The Prediction of Leaf Biomass Production from *Faidherbia albida* in Semi arid land, Pokot County, Kenya

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ABSTRACT

Faidherbia albida tree is important in feeding the livestock during dry seasons when livestock feed is scarce among the people in the semi-arid regions. Despite this unique value of the tree, no models have been developed for estimating its local leaf biomass production, thus hampering its resource assessment and management planning. Hence this study was conducted to determine allometric relationships between leaf biomass production from *F. albida* tree and its diameter at breast height, tree height and crown diameter. Between January and March 2016, random sample of 20 trees were partially harvested in Chepareria Division. Diameter at breast height, crown diameter and total tree height were measured in the field. Sample weights of the leaves were determined then extrapolated to the whole tree production and used as a basis for developing leaf biomass models. Correlation regression analysis as provided in R-software was used to establish the relationship between *F. albida* leaf biomass production and the measurable tree parameters. Nine models were fitted in the study and their suitability in predicting leaf biomass established. Comparison of different models was based on: adjusted coefficient of determination (adj. R^2); significance of parameter estimates when tested at the 5% probability level; homogeneity of residual variance and distribution of the residuals; Standard Error of the Estimates (SEE). Among tested models, the study suggested $\text{Leaf biomass, (kg)} = 8.5 + 9.5\text{DBH}^2$ with adjusted R^2 = 0.82 for local use.

Key words: allometric models, *Faidherbia albida*, leaf biomass, production

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1. INTRODUCTION

Livestock mainly produce first class protein sources (meat and milk) and as a source of income [1]. Livestock production is however affected by the availability of quality forage that varies seasonally in the developing countries and especially in the arid and semi-arid regions [1,2]. During the rainy season when pastures are considered to be in surplus, they tend to be of low protein and thus cannot meet the nutritional need of the livestock. High quality rations have to be supplemented to the animals in order to avert malnutrition particularly during the dry seasons when the pastures are scares [1,3]. Livestock dietary supplement is very expensive and cannot be afforded by a number of small scale livestock farmers in the developing nations due to prevailing economic pressures [1].

Livestock and other ruminant animals are usually held at home during the rainy season by herders and other sedentary people and are fed with biomass from fodder banks particularly trees. According to Sanon *et al*. [3], fodder is obtained from trees through slashing or pruning. Pruning is the main method used in collecting animal feeds from trees [4]. During the dry season and at the onset of rains, zero grazing is carried out in such areas to reduce overgrazing and enhance grass regrowth. Zero grazing also assists in increasing the capacity of manure production of a farm [5].

Legume tree species are known as miracle trees in providing high quality protein feed for livestock [1,2]. *F. albida* is a multipurpose tree species (MPTS) in most parts of the arid and semi-arid regions of East Africa and is majorly used as feed for livestock in such regions. This wonder tree, as it is known among the arid and semiarid communities, depicts a wonderful survival growth and has a reverse phenology. It produces leaves and fruits during dry season (January to March) in dry areas when most of other trees shed their leaves [6]. There is a need for the smallholder livestock farmers to know and understand the amount of available animal feeds in order to ensure feeding of the livestock to optimal production levels. Various methods to measure the quantity of forage vegetation have been described to this regard [7]. Even though farmers may not need accurate forage measurement, there is need for a good estimate of the amount of forage and fodder available on their farms. Past studies on *F. albida* have focused mainly on its propagation and management, fodder roles and soil nutrient fixation ability [1,8] but not on fodder measurement. In view of this background, the study was designated to assess the leaf biomass production from *F. albida* in Chepareria Division in Pokot South Sub-County in Kenya. The information from this study is valuable

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in quantifying animal feed supplementation more so in the dry seasons when animal feeds are in short supply in the dry regions.

2. MATERIALS AND METHODS

2.1 Study area

Chepareria Division is located in West Pokot County, Kenya (Figure 1). Chepareria Division lies at a latitude between 1º 15' 40''N and 1º 55' 37''N and at longitude between 35º 7' 46''E and 35º 27' 10'' E. It lies between 708 m and 3516 m above the sea level and covers an area of approximately 500 Km^2 [9].

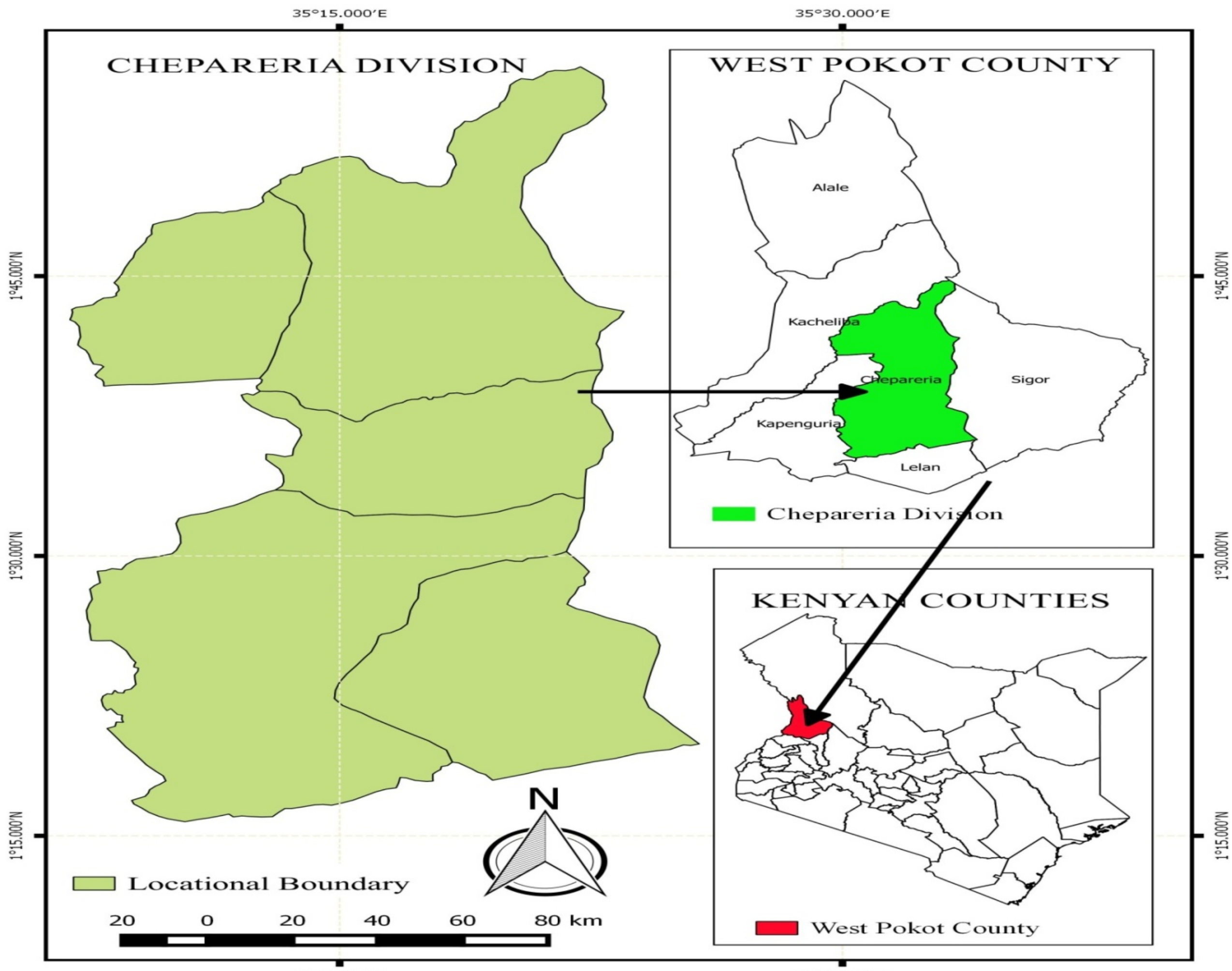

Figure 1: West Pokot showing Chepareria Locations

The rainfall regime in Chepareria division varies between 400mm (lower zone) part and 750mm (upper zone) per annum. The annual mean temperature ranges between 10 °C to 26 °C [10,11].

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Soils in the study area vary from loam silt soils, regosols to sand-loam soils [12,13]. The lower zones of Chepareria are semi-arid and characterized by fragile infertile soils [12].

The main economic activity in the study area is agropastoral. The upper zone has adopted improved breeds of livestock to a greater extent than the lower zone [11]. Keeping donkeys for transportation on rough roads and beekeeping is widespread [10,11].

2.2 Data collection Procedure

2.2.1 Measurement of *F. albida* parameters

The study was carried out in four sub-locations within Chepareria Division, namely: - Pserum, Naraman, Chepkobe and Cheptangwa. Study sites (farms) were randomly selected by first selecting the first farm on which *F. albida* tree was found in each sub-Location as the reference point and the other four farms identified systematically at 500m to the North, South, East and West of the first farm as indicated in Figure 2.

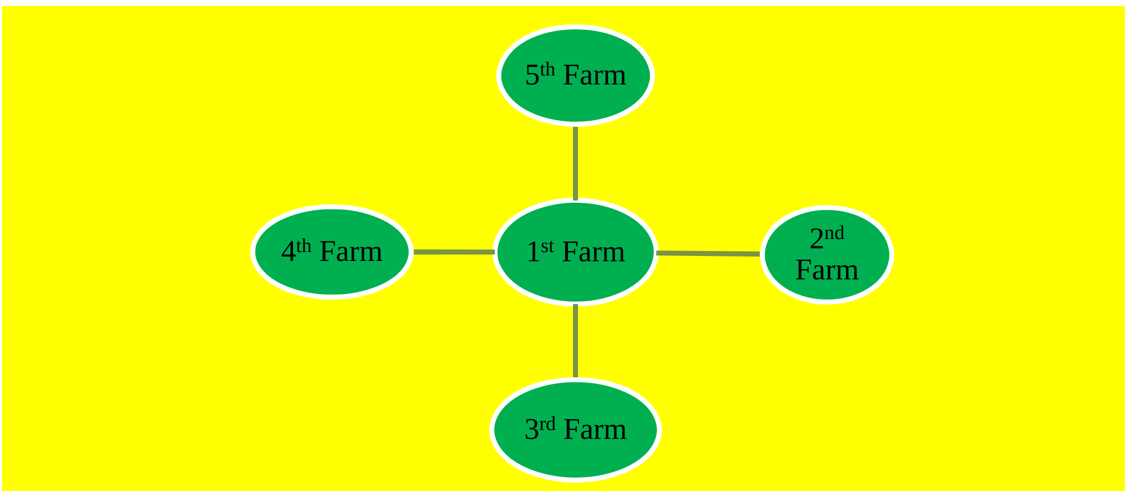

Figure 2: Sampling design for *F. albida*

From each farm, one mature *F. albida* tree was randomly sampled; giving a sample size of 20 trees and used to estimate leaf production. The study was done between the months of January and March, 2016 when *F. albida* tree was foliated. A mature tree in this study was a tree that bore fruits at the time of the study and had reasonable height and diameter [14].

Each *F. albida* tree sampled was numbered and corresponding parameters (diameter at breast height (DBH), crown diameter, total height and leaf sample weight) were measured and recorded accordingly.

DBH was measured directly using diameter tape at 1.30m above the ground. Total tree height was measured as described by Philip [15] and briefly as follows: From a distance approximately equal to the estimated tree height, its actual height was estimated with the help of Suunto clinometers and

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graduated pole. Crown diameter was measured using the three people technique by taking the average length of the two lines crossing the crown area as follows:- First, the extreme points perpendicularly below the branch tips on both ends of the tree crown were located and two people made to stand at each of the located points. The horizontal distance between the two people through the central mass of the crown was measured by the third person then the second measurement was taken perpendicular to the first line and the average of the two measurements was taken as the crown diameter.

Leaf weight was measured based on destructive method. To reduce the loss and mutilation of *F. albida* samples, 1/3 of the crown of a given tree sample was cut [14]. Total destruction of the entire crown was not possible due to the high fodder value of *F. albida* in the study area. The leaves of each sampled tree were carefully removed separately and weighed immediately.

2.2.2 Determination of biomass

0.05% of sampled fresh leaf of *F. albida* were taken to the University of Kabianga laboratory, sun dried for one week then oven dried for 48 hours at 70^{o}c to obtain constant weight [14,16]. This constant weight was then extrapolated to the whole tree to get the total leaf dry-weight (W_D).

Weights of leaves were estimated as the product of dry to green ratio (biomass ratio) and total green weight (kg) of the respective tree component as follows:-

$$\text{Biomass} = \left(\frac{W_D}{W_F}\right) \times W_F \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Where, W_D is oven dry weight of leaf and W_F is fresh weight.

2.3 Allometric Models Relationships

Correlation and regression analysis were used to establish the allometric relationship between the leaf productions of *F. albida* with its DBH, crown diameter and tree height.

2.3.1 Biomass models

A range of nine different tree biomass models commonly encountered in the literature were fitted as stated by [14,16,17,18]. The models were fitted as follows:

$B = a + b\mathrm{D}^2 \cdots\cdots\cdots\cdots$ Model 1

$B = a + b\mathrm{H}^2 \cdots\cdots\cdots\cdots$ Model 2

$B = a + b\mathrm{C}^2 \cdots\cdots\cdots\cdots$ Model 3

$B = a\mathrm{D}^b \cdots\cdots\cdots\cdots$ Model 4

$B = a\mathrm{C}^b \cdots\cdots\cdots\cdots$ Model

$B = a\mathrm{H}^b \cdots\cdots\cdots\cdots$ Model 6

$B = a + bD + c\mathrm{D}^2 \cdots\cdots\cdots\cdots$ Model 7

$B = a + bC + c\mathrm{C}^2 \cdots\cdots\cdots\cdots$ Model 7

$B = a + bH + c\mathrm{H}^2 \cdots\cdots\cdots\cdots$ Model 9

Where, D is DBH, H is total height of the tree, C is the crown diameter, B is biomass of oven-dry leaves of *F. albida* and a, b, and c are prediction parameters to be estimated.

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Regression for a straight line model (y= $a + bx$) was calculated by the least squares method (LSM). LSM differentiates to give the slope (b) and the Y intercept (a) of a line as follows:-

$$b = \sum xy - (\sum x)(\sum y)\, \pi r^2$$

$$= (\sum x^2) - \{(\sum x)^2/n\} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$a = \overline{y} - b\bar{x} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

Comparison of the nine models tested were based on adjusted coefficient of determination (adj. R^2) that made it possible to compare models with different parameters (Montgomery *et al*., 2001), 5% level of significance, homogeneity of residual variance (RV) and distribution of the residuals and Standard Error (RSE) of the Estimates or Standard Deviation of the Residuals (SEE).

3. RESULTS AND DISCUSSION

The ability of the nine different models to predict total leaf biomass production using diameter at breast height (DBH), total tree height (H) and crown diameter (C) was assessed.

3.1 Locality characteristics of *Faidherbia albida*

Table 1 gives the general tree characteristics of *F. albida* as assessed in Chepareria, Pokot South Sub-County.

Table 1

Locality characteristics of the *F. albida*

Location	Sub-Location	DBH (m)	Total height (m)	Crown diameter (m)	Total dry leaf biomass (kg)
Pserum	Pserum	0.59	10.24	12.84	39.02
	Naramam	0.79	12.78	15.12	41.38
Chepkobe	Chepkobe	0.74	9.98	11.54	64.60
	Cheptangwa	086	13.08	15.32	59.00
Minimum		0.42	6.2	8.6	27.7
Maximum		1.30	18.6	20.5	90.9
Mean		0.75±0.11	11.52±2.00	13.70±1.74	51.00±10.0

The measurable characteristics of *F. albida* trees in the area was found to range from 0.42 to 1.30m for DBH, total tree height ranged from 6.2 to 18.6 m and that of crown diameter ranged from 8.6 to 20.5 m. Derived total dry leaf biomass varied between 27.70 kg and 90.90 kg and the average dry leaf

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biomass per tree was 51.00±10.0 kg. Further analysis indicated that there were no significant difference ($p>0.05$) in tree parameters between the two ecological zones. These values were within the similar range reported in other studies [19, 20].

3.2 Prediction of *Faidherbia albida* total leaf biomass production

Figure 3a and Figure 3b present scatter diagrams for the nine models fitted. All the models indicate that there is a relationship between the total dry leaf biomass and tree DBH, height and crown diameter. The overall regression models are good fit for DBH, height and crown diameter hence predict dry leaf biomass.

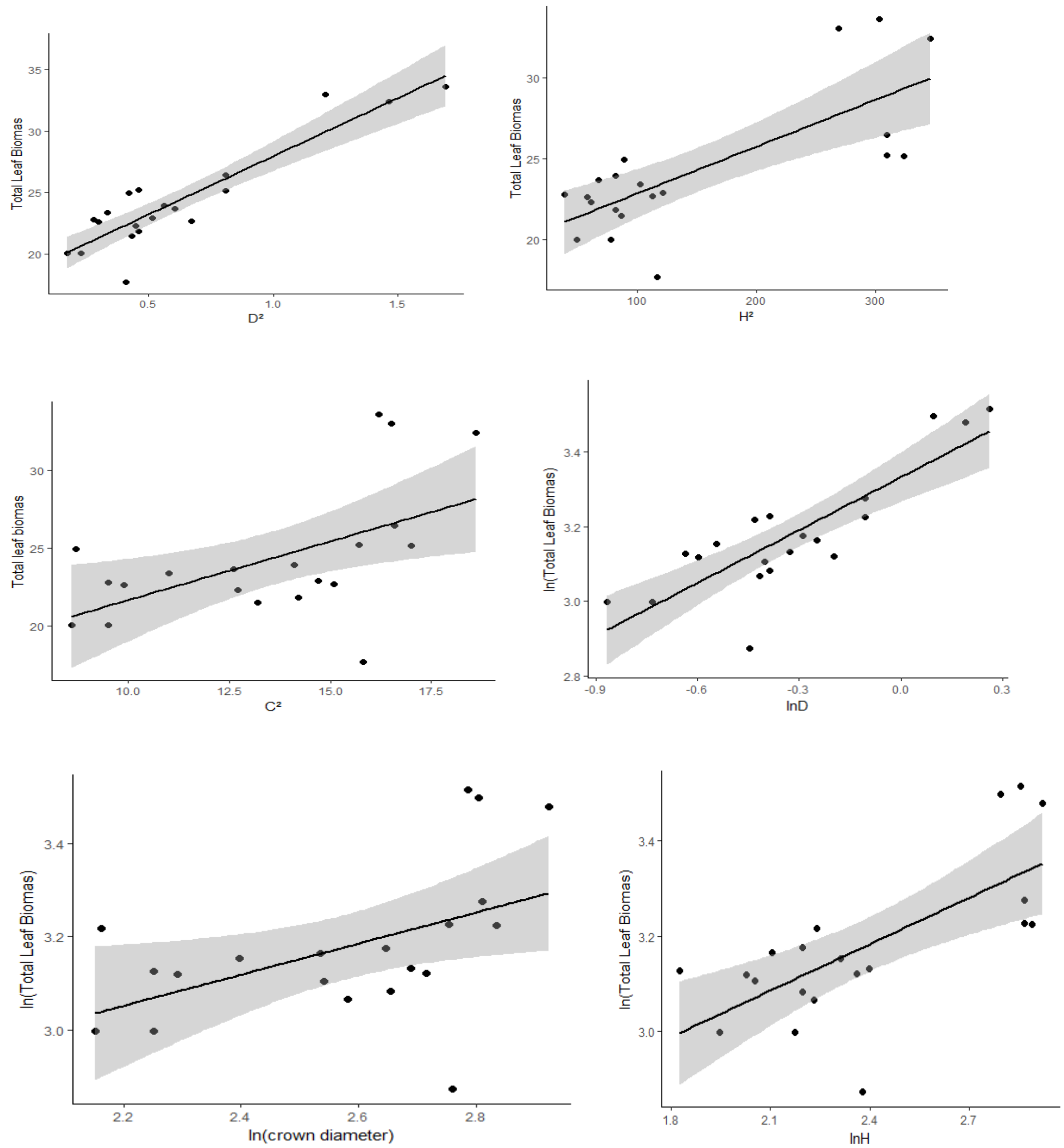

Figure 3a: Scatter diagrams of *F. albida* leaf biomass fitted models 1 to 6

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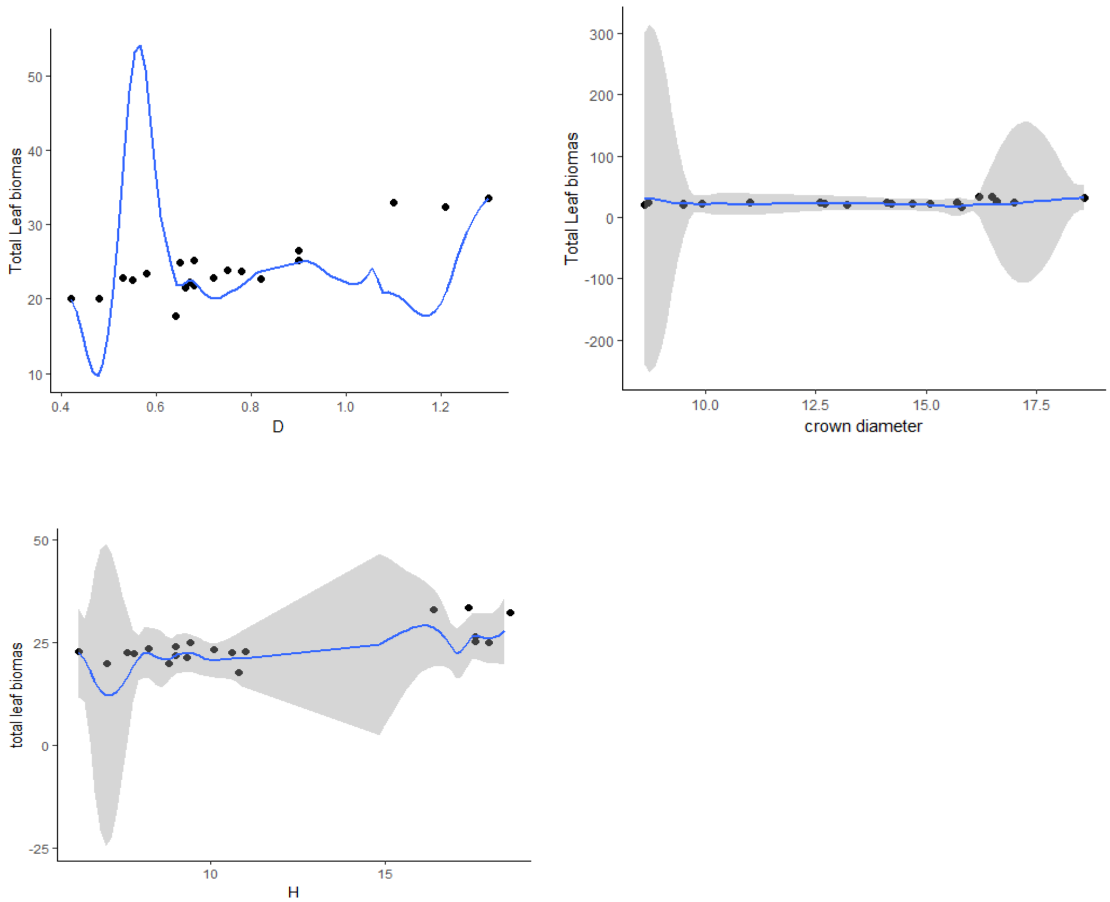

Figure 3b: Scatter diagrams of *F. albida* leaf biomass fitted models 7 to 9

Indeed the scatter diagrams of the nine tested models indicate the existence of a strong relationship between *F. albida* leaf biomass and its DBH, height and crown diameter. This agrees with the findings of [19] that tree biomass is a function of its DBH, height and crown diameter. Such relationship however varies with sites, regions and tree age [21].

Table 2 presents the regression equations derived from *F. albida* dry leaf biomass, DBH, height and crown diameter.

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Table 2

Regression models describing leaf biomass of *Faidherbia albida*

Model No.	Model equations	Model Attributes								
		RSE	**R^2**	**Adj. R^2**	**p-value**	**MAE**	**MSE**	**RMSE**	**RSR**	**REMARKS**
1.	$B = 8.5 + 9.5D^2$ (Linear)	1.82	0.82	0.82	3.15e-08	1.30	3.01	1.73	0.41	Best model
2.	$B = 2.0 + 0.03H^2$ (Linear)	2.90	0.56	0.53	0.00015	2.21	7.56	2.75	0.65	
3.	$B = 14.1 + 0.8C^2$ (Linear)	3.66	0.30	0.26	0.013	2.58	12.08	3.48	0.82	
4.	$B = 2149D^{0.47}$ (Power)	0.09	0.70	0.69	4.051e-06	0.07	0.01	0.09	0.53	
5.	$B = 208.7C^{0.33}$ (Power)	0.15	0.24	0.20	0.029	0.10	0.02	0.14	0.85	
6.	$B = 254.7H^{0.32}$ (Power)	0.12	0.49	0.46	0.00065	0.09	0.01	0.12	0.70	
7.	$B = 24.3 + 16.5D + 3.2D^2$ (2nd order Polynomial)	1.87	0.83	0.81	3.46e-07	1.32	2.98	1.73	0.41	
8.	$B = 24.3 + 10.0C + 7.0C^2$ (2nd order Polynomial)	3.37	0.44	0.37	0.0074	2.19	9.64	3.10	0.73	
9.	$B = 24.3 + 13.6H + 3.0H^2$ (2nd order Polynomial)	2.95	0.57	0.52	0.0008	2.11	7.42	2.72	0.64	

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Leaf biomass is highly correlated with DBH squared (D^2) for model 1 (high adjusted R^2 = 0.82 and residual standard error of 1.82 indicates that model 1 gives the best prediction of *F. albida* leaf biomass.

The derived equation is $B = 8.5 + 9.5D^2$ (for Model 1; Linear)

Where B = leaf dry weight in kg and D^2 is DBH squared

The residual plot (Figure 4) indicates that *F. albida* leaf biomass prediction based on model 1 was found to approximately normally distributed about mean zero and only few values are more than ± 2.

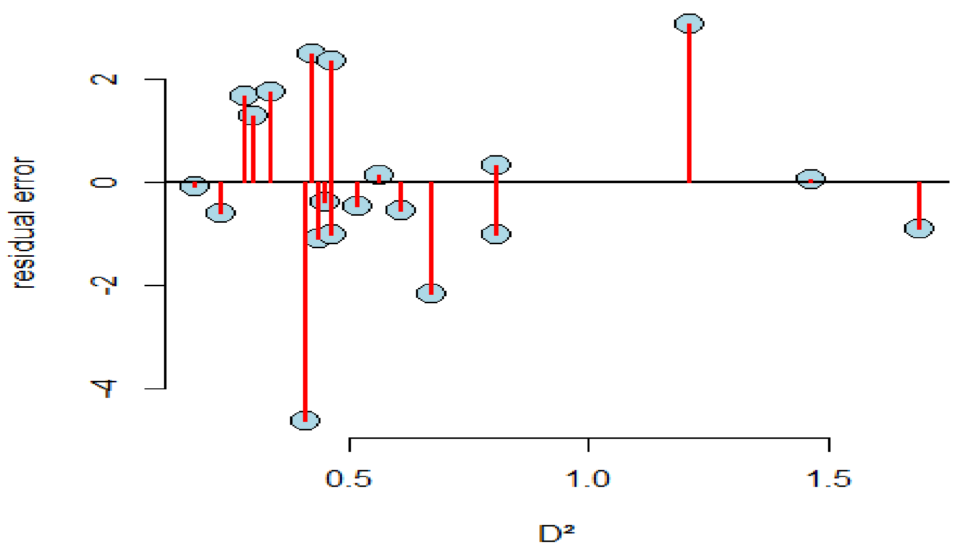

Figure 4: Residual distribution of model 1

Several authors have used regression analysis to predict tree biomass production [22,23]. Regression analysis was applied in this study. Different tree measurable parameters (diameter at breast height, total tree height and crown diameters) and their derivatives were used in selecting the best model. Dry leaf biomass regression model with $(DBH)^2$ as the independent variable and leaf dry weight as the dependent variable gave the highest adjusted R^2 = 0.82 and the lowest RSE= 1.82 (model 1). Since there are few models available for estimation of tree leaf biomass production [24], the model suggested in this study is expected therefore to be valuable in estimation of *F. albida* leaf biomass production. This study concurs with that of Das [24] and Burton *et al*. [25] who found that DBH was the best estimator of tree leaf biomass (R^2 > 80). The tree DBH contributes to the accumulation of biomass in dryland vegetations and models that only include DBH as the independent variable are

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easy to use since DBH can be measured easily using simple tools. Such models have practicability of use in local areas [17, 19, and 20].

The size of the DBH determines the canopy area, hence the leaf biomass. In fact, the larger the DBH, the larger the probability of a tree having more branches and twigs that eventually sprout more leaves hence increasing total leaf biomass and therefore the suitability of DBH in predicting total leaf biomass. This concurs with Karuki and Kigomo[26] and Rapp et al. [27]that DBH affects the tree branches, sub-branches, twigs and number of leaves. Meier and Leuschner [28] adds that DBH affects the upper canopy of trees thus small DBH trees have smaller upper canopy.

4. CONCLUSIONS

This study was based on a sample of 20 *F. albida* tree and a range of allometric biomass models were tested. One model was proposed for use in estimating of *F. albida* local leaf biomass production. This study shows that by regressing DBH against total dry leaf biomass, total leaf production level can be estimated. Based on this study, Model 1: $B = a + b\mathrm{D}^2$ (adjusted R^2 = 0.82, RSE = 1.82 and p= 3.15e-08) was found to be the best model in prediction *F. albida* total dry leaf biomass production in Chepareria Division. The equation fit was $B = 8.5 + 9.5\mathrm{D}^2$.

References

1. Maundu P, Bo Tengnas. *Useful trees and shrubs for Kenya*, World Agroforestry Centre. 2005.
2. Faye MD, Weber JC, Abasse TA, Boureima M, Larwanou M, Bationo AB *et al*. *Farmers' preferences for tree functions and species in the West African Sahel.* Forests, Trees and Livelihoods. 2010. 20: 1–15
3. Sanon HO, Kaboré-Zoungrana C, Ledin I. Behaviour of goats, sheep and cattle and their selection of browse species on natural pasture in a Sahelian area. Small Rumin. 2007. Res., 67: 64–74
4. Salis SM, Assis MA, Mattos PP, Piao ACS. *Estimating the aboveground biomass and wood volume of savanna woodlands in Brazil's Pantanal wetlands based on allometric correlations*. Forest Ecology. Management. 2006.
5. Bosma RH, Bos M, Kante S, Kebe D, Quak W. *The promising impact of ley introduction and herd expansion on soil organic matter content in southern Mali.* Agricultural Systems. 1999. 62(1): 1-15.

*Corresponding Author:- yuda.odongo@yahoo.com; +254 721 718 067

6. Adamu GK. *Use of Faidherbia albida for soil improvement in small holder farming system of Gezawa Local Government Area of Kano State, Nigeria.* Research Journal of Environmental and Earth Sciences.2012. 4(10):895-899.

7. 't Mannetje L. *Measurement of Grassland Vegetation and Animal Production*. Bulletin 52. CAB (Commonwealth Agricultural Bureaux), Farnham Royal, Bucks, England, UK. 1978. 260 pp.

8. Cissé MI, Koné AR. *The fodder role of Acacia albida Del. Extent of knowledge and prospects for future research*. *In*: Vandenbeldt R.J. (Ed.). *Faidherbia albida* in West African semi-arid tropics. Proceedings of a workshop held from 22nd to 26th April 1991 in Niamey, Niger. 1992

9. Wernersson JEV. *Towards a Critica Social Theory of Landscape: Perception and Experiences of Land-use Change in Chepareria, Kenya*. Msc thesis in Global Studies, University of Gothenburg. 2013.

10. Aholo R, Mukoya, Nemali E. *Chepareria baseline report 2001*. West Pokot. Vi Agroforestry report.2001.

11. Ityeng D, Hongo T, Obutu L, Merie F, District Steering Group DSG. " Pokot Districts 2008 Short Rains Assessment Report." Recommendations, Kenya Food Security Steering Group (KFSSG), Regional Assessment Team, 2008.

12. Sposito G. "Soil." *Encyclopaedia Britannica Online Academic Edition*. Web. Prod. Encyclopaedia Bratannica Inc. 2013.

13. FAO. *Grassland Index. A searchable catalogue of grass and forage legumes.* Food and Agriculture Organization of the United Nations, Rome, Italy. 2006

14. Larwanou M, Yemshaw Y, Saadou M. *Prediction models for estimating leaf and fruit dry biomasses of five Savannah tree species in the West African Sahel*. ICRAF. 2010

15. Philip MS. *Measuring Trees and Forests*. Second edition. CABInternational, Wallingford. 1994

*Corresponding Author:- yuda.odongo@yahoo.com; +254 721 718 067

16. Picard N, Saint-André L, Henry M. *Manual for building tree volume and biomass allometric equations: from field measurement to prediction.* Food and Agricultural Organization of the United Nations, Rome, and Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Montpellier. 2012

17. Rajchal R, Meilby H. Above-ground biomass models for Seabuckthorn (*Hippophae salicifolia*) in Mustang District, Nepal. Banko Janakari. 2013. 23(1), 23-24.

18. Mugasha WA, Mwakalukwa EE, Luoga E, Malimbwi RE, Zahabu E, Silayo DS *et al*. *Allometric models for estimating tree volume and aboveground biomass in Lowland Forests of Tanzania*. International Journal of Forestry Research. 2016, Article ID 8076271, 13 pages.

19. Luvanda, A.M., Wangeci, R., Nicholus, J., Mwendwa, P., Muchiri, D .and Sheikh, M. *The Ecological and Socio-economic importance of Faidherbia albida in Taita and Taveta, Kenya*. *Octa Journal of Environmental Research.* 2016.4(1): 001-007

20. Orwa, C., Mutua, A. ; Kindt, R. ; Jamnadass, R. ; Anthony, S. *Agroforestree Database: a tree reference and selection guide version 4.0.* World Agroforestry Centre, Kenya. 2009. (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp)

21. Whitmore, T.C. *Tropical rain forests of the Far East*. 2nd ed. Oxford: Clarendon Press. 1984.

22. Applegate, G.D., Gilmour, D.A. and Mohns, B. The use of biomass estimations in the management of forests for fuelwood and fodder production. Commonwealth. For. Rev. 1988. 67. 141–51.

23. Ballard, B.D., Stehman, S.V., Briggs, R.D., Volk, T.A., Abrahamson, L.P. & White, E.H. Aboveground Biomass Equation Development for Five Salix Clones and One Populus Clone. Interim Status Report No. 1. Niagara Mohawk Power Corporation, State University of New York, New York. 1998

24. Das, N. Modeling Develops to Estimate Leaf Area and Leaf Biomass of *Lagerstroemia speciosa* in West Vanugach Reserve Forest of Bangladesh. *Hindawi Publishing Corporation.* Vol. 2014. http://dx.doi.org/10.1155/2014/486478

*Corresponding Author:- yuda.odongo@yahoo.com; +254 721 718 067

25. Burton, A. J.. Pregitzer, K. S and Reed, D. D. Leaf area and foliar biomass relationships in northern hardwood forests located along an 800 km acid deposition gradient. *Forest Science*, vol. 37, pp. 1041–1059, 1991.

26. Kariuki JG, Kigomo JN. *Biomass prediction models for Acacia reficiens and Acacia mellifera in Kakuma, Turkana District.* Recent advances in forestry research for environmental conservation, improved livelihood and economic development. Proceedings of the 4th KEFRI scientific conference held on 6th to 9th in KEFRI Headquarters, Muguga in Nairobi.2009

27. Rapp M, Regina I S, Rico M' Gallego HA. Biomass, nutrient content, litter fall and nutrient return to the soil in Mediterranean Oak forests. *Forest Ecology and Management.* 1999. 119: 39–49.

28. Meier IC, Leuschner C.H. The belowground drought response of European beech: fine root biomass and carbon partitioning in 14 mature stands across a precipitation gradient. Global Change Biology Volume 14, Issue 9 (2008)

*Corresponding Author:- yuda.odongo@yahoo.com; +254 721 718 067