



Biomass, Carbon Stock and Economic Value of Carbon Sequestration Resulting from Forest and Landscape Restoration Actions in Semi-arid Ecosystems of Burkina Faso

**Sibiry Albert Kaboré ^{a,b*}, Emmanuelle Quilléro ^c,
Stéphanie Maiga-Yaleu ^d, Maguette Kairé ^e,
Ibrahim Bouzou Moussa ^f, Oumarou Malam Issa ^g,
Damien Hauswirth ^h and Hassan Bismarck Nacro ^b**

^a University Center of Tenkodogo/ Thomas Sankara University, 01 BP 1757 Ouagadougou 12, Burkina Faso.

^b Laboratory of Study and Research on soil Fertility and Production Systems (LERF-SP), Rural Development Institute, Nazi BONI University, 01 BP 10 91, Bobo-Dioulasso, Burkina Faso.

^c University of Western Brittany, UMR 6308 AMURE, IUEM, rue Dumont d'Urville, 29280, Plouzané Brest, France.

^d Joseph Ki-Zerbo University, 03 BP 7021 Ouagadougou 03, Burkina Faso.

^e AGRHYMET Regional Center, Permanent Interstate Committee for Drought Control in the Sahel, BP 11011, Niamey, Niger.

^f Abdou Moumouni University, BP 10896, Niamey, Niger.

^g French National Research Institute for Sustainable Development (IRD), BP 11 416, Niamey, Niger.

^h ECO-Consulting Group Niamey, Niger.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/ijecc/2024/v14i114589>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/126026>

*Corresponding author: E-mail: kaborealbert64@yahoo.fr;

Cite as: Kaboré, Sibiry Albert, Emmanuelle Quilléro, Stéphanie Maiga-Yaleu, Maguette Kairé, Ibrahim Bouzou Moussa, Oumarou Malam Issa, Damien Hauswirth, and Hassan Bismarck Nacro. 2024. "Biomass, Carbon Stock and Economic Value of Carbon Sequestration Resulting from Forest and Landscape Restoration Actions in Semi-Arid Ecosystems of Burkina Faso". *International Journal of Environment and Climate Change* 14 (11):800-813. <https://doi.org/10.9734/ijecc/2024/v14i114589>.

Original Research Article

Received: 09/09/2024
Accepted: 11/11/2024
Published: 19/11/2024

ABSTRACT

Plants contribute to mitigate global warming by capturing CO₂ from the atmosphere to produce biomass. This study aims to quantify the carbon stock sequestered in woody biomass of managed ecosystems in the semi-arid part of Burkina Faso (West Africa), and assess the economic value of additional carbon sequestered. Study sites include one managed forest and three agricultural lands restored from degraded soil. Forest and landscape restoration activities have been implemented over several decades and include zaï, stone barriers, natural regeneration and tree planting. Woody plant biomass is estimated using allometric equations which have been adapted to the case study site species and ecological conditions. The managed forest of the case study has an estimated 19.3-40.8 t/ha of woody biomass after 45 years. This corresponds to 0.7-1.5 tonne of CO₂ per hectare per year stored on average, i.e. a value of \$575-7,243 per hectare per year at current carbon prices. Payments to land users for carbon storage services may help provide alternative livelihoods and incentives for reforestation effort.

Keywords: *Forest and landscape restoration; agroforestry; assisted natural regeneration; carbon sequestration; carbon payments.*

1. INTRODUCTION

Emissions of greenhouse gases (GHG) cause climate change such as global warming and changes in precipitation patterns (Omotoso & Omotayo 2024). Different studies show that unsustainable energy use, land use and land use change, and modern ways of life have led to a global temperature increase of 1.1°C in 2011-2020 compared to 1850-1900 (IPCC 2023). Vulnerable communities, who have historically borne the least responsibility for GHG emissions, are disproportionately at risk (IPCC 2023). In West Africa, average precipitations declined between 1950 and 1990 by 180 mm/year (Le Barbé et al. 2002). In this region, temperatures are expected to be +2.8 °C higher in 2031-2060 compared to 1961-1990 (Sultan et al. 2014). The combustion of fossil energies, deforestation and land degradation are the main sources of anthropic release of CO₂ in the atmosphere (421 ppm presently versus 500–600 ppm by 2050) (Omotoso & Omotayo 2024).

Rising temperatures lead to reduced production of cereals such as sorghum (Sultan et al. 2014), wheat and maize (Farooq et al. 2023). Reduced rainfall has led to lower food crop yields (Farooq et al. 2023, Kang et al. 2009, Rezaei et al. 2023) and accelerated loss of vegetation cover (Hailu 2023 and Lemenkova & Debeir 2023). Likely direct impact of changes in rainfall seasonality in

the Sahel is a reduction in sorghum yields of around 16-20% (Sultan et al. 2014). In short, predictions from current models all seem to converge toward a significant reduction of food production.

At the same time, the population of the Sahel has more than tripled, from 40 million in 1970 to 135 million in 2020, and is projected to reach 330 million by 2050 (Bouquet 2021). This means increased demand for food in a context of decreasing food production. As a result, pressure on forest ecosystems, already weakened by natural phenomena, has increased. The social consequences are food insecurity (Gitz et al. 2016) and population migration (Alessandrini et al. 2021). In this context, the West African countries have set up the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), a political and operational instrument for taking action to halt desertification, with a view to achieving food security through the restoration of landscapes and the sustainable management of agricultural and forestry systems.

In Sub-Saharan Africa, the main greenhouse gases released are CO₂ (80% of all anthropic GHG emissions), CH₄ (15%) and N₂O (17%) (Omotoso & Omotayo 2024). A number of studies have shown that the excess CO₂ produced by burning fossil fuels can be partially absorbed and sequestered by woody plants (Tooichi 2018, Sierra et al. 2021). To this end,

one of the best strategies is plant formation conservation (maintaining the integrity of forest areas) and restoration of degraded forests and landscapes (Domke et al. 2020). Across Africa, tens of millions of US dollars have been mobilised for forest and landscape restoration (FLR) activities (Mansourian & Berrahmouni 2024). In the Sahel, FLR techniques include the use of local techniques and technologies to transform barren land into forest ecosystems. The technique of *zaï* and stone barriers has been used to reforest the site of Gourga. The landowner is Yacouba Sawadogo, an environmentally conscious farmer who has dedicated his life to the restoration of barre soils (Sawadogo et al. 2014, Belmin et al. 2023, Pédarros et al. 2024). On arable lands, agroforestry and assisted natural regeneration (ANA) are the main techniques used to allow woody plants to develop while crops are being produced (Mansourian & Berrahmouni 2024).

If Burkina Faso is to achieve the objectives associated with its international commitments, FLR activities will have to be rolled out on a large scale. Scaling up in this way means convincing potential investors of the benefits of financing this type of intervention. However, while the costs associated with FLR activities in the Sahel are relatively well known depending on the type of intervention implemented (Sawadogo et al. 2014) the same cannot be said for the ecosystem benefits (market or non-market) expected from this type of intervention.

At the international level, the Paris Climate Agreement, with its goal of limiting global warming to 2°C, is a powerful tool for negotiating the carbon market. The Kyoto Protocol and the voluntary carbon markets can finance the storage of carbon dioxide through biomass, but also through other approaches such as biochar (Michaelowa et al. 2023). Carbon markets use empirical credits, commercial insurance and buffer reserves (Michaelowa et al. 2023). In Burkina Faso, the implementation of REDD+ mechanisms is directly funding forest restoration and management projects by the national Ministry of the Environment. The direct payment for carbon sequestration to small users is not well implemented in Burkina Faso.

For several decades, numerous initiatives have been undertaken in the arid and semi-arid zones of the Sahel to restore forests and landscapes and to promote sustainable land management (SLM) techniques (Vinceti et al. 2020). However,

these actions remain poorly capitalised and/or replicated. The aim of this study is to quantify the carbon stock sequestered in woody biomass and to assess the economic value of additional carbon sequestered in different managed ecosystems in the semi-arid part of Burkina Faso. This work contributes to the scientific knowledge and national awareness of the capacity of FLR actions to improve carbon storage, which can help mitigate climate change.

2. MATERIALS AND METHODS

2.1. Study Area

Four sites were selected on the basis of the restoration activities undertaken and their location in the semi-arid area of Burkina Faso (Fig. 1). The first two sites are the Gourga Managed Forest (GMF) and the Agricultural Land number 1 (AL1), both located in Ouahigouya in the province of Yatenga (180 km north of Ouagadougou). The soil types are lithosols on cuirass and ferruginous soils. Shrub savannah is the predominant vegetation. Average annual rainfall is around 679 ± 172 mm (Yameogo et al. 2023). The other two sites are the agricultural land number 2 and 3 (AL3 and AL4), located in Kougriinsin and Pissila respectively in the province of Sanmatenga. These two sites are located about 30 km from Kaya (100 km north-east of Ouagadougou). The Kaya region belongs to the northern Sudanese phytogeographical zone. The average annual rainfall is 655 ± 133 mm (Yameogo et al. 2023).

The development of the Gourga managed forest began in 1973. The site was a *zippelé*, i.e. bare soil without vegetation. The site has been restored using the *zaï* technique, which involves digging small areas of soil to allow rainwater to seep through. This allows the seeds of woody and herbaceous plants to germinate. The farmer, Yacouba Sawadogo, has chosen restoration techniques based on helping vegetation to reclaim the site (for more details please see (Rodrigues et al. 2019 and Kaboré et al. 2024). In addition to *zaï*, he has mobilised stone barriers, organic fertiliser, crop-fallow succession, assisted natural regeneration (ANR), woody species plantations, techniques to encourage the return of termites, and the installation of water troughs and seeds to attract and settle birds and small mammals on the site. The site was first used to grow cereals (millet, sorghum) and then abandoned to allow the regenerating woody vegetation to develop into a

wooded savannah. For the three agricultural sites, restoration activities do not consist of reforestation. They consist of water and soil conservation/soil restoration and preservation activities to restore degraded land for agriculture. Agricultural land number 1 (AL1) covers 31 hectares. It was initially devoid of vegetation and had crusted soil. Management of the site began in 1991 and consisted of the use of zaï, stone barriers, RNA, fallow and crop rotation. Millet, cowpeas and peanuts are the main crops grown on the site.

Agricultural land number 2 (AL2) covers four hectares. It was initially a degraded and unproductive land, with a crusted surface. Soil restoration work began in 2007 with zaï, organic fertiliser amendments and stone barriers. The farmer currently has a good production of millet and cowpeas on the site. Agricultural land number 3 covers 2.7 hectares. Soil restoration

activities were initiated on bare, degraded soil in 2000. The techniques used are zaï, stone barriers, organic fertiliser and RNA. The farmer uses crop rotation with sorghum, cowpea and millet.

2.2 Data Collection and Allometric Equations

Control sites, identical to the restored sites prior to their development, were identified by the farmers carrying out the restoration works. A floristic inventory was carried out on all these restored and control sites in 2018 (Table 1). Oriented sampling was used to cover all the heterogeneities of the sites. The inventory was carried out on 36 plots of 900 m² each. The scientific names and dendrometric parameters (diameter at breast height -dbh-, height, crown diameter) of each woody species were recorded.

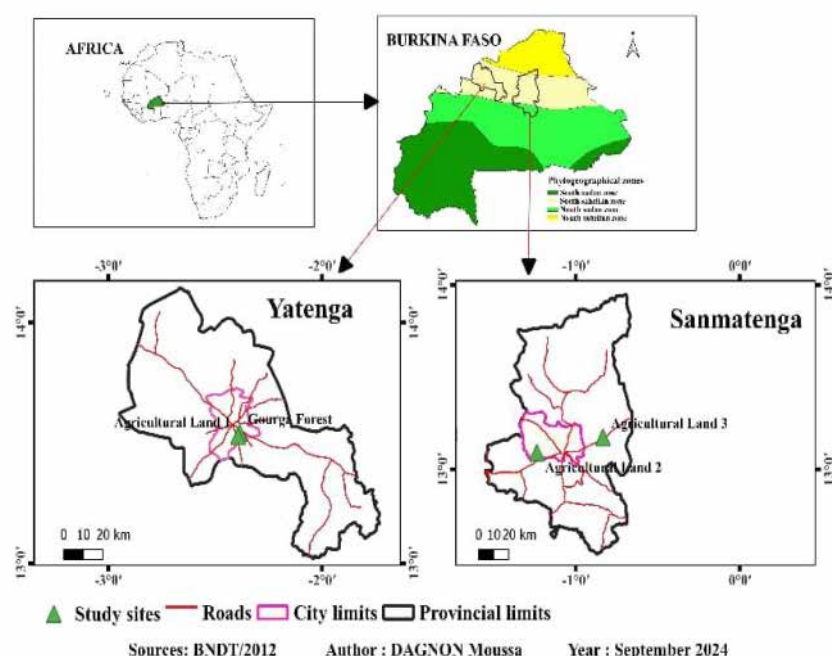


Fig. 1. Location of study sites

Table 1. Site characteristics and number of survey plots

Sites	Area (ha)	Number of plots	
		Restored sites	Controls
Gourga Managed Forest	27	9	6
Agricultural land 1	31	3	3
Agricultural land 2	4	4	3
Agricultural land 3	2,7	4	4
Total	64,5	20	16

Table 2. Allometric equations used to calculate plant biomass

Species	Location	Allometric equations	Sources
<i>Acacia nilotica</i> (L.) Willd. ex Delile	Senegal	$Y = 5.066Dbh - 0.696dbh^2 + 0.05dbh^3$	Mbow et al. (2014)
<i>Acacia senegal</i> (L.) Willd.	Senegal	$Y = 0.032dbh^3 - 1.016dbh^2 + 10.87dbh + 7.430$	Thiam et al. (2014)
<i>Acacia seyal</i> Delile	Senegal	$Y = 5.066dbh - 0.696dbh^2 + 0.05dbh^3$	(Mbow et al. 2014)
<i>Anogessus leiocarpa</i> Guill. & Perr.)	Benin	$\ln(Y) = -2.4996 + 1.5133\ln(dbh) + 1.1256\ln(h)$	Guendehou et al. (2012)
<i>Combretum micranthum</i> G.Don	Tiogo, Burkina	$Y = 0.827 + 0.184db + 0.0337dbh - 0.001db \times dbh + 0.0004dbh \times h$	Sawadogo et al. (2010)
<i>Guira senegalensis</i> Lam.	Tongomayel, Burkina	$\log_{10}Y(g) = (0.55 + (1.89 \times \log(X))) \times 10^{-3}$	Henry et al. (2011)
<i>Piliostigma reticulatum</i> (DC.) Hochst.	Kollo, Niger	$Y = 5.485Dbh + 15.717$	Larwanou et al. (2010)
<i>Pterocarpus lucens</i> Lepr. ex Guill. & Perr.	Senegal	$\log_{10} y (g MS) = 0.6156 + 1.862 \log_{10} C$	Ngom et al. (2014)
Other species		$Y = \text{EXP}((-1,996) + 2,32 \times \ln(dbh))$	FAO1, (Brown 1997)
Other species		$Y = 42,69 - 12,8 \times dbh + 1,24 \times dbh^2$	FAO2 (Brown 1997)
Other species		$Y = \text{EXP}((-2,134) + 2,53 \times \ln(dbh))$	FAO3 (Brown 1997)

Y: Aboveground biomass; DBH: Diameter at Breast Height; FAO: Food and Agriculture Organisation.

The scientific names of the plants and their diameter at breast height, were used to calculate the woody biomass. The research focused on allometric equations expressing the dry biomass of each species. The analysis included individuals with dbh $\geq$ 5 cm. Data on carbon stock estimates are patchy or non-existent for some species and for some countries such as Burkina Faso (Gibbs et al. 2007). Allometric equations for aboveground biomass (AGB) of the main species were determined from a literature review (Table 2). The allometric equations of Brown (1997) (FAO1, FAO2, FAO3) were applied to other species that do not have allometric equations (after unsuccessful literature search). Below-ground woody biomass (BGB) was calculated by multiplying the coefficient 0.27 by aboveground biomass (Mokany et al. 2007). Total woody biomass (DM) is the sum of AGB and BGB. Carbon stock was calculated by multiplying total woody biomass by 0.47 (IPCC 2006). The conversion rate from carbon stock to metric tonne equivalent of CO₂ is 44/12 (Mass of CO₂/Mass of Carbon). The monetary value of a tonne of CO₂ has been estimated on the basis of two sources in order to see how this value varies from a minimum value to a maximum value. These sources are REDD+, which estimates a tonne of CO₂ at \$30 (United Nations Environment Programme 2023 and Rennert et al. 2022) which estimates a tonne of CO₂ at \$185.

3. RESULTS

3.1 Diversity of Woody Species

3.1.1 Gourga managed forest

The soil restoration activities had an impact on the change in phytodiversity. In the Gourga managed forest, 31 adult woody species (dbh $\geq$ 5 cm) were recorded. *Combretum micranthum* (30.2%) was the most abundant species in terms of number of trees. It was followed by *Guiera senegalensis* (19.6%), *Sclerocarya birrea* (8.1%), *Cassia sieberiana* (6.5%) and *Balanites aegyptiaca* (6.0%) (Table 2). The average density of woody plants is 594 plants/ha, with a maximum of 1210 plants/ha in the woody savannah and a minimum of 178 plants/ha in the shrub savannah.

In contrast to the forest, the diversity of woody species in the controls is very low, with only 11 species. All of these species were recorded in the forest. Management therefore had the effect of conserving 11 species and regenerating 20

other woody species. The average density in the control was 22 plants/ha, with a maximum density of 44 plants/ha and a minimum density of 0 plants/ha in the bare soil (Table 3).

3.1.2 Agricultural lands

Five woody species were recorded in AL1 compared to none in the control. Average tree density is 93 plants/ha. AL2 has two woody species. The density of these woody species is 11 plants/ha. Seven species were inventoried on the controls. Four woody species were inventoried on AL3 (Table 4). The density of the woody plants is 19 plants per hectare. On the control plots, the same density is 14 plants per hectare for a woody species diversity of three species.

3.2 Woody Biomass and Stock of Carbon

The results show that the estimation of biomass differs according to the type of allometric equation that is used (Table 5). The results are often similar between the use of specific equations and FAO1. In all cases, the highest values are obtained with FAO2. The Gourga managed forest has a potential of 19.3 (40.8) tonnes of woody biomass (AGB + BGB) per hectare, compared to 1.2 (2.9) tonnes per hectare in the control area.

The difference between the biomass per hectare in the FMG and that in the control gives 18.1(37.8) t/ha, representing the effort of more than four decades of management with FLR activities. Woody biomass calculated for AL1 was 0.7 (4.3) t/ha versus 0.0 t/ha for control. In the Kaya region the results were 11.8 (24.6) and 1.3 (3.4) t/ha for AL2 and the control respectively.

3.3 CO₂ Sequestration and Economic Value

In the Gourga forest, the amount of carbon dioxide sequestered varies between 33.27 and 70.32 t CO₂/ha over a 45 years period, depending on the allometric equations used to calculate aboveground biomass. Assuming that the forest would follow the same trajectory as the controls, we can extract the contribution of soil restoration to carbon sequestration. The analyses therefore show that the efforts to restore the soil lead to a gain of 31.2 (65.3) tonnes of CO₂ per hectare over 45 years. This amounts to about 0.7 (1.5) tonne of CO₂ per hectare per year on average. If this rate is

Table 3. Woody plant diversity in the Gourga managed forest and in the control sites

Species	Frequency (%)	
	Site	Control
<i>Vachellia nilotica</i> (L.) P.J.H.Hurter & Mabb. (syn. <i>Acacia nilotica</i> (L.) Willd. ex Delile)	1.0	-
<i>Senegalia senegal</i> (Brenan) Kyal. & Boatwr. (syn. <i>Acacia senegal</i> (L.) Willd.)	1.3	6.7
<i>Vachellia seyal</i> (Delile) P.J.H.Hurter (syn. <i>Acacia seyal</i> Delile)	2.1	-
<i>Adansonia digitata</i> L.	4.4	-
<i>Albizia chevalieri</i> Harms	0.6	-
<i>Terminalia leiocarpa</i> (DC.) Baill. (syn. <i>Anogeissus leiocarpa</i> Guill. & Perr.)	0.2	-
<i>Azadirachta indica</i> A.Juss.	3.3	6.7
<i>Balanites aegyptiaca</i> (L.) Delile	6.0	6.7
<i>Combretum aculeatum</i> Vent.	0.4	-
<i>Combretum collinum</i> Fresen.	0.2	-
<i>Combretum glutinosum</i> Guill. & Perr.	1.0	6.7
<i>Combretum molle</i> R.Br. ex G.Don	0.2	-
<i>Cassia sieberiana</i> DC.	6.5	13.3
<i>Combretum micranthum</i> G.Don	30.2	6.7
<i>Dichrostachys cinera</i> (L.) Wight & Arn.	1.5	-
<i>Diospyros mespiliformis</i> Hochst. ex A.DC.	0.8	6.7
<i>Gardenia erubescens</i> Stapf & Hutch.	0.2	-
<i>Guiera senegalensis</i> Lam.	19.6	6.7
<i>Holarrhena floribunda</i> (G. Don) T. Durand. & Schinz	0.2	-
<i>Khaya senegalensis</i> (Desr.) A.Juss.	0.2	-
<i>Lannea microcarpa</i> Engl. & K.Krause	1.9	20.5
<i>Piliostigma reticulatum</i> (DC.) Hochst.	3.5	13.3
<i>Pterocarpus lucens</i> Lepr. ex Guill. & Perr.	2.7	-
<i>Bauhinia rufescens</i> Lam.	0.2	-
<i>Sclerocarya birrea</i> Hochst.	8.1	-
<i>Stereospermum kunthianum</i> Cham.	0.2	-
<i>Tamarindus indica</i> L.	0.2	-
<i>Terminalia avicenioides</i> Guill. & Perr	-	6.7
<i>Vitellaria paradoxa</i> C. F. Gaertn.	0.2	-
<i>Ximenia americana</i> L.	0.2	-
<i>Ziziphus mauritiana</i> Lam.	2.7	-

applied to the area of the forest (27 ha) and CO₂ prices, the minimum real value of carbon sequestration through restoration is \$575 and the maximum is \$7,243 per year. The same analysis gives \$46-\$1,588 for AL1, \$185-\$2,466 for AL2 and \$0,32-\$11,92 for AL2 as the value of carbon sequestration attributable to forest and land restoration actions per year (Table 6).

4. DISCUSSION

4.1 Woody Species and Carbon Stock

The most abundant species in the Gourga managed forest (*Combretum micranthum* and

Guiera senegalensis), the agricultural land 1 (*Vachellia seyal* and *Combretum micranthum*) and the agricultural land 3 (*Vachellia seyal* and *Cassia sieberiana*) are shrub species. *Combretum micranthum* and *Guiera senegalensis* are typical species of semi-aride sahelian zones (Becker & Müller 2007). The Gourga managed forest has more woody species diversity than outside the forest, as found by Bognini et al. (2023). The present study records 31 species versus 55 species recorded in the same forest by Bognini et al. (2023). They recorded all woody species whereas the present study recorded only woody species with dbh $\geq$ 5 cm. The owner of the Gourga managed forest, Yacouba Sawadogo, was called the "man who

stopped the desert" for his exploit to restore a bare soil to a forest (Rodrigues 2019 and Codur et al. 2022). Other plantation initiatives exist in the Sahel region of Burkina Faso but the case of Gourga remains the oldest and most successful experience (Vinceti et al. 2020). On the agricultural lands, farmers grown more diverse woody species compared to the control. The land can therefore be used to farm, while helping to preserve plant diversity.

The biomass of a given ecosystem cannot be evaluated with certitude but can be well estimated when many methods are used. In this study, four methods with different allometric equations adapted for the semi-arid regions were used. The dry biomass of woody species found in the Gourga managed forest is between 15.2 t ha⁻¹ and 32.2 t ha⁻¹. For comparison, two plantations of *Piliostigma reticulatum*, 5 and 15 years old, store a dry aboveground biomass of 3.65 t ha⁻¹ and 30 t ha⁻¹, respectively, at a density of 1100 plants ha⁻¹ in the Sudanese zone of Burkina Faso (Tyano et al, 2019). The carbon stocks in the GMF (9.075-19.178 t·ha⁻¹) is closed to those of woodland (10.2 ± 6.4 t·ha⁻¹) while the

carbon stocks in the agricultural lands are closed to shrub savannas (0.9 ± 1.2 t·ha⁻¹) found by Dimobe et al. (2018) in Dano (sudanian zone of Burkina Faso). The aboveground carbon stock in the Gourga managed forest (9.1-16.3 t C/ha) is near the range found in a stand of *G. senegalensis* (15.45-20.80 t C/ha) by Awé et al. (2024) and in a shrub savannah (12.52 t C/ha) by Awé et al. (2019) in Cameroon.

4.2 CO₂ Sequestered and Economic Potential

In semi-arid areas, afforestation with resilient species such as *Acacia nilotica* increases carbon assimilation and sequestration (Kumar et al. 2022). The CO₂ flux of *Combretum micranthum* and *Guiera senegalensis* has been studied well by Levy & Jarvis (1998). Stem respiration per hour is estimated at 3.97 mol CO₂ m⁻². The efflux of CO₂ is an important part of the annual carbon balance of the ecosystem [47]. The amount of CO₂ sequestered in AL2 (20.26-42.46 tCO₂ ha⁻¹) and in the GMF (33.27-70.32 tCO₂ ha⁻¹) is close to that found by [48] (24.71 tCO₂ ha⁻¹) in the parklands of Ouahigouya.

Table 4. Diversity of woody plants in agricultural lands and its controls

Species	Frequency (%)					
	AL1		AL2		AL3	
	Site	Control	Site	Control	Site	Control
<i>Azadirachta indica</i> A.Juss.	-	-	-	7.7	-	-
<i>Balanites aegyptiaca</i> (L.) Delile	-	-	-	23.1	-	-
<i>Vachellia nilotica</i> (L.) P.J.H.Hurter & Mabb. (syn. <i>Acacia nilotica</i> (L.) Willd. ex Delile)	-	-	-	-	-	40.0
<i>Vachellia seyal</i> (Delile) P.J.H.Hurter (<i>Acacia seyal</i> Delile)	32.0	-	-	15.4	-	-
<i>Balanites aegyptiaca</i> (L.) Delile	-	-	-	-	-	20.0
<i>Cassia sieberiana</i> DC.	8.0	-	-	7.7	-	40.0
<i>Combretum glutinosum</i> Guill. & Perr.	20.0	-	-	15.4	-	-
<i>Combretum micranthum</i> G.Don	32.0	-	-	-	-	-
<i>Faidherbia albida</i>	-	-	25	-	-	-
<i>Lannea microcarpa</i> Engl. & K.Krause	-	-	-	-	28.0	-
<i>Guiera senegalensis</i> Lam.	-	-	-	7.7	-	-
<i>Piliostigma reticulatum</i> (DC.) Hochst.	8.0	-	-	23.1	43.0	-
<i>Sclerocarya birrea</i> Hochst.	-	-	-	-	14.0	-
<i>Vitellaria paradoxa</i> C. F. Gaertn.	-	-	75	-	-	-
<i>Ziziphus mauritiana</i> Lam.	-	-	-	-	14.0	-

AL1, AL2, AL3: Agricultural land number 1, 2 and 3.

Table 5. Woody biomass and its equivalent in tonnes of carbon in the different types of ecosystems

Parameters	Specific allometrics equations	FAO1 allometric equation	FAO2 allometric Equation	FAO3 allometric equation
Gourga managed forest (GMF)				
AGB/ha	15,202.9	15,586.4	32,129.9	27,246.4
BGB/ha	4,104.8	4,208.3	8,675.1	7,356.5
DM/ha	19,307.7	19,794.8	40,804.9	34,602.9
Total DM	521,308.3	534,459.3	1,101,732.6	934,277.7
t C/ha	9.075	9.304	19.178	16.3
GMF t C	245.0	251.2	517.8	439.1
Control of GMF				
AGB/ha	929.5	989.6	2,316.4	1,599.6
BGB/ha	251.0	267.2	625.4	431.9
DM/ha	1,180.5	1,256.8	2,941.8	2,031.4
t C/ha	0.555	0.591	1.383	0.955
Agricultural land 1 (AL1)				
AGB/ha	604.9	1,546.3	3,415.4	2,356.7
BGB/ha	163.3	417.5	922.2	636.3
DM/ha	768.2	1,963.8	4,337.6	2,993.0
Total DM	23,815.7	60,876.9	134,466.1	92,782.5
t C/ha	0.361	0.923	2.039	1.407
AL1 t C	11.2	28.6	63.2	43.6
Control of AL1				
AGB/ha	0.0	0.0	0.0	0.0
BGB/ha	0.0	0.0	0.0	0.0
DM/ha	0.0	0.0	0.0	0.0
t C/ha	0.0	0.0	0.0	0.0
Agricultural land 2 (AL2)				
AGB/ha	9,258.2	9,258.2	19,398.4	18,158.5
BGB/ha	2,499.7	2,499.7	5,237.6	4,902.8
DM/ha	11,758.0	11,758.0	24,635.9	23,061.3
Total DM	47,031.9	47,031.9	98,543.8	92,245.1
t C/ha	5.526	5.526	11.579	10.839
AL2 t C	22.1	22.1	46.3	43.4
Control of AL2				
AGB/ha	986.1	1,528.3	2,647.1	2,264.0
BGB/ha	266.3	412.6	714.7	611.3
DM/ha	1,252.4	1,941.0	3,361.8	2,875.3
t C/ha	0.589	0.912	1.580	1.351
Agricultural land 3 (AL3)				
AGB/ha	305.2	186.1	362.1	249.1
BGB/ha	82.4	50.2	97.8	67.3
DM/ha	387.6	236.3	459.9	316.3
Total DM	1,550.3	945.2	1,839.5	1,265.3
t C/ha	0.182	0.111	0.216	0.149
AL3 t C	0.4	0.3	0.5	0.3
Control of AL3				
AGB/ha	172.7	148.2	340.0	205.3
BGB/ha	46.6	40.0	91.8	55.4
DM/ha	219.3	188.2	431.8	260.7
t C/ha	0.103	0.088	0.203	0.123

AGB: Aboveground biomass in kg; BGB: Belowground biomass in kg, DM: dry matter in kg; t C/ha: metric tonne of carbon per hectare

Table 6. Carbon sequestration and associated economic values for the different study sites (in USD)

Parameters	Specific allometrics equations	FAO1 allometric equation	FAO2 allometric Equation	FAO3 allometric equation
Gourga managed forest (GMF)				
t CO ₂ /ha	33.27	34.11	70.32	59.63
Total t CO ₂ sequestered	898.4	921.1	1 898.7	1 610.1
Average t CO ₂ sequestered /year	20.0	20.5	42.2	35.8
Minimum value/year	599	614	1 266	1 073
Maximum value/year	3 693	3 787	7 806	6 619
Control t CO ₂ /ha	2.03	2.17	5.07	3.50
Difference between GMF and control t CO ₂ /ha/year	0.7	0.7	1.5	1.2
Minimum value for CO ₂ sequestration due to restoration/year	562	575	1175	1010
Maximum value for CO ₂ sequestration due to restoration/year	3468	3546	7243	6231
Agricultural land 1 (AL1)				
t CO ₂ /ha	1.32	3.38	7.48	5.16
Total t CO ₂ in AL1	41.0	104.9	231.7	159.9
Average t CO ₂ sequestered/year	1.5	3.9	8.6	5.9
Minimum value/year	46	117	257	178
Maximum value/year	281	719	1588	1096
Control t CO ₂ /ha	0.0	0.0	0.0	0.0
Difference between AL1 and control t CO ₂ /ha/year	0.05	0.13	0.28	0.19
Minimum value for CO ₂ sequestration due to restoration/year	46	117	257	178
Maximum value for CO ₂ sequestration due to restoration/year	281	719	1588	1096
Agricultural land 2 (AL2)				
t CO ₂ /ha	20.26	20.26	42.46	39.74
Average t CO ₂ sequestered/year	7,4	7,4	15,4	14,5
Minimum value/year	221	221	463	434
Maximum value/year	1363	1363	2856	2674
Control t CO ₂ /ha	2.16	3.34	5.79	4.96
Difference between AL2 and control t CO ₂ /ha/year	1.6	1.5	3.3	3.2
Minimum value for CO ₂ sequestration due to restoration/year	198	185	400	379
Maximum value for CO ₂ sequestration due to restoration/year	1218	1138	2466	2340
Agricultural land 3 (AL3)				
t CO ₂ /ha	0.67	0.41	0.79	0.55
Average t CO ₂ sequestered/year	0.15	0.09	0.18	0.12
Minimum value/year	4	3	5	4
Maximum value/year	27	17	33	22
Control t CO ₂ /ha	0.38	0.32	0.74	0.45
Difference between AL3 and control t CO ₂ /ha/year	0,02	0,00	0,00	0,01
Minimum value for CO ₂ sequestration due to restoration/year	1,93	0,55	0,32	0,64
Maximum value for CO ₂ sequestration due to restoration/year	11,92	3,41	1,99	3,94

t CO₂/ha: metric tonne of carbon dioxide per hectare; t C/ha: metric tonne of carbon per hectare

There are a number of ecosystem benefits, including carbon sequestration, from restoring plant cover. Plants, especially woody plants, store CO₂ in the atmosphere. This reduces greenhouse gas levels Rodríguez-Calcerrada et al. (2014). According to the IPCC (2023) the net anthropogenic greenhouse gas emissions of the world is estimated to be 59 ± 6.6 GtCO₂-eq in 2019, 54% (21 GtCO₂-eq) higher than in 1990. The IPCC scenarios show that there is a rapidly closing window of opportunity to secure a liveable and sustainable future for all with a very high level of confidence IPCC (2023). Emitting one tonne of carbon into the atmosphere has warming consequences that cannot be offset by sequestering one tonne of carbon (Sierra et al. 2021). Sequestering atmosphere carbon by planting and preserving trees can help mitigate climate change but the best strategy is to decrease fossil fuel combustion in the first place.

Carbon storage in woody biomass only counts if such biomass is not harvest for cooking or heating purposes, which would release the carbon stored back into the atmosphere. Net carbon stored every year in woody biomass could qualify for carbon payments. This is in line with economic theory that prescribes that only additional carbon stored is paid for in a given year.

The implementation of the REDD+ mechanism is based on the quantification of carbon stored in order to propose compensation schemes (Awé et al. 2019). Neyá et al. (2020) showed that if the price of one tonne of additional CO₂ sequestered per hectare is around US\$4.00, the carbon payment system of the REDD+ initiative can, in theory, compensate smallholders for their efforts in planting and maintaining trees. Thus, the use of \$30 as the price of REDD+ (United Nations Environment Programme 2023) in this paper allows for an incentive price that could largely compensate smallholders' efforts if a project decides to finance a carbon project. It is important to note that REDD+ does not pay for carbon stocks, but for the enhancement of existing forest carbon stocks (SN-REDD+. Strategie 2022). It is this payment based on the performance of forest systems (additional carbon) that is presented in this article. Most articles on carbon sequestration only estimate the total value of carbon sequestered, without knowing how much additional carbon is sequestered per year. The payments based on the current carbon market are far from sufficient to provide the necessary incentives, since the

land restorer makes a net loss compared to "business as usual" (Kaboré et al. 2024).

One problem also is who receives the payment for carbon storage: national governments or small land users? If national government claim payments on the international market, then land users do not have an incentive to store carbon (plus land tenure insecurity may be a disincentive to plant more trees on their land). Small land users do not typically have access to international carbon markets, so they would require some form of broker to help them out with cashing in carbon payments against a small fee.

The various methods used to remove CO₂ from the atmosphere are not of equal maturity, durability, co-benefits or cost. The capture of CO₂ by photosynthesis is greatly enhanced. It is possible to protect forests for many decades, but it is virtually impossible to guarantee protection for more than a thousand years (Michaelowa et al. 2023). This will be one of the shortcomings of carbon sequestration in plant biomass.

5. CONCLUSION

The study quantified the carbon stock sequestered in woody biomass and assessed the economic value of additional carbon sequestered each year in the semi-arid region of Burkina Faso. The various techniques of forest and landscape restoration (FLR), such as zaï and stone barriers, have made it possible to restore both forest and agricultural lands. The woody plants growing in these ecosystems stored between 0.02 tonne and 1.5 tonne of CO₂ per hectare per year. This study contributes to the scaling up of FLR activities needed to convince potential investors of the merits of funding this type of intervention. Based on the economic value of carbon stored in plant biomass, farmers restoring degraded land could be encouraged to keep trees on their farms. Future research should focus on rethinking financial incentives for restoring and growing woody plants on degraded lands in Burkina Faso.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Alessandrini, A., Ghio, D., & Migali, S. (2021). Population dynamics, climate change and variability in Western Africa: The case of Sahel regions. *Publications Office of the European Union*. Luxembourg. <https://doi.org/10.2760/797541>
- Awé, D. V., Noiha, N. V., & Vroh, B. T. A. (2024). Biological carbon storage potential of *Guiera senegalensis* JF Gmel. stands in Central Africa: A case study from Cameroon. *International Journal of Low-Carbon Technologies*, 19, 236-244.
- Awé, D. V., Noiha, N. V., Zapfack, L., Vroh, B. T. A., & Saïdou, A. (2019). Carbon sequestration potential and economic value in agroforestry parkland to *Tectona grandis* L. f. (Verbenaceae) in Central Africa: A case study of the Department of Poli (Northern Region in Cameroon). *Advances in Research*, 18(5), 1-16. <https://doi.org/10.9734/air/2019/v18i530100>
- Becker, T., & Müller, J. V. (2007). Floristic affinities, life-form spectra and habitat preferences of the vegetation of two semi-arid regions in Sahelian West and Southern Africa. *Basic and Applied Dryland Research*, 1(1), 33-50.
- Belmin, R., Sawadogo, H., & N'Dienor, M. (2023). Cultiver sans eau ou presque: La technique du zaï au Sahel. *CIRAD Paper*. Accessed August 10, 2024. <https://agritrop.cirad.fr/607174/1/607174.pdf>
- Bognini, K., Bondé, L., Da, S. S., Mapendembe, A., & Gnabeli, R. Y. (2023). Promoting private forests for biodiversity conservation and ecosystems restoration in the Sahel region. *Nature Conservation*, 53, 17-38.
- Bouquet, C. (2021). Les équilibres eau-terre-population au Sahel. *Geovision*, 2(2), 434-441.
- Brown, S. (1997). *Estimating biomass and biomass change of tropical forests: A primer* (FAO Forestry Paper 134). FAO - Food and Agriculture Organization of the United Nations, Rome.
- Codur, A. M., Harris, J., & Fay, K. (2022). *Agriculture and climate: Economics and policy issues*. An ECI Teaching Module on Social and Environmental Issues in Economics, Economics in Context Initiative, Global Development Policy Center, Boston University. Accessed September 20, 2024. <https://www.bu.edu/eci/education-materials/teaching-modules-2/>
- Dimobe, K., Kouakou, J. L. N. D., Tondoh, J. E., Zoungrana, B. J. B., Forkuor, G., & Ouédraogo, K. (2018). Predicting the potential impact of climate change on carbon stock in semi-arid West African savannas. *Land*, 7(4), 124. <https://doi.org/10.3390/land7040124>
- Domke, G. M., Oswalt, S. N., Walters, B. F., & Morin, R. S. (2020). Tree planting has the potential to increase carbon sequestration capacity of forests in the United States. *Proceedings of the National Academy of Sciences*, 117(40), 24649-24651.
- Farooq, A., Farooq, N., Akbar, H., Hassan, Z. U., & Gheewala, S. H. (2023). A critical review of climate change impact at a global scale on cereal crop production. *Agronomy*, 13(1), 162.
- Gibbs, H. K., Brown, S., Niles, J. O., & Foley, J. A. (2007). Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. *Environmental Research Letters*, 2(4), 045023.
- Gitz, V., Meybeck, A., Lipper, L., Young, C. D., & Braatz, S. (2016). Climate change and food security: Risks and responses. *Food and Agriculture Organization of the United Nations (FAO) Report*, 110(2), 3-36.
- Guendehou, G. H. S., Lehtonen, A., Moudachirou, M., Mäkipää, R., & Sinsin, B. (2012). Stem biomass and volume models of selected tropical tree species in West Africa. *Southern Forests*, 74(2), 77-88. <https://doi.org/10.2989/20702620.2012.701432>
- Hailu, F. (2023). Climate change as a trigger for desertification and possible alternatives to reduce biodiversity loss. *Journal of the Selva Andina Biosphere*, 11(1), 94-111.
- Henry, M., Picard, N., Trotta, C., Manlay, R., Valentini, R., Bernoux, M., & Saint André, L. (2011). Estimating tree biomass of sub-Saharan African forests: A review of available allometric equations. *Silva Fennica*, 45(3B), 477-569.
- Intergovernmental Panel on Climate Change (IPCC). (2006). *Guidelines for National Greenhouse Gas Inventories*. National Greenhouse Gas Inventories Programme, IGES, Japan. Accessed June 15, 2024.

- <https://www.ipcc-nggip.iges.or.jp/public/2006gl/>
- Intergovernmental Panel on Climate Change (IPCC). (2023). Summary for policymakers. In *Climate Change 2023: Synthesis Report* (pp. 1-34). Geneva, Switzerland. <https://doi.org/10.59327/IPCC/AR6-9789291691647.001>
- Kaboré, S. A., Quillérrou, E., Maiga-Yaleu, S., Kairé, M., Moussa, I. B., Issa, O. M., Hauswirth, D., & Nacro, H. B. (2024). A cost-benefit analysis of ecosystem services from restoring degraded soils to forest ecosystems in the Sahel. *Journal for Nature Conservation*, 81, 126685.
- Kang, Y., Khan, S., & Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security: A review. *Progress in Natural Science*, 19(12), 1665-1674.
- Kumar, R., Pande, V. C., Bhardwaj, A. K., Dinesh, D., Bhatnagar, P. R., Dobhal, S., & Verma, K. (2022). Long-term impacts of afforestation on biomass production, carbon stock, and climate resilience in a degraded semi-arid ravine ecosystem of India. *Ecological Engineering*, 177, 106559. <https://doi.org/10.1016/j.ecoleng.2022.106559>
- Larwanou, M., Yemshaw, Y., & Saadou, M. (2010). Prediction models for estimating foliar and fruit dry biomasses of five savannah tree species in the West African Sahel. *International Journal of Biological and Chemical Sciences*, 4(6), 2245-2256.
- Le Barbé, L., Lebel, T., & Tapsoba, D. (2002). Rainfall variability in West Africa during the years 1950–90. *Journal of Climate*, 15(2), 187-202.
- Lemenkova, P., & Debeir, O. (2023). Environmental mapping of Burkina Faso using TerraClimate data and satellite images by GMT and R scripts. *Advances in Geodesy and Geoinformation*, 72(2).
- Levy, P. E., & Jarvis, P. G. (1998). Stem CO₂ fluxes in two Sahelian shrub species (*Guiera senegalensis* and *Combretum micranthum*). *Functional Ecology*, 12(1), 107-116. <https://doi.org/10.1046/j.1365-2435.1998.00156.x>
- Mansourian, S., & Berrahmouni, N. (2021). *Review of forest and landscape restoration in Africa*. Food & Agriculture Organisation. Accessed September 21, 2024. <https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1445107/>
- Mbow, C., Verstraete, M. M., Sambou, B., Diaw, A. T., & Neufeldt, H. (2014). Allometric models for aboveground biomass in dry savanna trees of the Sudan and Sudan-Guinean ecosystems of Southern Senegal. *Journal of Forest Research*, 19(3), 340-347. <https://doi.org/10.1007/s10310-013-0414-1>
- Michaelowa, A., Honegger, M., Poralla, M., Winkler, M., Dalfiume, S., & Nayak, A. (2023). International carbon markets for carbon dioxide removal. *PLoS Climate*, 2(5), e0000118.
- Mokany, K., Raison, R. J., & Prokushkin, A. S. (2006). Critical analysis of root : shoot ratios in terrestrial biomes. *Global Change Biology*, 12(1), 84–96. <https://doi.org/10.1111/j.1365-2486.2005.001043.x>
- Neya, T., Abunyewa, A. A., Neya, O., Zoungrana, B. J., Dimobe, K., Tiendrebeogo, H., & Magistro, J. (2020). 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. *Environmental Management*, 65(2), 203-211. <https://doi.org/10.1007/s00267-019-01260-4>
- Ngom, D., Agbangba, E. C., Fall, T., Diatta, S., & Akpo, L. E. (2014). Quantification of ecosystem services provided by *Pterocarpus lucens* Lepr. ex Guill. and Perrott.: Forage production, timber, and carbon sequestration in the Biosphere Reserve of Ferlo (Northern Senegal). *American Journal of Plant Sciences*, 5, 766-777. <https://doi.org/10.4236/ajps.2014.55091>
- Omotoso, A. B., & Omotayo, A. O. (2024). The interplay between agriculture, greenhouse gases, and climate change in Sub-Saharan Africa. *Regional Environmental Change*, 24(1), 1-13. <https://doi.org/10.1007/s10113-023-02159-3>
- Pédarros, É., Allouche, J., Oma, M. B., Duboz, P., Diallo, A. H., Kassa, H., Laloi, C., Müller-Mahn, D., Soumahoro, K. A., Bi, S. T., & Yao, Y. C. (2024). The Great Green Wall as a social-technical imaginary. *IDS Working Paper* 603. Brighton: Institute of Development Studies. <https://doi.org/10.19088/IDS.2024.018>

- Rennert, K., Errickson, F., Prest, B. C., Rennels, L., Newell, R. G., Pizer, W., & et al. (2022). Comprehensive evidence implies a higher social cost of CO₂. *Nature*, 610, 687–692. <https://doi.org/10.1038/s41586-022-05224-9>
- Rezaei, E. E., Webber, H., Asseng, S., Boote, K., Durand, J. L., Ewert, F., & MacCarthy, D. S. (2023). Climate change impacts on crop yields. *Nature Reviews Earth & Environment*, 4(12), 831-846.
- Rodrigues, A. D. (2019). From Pairidaeza to Planet Garden: The homo-gardinus against desertification. In M. P. Diogo, A. D. Rodrigues, A. Simões, & D. Scarso (Eds.), *Gardens and human agency in the Anthropocene*. New York: Routledge.
- Rodríguez-Calcerrada, J., Martin-StPaul, N. K., Lempereur, M., Ourcival, J. M., del Rey, M. D. C., Joffre, R., & Rambal, S. (2014). Stem CO₂ efflux and its contribution to ecosystem CO₂ efflux decrease with drought in a Mediterranean forest stand. *Agricultural and Forest Meteorology*, 195, 61-72. <https://doi.org/10.1016/j.agrformet.2014.06.016>
- Sawadogo, H., Hien, F., Soboro, A., & Kambou, F. (2014). Pits for trees: How farmers in semi-arid Burkina Faso increase and diversify plant biomass. In *Farmer Innovation in Africa*. Routledge.
- Sawadogo, L., Savadogo, P., Tiveau, D., Dayamba, S. D., Zida, D., Nouvellet, Y., Oden, P. C., & Guinko, S. (2010). Allometric prediction of aboveground biomass of eleven woody tree species in the Sudanian savanna-woodland of West Africa. *Journal of Forestry Research*, 21, 475–481.
- Sierra, C. A., Crow, S. E., Heimann, M., Metzler, H., & Schulze, E. D. (2021). The climate benefit of carbon sequestration. *Biogeosciences*, 18(3), 1029-1048.
- SN-REDD+. (2022). *Stratégie nationale REDD+ du Burkina Faso*. Ouagadougou, Burkina Faso. Accessed October 29, 2024. <https://redd.unfccc.int/submissions.html?country=BF>
- Sultan, B., Guan, K., Kouressy, M., Biasutti, M., Piani, C., Hammer, G. L., McLean, G., & Lobell, D. B. (2014). Robust features of future climate change impacts on sorghum yields in West Africa. *Environmental Research Letters*, 9(10), 104006.
- Thiam, S., Sambou, B., Mbow, C., & Guisse, A. (2014). Élaboration de modèles allométriques d'Acacia senegal L. Willd pour l'analyse du carbone ligneux en milieu sahélien: Cas de la zone sylvopastorale au Sénégal. *Afrique Science*, 10(3), 304-315.
- Toochi, E. C. (2018). Carbon sequestration: How much can forestry sequester CO₂. *Forestry Research and Engineering: International Journal*, 2(3), 148-150.
- Tyano, A., Yelemou, B., Hien, M., & Koala, J. (2019). Evaluation du stock de carbone aérien de *Piliostigma reticulatum* en zone soudanienne du Burkina Faso. *Journal of Applied Biosciences*, 144, 14784-14800.
- United Nations Environment Programme. (2023). *Pricing Forest Carbon*. Nairobi. ISBN 978-92-807-4013-4.
- Vinceti, B., Valette, M., Bougma, A. L., & Turillazzi, A. (2020). How is forest landscape restoration being implemented in Burkina Faso? Overview of ongoing initiatives. *Sustainability*, 12(24), 10430. <https://doi.org/10.3390/su122410430>
- Yameogo, W. V. M., Akpa, Y. L., Danumah, J. H., Traore, F., Tankoano, B., Sanon, Z., Kabore, O., & Hien, M. (2023). Spatio-temporal evolution of rainfall over the period 1981-2020 and management of surface water resources in the Nakanbe-Wayen watershed in Burkina Faso. *Earth*, 4(3), 606-625.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:

<https://www.sdiarticle5.com/review-history/126026>