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Effects of Cattle Stocking Rate on Soil Quality and Herbaceous Vegetation Composition in South Omo Zone, Ethiopia

Denbela Hidosa*

Southern Agricultural Research Institute, Jinka Agricultural Research Center, Ethiopia

Abstract

The range-land ecosystem is important because it provides vast grazing areas that serve as the primary source of feed for domestic and wild animals, as well as serving as their habitat. However, the current productivity of range-land is diminishing due to invasion of cultivation land, climate change as well as excessive livestock grazing pressure. This study aimed to assess impact of different cattle stocking rate soil chemical parameters, vegetation diversity and dry matter yield of herbaceous species. A total of one hectare of range-land which have nearly equal carrying capacity was divided into 12 paddocks in which 0.08ha each paddock and randomly stocked with heavily-stocking rate of five animals unit per month/ ha (T1); moderately-stocking-rate of 2.4 animal unity per month/ha (T2) and lightly-stocking-rate of 1.67 animal unity per month/ha (T3). The higher organic carbon and organic matter were observed from the plot stocked with T3 as compared to plot stocked withT1 and whereas, lower nitrogen content was obtained from plot area stocked with T1 than plots stocked T2 and T3. Likewise, lower dry matter yield of 2.77 t /ha was obtained from plot area stocked with T1 as compared to plots stocked withT2 (4.52 t/ha) and T3 (4.81 t/ha). The grass species diversity and richness were not influenced (P>0.05) by different stocking rates, but more grass species diversity was obtained from plot area that stocked with T2 than T1 and T3, whereas the lower (P<0.05) grass species richness was obtained from plot area that stocked withT1 as compared plots stocked withT2 and T3. Overall results from this study indicated that lightly stocking rate (T3) has the potential to improve forage dry matter yield, soil chemical compositions and herbaceous species diversity and richness as compared to heavily and moderately stocking rates.

Keywords: Dry matter yield; Species diversity; Soil composition; Stocking rates

Introduction

Range-lands are indispensible for extensive grazing, which is the principal basis of forage and habitat for both domestic and wild animals [1, 2]. In addition, range-lands provides vital goods and amenities for humans include food, timber, fresh water, protection from natural disasters, carbon storage, tourism and recreation [3]. However, currently the productivity of range-land is believed to be degraded due to many factors [4, 5]. It is evidenced that the extreme livestock grazing is among an important principal factors that dwindling the plant species structure, diversity, richness and biomass production potential of range-land [6-12]. Moreover, the extreme livestock grazing have been changed the palatable plant species composition (decreasers) to unpalatable species (increasers) [11, 12]. According to various scholars, moderate livestock stocking can be utilized as a beneficial management tool for maintaining plant species-diversity and enhancing the fertility of range-land soil [10-13]. The study reported by [14] also confirmed that the plant species dynamics and biomass production potential of range-lands that been grazed by cattle with low-to-moderate levels of stocking rate have been improved as compared to rangeland no grazed with cattle. Additionally, the discrepancy between the carrying capacity of the range-land and the number of livestock indicates the need for numerous alterations in different soil characteristics. The effects of light, moderate, and heavy cattle grazing on soil-chemical composition were studied by [15] and [16] and their findings revealed that areas with high stocking rate had lower levels of organic material and nitrogen content compared to areas with moderately and lightly grazed. In the study area, the main source of livestock feed is from range-land [17, 18]. However, this range-land has undergone serious degradation due to pastoralists grazing their livestock beyond the carrying capacity of the range-land. This is because pastoralists are unaware of the effects of high stocking rate on species diversity and richness, rangeland biomass yield, and the chemical composition of the soil [5, 19]. In this favors, evaluating appropriate grazing intensity for improved livestock production is imperative to use appropriate stocking rate as an important rangeland improvement tool. Hence, the aim of this study was to assess the impact of various stocking rates on the soil's chemical compositions, herbaceous vegetation composition and biomass yield production.

Materials and Methods

Experimental site

The study was carried out in the Shaba-Aregemenda Kebele, which is part of the Bena-Tsemay district, from 2017 to 2019. The study area is situated between 501'0" and 5073'0" North latitude and 36038'0" and 37007'0" East longitude in the Southern Nations, Nationalities and People's Regional States. The study area is known for its semi-arid and arid climate, with an average annual rainfall of 838mm and temperatures ranging from 26-35ºC. In terms of vegetation, the study area is predominantly covered by herbaceous and woody plants [17-19]. The dominant woody species were Acacia, Grewia, and Solanum, with varying densities. In the enclosures, the dominant grass species was Cenchrus ciliaris, while in communal grazing areas it was Cynodon dactylon and Tetrapogon tennulis, and in riverside grazing areas it was also C. dactylon [18].

***Corresponding author:** Denbela Hidosa, Southern Agricultural Research Institute, Jinka Agricultural Research Center, Ethiopia, E-mail: denbelahidosa@gmail.com

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Experimental site and treatments

In 2016, one hectare of rangeland was fenced using locally available woody material for the purpose of studying the effects of stocking rates on the condition of the range. The fenced area was divided into twelve paddocks, each with an area of 0.08 hectares and similar carrying capacity. The paddocks were carefully fenced off using locally available woody material, with the help of pastoral communities, to prevent the movement of experimental animal units from one paddock to another. Different cattle stocking rates were used per each paddock, and the vegetation was completely grazed and the standing biomass trampled down and partially incorporated into the upper soil layer. The cattle stocking rates used in this study as experimental units were: heavy stocking rate of five animal unit per month/ha (T1), moderate stocking rate of 2.4 animal unit per month/ha (T2), light stocking rate of 1.67 animal unit per month/ha (T3) and control comprised permanent enclosures only (T4) and each grazing treatment was replicated three times per paddock. An experimental site was protected from livestock for three years (2017-2019) after introduction of cattle with different stocking rates and whereas, animals in each paddock were allowed to continuously graze, with unrestricted and uninterrupted access to the grazing unit, for a period of 2 months (December and January).

Soil sample collection and analysis

Within each paddock, three samples every five meter transects were placed in a Z-shaped orientation, starting at least two meter away from the boundaries of each paddock in order to avoid edge effects at end of experimental periods (November, 2019). Three 0.5m² quadrats were placed along each paddock, with a distance of one meter between them. Soil samples from the upper 20 cm were collected at the center of each quadrat. These three soil samples from each quadrat were mixed together to create a composite sample weighing one kg. The soil samples collected from the field were taken to JARC- soil laboratory. Then samples were sieved through a 2 mm mesh to remove stones, roots, and large organic residues. After that, they were allowed to air-dry and sealed in plastic bags and stored at room temperature for further chemical analyses. The soil sample was analyzed at soil laboratory located at Debere Birhan Agricultural Research Center. The method of [20] was used to determine the levels of organic soil carbon and organic matter, while the Macro kjeldahal method [21] was used to calculate the total nitrogen. The method of [22] was employed to analyze the levels of available phosphorus (P) and exchangeable potassium (K).

Dry matter yield determinations

The herbaceous species within a one meter by one meter sample quadrat were harvested at ground level using hand shears to determine the yield of dry matter. From each paddock, samples of the three herbaceous species were harvested and categorized into highly desirable, moderately desirable, and less desirable species of grasses, legumes, and forbs. The dry matter yield was determined by drying the samples in an oven at 1050C for 24 hours at the Jinka animal feed and nutrition laboratory. The dry matter yield (in tons per hectare) was calculated using a recommended formula provided by [23].

The dry matter yield (t/ ha) = TFW x (DWss /HA x FWss) x 10; where TFW= total fresh weight kg/plot, DWss=dry weight of subsample in grams, FWss =fresh weight of subsample in grams, HA=Harvest plot area in square meters and 10 is a constant for conversion of yields in kg/m2 to t/ ha.

Determination of herbaceous species composition

The herbaceous species composition was assessed by harvesting three quadrats of 1m x 1m randomly by throwing the quadrat each time towards the back. The cut samples were transferred into properly labeled paper bags and fasten at the top. In addition, to help in identify the collected species, representative plants with flowering head and other vegetative parts from each species were collected and dried in presses. Following drying, the specimens were mounted and very few common species were identified right in the field using books [24] and almost all of the species were given code numbers and transported to the Adami Tulu Agricultural Research Center for identification and proper nomenclature. The nomenclature names were assigned with the assistance of trained botanists from the Adami Tulu Agricultural Research Centre. The identified herbaceous species were classified into highly desirable, moderately desirable and less desirable by cattle based on the information obtained from the experienced pastoralists from study area. The herbaceous species composition was determined by randomly harvesting three quadrats measuring 1m x 1m, each time throwing the quadrat towards the back. The harvested samples were then placed in labeled paper bags and sealed at the top. Additionally, to aid in identifying the collected species, representative plants with flowering heads and other vegetative parts were collected from each species and dried in presses. After drying, the specimens were mounted and a few common species were identified in the field using books [24], while the majority of the species were given code numbers and transported to the Adami Tulu Agricultural Research Center for identification and proper naming. The nomenclature names were assigned with the help of trained botanists from the Adami Tulu Agricultural Research Centre. Based on information provided by experienced pastoralists from the study area, the identified herbaceous species were classified as highly desirable, moderately desirable, or less desirable for cattle. Accordingly, highly desirable species are species that decrease in number and are perennial, and they are highly palatable according to the perceptions of pastoralists. On the other hand, moderately desirable species are those that increase in abundance with moderate over-utilization, are perennial, and have average or high palatability. The less desirable species are those that increase in abundance with severe or extremely severe over-utilization.

The Shannon-Wiener diversity index (H) was used to calculate species diversity by considering species richness(S) [25, 26]. The Shannon Index (H) = - ∑pi ln pi. In the Shannon index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log; Σ is the sum of the calculations.

Data analysis

The numerical response variables considered in this study were herbaceous species diversity and richness, herbaceous species biomass yield, and soil compositions such as organic carbon, organic matter, total nitrogen, carbon to nitrogen ratio, available phosphorus, and exchangeable potassium. Stocking rates, which were heavily, moderately and lightly, were considered as fixed variables. The data collected was checked for normality and analyzed using the General Linear Models (GLM) procedure of the statistical analytical system (SAS) [27]. Significant differences among means of the tested grazing intensity levels were declared at $P \leq 0.05$, and means were separated using Duncan's least significant difference (LSD) test with this model. Yijk = μ + Ti + eijk, where; yijk = dependent variables (species diversity and richness, dry matter yield and soil parameters);

μ = overall mean; Ti = the impact of cattle stocking rates (heave, moderate and lightly); and eijk = random error.

Results and Discussion

Impacts of stocking rate on soil chemical composition

The impacts of stocking rate on chemical compositions of soil are presented in Table 1. The nitrogen content was significantly (P<0.05) affected by stocking rate, lower value was recorded for the area received T1 than areas stocked T2 and T3. But, the organic carbon and organic matter were not significantly (P>0.05) affected by stocking rates but better soil organic matter and organic carbon were observed from plots stocked by T3 and T2 as compared to area stocked by T1. Moreover, the findings from this study revealed that carbon to nitrogen ratio, phosphorus and potassium contents were not significantly (P>0.05) affected by three cattle stocking rates (T1, T2 and T3), but the higher carbon to nitrogen ration and available phosphorus were obtained from the area stocked by T1 as compared to areas stocked by T3 and T2.The higher organic carbon and organic matter contents were observed from lightly stocked area than heavily and moderately stocked. This is might be low cattle trampling impact and cattle dunging and urination which promotes massive vegetation cover and this is add more little and hence, high level of carbon and organic matter. The study reported by [15] proved that a lower amount of organic matter was observed for the areas heavily stocked than lightly and moderately stocked. Moreover, [19] examined the effect of different cattle stocking rate on the soil chemical and physical properties, shown that amount of soil carbon was significantly decrease as cattle stocking pressure increased. On the other hand, the lower organic carbon and organic matter was recorded from heavily stocked area, is may be due to decreasing the vegetation cover. The another study with Bermuda grass, a low stocking rate resulted in greater increases in soil carbon and nitrogen than a high stocking rate [28]. However, the higher carbon to nitrogen ratio and phosphorus were noted for heavily stocked area than moderately and lightly stocked. Indeed, carbon to nitrogen ratio is positively associated with cattle stocking rate which demonstrated that stocking rate increased carbon to nitrogen ration increases as consequences. Previous study reported by [29] had demonstrated that the carbon-nitrogen ratio was increased with an increased stocking rate.

Table 1: Impact of different cattle stocking rates on Chemical composition of soil in Bena-Tsemay, South-western Ethiopia from 2017-2019. (T1= 5 animal unity per month/ha; T2 = 3 animal unit per month/ha; T3 = 1.5 animal unit per month/ha; T4 = Control; SEM = standard error of mean).

Parameters measured	Cattle stocking rates				
	T1	T2	T3	T4	SEM
Organic carbon (%)	0.82	1.14	1.2	0.96	0.24
Organic matter (%)	1.39	1.99	2.05	1.64	0.43
Nitrogen (%)	0.08[b]	0.14[a]	0.13a[b]	0.14[a]	0.02
Carbon : nitrogen ratio(µg/g)	10.89	10.25	8.01	9.04	1.3
Phosphorus(mg/g Soil)	11.05[a]	3.17[b]	4.02[b]	9.26[a]	2.56
Potassium (mg/g Soil)	0.4	0.36	0.4	0.43	0.14

Table 2: Impact of stocking rates on dry matter yield (t/ha) in Bena-Tsemay, South-western Ethiopia from 2017 to 2019.(Means with different superscripts (a, b, c) for dry matter yield within the same column was significantly different (P< 0.001); T1= heavily stocking rate; T2= moderately stocking rate; T3= lightly stocking rate; T4 =No stocking rate or control; DMY= Dry matter yield; LSD= Least significant difference; SEM = Standard error of mean).

Stocking rates	DMY (t ha^{-1})	SEM	P-value	LSD
T1	2.77[c]	0.57	0.003	1.23
T2	4.52[b]	0.57	0.003	1.23
T3	4.81[b]	0.57	0.003	1.23
T4	6.24[a]	0.57	0.003	1.23

Impact of stocking rate on dry matter yield

Table 2 presents the impacts of varying cattle stocking rates on dry matter yield (t/ha). The results indicate a significant (P<0.001) difference among stocking rates on the dry matter yield of pastureland. The highest dry matter yield was observed in plots stocked by T2 and T3, while lower yields were observed in heavily stocked areas. The lower dry matter yield (t/ha) in plots stocked by T1, compared to those stocked by T2 and T3, was due to the high concentration of cattle and frequent grazing of herbaceous biomass. Previous studies by [12] and [30] have reported that heavy grazing intensity leads to grassland deterioration and a reduction in biomass production. Additionally, reports by [31] and [32] suggest that heavy and continuous grazing can cause a reduction in herbaceous biomass production on range-land. Similar dry matter yields were observed in moderately and lightly grazed areas in this study, which can be attributed to the similarity in soil carbon, soil organic matter, and phosphorus.

Impact of stocking rates on species diversity and richness

The effect of different cattle stocking rates on species diversity (H) and richness(S) are presented in Table 3. The grass species diversity was not significantly (P>0.05) affected by stocking rates (T1, T2, T3), but more grass species diversity was obtained from plot area stocked by T2 than plots stocked by T1 T3. However, significantly (P<0.05) lower grass species richness was obtained from area stocked by T1 as compared to areas stocked by T2 and T3, but species richness for areas stocked by T2 and T3 were insignificant (P>0.05) each other. Pertaining to the herbaceous legume species, significantly (P<0.05) lower species diversity and species richness were observed for the area stocked by T1 than areas stocked by T2 and T3, but a latter of two were insignificant (P>0.05) each other. On the other hand, significantly higher (P<0.001) species diversity and richness of forbs observed for area stocked by T3 as compared to areas stocked by T1 and T2, whereas areas stocked with T2 and T3 were insignificant(P>0.001). The lower herbaceous species diversity and richness were found in heavily stocking rate compared to moderately and lightly stocked is due to high trampling effect affects soil stability and vegetation condition. The previous studies of [12, 33-34] were confirmed that more soil disturbance can occur due to the effects of heavy cattle trampling and year-round grazing

Table 3: Impacts of stocking rate for the herbaceous species diversity (H) and richness (S) (Means ±SE.) in Bena Tsemay, South-western Ethiopia from 2017 to 2019. (Means with different superscripts (a, b, c) for dry matter yield across row was significantly different (P < 0.05) each other; SE= standard error; T1= heavily stocking rate; T2= moderately stocking rate; T3= lightly stocking rate; T4 =No stocking rate or control).

Grasses species	Grazing Intensity			
	T1	T2	T3	T4
Means ±SE grass Species diversity(H)	1.97c±1.77	4.69b±1.77	3.63b±1.77	4.03b±1.77
Means ±SE Species richness (S)	13c ±10.4	34.00bc±10.4	45.67b ±10.4	71.67a±10.4
Means ±SE Legume species diversity(H)	1.4b±2.2	2.9a±2.2	1.5b±2.2	2.8a±2.2
Means ±SE Species richness (S)	6.6c±6.3	31.6b±6.3	45.6b±6.3	64.3a±6.3
Means ±SE Forbs Species diversity(H)	0.6b±0.3	0.7b±0.3	1.9a±0.3	2.5a±0.3
Means ±SE Species richness (S)	4b±7.3	17b±7.3	40a±7.3	49a±7.3

leads reduction in plant species composition. The higher herbaceous diversity and richness of annual and perennial species was moderately and lightly grazed lands. In contrast to this study, [35] reported that areas grazed with light grazing intensity in the desert rangelands does not increase perennial grass diversity and richness.

Conclusion and Recommendation

This study examined how different stocking rates of cattle affect dry matter yield, soil chemical compositions, and herbaceous species diversity and richness. Areas with moderate and light stocking rates had higher levels of soil organic carbon, organic matter, and dry matter yield compared to heavily stocked areas. The study also found that increasing the stocking rate of cattle may lead to a decrease in herbaceous species diversity and richness. Overall, the results of this study showed that heavy cattle stocking rate resulted in lower dry matter yield, soil organic carbon, soil organic matter, total nitrogen, and herbaceous species diversity and richness. The findings also suggested that a light stocking rate (T3) has the potential to improve forage dry matter yield, soil chemical compositions, and herbaceous species diversity and richness compared to heavy (T1) and moderate (T2) stocking rates. Additionally, future research should consider the potential effects of stocking rate on the chemical composition of herbaceous species.

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