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Management of *Acacia* Plantations for Charcoal Production: Local Economies and Sustainability

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Abstract: The objectives of this research were to estimate volume of charcoal produced per unit area of *Acacia seyal* plantations at Wadelbashier Forest Reserve and to estimate financial profitability (US\$ ha^{-1}) of charcoal production, using net present value (NPV) as a decision criterion. Data on tree growth was collected, using fixed-radius temporary circular sample plots. Present and harvest age standing wood volumes were estimated. Market-related data were collected through structured interviews of key informants of the staff of Forest National Corporation (FNC) of Algadarif State, members of Trade Union of Fuelwood Producers and Traders, and from secondary sources of the state forestry service. The results indicated that the present standing wood volume (m^3 ha^{-1}) ranged between 8.4 and 26.2 and that charcoal production from *A. seyal* plantations managed for a rotation of 20 years at 12% annual discount rate yielded a negative mean financial NPV of US\$ ha^{-1} -30.3 indicating that charcoal production at current stocking, factor costs, output prices, a 12% annual discount rate and a rotation length of 20 years is not financially profitable. The study concludes that policy and management interventions are inevitable for sustainable production.

Key words: *Acacia seyal*; charcoal profitability

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INTRODUCTION

There are diverse reasons for choosing wood as a source of energy. For many users the choice depends on the availability and affordability of other energy options (Horgan 2002). Charcoal has many uses, but its most significant applications are as a fuel for cooking and as a reductant in metallurgy (Ghilardi *et al*. 2013). The growing demand for charcoal in Africa driven by high population and urbanization growth rates makes charcoal the major primary source of energy for most urban dwellers for at least another generation (Arnold *et al*. 2006). The current high levels of demand for charcoal are one of the main factors leading to the destruction of forests, particularly those on the periphery of sprawling urban centers (Minten *et al*. 2013). This increased charcoal demand puts pressure on peri-urban wood sources, especially in absence of management of the sector (Arnold *et al*. 2006).

Charcoal is a major source of energy for a vast number of people in Africa as well as a driving force of household economies (FAO 2008). Charcoal production and trade contributes to the economy by providing rural incomes, tax revenue and employment. It also saves foreign exchange that would otherwise be used to import fuel (Mugo and Ong 2006; Vos and Vis 2010). Charcoal use cut across all income groups but high percent of users was more prevalent among low income groups (Okunade 2010). The position of charcoal as a household fuel in developing countries is largely due to its suitability as a relatively clean fuel for urban environments and its low costs for the end-user (FAO 2008). Charcoal has also unique cooking properties that make households go for it even when other fuels are also available (Seidel 2008), it has double the energy content of fuelwood, it is lightweight and thus easy to transport and store, it is easy to store over long period of time, without risk of insect or fungal attack, it produces less fumes and noxious compounds when burned.

Environmental impacts of charcoal occur at each step of its life-cycle, which includes feedstock supply, pyrolysis of wood and charcoal usage. The ultimate impacts may include deforestation, erosion, and soil impoverishment. The most significant impacts occurring during charcoal production and usage are emissions into the air and working environment. On the global and regional scale they contribute to the global warming, while on the local scale they may impose health risk for the workers and people living in the vicinity of production site (Kilahama 2005). The environmental costs of charcoal production are often not internalized in the product price, which contributes to resource depletion and ultimately threatens the sustainability of the livelihood activity (Chidumayo and Gumbo 2013). The adverse effects on the environment of charcoal production come into play due to the fact that the carbon sinks are destroyed through deforestation. Thus there are no sinks to absorb the greenhouse gases (GHG) and this aggravates the incidence of GHG concentration in the atmosphere (Nyembe 2011). Emissions of greenhouse gases from charcoal production in tropical ecosystems in 2009 are estimated at 71.2 million tons for carbon dioxide and 1.3 million tons for methane. The failure of past charcoal policies to address environmental impacts and achieve sustainability can be attributed to erroneous assumptions and predictions by national and international organizations regarding wood-based fuels (Chidumayo and Gumbo 2013).

Degradation of forests and woodlands as a result of increased charcoaling activities has widespread social and economic consequences (Nkonoki 1983) and with negative effects to the environment (Eckholm 1975). Currently, charcoal production in tropical countries of the world largely depends on natural forests in which natural regeneration is the main source of forest recovery. This general pattern and the perceived unsustainable harvesting and poor post-harvest forest management, are the primary reasons why there is widespread concern about the environmental impacts of charcoal production (Chidumayo and Gumbo 2013). In the case of charcoal consumption, identification and estimation of the factors influencing its choice and demand by households would facilitate smooth formulation of policy from three dimensions- health, energy and environment (Nyembe 2011). The challenge is to be able to develop and manage the wood source on a sustainable basis and to develop charcoal production technology that produces charcoal at a significantly lower cost and with lower environmental impacts than for current production (Norgate and Langberg 2009).

Although investment in charcoal production from forest plantations is increasing in tropical regions, for the most part, biomass for charcoal production is obtained from natural forests in which natural regeneration is the main source of forest recovery (WEC 2004). In low-rainfall areas, where regenerative capacity is relatively low, unplanned and unmanaged charcoal production can accelerate desertification processes (Vos and Vis 2010). One important cause of deforestation in arid and semi-arid countries is the overcutting of undervalued trees for fuelwood (Hassan and Hertzler 1988). The general pattern of almost complete dependence on natural forests for charcoal production and the perceived unsustainable harvesting and poor post-harvest forest management, are the primary reasons why governments, nongovernment organizations and civil societies are concerned about the environmental impacts of charcoal production (WEC 2004).

Charcoal, in Central Sudan, is mainly produced by the private sector. It is an institutionalized business with well-established division of responsibility and work relations (Abdel Nour 1984) and high skills developed by the Sudanese charcoal makers over years in recognition of the economic benefits of producing the maximum amount of charcoal from the restricted resource available (Abdel Nour and Satti 1984; Paddon and Satti 1986). However, informal production of charcoal is wide spread. The large quantities of charcoal produced without official permits illustrate the predominantly informal and illegal character of the sector and the difficulties in accessing the formal system. Producers have few incentives or disincentives to comply with formal systems and customary rules define access to the resource (Schure *et al*. 2013). This informal character causes constraints for sustainable management of forest resources for charcoal exploitation.

The Sudan presently derives over 80% of its total energy use from wood and charcoal, and the highest consuming sector is households (FAO 2007). Plantations for fuelwood have long been established, however, the major part of the production of charcoal comes from natural forests. The unsustainable extraction of fuelwood is a major problem in northern and central Sudan (Gaafar 2011). Because of its relative importance in the energy budget of the country, charcoal has long been considered in the national energy policies and programs. Policy and program interventions were designed to either reduce wood fuel demand, increase supplies, or some combination of the two. Supply-side approaches aimed to establish wood fuel plantations, especially in peri-urban areas, or to encourage increased planting and management of trees by farmers in wood fuel deficit areas. In addition, government regulation of the charcoal industry increased in many regions by imposing taxes and restrictions on transport and exports (Chidumayo and Gumbo, 2013).

The objectives of this research were to estimate volume of charcoal produced per unit area of *A. seyal* dry lands plantations and to estimate financial profitability of charcoal production from the National Forest Corporation, a para-statal service-oriented and independent body a self-financing entity, perspective using NPV as a decision criterion.

MATERIALS AND METHODS

Study area

The research was conducted during 2010 at Wad Elbasheir Forest Reserve which is located in Elhawata Locality, Algadarif State in eastern Sudan. Geographically the forest is located between latitudes 13˚ 30 and 13˚ 33' N and longitudes 34˚ 35' and 34˚ 40' E. The total area of the forest is 3461.2 hectares divided into 14 compartments. The present plantations of *A. seyal* were established during the period 1987-1998.

Stocking and growth data

Data on tree stocking and growth were collected using systematic sampling of *A.seyal* plantations. A 5% sampling intensity was used. Fixed-radius circular sample plots were distributed 100m apart along sample lines which were located 200m apart along a base line. A total of 364 sample plots were made with an area of approximately 0.1 ha each. In each sample plot tree count, diameter at breast height (dbh) of all trees and top heights of three representative trees with largest, medium and smallest dbh were recorded. Estimation of stem form factor, wood basal area, mean annual increment, present volumes of wood per unit area were estimated following standard forest inventory methods.

Estimation of future wood volume

Expected future volume is estimated as equal to today's volume per acre plus growth period (years) multiplied by annual volume growth (Jacobson 2008). Estimation of rotation age volume was made using Equation I.

$$V_n = V_0 + MAI * t \quad (1) .$$

where

V_n = future volume (m^3 ha^{-1})

V_o = present volume (m^3 ha^{-1})

MAI = mean annual (volume) increment (m^3 ha^{-1})

t = years to harvest (m^3 ha^{-1})

Charcoal production, marketing and policy data

Data on production, marketing and forest policy related to charcoal production from *A. seyal* were obtained through market surveys and structured interviews conducted with two principal stakeholders, i.e. FNC staff and members of Trade Union of Fuelwood and Charcoal Producers/ Traders. The interviews of two Forest National Corporation (FNC) staff were meant to reveal information about rotation age, method of sale of *A. seyal* wood and justification for that, accepted minimum stumpage price (US$/standing m^3) and to generate data on market price of fuelwood, cost of establishment and management operations including types, quantities, costs and timing of inputs and quantities and unit price of outputs.

Structured interviews addressed to three members of Trade Union were meant to obtain information on taxes, fees, royalties levied on *A. seyal* fuelwood, information on the cost of felling, loading, unloading and transportation to destinations. Data on number of 40-kg charcoal bags produced out of one stacked cubic meter of wood, cost of production of charcoal and price of a charcoal bag at the kiln-gate and local market were obtained, too.

Estimation of financial profitability of charcoal production

Financial profitability of *A. seyal* stands managed for production of charcoal at annual discounting rate of 12% for a single 20-year rotation was assessed using equation II.

$$NPV = \sum_{t=0}^{T} \frac{R_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad (2)$$

where

NPV = net present value

R_t = revenue at time t

C_t = cost at time t

T = length of rotation in years

Present value of fixed annual payments was calculated using annuity factor (equation 3) according to Klemperer (1996):

EquationIII.

$$V_0 = \frac{p}{r} * \left[1 - \frac{1}{(1+r)^n} \right] \quad (3)$$

where

r = annual discounting rate/100

V_0 = present value

n = number of years

p = amount of fixed annual payment in a series

RESULTS AND DISCUSSION

Growth and yield data

Table 1 summarizes mean values of stand characteristics of *A. seyal* plantations at Wad Elbashir Forest Reserve. Present stocking density generally agrees with NFTA (1994) that stocking at 10 and 14 years is 675 and 450 stems ha^{-1}, respectively. Higher stem number per unit area (672 and 579 for ages 14 and 22, respectively), and very low stocking of young crop (338 at age 12 and 299 at age 18) indicate that the prescribed management and/or silvicultural planning of *A. seyal* crop were not strictly adhered to. Either too heavy thinning or illegal felling was done, or the crop was poorly established at a very low stocking rate.

The present standing volume per unit area of 8.4 to 26.2 m^3 ha^{-1} is relatively low compared to 10-35 m^3 ha^{-1} of fuel wood indicated by NFTA (1994) for stands managed even on a shorter 10-15 years rotation. Estimates of rotation age standing wood volumes (m^3 ha^{-1}) were 27.5, 37.6, 11.2, 9.3, 11.3, 23.2 and 23.2 for compartment 3, 8, 11, 9, 13, 10, and 2, respectively.

Charcoal production, marketing and policy data

Results revealed that the total production cost (US$ /bag) in 2010 was 6.52 which was made up of labour (cutting and burning), material (water, earth and jute bag), transport to local market and other costs (taxes, locality fees and Zakat (alms-giving) of US$.3.04, 1.3, 0.22 and 1.96, respectively. Selling prices (US$/bag) of charcoal were 8.70 and 10.87 (equivalent to US$/ton 217.5 and 271.75) at forest gate and Elhawata city markets, respectively. The financial NPV (US$ ha^{-1}) of charcoal production from *A. seyal* plantation for a rotation of 20 years at 12% discount rate was negative for all compartments except compartment 8 which generations a NPV of 35.08. The mean NPV (US$ ha^{-1}) of the plantations was -30.3. This result may be explained by the poor producers' price of fuel wood reflected in low producers' revenue, absence of early income as the current plantation management system involves no thinning, high discounting rate or most importantly is the low volume per unit area at harvest. Pervious evaluation studies show that the traditional Sudanese earth clamp method of charcoal production is remarkably efficient when compared with reported conversion efficiencies for similar operation in other countries (Abdel Nour and Satti 1984, Paddon and Satti 1986).

The plantations obviously experience crop management problems. First, the comparatively low stocking density negatively influences profitability of the plantations. FAO (1987) identifies that the two major ways to reduce the land area committed to produce the necessary fuel wood for the projected charcoal production are to make the forest more productive by improving growth and reducing waste in harvesting and to improve the conversion ratio of raw fuel wood to finished charcoal at the user's door. Second, retaining crop on land beyond prescribed rotation length involves management expenses that raise the cost of charcoal production.

Financial cost benefit analysis of production of charcoal from *A. seyal* plantations

Analysis of responses to structured interviews addressed to FNC and members of Trade Union revealed inputs types and quantities scheduled in table 2. Output per ha at harvest time was 315.9 charcoal bags at a unit price of US$ 10.87 at local market.

Table 3 displays in- and out-cash flows and NPV (US$ ha^{-1}) of charcoal production from *A. seyal* plantations calculated for compartment 8, as a young crop with the highest volume, at annual discount rate of 12%. NPVs of charcoal production from compartments 2, 3, 9, 10, 11 and 13 calculated similarly were -19.86, -4.48, -72.69, -19.78, -65.48 and -64.87, respectively.

Sustainability of resource base and charcoal production system requires indispensable interventions. Improvement of growing stock, adoption of shorter rotations, proper application of silvicultural plans and minimizing management costs may contribute to better financial returns. However, financial analysis of charcoal production from *A. seyal* plantations is incomplete to justify their economic profitability. Inclusion of the values of forest services e.g., fodder production, *A. seyal* gum, soil and environmental conservation and consideration of other ecosystem services, provided by the system may help make them economically attractive.

Table 1. Stand characteristics of *A. seyal* plantations at Wad Elbashir Forest Reserve

Compt[1].	Age	S.P.[2] No.	Stand						
			dbh	BA (G)	Height (h)	FF[3] (f)	Trees (N)	Volume (V)	MAI_t
No.	Year		(cm)	(m^2 ha^{-1})	(m)		(No. ha^{-1})	(m^3 ha^{-1})	(m^3 ha^{-1})
3	12	49	10.42	3.42	6.96	0.62	338	16.33	1.36
8	14	32	9.21	5.18	8.34	0.57	672	26.22	1.87
11	15	25	7.34	2.17	6.12	0.53	444	8.37	0.56
9	18	47	8.95	2.14	6.38	0.55	299	8.35	0.46
13	21	58	8.46	2.56	6.53	0.62	409	11.94	0.57
10	22	83	10.01	5.34	6.98	0.66	579	25.63	1.17
2	23	70	10.21	4.44	7.83	0.56	520	26.22	1.01

1. Compartment, 2. Sample plot 3. Form factor

Table 2. Physical inputs/outputs for the production of charcoal from *A. seyal* md = man day, bag = 40kg

Year	Operation	Unit	Quantity	Cost (US$/unit)	Cost (US$ ha^{-1})
1	Land preparation	(md* ha^{-1})	2	6.21	12.42
	Seeds	(kg ha^{-1})	1.5	4.66	6.98
	Seed sowing	(md ha^{-1})	2	5.17	10.35
	1st weeding	(ha)	1	28.98	28.98
	Opening fire line (200 m ha^{-1})	(ha)	1	25.87	25.87
	Protection	(ha)		1.21	1.21
2	2nd weeding	(ha)		28.98	28.98
	Protection	(ha)		1.21	1.21
3-19	Protection	(ha)		1.21	1.21
20	Charcoal production	(bag*)	1	6.52	2060.37

Table 3. Financial NPV (US$ ha^{-1}) of charcoal production from *A. seyal* plantation

Year	TC	TB	DF	$PVC_{12\%}$	$PVB_{12\%}$	$NPV_{12\%}$
1	86.06	0	0.893	76.85	0	
2	30.18	0	0.797	24.05	0	
3-19		0		6.87	0	
20	2060.37	3433.96	0.104	214.28	357.13	
Sum				322.05	357.13	35.08

TC = total costs, TB = total benefits, DF= discounting factor, PVC = present value of cost, PVB = present value of benefits

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