.7 ℃ (Figure 2c).

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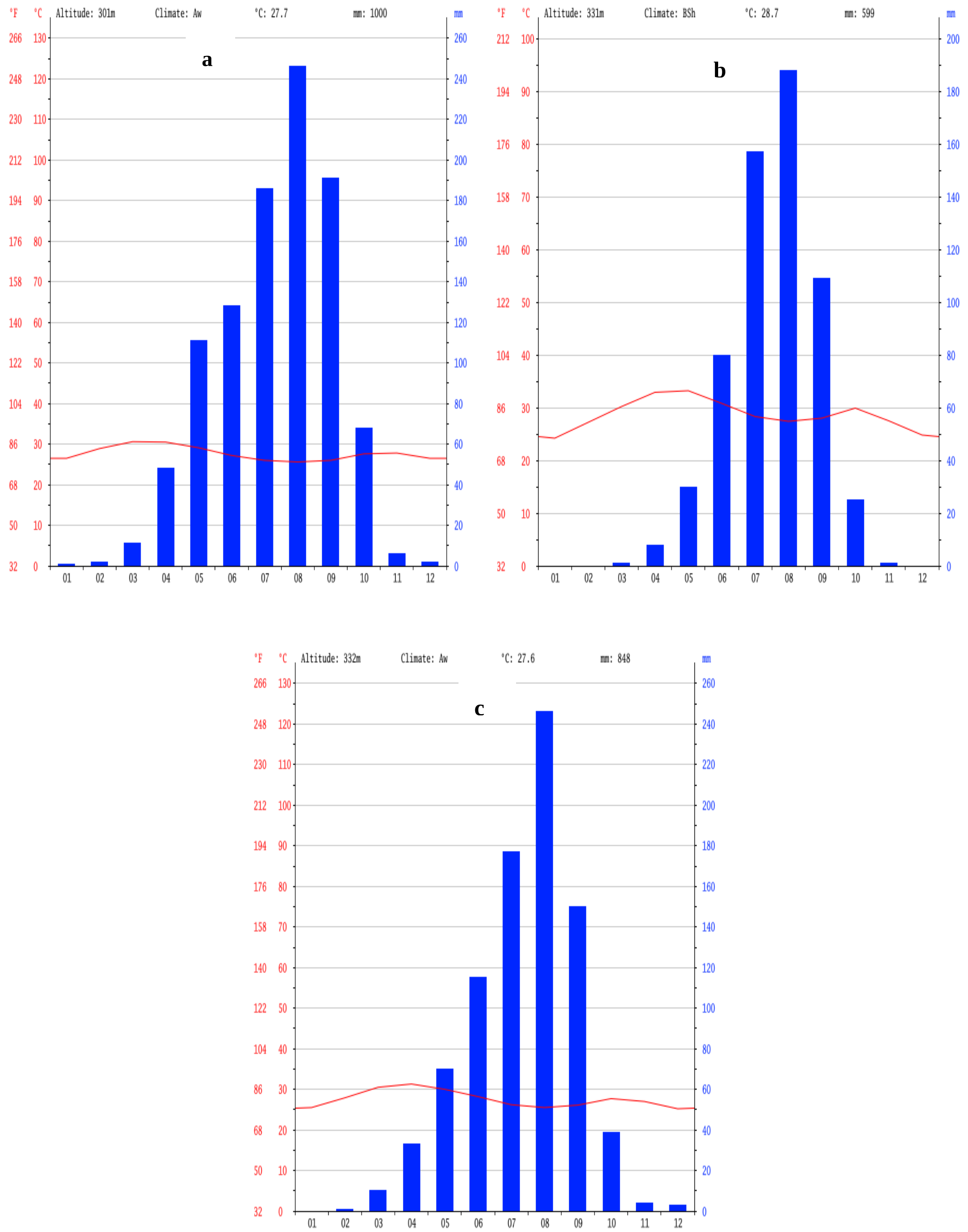


Figure 2. Average temperature and precipitation trend in Bouroum_Bouroum (2a), Sapouy (2b) and Ouahigouya (2c)

Source's: https://en.climate-data.org

The three municipalities were chosen based on farmers' experience gained through the National Forestry Investment Programme (FIP) and the Ecosystem Based Adaptation project

(EBA) and their ability to work with partners. In each of the three municipalities, 30 households were randomly selected among farmers that had participated in similar activities with FIP or EBA and the total area covered was about 35 ha per municipality.

2.2 Tree Canopy Cover

Canopy cover is defined in this study as the vertical projection of a tree's outmost perimeter and constitutes the potential shaded area which can influence crop production (Jennings, *et al*., 1999). To estimate canopy area all trees were inventoried and the big radius of canopy cover (R_b) and the small radius of canopy cover (R_s) were recorded. The formula of ellipse (Equation 1) was applied to obtain the area of canopy (C_a).

$$C_a = \pi \ x \ R_b x \ R_s \tag{1}$$

Total canopy area under trees (TC_a) of each farm was obtained by summing up the canopy cover areas of all trees within the farm (Equation 2).

$$TCa = \sum_{i=1}^{n} Ca_i \tag{2}$$

The total farm size for each municipality (Tb) was computed as indicated in Equation 3.

$$Tb = \sum_{i=1}^{n} bi \tag{3}$$

Where bi: area of each farm

The average tree canopy cover is the sum of canopy cover in m^2 of the agroforestry parkland divided by the total number of trees in the parkland (Equation 4).

$$m = \frac{TCa}{N} \tag{4}$$

With m: average canopy cover

TCa: total canopy cover of agroforestry parkland

N: total number of trees in the agroforestry parkland

2.3 Tree Cover

Tree cover is the ratio (r) of tree canopy area over the total size of the farm. It is used for the estimation of vegetation cover of the site. It was computed using (Equation 5).

$$r = 100\left(\frac{\sum_{i=1}^{n} Ca_i}{\sum_{i=1}^{n} b_i}\right) \tag{5}$$

2.4 Estimation of Crop Yield

For crop yield, a database of the last eleven years from the ministry of agriculture of common crops such as red sorghum, white sorghum and millet was used. The average yield of common crop (Y) was obtained using (Equation 6)

$$Y = \frac{\sum_{i=1}^{n} y_i}{N} \qquad (6)$$

Y: average yield of a given crop

y_i: annual crop yield of common crop i

N: number of years

2.5 Trade-offs Between Tree Coverage and Crop Production

Trade-off (T) in this study is defined as the crop production that a farmer would have harvested on the farm land occupied by trees (TCa). It was obtained by multiplying crop yield (Y) by tree cover in the farm (Equation 7). The measurement was applied on 1154 trees in Bouroum-Bourom, 884 trees in Ouahigouya and 1054 trees in Sapouy.

$$T = Y\sum_{i=1}^{n}(\ a)_i \qquad (7)$$

2.6 Data Analysis

Statistical analyses were done with Minitab 17, Excel and Sigma plot 13.0 software. One-way Fisher Pairwise Comparisons and Tukey Pairwise Comparisons tests using One-way Anova were used to see how tree canopy cover, tree cover, trade-off differ between the three climatic zones. For the all tests the significance level was set at 5%.

3. Results and Discussion

3.1 Tree Canopy Cover

The results revealed a mean tree canopy cover of 66.25 m^2, 59.92 m^2 and 42.1 m^2 in Bouroum-Bourom, Sapouy and Ouahigouya municipalities, respectively. These means tree canopy cover was significantly different (p=0.001) from one site to another (Figure 3).

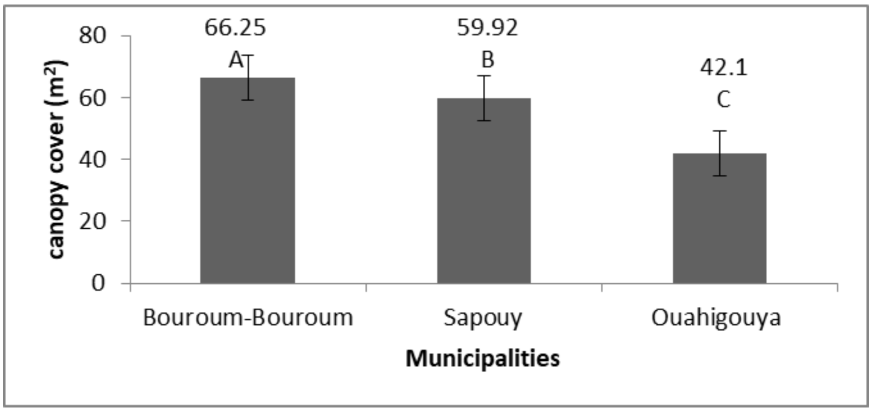


Figure 3. Mean tree canopy cover in the study sites located in three different climatic zones in Burkina Faso, A= Bouroum-Bouroum (Sudanian zone), B = Sapouy (Sudan-Sahel zone) and C= Ouahigouya (Sahel strict zone)

The differences observed between mean tree canopy cover in the three sites can be explained by difference in dominant tree species in the three zones. Indeed, individual tree canopy varies significantly from a species to another one (Table1). Also, on farm management practices such as tree pruning (Picture 1) can influence a lot tree canopy.

Table 1. Average tree canopy cover (TCC) of trees in the three study sites, located in three climatic zones of Burkina Faso

Municipalities	**Tree species**	**Average canopy cover (m^2)**	**IVI (%)**
Ouahigouya	*Lannea microcarpum*	$63.71+12.5^{a}$	19
	Sclerocarya birrea	$53.86+11.18^{a}$	15
	Azadiratha indica	$48.49+11.18^{ab}$	13
	Balanites aegyptyaca	$25.99+11.19b^{c}$	11
	Adensonia digitata	$8.99+11.18^{c}$	8
	Feiderbia albida	$47.81+11.18^{ab}$	7
Sapouy	*Vitellaria paradoxa*	$60.57+23.45^{ab}$	61
	Parkia biglobosa	$96+23.5^{a}$	6
	Bombax constatum	$48.7+26.21^{b}$	4
Bouroum-Bouroum	*Vitellaria paradoxa*	55.51+4.54	78

Picture 1. Trees pruning affecting tree canopy in Ouahigouya agroforestry parklands

Among the six major species found in the agroforestry parkland in Ouahigouya municipality, statistical analysis revealed significant differences in canopy cover (p-value= 0.001) with high value at 63 ± 12.5 for *Lannea microcarpum* and low value at 8.99 ± 11.8 for *Adansonia digitata*. The lower canopy cover of *Adansonia digitata* observed in this area can be explained by the fact that it leaves are usually harvested by farmers for stew/sauce preparation. However, the fruit of *Lannea microcarpum* is the most sought as ecosystem service by farmers. Therefore, a big canopy cover of this species augurs a promising fructification capacity. The type of ecosystem service provided by each tree species guide it canopy cover management by farmers.

The results of this study are similar to the findings of Nelson *et al*., (2009) who reported that, the morphological characteristic of agroforestry tree species determined their canopy cover shape. Moreover, the morphological characteristic of the species and the management practices developed by the farmers also contributed to shape the canopy cover (Bationo *et al*., 2012; Bayala *et al*., 2014). According to Bationo *et al*., (2012), farming system should play various role to cover farmers' needs in term of wood and non-timber products where the forests resources are scarce. And regarding forest resources availability, it has been argued that in Burkina Faso, forest resources decreased from the southern to the northern region of the country (DIFOR, 2007).

3.2 Tree Cover

Tree cover in Bouroum-Bouroum and Ouahigouya municipalities were significantly different while no significant difference was observed between tree cover in Sapouy and any other site. However, this parameter seems to decrease along a climatic gradient going from Bouroum-Bouroum (Sudanian) to Ouahigouya (Sahel strict) municipality (Figure 4).

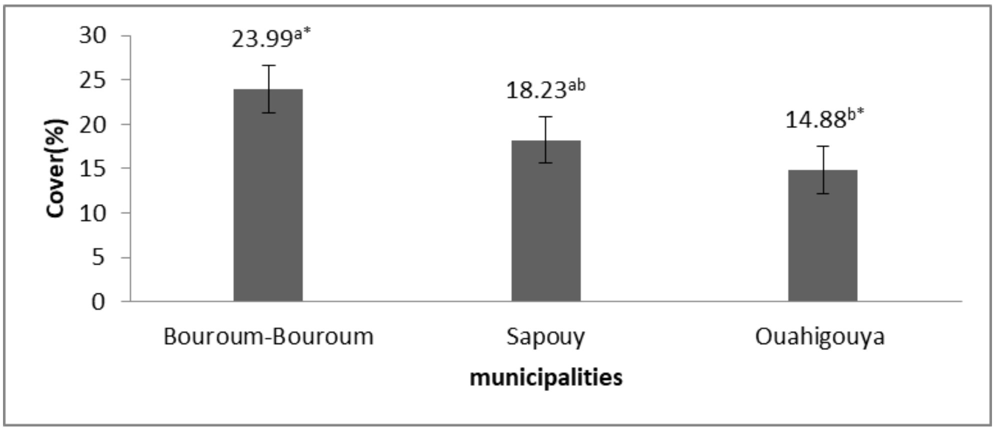
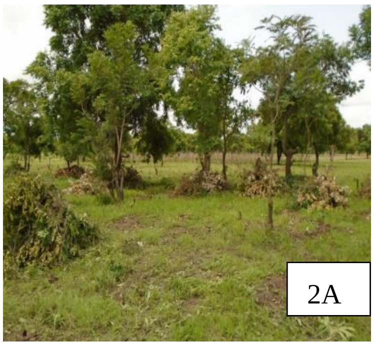


Figure 4. Tree cover in the study sites located in three different climatic zones in Burkina Faso, Bouroum-Bouroum (Sudanian zone), Sapouy (Sudan-Sahel zone) and Ouahigouya (Sahel strict zone)

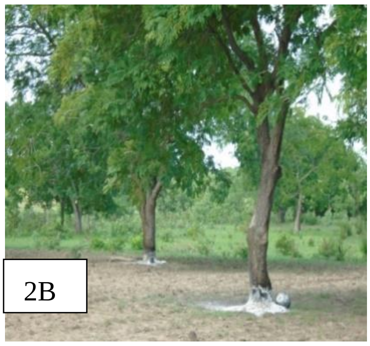
(* significance at p= 0.001)

The highest tree cover value of 23.99% ±3.61 was observed in Bouroum-Bouroum and the lowest value of 14.88%±3.61 in Ouahigouya municipality. These results can be explained by the difference observed between the canopy cover of tree species (Table 1). United Nations Food and Agriculture Organization (FAO, 2015) has defined forest as land with a tree canopy cover higher than 10% in an area larger than 0.5 ha. Based on this definition, all agroforestry parklands investigated in this study may be considered as forests. This corroborates the findings reported by Zoungrana *et al.* (2015), who argued that high density of trees in farmlands in Dano (Sudanian zone) did not allow a good distinction between a forest and a farmland using Landsat images. Yet, the high tree cover values of this study contradict the findings of Gijsbers *et al*. (2003), who estimated tree cover in West Africa parkland systems at 10%.

The relative high tree cover value observed in all the study sites can be interpreted as the effects of sensitization at national level on the importance and the roles that trees can play on farms regarding building farmers resilience. One would have expected tree cover to be significantly different from the Sahel strict zone (Ouahigouya) to the Sudan-Sahel zone (Sapouy). This lack of significance in difference may be explained by farming practices (Picture 2A, 2B and 2C) adopted by some farmers in the second zone to reduce tree density within the farms as prerequisite for more mechanisation in this area.



Fire method to destroy tree new farm



Fire mothod to destroy tree old farm

Cernage method to destroy tree in the farm

Picture 2. Methods used by some farmers to eliminate trees in agroforestry parklands in Sudan-Sahel and Sudanian zones of Burkina Faso

3.3 Crop Yields

The mean yield of crops used for this study purpose are given by Table 2.

Table 2. Mean yield of the three crops commonly planted in the study sites located in three different climatic zones in Burkina Faso, Bouroum-Bouroum (Sudanian zone), Sapouy (Sudan-Sahel zone) and Ouahigouya (Sahel strict zone)

Municipalities	**Crop types**	**Yield(kg)**	**CI (95%)**
	White sorghum	1169	(965, 1373)
Bouroum-Bouroum	Red sorghum	962.4	(777, 1147.8)
	Millet	840	(652, 1027)
	White sorghum	842.4	(638.7, 1046.0)
Ouahigouya	Red sorghum	-	-
	Millet	922.1	(734.2, 1109.9)
	White sorghum	1205.3	(1001.7, 1409.0)
Sapouy	Red sorghum	1317	(1132, 1502)
	Millet	1009.5	(821.7, 1197.4)

Source: Ministry of Agriculture (2017), Burkina Faso

3.4 Trade-off

Figure 5 shows the trade-off by hectare calculated based on mean yield of each crop (millet, white sorghum and red sorghum) and tree canopy cover in the three climatic zones.

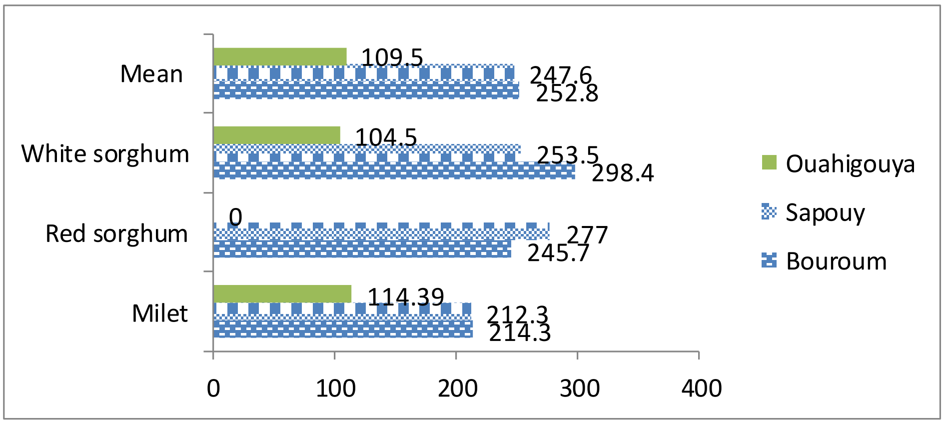


Figure 5. Trade-off per hectare (kg/ha) for three major crops and their global mean trade-off in the study sites located in three different climatic zones in Burkina Faso, Bouroum-Bouroum (Sudanian zone), Sapouy (Sudan-Sahel zone) and Ouahigouya (Sahel strict zone)

For the three major crops considered in the study, trade-off analysis showed that the impact of tree canopy cover on crop production is less for millet compared to the two other crops (red sorghum and white sorghum) and statistical analysis revealed a significance difference between millet and sorghum trade-off at p-value = 0.001. The higher trade-off recorded with sorghum can be attributed to the difference between millet and sorghum yields as the mean yield of crop showed a lower yield of millet compared to sorghum varieties (Table 2). Considering study sites, the lowest global mean trade-off (109.5±12 kg/ha) was observed in Ouahigouya while the highest (252.8±12 kg/ha) was observed in Bouroum-Bouroum. Turkey test showed significant trade-off in Ouahigouya compared to Sapouy and Bouroum-Bouroum (p-value = 0.001). The lower trade-off in Ouahigouya (Sahel strict climatic zone) can be explained by the low soil fertility and the low rainfall (Figure 2).

The trade-off analysis showed 109kg/ha, 247kg/ha and 252 kg/ha, respectively for the study sites of Ouahigouya (Sahel strict zone), Sapouy (Sudan-Sahel zone) and Bouroum-Bouroum (Sudanian zone). These quantities of crops represent respectively 0.6, 1.36 and 1.4, of mean yearly cereal need per person in Burkina Faso (MAAH, 2017). These proportions highlight the importance of this trade-off analysis for food security issues as the trade-off per hectare in Ouahigouya, Sapouy and Bouroum-Bouroum represent respectively 60, 136 and 140% of the yearly cereal need of one Burkinabe.

Burkina Faso plans to promote agroforestry parklands as key actions in the implementation of its National Determined Contribution in the framework of the UNFCCC Paris Agreement (MEEVCC, 2015). This would mean that some compensations must be set up to cover the trade-off induce by tree conservation in agroforestry parklands. Whenever a tree is cut to increase farming area, ecosystem service such as support to crop production is preferred to other services like provision of non-timber forest products and carbon sequestration that could have been rendered by the tree. Each tree cut, reduces agroforestry parkland capability to sequester atmospheric CO_2 while burning of the wood of cut tree increases the atmospheric CO_2. Some scientists had argued that less trade-off in favour of tree conservation could be considered as enough reason of cutting trees (Carpenter *et al*., 2006, Cork *et al*., 2006, Rodríguez *et al*., 2006). However, according to Waggoner (1996), whatever is the difference in terms of crop production, effect of trees on crop production should not be considered as the trade-off. For these authors scattered trees contribute to secure human security through ensuring biodiversity portfolio and saving smallholder money through multiple free ecosystem services provided in terms of climate regulation, soil water and fertility improvement, timber and no timber products provision. It has been argued that, in developed countries, more importance is given to services provided by ecosystems, making their conservation for human wellbeing easier. On the other hand, in developing countries, the conservation of some intangible ecosystem services is not considered as a priority. For instance, alleviation of poverty is usually considered as more important than environmental problems that would be incurred as consequence of tree cutting (Gray and Clara, 2005; Rodríguez *et al*., 2006).

4. Conclusions

The investigation has revealed that tree canopy cover (TCC) is a function of tree species and *Parkia biglobosa* has the highest TCC (96±23.5) in the study area. Based on the study data, average TCC decreased from high rainfall area (Sudanian) to low rainfall area (Sahel). The average tree cover (TC) in whole study area was high (14%) and therefore could be classified as forest in the Sahelian zone (FAO, 2015). However, this increase of TC in the farm level significantly affects crop production and subsequently the trade-off. Millet crop was less affected by increasing TCC compared to sorghum species. Tree conservation of farm may have some implications for food security as the trade-off in terms of crop production was found to be important in all the three climatic zones covered by the study. To encourage conservation of trees in the agroforestry parklands, it is highly recommended that in addition to other ecosystem services, carbon stock of agroforestry trees be assessed to determine the benefit that could be gained by smallholders' farmers in carbon payment using REED+ initiative.

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