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Carbon Sequestration Potential and Marketable Carbon Value of Smallholder Agroforestry Parklands Across Climatic Zones of Burkina Faso: Current Status and Way Forward for REDD+ Implementation

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Abstract

Agroforestry plays an important role in climate mitigation through atmospheric carbon removal by photosynthetic activity of tree. However, the carbon sequestration potential of smallholder's agroforestry's parklands is not well documented in Burkina Faso. Therefore, agroforestry parkland of smallholders' farmers in three climatic zones was studied. Thirty household farmlands in each climatic zone representing about 35 ha were selected on which systematic woody species inventory and dendrometry data collections were undertaken. Nondestructive method using fitted allometrics equations was used to compute carbon stock. Sustainability analysis of carbon sequestration potential was done using]0–10],]10–40], and]40–110 cm] diameter class as long term, medium term, and short term, respectively. The balance between marketable carbon value and the trade-off from tree conservation of three major crops was also analyzed. The results revealed 24.71 ± 5.84 $tCO_2\ ha^{-1}$, 28.35 ± 5.84 $tCO_2\ ha^{-1}$, and 33.86 ± 5.84 $tCO_2\ ha^{-1}$ in Ouahigouya, Sapouy, and Bouroum-Bouroum at $p < 0.1$ respectively. Long- and short-term carbon sequestration potential was attributed to Ouahigouya with 1.82 and 68.03%, respectively. With, the medium term analysis Sapouy came first with 71.71% of total amount of carbon. The marketable carbon value was less than trade-off value resulting in keeping trees and crop production. The balance analysis revealed that carbon payment system promoted by REDD+ initiative will be profitable and compensable to smallholder farmers effort to plant and keep tree when the $tCO_2\ ha^{-1}$ price will be around US$ 4.00. By taking into account farmers' interests and profitability on carbon market will be the most relevant incentive method to enhance carbon stock in agroforestry parkland.

Keywords Carbon dioxide · Trade-offs · Carbon market · Farmland · Smallholders · Burkina Faso

Introduction

Greenhouse gas reduction to combat climate change is among the major developmental challenges in the world (IPCC 2007; Pachauri 2014; Paris 2015). Atmospheric carbon dioxide (CO_2) rising is cited as the main factor and cause of global warming (Lindzen 2009). Removing atmospheric carbon (C) and storing it in the terrestrial biosphere is one of the options, which have been proposed to deal with temperature rising and to mitigate climate change effect. However, only trees have a long-term capacity to remove atmospheric carbon through their photosynthetic activity and store it as biomass (David and Crane 2002; Thangata and Hildebrand 2012). Agricultural lands, which constitute the most important land use type in the world, are believed to be major potential sinks and could absorb large quantities of carbon if trees are reintroduced to

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these systems and judiciously managed together with crops and/or animals (Albrecht and Kandji 2003). For instance, in Burkina Faso, the annual deforestation from agriculture e.g.: sifting cultivation was estimated at 60,000 ha from 1980 to 1983, 113,000 ha from 1983 to 1992, and 360,000 ha from 1992 to 2000 (SP/CONEDD 2010). Thus, the importance of agroforestry as a land-use system is receiving wider recognition, not only in terms of agricultural sustainability but also in issues related to climate change. However, the capability of agroforestry parkland (AFP) to sequester carbon still stimulates debate, particularly in developing countries.

AFP seem to have a high potential to sequester carbon and needs special attention from both developed and developing countries (Makundi and Sathaye 2004; Takimoto et al. 2008; Gutierrez-Velez et al. 2009) in order to combat the common enemy which is climate change. However, carbon stock and the potential of CO_2 sequestration in small farmers farms are not well documented locally (Woomer et al. 2001) neither its contribution to global effort to reduce atmospheric CO_2 is also not documented (Thangata and Hildebrand 2012) to enable low-income countries defend the smallholder farmers during UNFCCC meetings. The lack of information on smallholder AFP capacity to sequester carbon to support the inclusion of agroforestry in climate change discussions is problematic (Albrecht and Kandji 2003). This may confuse policymaker in the decision to promote smallholders agroforestry (Cheng and Kimble 2001) particularly for developing countries. However, Burkina Faso submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC in 2015 where the CO_2 emitted was estimated at 103,424 $MgCO_2$ through agriculture and representing 87.47% of total emission. In the INDC, the country pledges to reduce carbon emissions to 6.6% below business-as-usual levels by 2030. The integration of trees in farmland appear to be a good option to reduce atmospheric CO_2 concentration (Post and Kwon 2000) and suitable agroforestry area has been estimated to be 10,392,211 ha representing 38% of the country side (IFN 2 2015). To meet this ambitious target of the country INDC, a number of measures will be required including expanding solar, wind, and hydro power, and improving agricultural tree cover through AFP promotion (MEEVCC 2015). Success of any of these measures is intimately link to the incentives in place to motivate stakeholders. For instance the carbon offset potential of carbon sequestered through subsistence farmer AFP to industrialized countries could be an attractive economic opportunity for smallholder farmers in low-income countries (Takimoto et al. 2008, Schroth and McNeely 2011). It reported that the technology that may not be very profitable at the farm level, but beneficial from a global perspective to mitigate climate change and might require appropriate incentives to enable farmers to adopt it (ICRAF 2002; Vallejo et al. 2015). It has been reported that agroforestry practitioners are often poor people living in the rural areas. There is therefore the need to develop innovative mechanisms that have the potential to help the poor locally and contribute to climate change mitigation globally (Pandey 2002). Policies that promote agroforestry will help to increase carbon sequestration in agro ecosystems, thereby providing climate change mitigation benefits to smallholder's farmers (Watson et al. 2000). Unfortunately farm subsidies and national level policies do not incentivize farmers to adopt conservation agriculture and integrated landscape management in Burkina Faso. Furthermore, the Reduction of Emissions from Deforestation and Forest Degradation (REDD+) initiative, in which Burkina Faso and most least developed countries are participating, stresses on the following three activities: (i) conservation of forest carbon stocks, (ii) sustainable management of forests, and (iii) reinforcement of forest carbon stocks (Peters et al. 2012). In addition, it has been argued that REDD+ initiative implementation could contribute to increase trees in the parkland and thereby increase carbon stocks (Guessa et al. 2017). With the INDC, a proper implementation process of REDD+ program in Burkina Faso would suppose the existence of baseline data including data on AFPs carbon stocks. This study aim: (i) estimating carbon stock of smallholder AFP, (ii) assessing the balance between marketable carbon opportunity and trade-off resulting by tree conservation and crop production in farmed system. Based on the outcomes of these specific objectives, policy incentive can be drawn in order to stimulate parkland promotion in the context of agricultural mechanization in Burkina Faso and make the INDC a success

Material and Method

Study Area and Data Collection

The study was carried out in Ouahigouya (13° 35′ 00″ N, 2° 25′ 00″ W), in Sahel strict zone where annual rainfall is <600 mm, Sapouy (11° 33′ N, 1° 46′ W), in the Sudan–Sahel zone with annual rainfall between 600 and 900 mm, and Bouroum-Bouroum (10° 32′ N, 3° 14′ W) in the Sudanian zone with the annual rainfall greater than 900 mm (Fig. 1) (IFN2 2015; Thiombiano and Kampmann 2010). For data collection, in each municipality, five villages were randomly selected and in each village six smallholder farms, where the farm size is around 2500–30000 m^2, were randomly selected. The total area of all farms covered about 35 ha per municipality. On these farms, systematic woody species inventory was done and

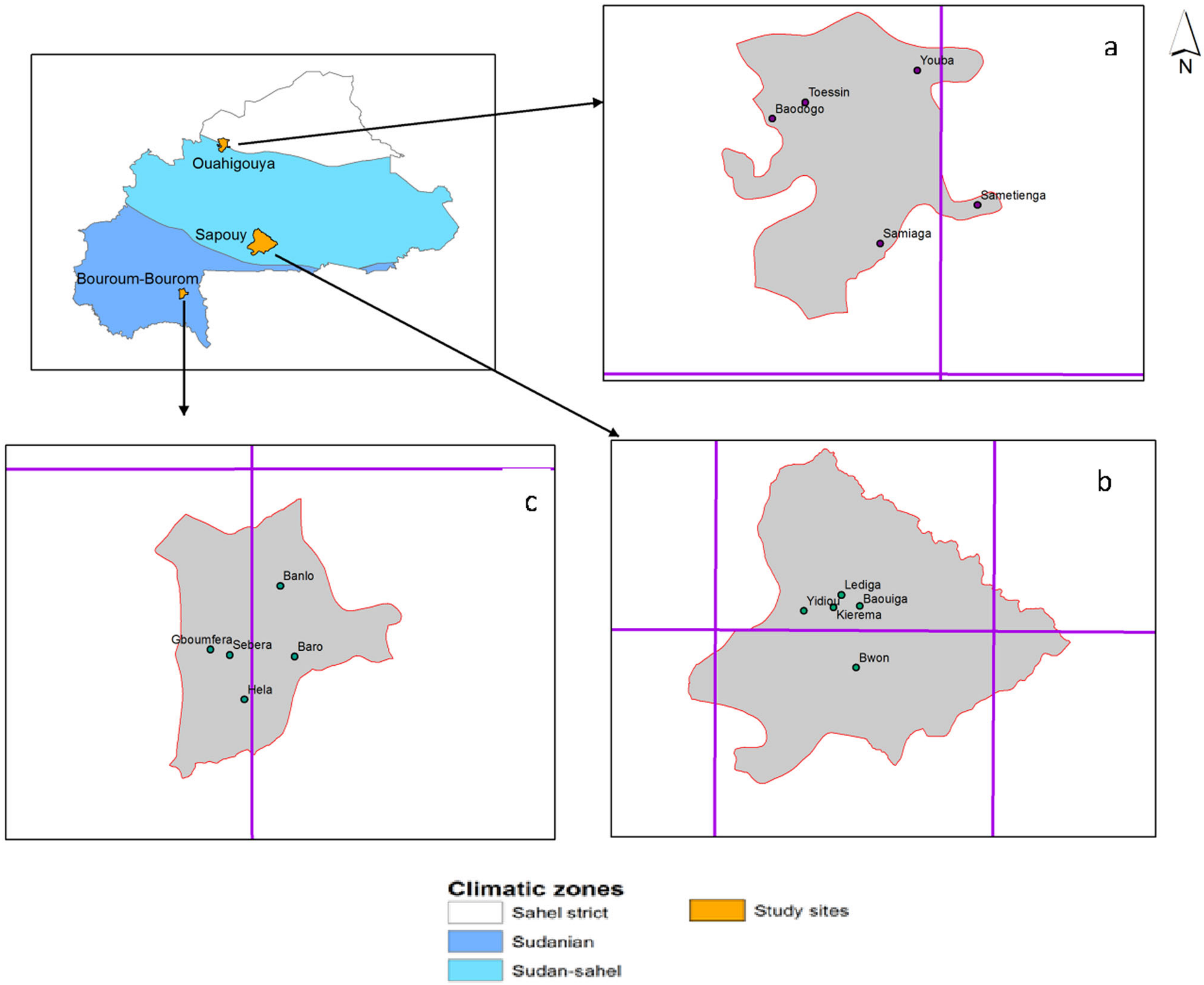

Fig. 1 Three selected communities from each climatic zone in Burkina Faso. **a** Ouahigouya municipality presenting Sahel strict zone. **b** Sapouy representing Sudano–Sahel zone. **c** Bouroum-Bouroum for Sudanian zone

the diameter of individual trees equal or than 2 cm at breast height (DBH) was also recorded.

Average Diameter of Woody Species (D)

The average of woody species diameter (D) was computed using the sum of total DBH over the total number of individual woody species found per farm/village/municipality. Before, computing (D), all the individual woody species which have more than one trunk at 1.3 m, the equivalent diameter (d_{eq}) has been estimated using Eq. (1) below.

$$d_{eq} = (d_1^2 + ..d_n^2)^{\frac{1}{2}}, \quad (1)$$

where d_1 is the diameter of trunk 1 first and d_n is the last diameter of the trunk (n).

Biomass Estimation

To estimate the aboveground biomass (AGB), woody species with DBH > 2 cm were considered. Existing allometric models (nondestructive method) was used to compute the AGB. The best-fit pantropical allometric equation developed for *Vitellaria Paradoxa* based on tree DBH (cm) was used (Sanogo et al. 2016). For other woody species the equation developed by Chabi et al. (2016) based also on DBH was used (Table 1).

For the belowground biomass (BGB) computation, the allometric equation developed by Sanogo et al. (2016) was applied for *Vitellaria paradoxa* (Table 1). For the other woody species with no specific allometric equation to estimate the biomass, the BGB was derived from the AGB (Ekoungoulou et al. 2015). Allometric equation with

Table 1 Allometric equation used for woody species biomass estimation

Species	Pool	Formula	R^2	Locations	References
Vitellaria paradoxa	AGB	$0.062D^{2.64}$	0.89	Mali	Sanogo et al. (2016)
	BGB	$0.039D^{2.35}$	0.93	Mali	Sanogo et al. (2016)
	AGB	Exp(2.751514 + 0.091492D)	0.91	Benin	Chabi et al. (2016)
Others woody species	BGB	Exp (−1.0587 + 0.8836 × Ln (ABG))	0.84	West Africa	Cairns et al. (1997), Somarriba et al. (2013)

$r^2 = 0.84$ (Table 1) developed by Cairns et al. (1997) and widely used by other authors (Somarriba et al. 2013; Guessa et al. 2017) was used. Total biomass (TB) is the sum of AGB and BGB (Eq. 2).

$$TB = \sum_{i=1}^{n} ABGi + \sum_{i=1}^{n} BGBi \tag{2}$$

Carbon Stock Estimation

To obtain the total carbon stock (TC_S), estimated TB was multiplied by 0.4748 (IPCC 2007) because it is established that the TB of tree contains 47.48% of carbon (Eq. 3).

$$TCs = 0.4748\left(\sum_{i=1}^{n} ABGi + \sum_{i=1}^{n} BGBi\right) \tag{3}$$

Carbon Sequestration Potential

Quantity of Carbon Dioxide per Municipality

The carbon stock of woody species when released reacts with air (Oxygen (O_2)) and forms CO_2 which is released to the air. To obtain total carbon dioxide (TCO_2) contain in carbon stock, TCs was multiplied by 3.67 (44/12) because CO_2 contain one carbon atom and each carbon atom weights 12 g (Eq. 4). The total weight of one molecule of CO_2 is 44 g so the ratio, weight of one molecule of CO_2 to weight of one atom of carbon, gives 3.67.

$$TCO_2 = 3.67\ TCs = 3.67 \times 0.4748\left(\sum_{i=1}^{n} ABGi + \sum_{i=1}^{n} BGBi\right) \tag{4}$$

Distribution of CO_2 per DBH Class

To analyze the parkland capability to sequester carbon over long period of time the woody species diameter at breast height (DBH) have been put into three groups]0–10 cm] representing the part of regeneration,]10–40] cm representing the mature woody species and]40–110] representing the old woody species. In this study the]0–10 cm] represents the woody species diameter class that will continue to sequester carbon over long time, the] 10–40 cm] represents the potential to sequester carbon over a medium term and]40–110 cm] the potential to sequester carbon over short term. For each diameter class the amount of carbon was computed and the contribution of each class was obtained using the amount of carbon over the total carbon in each climatic zone/ municipality multiplied by 100.

Predicting Amount of Carbon Dioxide in Croplands/ Agroforestry

In addition to the carbon data obtained from field campaign, Landsat 8 OLI images of October 2016 were downloaded for the municipalities of Boruroum-Bouroum, Sapouy, and Ouahigouya. All the images were geometrically and atmospherically adjusted, and the normalized difference vegetation index and simple ratio (Vi) were derived. Besides, land use land cover data of the three municipalities were collected from the Geographic Institute of Burkina Faso for extraction of cropland area. The carbons in croplands were predicted with random forest regression algorithm as a function of the Landsat bands (blue, green, red, near infrared, and middle infrared) and derived vegetation indices. The model yielded RMSE ranging between 1 (tCO_2/ha) and 1.5 (tCO_2/ha).

Balance between Marketable Carbon and Trade-Offs Resulting from Woody Species-Crop Production

To analyze this balance, the trade-off computed (Neya et al. 2017, chapter 3 section 2.3.4) for major crops such as red sorghum, white sorghum, and millet in Burkina Faso was used. To complete the analysis, secondary data on carbon price and the price of the major crop was also used (Table 2). The balance is obtained using the equivalent CO_2 value minus the equivalent of trade-off resulting from tree conservation and major crop production in US$. In this study, US$ 1.00 equals 500 CFA and corresponds with the carbon price usually promoted in the Sahelian zone (Table 2).

Table 2 Trade-off of tree conservation and crop price per municipality with carbon price

Municipalities	Trade-off (kg/ha)	Corp price (CFA/kg)	Carbon price on the market (US$/$tCO_2$)		
			Years		
			2017	2020	2030
Bouroum-Bouroum	252.8	200			
Sapouy	247.6	234	1−14	40−80	50−100
Ouahigouya	109.5	306			
References	Neya et al. (2017)	MAAH (2017)	World Bank (2017)		

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 woody species diameter, carbon stock, and the balance of crop trade-off and marketable carbon differed between the three climatic zones. For the all tests the significance level was set at 0.05.

Results

Mean Diameter

The average diameters observed in Sapouy were significantly higher than average diameter observed in Ouahigouya and Bouroum-Bouroum municipalities (Table 3).

Carbon Sequestration Potential

Carbon sequestration potential analysis with Fisher LSD method at (*p* value, 0.0092) revealed significance difference between Bouroum-Bouroum municipality and the both other municipalities and decrease from Bouroum-Bouroum communities to Ouahigouya (Fig. 2) following the rainfall gradient.

Carbon Dioxide Distribution

The woody species with diameter within]40–110] had high percentage of total amount of carbon in Bouroum-Bouroum and Ouahigouya (Fig. 3a, c) while the diameter class within]10–40] had the higher value in Sapouy municipality (Fig. 3b). However, high percentage of individual woody species was observed in all the three sites in]10–40] class: 64.37% in Ouahigouya, 89.18% in Sapouy, and 66.72% in Bouroum-Bouroum municipality (Fig. 3).

The prediction of carbon sequestration potential in the three sites using random forest regression revealed low potential of CO_2 in Sapouy area compared with Bouroum-Bouroum and Ouahigouya (Fig. 4).

Balance between Marketable Carbon and Trade-Off Resulting from Woody Species and Crop Production

Trade-offs value in US$ resulting from crop production and tree keeping in the farm represent 3, 4.1, and 2. 7 times the value of marketable carbon stock in the AFP in Bouroum_Bouroum, Sapouy, and Ouahigouya municipalities respectively (Fig. 5).

Discussion

Carbon sequestration potential of agroforestry system has been subjected to several researchers in the last two decades (Chabi et al. 2016; Sanogo et al. 2016; Guessa et al. 2017). This is to determine the contribution of agroforestry to carbon sequestration and to enable smallholder farmer benefit from REDD+ initiative. The investigation revealed that AFPs in Bouroum-Bouroum municipality (33.86 tCO_2 ha^{-1}) sequester more carbon than Sapouy and Ouahigouya with 28.35 $tCO_2\,ha^{-1}$ and 24.71 $tCO_2\,ha^{-1}$, respectively. The higher value observed in Bouroum_Bouroum can be attributed to the high tree density and the high tree diameter (Table 3) allowing more fixation of carbon dioxide. It seems that carbon sequestration potential is influenced by tree density and tree diameter (David and Crane 2002; Thangata and Hildebrand 2012; Shulka and Viswanath 2014). Some authors reported that tree density in farms in Burkina Faso varies from one site to another and is relatively a function of farmers' decision (Keith et al. 2000; Kuyah et al. 2012; Bayala et al. 2014) and the size of tree diameter is also function of farmers' decision (Eamus et al. 2000; Ofori-Frimpong et al. 2010; Neya et al. 2017). Farmers' decision and land management are therefore the key factors influencing carbon stock in smallholders farming system.

With regards to the sustainability of AFP to sequester carbon, it was observed that diameter class]40–110 cm] had the higher proportion of amount of total carbon in Bouroum-Bouroum and Ouahigouya with 60% and 68.03%, respectively, compared with Sapouy where this class represents only 28% of TCO_2. These results can be explained by the higher proportion of individual woody species in this diameter class (Fig. 3). In short term, AFP has less potential carbon sequestration in Sapouy municipality compared with the other two municipalities. For medium term analysis at]10–40 cm] diameter class Sapouy municipality has higher potential (71.78%) to sequester carbon compared with Bouroum-Bouroum and Ouahigouya

Table 3 Individual woody species number, tree density, and average diameters per municipality

Municipalities	Individual number	Density (tree/ha)	Mean diameter (cm)	*p* value
Bouroum-Bouroum	1154	37	26.490 ± 0.819	0.001
Sapouy	1054	30	27.697 ± 0.935[a]	0.001
Ouahigouya	884	35	24.010 ± 0.857	0.001

[a]Significant

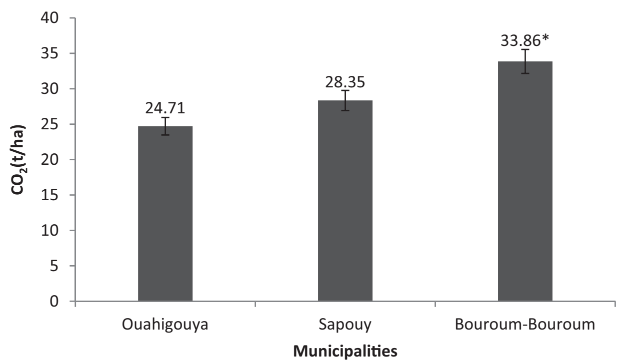

Fig. 2 Amount of tCO_2 ha^{-1} per municipality in three climatic zones in Burkina Faso. *Significant at $p < 0.05$

municipalities. The marginal difference observed between Bouroum-Bouroum and Ouahigouya can be attributed to the low mean diameter recorded in]10–40 cm] (Table 4).

While Ouahigouya municipality has a higher potential to sequester carbon in long term (Fig. 4), compared with Bouroum-Bouroum and Sapouy municipalities despite the higher amount of rainfall observed at both sites. This potential could be due to the higher regeneration observed in Ouahigouya zone, representing 20.70% of total number of individual woody species found (Fig. 3). These results corroborate previous works, which showed that woody species carbon stock is intimately linked to the DBH and tree density (Segura et al. 2005; Litton and Kauffman 2008; Vahedi et al. 2014; Xiang et al. 2016; Sanogo et al. 2016; Chabi et al. 2016; Guessa et al. 2017; Dimobe et al. 2018). The capability of AFP to sequester carbon in medium and long term is a good sign and opportunity for REDD+ initiative implementation because one of REDD+ target is to promote sustainable land management and carbon conservation over long time.

The lower carbon sequestration potential predicted in Sapouy zone compared with the two other zones of studies with random forest regression could be due to agricultural mechanization which reduces as much as possible the number of trees (tree density) in the cropland. Neya et al. (2017) showed that tree density in Sapouy was lower compared with Ouahigouya and Bouroum-Bouroum zone which can negatively influence the amount of carbon in this zone. Moreover, some authors have argued that carbon sequestration potential is related to the number of tree in a given area (Schulp et al.

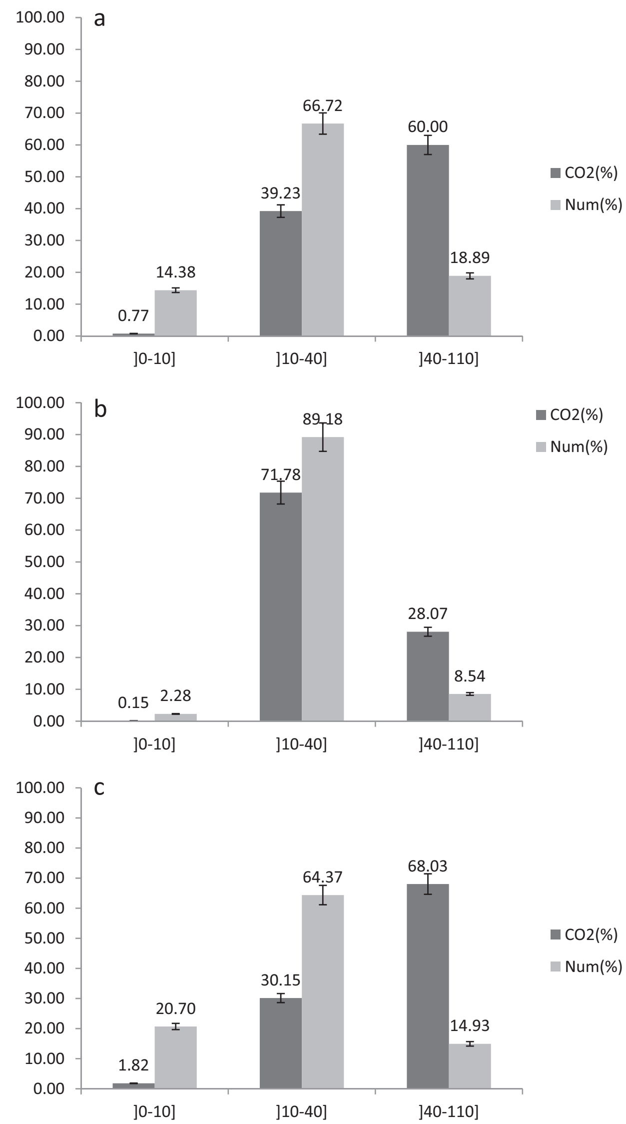

Fig. 3 Proportion of amount of CO_2 and woody species per diameter class in Bouroum-Bouroum (**a**), Sapouy (**b**), and Ouahigouya (**c**) municipalities of Burkina Faso

2008; Bunker et al. 2012) as confirmed by the results obtained in this study. Carbon dioxide analysis throughout ground thrust data combine to remote sensing analysis give more insight and accurate for carbon sequestration potential comparison within different site.

The low value of marketable carbon estimated in all study sites can be explained by the higher amount of trade-

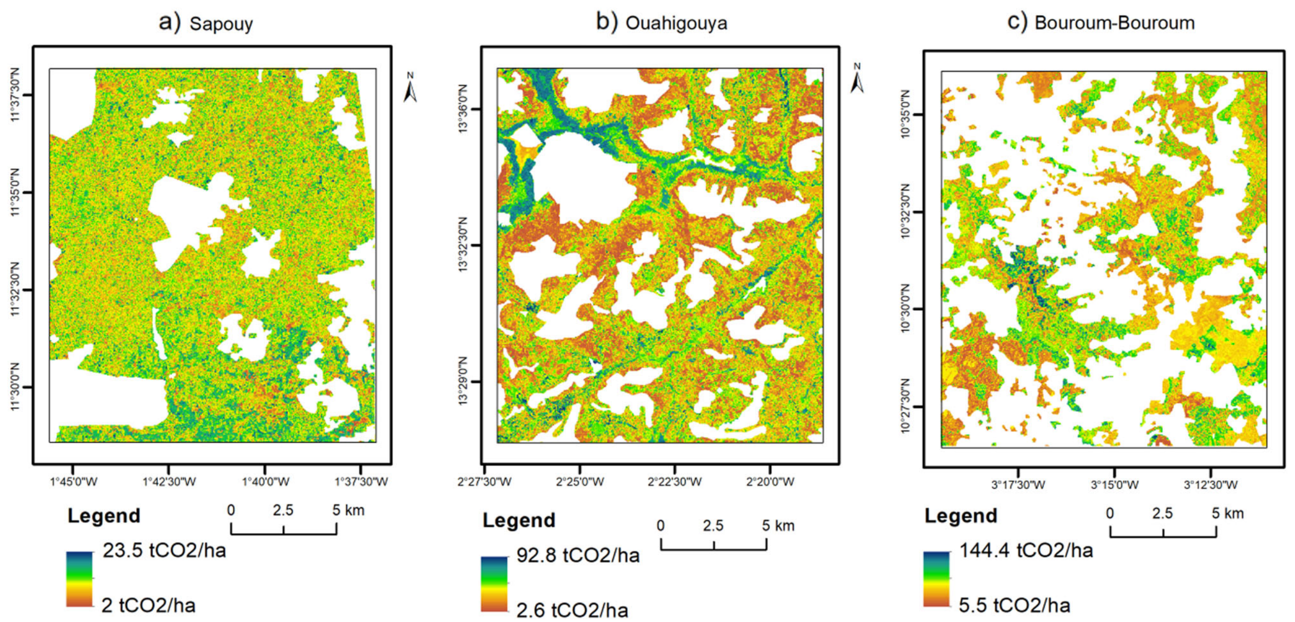

Fig. 4 Spatial distribution of carbon in the study sites: Sapouy (**a**), Ouahigpuya (**b**) and Bouroum-Bouroum (**c**) municipalities of Burkina Faso

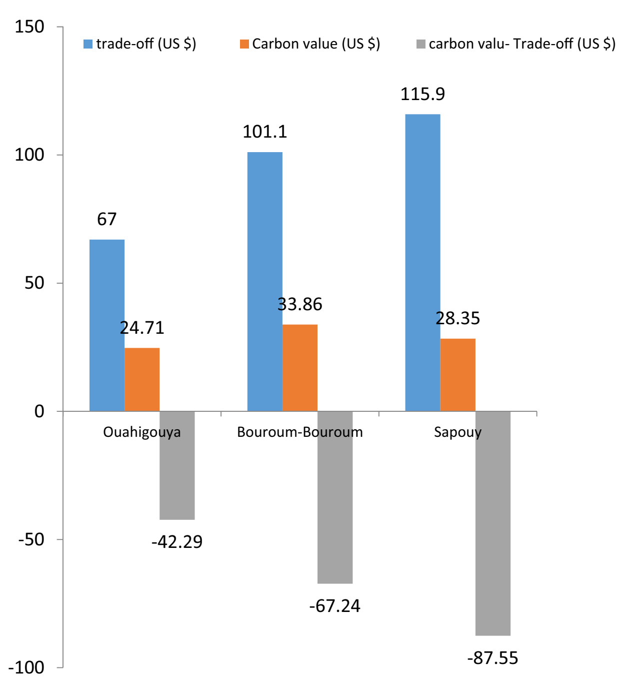

Fig. 5 Trade-offs value and marketable carbon stock value in US$ in Bouroum-Bouroum, Sapouy, and Ouahigouya municipalities of Burkina Faso

offs and low carbon price per tCO_2, which is about US$ 1.00 (Table 2). At this carbon price REDD+ initiative through carbon payment will not be able to compensate farmers' effort and stimulate an overall adoption of agroforestry parkland desired by policymakers and scientist at smallholders' level. It is therefore obvious that, carbon price should be about US$ 3.00 in Bouroum-Bouroum, US$ 4.10 in Sapouy, and US$ 2.70 in Ouahigouya municipality to cover at least trade-offs found in those zones (Fig. 5). It has been reported that agroforestry practitioners are often poor people living in the rural areas, so there is the need to develop innovative mechanisms that have the potential to help the poor locally and contribute to climate change mitigation globally (Pandey 2002). And carbon offset potential of carbon sequestered through subsistence farmer agroforestry parkland to the industrialized countries could be an attractive economic opportunity for smallholder farmers in low-income countries (Takimoto et al. 2008). This statement corroborates several authors who reported that policies which promote mitigation action at smallholder's level should contribute to increase the income and enhance those poor people resilience to climate change (Watson et al. 2000; Pandey 2002; Takimoto et al. 2008). Moreover, it has been reported that land management practice which has global benefit perspective to climate mitigation, but may not be very profitable at the farm level for smallholders, might require appropriate incentives to enable farmers to adopt it (ICRAF 2002, Vallejo et al. 2015).

Table 4 Trees mean diameter per classes in three municipalities representing three climatic zones of Burkina Faso

Diameter classes (cm)	Ouahigouya	Sapouy	Bouroum-Bouroum
]0–10]	6.59 ± 0.29	7.73 ± 0.79	6.81 ± 0.30
]10–λ40]	22.63 ± 0.63	26.32 ± 0.49	23.24 ± 0.54
]40–110]	54.09 ± 1.62	47.36 ± 1.96	52.96 ± 1.26

Conclusion

Bouroum-Bouroum agroforestry parkland displayed the most promising capacity to sequester carbon dioxides (33.86 ± 5.84 tCO_2 ha^{-1}) than Sapouy (tCO_2 ha^{-1}, 28.35 ± 5.84 tCO_2 ha^{-1}) and Ouahigouya (24.71 ± 5.84 tCO_2 ha^{-1}). Long-term, medium-term, and short-term carbon sequestration potential could be attributed to Ouahigouya with 1.82%, Sapouy with 71.71%, and Ouahigouya with 68.03%, respectively of total amount of carbon recorded in each zone of study. The trade-off value was greater than the carbon value. To enable smallholders to adopt and promote agroforestry parkland all over the country, the carbon price should be at least US$ 4.00 per tCO_2. REDD+ initiative will be successful in many low-income countries only if farmer's interest and profitability are taken into account by policymakers in fixing carbon price. The results of this work could be used as a key argument to defend a "fair" carbon price for smallholder farmers during the UNCCCF meetings on carbon market.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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