
Repercussions of Agro-Pastoralism on Soil Condition in Western Serengeti, Tanzania

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Abstract: Overgrazing of rangeland and continuous cultivation of cropland are among human activities contributing to the deterioration of soil properties. To elucidate the effect of agro-pastoral activities on soil properties in western Serengeti, we examined soil properties in four land use types, namely fallow land, communal grazing land, mixed grazing land and wildlife dominated grazing land. The soil sampling sites were along the landscape from village lands towards protected areas while crossing all four land use types. Soil pH was not significantly different ($p \geq 0.05$) although it was relatively low in fallow and communal grazing lands. Clay content in soils was not affected by land use types whereas sand and silt contents were significantly different ($p \leq 0.05$) among land use types. In terms of soil nutrients, OC, CEC and soil P showed a significant difference ($p \leq 0.05$) among land use types but land use did not affect TN and Ca^{2+} . Bare land within quadrats was highest in communal grazing lands (1233 cm^2 /quadrat) and lowest in wildlife dominated grazing lands (906 cm^2 /quadrat). Protected areas represented by wildlife grazing sites had the highest soil stability expressed in terms of soil structure stability index. Soil quality declined with increase in bare land. Further, high density of grazing animals caused a decline in soil properties. The study demonstrated that the four land use types had negative influence on soil properties. It was further noted that the current practices of livestock grazing and cultivation had higher negative effects on soil properties than the other land use types. Long term monitoring study on impacts of agro-pastoralism in western Serengeti is needed so as to establish proper stocking rates to avoid reaching an irreversible soil properties deterioration situation.

Keywords: Animal Density, Degradation, Grazing Animals, Land Use Type, Soil Properties, Quadrat

1. Introduction

Agro-pastoralism is the integration of crop production and livestock production as a livelihood strategy where crop production constitutes the basis of household economy [4, 32, 23]. The agro-pastoral activities involve land clearing that consequently causes land cover changes. Land cover changes associated with human activities and natural factors compromise many ecosystem attributes including soil and site stability,

hydrologic function and biotic integrity [5] and hence reduction of important ecosystem services such as crop and livestock production. Agro-pastoral activities that involve overgrazing of rangeland and continuous cultivation of cropland are among human activities that contribute to land degradation [59]. Continuous grazing of large herds on the same area cause land degradation due to high grazing pressure on plant species and soil disturbance caused by trampling. Extensive cultivation involves land clearing and pulverization of soil that subjects the

land to soil erosion due to wind and rainfall runoff. Trampling by animals causes compaction of soil that leads to increased surface water runoff. Removal of plants due to large number of grazing animals causes bare land that in combination with poor water infiltration causes surface water runoff and accelerated soil erosion during the rainy season. Different land uses types influence land degradation differently; cultivation and human settlements considered to cause higher land degradation than grazing [24]. Conversion of vegetated land to bare land through cultivation results in soil nutrient loss due to disruption of soil surface and mineral horizons as well as organic matter supply cut off [42]. Continuous cultivation without appropriate management practices results in low soil fertility due to overutilization of soil nutrients by crops [21, 41]. Different grazing managements tend to affect soil properties differently [39]. Normally, livestock grazing is managed by herders but wildlife graze freely in rangelands [54, 20]. In that manner, livestock and wildlife may affect soil properties differently in grazing lands. This study therefore was designed to evaluate the impacts of agro-pastoral activities on soil properties in different land use types of western Serengeti. It was hypothesized that there are no variations in soil properties as a result of agro-pastoral activities in fallow, livestock, mixed and wildlife-dominated land use types.

2. Materials and Methods

2.1. Site Description

The study was conducted in western Serengeti within five villages that are adjacent to protected areas as shown in Figure 1. The western Serengeti lies in agro-ecological zones 1/5 and 1/4 characterized as low potential areas less suitable for arable agriculture [19]. Average annual rainfall ranges between 500-1200 mm, declining eastwards towards the Park boundary and increasing westwards towards Lake Victoria [7]. It is the most densely populated area in Serengeti ecosystem surpassing the north-east and south of the Serengeti National Park [7, 45, 33]. While the western Serengeti is considered to be unsuitable for arable agriculture, the subsistence economy depends mainly on agro-pastoralism [15]. Agro-pastoralism in this area is practiced by extensive cropping and livestock keeping which normally lead to encroachment of protected areas [44]. Common grazing livestock kept in western Serengeti include cattle, goats and sheep while crops cultivated include maize, sorghum, paddy, cassava, sesame and cotton. The study area is diverse in terms of ethnic groups as it is composed of over 25 tribes which are dominated by the Ikoma, Ikizu, Kurya, Natta and Sukuma [16].

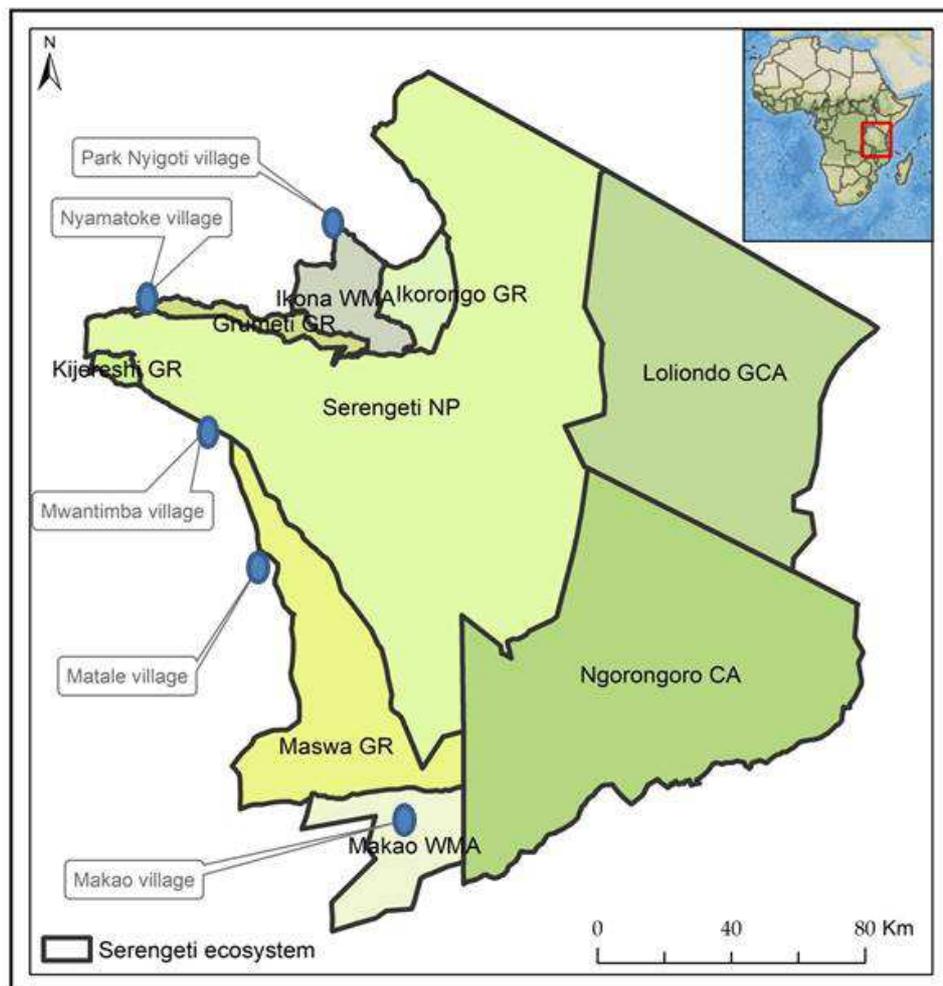


Figure 1. Map of Serengeti ecosystem showing study villages in western Serengeti.

2.2. Data Collection

Transects were aligned in each village to cross different land-use types where each transect started in the village land. Transects traversed 0–1,000m in lands dominated by cropping, 1,000–2,000m in lands dominated by livestock grazing, 2,000–3,000m crossing the boundary between village land and protected areas, where mixed grazing of livestock and wildlife occurred, and the remaining 3,000–4,000m was in the protected land dominated by wildlife grazing.

The properties of a particular soil are the result of soil-forming processes acting through time and under the influence of parent material, climate, topography, and biota. There are four general soil-forming processes: 1) transformations, which are the modification, loss, or creation of soil materials such as the breakdown of organic matter or the formation of secondary clays and carbonates; 2) translocations of soil material up or down the profile, mostly by water but also by soil organisms; 3) additions of new material to the soil, such as dust, organic matter, and soluble salts; and 4) losses from the soil profile due to such processes as leaching and erosion [14]. The relative dominance of these four processes creates differences in soil properties at different depths. Soil was sampled at the central point of each 0.25m² quadrat. The samples were taken from the depth of 0-30 and 30-50cm at every 300m along transect. Soil depth of 30 – 50 cm was considered for understanding soil properties that accommodate deep rooted plants because the study was conducted in wooded grasslands. Bare land within quadrat was estimated according to Peratoner and Pötsch [50] by taking the difference between 100% and the top cover corresponds to the proportion of vegetation coverage. Densities of both livestock and wildlife for determination of grazing pressure in the study areas were estimated based on observations made along transects in accordance to Caro [8]. Animal counts were converted to tropical livestock units (TLU) based on their species average weight where tropical livestock units was considered as 1 TLU = 250 kg live weight according to LEAD/FAO [37].

2.3. Laboratory Analysis

A total of 150 soil samples were collected where 35 samples were collected from each land use type namely livestock grazing, mixed grazing and wildlife grazing while 45 soil samples were collected from fallow land. All 150 soil samples collected were taken to the laboratory at Sokoine University of Agriculture for determination of soil texture, bulk density, pH, organic carbon (OC), total N, available P, Ca²⁺ and CEC according to standard procedures [49].

3. Data Analysis

All statistical analyses were performed with R software (R_{x64} 3.5.0). Analyses were performed using pooled data for respective land use type with type III sum of squares in ANOVA. The relationship among bare land area, animal

density and soil properties was evaluated by using global mixed effects model using lmer package of R statistical software [35]. Bare land area was considered as an output variable while the input variables included animal density, soil texture components (clay, silt and sand), soil pH, total nitrogen content, organic carbon, extractable phosphorus, available calcium and CEC. Land use type (fallow, livestock, mixed and wildlife) was defined as a random effect. The input variables were standardized using Gelman's approach [22] and the dredge function in package MuMIn [2] was used to perform automated model selection with subsets for each of the standardized global models. The best fitting model procedure was used to select the most accurate model. Model averaging was used to calculate model averaged parameters and used the second-order Akaike information criterion (AICc) [6] to obtain the top model based on variables with highest relative importance. Assessment of collinearity among explanatory variables was performed using step-wise variance inflation factors (VIF) with all predictor variables initially included in the linear regression equation. Variables with VIF greater than 4 were eliminated from the model progressively, while the predictor variables with VIF less than 4 were retained. The resulting linear regression model was then used to assess variables that were significantly associated with the response variable bare land area. Spatial heterogeneity of soil properties in the study area was assessed based on coefficient of variation (CV) according to Wilding [61] where parameters CV > 35% considered as most heterogeneous, CV 15 -35% was moderately heterogeneous and CV < 15% considered as the least heterogeneous. Soil structural stability index (SSSI) of different land use types was estimated according to Serme et al [56]. Soil structural stability index expresses the risk for soil structural degradation associated with soil OC depletion. It is expressed as follows:

$$SSSI = [(1.72 \times SOC) / (\text{Clay} + \text{Silt})] \times 100$$

Where; SOC is the soil organic carbon content (%) and clay + silt constitute the combined clay and silt content of the soil (%).

4. Results

4.1. Effect of Land Use Type on Soil Quality

Results from this study showed that soil pH was not statistically different ($p \geq 0.39$) among different land use types though pH was relatively lower in fallow and livestock grazing than in mixed and wildlife dominated grazing lands (Figure 2a). The slight low pH in agro-pastoral dominated land use types (fallow and livestock) indicates progress in lowering of pH due to agro-pastoral activities. The soil pH and clay were not affected by land use types (Figures 2a and 2b) but silt and sand contents showed significant difference ($p \leq 0.02$, 6.9×10^{-11}) as shown in Figures 2c and 2d respectively.

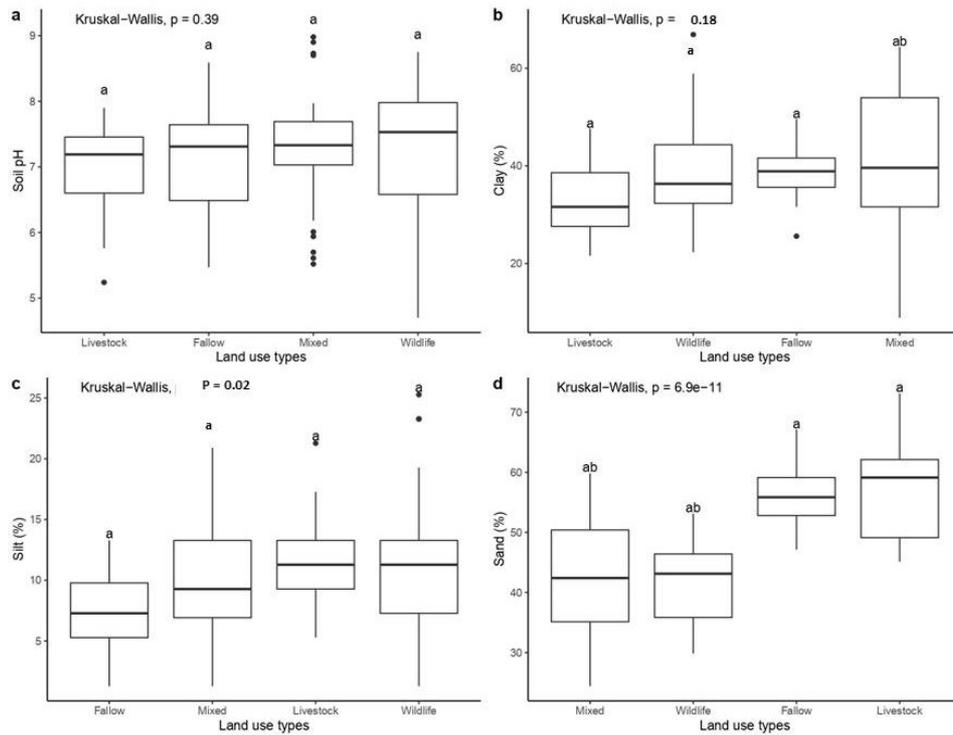


Figure 2. Effect of land use types on soil pH and texture components in western Serengeti.

Land use types showed significant difference ($p \leq 0.05$) in terms of OC and soil P (Figures 3b and 3c). Soil total nitrogen did not show significant difference among land use types and the total nitrogen content in the soil ranged between 0.1 to 0.2% (Figure 3a).

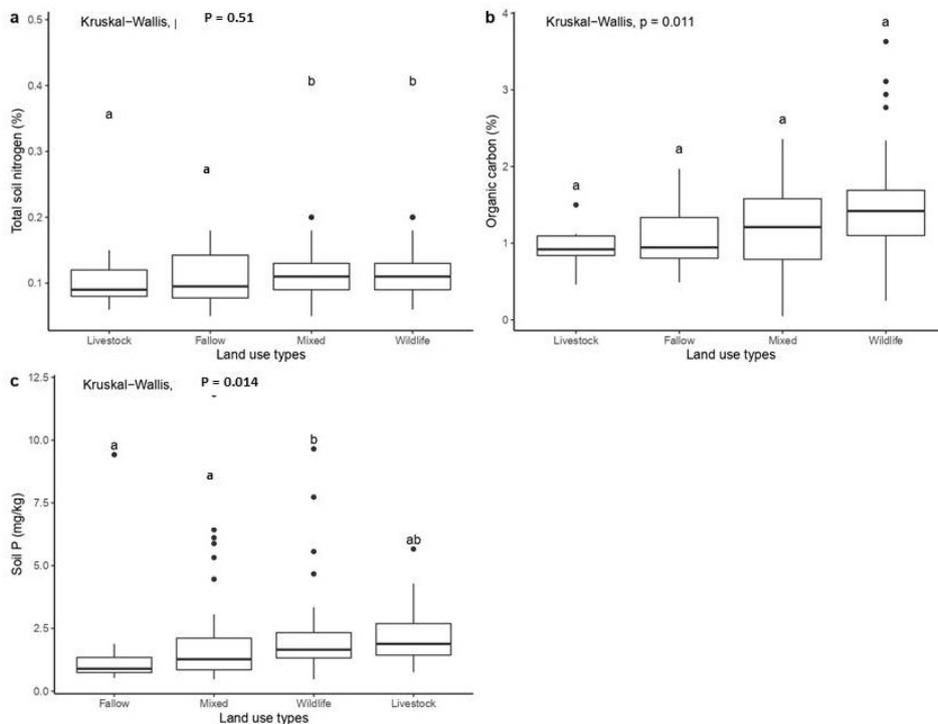


Figure 3. Effect of land use type on soil TN, OC and P in western Serengeti.

Furthermore, results from this study showed that land use types had highly significant effect on CEC as well as in Ca^{2+} (Figure 4).

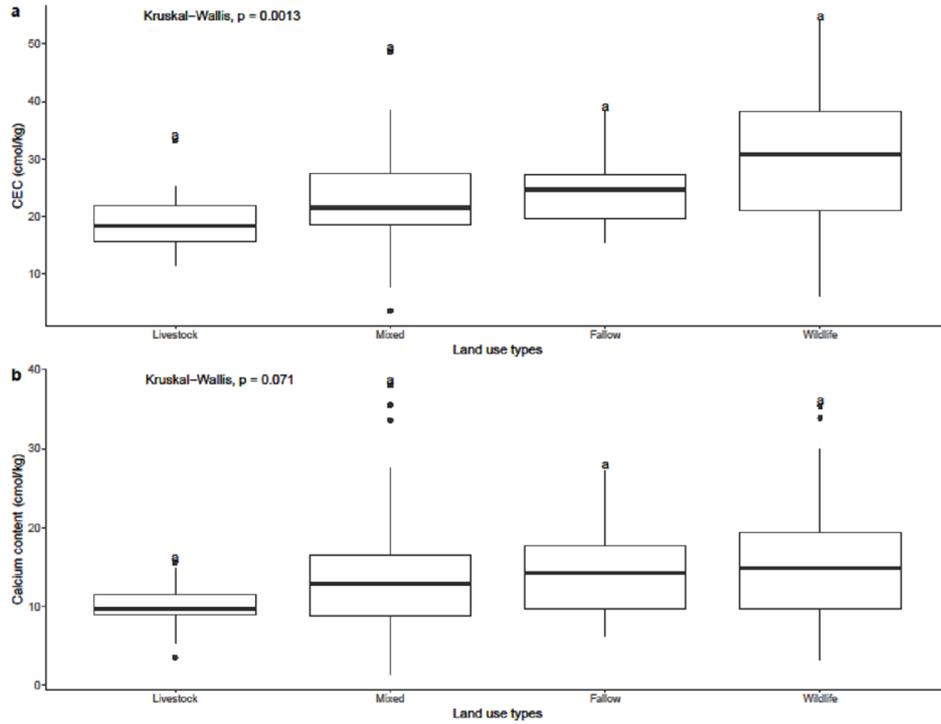


Figure 4. Effect of land use types on CEC and available calcium in the soil of western Serengeti.

4.2. Influence of Land Use Type on Bare Land and Soil Stability

In our study, results showed significant difference ($p \leq 0.019$) in terms of bare land area among different land use types. Fallow and livestock grazing land use types had higher bare land within quadrats than in mixed and wildlife

dominated land use types (Figure 5a).

Soil structure is an important property that mediates many biological and physical processes in the soil. Differences in soil structure stability obtained in this study are shown in Figure (5b). The highest soil structure stability index (SSSI) was found in soils within protected areas.

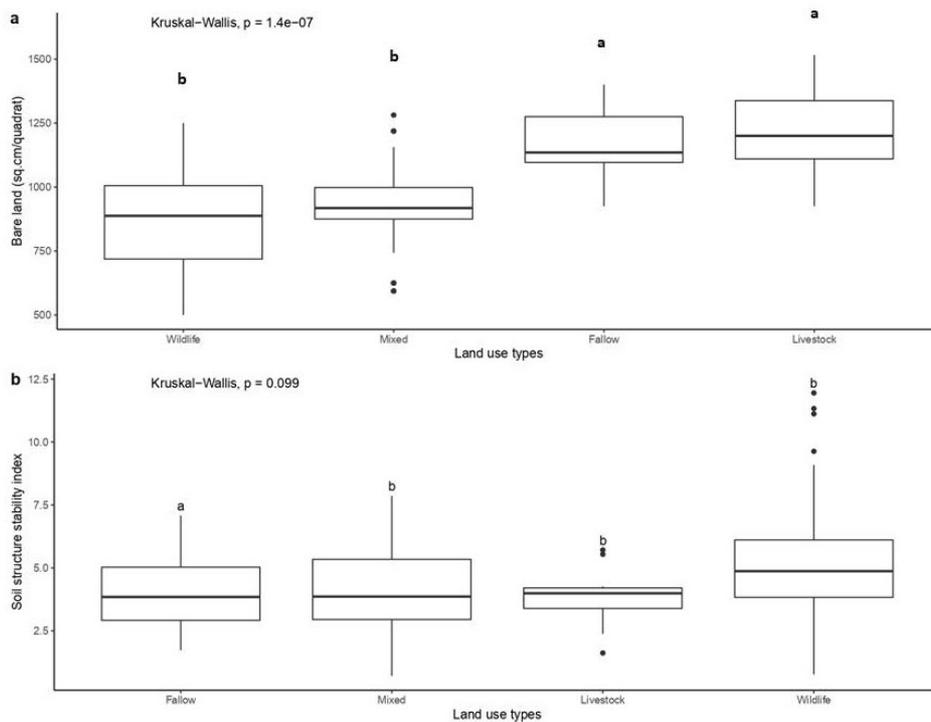


Figure 5. Effect of land use type on presence of bare land and soil structure stability in western Serengeti.

4.3. Effect of Bare Land on Soil Properties

Bare land affects soil properties due to the removal of top soil that contains soil nutrients by erosion. The observed effects of bare land on soil properties are presented in Figure 6. Results show that an increase in bare land area caused a decline in soil pH, CEC and nutrients contents.

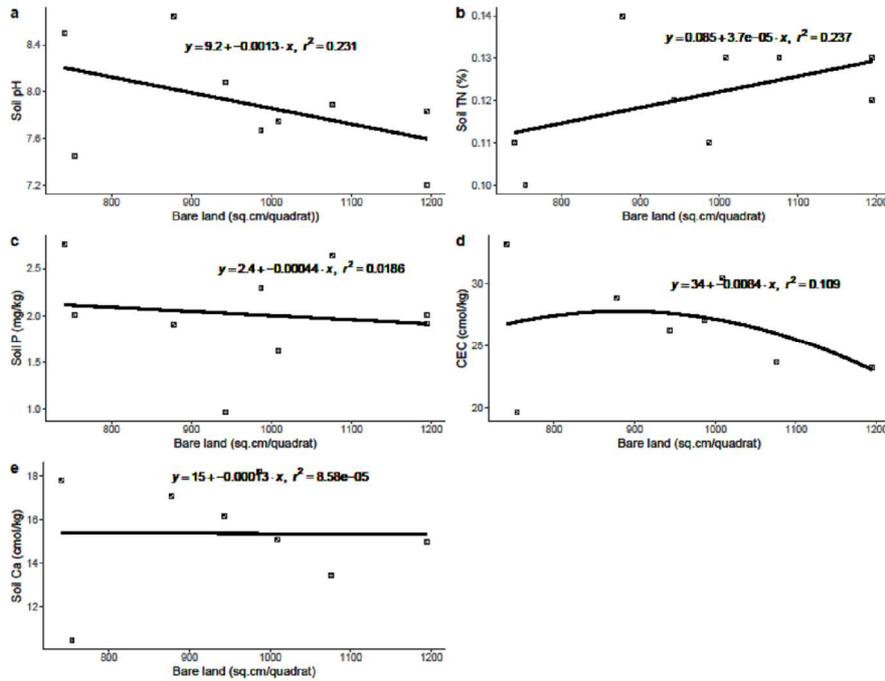


Figure 6. Effect of bare land size on soil properties in western Serengeti, Tanzania.

4.4. Effect of Grazing Animals' Stocking Rate on Soil Properties

Our study showed that increase in animal density expressed as stocking rate caused decrease in soil pH, OC, CEC and nutrient elements as shown in Figure 7.

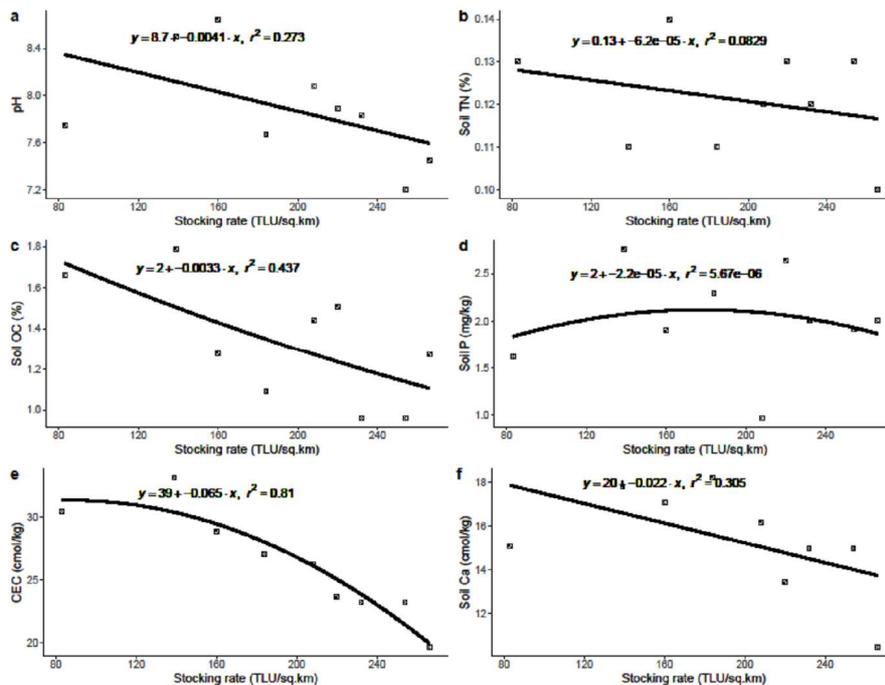


Figure 7. Effect of grazing animals' density on soil properties in western Serengeti, Tanzania.

Correlation analysis results (Table 1) indicated that animal density was positively correlated to clay soil, sandy clay soil, sandy loam soil and bare land area which implied that the effect of high animal density manifested well in these soil properties. On the other hand, animal density was

negatively correlated to clay loam soil, pH, total nitrogen content, organic carbon, extractable soil phosphorus, cation exchange capacity and available calcium in the soil implying decrease in these parameters due to high animal density.

Table 1. Correlation coefficients of the relationship between soil properties and stocking rates in western Serengeti.

	Clay soil	Clay loam soil	Sandy clay soil	Sandy clay loam soil	Sandy loam soil	Bare land area	pH	TN	OC	P	CEC	Ca ²⁺	Animal density
Clay soil	1.00												
Clay Loam soil	-0.50	1.00											
Sandy clay soil	-0.65	0.00	1.00										
Sandy clay loam soil	0.32	-0.42	-0.69	1.00									
Sandy loam soil	-0.30	-0.51	0.11	0.64	1.00								
Bare land area	-0.27	-0.69	0.64	0.06	0.72	1.00							
pH	0.61	0.35	-0.84	0.19	-0.62	-0.92	1.00						
TN	-0.50	1.00	0.00	-0.42	-0.51	-0.69	0.35	1.00					
OC	-0.20	0.93	-0.37	-0.15	-0.54	-0.89	0.65	0.93	1.00				
P	0.08	0.76	-0.16	-0.59	-0.94	-0.84	0.66	0.76	0.78	1.00			
CEC	-0.50	0.99	-0.08	-0.30	-0.42	-0.70	0.38	0.99	0.95	0.70	1.00		
Ca ²⁺	-0.20	0.94	-0.35	-0.20	-0.58	-0.89	0.65	0.94	1.00	0.81	0.95	1.00	
Animal density	0.18	-0.93	0.37	0.18	0.58	0.90	-0.67	-0.93	-1.00	-0.81	-0.94	-1.00	1.00

4.5. Heterogeneity of Soil Properties in Western Serengeti

Results showing coefficient of variation in Table 2 indicate that only soil pH was least heterogeneous (CV ≤ 15%). Clay and silt contents in soil texture classes as well as OC and total N were moderate heterogeneous (15 – 35% CV). The most heterogeneous soil parameters were sand content in soil textural classes, soil extractable P, exchangeable calcium and CEC.

Table 2. Variation of soil properties in western Serengeti.

Parameter	Mean	SD	Minimum	Maximum	F-value	CV	P-value
Soil pH	7.14	0.81	4.70	8.98	0.676	0.11	0.568
Clay (%)	40.04	11.52	8.88	68.88	0.469	0.30	0.704
Silt (%)	10.22	4.74	1.28	25.28	3.503	0.30	0.017
Sand (%)	49.74	12.59	24.40	87.84	0.807	0.52	0.492
Total N (%)	0.11	0.04	0.05	0.20	0.587	0.28	0.625
OC (%)	1.19	0.47	0.05	3.63	4.159	0.35	0.007
Soil P (mg/kg)	2.00	1.82	0.47	11.82	0.797	0.45	0.498
Exchangeable Ca (cmol/kg)	13.38	6.14	1.33	38.03	2.490	0.52	0.063
CEC (cmol/kg)	24.60	8.27	3.60	54.00	9.244	0.40	≤0.001

4.6. Differences in Soil Properties Between Depths

Top soil had significantly higher pH, Clay, Sand, total N and OC than sub soil (Table 3). Top soil, however did not differ significantly with sub soil in terms of silt content, extractable P, Ca and CEC.

Table 3. Difference in soil properties between soil depths regardless of land use types.

Parameter	Soil depths		F-value	P-value	Level of significance
	0 – 30 cm	30 – 50 cm			
pH	7.33 ^a	7.04 ^b	4.240	0.0413	*
Clay (%)	40.23 ^b	43.03 ^a	4.628	0.0332	*
Silt (%)	10.14 ^a	10.70 ^a	6.075	0.0749	NS
Sand (%)	50.06 ^a	46.30 ^b	8.872	0.003	**
Total N (%)	0.12 ^a	0.10 ^b	4.204	0.042	*
OC (%)	1.36 ^a	1.11 ^b	6.926	0.009	**
Soil P (mg/kg)	2.20	1.73	2.012	0.158	NS
Available Ca (cmol/kg)	14.63	13.35	1.024	0.313	NS
CEC (cmol/kg)	26.45	23.63	2.836	0.943	NS

^{a,b}Values with different superscripts within a row differ significantly (p≤0.05), *= level of significance at p≤0.05, **= level of significance at p≤0.01, NS= not significant.

4.7. Effect of Animal Density and Soil Properties on Bare Land

Using stepwise variance inflation factor (VIF) of Log(bare land area), pH, Clay, Silt, Sand, Total Nitrogen, Organic carbon, Soil P, CEC, Ca and Animal Density (AD) indicated that log (Bare land area), animal density, Soil pH, OC and Soil P had VIF values below the threshold that sufficed development of a linear model (Table 4) for prediction of bare land area based on animal density and soil properties. The model developed for relationship of bare land area with stocking rate and soil properties is expressed as follows:

$$\text{Log(Bare)} = 0.001\text{AD} + 0.072\text{OC} - 0.012\text{P} + 0.001\text{pH} + 2.762$$

Table 4. Variables for bare land prediction model.

Variable	Coefficient (estimate)	VIF
Intercept	2.762	
Animal density	0.001	3.804
OC (cmol/kg)	0.072	2.018
Soil P (mg/kg)	-0.012	1.041
Soil pH	0.001	0.002

5. Discussion

5.1. Effect of Land Use on Soil Properties

This study demonstrated high sand contents in areas dominated with agro-pastoral activities (fallow and livestock grazing). This is most likely resulting from the preferential removal of clay and silt after disturbance caused by tillage and trampling by livestock. Surface runoff due to rainfall tends to remove light soil particles that include clay and silt in disturbed soil, leaving denser particles such as sand. This result is in agreement with Tufa *et al.* [60] who reported high sand content in soils subjected to cultivation and livestock grazing in Ethiopia. Soil texture is an inherently stable soil property but it is subject to changes due to long term disturbance such as continuous cultivation and overgrazing (Boke, 2004). Overall results in this study indicate that clay was higher in subsurface soils (30-50 cm) than upper surface soils (0 – 30 cm). The overall increase in clay contents with soil depth may be due to translocation of clay from surface to subsurface layers, which ultimately increased the proportion of sand in the surface soil layers. This suggests that the upper soil surfaces in western Serengeti are subjected to disturbances even in protected areas. Soils in protected areas could be subjected to trampling by wild animals especially large herds of wildebeest during migration periods.

Soil pH is one of the major factors affecting soil processes and properties, including chemical, physical and biological processes and properties [3]. Our study showed that soil pH in western Serengeti was similar among different land use types. However, variation in soil pH occurred across soil depth with low soil pH occurring in subsurface soils. This indicates that spatial distribution of shallow rooted plants like herbaceous plants in western Serengeti is determined by other factors such as soil texture [31]. Likewise, soil pH was

spatially moderately heterogeneous implying that variation of soil pH in the study area was influenced by soil structure and random factors [63].

Soil organic carbon content varied among the land use types and was highest in protected areas. Disturbance in protected area was relatively low as shown by low bare land area. This allowed accumulation of organic material in protected area that decomposed and contributed to the accumulation of soil organic matter. The results were in agreement with [52] who found higher soil organic carbon content in protected area than farmlands of Thailand. Low organic carbon content in agro-pastoral areas could be associated with removal of organic matter due to livestock grazing and use of fire in land preparation before cultivation. The amount and distribution of Soil Organic Carbon (SOC) affects and is affected by plant biomass [28]. This is because carbon storage in soils is a dynamic balance between detrital inputs (primarily litter and dead roots) and organic matter outputs in the form of CO₂ efflux from the soil [9]. This study showed that three land use types expressed in terms of fallow, continuous livestock grazing and mixed grazing of livestock and wildlife resulted in soil organic carbon contents that were below optimum level. The organic carbon between 3 and 5% is considered as optimum with low risk of structural degradation [11]. Soil structural stability index (SSSI) suggested by Pieri (1992) show that SSSI ≤ 5% indicates a structurally degraded soil; 5% ≤ SSSI ≤ 7% indicates a high risk of soil structural degradation; 7% ≤ SSSI ≤ 9% indicates a low risk of soil structural degradation; and SSSI ≥ 9% indicates sufficient SOC to maintain the structural stability. Results from our study demonstrate that agro-pastoral activities expressed in terms of fallow and continuous livestock grazing, and mixed grazing of livestock and wildlife lead to structurally degraded soil. This implies that soils under these land use types were undergoing soil structure disintegration that subjected the land to soil erosion. On the other hand, soil in protected area had soil structural stability index between 5.0 and 7.5. This implies that soils in protected areas of western Serengeti were at high risk of soil structure degradation. This provides an alarm to management authorities that poor management of rangeland in protected areas could cause land degradation in future.

Soil P and exchangeable calcium were positively correlated ($r = 0.81$). This indicates that most of the soil phosphorus in western Serengeti occur in form of P-Ca bond *i.e.*, calcium phosphate which is sparingly soluble in water depending on soil pH. This relationship is depicted on similar trends of soil P and exchangeable Ca in different land use types. This form of calcium and phosphorus bonding in the soil limits phosphorus availability to plants [27]. Lowest soil phosphorus and exchangeable calcium in livestock dominated grazing land demonstrated in this study could be attributed to overgrazing. High livestock grazing pressure limited accumulation of organic matter in the soil for recycling of phosphorus and soil trampling that caused phosphorus and

calcium loss due to erosion. Findings of the current study are in agreement with Davidson et al. [13] and Arevalo et al. [1] who described that decrease in calcium and phosphorus in grazing lands could be attributed to mineral export by grazing animals. An explanation of this is that grazing animals consume plants that extract minerals from the soil which are deposited elsewhere as manure. On the other hand, reduction of exchangeable bases in the soil caused the reduction in pH which led to lowered pH with consequent effect onto increased exchangeable aluminium and decreased availability of phosphorus.

5.2. Effect of Land Use on Bare Land and Soil Properties

Bare land is devoid of vegetation and exposes the surface soil to agents of soil erosion such as wind and water runoff [17]. The semi-arid areas of Africa particularly Sub-Saharan Africa have fragile soils and get low input from agriculture, as a result they are vulnerable to degradation [18, 40]. The East Africa rangelands' soils are inherently low in fertility [10] which implies that exposing land surface to soil erosion aggravates the problem of low soil fertility in rangelands. The current study showed that agro-pastoral activities (fallow and continuous livestock grazing) caused higher bare land areas within quadrats as compared to mixed and wildlife grazing. This was attributed to weeding in crop farms and overgrazing in communal grazing lands within villages. Decrease in soil properties with increase in bare land area is consistent with previous findings that bare lands contain low OM, TN, pH, CEC, Exchangeable Ca and soil organic carbon [38, 58]. The low soil nutrients in bare lands result from nutrient losses due to a combination of soil erosion, surface runoff [43]. Paradoxically, Yu et al. [64] found that TN, SOC and TP of bare land significantly decreased but available nutrient concentrations NO_3^- -N, NH_4^+ -N and available phosphorus (AP) of bare land significantly increased in Qinghai-Tibetan Plateau of China. The possible explanation for low nutrient in bare land is lack of vegetation that cuts off nutrient recycling from organic matter whereas the remaining nutrients on surface soil are taken away by wind and water runoff. Increase in NO_3^- -N, NH_4^+ -N and AP in bare land is associated with burrowing small mammals where burrows increases soil moisture and oxygenation of bare land [25] due to breakdown of soil aggregates of soil particles [66]. Consequently, it increases the nitrogen mineralization of undegraded organic matter that increases concentration of available nutrients in bare land soils.

5.3. Spatial Heterogeneity of Soil Properties

Spatial heterogeneity refers to the lack of homogeneity and the complexity in the distribution in space of the properties of a system [47]. Understanding the spatial heterogeneity of soil parameters such as pH, organic carbon, nitrogen, phosphorus and potassium, is important due to their influence on the distribution and spatial pattern of plants in the ecosystem [57]. Our study considered spatial heterogeneity of soil pH because it reflects physical and chemical properties that

determine soil quality [47] and has a profound impact on various soil properties [63]. Results based on CV indicated that soil pH was least heterogeneous and low positively correlation with TN and CEC but high positive correlation with OC, P and Ca^{2+} . This implies that variations observed in soil parameters contents in various soils of western Serengeti were caused by factors other than soil pH. Many studies have shown that the spatial variability of soil pH is related to many factors such as soil parent rock material, topography, climate, soil biology, human activities, sampling design and personal error [53, 34, 55]. Our study demonstrated that current agro-pastoral activities expressed in terms of fallow and livestock keeping are the main human activities that affect soil properties negatively in western Serengeti.

5.4. Effect of Grazing Animal Density on Soil Properties

Soil properties contribute to numerous ecosystem services within agro-pastoral system such as water supply through filtration and retention of rain water, climate regulation, and biodiversity conservation and production of both plants and animals. The importance of soil entails the need for assessment of its quality to understand the impact of a particular land use. Livestock keeping particularly grazing animals affects soil properties differently depending on pressure exerted by different number of animals, hence the need for assessment. Results obtained from this study indicated that increase in number of grazing animals within a unit of land caused decline of soil properties such as pH, TN, OC, P, CEC and Ca. Our results conform to findings of a global meta-analysis of livestock grazing impacts on soil properties reported by Lai and Kumar [36] except for soil pH. Contrary to the increase in soil pH due to high grazing density, our study showed that increase in grazing density caused a decrease in soil pH which agrees with few studies reported by Hiernaux et al. [26], Cui et al. [12] and Zhang et al. [65] who conducted studies in sandy soils in semi-arid lands. The reason for this phenomenon could be our study was conducted in area dominated with sandy clay soils [31]. Furthermore, high grazing animals' density subjected sandy soil to erosion and removal of exchangeable bases by water runoff leaving high concentration of hydrogen ions that increased soil acidity.

5.5. Implication of Agro-Pastoralism on Grazing Land

Agro-pastoralism impacts negatively on grazing land when large herd of grazing animals exert high grazing pressure on vegetation for a long period. This situation affects soil properties in a long run though soil properties can change slowly particularly in semiarid regions where soil responses to management practices occur slowly [46]. Results obtained in this study demonstrated that agro-pastoral activities practiced in western Serengeti triggers decline in soil pH due to high animal density, decrease in soil OC and plant nutrient elements due to cultivation and removal of standing biomass by grazing animals. In addition animal trampling exposes top soil to agents of soil erosion, consequently reduce plant cover

leading to expansion of bare land. The model developed in this study pin point animal density as the main agro-pastoral input variable that contribute in prediction of bare land area occurrence. This is because traditionally livestock graze in communal grazing lands and cultivated areas after crop harvest. Therefore grazing animals cause impacts on both communal grazing and cultivated lands. Other input variables include organic carbon which determines texture and holding capacity of nutrients and moisture in the soil for establishment of plants, soil P as an important nutrient for plant roots establishment in the soil and soil pH that determine nutrients availability to plants. The strength or weaknesses of these input variables determine existence of bare land in western Serengeti regardless of climatic condition.

6. Conclusion

Continuous grazing in communal grazing lands and fallows affected soil properties due to high animal density. Trampling loosened soil particles that were easily eroded by wind and rainfall. Removal of soil particles led to existence of bare land with consequence lowering of soil pH, OC, P Ca²⁺ and CEC in communal grazing lands and fallows.

Removal of soil nutrients in upper layer of soil caused overall decline in soil nutrients because the underneath layer of soil showed relative low soil nutrient contents. The magnitude of soil properties deterioration varied with increase in grazing animals' density and it was manifested in all land use types examined.

This study therefore demonstrated that the four land use types namely fallow, livestock grazing, mixed grazing and wildlife grazing negatively affected soil properties. However, agro-pastoralism represented by the magnitude of the current practices of livestock grazing and fallows produce more negative effects than the other two land use types on soil properties.

7. Recommendation

Grazing animals' density in communal grazing lands and fallows should be monitored and their effects on soil properties be alleviated by either reducing their number or duration of grazing.

The current fallowing system practiced in western Serengeti need to be reviewed in order to assist improvement of soil properties in fallows.

Long term monitoring study on impacts of agro-pastoralism in western Serengeti is needed so as to establish proper stocking rates to avoid reaching an irreversible soil properties deterioration situation.

Data Availability

Data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no competing interests.

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