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RESEARCH

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Grazing effects on vegetation dynamics in the savannah ecosystems of the Sahel

Haftay Hailu Gebremedhn^{1,2*} , Ousmane Ndiaye^{2,3}, Sylvanus Mensah^{4,5} , Cofélas Fassinou⁶, Simon Taugourdeau^{2,7}, Torbern Tagesson^{8,9} and Paulo Salgado^{2,7}

Abstract

Background The savannah ecosystems of Sahel have experienced continuous and heavy grazing of livestock for centuries but still, their vegetation response to grazing pressure remains poorly understood. In this study, we analysed the herbaceous plant dynamics, measured by species diversity, composition, cover, and biomass in response to grazing pressure in the savannah ecosystems of Sahel. In Senegal, we selected four savannah sites represented with high, moderate, light and no grazing intensity levels. Transect survey methods were used for sampling the vegetation data within each of the sites. Species richness and composition were analysed using species accumulation curve and multivariate analyses. Furthermore, we used General Linear Models and a piecewise Structural Equation Model (pSEM) to examine the relationships between grazing intensity, vegetation cover, diversity and biomass.

Results The herbaceous species diversity and composition varied significantly among the different grazing intensity levels ($p < 0.001$). The plant species composition shifted from the dominance of grass cover to the dominance of forb cover with increasing grazing pressure. Moreover, the attributes of species diversity, herbaceous biomass, and ground cover were higher on sites with low grazing than sites with high and moderate grazing intensity. Across all sites, species diversity was positively related to total biomass. The pSEM explained 37% of the variance in total biomass and revealed that grazing intensity negatively influenced total biomass both directly and indirectly through its negative influence on species diversity.

Conclusions Managing grazing intensity may lead to higher plant production and higher mixed forage establishment in the dryland savannah ecosystems. This information can be used to support land management strategies and promote sustainable grazing practices that balance the needs of livestock with the conservation of ecosystem health and biodiversity.

Keywords Biomass, Biodiversity, *Diodella sarmentosa*, Forb, Grazing intensity, Invasive species, Pastoral ecosystem, Senegal, West Africa

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Background

Two opposing directions of changes in semi-arid rangeland vegetation in response to climatic variables and grazing intensity have been suggested (Behnke 2000; Derry and Boone 2010). First, it is suggested that changes in rangeland vegetation in arid and semiarid areas are primarily driven by rainfall variability (Behnke 2000; Booker et al. 2013), and therefore, moving livestock to cope with periodic droughts is seen as the most appropriate management system for pastoralists (Seid et al. 2016). Second, it is argued that the intensity of livestock grazing should be maintained at a level matching the carrying capacity of the rangelands (Oba et al. 2000; Kassahun et al. 2008; Pricope et al. 2013). Therefore, managing grazing intensity, timing, and distribution can lead to better plant productivity and higher quality mixed forage (Biondini et al. 1998; Egeru et al. 2020). These concepts have strongly influenced the development of rangeland management over the years. Currently, it is difficult to predict which management actions facilitate positive vegetation changes.

Vegetation grazing resistance is a term used to describe the relative ability of plants to survive different grazing conditions (Milchunas and Noy-Meir 2002), and different plant forms and species respond differently to grazing strategies. However, more insights can be gained by considering vegetation grazing resistance as outcome of tolerance (i.e., capable of regrowing more rapidly following defoliation) and avoidance (i.e., species grazed less severely by developing escape mechanisms) or a combination of these two resistance components to realize a competitive advantage within the community (Archer and Pyke 1991). These mechanisms of grazing avoidance include physical characteristics, such as thorns, prickles, and spines that make plants less likely to be grazed by livestock (Milchunas and Noy-Meir 2002). The size, shape, or arrangement of leaves and seeds may also make it difficult for animals to access and feed on the plant (Trlica and Rittenhouse 1993).

Grazing resistance mechanisms and the intensity of grazing shape the species composition and community structure of grazed ecosystems. For example, in heavily grazed rangelands, more palatable plant species are less encountered (Weber et al. 1998; Haftay et al. 2013), while the less or unpalatable species become dominant (Fleischner 1994; Vesik and Westoby 2001; Gemedo-Dalle et al. 2006; Hailu 2017). Moreover, it is common that invasive plant species dominate heavily grazed rangelands, fill the spatial niche left by the suppressed palatable plants, and replace highly diverse native plant communities with uniform communities (Oomen et al. 2016). This makes species composition one of the most important attributes of ecosystems, reflecting the outcomes

of important ecological processes in arid and semiarid rangelands (Rydgren et al. 2020).

Studies showed that forbs (i.e., non-graminoid herbaceous vascular plants) and grasses exhibited different responses to grazing in terms of their vegetation cover (Stahlheber and D'Antonio 2013; Koerner et al. 2018; Siebert and Dreber 2019). Fulbright et al. (2021) noted that cattle selectively forage on grasses, which can reduce competition between forbs and grasses, resulting in an increased abundance of forbs. This increase of forbs' ground cover in response to grazing might be because they have better grazing tolerance than grass. In addition, forb response to grazing in terms of their ground cover may vary depending on the forb species, life form (annual vs. perennial) (McIntyre and Lavorel 2001; Hayes and Holl 2003), origin to the area (native vs. invasive) (Koerner et al. 2018), soil texture (Drawe and Box 1968) and precipitation (Fulbright et al. 2021).

The African Sahel, located at the Saharan desert border, is a region dominated by herbaceous plants and a scattered population of shrubs and trees (Amole et al. 2022). The annual rainfall in the typical Sahel ranges from 400 and 600 mm, and is unimodal with a short rainy season. This limited and unreliable rainfall in combination with poor soils make it difficult to cultivate (Grillot et al. 2018). So for centuries, people have instead support their livelihoods through pastoralism. However, these arid and semi-arid rangeland ecosystems experience different forms of land and vegetation degradation due to external factors such as climate change, drought, desertification (Le Houérou 2002; Tagesson et al. 2015), and grazing is thought to play a major role (Hiernaux et al. 1999; Miede et al. 2010). A grazing pressure beyond a certain threshold may affect these rangelands and thus the native species composition (Amiri et al. 2008), diversity and biomass production is lost (Cingolani et al. 2005). However, defining the native plant species of African rangelands is problematic, because these ecosystems have been exposed to long evolutionary grazing pressure (Backéus et al. 1994).

The dynamics of herbaceous plant species composition, diversity, and biomass production in response to grazing intensity in the savannah ecosystem of the Sahel remain poorly understood mainly due to the absence of permanent sites protected from grazing. Characterizing the livestock grazing intensities and assessing their effect on vegetation attributes are also challenging in these rangeland ecosystems, because the livestock stocking rates are generally unknown. Moreover, even though forbs are a significant part of the herbaceous layer in the Sahelian savannah, studies on the response of forbs to grazing are limited. Most studies have traditionally focused on maximizing forage productivity rather than considering plant

diversity. This approach may result in misinterpretation regarding local species diversity conservation, restoration and management of these ecosystems. Hence, studying the response of both the forbs and grass species to grazing is important to ensure an understanding of the overall ecological dynamics.

Here, we study the response of herbaceous plant dynamics, as measured by species diversity, composition, vegetation ground cover and herbaceous biomass in response to grazing intensity in savannah ecosystems of Senegal. Specifically, we (i) determined the impacts of grazing intensity on species richness and composition; (ii) examined the effects of grazing intensity on percentages of forbs cover, grass cover, total cover, Shannon diversity and total biomass; and (iii) investigated how grazing intensity influenced biomass directly and indirectly through species diversity and vegetation cover.

Methods

Study area

The study was carried out in the savannah ecosystem of the Dahra field site (15° 21' N, 15° 28' W) in the Senegalese pastoral zone (Fig. 1) which is located in the western part of the Sahel region. Mean annual rainfall over the last 50 years in the current study area was 371 mm, which is typical of the Sahel (Taugourdeau et al. 2022). The rainfall in the study area is unimodal with a rainy season from July to October. The soils are mainly sandy loams (Ndiaye et al. 2015a). All life forms of herbaceous plants in the study area are annuals. *Cenchrus biflorus*, *Chloris prierii*, *Diodella sarmentosa* and *Zornia glochidiata* are the most dominant herbaceous species, whereas Balanitaceae, Combretaceae and Mimosaceae are the most dominant woody families in the study area (Ndiaye et al. 2015b). The land-use system is predominantly pastoral and the pastoralists depend on the livestock, with nomadic in lifestyle and much of the land for grazing.



Fig. 1 Map of Senegal with the location of the Dahra field site in the savannah ecosystem of the Sahel

Site selection and management

Characterizing the livestock grazing intensities and assessing their effect on vegetation attributes are difficult in the pastoral production system of the Sahel, because the stocking rate to traditional grazing management system is unknown. To overcome this gap, we used the distance to settlement to characterize the different levels of grazing intensity. We assumed that sites near/surrounding settlements are frequently grazed by livestock and considered high grazing sites, whereas the intensity of grazing decreases with increasing distance from the settlements.

Prior to the selection of the study plots and sampling techniques, a reconnaissance survey was made with resource managers having considerable knowledge of the historical and present grazing of the study area. Following the discussion, sites representing four different levels of grazing intensity were selected to investigate the effects of grazing on the vegetation attributes of the herbaceous plants. They are described as follows:

(1) “High grazing” intensity: One settlement site within the “*Centre de Recherche Zootechnique (CRZ)*” which is managed by the *Institut Sénégalais de Recherche Agronomique (ISRA)* was selected and considered as having highly grazing intensity level (Additional file 1: Fig. S1-A). The settlement site (CRZ) was established in 1950 to study livestock demography trends through restricted mobility with other animal sciences-related research. The livestock species belonging to CRZ were cows (*Bos taurus indicus*). The demographic analysis of the cow herd indicates the variability of the number which reach its peak in 1984 with 2203 heads with subsequent decrease reaching 138 heads during the study period in 2022. The size of the CRZ, surrounding the settlement area, is 900 ha. This grazing site has two forms of grazing pressures: (i) it has been grazed throughout the year by cows belonging to the CRZ, and for decades since the establishment of the farm. These cows have no other alternative feed sources and are not mobile like the pastoralist’s livestock. During the prolonged dry season, the vegetation within the settlement is always over grazed leading to poor animal body condition performance and death due to feed shortage. (ii) It has been grazed by livestock species of cattle (*Bos taurus indicus*), sheep (*Ovis aries*), goat (*Capra aegagrus hircus*), and horses (*Equus ferus caballus*) belonging to the pastoralists who settled within and around the area and came from other places for a short period to search for feed. However, when the vegetation around the area is grazed these pastoralists move their animals to other grazing sites.

(2) “Moderate grazing” intensity: one site far away (approximately 10 km) from the settlement was selected and considered as a moderately grazing intensity level

(Additional file 1: Fig. S1-B). This communal open grazing area represents the most common land-use system in Senegal and it is a typical Sahelian savannah ecosystem. The pastoralists use such type of land for livestock grazing throughout the year. Cattle, goats, and sheep are the dominant livestock species that graze in the area. The forage availability and biomass production vary by season. Higher forage biomass and better nutritive value are available during the vegetation growth period and early dry season (August to December). From January to May, a low forage biomass remains. Consequently, most of the pastoralists start to move their cattle in the search for better feed resources. From May to July, this animal largely depends on foliage and pods from woody plants. Assouma et al. (2018) estimated that the average livestock stoking rate in the region varied, with a maximum of 0.43 Tropical Livestock Unit-TLU/ha in the rainy season and a minimum of 0.31 TLU/ha in the dry season. However, we assumed that the grazing intensity was greater in areas close to the settlement because of higher livestock concentrations.

(3) “Light grazing” intensity: an enclosure site used for grazing during the dry season only was selected and considered as a site with light grazing (Additional file 1: Fig. S1-C). This site was established within some part of the highly grazing sites (within the CRZ settlement) and adjacent to the moderately grazing site. The size of the enclosure was about 20 ha and fenced for about 5 years. The objective of enclosure was to assess the regeneration of grass species and forage productivity by controlling livestock access during the vegetation growth period. Like the other grazing site, cattle, goats, and sheep are the dominant livestock species that graze the area during the dry season from January to July. However, because the animals could randomly enter and graze in the enclosure, we could not estimate the stoking rate at this site.

(4) “No grazing” intensity: finally, an area with no grazing activity was selected, which has been fenced for about 18 years (Additional file 1: Fig. S1-D). This site is approximately 0.32 ha in area, and was established in the centre of the highly grazing intensity site (i.e., within the CRZ settlement). The site has been protected from livestock access throughout the year; however, the standing dry biomass is used for hay production by cutting the herbs at a sustainable utilization factor (25–35%) during dry season (mainly in April).

Sampling design

Transect survey methods were used to sample the vegetation data within the four sites. At the highly grazing site, a 7-km transect was laid out, covering the periphery from the east to west of the CRZ settlement. Along this transect, 1-m² quadrats at 200-m intervals were

placed, yielding 36 quadrats. At the site of the moderate grazing, a 4-km transect was laid out from the east to west, and 1-m² quadrats at 200-m intervals were systematically installed, resulting in 21 quadrats. The light-grazing (enclosure) site was 400 m × 500 m. A 400-m transect was laid out to sample the vegetation, covering the periphery from the east to west of the enclosure. 21 quadrats of 1-m² each were placed along this transect at 20-m intervals. The no-grazing site was 80 m × 40 m. In the 80-m long direction, we established three parallel transects separated by 10-m intervals. Within these transects, 1-m² quadrats at 10-m intervals were placed, yielding 21 quadrats.

Data

From each of the 1-m² quadrats, data on species composition and richness, ground cover and biomass were collected. The measurements were taken in September 2022 when the vegetation was at its peak flowering stage. Species composition was estimated by rating the percentage of each species abundance in the quadrats and assigned them to one of two growth forms: forbs or graminoids (henceforth ‘grasses’). We did not subdivide forbs into nitrogen-fixing and non-fixing species because of the low number of nitrogen-fixing species in the area. Then, the proportion of all forbs and grass species dominance was summed up for each quadrat across the sites to estimate forbs and grass cover separately. The proportion of soil surface covered by herbaceous plants (vegetation ground cover) was also estimated visually for each quadrat. Species richness was determined as the total number of species encountered in the quadrats. The diversity of species was computed using the Shannon–Wiener index (H') calculated following Krebs (1999):

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

where s = number of species; p_i = proportion of individuals or abundance of the i^{th} species; and \ln is the natural logarithm to the base e .

The aboveground herbaceous biomass was estimated by harvesting live and dead material at ground level from each of the quadrats and all the 99 quadrats across the four sites. The harvested samples were weighed in the field to get fresh weight. Thirty percent of the harvested samples from each quadrat were placed in a paper bag for later dry matter analysis. This harvested biomass was dried in an oven at 105 °C for 48 h, and then weighed to obtain the dry matter. Then, the total dry biomass in each quadrat was calculated by multiplying the proportion of each dried sample biomass by the weight of the total fresh biomass.

Statistical analyses

All analyses were performed with the R Statistical Software version 4.2.2 (R Core Team 2022). We determined the impacts of grazing intensity on species richness and composition using species accumulation curve and multivariate analyses. The grass and forb diversity was quantified based on the species × quadrat abundance matrix, the estimated species richness using the *accuncomp* function of the *Biodiversity R* package (Kindt and Coe 2005). A sample-based rarefaction procedure was used to estimate the 95% confidence intervals and compare the patterns of plant richness among grazing intensities. To determine the impact of grazing on the species similarity, we performed an Analysis of Similarities (ANOSIM) test using the “*anosim*” function in the *vegan* package (Oksanen et al. 2022). ANOSIM is a non-parametric test of significant difference between two or more groups, based on any distance measure (Clarke and Ainsworth 1993), and used for taxa-in-sample data, where groups of samples are to be compared. Then, a non-metric multidimensional scaling (NMDS) was used to group plots with similar species into separate classes using the Bray–Curtis dissimilarity matrix. The NMDS analysis was performed using the *metaMDS* function in the *vegan* package (Oksanen et al. 2022). Stress value was used as a criterion of efficiency, where stress is the departure from monotonicity in the plot of distance in the original p -dimensional space (dissimilarity) vs. distance in the ordination space (k -dimensional space) (Fasham 1977). A rule of thumb is that stress < 0.05 provides an excellent representation in reduced dimensions, < 0.1 is great, < 0.2 is good/ok, and stress > 0.3 provides a poor representation (Clarke 1993). Moreover, species composition collected from the quadrats was averaged for each of the four grazing areas to determine the relative dominance of each species of the four grazing sites.

We used General Linear Models (GLM) to test for significant ($p < 0.05$) effects of grazing intensities on forb-, grass- and total percentage cover, Shannon diversity and standing aboveground biomass. Specifically, GLM with family binomial was used for forb-, grass- and total percentage cover modeled as percentage data (Zuur et al. 2009), while the Gaussian family was used for Shannon diversity and total biomass due to the normality of their distribution. Mean values and standard errors were represented graphically for better visibility. In addition, we tested for the significance of grazing intensity-dependent effects of Shannon diversity on biomass. Specifically, we assessed both the main and interaction effects of the grazing intensity with Shannon diversity, using linear models (biomass ~ grazing intensity × Shannon diversity).

Finally, we used piecewise Structural Equation Modelling (pSEM) to investigate how grazing intensity

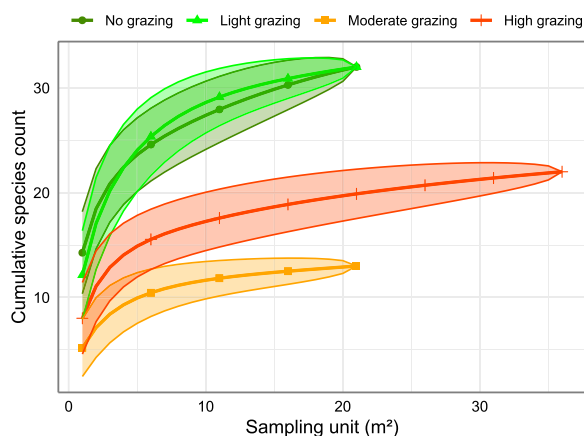


Fig. 2 Species accumulation curves showing for each grazing intensity the expected number of species as a function of sampled m^2

influenced biomass directly and indirectly through species diversity and vegetation ground cover. We used pSEM because it can accommodate a variety of model structures and assumptions on the response variables (Lefcheck 2016). Specifically, we first assessed how grazing intensity influenced vegetation ground cover, species diversity and biomass. Next, we evaluated the direct influence of ground cover and species diversity on biomass. In the pSEM grazing intensity was analysed as an ordinal categorical variable recoded as 0 for no grazing, 1 for light grazing, 2 for moderate grazing and 3 for high grazing intensity. The pSEM was fitted using pSEM function in the piecewiseSEM package (Lefcheck

2016). The overall fit of the pSEM was assessed based on the Fisher’s C statistic and associated p value (Lefcheck 2016).

Results

Species richness and composition

A total of 48 herbaceous species from 17 families were identified in the study area. The higher numbers of species were observed in the no and light grazing sites than in the moderate and high grazing sites (Fig. 2).

The herbaceous plant community composition varied significantly (ANOSIM: $R=0.46$, permutations=999, $p<0.001$) among sites with different grazing intensity (Fig. 3). The NMDS ordination revealed that plant community composition changed markedly with decreasing grazing intensity (half change = 1.16, stress value = 0.18, and $R^2=0.97$; Fig. 3b).

Notably, about 85% of the sites in the moderate and high grazing and 80% of the site in the light grazing were dominated by the forb species of *Diodella sarmentosa*. However, in the no grazing site, *D. sarmentosa* was not found, while grass species such as *Cenchrus biflorus* and *Chloris prierii* were dominant at 28% and 33%, respectively (Additional file 1: Table S1).

Herbaceous ground cover, diversity and biomass

Percent of vegetation ground cover was significantly (Chi-square=80.6, $p<0.001$; Table 1) different between the different grazing intensities. The vegetation total cover and grass cover decreased with increasing grazing intensity (Fig. 4). On the contrary, forb cover was

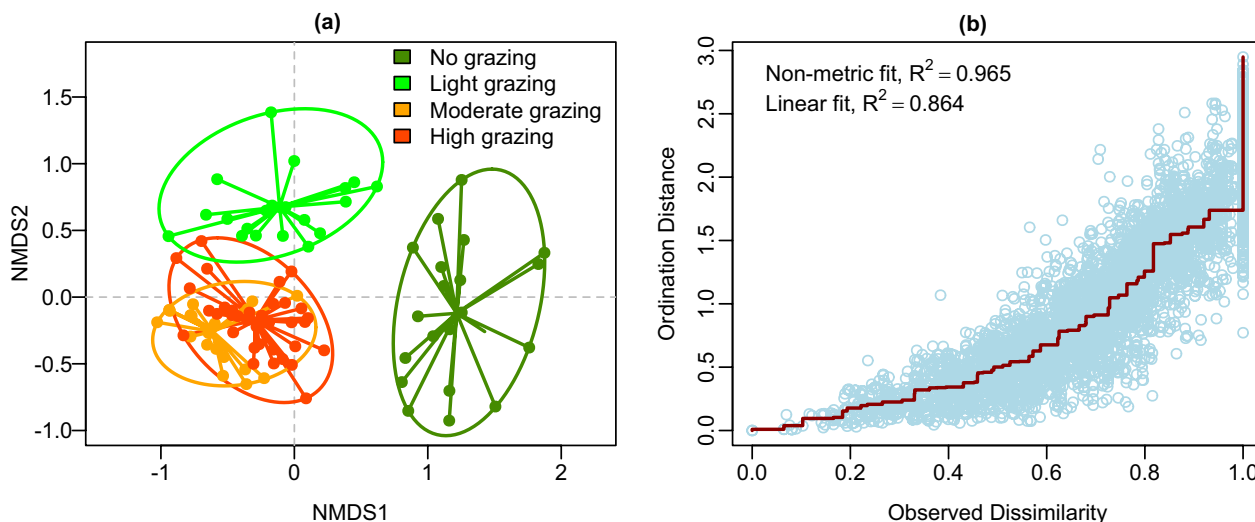


Fig. 3 Ordination plot **a** of the plant community composition obtained from the non-metric multidimensional scaling analysis (NMDS) based on Bray–Curtis dissimilarities, and **b** stress plot of the NMDS

Table 1 Results of general linear models testing the effects of grazing intensities on forb, grass and total percentage cover, Shannon diversity and total biomass

	Df	Deviance/Sum Sq	Mean Sq	LR Chisq/F value	p value
Percentage of forb cover					
Grazing intensity	3	50.11		420.3	< 0.001
Residuals		9.58			
Percentage of grass cover					
Grazing intensity	3	50.21		437.1	< 0.001
Residuals		9.26			
Total percentage cover					
Grazing intensity	3	17.23		80.6	< 0.001
Residuals		9.50			
Shannon diversity					
Grazing intensity	3	7.43	2.48	20.79	< 0.001
Residuals	95	11.31	0.12		
Shapiro–Wilk test ($W=0.98$; $p=0.525$)					
Total biomass					
Grazing intensity	3	9.59	3.19	23.61	< 0.001
Residuals	95	12.88	0.14		
Shapiro–Wilk test ($W=0.97$; $p=0.105$)					

Df: degrees of freedom; sum Sq: sum of squares; Mean Sq: mean square; LR Chisq: likelihood ratio Chi-square

significantly lower in the no grazing sites than in the grazing sites (Table 1; Fig. 4).

Species diversity (Shannon diversity) was also significantly ($F=20.79$, $df=3$, $p<0.001$) different among grazing intensities. Significantly higher species diversity was found in the low compared to the high grazing intensity plots (Fig. 4), also corroborating the results of species accumulation curves. Total biomass varied significantly among grazing intensities, with higher values on no grazing and light grazing sites and lowest values on moderate and high grazing sites (Table 1; Fig. 4).

Main and interaction effects of grazing and diversity on herbaceous biomass

Herbaceous total biomass was significantly related to diversity ($p<0.001$) and grazing intensity ($p<0.001$). However, the interaction effects of diversity and grazing intensity were not significant (Table 2). Results further showed a positive relationship of species diversity with total herbaceous biomass across all grazing sites (Fig. 5).

Direct and indirect influence of grazing intensity on total herbaceous biomass

The piecewiseSEM explained 37% of the variance in total biomass and showed a good fit to the data ($p>0.05$; Fig. 6). In terms of the direct effects, increasing grazing intensity significantly decreased species diversity, vegetation cover and total biomass (Table 3; Fig. 6). However,

unlike vegetation cover, increasing species diversity was associated with higher total herbaceous biomass (Fig. 6). Grazing intensity also influenced total herbaceous biomass indirectly through its negative effect on species diversity ($\beta=-0.56\times 0.21=-0.12$; Table 3; Fig. 6).

Discussion

We found that the species richness accumulations for no, light, moderate, and high grazing intensities were 31, 30, 22, and 13, respectively (Fig. 2). The sites considered as high and moderate grazing in this study severely impede the regenerative ability of grass species and result in a decline in species richness possibly due to the local extinction of native species. Higher number of grass species were found in the no-grazing and light-grazing sites, but abundance was low in the light-grazing sites (Additional file 1: Table S1). The low abundance of grass species in the light grazing site might be related to the deficiency of viable soil seed banks. It has been suggested that the recovery of vegetation after the removal of grazing depends on several factors, including the availability of soil seed banks (Gebregergs et al. 2019).

Moreover, the species composition showed a clear relationship with grazing intensity (Additional file 1: Table S1; Fig. 3). The ability of a species to persist in a grazing environment is a result of both grazing resistance through tolerance and avoidance (Zainelabdeen

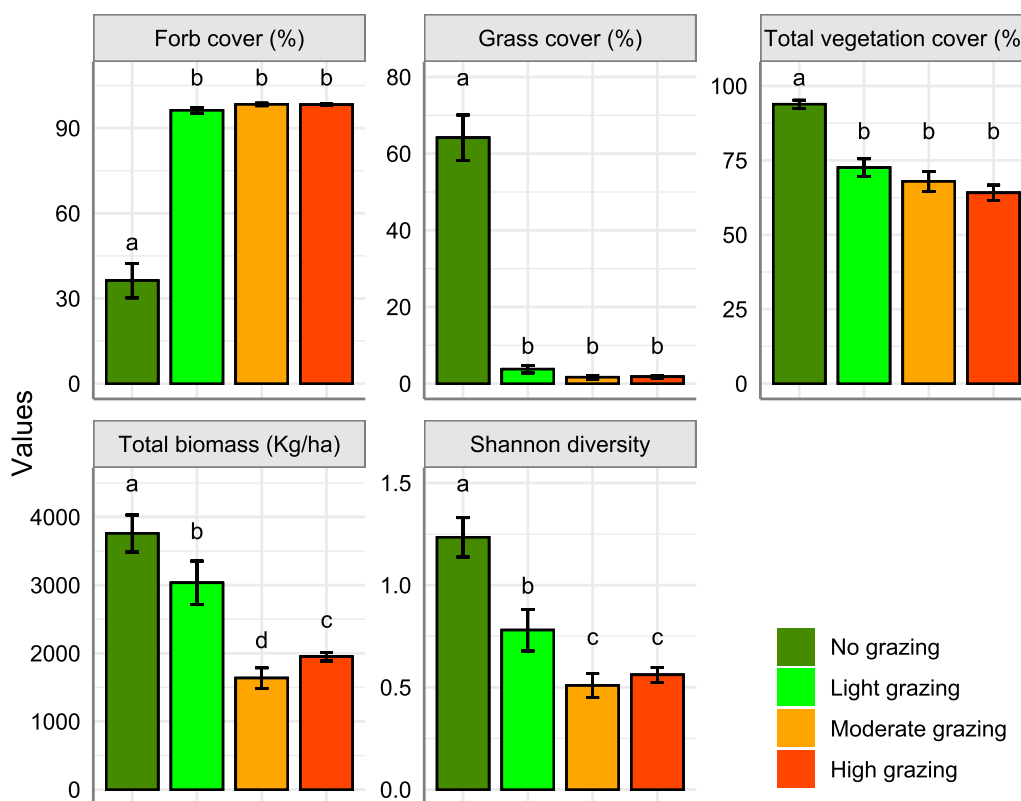


Fig. 4 Barplots showing means ± standard error of forb, grass and total vegetation cover, total biomass and Shannon diversity. The letters denote comparison between grazing intensity levels

et al. 2020), as can also be seen in the finding that about 85% of the high and moderate grazing and 80% of the light grazing areas were dominated by *Diodella sarmentosa* (Additional file 1: Table S1). This species was not identified during the period 1964 to 2011 (Ndiaye et al. 2015b), indicating that it aggressively invaded the study area in recent years suppressing the formerly dominant native species of the area. *D. sarmentosa* produces a large number of viable seeds, hairy leaf surface, and delayed elevation of growing points as mechanisms for grazing tolerance and avoidance.

Table 2 Analysis of variance resulting from the linear model testing for effects of grazing intensity and Shannon diversity on total herbaceous biomass

Total herbaceous biomass	Df	F value	Pr (>F)
Shannon diversity	1	37.14	<0.001
Grazing intensity	3	11.74	<0.001
Grazing intensity × Shannon diversity	3	0.87	0.462
Residuals	91		

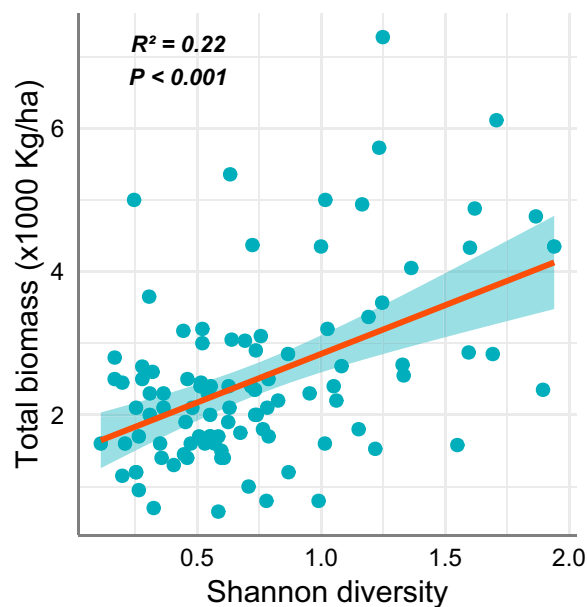


Fig. 5 Scatterplot showing the effect of species diversity (Shannon diversity) on herbaceous biomass across all grazing sites

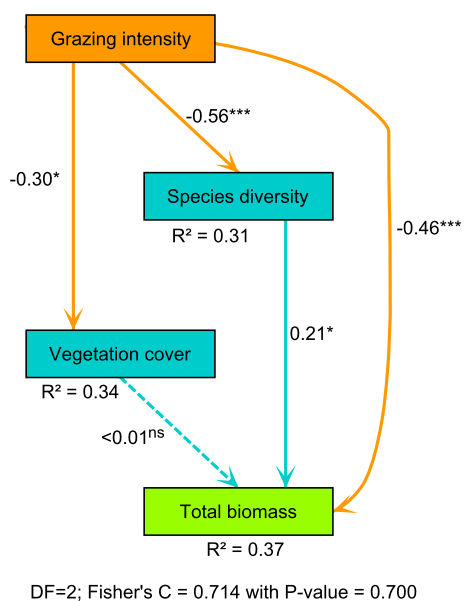


Fig. 6 Graphical representation of the piecewise structural equation model showing the inter-related pathways between grazing intensity, species diversity (Shannon diversity), vegetation cover and total herbaceous biomass. Arrows are the hypothesized causal paths. The values next to the arrows are the standardized path coefficients and their significance is given in Table 3. Paths with dark-orange colour stand for negative effects, whereas paths in turquoise colour indicate positive effects. Non-significant effects are shown with dashed arrows. *df* degree of freedom; ns: $p > 0.05$; * $p < 0.05$; *** $p < 0.001$

However, plants that invest heavily in defence may not be as competitive as plants that invest little in such mechanisms under low grazing (Trlica and Rittenhouse 1993). In line with this, *D. sarmentosa* was not observed in the no-grazing site; instead, the grass species such as *Cenchrus biflorus* and *Chloris prieruii* were the most dominant. These results collectively imply that dominance of plant species depends on a trade-off between grazing avoidance and competitive ability. Moreover, *Senna obtusifolia* is an invasive forb species recently introduced to the study area, but its distribution is still low (Additional file 1: Table S1). Studies demonstrated that *S. obtusifolia* could completely dominate grass species, reducing pasture growth and excluding stock (Dunlop et al. 2006; Gebrekiros and Tessema 2018). Hence, proper management that restricts the expansion of this species is required before the natural ecosystems in the Sahel are under threat of invasion.

Studies have shown that herbaceous plants with prostrate growth form might have a competitive advantage, as they can better escape frequent grazing and shading by the tall grass species (Noy-Meir et al. 1989; Hirata et al. 2010). In the current study, *Zornia glochidiata* with prostrate growth form was the second most

Table 3 Significance of the piecewiseSEM paths testing the inter-relations between grazing intensity, species diversity (Shannon diversity), vegetation cover and total biomass

Response variable	Predictor	Standardized estimate	p value
Shannon diversity	Grazing intensity	-0.560	0.000
Percentage cover	Grazing intensity	-0.301	0.024
Total biomass	Shannon diversity	0.213	0.033
Total biomass	Percentage cover	0.002	0.982
Total biomass	Grazing intensity	-0.464	0.000

dominant species at the sites with high and moderate grazing pressure. Moreover, previous studies showed that the species with prostrate growth form, such as *Dactiloterium aegyptium* and *Z. glochidiata*, were the most dominant in the current grazing sites (Ndiaye et al. 2015b; Tagesson et al. 2015). This indicated that in the absence of the invasive species of *D. sarmentosa*, the native species with prostrate growth form could have a better competitive ability for grazing pressure and the harsh environmental conditions in the Sahelian savannah ecosystem.

Overall, grazing had a significant impact on the segregation of vegetation cover of the rangeland. All the grazing sites were dominated by forb species, whereas the site without grazing had a dominant grass cover (Fig. 4). This suggests that certain forb species benefit from reduced competition with grass and were able to colonize the grazed areas. The decline in the cover of highly palatable grass species observed is also consistent with findings from other semi-arid ecosystems (Sanaei et al. 2021). As indicated by Gemedo-Dalle et al. (2006) the decrease in grass species with increasing grazing pressure might be an indicator of the deteriorating conditions of the rangelands. The total vegetation ground cover decreased with the increase in grazing intensity. This finding aligns with the results reported by Sternberg et al. (2000), who observed a decrease in vegetation ground cover with higher grazing intensity in the Mediterranean herbaceous community.

Species diversity was significantly higher in the no-grazing site than in the light-grazing site (Fig. 4). Moreover, higher species diversity was recorded in the light-grazing site than in the moderate and high-grazing sites. This result also complements previous findings that areas protected from grazing yield higher species diversity compared with continuously grazed sites (Miehe et al. 2010). The intermediate disturbance hypothesis suggests that species diversity is expected to be highest at intermediate levels of disturbance and decline at low or high levels of disturbance (Connell

1978). However, in this study, high species diversity was observed in the low disturbance, no-grazing site and increasing species diversity was associated with higher total biomass. This finding deviates from the expectations of the intermediate disturbance hypothesis. A possible explanation could be that the medium grazing intensity area is most likely also relatively highly grazed, even though being less than the highly grazing site.

The herbaceous biomass in the high-grazing sites was twice lower than the no-grazing sites. In line with this study, Biondini et al. (1998) found that grazing pressures lead to a removal of 50% of vegetation productivity. In contrast, Tagesson et al. (2016) reported that years with high grazing had higher vegetation productivity than years with low grazing. The increase in herbaceous biomass in light and no grazing sites could be linked to the reduction in grazing pressure and subsequent accumulation of soil organic matter during the resting period (Noulèkoun et al. 2021a; Gebremedhn et al. 2022). In line with this study, there exists a possibility for increased biomass under wet-season resting periods (Ash et al. 2011) and less or no grazing (Mekuria et al. 2018).

While both diversity and biomass declined with increasing grazing intensity, there was little evidence for significant interaction effects of grazing intensity and species diversity on biomass, which suggests that diversity effect on herbaceous biomass did not depend on grazing intensity. A plausible explanation for this finding is the proportionate response of diversity and biomass to grazing intensity (Fig. 4), but the idiosyncratic patterns of forb and grass response to increasing grazing could also partly play an active role. In particular, we argued that the dominance of grasses contributed to the diversity effects on biomass in the no grazing sites while dominance of forbs seemed to contribute to the diversity effects on biomass in higher grazing sites.

The bivariate analysis of species diversity and herbaceous biomass indicated that, across all grazing sites, diversity had a positive effect on biomass. The piecewiseSEM revealed that increasing grazing intensity had direct effects on species diversity, vegetation ground cover, and total herbaceous biomass. In addition, grazing intensity had an indirect negative influence on total herbaceous biomass through its negative impact on species diversity. These results corroborate the insights that grazing intensity plays a crucial role in shaping these ecological variables. The positive effect of diversity on herbaceous biomass is reminiscent of recent findings, and has repeatedly been explained by mechanisms, such as complementarity and dominance effects as diversity increases (Noulèkoun et al. 2021b). Specifically, increase in biomass production with increasing species diversity is attributed to the fact that species-rich ecosystems

experience high-level resource-use complementarity and facilitation by co-occurring species. This is possibly the case in the no-grazing sites which had high number of grass species (>60% cover) but also >30% coverage in forb species. On the contrary, high occurrence of forb species (e.g., *Diodella sarmentosa*) in the moderately and heavily grazed sites reflect the dominance effects facilitated by grazing activities, but also some reduced competition with grass, enabling these forbs to colonize grazed areas and increase biomass production.

Conclusions

The results of the study indicate that there were significant differences in herbaceous species richness and composition among the plots with varying grazing pressure. The plant species composition shifted from a dominance of grasses in no grazing sites to a dominance of forbs in higher grazing sites. Plots with low grazing pressure had higher species diversity, herbaceous biomass, and ground cover compared to plots with moderately and highly grazing pressure. Species diversity was found to be significantly related to total herbaceous biomass across all sites. However, diversity effect on biomass did not vary between grazing intensities, possibly due the dominance of grass species in no-grazing site, and of forb species on sites with higher grazing intensity. Grazing intensity also had a negative indirect influence on total biomass through its negative influence on species diversity. Based on these findings, it can be concluded that managing grazing intensity can result in higher plant productivity and promote the establishment of mixed forage in the dryland savannah ecosystem of the Sahel. This information is valuable for guiding land management strategies and promoting sustainable grazing practices that consider both livestock needs and the conservation of the ecosystem health and biodiversity.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13717-023-00468-3>.

Additional file 1: Contains Figure S1 and Table S1. Figure S1. Pictures of field sites in dry and rainy season at Dahra savannah ecosystem of Senegal. **Table S1.** Herbaceous species origin, growth form and their composition (%) under the four different grazing intensities in savannah ecosystem of Sahel (NG = No grazing; LG = light grazing, MG = moderate grazing; HG = High grazing). Intermediate falls between prostrate and erect growth forms; Climbing means twining growth form or using surrounding structures for support.

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Author contributions

Conceptualization, HHG; methodology, HHG; software, HHG; validation, HHG, SM and PS; formal analysis, HHG and SM; investigation, HHG, ON, CF, ST, TT and PS; data curation, HHG; writing—original draft preparation, HHG; writing—review and editing, HHG, ON, SM; CF, ST, TT and PS; project administration, HHG and PS; funding acquisition, HHG, ST and PS. All authors read and approved the final manuscript.

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Availability of data and materials

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations**Ethics approval and consent to participate**

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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