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A bioeconomic analysis of the carbon sequestration potential of agroforestry systems: A case study of *Grevillea robusta* in South Western Uganda

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Abstract

***Grevillea robusta* is an agroforestry tree species that has been widely promoted under the carbon forestry schemes in South Western Uganda. The objective of the study was to estimate the amount of carbon sequestered and the profitability of carbon offsets in *G robusta* woodlot and agroforestry management options under the Plan Vivo system and small-scale Clean Development Mechanism (CDM). An allometric equation for *G robusta* was used to calculate the carbon stocks and merchantable wood volume in the woodlot and agroforestry management options over different crediting periods. The results indicated that *G robusta* woodlots and agroforestry management options sequestered 470 and 225 t CO_2e ha^{-1} respectively, over a 20 year rotation. The net present values (NPVs) of the *G robusta* agroforestry management option of US$4367 and 4447 ha^{-1} under the Plan Vivo and small-scale CDM, respectively, were higher than US$1358 and 1902 ha^{-1} in the *G robusta* woodlot management option. The NPV of the traditional agroforestry system was US$ 3992 ha^{-1}. These results show that, whereas the woodlot option stores more carbon, it is the least profitable option. Analysis also revealed that, although poor households were well represented in the Plan Vivo scheme, they preferred the agroforestry option. This suggests that forest carbon offsets on productive agricultural land, should focus on promoting agroforestry technologies in order to increase profitability and targeting of the poor households.**

Key words: Allometric equation, carbon offsets, profitability

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Introduction

There is increasing concern about the devastating effects of climate change on the environment, human health and food security (UNFCCC, 2008). It is widely accepted that climate change is closely linked to increased concentrations of atmospheric carbon dioxide (CO_2) and other greenhouse gases (Schmitt-Harsh *et al.,* 2012). Afforestation and reforestation have been considered as some of the measures for climate change mitigation under the Kyoto Protocol (Biocarbon Fund, 2011). Planting trees that are able to sequester greenhouse gases, such as carbon dioxide, is one of the options of mitigating climate change.The carbon sequestered by forest plantations and agroforestry systems can be traded under voluntary emissions reductions (VERs) or certified emission reductions (IPCC, 2007).

In South Western Uganda, the Environmental Conservation Trust of Uganda (ECOTRUST) has been implementing a voluntary carbon scheme under the Plan Vivo land system. The Plan Vivo system is a framework for planning, managing and monitoring the supply of Voluntary Emissions Reductions (VERs) from community based sustainable land-use projects (Carter, 2009). Similarly, the National Forestry Authority and other forest companies have been implementing the certified carbon scheme under the Clean Development Mechanism (CDM) (Peskett *et al.*, 2011). CDM is one of the market-based instruments designed by the Kyoto Protocol to ensure developed countries support joint implementation of climate mitigation projects to meet their agreed emission targets.

Grevillea robusta is among the tree species that have been widely promoted in the carbon offset schemes in Uganda. The species has also been promoted widely as shade trees for banana and coffee farming systems. Consequently, many tree farmers have adopted *G. robusta* in woodlot and agroforestry management options.

Several studies have investigated the amount of carbon that can be stored in forest carbon offsets (Aune *et al.,* 2004; De Jong *et al., 2005*; Shiufa *et al.,* 2010; Glomsrod *et al.,* 2011; Vonada *et al.,* 2011), while others have investigated the profitability of the carbon offsets (Palmer and Silber, 2012; Schmitt-Harsh *et al.,* 2012). However, to our knowledge, no study has specifically assessed the carbon sequestration potential of *G. robusta* under woodlot and agroforestry management options and under alternative carbon accounting systems. Therefore, this study was aimed at determining the amount of carbon sequestered, financial profitability of *G.robusta* under alternative management options and accessibility of forest carbon offsets in Uganda.

Methodology

Study area

The study was conducted in Rubirizi, Mitoma and Kabale districts in South-West Uganda, lying approximately between 00°162 S 30°062 E and 00°362 S 30°002 E. The total population in the 3 districts is 643,928 (UBOS, 2017) and the main agricultural activity in these areas is growing coffee and bananas, intercropped with other crops and tree species (Fisher, 2013).

Several farm forestry projects have been implemented in the study area, with the common aim of improving rural household income and livelihood. The Farm Income Enhancement and Forest

Conservation Project (FIEFOC) and the 'Trees for Global benefits' (TGB) project are the two major farm forestry projects that have been implemented in the study area. One of the objectives of the FIEFOC project was to improve rural household incomes, and livelihood, by providing an enabling environment for small-scale farming households to participate in tree planting for wood supply and environmental protection (OAG, 2011). This was achieved through provision of free tree seedlings and forestry advisory services to farming households in rural areas.

The TGB project was a community payment for Ecosystem Services (PES) scheme linking small-scale landholder farmers to the voluntary carbon market (Schreckenberg *et al.*, 2013). The project contracted farmers to plant a variety of indigenous tree species in order to sell voluntary emissions reductions on the voluntary carbon market. The project has more than 1500 registered participants using the Plan Vivo land use system (Schreckenberg *et al.*, 2013).

Data collection

A face-to-face questionnaire survey was conducted among tree farmers in Rubirizi and Mitooma districts to collect economic data on the quantity, price and flow of farm outputs (timber production, firewood) and transaction costs associated with *G. robusta* wood lots, *G. robusta* agroforestry and the traditional agroforestry systems. Stratified random sampling was used to select households for questionnaire interviews. The households were randomly sampled from lists of G. *robusta* tree farmers, according to their population proportions by district. The sampling frame for the households growing *G. robusta* under the different management options was provided by the district forest department staff and local leaders. Accordingly, 78, 86 and 88 respondents were sampled in the two districts from the *G. robusta* woodlot, *G. robusta* agroforestry and traditional agroforestry categories, respectively.

The questionnaire survey was complemented by focus group discussions (FGDs) with G. *robusta* farmers and Key informant interviews (KII) with district forest department and ECOTRUST staff. The FGDs provided information about the typical management regimes, carbon payments schedules and institutional arrangements within the carbon offset schemes. Key informant interviews provided information about technical specifications for tree farming under the projets, such as tree species, tree spacing and number per hectare and expected sequestered carbon.

Biomass inventory

Tree inventory data were collected from *G. robusta* tree farmers in Rubirizi, Mitooma and Kabale districts in South Western Uganda. The data collected from *G. robusta* woodlots and agroforestry gardens included plantation area (hectares), age of trees and diameter at breast height (dbh). The data were collected from plantations of 15 to 20 years of age. District forest department staff and NGO staff in the study area provided information about the location of plantations of known age. Tree inventory data, including number of merchantable trees per plot, were also collected from traditional agroforestry gardens. The data were collected from 53, 59 and 86 plots of *G.robusta* woodlots, *G.robusta* agroforestry gardens and traditional agroforestry gardens, respectively. Plot size was 20 m x 20 m. The number of plots established on each farm depended on the farm size.

Data analysis

Estimation of biomass stock

Above-ground biomass (AGB) for individual *G. robusta* trees was computed based on the allometric equation (Tumwebaze *et al.*, 2013) represented as:

$$lnTAGB = 0.01 + 1.81\ln(DBH)$$

Where:

ln is natural logarithm, DBH is diameter at breast height and TAGB is total above ground biomass

The below ground biomass component (root system) is accounted for by multiplying the above ground biomass stock by a specific root factor. Below-ground root biomass is estimated as 20% of the above-ground tree biomass (IPCC, 2007). The below-ground biomass was added to the estimated above-ground biomass to obtain an estimate of the total biomass. Oven-dry matter was converted to carbon stock in above-ground tree biomass (CSTAG) using conversion factor (CF) of 0.50 (Brown, 1997; IPCC, 2007).

$$CST_{AG} = W_{ovendry} * CFc$$

Where:

CST_{AG} is carbon stock in above-ground tree biomass; $W_{ovendry}$ is the oven-dry weight of above-ground tree biomass; *CFc* is conversion factor (0.50).

The total carbon dioxide equivalent in above-ground and below-ground tree biomass was calculated as:

$$C_{TREE} = \frac{44}{12} * (CS_{TAG} + CS_{TBG})$$

Where:

C_{TREE} is carbon in above and below-ground biomass in trees (tCO2e); CS_{TAG} Carbon stock in above-ground tree biomass (tC); CS_{TBG} Carbon stock in below ground biomass in tree roots (tC); 44/12 is the Ratio of molecular weights of CO_2 and carbon, which was converted to carbon by assuming 50% carbon content (IPCC, 2003).

Individual tree carbon stock was summed to plot level and then extrapolated to a hectare. Due to insufficient data on G. *robusta* trees above 20 years, the current annual increment at 20 years under the different management options, was used to project carbon stock and tree volume to 25 years.

Estimation of G. robusta timber volume

The above ground oven dry biomass was converted to merchantable biomass using the biomass expansion factor of 1.4 (IPCC, 2003) as:

$$\textit{Merchantable biomass} = \frac{\textit{Above ground biomass}}{\textit{Biomass expansion factor}}$$

The merchantable biomass was converted to merchantable volume using an average wood density of 630 kg m^{-3}(IPCC, 2007). Merchantable tree volume was estimated as:

$$\text{Volume} = \frac{\text{Merchantable biomass (kg)}}{\text{Wood density (kg m}^{-3}\text{)}}$$

Valuation of products

The harvests from the different management options were valued using the farm gate prices. Harvestable shade trees in the traditional agroforestry system were valued based on their timber grade, size and number of standing trees per hectare. This was based on the fact that there is a substantial difference between the residual values of different tree species. To ease analysis, the residual value of shade trees was assumed to be evenly spread throughout the rotation. Food crop production in the base year was also assumed to represent the rest of the rotation. In this study, household income includes cash sales and value of home consumed production.

Economic model

The profitability of the three options was estimated using the Net Present Value (NPV). To make the alternatives comparable over time, the costs and benefits were discounted into a present value over 20 and 25 year crediting periods under CDM and Plan Vivo carbon accounting systems respectively (Gittinger, 1982; Graves, 2007). A discount rate of 10% and 2016 constant prices were used in the base case scenario. The net present value (NPV) is represented as:

$$NPV = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+p)^t}$$

Where:

B = Benefit; C = Cost; t = Production Period or time in years; p = Discount Rate; n = Rotation length in years.

Results and discussion

Participation of vulnerable groups in TGB project

Households were assigned to quantiles (Table 2) using household income and the same bounds calibrated from the Uganda National Household Survey (MFPED, 2014). Overall, the poor households were well represented in the TGB project in terms of numbers. About 35% of the project participants were poor (Table 2), which was above the national average of 24.5% in 2014 (MFPED, 2014). However, closer scrutiny revealed that poor households were better represented in the agroforestry than the woodlot category. Focus group discussions indicated that poor households, with small land holdings, preferred the agroforestry option where trees can be integrated with agricultural crop production. The agroforestry option provides a more continuous cash flow from agricultural production, which is essential for their survival. Conversely, it was observed that *G. robusta* woodlots were mainly adopted by the non-poor households, which had land to spare for woodlots after growing food crops. This suggests that the carbon forestry projects need to focus on agroforestry management options in order to increase targeting of the poor households.

The results also indicated low participation (less than 22%) of youth (18 – 35 years) and the female headed households (Table 2). The low participation of youth was attributed to the fact that only few of them owned land. On the other hand, the low percentage of female headed households participating in the TGB project is approximately equal to the share of female headed households

Table 1. Base-case assumptions and parameter values for *G.robusta* and traditional system in South Western Uganda

Description	Grevillearobusta		Traditional system		Source
	Value	Units	Value	Units	
CDM carbon price	4.15	US\$/tCO$_2$e	-	-	Tennigkeit and Windhorst (2007)
Stumpage price	30	US\$ m^{-3}	(40-0)	US\$/tree	Field data collection
Price of firewood	5	US\$ m^{-3}	5	US\$ m^{-3}	Field data collection
Discount rate	10	%	10	%	Gittinger, 1982; Cacho *et al.*, 2005
Baseline carbon	9	tCO$_2$e ha^{-1}	-	tCO$_2$e ha^{-1}	Hayward *et al*. (2009)
Establishment costs	356	US\$ ha^{-1}	-	-	Field data collection
CDM annual monitoring costs	5	US\$ ha^{-1}	-	US\$ ha^{-1}	Cacho *et al.,* 2004; Biocarbon Fund, 2011
CDM contract establishment cost (under bundling)	100	US\$	-	-	Biocarbon Fund (2011)
Wood density	630	kg m^{-3}	-	-	IPCC, 2003; Santos *et al.*, 2004; Orwa *et al.,* 2009
Wood carbon content	0.5	-	-	-	IPCC (2003)
Biomass expansion factor	1.4	-	-	-	IPCC, 2003; Rawat *et al*., 2015
Planvivo carbon revenue	(300-600)	US\$ ha^{-1}	-	-	Field data collection
Net crop income	0-374	US\$ ha^{-1}	362	US\$ ha^{-1}	Field data collection

in the population. Therefore, this may not reflect a lack of participation of female headed households in the project.

Carbon sequestration

The results indicate that *G. robusta* woodlots and agroforestry gardens sequestered 470 and 225 tCO_2e ha^{-1}, respectively over a 20 year rotation (Fig. 1). The average merchantable wood volume accumulated in *G. robusta* woodlots and agroforestry gardens over the same period was 231 and 110 m^3 ha^{-1}, respectively.

Table 2. Participation in TGB project by vulnerable groups

Demographic group		G. robusta woodlot Participant distribution (%)	G. robusta agroforestry Participant distribution (%)
Population quantile	National income distribution (2014)		
Poor	24.5	21.7	48.5
Insecure	42.9	38.8	33.2
Middle class	32.6	39.5	18.3
Gender			
Male		85.8	79
Female		14.2	21
Age group			
18 - 35		21.3	20.6
36 and above		78.7	79.4

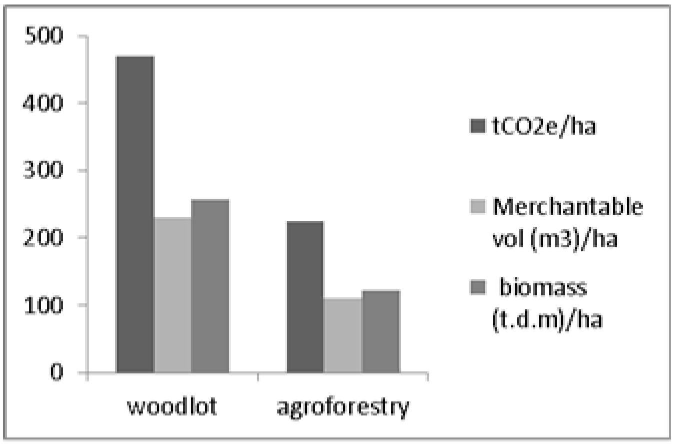

Figure 1. Merchantable wood volume (m^3 ha^{-1}) and carbon stocks in standing tree biomass (tCO_2e ha^{-1}) for *G. robusta* at 20 years.

Carbon revenue

The mean annual carbon revenue from *G. robusta* woodlots was US\$97.5 and 44.85 ha^{-1} yr^{-1} for CDM and PlanVivo systems, respectively (Fig. 2). This was higher than the mean annual carbon revenue from *G. robusta* agroforestry option of US\$46.6 and 44.6 $ha^{-1}yr^{-1}$ for CDM and Plan Vivo systems, respectively. Mean carbon revenue from *G. robusta* woodlots contributed 18.2% to the overall mean annual revenue under the CDM carbon accounting system. In comparison, the mean carbon revenue from *G. robusta* woodlots contributed 5.7% to the overall mean annual revenue under the Plan Vivo carbon accounting system. In this study, income includes home consumed production and cash income.

Profitability

The discounted cash flows indicated that the NPVs of the 3 management options were positive under the assumptions analysed (Table 3). However, *G. robusta* agroforestry and woodlots under small-scale CDM with bundling had higher NPVs (US\$4447 and 1902 ha^{-1}) respectively, compared to US\$4367 and 1358 ha^{-1} under the Plan Vivo system (Table 3).The results are robust to 15%

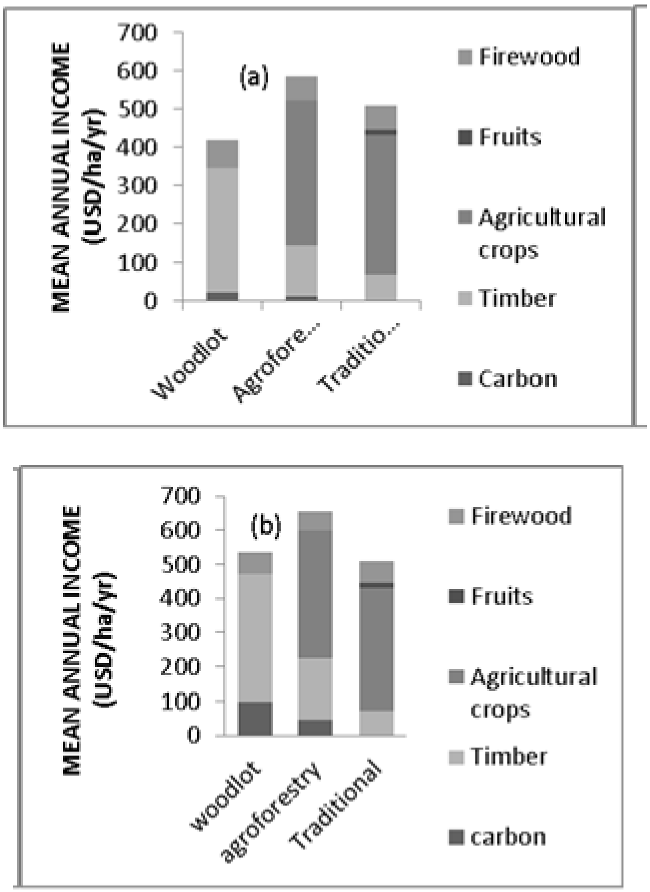

Figure 2. Contribution of carbon revenue to mean annual income under the PlanVivo (a) and CDM (b) carbon accounting systems.

Table 3. Summary of cashflow for *Grobusta* and traditional agroforestry management options

Variable	Plan Vivo		CDM		Traditional
	Agro-forestry	Woodlot	Agro-forestry	Woodlot	
NPV (US\$ ha^{-1})	4367	1358	4447	1902	3992
Sensitivity					
15% increase in timber value					
NPV	4423	1493	4640	2069	4021
6% increase in timber harvest					
NPV	4529	1650	4632	2117	4123
5% Discount rate					
NPV	7082	3388	6535	3979	6310

increase in timber value, 6% increase in timber harvest and 15% increase in discount rate. These results imply that it is more profitable for *G. robusta* carbon forestry farmers to participate in the small-scale CDM, if they are assisted to bundle, than to participate in the Plan Vivo system. Therefore, efforts to enhance profitability of carbon forestry should focus on facilitating the process of bundling tree farmers together in sizable groups in order to reduce costs per project.

The results also show that the NPV of *G. robusta* woodlots option was consistently lower than for traditional agroforestry and *G. robusta* agroforestry options. These results show that, whereas the woodlot option stores more carbon (Fig. 1), it is the least profitable option. This suggests that at the current carbon price, carbon forestry initiatives on productive agricultural land should focus on promoting agroforestry technologies.

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