LEAF AREA DYNAMICS AND ABOVEGROUND BIOMASS OF SPECIFIC VEGETATION TYPES OF A SEMI-ARID GRASSLAND IN SOUTHERN ETHIOPIA

[DINÁMICA DE AREA DE HOJA Y BIOMASA AEREA DE TIPOS ESPECÍFICOS DE VEGETACIÓN EN UN PASTIZAL SEMI-ÁRIDO IN EL SURESTE DE ETIOPÍA]

Bosco Kidake Kisambo[1*], Jan Pfister[2], Angela Schaffert[2] and Folkard Asch[2]

[1]*Arid and Range Lands Research Institute, Kiboko - Kenya Agricultural and Livestock Research Organization, P.O. Box 12-90138, Makindu, Kenya.*
Email: bkkidake@gmail.com
[2]*Department of Crop Water Stress Management, Institute of Agricultural Sciences in the Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany.*
Emails: Jan_Pfister@uni-hohenheim.de, angelaschaffert@web.de, and fa@uni-hohenheim.de
**Corresponding author*

SUMMARY[1]

Leaf Area Index (LAI) dynamics and aboveground biomass of a semi-arid grassland region in Southern Ethiopia were determined over a long rain season. The vegetation was categorized into four distinct vegetation types namely Grassland (G), Tree-Grassland (TG), Bushed-Grassland (BG) and Bush-Tree grassland (BT). LAI was measured using a Plant Canopy Analyzer (LAI2000). Biomass dynamics of litter and herbaceous components were determined through clipping while the aboveground biomass of trees and shrubs were estimated using species-specific allometric equations from literature. LAI showed a seasonal increase over the season with the maximum recorded in the BG vegetation (2.52). Total aboveground biomass for the different vegetation types ranged from 0.61 ton C/ha in areas where trees were non-existent to 8.80 ± 3.81ton C/ha in the Tree-Grassland vegetation in the study site. A correlation of LAI and AGB yielded a positive relationship with an R^2 value of 0.55. The results demonstrate the importance of tropical semi-arid grasslands as carbon sinks hence their potential in mitigation of climate change.

Keywords: Biomass; carbon; Leaf Area Index; sequestration; grassland

RESUMEN

Se determinó la dinámica del índice de área foliar (LAI) y la biomasa aérea de una región de pastos semiáridos en el sur de Etiopía durante la temporada larga de lluvias. La vegetación se clasificó en cuatro tipos distintos de vegetación: praderas (G), árboles-pastizales (TG), arbustivas-pastizales (BG) y arbustivas-pastizales-arbóreas (BT). El LAI se midió utilizando un analizador de copa de plantas (LAI2000). La dinámica de la biomasa de la hojarasca y los componentes herbáceos se determinó a través de corte mientras que la biomasa de árboles y arbustos por encima del suelo se estimaron utilizando ecuaciones alométricas específicas para las especies tomadas de la literatura. El LAI mostró un incremento estacional durante la temporada con el máximo registrado en la vegetación BG (2.52). La biomasa total sobre el suelo para los diferentes tipos de vegetación varió de 0.61 ton C/ha en áreas donde los árboles eran inexistentes a 8.80 ± 3.81ton C/ha en la vegetación TG en el sitio del estudio. La correlación de LAI y AGB fue positiva con un R^2 de 0,55. Los resultados demuestran la importancia de las praderas semiáridas tropicales como sumideros de carbono, de ahí su potencial en la mitigación del cambio climático.

Palabras clave: Biomasa; carbón; Índice de área foliar; secuestro; pradera

1 *Submitted March 06, 2016 – Accepted September 14, 2016.*

INTRODUCTION

The Savannah semi-arid grasslands are one of the world's major terrestrial ecosystems, comprising between 10% and 15% of the world's land surface (Scholes and Hall, 1996). These regions sustain a variety of life offering services such as production of biomass for ruminants, food production, habitat for wildlife and ecosystem services including, provision of wood fuel, water catchment and in-situ protection of genetic resources (Carlier et al., 2009). In addition, they are important carbon sinks through the capture and storage of carbon dioxide, slowing accumulation in the atmosphere and hence mitigation of climate change. The semi-arid savannah environments are important components of the general global carbon cycle storing as much as 30 ton C/ha (Grace et al., 2006).

The rapid increase in CO_2 concentration in the atmosphere has led to an increased attention to the preservation of carbon stocks in tropical ecosystems (Ryan et al., 2011). Biomass plays an important role in climate systems including withdrawal of CO_2 from the atmosphere and storage provided it is not harvested unsustainably (IPCC, 2005). In semi–arid grasslands, biomass accumulation is driven mostly by seasonality (Grace et al., 2006); hence, the length and duration of dry and wet seasons influence its allocation in plants. Natural grassland ecosystems may contribute as much as 20% of total terrestrial primary production, to provide an annual sink of about 0.5 Pg Carbon hence the increased attention (Scurlock and Hall, 1998). However for these regions, especially in semi-arid savannah grasslands, aboveground biomass dynamics are poorly understood and only few estimates are available from *in situ* measurements (Ciais et al., 2011).

A primary quantity of plants used to monitor growth and changes in vegetation is leaf area index (LAI). LAI has been defined as the total one-side area of photosynthetic tissue per unit ground surface area (Jonkheere et al., 2004). It determines the size of the plant–atmosphere interface thus playing a key role in the exchange of energy and mass between the canopy and the atmosphere. LAI drives both the within-canopy and the below-canopy microclimate, determines and controls canopy water interception, radiation extinction, water, carbon and gas exchange and is, therefore, a key component of biogeochemical cycles in terrestrial ecosystems (Brèda, 2003).

To determine the potential contribution of tropical semi-arid ecosystems to carbon storage, biomass and carbon estimates are needed. This study broadly set out to determine the LAI and estimate the amounts of biomass and carbon stocks stored in different vegetation types and aboveground carbon pools. The specific objectives put in place to achieve this were to: - (i) Determine the leaf area index and LAI dynamics of specific vegetation types over the long rain season and to (ii) Estimate aboveground carbon stocks found in the different carbon pools (trees and shrubs, herbaceous biomass and litter) in the semi-arid grassland of Southern Ethiopia.

MATERIALS AND METHODS

Study site

The study was carried out in Dire district of Southern Ethiopia located 650 Km south of Addis Ababa which has an arid to semi-arid climate with average bimodal annual rainfall ranging from 110 mm to 600 mm. Long rains are received between March and May while the short rains fall between September and November. The region has diverse vegetation associations ranging from wooded and bushed grassland to open grassland. They are described in detail in Solomon et al. (2006a and 2006b). *Acacia spp* are the common tree species while the herbaceous component comprises of annuals and perennials that provide an important feed resource base for livestock. Different geological associations characterize the region comprising mainly of Precambrian basement complexes (38%) of the parent material, sedimentary deposits (2%) quaternary deposits (40%), and volcanics (20%), Cappock (1994).

Plot selection

Four vegetation types, replicated three times and nested within a 10 x 10 km site were selected for this study to represent the general vegetation and associations of the region. These were Grassland (G), Tree-Grassland (TG), Bushed-Grassland (BG) and Bush-Tree Grassland (BTG). The G vegetation was composed mainly grasses, short herbaceous and forbs layer, and, if any, sparsely distributed very short woody species. The BG vegetation type was primarily dominated with thickets of bush species, while the Tree-Grassland vegetation type had trees dominating the landscape. The BTG had a mixture of bushes and tree species. The size of the plots was 30 x 30 m and each was located 2-8 km away from one another.

The experiment was conducted in a communal set up and no exclusion was made to deter grazing or browsing animals from the plots. It was assumed that most of the animals were in the dry season grazing zones during the dry season as all the sites exhibited evidence of light grazing especially during the peak of the rainy season.

Data collection and sampling

Determination of Leaf Area Index.

A Plant Canopy Analyzer, LAI-2000 (LI-COR Inc., Lincoln, USA), described in Welles and Cohen (1996) was used to repeatedly determine the LAI of each plot at selected points in the different vegetation types. A 5 by 5 m grid was set up in the plots with wooden pegs set up at points where LAI was to be measured as shown in the schematic Figure 1. This was done at 3 vertical heights (ground level, 1 m and 2 m heights for the BT, BGL and TGL plots. For the GL plots, the LAI was only measured at the ground level (0m). Measurements were taken from 14th March to 29th June, 2013 at sampling intervals of between 7 to 14 days. During measurement, the operator was always facing the center of the plot. Protocols of LAI measurement were followed as per the device protocol and manual.

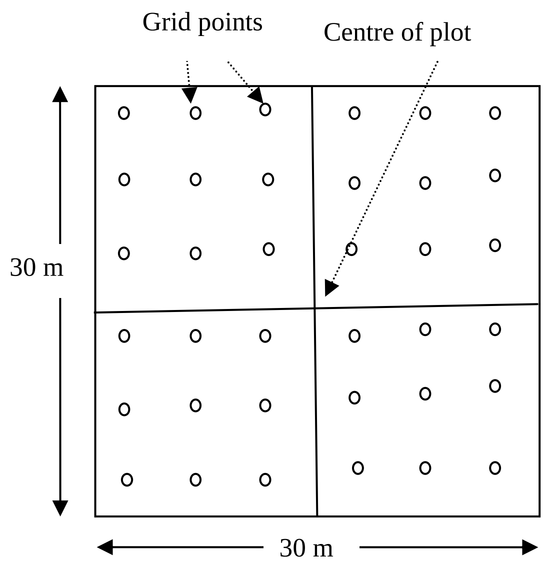

Figure 1: Schematic design for LAI measurement points within each plot showing the grid points where LAI was repeatedly taken.

Estimation of aboveground biomass

Herbaceous biomass and litter.

The direct harvesting through clipping was used to determine herbaceous biomass. Three quadrats were randomly placed in each of the plots at each sampling time with all herbaceous material within the quadrat cut and put in paper bags separately and oven dried continuously at 65°C for 48 hours. In addition, litter was swept off the cut surface in the quadrats, put in paper bags and also taken for oven drying after sieving out unwanted material including pebbles, soil and inorganic substances using appropriate sieves. These were then weighed to the nearest gram. This activity was done at the beginning of the season (from 19th - 22nd March) and at the peak of the season (26th April - 1st May). The peak time was the period when almost 80% of the herbaceous material had set seed.

Estimation of Above-ground Woody Biomass (tree and shrub biomass).

For trees, shrubs and understory vegetation, species-specific allometric equations were used to estimate the biomass. Plot tree parameters measured include total height, crown height, diameter-at-breast height (DBH), canopy dimensions (height, diameter) and circumference at ankle height. The equations used were obtained from the review by Henry et al. (2011) and from Hasen-Yusuf et al. (2013). The equation by Sah et al. (2004) was used for broad-leaved understory vegetation. These are as shown in Table 1.

Crown Area (CA) was obtained from the mathematical formular of πr^2 while the Crown Volume (CV) was obtained from the formular $2/3\pi H(D1/2\times D2/2)$, derived by Thorne et al. (2002) for shrubs. A mean of 0.58 was used to convert fresh biomass into dry biomass based on the relationship between sampled fresh biomass and oven dry biomass, Brown (1997). A factor of 0.5 was then used to estimate the carbon content from dry biomass in all the cases as per IPCC guidelines, IPCC (2003).

Data Analysis

The LAI data was first processed by the FV2000 software (LI-COR, Nebraska). The output, and the biomass data collected was handled by Excel 2007 (Microsoft) and later analyzed by the SAS software (Version 9.1, SAS Institute) at the University of Hohenheim. Prior to analysis, data was tested for normality under the Shapiro-Wilk test in SAS software and transformed using natural logarithms where necessary. Analysis of Variance (ANOVA) followed by mean comparisons using Tukey tests was used to test statistically significant differences of LAI and AGB dynamics in the different vegetation types.

RESULTS

Rainfall and temperature over the study period

Rainfall and temperature data collected in the study site over the sampling period (March –May 2013) is as indicated in Figure 2.

Table 1: Species and equations used to estimate aboveground tree biomass

Species	Regression function
Acacia nilotica, A. tortilis and A. bussei	$Y= 0.0096 \times(HT+D1+D2)^{3.301}$
Acacia mellifera	$Y=0.0548\times(HT+D1+D2)^{2.576}$
Acacia nubica	$ln(Wt) = -1.32 + 1.108\ ln(CV)$
Acacia drepanolobium	$Y= 3.7704\times DBH+1.168$
Understory broad leaved species (less than 1m tall)	Y = 0.446 (CA^ 0.869) (HT^ 1.112)

Where; Y – AGB Biomass; CA – Crown Area; HT – Total Height; CV – Crown Volume; D1 & D2 – 1st and 2nd Crown Diametres.

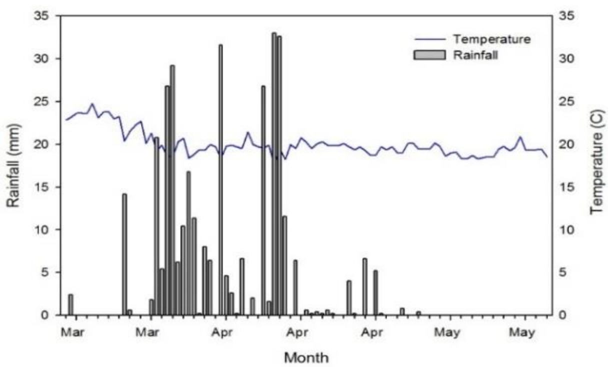

Figure 2: Rainfal and temperature diagram during the study period.

General vegetation characteristics

The mean number of trees, density, height and basal area was determined and is as shown in Table 2.

Leaf Area Index

Mean LAI. LAI at the different heights (0m, 1m and 2m respectively) for the different vegetation types at the beginning and peak of the season was as shown in Table 3.

Seasonality of LAI. The seasonal trend of LAI for 2 contrasting vegetation types was as shown in Figure 3

Table 2: General tree stand characteristics determined in the study plots.

Vegetation Type	Number of trees/bushes (trees/ha)	Mean height (m)
Bush-Tree (BT)	459.26±123.89	2.99±1.07
Bushed grassland (BG)	877.78±622.52	3.08±0.56
Tree-Grassland (TG)	93.30±6.42	3.50±0.81
Grassland	-	-

Table 3: Mean LAI and standard deviations of LAI taken at the ground level (LAI_0), 1M level and 2M levels. Significant differences within each height level are represented by minor letters at $\alpha = 0.05$

HEIGHT	VT	LAI START	LAI PEAK
0 (Ground Level)	Bushed GL	0.76 ± 0.18 b	2.52 ± 0.02 a
	Bush-Tree	0.53 ± 0.27 b	2.18 ± 0.09 a
	Grassland	0.21 ± 0.36 c	0.76 ± 0.24 b
	Tree-Grassland	0.84 ± 0.14 b	1.98 ± 0.13 a
1 Metre level	Bushed GL	0.59 ± 0.24 ab	1.08 ± 0.08 ab
	Bush-Tree	0.53 ± 0.23 b	1.25 ± 0.22 a
	Tree-Grassland	0.82 ± 0.07 ab	1.17 ± 0.18 ab
2 Metre level	Bushed GL	0.17 ± 0.40 b	0.84 ± 0.38 a
	Bush-Tree	0.51 ± 0.25 ab	0.83 ± 0.19 a
	Tree-Grassland	0.86 ± 0.17 a	1.40 ± 0.24 a

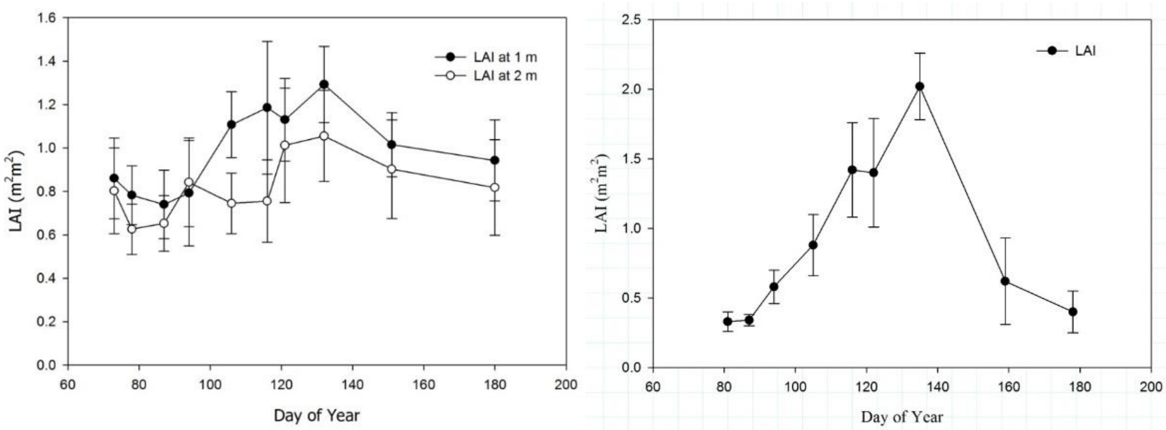

Figure 3: Weekly LAI of Plot BT5 (left) and G7 (right). Filled and blank points represent mean values (n=4) at the height 1 and 2 meters for the BT5 plot and ground level for G7 plot, whiskers indicate standard errors of mean.

Aboveground biomass

Herbaceous and litter biomass dynamics

The herbaceous biomass and litter dynamics obtained was as illustrated in Figures 4.

Aboveground tree and shrub biomass and carbon densities

The above ground biomass of trees and shrubs calculated from species-specific allometric equations and total aboveground carbon densities is illustrated in Table 4.

LAI and aboveground biomass relationship

The relationship between the total woody aboveground biomass calculated using allometry in different plots and the respective LAI estimated by the LAI2000 device was as indicated in Figure 5.

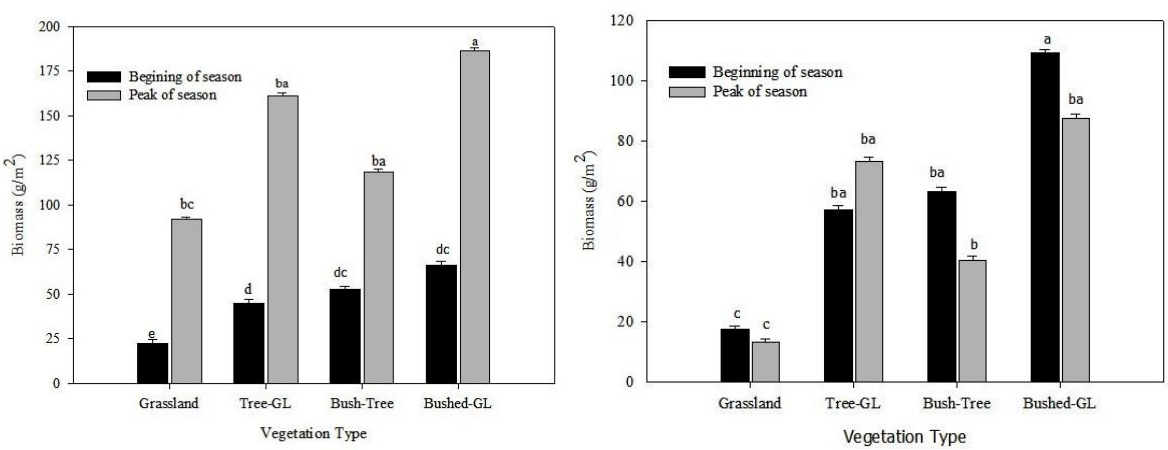

Figure 4: Aboveground herbaceous biomass dynamics (left) and litter dynamics (right) from destructive sampling over the season in the different vegetation types at the beginning and peak of the season

Table 4: Aboveground biomass of trees and shrubs calculated from species-specific allometric equations and total above ground carbon densities

Vegetation Type	Aboveground Biomass (ton/ha)	Aboveground carbon Density (tonC/ha)
Bushed Grassland	8.20±1.97	5.60±1.34
Bush-Tree GL	14.44±10.66	7.88±5.52
Tree-GL	14.76±8.01	8.80± 3.81
Grassland	-	0.61±0.09

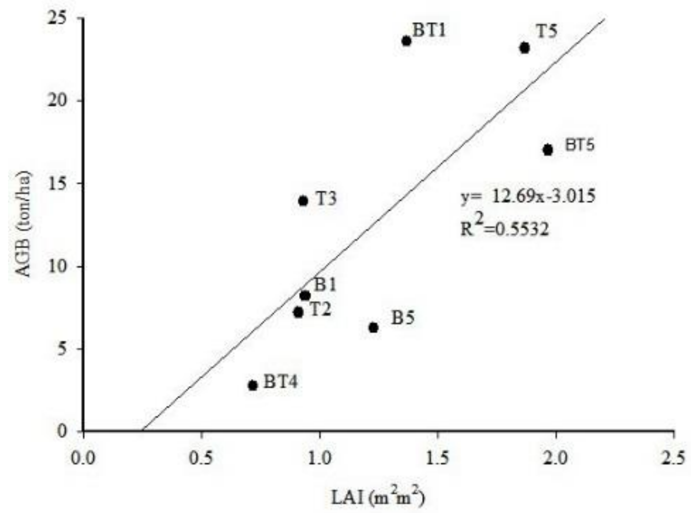

Figure 5: Relationship between aboveground biomass of different plots estimated from allometric equations and in situ peak LAI measured by LAI-2000 at 1 m canopy height

DISCUSSION

Mean LAI

Favorable environmental and growth conditions mainly rainfall was the main contributor to the high LAI at peak of the season. This is attributed to vegetation growth through development of new tissues including foliage, stems, new tillers and fruits, thereby increasing LAI. LAI reduced vertically in the vegetation with trees and bushes due to reduced canopy density and increasing gap sizes. Generally, the region is dominated with acacia species which are known to have low leaf area as shown by the values obtained. Variability of LAI between the vegetation types with trees is however small as observed with the values at 1 and 2 meter heights due to similarity of species, hence the non-significant differences in some of the means obtained. The means for LAI obtained for the different vegetation types relate closely to the mean value of 1.81 reviewed for tropical savannah grasslands by Scurlock et al. (2001). The low mean values obtained also relate with those obtained in mixed vegetation dryland environments of Namibia by Privette et al. (2004) who obtained values ranging between 0.75–3.09 by using different methods including optical instruments as applied in this study.

Seasonal pattern of LAI

Grazing, browsing, and other environmental conditions influence leaf area index. The highest LAI was recorded around day 130 of the year as shown on figure 3. This corresponds to the period when rainfall had peaked and primary production was high. Most deciduous C3 plants shed leaves during the dry season thus the low LAI at the beginning of the season, and later on at the onset of the dry season. Towards the end of the growing season, the decrease on LAI in grassland vegetation can also be attributed to the 'dying' out and depletion of most of the annual grasses. Heavy grazing and browsing was also noted at the onset of the rains and at the end of the rains, thus the results obtained during these periods correspond to the effect of grazing pressure, though it was not tested for this work. Grazing has been reported to decrease LAI in grasslands ecosystems (Fan et al., 2009, Erkovan et al., 2009)

The low seasonal LAI variability has also been reported for an Australian semi-arid Acacia-savannah woodland by Eamus et al. (2013) with values of 0.3 – 0.9 determined. In this study, taking the differences between peak and beginning of season LAI, at 1 and 2 m level, a range of between 0.32 – 0.79 for the different vegetation types was determined.

Herbaceous biomass

The seasonal change in herbaceous biomass was highly significant (F=61.8; p<0.0001). At the beginning of the season, the highest biomass was in the BGL (66.32±2.19 g/m^2) which increased to 186.39±4.15 g/m^2 at peak of the season. The Bush-Tree and Tree-Grassland vegetation types had 52.58±2.02 and 45.05±2.29 g/m^2 respectively. Most herbaceous plants in drylands tend to reallocate resources to aboveground components in new leaves, shoots and reproductive organs during the wet season (Cleverland et al., 2005; Fidelis et al., 2012, House and

Hall, 2001). In addition, the non-structural nature of herbaceous plants, makes them highly flexible to respond to changes in environment (Bazzaz, 1997), in our case, moisture availability. Similar seasonal observations have been observed in the same region by Angassa et al. (2010) and Angassa and Obba (2010), with rainfall, the major driver.

Increased harbaceous production in savanahs beneath tree canopies have been associated with a variety of factors such as favourable microclimates and increased resource availability as discussed by Scholes and Archer, 1997. Thickets and bushes in semi arid grasslands are sometimes inaccesible to large grazers. They sometimes therefore tend to have more grasses, forbs and herbs as understory vegetation as found in the BGL vegetation.

Litter

In all VTs, except TGL, the litter was higher at the beginning and decreased at peak of the season. Dead plant tissues contribute to the higher litter in the vegetation types with trees at the beginning of the rain season. The probable decomposition processes setting in is reflected in the low values at the second sampling time. The seasonal trend of lower litter after a rain season, than during dry season for different vegetation types determined in this work is similar to that reported in a dryland forest in Tigray, Ethiopia (Descheemaeker et al., 2006) and by Abanda et al. (2011) in a South African shrubland. Generally, the mean values ranging between 0.15-1.09 ton C/ha were determined in this study and are in agreement of the normally low values for dryland environemnts as reviewed by Tiessen et al. (1998). The differences between the vegetation types was also significant (6.35; $p=0.0008$).

Aboveground tree and shrub biomass

Aboveground biomass and carbon density estimates obtained for this study fall within the range reviewed by Grace et al. (2006) for tropical semi-arid grasslands of between between 1.8 tons C/ha in areas where trees are absent, to 30 tons C/ha where there is considerable tree cover. This demonstrates the important contribution of the tropical savannah biomes to carbon sequestration.

LAI and AGB relationship

Despite the correlation of the two variables (AGB and LAI) not being strong ($R^2=0.55$), it can be shown that AGB increases with a corresponding LAI increase which is in agreement with relationships reported for tropical dry deciduous forests when similar approaches were employed (Madungundu et al., 2008). Vegetation indices such as LAI can therefore be used as indirect predictors of vegetation trends (biomass) in semi-arid grasslands.

The estimates of aboveground biomass obtained in this study however not conclusive and are subject to uncertainty. The most accurate methods of estimating biomass involve destructive sampling which is not practical for many environments (Brown, 1997). Some of the allometric equations used for estimation of tree and shrub biomass in this study were not developed for the site hence the possibility of overestimation or underestimation. There's need to develop site species-specific equations when estimating biomass since the use of equations from other regions are likely to give over- or underestimated results (Ryan et al., 2010). Lack of species specific equations however necessitate the need to use generalized equations or equations from other areas which was partially applied for this study. Despite this, the contribution of semi-arid grasslands to the global carbon budget is demonstrated for the vegetation types in this study.

CONCLUSION

Savannah semi-arid grasslands with heterogeneous vegetation structure have a considerable carbon stock capacity in the different aboveground pools. They are therefore important carbon sinks and contribute to climate change mitigation through the capture and storage of CO_2. Conservation and preservation of the different vegetation species, sustainable management and utilization practices will go a long way to ensure they continue playing their role in the regional and global carbon cycles, as well as offering other ecosystem services.

Acknowledgements

We acknowledge the GrassNet Project funded by DAAD (Deutscher Akademischer Austausch Dienst) for financial support, University of Hohenheim (Stuttgart, Germany) as well as the Oromia Agricultural Research Institute, Ethiopia for allowing us to use their laboratories.

REFERENCES

Abanda, P. A., Compton, J. S. and Hannigan, R. E. 2011. Soil nutrient content, aboveground biomass and litter in a semi-arid shrubland, South Africa. Geoderma. 164 (3-4): 128-137. http://www.sciencedirect.com/science/article/pii/S0016706111001388

Angassa, A. and Obba, G. 2010. Effects of grazing pressure, age of enclosures and seasonality on bush cover dynamics and vegetation composition in southern Ethiopia. Journal of Arid Environments. 74 (1): 111-120.

http://www.sciencedirect.com/science/article/pii/S0140196309002468

Angassa, A., Oba, G., Trydte, A. C. and Weladji, R. B. 2010. Role of traditional enclosures on the diversity of herbaceous vegetation in a semi-arid rangeland, southern Ethiopia. Livestock Research and Rural Development 22(9), Article 163 retrieved October 4, 2013, from http://www.lrrd.org/lrrd22/9/anga22163.htm

Bazzaz, F. A. 1997. Allocation of resources in plants: State of the science and critical questions. In F. A. Bazzaz, and J. Grace, Plant Resource Allocation (pp. 1-37). http://www.sciencedirect.com/science/article/pii/B9780120834907500025

Brèda, N. J. 2003. Ground-based measurements of leaf area index: A review of methods and current controversies. Experimental Botany. 54 (392): 2403-2417. Retrieved Febraury 26, 2016 from http://jxb.oxfordjournals.org/content/54/392/2403.full

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: A primer. In FAO, FAO Forestry Paper 134. Rome: FAO. Retrieved January 2, 2014 from http://www.fao.org/docrep/w4095e/w4095e00.HTM

Cappock, D. L. 1994. The Borana plateau of Southern Ethiopia: Synthesis of pastoral research, development and change 1980-91. Addis Ababa, Ethiopia: International Livestock Centre for Africa. Pp299.

Carlier, L., Rotar I., Vlahovar, M. and Vidican R. 2009. Importance and functions of grasslands. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 37 (1) 2009, 25-30. Retrieved from http://www.notulaebotanicae.ro/index.php/nbha/article/view/3090

Ciais, P., Bombelli, A., Williams, M., Piao, S. L., Chave, J., Ryan, C. M., Henry M., Brender P. and Valentini, R. 2011. The carbon balance of Africa: Synthesis of recent research studies. Philosophical Transactions of the Royal Society. 369 (1943): 1-20. Retrieved Jan, 4, 2014 from http://rsta.royalsocietypublishing.org/content/369/1943/2038

Cleverland, C. C., Townsend, A. R. and Mcknight, D. M. 2005. Trophic dynamics. In M. G. Anderson, Encyclopedia of Hydrological Sciences (pp. 1557-1573). Colorado: John Wiley & Sons, Ltd. DOI: 10.1002/0470848944.hsa106

Descheemaeker, K., Muys, B., Nyssen, J., Poesen, J., Raes, D., Haile, M. and Deckers, J. 2006. Litter production and organic matter accumulation in exclosures of the Tigray highlands, Ethiopia. Forest Ecology and Management. 233 (1): 21-35. http://www.sciencedirect.com/science/article/pii/S0378112706003859

Eamus, D. C., Boulain, J., Grant, N., Faux, N., Villalobos-Vega, R., and Randol, R. 2013. Carbon and water fluxes in an arid-zone savannah woodland: An analyses of seasonal patterns and responses to rainfall events. Agriculture and Forest Meteorology. (182-183) pp 225-238. http://www.sciencedirect.com/science/article/pii/S016819231300097X

Erkovan, I. H., Gullap, K. M., Dasci, M., and Ko-c, A. 2009. Changes in leaf area index, forage quality and aboveground biomass in grazed and ungrazed Rangelands of Eastern Anatolia region. TARIM BİLİMLERİ DERGİSİ. 15 (3): 217-223. Retrieved February 26, 2016 from http://dergiler.ankara.edu.tr/dergiler/15/1494/16472.pdf.

Fan, L., Gao, Y., Bruck, H., and Bernhofer, C. 2009. Investigating the relationship between NDVI and LAI In semi-arid grassland In Inner Mongolia using in-Situ measurements. Theoretical and Applied Climatology. 95 (1): 151-156.

Fidelis, A., Fernanda di Santi Lyra, M. and Pivello, R. V. 2012. Above and belowground biomass and carbon dynamics in Brazilian cerrado wet grasslands. Journal of Vegetation Science. 24 (2): 356-364. Retrieved January 4, 2013 from http://onlinelibrary.wiley.com/doi/10.1111/j.1654-1103.2012.01465.x/full

Grace, J., Jose, J. S., Meir, P., Miranda, S. H., and Montes, R. A. 2006. Productivity and carbon fluxes of tropical savannahs. Journal of Biogeography. 33 (3): 387-400. Retrieved October 23, 2013 from http://www.geosciences.ed.ac.uk/miombo/JG2006.pdf.

Hasen-Yusuff, M., Trydte, A. C., Abule, E., and Sauerborn, J. 2013. Predicting aboveground biomass of woody encroacher species in semi-arid rangelands, Ethiopia. Journal of Arid Environments. 96: 64-72.

Henry, M., Picard, N., Trotta, C., Manlay, R. J., Valentini, R., Bernoux, M. and Saint-Andre, L. 2011. Estimating tree biomass of Sub-Saharan African forests: A review of available allometric equations. Silva Fennica. 45: 477-569. http://www.metla.fi/silvafennica/full/sf45/sf453477.pdf

House, J. I. and Hall, D. O. 2001. Productivity of tropical savannahs and grasslands. In J. Roy, B. Saugier, and H. A. Mooney, Terrestrial Global Productivity. (pp. 363-400). San Diego: Academic Press. http://www.sciencedirect.com/science/article/pii/B978012505290050017X

IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Hayama, Kanagawa: Institute for Global Environmental Strategies (IGES).

IPCC, 2005: IPCC Special report on carbon dioxide capture and storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B.,O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

Jonkheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M., and Baret, F. 2004. Review of methods for in-situ leaf area index determination. Agricultural and Forest Meteorology. 121 (1-2): 19-35. http://www.sciencedirect.com/science/article/pii/S0168192303001643

Madungundu, R., Nizalapur, V. and Jha, C. S. 2008. Estimation of LAI and aboveground biomass in deciduous forests: Western Gharts, Karnataka India. International Journal of Applied Earths Observation and Geoinformation. 10 (2): 211-219. http://www.sciencedirect.com/science/article/pii/S0303243407000773

Privette, J. L., Tian, Y., Roberts, G., Scholess, R. J., Wang, Y., Kaylor, K. K., Frost P. and Mukelabai, M. 2004. Vegetation structure characteristics and relationships of Kalahari woodlands and savannahs. Global Change Biology. 10, (3): 281-291. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2004.00740.x/epdf

Ryan, M. C., Williams, M. and Grace J. 2011. Above- and belowground carbon stocks in a Miombo Woodland landscape of Mozambique. Biotropica. 43 (4): 423-432. Retrieved November, 10, 2013 from http://onlinelibrary.wiley.com/enhanced/doi/10.1111/j.1744-7429.2010.00713.x

Sah, J. P., Ross, M. S., Koptur, S. and Snyder, J. R. 2004. Estimating aboveground biomass of broadleaved woody plants in the understory of Florida Keys pine forests. Forest Ecology and Management. 203 (1-3): 319-329.

Scholes, R. J and Archer, S R. 1997. Tree-Grass Interactions in Savannahs. Annual review of ecology and systematics. 28: 517-544

Scholes, R. J. and Hall, D. 1996. The carbon budget of tropical savannas, woodlands and grasslands. Global change, effects on coniferous forest and grasslands. SCOPE (ed. by A. I. Breymeyer, I. D. Hall, J. M. Melillo & G. I. Agren) pp. 69–100. Scurlock, J. M., and Hall, D. O. 1998. The global carbon sink: A grassland perspective. Global Change Biology. 4 (2): 229-233. Retrieved November 11, 2013 from http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2486.1998.00151.x/epdf

Scurlock, J. M., Asner, G. P. and Gower, S. T. 2001. Worldwide Historical Estimates of Leaf Area Index, 1932-2000. Oak Ridge Tennessee: Oak Ridge National Laboratory pp19. Retrieved September 23, 2013 from http://web.ornl.gov/~webworks/cppr/y2002/rpt/112600.pdf.

Solomon, T. B., Snyman, A. H., and Smit, N. G. 2007. Rangeland dynamics of Southern Ethiopia: (1). Assessment of woody vegetation structure in relation to land use and distance from water in semi-arid Borana rangelands. Journal of Environmental Management. 85 (2): 429–442.

Solomon, T. B., Snyman, A. H., and Smit, N. G. 2007. Rangeland dynamics of Southern Ethiopia: (2). Assessment of woody vegetation structure in relation to land use and distance from water in semi-arid Borana rangelands. Journal of Environmental Management. 85 (2): 443–452.

Thorne, S. M., Skinner, D. Q., Smith, A. M., Rodgers, J. D., Laycock, A W., and Cerekci S.A. (2012). Evaluation of a technique for measuring canopy volume of shrubs. Journal of Range Management 55: 235-241. https://journals.uair.arizona.edu/index.php/jrm/article/view/9713/9325

Tiessen, H., Feller, C., Sampaio, E. V. and Garin, P. 1998. Carbon sequestration and turnover in semi-arid savannahs and dry forest. Climate Change. 40 (1): 105-117. Retrieved October, 8, 2013 from http://link.springer.com/article/10.1023/A:1005342932178#page-1

Welles, J. M., and Norman, J. M. 1991. Instrument for indirect measurement of canopy architecture. Agronomy Journal 83 (5): 818-825. doi:10.2134/agronj1991.00021962008300050009x