Biomass estimation techniques for enclosures in a semi-arid area: a case study in Northern Ethiopia

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Abstract

For centuries, land degradation triggered by deforestation has occurred in Ethiopia, in particular in the northern regional state Tigray, the area under study. In order to change this situation, the local government started to establish enclosures. In these sites, grazing is no longer permitted so that forest can naturally regenerate. In order to develop sustainable yield planning for forest rehabilitation areas in Tigray, one needs to know the effect of closing areas on biomass accumulation. In an enclosure, aboveground dry weight of herbaceous and woody species was estimated at 1,84 ton/ha. A combination of destructive and non-destructive methods was tested. The non-destructive study was rejected because of a non-accurate wood density estimation, and low correlation coefficients for the weight predicting models. Best fit-least square regression models were developed using diameter at 30 cm height as the independent variables and dry weight as the dependent variable. Coefficients of determination for the selected total biomass models of the destructive study ranged from 0,67 up to 0,99, whereas they ranged from 0,20 to 0,90 for the woody species in the non-destructive study. Equations for foliage biomass generally had lower coefficients of determination than the equations for either stem or total biomass of the woody species. Non woody biomass was measured in different enclosures in order to estimate the biomass production in function of the management technique. 98% of the total herbaceous biomass of the sampled grass plots belonged to *Hypperrhenia hirta,* while in the grazing land nearby it was only 11%. The correlation coefficient between grass biomass and basal area of the woody vegetation was -0,11. Based on this study this enclosure is not adopted for fuelwood collection.

Keywords: biomass yield, enclosures, destructive study, non-destructive study, Hyperrhenia hirta

2. Introduction

Fuel wood is an important energy resource in the highlands of Tigray National Regional State. Much of the population resides in this area, and they live mainly of extensive farming and livestock management. Shortage of animal fodder and fuel wood is permanent. An indicator of this problem is the abundance of hand-molded dung patties drying in the sun. Farmers who once returned all or part of the available dung to the fields for soil improvement have been forced to use it for energy (cooking). In order to mitigate the energy problem, the regional government has decided to establish in each village enclosures where natural vegetation is allowed to grow freely. People are neither allowed to cultivate nor to introduce cattle for grazing. For the latter reason, these enclosures are also called “exclosures”. The idea is to let nature take over and let indigenous tree species regenerate and grow undisturbed. Until 1996, close to 143 000 hectares of land were protected within these enclosures and there was a plan for 128 000 ha more for the next five years (EFAP 1993).

Prime bottleneck when developing management plans for firewood and fodder supply in these areas is that there is practically no knowledge on biomass yield. This study aims at estimating the annual biomass yield of grass that can be used for animal fodder and tree/shrub-based biomass from the community-managed enclosures (Gebremedhin 2002).

3. Materials and methods

3.1 Site description

Two research sites, an enclosure and a grazing land were chosen. Both sites are situated in the central zone of the National Regional State of Tigray at about 600 km North of Addis Ababa or some 50 km West of Mekelle, the capital of the Tigray Region. The topography of the region is characterised as mountainous plateau and the climate as tropical semi-arid. Hagere Selam is the main town of the district; the surrounding villages of Heichi and Adi kwanti are mostly only accessible on foot. The surface of the enclosure is estimated around 40 ha. The altitude within the study area ranges from 2148 till 2185 m.a.s.l. It is located at 15°06’N latitude and 52°20‘E longitude. Slopes vary between 0 and 30% and have an average value of 15%. The soils are classified as

Cumulicalcari-humic Regosols (De Geyndt 2001). The area is classified in the Weyna-Dega agro ecological zone (Hurni 1986). The rainfall has an average value of 787 mm. Most of the precipitation falls within the three months of June, July and August, and with high intensity (ILRI 2002). The average daily temperature is fairly constant throughout the year, during the growing season the temperature is 17.8 °C (Parent et al. 2000). In the enclosure, there is no grazing, nor any other agricultural activity. Except for yearly grass cutting by the community, there is no human interference with vegetation regeneration (own observation). Information by local people is that the enclosure had been closed for 11 year at the time of this research. It is under supervision by an agent of the community (guard) who is nominated by the local people (ILRI 2002). Prior to enclosure, the land uses were cropland and rangelands. The vegetation is made up of bushes and shrubs of varying status, from site to site, mostly mixed with some widely scattered tree species. As a result of repeated cutting over a long period of time, coppice regeneration of multiple stems per stool was the most common characteristic of the vegetation (Teklu 2000). The grazing land at the border of the enclosure is open for cattle during a third part of a calendar year. It has the same topographical and climatic characteristics. The main difference is the vegetation coverage, which is less dense and bushy.

3.2 Sample collection and data analysis

Systematic samples were collected from both sites. Two sampling systems were selected, (1) a systematic grid for the enclosure and (2) a transect line for the grazing land. The permanent plots of the first system were mechanically spaced at uniform intervals on both axes. A sub-plot of 1 m² was positioned at the beginning of each main plot for the grass biomass assessment. The number of plots and transect lines required were determined on the basis of estimations from a reconnaissance survey. The transect line of the second design was chosen to compare differences in annual grass yield.

For all eleven species, a power equation was used. In view of the potential for bias in predicting biomass from equations developed with transformed data (Sprugel 1983), power equations provide a good alternative to log-log equations for the shrub species in our study. A disadvantage to the use of this equation is that the component predictions are not additive (Kozak 1970). This means, for example, that the predicted weight of branch plus the predicted weight of stem may not equal the predicted value for stem and branch. To overcome this limitation, equations are calculated for the individual components as well as for combinations of the components such as total fuel wood (stem and branch) or total tree weight (above ground biomass).

3.3 Destructive weighing study for the woody species

For the destructive weighing study of the woody species, the plants were grouped by species into diameter classes in order to get the corresponding frequency distribution. Only the shrub species, which contribute a large proportion to the vegetation cover in the areas, were identified for the weighing study. In this study only one sample was selected for each 0,5 cm increment in diameter at 30 cm height, because felling was restricted. Diameter at the base of the crown, crown diameter, diameter at 30 cm height and bole height were measured before felling. After felling, samples of trees/shrubs that cover the range of diameter measured were taken randomly, and separated into stem, branch wood, green wood and foliage. Because of the amount of practical work involved, an assessment of the green wood could not be done for all species. Fresh weight of stem wood, branch wood and foliage was measured separately, using a spring balance. Sample discs were taken from each tree and shrub. They were taken at random in the branch section, whereas it was preferred to standardize at 30 cm height for the stem wood section. The foliage sample was taken from the crown at random. To minimize errors by loss of moisture, the slices and leaves were clipped into plastic bags and transported to the base camp. The same day, the fresh weight was measured, at 0,1 g precision with an electronic balance. The following day the samples were transported to the main laboratory at Mekelle University. In the laboratory the sub-samples from each component were air dried for 78 hours at 25 °C (room temperature) and oven-dried at 65 °C for 78 hours (constant weight) (Hoff et al. 2002). Once the dry and fresh weights were known, the percentage moisture content (%mc) on a fresh weight basis was calculated. The moisture content was then used to convert the respective total fresh weight of the components measured in the field to air- and oven-dry weights, for the tree, shrub and grass level.

3.4 The destructive study for the most dominant grass species

The estimation of annual grass production of the selected closed area was done after the dominant species was selected. According to Newbould (1967) a quadrate size of 1 m² for uniform fine grass was placed at the beginning of the plots used in the woody biomass inventory.

The linearized form of the allometric equation, to obtain linearity and constant variance, was selected to estimate the grass biomass:

$LogY = B . (logX) + C$

Y = biomass of the grass;
X = Basal area;
and where B and C are constants.

Plant basal area proved to be the best predictor of plant biomass (Andariese and Covington 1986). Plant basal area is defined as the surface of the circle at the height where the grass is bound together during harvesting time (estimated at +/- 15cm height of the harvested grass).

3.5 The non-destructive study for the firewood species

The non-destructive volume and weighing study of the firewood species, was based on the randomised branch sampling procedure of Valentine et al. (1984).
- A "path" is defined as a sequence of connected branch segments. The number of possible paths in a tree equals the number of terminal shoots.
- A "branch" is defined as the entire stem system that develops from a single bud. The path starts from the bud of the main stem to a terminal shoot (Gregoire et al. 1995). The stem is starting from the soil surface untill the first forking (first segment). The next branch segments are classified to the crown system. In this way, the biomass estimation is divided in different components. Each path followed during one sampling session was selected with a weighing coefficient based on the amount of woody mass available in the upper part. The length and mean diameter of each segment, starting from the main stem to a terminal bud was measured. For additional biomass calculation, there is a need for conversion of the volume data with the density data (Ketterings et al. 2001). Wood density here is defined as the oven-dry mass per unit of green volume, usually the "basic density" or "green density " (Parent et al. 2000).

We used the following model:

$Y=a . X^b$
Y = biomass or firewood
X = morphological variable,
and where a and b are constants

4. Results and discussion

4.1 The destructive study for the woody species

The shrubs selected for the destructive study had a lower average height, (138 cm) ranging from 30 to 254 cm. In view of the potential for bias in predicting biomass from equations developed with transformed data (Sprugel 1983), power equations provide a good alternative to logarithmic equations for the shrub species in this study. For all the shrub species, at least one of the morphological measurements was a good predictor of total aboveground biomass and for the biomass of each component (Table 1). This was also found by Hierro 2000. For *Otostegia integrifolia*, the diameter of the crown was the easiest field measurement, because of the long branching patterns. The best predictor is in general the diameter at 30 cm. The diameter of the crown is only used for the prediction of the leaf mass. A separation between small branches and big branches was not made, because of the practical problems with this more detailed study.
The stem section was considered as the part below 30 cm. This gave rather a poor low correlation with the *Dichrostachys cinerea*: corr (Biomass stems, dsh= 0,71). The power equations where tabled for all shrub species and are given in Table 1.

4.2 The destructive study for the most dominant grass species

The site is dominated by an annual grass species *Hyperrhenia hirta*, This can be caused by the human cut-and-carry activity in the area. In the enclosure 98% of the total herbaceous biomass of the grass plots sampled belonged to this species. While in the grazing land near by, only 11% of the total herbaceous biomass of the sampled plots was originated from this *Hyperrhenia hirta* species. Note that the term 'herbaceous' is used here to denote all plant species that are not predominantly woody. The fodder grasses were mixed with herbs of minor nutritional value. Some identified species were *Medicago polymorpha L.* and *Cynodon dactylon*. The dominant grass species is *Hyperrhenia hirta*. The mean annual yield of the grass for the closed area is 1,11 ton ha^{-1} (stdev=0,38, N=13) (table 2), while the unprotected area with the different grazing system has a mean value of 0,16 ton ha^{-1} for the 13 sampled plots (stdev=0,21 ton ha^{-1}).

TABLE 1. Characteristics of the biomass equations for the shrub species. The firewood model represents the air dry woody part of each individual sample tree *

Species	Sample Size	Biomass	Power equation	R'²
Grewia bicolor	8	Total	$y=52{,}97dsh^{1,91}$	0,96
	8	Firewood	$y=52{,}43dsh^{1,99}$	0,95
	8	Leaves	$y=7{,}06dsh^{1,75}$	0,89
	8	Branches	$y=1{,}93dsh^{0,39}$	0,77
Euclea shimperi	7	Total	$y=63{,}07dsh^{1,78}$	0,95
	7	Stem	$y=20{,}55dsh^{1,69}$	0,92
	7	Firewood	$y=57{,}30dsh^{1,87}$	0,31
	7	Leaves	$y=4{,}88dsh^{3,54}$	0,67
	7	Branches, twigs	$y=22{,}09dsh^{22,09}$	0,95
Otostegia integrifolia	7	Total	$y=45{,}80dsh^{2,26}$	0,99
	7	Firewood	$y=43{,}77dsh^{2,4}$	0,98
	7	Leaves	$y=0{,}54dsh^{-0,09}$	0,94
	7	Branches, twigs	$y=14{,}20dsh^{2,50}$	0,91
Dychrostachys cinerea	5	Total	$y=230{,}98dsh^{1,47}$	0,87
	5	Stem	$y=274{,}95dsh^{1,37}$	0,83
	5	Firewood	$y=135{,}24dsh^{0,83}$	0,71
	5	Leaves	$y=0{,}016dcr^{1,60}$	0,96
	5	Branches, twigs	y=46,50dsh2,71	0,99

*Model explanation: R'² = coefficient of determination for the equations; y = ovendry weight (g); dsh = diameter of the longest stem at 30 cm height (cm); dcr = maximum crown width.

TABLE 2. Average grass weights for each protected plot vs. the woody biomass. *H. hirta* was separated from the other grass species in order to compare its abundance over the area.

PLOT	BIOMASS (TON/HA)		
	WOODY	HERBACEOUS	
	Shrubs/trees	*H.hirta*	Fodder grass
T1	1,38	0,77	0,04
T2	1,06	0,93	0,11
T3	1,13	1,16	0,1
T4	0,76	1,6	/
T5	1,14	1,24	/
T6	2,19	1,12	0,03
T7	1,42	1,78	/
T8	2,57	0,8	/
T9	3,49	1,22	0,05
T10	1,42	1,2	0,01
T11	2,08	0,42	/
T12	1,58	1,52	/

The basal area diameters proved to be an objective prediction variable comparing to the most traditional percent cover estimations, which vary substantially from observer to observer and even with observer among sampling dates (Andariese and Covington 1986).

At the present time, the system of management allows the conversion to closed woodland. The annual cutting of the grass does not limit the new regeneration of the woody species.Woody and herbaceous specious compete for the same space as can be seen from the slight negative correlation between their respective basal area (–0,11) and confirms that the study area is evolving to a closed woodland structure which could lead to an increase in woody biomass production (Burrows 1999).

4.3 The non-destructive study for the firewood species

Coefficients of determination for the selected total biomass models ranged from 0,20 - 0,90 for woody species from the non-destructive study. Weight estimations for the biomass and firewood of an individual tree or shrub had a range of 106 g -60.552 g. A reason for this high range can be found in the conversion with the density data. These data varied from 0,49 g/cm³-1,96 g/cm³. The upper limit is remarkable high for this kind of wood. This indicates that the measurement technique of the specific weight study might have failed. This could be also a reason for the relatively low correlations of the weight predicting models of the non-destructive study.

4.4 Destructive vs. non-destructive study

The non-destructive study exhibits lower correlation than the destructive study. Therefore, the models from the destructive study were used in the final estimation of the biomass of the enclosure which resulted in an average value of 1,84 ton/ha. With this value, the study area can be classified according to the literature (Parent et al. 2000) as open shrubland, with an average biomass value of 1,25 ton/ha probably without grass biomass.

5 Recommendations

Developing biomass predictors is time consuming and expensive. Therefore, regardless of the approach and the scale of application, the possibility of using existing predictors should be considered before collecting new data.

Although it is desirable to develop equations for individual sites, doing so may not be possible or practical. The prediction models presented here are most likely to be useful for stand and site conditions as well as ranges in plant sizes similar to those under which they were developed. The regression equations here presented are recommended to be used for studies in open shrubland in the Northern Ethiopian Highlands

For reasons of sustainability and habitat conservation, enclosures are not adopted as fuelwood collection reserves. However it has been proven that the annual cutting of the grass seems not to threat the development of further woodland structures. Hence, these enclosures can benefit the surrounding communities with a single annual grass harvest.

5. Acknowledgements

This case-study was accomplished in the framework of a thesis from Stijn Cleemput in the research project ‘Forest Rehabilitation through Natural Regeneration in Tigray, Northern-Ethiopia’ (VL.I.R. EI-2000 / PRV-06). This study was made possible by the intensive support of the local project coordinator ir. Raf Aerts, and Prof. dr. Geert Baert from the Hogeschool Gent who was the promoter of this thesis.

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