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Research Article

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Dry Matter Production and Carbon Sequestration Potential of Selected Indigenous and Introduced Grasses under Rangeland Ecosystems of South Eastern Kenya

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Abstract

This study determined dry matter production and carbon sequestration potential of three indigenous and two introduced grass species under rangeland ecosystems. The indigenous grasses were: - Masai love grass (Eragrostis superba), Foxtail (Cenchrus ciliaris), Bushrye (Entropogon macrostachyus) and the introduced grasses were: - Boma rhodes and Extozi rhodes. The study was in South eastern rangeland of Kenya and data was collected during peak growing period of short and long rain seasons from established pasture plots. Plant samples (above ground, below ground and litter) were harvested by randomly placing 1m² quadrats in each plot in triplicate. Soil samples were randomly collected from each plot at a depth of 0-20 cm, air-dried and analysed for carbon content using Chromic acid digestion method from each plot under selected grasses, bulk density was determined. Harvested plant samples were oven-dried for 48 hours to stable mass at 65°C, ground (± 2mm size) and combusted in a muffle furnace at 550oc for 4 hours to determine organic matter concentration. The results revealed that indigenous grasses were 24% higher in dry matter production (17.3 vs 14.0tons/ha) and 23% higher in carbon stock (11.3 vs 9.2 tons) ($p<0.05$). The implication of the results is that indigenous grasses would offer co benefit of higher dry matter production for livestock feeding and higher carbon sink capacity contributing to minimising emission and global warming potential. This is beneficial to mitigating climate change when increasing ruminant production under often degraded rangeland ecosystems. with this evidence, utilisation of indigenous grass species is highly recommended for sustainable rangeland livestock production supporting increased productivity while minimising carbon emissions.

Keywords: Biomass, Carbon Sequestration, Grass Species, Ruminants, Rangelands

Introduction

Extensive grazing of ruminants in the rangelands creates several interactions between livestock production and climate change. Ruminants emit methane, pasture sequester carbon, ruminant animals generate manure which recycles nutrients thus removing the need for inorganic fertilizer, and the production system is vulnerable to climate change (Rivera-Ferre *et al.*, 2016). Carbon sequestration through the use of grass pastures with high photosynthetic capacity, high biomass and the deep root system is an important climate change mitigation approach in the rangeland ecosystem through carbon dioxide capture. Carbon sequestration is the process of capturing and long-term storage of carbon dioxide as carbon in carbon pools. Grasses that ruminants graze in the rangelands can be an important carbon sink, yet there is scanty empirical evidence on their carbon dynamics and biomass yields (Nijdam *et al.,* 2012; Fidelis *et al.,* 2012).

Feed interventions in the rangelands to support increased ruminant productivity have prioritized the introduction of grasses with high biomass yield, high nutritive quality and low moisture demand.

Yet, with the growing threats of climate change, the choice of grass species for ruminant production to support increased productivity needs to consider as well as enhancing carbon sequestration to mitigate climate change impacts. For instance, indigenous grass pastures like *Cenchrus ciliaris (C. ciliaris), Eragrostis superba (E. superba) and Enteropogon macrostaschyus (E. macrostachyus)* are utilized for ruminant production in the rangelands. The indigenous grass species show good adaptation to climate shocks and too low soil moisture, which is manifested in their rapid establishment, faster growth rate and high biomass production (Kidake *et al.,* 2016)[1]. Added to these are co-benefits of sequestering carbon from the atmosphere by capturing carbon dioxide during photosynthesis and storing it in carbon pools (above-ground biomass, belowground biomass and in the soil as soil organic carbon). These have been articulated by Soussana *et al.,* (2010) [2]. Their deep rooting system enhances the storage of soil organic carbon (SOC) deep in subsoil. Grass pastures store much of carbon in the below-ground biomass (Liu *et al.,* 2010; Fidelis *et al.,* 2012) [3] and in the top soil layers within 30cm (FAO, 2019) [4].

Despite indigenous grasses manifesting co-benefits in sustainable ruminant production in the rangelands, the interventions have instead utilized grass species introduced from high rainfall areas *(Chloris gayana var Extozi rhodes and var Boma rhodes)* to increase animal productivity (Mganga *et al.,* 2015) [5]. This ignores that utilization of these introduced grass species under rangeland could potentially increase the contribution of ruminants to the global carbon footprint (Ripple *et al.,* 2014)[6] in greenhouse gas emission through transportation, fertilizer application and enteric fermentation. Utilizing grasses with a high capacity for carbon sequestration in ruminant feeding can substantially offset greenhouse gas emissions from ruminant production systems (FAO and IFAD, 2021). This involves stocking carbon while producing livestock products and mitigating climate change (Seo *et al.,* 2017) [7]. Conservation of ecosystems is necessary to avoid losing carbon since it is easy to lose carbon than building carbon stock (Soussana *et al.,* 2010; Smith, 2014) [2, 8].

It is possible to implement the agenda of low carbon livestock development through pasture establishment and utilization by informing livestock producers to utilize grass pastures with a high capacity for carbon sequestration in soils. However, there remains limited research on the role of grass pastures as potential carbon sinks (Odiwe *et al.*,2016) [9]. This is linked to their short- term carbon storage nature. This study addressed this knowledge gap area by determining dry matter production and carbon sequestration potentials of three indigenous grass species; Eragrostotis superba (E. superba), Enteropogon macrostachyus *(E.macrostachyus)* and *Cenchrus ciliaris (C.ciliaris)* and two introduced grass species *(Chloris gayana Var Extozi and Boma rhodes)* in rangeland ecosystems of South eastern Kenya.

Materials and Methods

Study site

The study was conducted in Arid and Rangelands Research Institute (ARLRI) of the Kenya Agriculture and Livestock Research Organization (KALRO). The station is located at Kiboko in Makindu Sub County of Makueni County, which is in the rangelands found in the south eastern Kenya. The area is in Agro Ecological Zone V at an elevation of 975 metres above sea level and lies within latitude 2° 10' and 2° South and longitude 37° 40' and 37° 55' East (Fig 1). The precipitation in the area follows bimodal distribution, with long rainy season from March to May and short rainy season from October to December. The remaining months in calendar year comprises the dry season. The area receives mean annual rainfall of 600mm and mean annual temperature of 23°C.

The grass samples were collected from established pasture plots that were seven years old. The plots where grass samples were obtained had Ferralsols soils ranging from sandy clay to loamy sand that were low in organic matter and highly vulnerable to erosion and biological degradation.

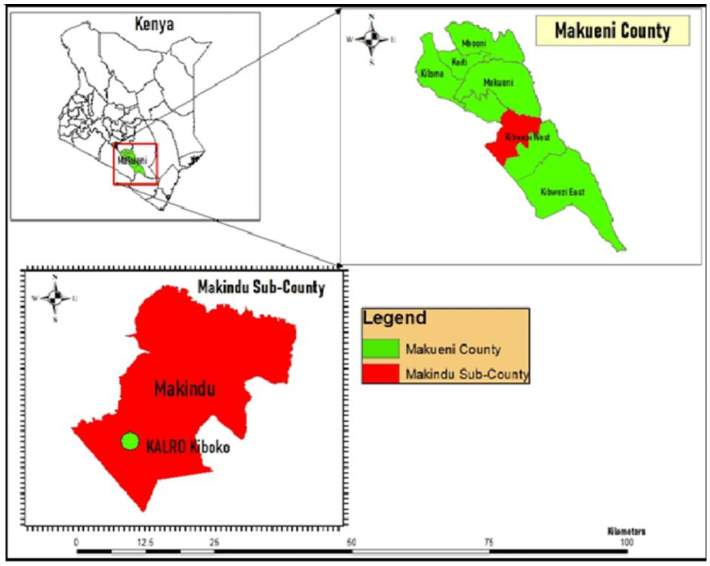
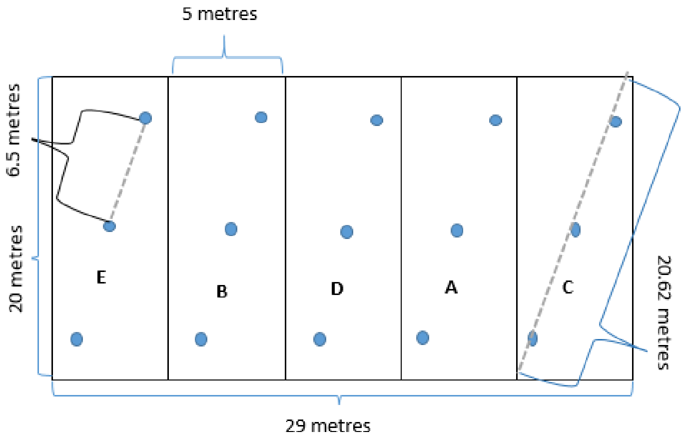


Figure 1: Map showing KALRO Kiboko in Makindu Sub-county

Sampling Procedures

Sampling design

Sampling was in a Completely Randomised Design (CRD). Samples for the experiment were collected in triplicate from already established seven years old grass pasture plots. Sampling was done at the peak of the growing period during the short rains, in January 2020, to coincide with the peak growing period for the October – December short rainy season and in May 2020 to coincide with peak growing period for March – May long rain season. In each plot, a line transects of 20.62 metres was set. Three selected sub sites along the transect were identified as illustrated in fig 2



A = *C. ciliaris*, B = *E. macrostachyus*, C = *E. superba*, D = *Extozi Rhodes*, E = *Boma rhodes*

Figure 2: Sampling Design for The Experiment In The Five Established Pasture Plots

Determination of dry matter production(biomass) of experimental grass pastures

The above-ground biomass of the grass samples studied was collected in triplicate using randomly positioned 1 m^2 sized quadrants in triplicate. This applied to each of the established plots at the peak of growing period for the two seasons. All the above-ground material within the quadrant were collected through destructive harvesting by clipping to ground level, then packing in a sampling bag, ready for laboratory determination of biomass. The litter material on the above ground was also collected. The samples were then put in oven for oven drying at 65˚C to constant weight for 48 hours, cooled, weighed, recorded and ground through a 2mm mill

The biomass of the sampled grass pastures was determined from the oven dry weight of the sub-samples at 65˚C, which was then converted to total dry biomass weight per unit area of 1m^2 following the equation (i) of Pearson *et al.,* (2005)[10] and later extrapolated to one hectar

$$TDB = \frac{ODWSS}{WWSS} * WWTS \text{...............(i)}$$

Where

TDB = Total dry biomass in one metre square, ODWSS= Oven dry weight of sub –sample, WWSS= Wet weight of sub sample, WWTS= Wet weight of total sample per hectare

Estimation of Carbon Stocks in Above Ground Biomass (AGB)

After grinding the AGB and litter, the resulting samples were analysed for ash concentration by combustion in a muffle furnace at 550oC for 4 hours (HeraeusM110 muffle furnace, Heraeus Holding GmbH, Hanau, Germany). This was then used to calculate the percentage of organic carbon concentration according to equation (ii) of Allen *et al.,* (1986)[11]:

$$Cconc"\%"=(100-Ash"\%")*0.58 \text{......................(ii)}$$

where

Cconc % = percentage organic carbon concentration, 100 - Ash% = organic matter, 0.58= mass of organic matter.

The percentage organic carbon concentration obtained was then used to compute, carbon stocks using the equation (iii):

$$Carbon\ stock=Cconc"\%"*drymatterweight \text{.....................(iii)}$$

Where

Carbon stock = carbon stored in above ground carbon pool in tons / hectare, *Cconc%* = percentage organic carbon concentration,

Dry matter weight =Dry biomass of the above ground material in one hectare

Estimation of Carbon Stocks in Below-Ground Biomass (BGB)

Soil samples along with roots were collected from the same plots after collecting samples for AGB using soil auger in triplicate during the two peak collection times. The soil samples were then processed by crumbling by hand to extract the roots then packaged for laboratory analysis. Extracted roots were washed with water over a sieve to remove soil. Cleaned roots were oven-dried at 65oC, periodically weighed and removed from the oven when the mass stabilized (48 hours). The extracted root biomass was then ground to achieve 2mm mill and used for determining ash content by combusting in a muffle furnace at 550oc for 4 hours. Carbon stock stored in the roots biomass was then calculated using equation (ii)

Estimation of Soil Organic Carbon (Soil Carbon)

Soil samples were randomly collected from each of the plots where samples for above and below-ground biomass were previously collected to a depth of 20cm using a soil auger in triplicate. Processing involved bagging, labelling, ready for laboratory analysis. In the laboratory, each soil sample was air-dried, passed through a 2-mm sieve for determination of percentage organic carbon content using the Chromic acid digestion method (Walkley-Black method, 1934) [12].

Soil samples for determination of bulk density were collected using core ring at 0-30cm depth down the profile from each plot in triplicate. The collected samples were then oven dried at 105°C to constant weight and weighed to obtain the mass of dry soil. The volume of the cylindrical core ring was also calculated to obtain the volume of the dry soil in the core ring The soil bulk density was then determined by dividing the oven dry weight by the volume of cores according to Blake &Hartge (1986) [13] following equation (iv)

$$Y=Md/Vd\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iv)}$$

where
Y= Bulk density of dry soil (Kg/m^3)
Md= Mass of dry soil in Kg
Vd= volume of dry soil in M^3

The soil bulk density obtained was then used to convert soil carbon concentration to mass carbon per unit area ($1M^2$). Soil organic carbon stock was then calculated using the equation (v) expression

$$SOC_{stock}=C*BD*D\ldots\ldots\ldots\ldots\ldots\ldots\text{(v)}$$

Where SOC_{stock}= soil organic carbon stock (tons C per hectare)
C=Carbon concentration in the soil; BD =Bulk density (Kg/m^3)
D=soil depth in meters

Total carbon stock ($C_{total\ stock}$)

Total carbon stock (tons /ha) of each grass species was obtained by summation of carbon stock in carbon pools using the equation (vi)

$$C_{total\ stock}=C_{AG}+C_{BG}+C_L+C_{Soil}\ldots\ldots\ldots\ldots\text{(vi)}$$

Where
C_{AG} is aboveground carbon, C_{BG} is belowground carbon, C_L is litter carbon, and C_{Soil} is soil carbon

Statistical analysis

Statistical analysis fitted Completely Randomized Design (CRD), expressed in equation (vii) as:

$$Y_{ij}=\mu+\alpha_i+\varepsilon_{ij}\ldots\ldots\ldots\ldots\ldots\ldots\text{(vii)}$$

Where; Y_{ij}= Carbon sequestration potential of ith grass pasture on jth replication
μ =overall mean; α_i= fixed effect of grass pasture i; ε_{ij}=Residual error associated with i^{th} grass pasture and j^{th} replication
The model was fitted to Analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS version 22). The level of significance was set at $p<0.05$ for detecting grass effects on dry matter production and carbon stock. The separation of the means proceeded with Tukeys HSD procedure for multiple mean comparisons.

Results

Above and below ground dry matter production

Table 1 presents the results of the dry matter production of the above and below-ground biomass for the samples of indigenous and introduced grass species. The dry matter production in the AGB and BGB were both on average lower ($p<0.05$) for the introduced grass (12.6 ton/ha) species when compared to the indigenous grass species (14.9 tons/ha). The above-ground biomass was lower for the introduced grass species (*C. gayana var Extozi rhodes* (12.0 tons/ha) and *C. gayana var Boma rhodes* (13.2 tons/ha) than the estimates for the indigenous grasses (*C. ciliaris* 14.4 tons/ha, *E. superba* 6.2 tons/ha and *E. macrostachyus* 14.0 tons/ha). Similarly, the below-ground biomass was lower for the introduced grasses (*C. gayana var Extozi rhodes* 1.4 tons/ha and *C. gayana var Boma rhodes* 1.3 tons/ha than the estimates for the indigenous grasses (*C. ciliaris* 3.4 tons/ha, *E. superba* 2.6 tons/ha and *E. macrostachyus* 1.3 tons /ha)

Table 1: Dry Matter Production of the Above and Belowground Biomass for the Sample Indigenous and Introduced Grasses

Grass	Species	Above-ground biomass (tons DM/ha)	Below-ground biomass (tons DM/ha)
Indigenous	*C. ciliaris*	14.4^{bc}	3.4^{c}
	E. superba	6.2^{c}	2.6^{bc}
	E. macrostachyus	14.0^{b}	1.3^{a}
	Average	**14.9**	**2.5**
Introduced	*C. gayana var Extozi*	12.0^{a}	1.4^{b}
	C. gayana var Boma	13.2^{ab}	1.3^{a}
	Average	**12.6**	**1.4**
	SEM	**0.42**	**0.24**
Grass effect		**	**

$^{a\text{-}c}$ Means within a column without a common letter superscript differ at $p<0.05$
Grass effect insignificant (NS) or significant at $p<0.05$ (**)

Carbon Stocks in Biomass and Soil

The carbon stocks in carbon pools estimated in AGB and BGB of the three indigenous and two introduced grass species samples is presented in Table 2. Compared to the indigenous grass species, the introduced grass species were on average lower ($p<0.05$) in above ground carbon (C_{AG}) (6.7 tons /ha vs. 8.0 tons /ha), in below ground carbon (C_{BG})(0.7 tons /ha vs. 1.3 tons /ha) and in soil carbon (C_{soil}) (1.8 tons /ha vs. 2.0 tons /ha). The C_{AG} from introduced grasses (*C. gayana var Extozi* 6.4 tons /ha and *C. gayana var Boma* 7.1 tons /ha) were lower than those of indigenous grasses (*C. ciliaris* 7.7 tons /ha, *E. superba* 8.7 tons /ha and *E. macrostachyus* 7.5 tons /ha). For the C_{BG}, the introduced grasses (*C. gayana var Extozi* 0.8 tons /ha and *C. gayana var Boma* 0.7 tons /ha) were also lower than the indigenous grasses (*C. ciliaris* 1.8 tons /ha, *E. superba* 1.4 tons /ha and *E. macrostachyus* 0.7 tons /ha). Even the C_{soil} from plots planted with introduced grasses (*C. gayana var Extozi* 1.8 tons /ha and *C. gayana var Boma* 1.8 tons /ha) were lower than the estimates from indigenous grasses (*C. ciliaris* 2.3 tons /ha, *E. superba* 2.0 tons /ha and *E. macrostachyus* 1.9 tons /ha).

Table 2: Carbon Stocks (Tons /Ha) Estimates In the Carbon Pools Above-Ground Biomass, Below-Ground Biomass and Soil of Sample Indigenous and Introduced Grasses

Grass	Species	Above-ground biomass (tons DM/ha)	Below-ground biomass (tons DM/ha)	Soil carbon (tons /ha)
Indigenous	*C. ciliaris*	7.7^{bc}	1.8^{c}	2.3^{b}
	E. superba	8.7^{c}	1.4^{bc}	2.0^{a}
	E. macrostachyus	7.5^{c}	0.7^{a}	1.9^{a}
	Average	**8.0**	**1.3**	2.0
Introduced	*C. gayana var Extozi*	6.4^{a}	0.8^{b}	1.8^{a}
	C. gayana var Boma	7.1^{ab}	0.7^{a}	1.8^{a}
	Average	**6.7**	**0.7**	1.8
	SEM	**0.23**	**0.13**	0.04
Grass effect		**	**	

$^{a-c}$ Means within a column without a common letter superscript differ at $p<0.05$

Grass effect insignificant (NS) or significant at $p<0.05$ (**)

Total Carbon Stocks

In Table 3 are the total dry matter production and total carbon stocks of different carbon pools for the three indigenous and two introduced grass species samples extrapolated to tons/ha. The total carbon stocks are pooled estimates of carbon in the above-ground, below ground and in the soil. Relative to the indigenous grass species, the introduced grass species had on average 23% lower ($p<0.05$) total carbon stocks (9.2 tons /ha vs. 11.3 tons /ha) and 24% lower total dry matter production (14.0 tons /ha vs. 17.3 tons /ha). The total carbon stock estimates of the introduced grasses *(C. gayana var Extozi* 8.9 tons /ha and *C. gayana var Boma* 9.5 tons /ha) were lower than the estimates of the indigenous grasses *(C. ciliaris* 11.8 tons /ha, *E. superba* 12.1 tons /ha and *E. macrostachyus* 10.1 tons /ha). The same pattern was observed for the total dry matter production estimates, with the introduced grasses *(C. gayana var Extozi* 13.4 tons /ha and *C. gayana var Boma* 14.5 tons /ha) being lower than the estimates from indigenous grasses *(C. ciliaris* 17.8 tons /ha, *E. superba* 18.8 tons /ha and *E. macrostachyus* 15.3 tons /ha).

Table 3: Total Dry Matter Production and Total Carbon Stocks of Different Carbon Pools for Sample Indigenous and Introduced Grasses

Grass	Species	Total carbon stocks (tons /ha)	Total dry matter (tons /ha)
Indigenous	*C. ciliaris*	11.8^c	17.8^b
	E. superba	12.1^c	18.8^b
	E. macrostachyus	10.1^b	15.3^a
	Average	11.3	17.3
Introduced	*C. gayana var Extozi*	8.9^a	13.4^a
	C. gayana var Boma	9.5^{ab}	14.5^a
	Average	9.2	14.0
	SEM	0.21	0.40
Grass effect		**	**

$^{a\text{-}c}$ Means within a column without a common letter superscript differ at $p<0.05$

Grass effect insignificant (NS) or significant at $p<0.05$ (**)

Discussion

The high dry matter production observed with the indigenous grasses relative to the introduced grasses can be attributed to adaptability and resilience of indigenous grass pastures. These attributes include adaptability to high temperatures, low soil moisture demand and the ability to recover rapidly after climatic shock (Kipchirchir *et al.,* 2015). Further, they are deep-rooted with high vegetative nature, which could explain their high biomass production. Supporting this is the observation that *E. superba* produced the highest above-ground dry matter biomass while *C. ciliaris* produced the highest below-ground dry matter biomass; which is attainable with deep stabilizing rootstock as deep as 2 m (Marshall *et al.,* 2012) [14]. For the introduced grass species, low above-ground dry matter production can be attributed to their shallow root system not reaching deep in the subsoil to benefit from scares soil moisture needed to support growth.

High total carbon stocks observed with the indigenous grass species can be related to their high above ground biomass which support the accumulation of high carbon from the photosynthesis process, high below-ground biomass which is characterised by deep rooting system and high soil carbon. The high soil carbon stock can be linked to a high rate of root decomposition which might have contributed to the enhanced addition of carbon from the plant's root to the soil during the decomposition process (Odiwe *et al.,* 2016)[8]. The findings of Anderson *et al.,* (2010) corroborates the present observation. The authors explained that the deep root system of indigenous grasses stores a higher amount of carbon in their roots. Further, Tessema *et al.,* (2021) [15] made the supportive observation that the deep root system facilitates long term carbon storage in soil by reducing the chances of carbon loss from root decomposition.

The indigenous grass pastures showed the potential to store high carbon in different carbon pools while at the same time producing the highest biomass. This is an important attribute in climate change mitigation because of its high capacity to capture much carbon dioxide concentration from the atmosphere during photosynthesis. Aiding this attribute is their rapid establishment / growth rate, high biomass production and deep root system that store soil organic carbon deep in subsoil. Therefore, utilization of indigenous grasses in ruminant feeding would achieve some co-benefits of higher dry matter biomass production and total carbon capture, which is beneficial to mitigating climate change when producing ruminants under the rangeland ecosystem. For nutritive value improvement of the indigenous grasses to support increased ruminant productivity levels, carbon sequestration capacity should not be lost, especially when breeding for nutritive value improvement.

Conclusion

The indigenous grass pastures demonstrated high potential for carbon capture and biomass yield than the introduced grass pastures in the rangeland ecosystem, thus proved more suitable for increased sustainable livestock productivity while mitigating climate change impacts. With this evidence, utilisation of indigenous grass species is highly recommended for sustainable rangeland livestock production supporting increased productivity while minimising carbon emissions [16, 17].

Conflict of interest

The authors declare no conflict of interest

Acknowledgement

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author, [Annastacia Nduku Maweu], upon reasonable request

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