International Journal on Science and Technology (IJSAT)

E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Estimating Biomass Yield of Browse Species Preferred By Free-Ranging Goats In Agro-Ecological Zones Iv And V Of Zimbabwe

Onious Mtetwa[1], Khanyisile R. Mbatha[2]

[1]PhD Student, Department of Agriculture and Animal Health, College of Agriculture & Environmental Sciences, University of South Africa.
[2]Lecturer (Professor) Department of Agriculture and Animal Health, College of Agriculture & Environmental Sciences, University of South Africa.
Corresponding author, Email: onmtetwa@gmail.com

ABSTRACT

This was a study to estimate density, species composition and biomass yield of forage species preferred by free-ranging goats in two semi-zones of Zimbabwe. Many methods have been developed for estimation of biomass, ranging from aerial photography and imagery to destructive sampling. We applied a combination of direct harvesting and none-destructive techniques to estimate annual biomass yield for 35 herbaceous plants and 55 browse species were purposively selected based on preference indices. Shurugwi recorded a higher count of key woody species and accounted for 54% of forage species selected for biomass yield estimation than Chiredzi. *Cynodon dactylon* (Shurugwi) was the most abundant key grass species (23%) across the two sites followed by P. maximum (18%) for Chiredzi. Results showed a mean of 367 woody plants, with more trees reported in Shurugwi (400) than Chiredzi. Mean annual above-ground biomass yield for herbaceous species 0.655 kg/ha while woody plants recorded 1646.65t/ha with Shurugwi recording higher mean yields both parameters across the three seasons. Total annual biomass yield for all browsable plant parts (leaf, twig, fruit, and pod) was 1150.53 kg/ha, which is lower than potential for the agro-ecological zone. The two rangeland sites are degrading due to absence of grazing plans and uncontrolled access to resources. Rangeland rehabilitation measures to restore bare patches and degrading sites through climate-responsive farmer-led solutions based on economic incentives will restore annual biomass production. Multi-stakeholder participatory rangeland planning to develop community grazing plans and formulate by-laws that govern utilization communal rangelands guide implementation of appropriate rangeland restoration and management principles. Bush control of invasive *L. camara* (Shurugwi) and *D. cineria* in Chiredzi coupled with rangeland reinforcement using high yielding locally adapted grasses and legume species will improve biomass yield and nutritive value. Studies to investigate the appropriate mix of woody species to herbaceous plants that can achieve optimum annual biomass yield, multispecies livestock production and continue to provide other services (firewood, small game habitats, etc). Pilot short-term integrated participatory communal rangeland management projects that involve control of animal movement, rangeland fortification, gulley reclamation and use of community bylaws to restore degraded areas.

Key words: biomass, fruits, pods, forage, herbaceous, key species, dominant, annual yield, dry season, hot wet, cold dry, hot dry, grass, species composition, plant density, vegetation, formation.

1. INTRODUCTION

Many methods have been developed for estimation of biomass, ranging from aerial photography and imagery to destructive sampling. Direct measurements, involving destructive sampling are usually preferred for accurate estimations (Osada et al. 2003; Lehtonen 2005; Savadogo and Elfving 2007; Balehegn1 et al., 2012) and require either expensive or labour-intensive assessment methods (Savadogo and Elfving, 2007). This study applied a combination of direct measurements and dendrometric parameters to estimated biomass yield of rangelands as discussed by Balehegn et al. (2012).

2. LITERATURE REVIEW

2.1 Agro-ecological zones of Zimbabwe

Zimbabwe is classified into five agro-ecological zones based on the agriculture potential for each locality as described by Vincent and Thomas (1960), which is being revised (Mugandani, et al., 2012; Chikodzi, et al., 2013). According to Mugandani, et al., (2012) zoning considered average annual rainfall, temperature, soil and vegetation type. A map of Zimbabwe showing the traditional agro-ecological zones as delineated by Vincent and Thomas in 1960 (Figure 1).

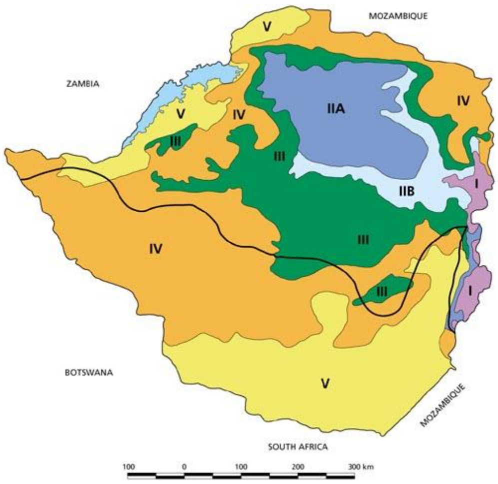


Figure 1: Agro-ecological zones of Zimbabwe (Source: Chikodzi *et al*., 2013)

The agricultural zones are increasingly becoming invalid; (Mugandani et al., 2012) because some farming activities that were traditionally practiced in specific zones have become unsuitable. Mugandani, et al., (2012) identified that the agro-ecological boundaries were altered by the increased variability of rainfall and temperatures. Zimbabwe is in the process of reclassifying the agro-ecological zones (Chikodzi, et al., 2013) that will aid to re-planning of strategic agricultural activities.

2.2 Plant species composition

The plant composition, yield and quality of tropical rangelands are temporally heterogeneous (Alassan et al., 2019) and their growth stages are influenced by three growing seasons (wet, cold-dry and hot-dry seasons) of the year. Seasonal rainfall pattern determines growth, availability and nutritional variability of forages (Katema et al., 2015). Rangelands have dominant annual grasses and forbs in summer (Castellaro et al., 2018) while the proportion of browse species increases in the cold dry and hot dry seasons.

Rangelands of agro-ecological zones IV and V of Zimbabwe have 'sweet veld' characterised by a high proportion of annual gasses and herbs mixed with few biennials and perennial species. According to Sanon (2007); Mudzengi et al. (2020) annual grasses are *Chloris spp., Cynodon dactylon, Digitaria spp., Eragrostis spp.* and *Setaria verticilata*. Common perennial grass species include *Chloris gayana* Kunth, *Chrysopogon plumulosus*, *Tetrapogon tenellus, Panicum coloratum, Heteropogon contortus* (L.), *Cenchrus ciliaris* (L.) and *Hyparrhenia rufa*. Herbaceous plant species common in agro-ecological zones IV and V of Zimbabwe are; S*clerocarya birrea, Aristidia spp, Chloris spp, Tagetus minuta* and *Bidens pilosa* (Mudzengi et al., 2020). McIvor and Reid (2011); Tessama (2011); Axelsonn (2018) identified *Acacia spp., Ziziphus mucronata, Baikiaea plujuga, Terminalia spp., Combretum spp., Colophospermum mopane*, and *Aloe cameroni* as dominant browse species of the sub-tropical rangelands.

2.3 Tree grass interactions in rangelands

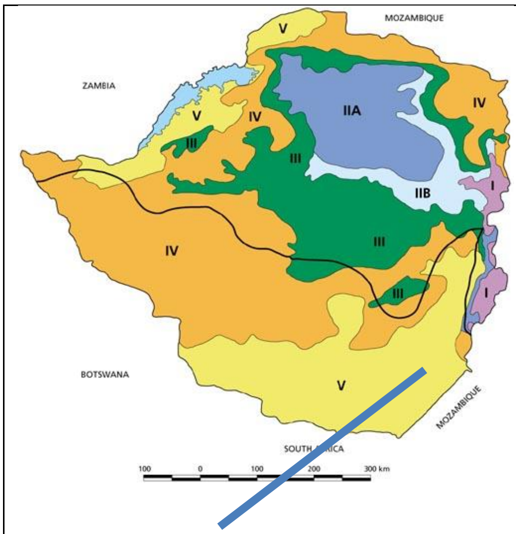
Trees, grasses, and water are major rangeland resources that interact to support animal production and food, medicine and firewood that support livelihood of communities (Inman, 2021). According to Thokozwayo (2021) the coexistence of these three elements of a pastoral ecosystem has been extensively described by researchers. Many communal livestock production systems rely on annual biomass production (Notenbaert, 2010), which is dependent on amount of precipitation received each year (Assan et al, 2019; Katema et al., 2015). Frequent droughts have become a common phenomenon due to rising climate variability (Brown et al, 2012). The net effect is alteration of vegetation composition evidenced by disappearance of plant species sensitive to stressful extreme weather conditions.

Communal livestock producers in Zimbabwe practice multispecies system (including small game) integrated with annual crop and vegetable gardening. This system lacks grazing plans and bylaws that govern utilization of rangelands. According to Inman (2021) forage plants preferred by herbivores suffer excessive defoliation and disappear steadily when unnoticed. Depending on mix of livestock species, unpalatable plant species gradually increase in abundance, which is a sign of rangeland deterioration. Overtime, woody plants dominate giving rise to bush encroachment (Hare et al, 2021; Inman, 2021) which suppress grass growth and total annual biomass production.

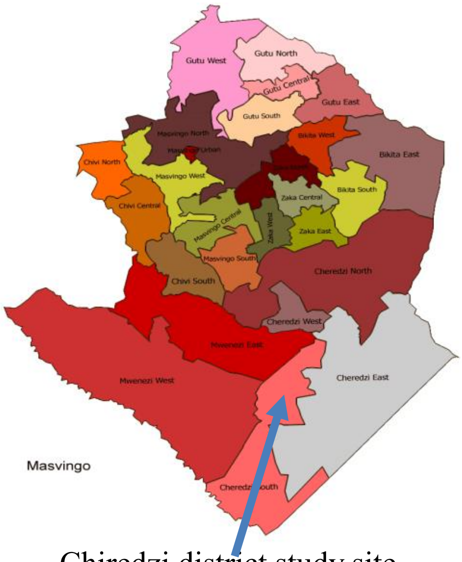
3. MATERIALS AND METHODS

3.1 Study site

The study was conducted in Shurugwi and Chiredzi districts found in the agro-ecological zones IV and V of Zimbabwe. Shurugwi district is found in southeast of Midlands province while Chiredzi is the southeastern district of Masvingo province bordering Mozambique and South Africa. (see fig 4 below). Chiredzi lies between 18°55'S and 29°49'E covering a significant part of the province (Jiri, et al, 2017). Shurugwi is located between latitude: -19°40'12.58"S and 30°00'21.20"E.



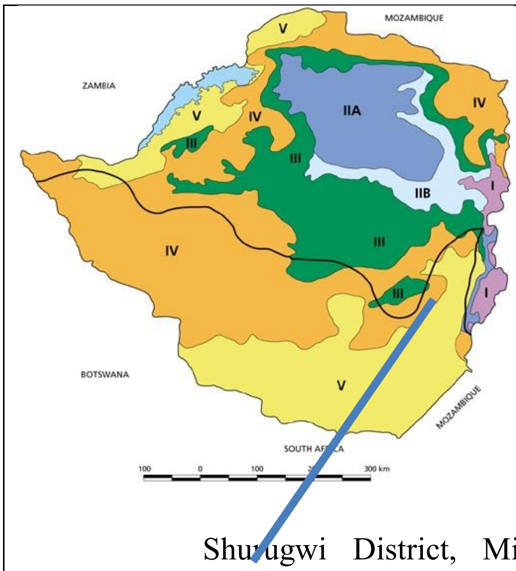
Chiredzi District, Masvingo Province



Chiredzi district study site

Map of Zimbabwe	Masvingo Province, Chiredzi District

Figure 2: Map of Zimbabwe showing location of Chiredzi District, Masvingo Province



Shurugwi District, Midlands Province

Shurugwi District, Midlands Province

Map of Zimbabwe	Midlands Province, Shurugwi District

Figure 3: Map of Zimbabwe showing location of Shurugwi District, Midlands Province

The two sites have a sub-tropical climate and receive average annual rainfall below 650mm received between November and April (Mugandani, et al., 2012; Chikodzi, et al., 2013). Soils range from sandy to loamy textures derived from granite rock. Vegetation is composed of two main layers: a woody layer (consisting different bushes and browse trees) and an herbaceous layer dominated by grasses and forbs.

The vegetation type for Shurugwi is bush savannah grassland with *Hyperrania, Hypothelia* and *Digitaria* as the major grass types dotted with *Brachystegia, Terminalia* and *Julbernadia* tree species (Madebwe and Madebwe, 2005; Matsa and Maringaniza, 2011). According to Mabika et al. (2013) Chiredzi district plant communities are of the savanna vegetation, comprised of trees and grass dominated by *Colophospermum mopane, Acacia nigrescens* and *Combretum apiculatum*. Grass species include *Pannicum maximum, Urochloa, Digitaria milanjiana* and *Perotis patens* and *Pogonarthria squarrosa* on heavy loamy Malvernia soils (Cunliffe et al. 2012).

3.2 Grazing sites

The study was conducted in two districts purposively selected based on annual goat populations from national livestock production statistics published by the Ministry of Lands, Agriculture, Water, Irrigation and Fisheries Development (MLAWIFD). Two smallholder goat producers with access to unrestricted communal rangeland and a minimum of 30 SEA goats were identified to host the study. A high number of animals on the farm would allow replacement of target class of study animals in cases of death or loss during period of study. Total grazing area for Chiredzi site measured 86 ha while Shurugwi was bigger (93ha) during the cropping season when goats are restricted to grazing areas. Goats had access to an extended grazing area in the cold-dry and the hot-dry seasons of the year when they are free to graze arable lands during off-cropping seasons. Cumulatively, the grazing area was 106ha and 113ha for site Chiredzi and site Shurugwi respectively during none-cropping seasons.

Goats were left to browse undisturbed on open rangeland so that they exhibit their natural behaviour with minimum interference from the researcher. The land size was enough to allow goats traverse different rangeland terrains that expose them to natural conditions, which demand flocks to use their senses, experience and memory built over time. Each grazing site was divided into three equal distance zones from the overnight pen (homestead) to the nearest stable watering point for that season. Zoning the grazing area caters for possible variations in grazing intensity with distance from overnight pens and the water point.

The nearest reliable water point for Shurugwi (site 1) was 2.6km from the homestead. Zone A was grazing distance from overnight pen to 1km, second zone was 1 to 2km and zone C was extended from 2km to 3.6km. The additional 1km distance was added upon observation that after watering, goats would move about 1km beyond the water point so that they drink water for second time late afternoon as they return to the homestead. Site 2 had a distant water point 4km from the overnight pen. The three distance zones for Chiredzi were much longer than zone 1. The first 1.5km from homestead marked zone A, second zone was 1.5 to 3.5km and zone C was 0.5km before water point extending for 1km beyond.

A permanent plot measuring 50m x 50m was marked using primary natural features on each distance zone where the measurements of browse plants conducted. The plots were maintained across the three data collection seasons so that vegetation samples collected for yield estimation, relative feed preference index, and chemical analysis reflect seasonal variations on the same plots. Use of same sites throughout the research period allowed tracking temporal variations in forage yield, quality, and browse preference by goats. Three quadrants (1m x 1m) were established on each bigger plot with representative herbaceous vegetation cover each time forage data collection was collected. These were changed every season (within the same 50m x 50m) for forage estimation because grasses and forbs biomass were estimated using destructive method. An average value for parameter under investigation would be calculated for the distance zone.

3.3 Woody species biomass estimation

A combination of direct sampling (destructive) and visual estimates described by Saleem, *et al*., 2020; Costa, *et al*., 2009; Soriano, *et al*., 2013; Edvan *et al*., 2014. Forage yield estimates for key woody (bush, tree) species was conducted within the demarcated 50m x 50m large plot for each zone over three seasons of the year. The first step was total count of the key woody species, tree height measured and categorised into three classes, <1.5m, 1.5 to 2m, and > 2 m. The woody species were further categorised by relative browsing value (preferred and non-preferred) based on number of bites and time spent browsing.
A maximum of five species were sampled for biomass yield estimation per distance zone (each height category represented) for the purpose of time, resources, and environmental protection. As discussed earlier, the study could not harvest plant parts from the whole tree because it is destructive to environmental and prevents further studies in the harvested areas due to forage removal (Edvan 2014). For each tree, 10% of edible leaves, twigs and fruits/pods area was clipped using hand shears and weight measured for the separate plant parts. The samples were dried under shed for maximum three days, packed in clean/new plastic bags, and labelled and taken to Matopos Research Institute for DM estimation.

Tree biomass yield was extrapolated from the sample weights (DM%) and summed for each site distance zone, site and season. Mean annual biomass yield (kg/ha) from woody species calculated and combined with same from herbaceous layer to estimate annual forage biomass per site. The same trees were maintained throughout the three different seasons of the year namely, hot-wet (December to March), cold-dry (April to July) and hot-dry (August to November) of the year in Zimbabwe.

3.4 Biomass estimation for standing herbaceous species.

Grass and other herbaceous plants were sampled from quadrants measuring $1m^2$ purposively replicated 3 times on areas with representative vegetation for the research site and within the 50m x 50m bigger plots on each distance zone. All vegetation were directly measured using the clip and weigh method described by Saleem *et al*. (2019). The parameters were measured prior to biomass harvesting; key grass species name, total count of the species, estimated average height, relative grazing value based on as described in the above section.

All grass and forb species within the quadrants were clipped to measure biomass. This involved harvesting of all edible parts (leaf, stem, twig, etc.) from total standing crop rooted and hanging in the perimeter of the plot. A hand grass shear was used to clip vegetation from individual quadrants. The material put in clean khaki bags, weighed on site using 2.5kg digital scales and recorded in a research diary. It was further wilted under shade and taken to Matopos Research Institute within 3 days for DM analysis using the described by AOAC (2019); Thiex and van Erem (2002). Vegetation was harvested three times i.e., mid hot wet, cold dry and hot dry seasons to cater for variations in forage yield and available plant part during different periods of the year.

3.5 Vegetation parameters measured.

The study collected data on plant species diversity, density, frequency, abundance, and estimated biomass yield as described by Saleem *et al*. (2019); Edvan (2014).

(i) Species composition and diversity

Total number of species present at each quadrant size. Vegetation species were identified using a field guide by Coates-Pelgrave (1997) and with the aid of an experienced research technician.

(ii) Plant density

Density number of individuals of a species that occurs within a given sample unit or study area. It was recorded as:

$$\textit{Plant species density} = \frac{\textit{Number of stems}}{\textit{Plot area}} \times 10{,}000$$

(iii) Species frequency.

Frequency is the number of times a plant species is present in each sample unit. It was calculated by the formula:

$$\textbf{Frequency (\%)} = \frac{\textit{Total plants per spp}}{\textit{Size of quadrant}} \times 100$$

(iv) Herbage yield per quadrant

Mean estimated plant yield per quadrat for each distance zone. Calculated using formula:

$$\textbf{Herbage yield per quadrat} = \frac{\textit{Total edible biomass}}{\textit{Size of quadrant}} \times 10{,}000$$

4. RESULTS AND DISCUSSIONS

4.1 Species diversity

4.1.1 Grass species diversity

Chiredzi had a lower mean annual species diversity (5.33 ± 0.51) across all the distance zones with a higher woody species count in Shurugwi with 6.33 ± 0.49). Both sites had an equal proportion of preferred herbaceous plants in zone II and woody species in zone III. The highest number of forage species were recorded in the zone near home for Chiredzi compared to the other two zones. Contrary, Shurugwi recorded the highest vegetation species diversity in the second distance zone.

Table 1: Number of key species per distance zone

Site	Zone	Mean herbaceous species	Mean of woody species	Total
Chiredz	I	3	3	6
	II	3	2	5
	III	2	3	5
S h ur	I	2	4	6

	II	3	4	7
	III	3	3	6
Totals		**16**	**19**	**35**
Mean		**2.67**	**3.17**	**5.84**

4.1.2 Frequency of herbaceous species occurrence

The grass layer for Chiredzi was composed of three dominant annual grass species while perennials constituted 66% of preferred herbaceous forage in Shurugwi. *Urochloa pannicoides* was the dominant grass species (21%) in Chiredzi while *C. dactylon* recorded the highest frequency (23%) for all herbaceous plants in Shurugwi and across all the study sites. *Panicum maximum* and *H. contortus* ranked third and fourth frequent grass species with 18% and 16% respectively. The grass layer for Chiredzi disappeared late cold dry and the whole of hot dry season in Chiredzi, with pockets of occurrence in hidden sites (e.g., under thick bush, in brushwood fence). Figure 3 below shows six dominant grass species and their frequency of occurrence for the two sites.

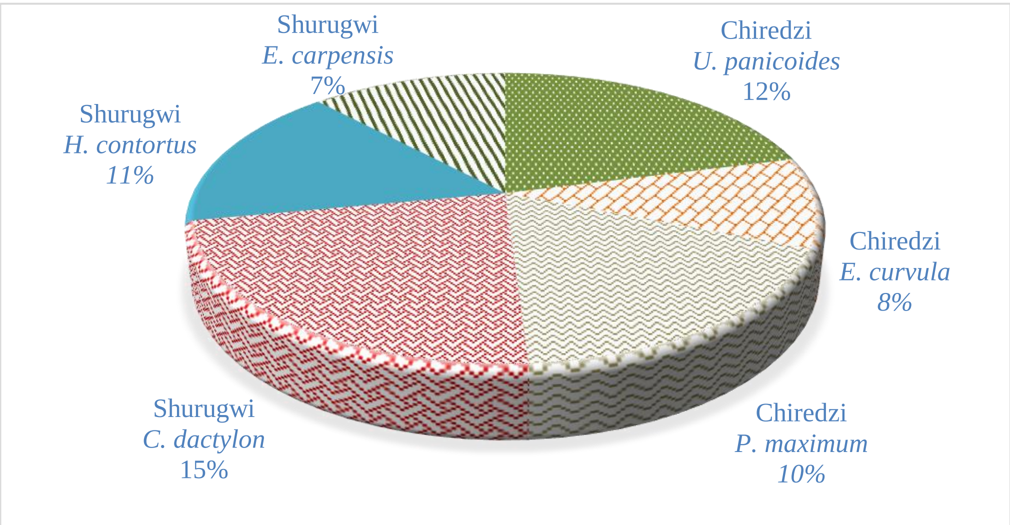


Figure 4: Frequency of key grass species for Chiredzi and Shurugwi, Zimbabwe

4.2 Discussion

Key woody species were diverse compared to the herbaceous layer, with more browse plants in Shurugwi than Chiredzi. The two sites had a high mean species diversity of 2.92, which is close to the Shannon-Wiener index mean value of 3.12 described by Zimudzi and Chapano (2016). The annual ratio of grass to browse preference (46:54) is consistent with results reported by FAO (2023) from a rangeland condition assessment in semi-arid zones of southwest Zimbabwe. Gusha and Mugabe (2013) confirmed that communal rangelands are poorly managed, and this reduces species diversity. Species composition in the near-home zone (I) had more broadleaved herbs, fewer grasses, and low count of browse trees.

Unlike *Helichrysum krausii*, reported by Gusha and Mugabe (2013) the dominant increasers in the near-home zone were *Eleusine indica* and *Acanthospermum hispidum* (Chiredzi) with *Cynodon dactylon* and *Sporobolus pyramidalis* dominant in Shurugwi. The area had the least grass cover even during the hot wet season and slowly becoming degraded compared to zone II and III. This was attributed to high intensity grazing, which results in loss of palatable grass species and emergency of increasers. Goats spent 56% of mean foraging time per day near home when they are released in the morning and as they return home in the late afternoon. The low browse is due to cutting down of trees for firewood and bush clearing to reduce predators, birds that destroy crops and gathering brushwood to fence arable lands.

4.2.2 Frequency of key browse species

Acacia, D. cineria and Z. mucronata were common species across the two sites. *Lantana camara* was the dominant species in Shurugwi and second overall most frequent woody species (17%) across the study. Chiredzi recorded the most frequent browse tree (*C. mopane*) with 24% frequency. For both districts, pods from *D. cineria, A. karoo* (Chiredzi) and *A. tortilis* (Shurugwi) were available during cold dry and first half of hot dry seasons. Table 2 below shows the frequency of occurrence for the key browse species in the two study sites.

Table 2: Mean annual frequency of occurrence key woody species per distance zone.

Site	Species	Zone 1	Zone 2	Zone 3	Mean frequency spp. %
Chiredzi	*Karoo*	3	5	4	13
	D. cineria	3	2	3	9
	C. mopane	6	7	8	24
	Z. mucronate	2	3	2	8
Shurugw	*Tortilis*	3	3	3	10
	D. cineria	3	2	4	10
	Z. mucronate	2	4	2	9
	L. camara	7	3	5	17
Mean	**4**	**4.83**	**4.83**	**5**	**100**

4.2.3 Woody species diversity per hectare

Mean diversity for preferred browse species was 3.12. Chiredzi recorded a higher number of woody species (x̄ = 3.23) than Shurugwi with 3.00. Goats had limited selection of browse species (fallen leaf, pods and standing plants) during the hot dry season for both sites. There many browse plant species during the cold dry season in Chiredzi than other parts of the year.

Table 3: Woody species diversity per ha

Site	Season	Woody species mean count		
		Zone 1	**Zone 2**	**Zone 3**
Chiredzi	Hot wet	3	4	3
	Cold dry	4	4	3
	Hot dry	3	3	2
	Mean per zone	**3.34**	**3.67**	**2.67**
Shurugwi	Hot wet	3	3	2
	Cold dry	4	3	3
	Hot dry	3	3	3
	Mean per zone	**3.34**	**3.00**	**2.67**
Overall mean		**3.34**	**3.34**	**2.67**

4.2.4 Discussion

Mean species diversity of 3.12 was higher than $\bar{x}$ =2.66 reported by Gandiwa et al (2013); $\bar{x}$ =1.8 Ganiwa G, P Gandiwa and Mxoza (2012) in the Gonarezhou National Park. Gusha and Mugabe (2012) also recorded a lower mean browse plant species density ($\bar{x}$ = 1.57) in Masvingo. The higher diversity could be attributed to different study objectives since the current research sought to assess diversity of annual rangeland feed resources for goats.

Colophospermum mopane was the dominant browse species for Chiredzi, which is in line with Cunliffe, Muller and Mapaula (2012). This species was also found dominant in a study by Martini et al (2016) in Gonarezhou National Park. However, it was established that goats had a lower preference for *C. mopane* leaf and pod when green. The species (dry leaf and pod) constituted more than 70% of dry season det for goats. Further studies to profile the seasonal PSM concentrations for mopane are necessary to establish reasons for low intake of green leaf and pod.

Shurugwi rangeland was dominated by the invasive *L. camara* (Ntalo et al, 2022) which was least preferred by goats during the hot rainy season. Results of this study showed that goats preferred this species during the dry period because it remained green throughout the year. The same findings were reported by Gusha et al (2020) who argued that *L. camara* is a high protein (Ntalo et al, 2022) forage resource for the smallholder livestock in Zimbabwe (Gusha et al, 2016). Acacia spp. and *D. cineria* were second and third key forage species for goats on both sites after *C. mopane* and *L. camara* because they have low forage yield limited to two seasons.

4.3 Density of herbaceous plant species per season

Overall mean annual plant stem density for Chiredzi was lower (343.34) per hectare than Shurugwi (428.67). Results showed the highest density of potential forage plants during the cold dry season for Chiredzi while Shurugwi had the highest density of forage plant stems during the hot wet season (see figure 4 below). Near-home zone recorded a low grasses yield (mean 31.8%) than herbs (44.2%) while the remainder (24%) constituted crop residue and fallen leaf from and fruits from large trees. Both sites had the least density of vegetation during the hot dry season (Shurugwi = 381.00; Chiredzi = 281.00) plants/ha. Dry season vegetation cover was dominated by woody species when annual grasses disappear.

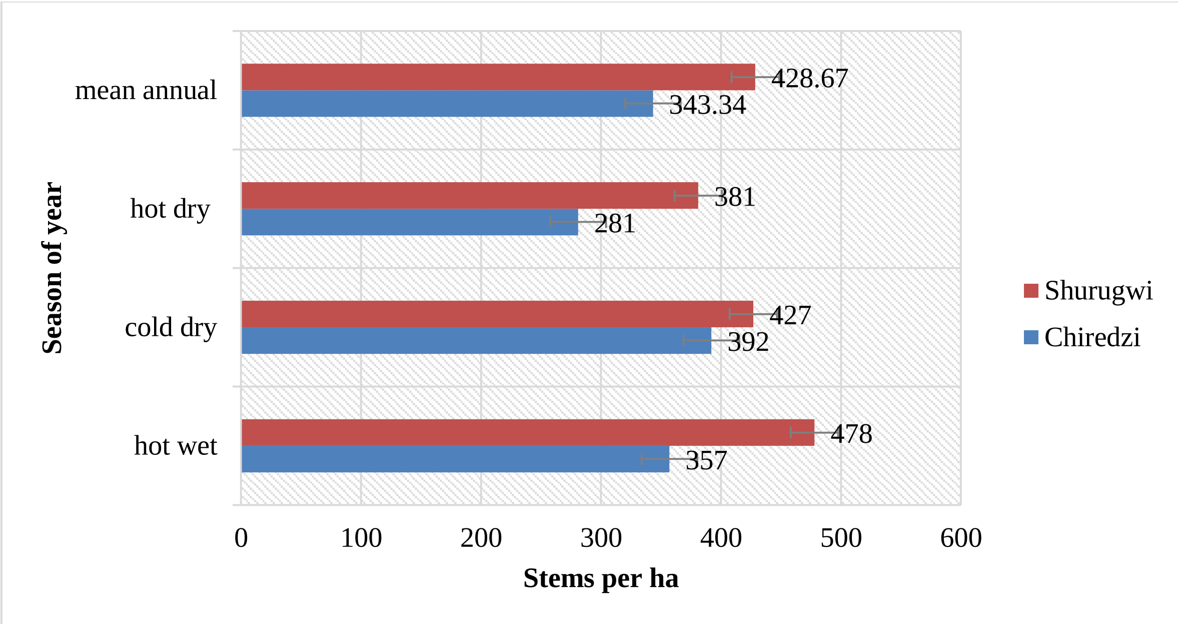


Figure 5 Density (plants/ha) of herbaceous species

4.3.1 Discussion

The total stem density for herbaceous plants range of 281 to 478 plants per hectare confirm a recent report by FAO (2023) in 6 semi-arid districts of southwest Zimbabwe. Results showed that majority of herbaceous plants were annuals, which grow and mature during the hot wet season. According to FAO (2023) the area close to homesteads has a low plant density due to frequent and high intensity defoliation resulting in loss of decreases as discussed in sections above. In a related study, Hare (2021) obtained a grass yield of 885.8 ± 369.1kg/ha from a semi-arid rangeland in Southern Ethiopia. The two sites under current study have a low grass yield, a sign of rangeland deterioration.

Broad-leaved weeds dominated the near-home foraging zone perhaps because they are consumed as traditional vegetables (Dube, 2018; Maroyi, 2013) by the farmers. It was observed that goats spent the least foraging time in the second distance zone. Animals rush through this zone enroute to watering points (zone III), which ranked second on plant species density. As a result, zone II had the highest plant density.

4.4 Biomass yield for herbaceous plants yield

A mean annual above ground biomass yield of 0.62kg per hectare ($p < 0.05$) was recorded over three growing seasons in Chiredzi. This included all stems and leaves of grass and other herbaceous plants like annual broad-leaved weeds. *Urochloa pannicoides, Panicum maximum* and *Eragrostis curvula* dominant the grass layer while *Richardia scabra*, *Amarantus spps.* and *Echinocystis lobata* occupied the greater proportion of annual herbs. The cold dry season had the highest herbaceous cover followed by hot wet season while the hot dry season produced the least herbage. The mid-distance zone maintained the highest yield of herbaceous forage across the three seasons of the year.

Shurugwi site had a higher mean annual grass yield ($\bar{x} = 0.69$kg/ha) than Chiredzi. The highest herbaceous yield ($\bar{x} = 0.84$kg/ha**)** during the hot wet season followed by cold dry ($\bar{x} = 72$kg/ha) and least was found in the hot wet season ($p < 0.05$) as shown on table 4 below). This included broad-leaved annual herbs (*Gynandropsis gynandra, Amaranthus hybridus* and *Cleome monophylla*) while the grass layer was dominated by perennial species (*Eragrostis carpensis, Cynodon dactylon, Digitaria milanjiana, Heteropogon contortus* and *Hyperrhenia spp.*).

Table 4: Chiredzi herbage yield per plot (kg) and seasonal standard errors for each zone

Site	Season	Zone 1	Zone 2	Zone 3	Mean
	Hot rainy	0.157 ±0.05	0.191± 0.29	0.138 ± 0.24	**0.162**
	Cold dry	0.168 ± 0.06	0.235 ± 0.13	0.183 ± 0.19	**0.195**
Chiredzi	Hot dry	0.098 ± 0.03	0.128 ± 0.22	0.096 ± 0.20	**0.107**
	Mean	**0.141 ± 0.014**	**0.185 ± 0.030**	**0.1140 ±0.041**	**0.155**
	Hot rainy	0.205 ± 0.006	0.216 ± 0.005	0.211 ± 0.000	**0.211**
	Cold dry	0.187 ± 0.007	0.191 ± 0.110	0.162 ± 0.018	**0.180**
Shurugwi	Hot dry	0.124 ± 0.000	0.129 ± 0.005	0.120 ± 0.004	**0.124**
	Mean	**0.220 + 0.010**	**0.240 ± 0.010**	**0.22 ± 0.010**	**0.172**

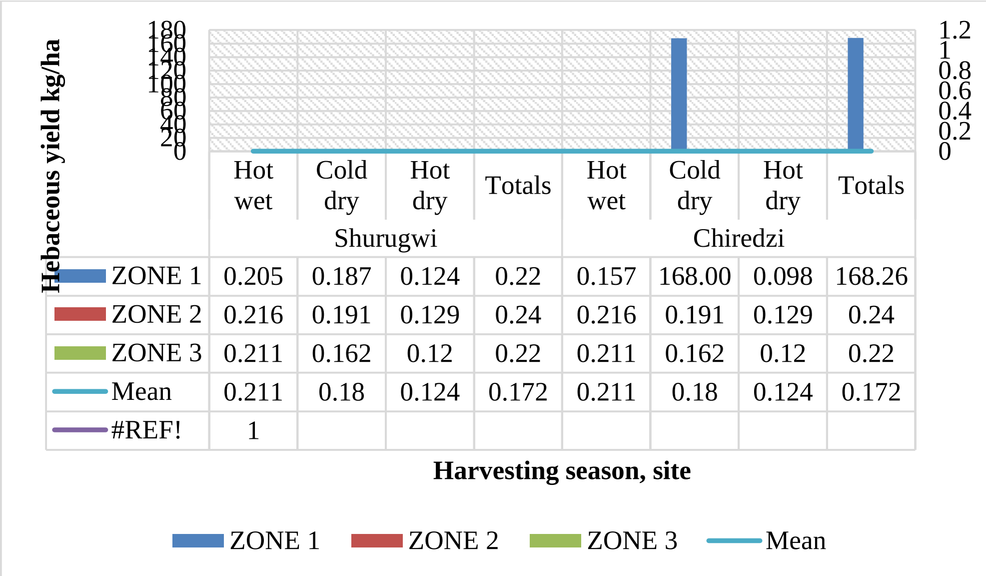


Figure 6: Herbaceous yield by season (kg/ha)

4.4.1 Discussion

Herbaceous species biomass yield for the two rangelands ranged between 0.620 – 0.690 kg/ha, with Shurugwi recording higher mean yields for all the three seasons. The two rangeland sites had higher grass compared to mean of 0.103t/ha reported by FAO (2023) for six districts of southwest Zimbabwe. This is probably because of different research goals between the two studies. The FAO assessment focussed on degradation hotspots to identify appropriate rangeland reclamation strategies while the current study aimed at estimating potential mean herbage yield on homogeneous (near-climax) sites over three growing seasons. Higher yields obtained in this study were due to incorporation of forage contribution from croplands, which dominant dry season feed resource described by Sibanda et al (2011).

Despite the reported yields, Chiredzi rangeland grass resources are getting depleted as shown by a higher proportion of annual broad-leaved herbs least preferred by goats. Dominant perennial grass species in Shurugwi have high yields but majority have been reported to offer low value forage (Dahwa et al, 2014). While majority of this class of herbage is edible traditional vegetable by humans discussed by Dube (2018); Maroyi (2013) an investigation of nutrient content and presence of chemical plant metabolites will inform rangeland management decision making. Both sites recorded a mean 41.34% ($p < 0.05$) bare patches during the hot dry season, which is exposed to soil loss by wind, runoff water and other agents of erosion.

Dry season vegetation cover was dominated by fallen leaf from woody species and tophamper on areas with more perennial grasses (de Camargo et al., 2018; Holland, 2017; Sannon et al, 2005). Fruits, pods, and scanty grass swads under trees and along low-lying areas like erosion rills constituted goat diet during the hot-dry season. Few patches of green grasses and herbs got limited to waterways, erosion rills, in thick tree areas and along brushwood fences. Areas close to dry season water points had the lowest vegetation cover consistent with FAO (2023).
Goats and other livestock species camp near permanent water sources during the dry seasons and abandon the other distance zones. These areas are prone to degradation and soil loss when first rains fall, hence require protection. Establishment of alternative watering points in the dry season will not only reduce pressure on perennial rivers and dams but also a strategic control of internal parasites on livestock.

4.5 Density of woody species

Results showed a mean of 367 plants per hectare for the 2 sites. Shurugwi had a higher mean species count per hectare (400) compared to Chiredzi with 324. Mean number of browse plants sampled was 5.6 per species category during the study. The table 6 and 7 below summarize number of woody plants selected for each key species category over the three seasons.

Table 5: Key woody species selected for annual yield estimation in Chiredzi.

Species	Sum of plants per plot	Sum of plants per ha	Sum of sample size	Species frequency %
D. cineria	21	84	6.3	26
C. mopane	18	72	5.4	22
Z. mucronata	16	64	4.8	20
A. karoo	11	44	3.3	14
Other	15	60	4.5	19
Season Total	**81**	**324**	**24.3**	**100**

Table 6: Number of woody species sampled in Shurugwi.

Species	Sum of plants per plot	Sum of plants per ha	Sum of sample size	Species frequency %

D. cineria	27	108	8.1	27
Z. mucronata	19	76	5.7	19
L. camara	19	76	5.7	19
A. tortilis	12	48	3.6	12
Other spp.	23	92	6.9	23
Season Total	**100**	**400**	**30**	**100**

4.6 Annual forage yield for tree species

A total of 55 woody plants ($\bar{x} = 5.5$; $p < 0.05$) were proportionately selected for estimation of annual forage yield. Results show a mean biomass yield of 2 301.65kg/ha for browsable parts of standing crop including fruits and pods (a.k.a. mast) for the 2 study sites per annum. Paradoxically, the more humid Shurugwi recorded a higher annual forage yield of 2 651.7kg/ha ($\bar{x}$ = 2301.65 kg/ha) with a lower total forage yield of 1 951.43kg/ha for Chiredzi with a drier climate. Woody species accounted 79% of total annual plant biomass with herbaceous layer contributing the remainder 31%. The rangeland for Shurugwi had a lower annual yield for fruits and pods combined (184kg/ha) compared to Chiredzi with 243.1kg/ha ($\bar{x}$ = 213.55). The results are shown in figure 6 and table 7 below.

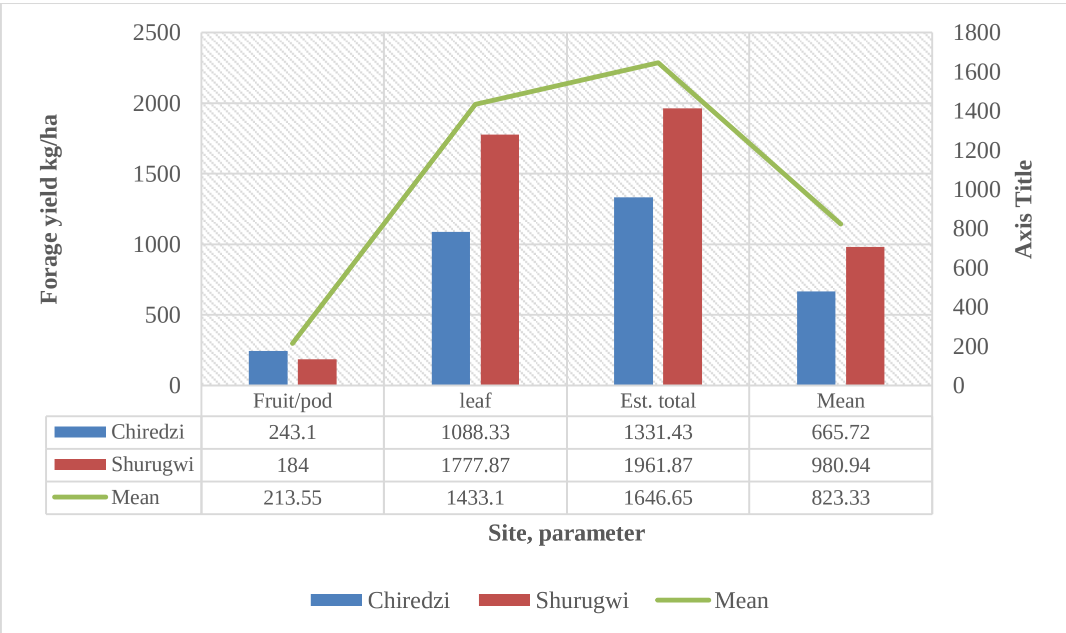


Figure 7: Estimated annual browse forage yield (kg/ha)

Table 7: Estimated total forage yield combined grass and woody spp (kg/ha)

Site	Browse	% of annual forage	Grass	% of annual forage	Est. total	Plant Part Mean
Chiredzi	1331.43	0.68	620.00	0.32	1951.43	975.72
Shurugwi	1961.87	0.74	690.00	0.26	2651.87	1325.94
Mean	***1646.65***	***0.71***	***655.00***	***0.29***	***2301.65***	***1150.83***

4.6.1 Discussion

The two rangelands had a higher proportion of total woody species with a lower herbaceous cover (79:21) both in density and biomass yield, which may result in loss of productivity (Thokozwayo et al, 2021; Meyer et al, 2019; Cunliffe, 2013). Shurugwi has the risk of invasion by *L. camara* while Chiredzi traditional rangeland areas are stable except parts of croplands left fallow. These areas require thinning of *D. cineria* bush that is slowly encroaching due to short-duration utilization to avoid proliferation, which alters the ratio of browse to grass preferred by goats.

Assuming all forage production is consumed, both sites require bush control to match browse preference of goats presented in chapter 3. The composition of browse and grass species for Chiredzi (68:32) closely match 60:40 foraging preference for goats while Shurugwi woody species are by-far higher than goat preference. Ayele et al (2022) reported a contrary composition of 73.13% grass with woody layer constituting 26.87% of total annual forage in a lowveld of Ethiopia. According to Inman (2020); Meyer et al, (2019) proliferation of woody species is a sign of rangeland degradation. Eventually, it fails to offer multiple functions to human and communities of flora and fauna. This suggests that annual grass production is lower than what goats require for the latter site, which forces goats to take more time on woody species than normal.

An unbalanced forage availability will likely reduce goat productivity in Shurugwi regardless of a higher total biomass yield when animals struggle to adjust foraging behaviour. The rangeland structure forces them to compensate the forage deficit from herbaceous plants by increasing time spent on browse. Goats in Chiredzi have bigger frame and produce more than Shurugwi because the species composition matches animal browse to grass preference. Perennial grasses common in Shurugwi are of a lower digestibility, palatability hence low VFI even during the hot wet season when quantity is not limiting.

Woody species density of 324 - 400 plants per hectare is higher than 266 reported by Mashapa, Gandiwa and Muboko (2018) for the same area. Current results were higher because the study sites are distant from Gonarezhou National Park which is likely overgrazed and affected by multispecies and uncontrolled veld fires (Cunliffe, 2013). The other study was conducted in areas adjacent to wildlife, which suggests a higher herbivore stocking density. While the study areas had open spaces with low vegetation cover, it should be noted that some rangeland sites are threatened by bush encroachment.

Shurugwi offers a higher annual forage yield potential with capacity to carry more goats (herbivores) than current. This is hindered by *L. camara* invasion with *D. cineria* presenting similar effects in less grazed pockets of zone 2 and fallow croplands in Chiredzi. Many factors (climate, anthropogenic) contribute to low productivity and deterioration of rangelands in Chiredzi. These include absence of grazing plans, recurrent droughts, uncontrolled veld fires and unsustainable methods of harvesting *Imbrasia belina* (World Food Program, 2023; Dube et al 2017; Benisiu, 2013; Gondo et al 2010) and many other factors.

Total plant biomass estimates for the two sites (975.72 - 1325.94kg/ha) is consistent with yields (903kg/ha and 1472t/ha) presented by Yilangai (2023) and Ayele (2022) respectively. A higher mean annual forage yield obtained in Shurugwi is due to better precipitation pattern (Masara et al, 2022; Maroyi, 2013;

Mudebwe V and Madebwe C, 2005) and lower population of goats compared to Chiredzi (Mhembwe et al 2018; ZimVAC, 2016; Ministry of Lands, Agriculture, Water and Fisheries, 2023). Contrasting forage yields were reported by Zezai et al (2022) who A study by Zezai et al (2022) recorded higher mean forage yield (78 880kg/ha) at University of Zimbabwe farm. This could be because University of Zimbabwe farm is a commercial cattle ranch that receives high precipitation (Zezai et al, 2022; Brown et al, 2012) and applies commercial rangeland management principles opposed to the communal multispecies livestock production system located in semi-arid zones. The farm has low tree count because bush is cleared for beef cattle and to allow movement of machinery for hay making.

4.7 Conclusions

i. This was a study to estimate density, species composition and biomass yield of forage species preferred by free-ranging goats in two semi-zones of Zimbabwe.

ii. A total of 35 herbaceous plants and 55 browse species were purposively selected for total annual biomass estimation using a combination of direct harvesting and none-destructive techniques.

iii. Shurugwi recorded a higher count of key woody species and accounted for 54% of forage species selected for biomass yield estimation than Chiredzi.

iv. Perennial grasses are dominant in Shurugwi (*Cynodon dactylon 23%*) while key species for Chiredzi are annuals (*P. maximum* 18%) with high forage value.

v. Results showed a mean of 367 woody plants, with a higher tree count reported in Shurugwi (400) than Chiredzi due to bush encroachment with *L. camara* on the near-home zone.

vi. Mean annual above-ground biomass yield for herbaceous species 0.655 kg/ha while woody plants recorded 1646.65t/ha with Shurugwi recording higher mean yields both parameters across the three seasons.

vii. Total annual biomass yield for all browsable plant parts (leaf, twig, fruit, and pod) was 1150.53 kg/ha, which is lower than potential for the agro-ecological zone. The two rangeland sites are degrading due to absence of grazing plans and uncontrolled access to resources.

4.8 Recommendations

(i) Rangeland rehabilitation measures to restore bare patches and degrading sites through climate-smart farmer-led solutions based on economic benefits will restore biomass production.

(ii) Integrated crop/livestock systems, participatory rangeland planning and formulation of by-laws that govern utilization communal rangelands guide implementation of appropriate rangeland restoration measures.

(iii) Bush control of invasive *L. camara* (Shurugwi) and *D. cineria* in Chiredzi coupled with rangeland reinforcement using high yielding locally adapted grasses and legume species will improve biomass yield and nutritive value.

4.9 Areas for further research

(i) Studies to investigate the appropriate mix of woody species to herbaceous plants that can achieve optimum annual biomass yield, multispecies livestock production and continue to provide other services (firewood, small game habitats, etc).

(ii) Pilot short-term participatory communal rangeland management models that involve control of animal movement, rangeland fortification, gulley reclamation and use of community bylaws to restore degraded areas.

REFERENCES

1. Abule E, G.N. Smit, H.A. Snyman. (2005). The influence of woody plants and livestock grazing on grass species composition, yield, and soil nutrients in the Middle Awash Valley of Ethiopia. Journal of Arid Environments, Volume 60, Issue 2, 2005, Pages 343-358.
2. AOAC (2023). Official Methods of Analysis (22nd Edition). Association of Official Analytical Chemists, Washington, DC. USA.
3. Benisiu T. (2013). Sustainable harvesting and trading of mopane worms (Imbrasia belina) in Northern Namibia: An experience from the Uukwaluudhi area. International Journal of Environmental Studies. 70. 494-502.
4. Brown D, RR Chanakira, K Chatiza, M Dhliwayo, D Dodman, M Masiiwa, D Muchadenyika, P Mugabe and S Zvigadza (2012). Climate change impacts, vulnerability, and adaptation in Zimbabwe. IIED Climate Change working paper No.3: December 2012: London.
5. Dahwa E., Kativu S., Hungwe T., Mudzengi C. P., Poshiwa X., Murungweni C., Shoko M. D (2014). Influence of grazing intensity on plant community diversity, structure, and composition in dambo wetlands of communal Zimbabwe. Global Journal of biology, agriculture, and health science. Vol.3 (1):259-266.
6. Dube P. (2018). Traditional Leafy Vegetables in Zimbabwe: Agronomic and Market Studies. PhD Thesis. Wageningen University.
7. FAO (2023). Range land condition assessment, ground truthing and mapping report. Enhanced resilience for vulnerable house in Zimbabwe (ERVHIZ) Project: Harare.
8. Gusha J, M Masocha, K Muchaya and S Ncube (2016). Chemical analysis of the potential contribution of lantana camara to the nutrition of browsing livestock.
9. Gusha, J. and Mugabe, P.H. (2013), “Unpalatable and wiry grasses are the dominant grass species in semi-arid savanna rangelands in Zimbabwe”, *International Journal of Development and Sustainability,* Vol. 2 No. 2, pp. 1075-1083.
10. Hare ML, X Wen Xu, YD Wang, Y Yuan, AE Gedda (2021). Do Woody Tree Thinning and Season Have Effect on Grass Species’ Composition and Biomass in a Semi-Arid Savanna? The Case of a Semi-Arid Savanna, Southern Ethiopia. Journal for Environ. Sci., Volume 9 – 2021.
11. Holland, E P, Mugford, J, Binny, R N et al. (1 more author) (2017) How herbivore browsing strategy affects whole plant photosynthetic capacity. Bulletin of Mathematical Biology, 79 (4). pp. 772-787. ISSN 0092-8240.
12. Khati U, M Lavalle, GHX Shiroma, V Meyer and B Chapman (2020). Assessment of Forest Biomass Estimation from Dry and Wet SAR Acquisitions Collected during the 2019 UAVSAR AM-PM Campaign in Southeastern United States.
13. Loje HM; XX Wen; WY Dong; Y You and GA Ebro. (2021). Do Woody Tree Thinning and Season Have Effect on Grass Species’ Composition and Biomass in a Semi-Arid Savanna? The Case of a Semi-Arid Savanna, Southern Ethiopia. Frontiers in Environmental Science 9 (2021). - ISSN 2296-

665X.
14. Madebwe, Victor & Madebwe, Crescentia. (2023). An Exploratory Analysis of the Social, Economic and Environmental Impacts on Wetlands: The Case of Shurugwi District, Midlands Province, Zimbabwe.
15. Maroyi, A. (2013). Use of weeds as traditional vegetables in Shurugwi District, Zimbabwe. *J Ethnobiology Ethnomedicine* 9, 60.
16. Meyer T, Holloway P, Christiansen TB, Miller JA, D'Odorico P, Okin GS. An Assessment of Multiple Drivers Determining Woody Species Composition and Structure: A Case Study from the Kalahari, Botswana. Land. 2019; 8(8):122. https://doi.org/10.3390/land8080122.
17. Mhembwe S, N Chiunya and E Dube (2018). The contribution of small-scale rural irrigation schemes. JÀMBÁ: Journal of disaster risk studies.
18. Moyo, M., Mlilo, T., Dhlamini, T., Chakoma, I. and Lukuyu, B. (2022). Livestock production systems and potential feed and forage options in Zwabagamba in Gwanda District, Zimbabwe. Nairobi, Kenya: ILRI.
19. Musara, K., Nadarajah, S. & Wiegand, M. (2022). Statistical modelling of annual highest monthly rainfall in Zimbabwe. Sci Rep 12, pg.76-98.
20. Ntalo M, KE Ravhuhali, B Moyo, O Hawu and NH Msiza (2022). *Lantana camara*: Poisonous Species and a Potential Browse Species for Goats in Southern Africa—A Review
21. Okorio J, J.A. Maghembe (1994). The growth and yield of *Acacia albida* intercropped with maize (*Zea mays*) and beans (*Phaseolus vulgaris*) at Morogoro, Tanzania. Forest Management and Rangelamnd. Vol 64 Issue 2-3 pp 183-190: Elsevier
22. Papanastasis, V. (1977). Optimum Size and Shape of Quadrat for Sampling Herbage Weight in Grasslands of Northern Greece. Journal of Range Management. 30. 446. 10.2307/3897808.
23. Ran, F., Chang, Ry., Yang, Y. (2017). Allometric equations of select tree species of the Tibetan Plateau, China. *J. Mt. Sci.* 14, 1889–1902.
24. Saleem I, J.A. Mughloo, A.H. Mugha and Afshan Anjum Baba (2019). Quadrant Standardization for Herbaceous Species of Benhama, Ganderbal Area in Kashmir. Int. J. Curr.Microbiol. App.Sci (2019) 8(3): 1697-1705.
25. Sibanda A, S Homann, K Tui, A van Rooyen, J Dimes, D Nkomboni and G Sisito. (2011) Understanding community perceptions of land use changes in the rangelands, Zimbabwe. Experimental Agriculture, Volume 47 / Supplement S1/ January 2011, pp 153-168.
26. Tilahun, Biniam Sisheber and Marshall, Michael and Mengistu, Daniel and Nelson, Andrew. (2023). Assimilation of Earth Observation Data for Crop Biomass and Yield Estimation in Fragmented Agricultural Landscapes.
27. Tokozwayo S, K Mopipi, EC Timpong-Jones (2021). Influence of Tree Density on Vegetation Composition and Soil Chemical Properties in Savanna Rangeland of Eastern Cape, South Africa. Agricultural Sciences. Vol.12.

28. Xu Y, J Zhang, SB Franklin, J Liang, P Ding, Y Luo, Z Lu, D Bao, M Jian. (2015). Improving allometry models to estimate the above- and belowground biomass of subtropical forest, China.
29. Yilangai RM, JD Onoja, S Saha, EB Elisha, SA. Manu, Y Barshep and M Molokwu-Odozi. (2023). Diversity, abundance, and conservation status of woody species in a West African dry forest. Wiley Periodicals LLC:
30. Yilangai RM, JD Onoja, S Saha, EB Elisha, SA. Manu, Y Barshep and M Molokwu-Odozi. (2023). Diversity, abundance, and conservation status of woody species in a West African dry forest. Wiley Periodicals LLC:
31. Zezai1 TA, P H Mugabe and V E Imbayarwo-Chikosi. (2022). Exploring the herbaceous plant height and dry matter relationship on a sub-humid rangeland in Zimbabwe. International Conference on Environmental, Energy and Earth Science. IOP Conf. Series: Earth and Environmental Science 1041 (2022) 012013. IOP Publishing.