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Biomass Estimation of Exclosure in the Debrekidan Watershed, Tigray Region, Northern Ethiopia

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Abstract The study was conducted in *Debrekidan* watershed of central zone of *Tigray* Regional State which is located about 120 kms away from the regional capital *Mekelle* in the northern Ethiopia. The study site, bush land, was enclosed from human and livestock interferences in 1996. Exclosure is one of the mechanisms of rehabilitation and restoration in arid and semi-arid environment. The site has been also enriched for many years with various exotic and indigenous species. However, the survival rate and growth performance of the enrichment plantation was extremely low. In contrary to enrichment plantation, *Acacia etbaica* Schweinf was dominant species (90%) with better morphological and physiological adaptations to arid and semi arid environment. In order to estimate the total above ground live woody biomass of the exclosure, circular plots ($100m^2$) with 100 m interval between each plot and transect lines were used. Sample trees (n = 10) were cut from different diameter classes of the species. Diameter at stump height and height were measured with diameter tape and stick before felling respectively. Fresh weight and dry weights of sample disks of both stems and branches were measured in the field and laboratory. Diameter at stump height was found the best estimator with co-efficient of determination, $R^2 = 0.96$ for the selected total and component biomass models. Two tons biomass per ha could be distributed into the age of the exclosure (10 years) giving growth of 0.2 tons $ha^{-1}year^{-1}$. Biomass study is one of the best scientifically accepted methodology to determine the overall ecosystem productivity and its sustainability. The *Acacia* species, with relatively low biomass, invades the arid and semi-arid environment in unpredictable rate and aggressively threatens species diversity and sustainability of the forest ecosystems. Biomass improvement through high biomass species and other integrated conservation strategies are options that address the sustainability of ecological restoration and biomass improvements.

Keywords Exclosure, Biomass, Restoration

1. Introduction

Energy is one of the most absolute needs of human beings in the globe and its usage has been such a basic element of human advancement for so long. Energy can be derived both from renewable and non-renewable masses. Development of new alternate energy sources and bioenergy can make a country energy independence. Biomass materials are used since millennia for meeting myriad human needs including energy and main sources of biomass energy are trees, crops and animal waste. Until the middle of 19th century, biomass dominated the global energy supply with a 70% share [1]. Biomass is a renewable energy source because we can always grow more trees and crops. Energy and fuels from biomass can improve economy and provide tremendous, environmental, and energy security benefits. The challenge for Ethiopia is therefore, to secure adequate energy supplies at the least possible cost and it is imperative to encourage use of indigenous sources of energy, exploration of domestic production, promoting use of bioenergy. The renewable bioenergy, which gains significance in many countries, has the capacity in improving energy security of Ethiopia. Bioenergy and biofuel from plant and tree resources open a potential avenue for meeting the energy need of the country.

Exclosure is the area where, for management or research purpose, certain animals are excluded or biomass harvesting is controlled. It denotes any area or activity that involves excluding unwanted species or practices from degraded sites. Since 1980s, the most significant reform in natural resource management in Ethiopian highlands has probably been the introduction of exclosures, defined as areas of natural vegetation protected from the intrusion of humans or livestock [2-3]. Exclosures are a type of land management implemented with the aim to improve environmental conditions on degraded and generally open access lands. Exclosures are areas where grazing and other agricultural land use are not allowed [4].

Exclosure is a renewable source of massive biomass that generates bioenergy for many purposes. Establishment of exclosure is a method for land reclamation and re-vegetation by protecting an area from human and animal interferences

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for limited period of time depending on the re-vegetation capacity of the area [5]. Plant biomasses are the primary source of energy in any ecosystem [6]. Ethiopia is amongst the highest biomass energy consuming countries in the world [7]. In Tigray Regional State, bio-fuels provide 99.1% of the total (urban and rural) domestic energy supplies, with 69.2% derived from woody biomass, 2.5% from charcoal, 4.4% from crop residues and 23% from dung. Households clearly dominate the energy patterns (89%) and within the households, traditional fuels contribute a massive 99.6% of the total household energy consumed [8]. An unimaginative deforestation rates are common both in the region and the country mainly due to high and massive dependency on woody biomass energy. For example, with its estimated annual demand of 45 million cubic meters of fuel wood and its estimated annual sustainable supply of only 12.5 million cubic meters, Ethiopia experienced a deficit of 44% of the sustainable supply [8].

Similarly with continuing deforestation and land degradation, depletion of soil fertility, loss of biodiversity, climatic change and global warming are inevitable. People with virtually no option start burning large amount of crop residues and dung that leads to declining of soil fertility and in turn to decline of crop yields that aggravates food insecurity. To reverse this serious deforestation trends ‘cutting should not exceed growing’. This issue of forest sustainability can be realized through woody biomass studies and defining the amount of cut or harvest. Therefore, the present study is contributive to sustainable management of exclosures through developing functions for estimating woody biomass density of the exclosure, estimating the total above ground live woody biomass of the exclosure and analyzing supply and demand of fuelwood for the community from the exclosure.

2. Materials and Methods

2.1. Description of the Study Site

The study was conducted in *Debrekidan* watershed of central zone of *Tigray* Regional State which is located about 120 kms away from the regional capital Mekelle (Figure 1). Longitudinal and latitudinal extents of *Debrekidan* watershed is 39° 25′ to 39° 29′ E and 13° 52′ to 13° 57′ N respectively in the northern Ethiopia. The watershed (901 ha) has an elevation range from 2060 m to 2451 m a.s.l. According to the agro-ecological zone of Ethiopia, the study area belongs to midland (‘*Weinadega*’) agro-ecology getting main rainy season in summer (June to September). The watershed is drought prone area with long dry periods and semi-arid climate [9]. Moreover, the mean annual rainfall and mean annual temperature of the watershed are 479 mm and 21 ^{0}C respectively. The dominant soil of the watershed is Vertisol followed by Cambisol, Lepto and Alluvisol with major soil texture of silt loam [10].

Rehabilitation of degraded land in arid and semiarid environments often involves the excluding of livestock from degraded sites, creating what are usually called “exclosures” [11]. An exclosure refers to a specific land unit that is protected from the activities of a particular class of animals using appropriate barriers and is commonly used to determine the potential for restoration of degraded land [12]. Their main objective is to allow native vegetation to regenerate as a means of providing fodder and woody biomass, to reduce soil erosion and to increase rain water infiltration. The exclosure, located in the *Debrekidan* watershed, has a size of 50 ha.The vegetation is predominantly dry land forest with scanty, shrubby and bushy type. A few of the most dominant woody plant species found in the exclosures are *Acacia etbaica* and *Becium grandiflorum*.

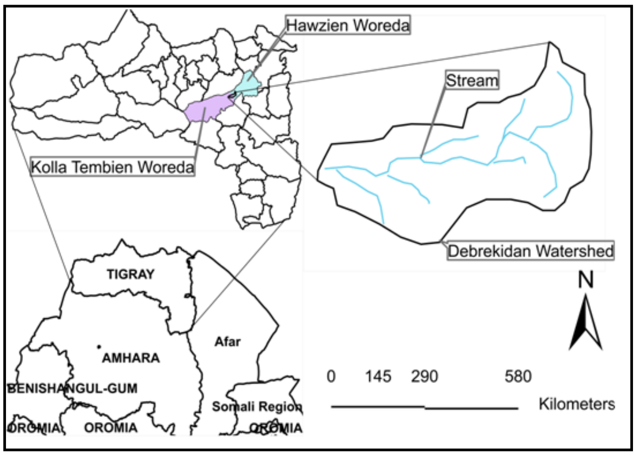

Figure 1. Map of Study Area: *Debrekidan* Watershed, *Tigray* Region, Ethiopia

2.2. Methodology

To determine woody biomass of the exclosure circular plots and parallel lines were located by Geographic Positioning System (GPS) in the study site. Circular plots (A=100m^2) with 100 m interval between each plot and transect lines were used. Totally 40 plots were used to assess and investigate the woody biomass of the exclosure. Fixed plot size and shape were used for all plots which greatly eased the planning in the office, the field work, the data base verification and compilation, without jeopardizing the final result [13]. The sample plots were circular in shape with fixed dimension of 100 m^2 (0.01 ha). It is circular which was oriented in the same directions as the transect line. In each plot height and diameter at stump height (with ≥ 2.5cm) of all living woody plants were recorded and measured. Height and diameter at stump height (DSH) of individuals were measured by stick and diameter tape respectively. Moreover, all living woody plants (≤ 2.5 cm) and any stem ≥ 1 cm in the circular plots were counted and recorded to investigate the regeneration status of the study site. Destructive sampling was used to estimate woody biomass of the exclosure in the watershed. Sample trees (n = 10) were cut from different diameter classes of the species. Diameter at stump height and height measured before felling respectively. Fresh weight and dry weights of sample disks of both stems (4cm) and branches (8cm) were measured in the field and laboratory. To develop the functions; the allometric regression model was selected due to its desirable qualities in reflecting a biological phenomenon, ease of extrapolation, and possibility of linearization [7]; [14-15]. The non-linear allometric model used was linerzed through transformation since it is a requirement to apply the methods of linear regression analysis that assumes the homogeneity of variances over the whole range of data [14]; [16-18]. In developing the functions H (1-3.8 m) and DSH (2.5.0-12.5 cm) were considered. Different options were used to test the functions by applying DSH and H treated one by one and compounded to see their precision in predicting above ground total dry weigh (TDW) which is the sum of above ground stem dry weight (SDW), above ground branch dry weight (BDW) and leaf dry weight consecutively.

2.3. Data Analysis

An intensive verification of the biomass data was meticulously executed. The field data was analyzed to determine the existing woody biomass stock and annual yield per exclosure. Green weight in the field was transformed to a standardized oven dry weight to develop the regression model. Dry weight ratio was determined by dividing the dry weight of each disk (branch, stem) to the corresponding fresh weight of the same disk measured in the laboratory. Using this ratio, the dry weight of each component of a tree (branch, stem) was calculated as follows:

$$sdw = {dwdisk}/{fwdisk} \times sfw$$

Where, (1) SDW and SFW are the dry weights and fresh weights of the stem in kg, respectively, (2) $dwdisk$ is the dry weight of the disk and $fwdisk$ is fresh weight of the disk (gm). Then the total dry weight of a tree was calculated as: TDW=SDW+BDW Where, TDW is the total dry weight of the tree and BDW is the branch dry weight of the tree both measured in kg respectively.

Values of SDW, BDW, and TDW were determined and entered as dependent variables to develop regression functions with diameter at stump height (DSH) and height (H) as predictor variables. The production of regression models were done by specialized MINTAB version. A visual investigation of scatter diagrams of the dependent and independent variable revealed that there is an exponential relationship between the predictor variables (DSH and H) and predicted values (TDW, SDW and BDW). Finally, the logarithmically transformed allometric model was found appropriate for construction of the functions, since the allometric model reflects the relative growth of the components of the biological entity of the species. For the sake of simple estimation of the parameters and variance analysis, this basic model, $Y = b_o X_i^{bi}$, was transformed in to its logarithmic form as:

$$Ln(Yi) = Ln(b0) + bi\ln(Xi) + Ln(\sum i)$$

Where, y is the response variable, b_0 & b_j are the regression coefficients, X_i is the independent / predictor variable and 'Σi' is the normally distributed random error term. The total biomass in the exclosure and the biomass per hectare were calculated using the developed functions. The estimation was made using the following formula.

$$Ytot = \sum Yi / Pi$$

where, Y_{tot} is the total biomass of the exlosure, Y_i the biomass of the tree in each plot and P_i the selection probability as n*a/A where A, a, n denote the total area of the land units, the plot area and the number of sample plots respectively. Finally, biomass per hectare is calculated by dividing total biomass of each land unit area, by the total land unit area, i.e.

$$y/ha = Ytot/A$$

3. Results and Discussion

3.1. Biomass Function of the Exclosure

The biomass function was developed based on a single *Acacia etbaica* that was found to be dominant and accounted 90% of the total population in the exclosure (Table 1).

Table 1. Total number of stems tallied (sum of plots No 1, 2….and 40)

Name of Woody Species	Diameter Class (cm)						
	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	Total	%
Acacia etbaica	1112	2770	660	80	38	4660	90.19
Dodonaea angustifolia	12	2	-	-	-	14	0.27
Euclea schimperi	9	2	-	-	-	11	0.21
Acacia saligna	2	9	2	2	-	15	0.29
Carissa edulis	3	5	-	-	-	8	0.15
Eucalyptus camaldulensis	4	5	9	67	80	165	3.19
Acacia seyal	15	18	23	8	3	67	1.3
Croton macrostachyus	5	7	11	7	-	30	0.58
Ziziphus spina christi	2	7	8	5	11	33	0.64
Maytenus arbutifolia	40	10	-	-	-	50	0.97
Others	60	37	17	-	-	114	2.21
Total	**1264**	**2872**	**730**	**169**	**132**	**5167**	**100**

Table 2. Functions for estimating above ground total tree and component biomass in *Debrekidan* exclosure (n =10 and 2.5.0≤ DSH ≤12.5)

Component	Function	b_0	b_1	R^2	SE	n
TDW	Ln totWt = b_0+ b_1LnDSH	-2.11	2.19	0.96	0.13	10

TDW - Total dry weight
totWt - Total dry weight
DSH - Diameter at stump height
b_0, b_1 - Regression parameters
R^2 - The coefficient of determination and SE the standard error of the residuals
n - Number of samples

Representative sample trees (n = 10) were cut from *the* exclosure because *Acacia etbaica* is the dominant species and at the same time it is neither endangered nor extinct. Moreover, it is the most dominant species with prominent morphological and physiological adaptations.

When DSH (n = 10) was applied for predicting TDW, the R^2 and SE was 0.96 and 0.13 respectively. The estimates can be seen from the estimates of the SE (n = 10) found (13%) for the total tree. Therefore, it is cost effective to apply DSH as the only predictor in the function. Similar coefficient of determination of these functions was found and reported by [7] and [19]. This model or function implies that it can be used to estimate single tree above ground biomass in similar agro ecological conditions. The absence of such models or functions is often reflected in the form of unsustainable utilization and management of exclosures. Sustainable exclosure management requires an accurate and precise modeling to determine the annual cut that should not exceed the mean annual increment (MAI) of the exclosures. Modeling biomass production of exclosure is also an important parameter to quantify its structure and condition [20-21] and determine the overall productivity of the ecosystem [22]. Such models also play significant roles in predicting the future growth and yield of a forest stand for estimating biomass and carbon stock potentials [23-26].

3.2. Woody Biomass Estimates of Exclosure

The total above ground biomass estimated in the exclosure of *Debrekidan* was 80.0 tons with 2.0 tons per hectare. Mean annual increment of the exclosure could be calculated by dividing the annual increment by the age of the stand. Two tons per ha could be distributed in to the age of the exclosure (10 years) giving growth of 0.2 tons $ha^{-1}year^{-1}$. The aformentioned total above ground biomass was low compared with other similar woodlands of East Africa [27-28]. Finally, estimation of leaf biomass was not considered because the species is expected to contribute insignificant amount of biomass and bio-energy to the community.

3.3. Bio-energy Contributions of Exclosure

Acacia etbaica is one of the most common multiple stem species used for bio-energy in the watershed. The demand of woody biomass could be satisfied not only by large single stem trees but also from small multiple stems and shrubs. The developed functions can be applied for sustainable energy planning in the watershed at large and in other similar agro-ecological zones in a similar manner.

The estimated fuel wood per capita consumption of the watershed was 0.535 tons. Per capita consumption patterns of the watersheds was calculated from rural per capita consumption patterns of central zone of the region as the watershed is located in this zone. The total mean annual increment of the exclosure (16 tons) could only satisfy 30 individuals on sustainable ways. Only 1.7% of the total population (1740 households) in the watershed could be accommodated in terms of bio-energy supply from this exclosure on sustainable ways. This mean annual increment of the dominant *Acacia etbaica* species could be harvested by mild disturbances through pruning that favours lower storey species diversity.

4. Conclusions

A serious pressure exerted on exclosures has resulted in low above ground woody biomasses; most of the communities have been shifted from burning woody biomasses to non woody biomasses. This phenomenon leads to declining of soil fertility and in turn to declining of agricultural yields that aggravates food insecurity. Proper and sustainable exclosre management requires accurate and precise data to determine the annual wood cut that should not exceed the mean annual growth of the exclosure in the watershed. The annual wood cut can be determined through biomass studies. For this biomass determination models, methods and functions are important. Therefore, this predictive functions and methods in this work are contributive to woody biomass estimation of exclosure for sustainable management. Moreover, these developed biomass functions are important for future exclosure resource assessment, planning and decision making in areas having similar site conditions and agro-ecological zones. Reliable biomass estimates is also important to make policy recommendations related to exclosure resource management. Well managed exclosure can also be seen beyond reclamation and rehabilitation sites to satisfy various demands of the communities. Therefore, for sound full and sustainable exclosure management, the following recommendations were drawn:

- From management point of view, pruning should be carried out on *Acacia etbaica* in the exclosure based on the mean annual increment of the exclosure.
- One of the best ways to increase woody biomass of the exclosure is to promote integrated exclosure management and carry out enrichment planting.
- Moreover, introduction of energy saving

technologies to the community are important to support and fill the gap between demand and supply of bio-energy of the community which are important to reduce the rate of exclosure degradation.

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