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Cattle Grazing Exclusion Increases Basal, Crown and Mulch Cover in the Sierra de Órganos National Park, Sombrerete, Zacatecas, Mexico

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ABSTRACT

Objective: To estimate the effects of cattle grazing exclusion on soil and vegetation conditions in grasslands of Sierra de Órganos National Park (SONP), Sombrerete, Zacatecas, Mexico.

Design/Methodology/Approach: Four transects with cattle grazing exclusion were strategically established in SONP grasslands. In each transect the basal, crown and organic mulch cover, soil cover, bare soil, and the form of the autumn plant were measured from 2008, 2010, 2012 and 2014.

Results: Cattle grazing exclusion caused an increase in basal, crown and organic mulch cover, soil cover, as well as over-rested plants and deteriorated plants; bare soil cover and the percentage of normal plants decreased.

Study Limitations/Implications: Increase of organic mulch cover implies the accumulation of combustible material that represents a potential risk of fire occurring in the SONP.

Findings/Conclusions: Increase of organic mulch, over-rested plants and deteriorated plants shows that SONP grasslands are transiting to a less stable ecological state.

Keywords: plant cover, bare soil, degraded grassland.

INTRODUCTION

The Sierra de Órganos National Park (SONP) is an important ecotourism zone due to the scenic beauty produced by a number of steep elevations and rock formations. The SONP also stands out for social, economic, environmental, and scientific values that represent the large biodiversity present in ecosystems that comprise it (SEMARNAT, 2013) In the SONP land, cattle grazed continuously during the whole year for a long time. The animal load exceeded the forage capacity, therefore causing vegetation and soil deterioration (Márquez *et al*., 2006). On November 27th, 2000, the SONP was declared (DOF, 2000), but it was not until the second semester of 2008

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that bovine and equine grazing was excluded. Grazing exclusion is an efficient management strategy to restore degraded grasslands worldwide (Li *et al*., 2018; Bi *et al*., 2018). Grazing exclusion can improve characteristics of the plant community, and the physicochemical and biotic properties of the soil in degraded grassland areas. Therefore, it can serve as an efficient way to rejuvenate the grasslands (Wang *et al*., 2018). Grazing exclusion also increases leaf litter accumulation (organic mulch), which may lead to light limitation and increase growth points of plants that are then more susceptible to damage (Vermeire *et al*., 2018); in the long term this could negatively influence the renovation and productivity of species (Jing *et al*., 2013). Likewise, the structure and function of the plant community has been altered significantly in some regions due to the excess of mulch accumulation, particularly in pastures of tufted grasses and rhizome grasses (Hou *et al*., 2019). Physical interference from mulch reduces grassland diversity and modifies the composition of species within diverse grassland communities.

Knowledge of the effects of grazing exclusion on the soil and vegetation can be important and timely for the SONP managers. Managers are able to know if the objectives of the SONP management program are being achieved; mainly the one related to protection, which implies "safeguarding the permanence and conservation of biological diversity and representative geological formations, through the establishment and promotion of a set of policies and measures to improve the environment and control the deterioration of ecosystems" (SEMARNAT, 2013). This type of information may be useful to cattle breeders with production systems with grazing conditions similar to those found in the SONP. For these reasons, the effects of cattle grazing exclusion on soil and vegetation conditions of the Sierra de Órganos National Park, in Sombrerete, Zacatecas, Mexico, were estimated.

METHODS AND MATERIALS

Description of Study Area

The study was carried out in the Sierra de Órganos National Park (SONP) located in northwest of the municipal township of Sombrerete, Zacatecas, Mexico; the SONP covers an area of 1,124.65 hectares of ejido property and has an altitudinal range of 2,120 to 2,560 meters. The SONP is located within the extreme geographic coordinates: 23° 46' 54.31'' N and 103° 46' 37'' W, 23° 48' 06.39'' N and 103° 49' 08.66'' W, 23° 46' 07.71'' N and 103° 47' 01.26'' W and 23° 48' 28.80'' N and 103° 48' 57.93'' W (SEMARNAT, 2013). The climate in the SONP is temperate sub-humid (C (w0) (w) to (e)), with summer rains (UNAM, 1970). The physiography is low sierra of volcanic rock with escarpments, ridges and small valleys (UACH, 2002). The soil types in the SONP are Fluvisol, Xerosol and Eutric Lithosol associated with Eutric Cambisol. In the SONP, the vegetation types present are: Pine forest, Oak forest, Natural grassland, Scrubland, Riparian vegetation, and Aquatic and underwater vegetation (UACH, 2002). In addition, Enríquez *et al*. (2003) identified 406 species, 254 genera and 75 families of vascular flora.

Within SONP biodiversity, there are 36 mammal species (Rodríguez-Maturino *et al*., 2013); 19 reptile species (Rodríguez *et al*., 2018); 97 bird species (Rodríguez *et al*., 2018); 43 diurnal butterfly species, (Álvarez-García *et al*., 2017). Of these species, 17 are within some category of risk and eight are endemic, according to the NOM-059-SEMARNAT-2010 (SEMARNAT, 2010).

Sampling Procedure

Four transects (I, II, III and IV) were established in the SONP grasslands. One hundred observation points were randomly selected in transects I, II and IV; and 66 points were selected in transect III. Four measurements of the variables basal, canopy and organic mulch cover, soil cover, bare soil and plant form were made in each transect. The first measurement was made in 2008, when cattle grazing exclusion began; then, the remaining three measurements were made in 2010, 2012 and 2014. The results are presented in the results section as zero (0), two (2), four (4), and six (6) years of grazing exclusion, respectively. The data were obtained at the beginning of autumn in each of the above-mentioned years using the Early Warning Biological Monitoring -Rangelands and Grasslands method (ASCHM, 1999). The plant species identified in the grassland were grouped into three functional plant groups (Vega *et al*., 2019).

Description of Estimated Attributes

Basal cover: is the vertical projection of plant material toward the surface when viewed from above.

Canopy or crown cover: is the perimeter of the plant's foliage in its widest horizontal plane.

Organic mulch: is the layer of residue on the soil surface composed of leaves, stems and manure; also, organic mulch includes material that is decomposing and being incorporated into the soil.

Soil cover: is the proportion of soil area covered by some type of protective material such as mulch, gravel, stones and standing plant material.

Bare soil cover: is the proportion of soil surface area devoid of some type of protective material.

Plant form includes three categories: a) Normal plants are vigorous plants, with presence of stems, leaves and seed production and where no old growth is observed. b) Over-rested plants are those plants that have been esceedingly rested for several seasons; the grasses show rusty leaves and stems of two or more years, which impede growth, and the hollows in the plant's center may contain remnants of that ungrazed material. c) Deteriorated plants are plants with evidence of overgrazing or over-resting, but the plants are dying.

Statistical Analysis

Basal and crown cover, organic mulch cover, soil cover, bare soil, and plant form were the response variables as a result of maintaining the pasture with grazing exclusion for several years. In the variance analysis, the source of variation was the years with grazing excluded. The variance analysis was carried out for each response attribute by considering a completely randomized design. When significant effects were evident in any variable, the comparison was made with Tukey's multiple range test at $\alpha=0.05$ (Stell *et al*., 1997). The statistical analyses were performed using the Minitab 16 software, through the 'General Linear Model' statistical procedure.

RESULTS AND DISCUSSION

The basic statistical estimators of soil and vegetation attributes measured at baseline (0 years) and at 2, 4 and 6 years after grazing exclusion are shown in Table 1. Extremely large means and coefficients of variation (>30%) and variance analysis results (not shown) suggest that differences between the year of initiation (0) and 6 of grazing exclusion tend to be significant in all eight attributes involved. Therefore, the comparison results are presented below.

Differences ($p<0.01$) were associated to the grazing exclusion time factor in the following attributes of the SONP grassland: basal cover, crown cover, organic mulch cover, soil cover, bare soil cover, normal plants, over-rested plants and deteriorated plants. The mean basal cover of plants in the exclusion period increased 19.94 percentage points, from 9.02% to 28.96% (Table 1). In the first two years of exclusion, the increase in cover was not significant, but between years four and six the increase was very significant (Figure 1). Poaceae (formerly grasses) contributed 92.35% to 95.35% of the basal cover identified in the exclusion period; herbaceous plants contributed 1.34% to 6.28%; and trees and shrubs contributed 1.37% to 3.36% (Figure 2). Only herbaceous plants had a significant increase in year four of the exclusion; changes were not significant during the exclusion period in the other functional plant groups.

The mean crown cover of vegetation during the exclusion period increased 79.24 percentage points, from 13.93% to 93.17% (Table 1). The largest increases occurred during the first two years of exclusion and then from the fourth to the sixth year; during the interim period of exclusion, a slight decrease took place (Figure 3). The mean organic mulch cover during the exclusion period increased 124.61%, by changing from 17.76% to 39.34% (Table 1). During the first two years of exclusion, mulch increase was significant, but between the fourth and sixth year, the increase was not significant (Table 1). During the exclusion period the mean soil cover, integrated by basal cover of plants and organic mulch, was increased in 41.53 percentage points, by changing from 26.78% to 68.31% (Table 1). The largest increases belong to the first two years of the exclusion and from the fourth to the sixth; growth was moderate during the third year (Figure 1).

Mean cover of bare soil decreased during the exclusion period 41.53 percentage points, from 73.22% to 31.69% (Table 1). The largest decreases corresponded to the first two years of exclusion, and to the fourth, fifth and sixth; the decrease was moderate in the third year (Figure 1).

The percentage of normal plants during the exclusion period decreased 53.55 percentage points, from 99.45% to 45.90% (Table 1). The largest decrease was in the last two years of the exclusion, from the second to the fourth year the decrease was moderate, and in the first two years the decrease was small (Figure 3).

The percentage of over-rested plants increased by 17.21 percentage points during the exclusion period, from 0.55% to 17.76% (Table 1). The highest increases were observed from the second to the fourth year, and from the fourth to the sixth; in the first two years of exclusion the increase was small (Figure 3). The percentage of deteriorated plants in the exclusion period increased

Table 1. Basic statistical estimators of vegetation and soil surface attributes in Sierra de Órganos National Park grasslands, in cases of 0, 2, 4 and 6 years of cattle grazing exclusion.

Variable (%)	Years of exclusion	N	Mean	Standard error	Standard deviation	Coefficient of variation
Basal cover	0	366	9.02	1.50	28.68	318.10
	2	298	16.44	2.15	37.13	225.80
	4	366	16.67	1.95	37.32	223.91
	6	366	28.96	2.37	45.42	156.83
Crown cover	0	366	13.93	1.81	34.68	248.87
	2	298	34.90	2.77	47.75	136.81
	4	366	27.87	2.35	44.90	161.10
	6	366	93.17	1.32	25.26	27.11
Organic mulch cover	0	366	17.76	2.00	38.27	215.49
	2	298	36.24	2.79	48.15	132.86
	4	366	39.89	2.56	49.03	122.92
	6	366	39.34	2.56	48.92	124.33
Soil cover	0	366	26.78	2.32	44.34	165.60
	2	298	52.68	2.90	50.01	94.93
	4	366	56.56	2.59	49.64	87.76
	6	366	68.31	2.44	46.59	68.21
Bare soil cover	0	366	73.22	2.32	44.34	60.55
	2	298	47.32	2.90	50.01	105.70
	4	366	43.44	2.59	49.64	114.26
	6	366	31.69	2.44	46.59	147.01
Normal plants	0	366	99.45	0.38	7.38	7.42
	2	298	98.99	0.57	10.00	10.10
	4	366	91.26	1.48	28.29	31.00
	6	366	45.90	2.61	49.90	108.71
Over-rested plants	0	366	00.55	0.39	7.38	1350.92
	2	298	01.01	0.58	10.00	993.30
	4	366	08.74	1.48	28.29	323.51
	6	366	17.76	2.00	38.27	215.49
Deteriorated plants	0	366	0.00	0.00	0.00	0.00
	2	298	0.00	0.00	0.00	0.00
	4	366	0.00	0.00	0.00	0.00
	6	366	36.34	2.52	48.16	132.54

36.34 percentage points, from 0.00% to 36.34% (Table 1). Deteriorated plants occurred in the last two years of exclusion (Figure 3).

The increase in basal cover during the exclusion period is congruent with the results of other experiments (Li *et al*., 2018; Bi *et al*., 2018; Wang *et al*., 2018). It is possible that rainfall influenced the behavior of the basal cover. In fact, a very small increase (0.23%) was associated with basal cover from the second to the fourth year of exclusion; notably, the increase was greater from the fourth to the sixth year (Table 1). Likewise, the volume of precipitation was 24% lower than the mean in the fourth year of exclusion, while precipitation in the sixth year was 21% higher than the annual mean (526 mm). In this context, Strand *et al*. (2014) point out that precipitation is a key element influencing basal cover behavior.

The dynamics of canopy cover changes were similar to those of basal cover during the exclusion period;

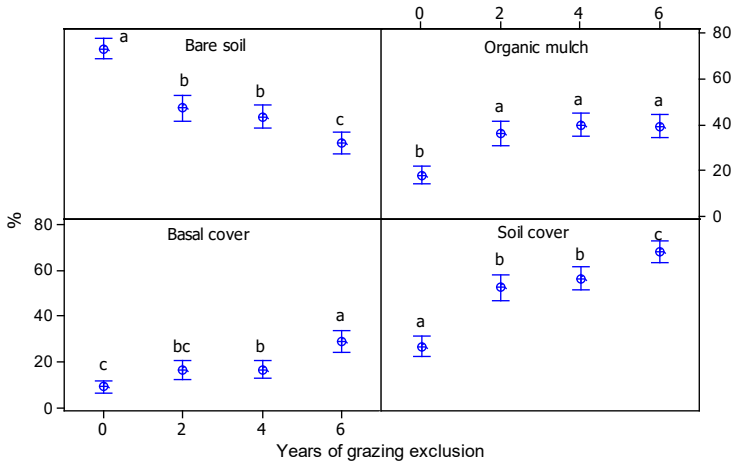

Figure 1. Percentages of mean basal cover, organic mulch, bare soil and soil cover in the SONP grassland during six years of exclusion. Means with different letters are different according to Tukey's test ($p<0.01$). Bars represent the mean ±1 standard error.

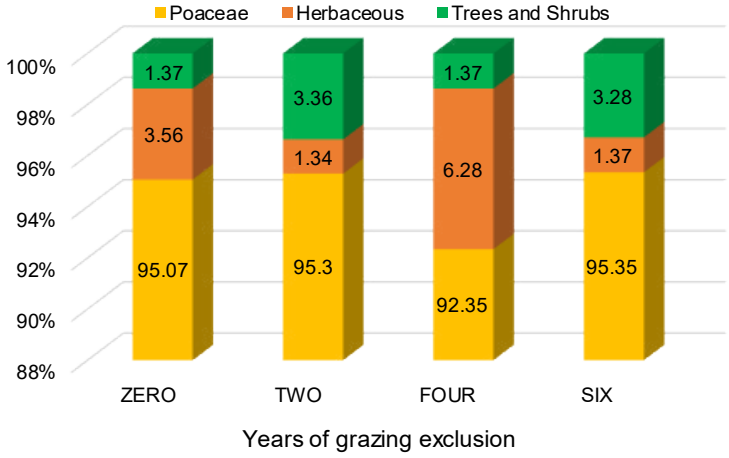

Figure 2. Percentage of functional plant groups in SONP grassland during six years of exclusion.

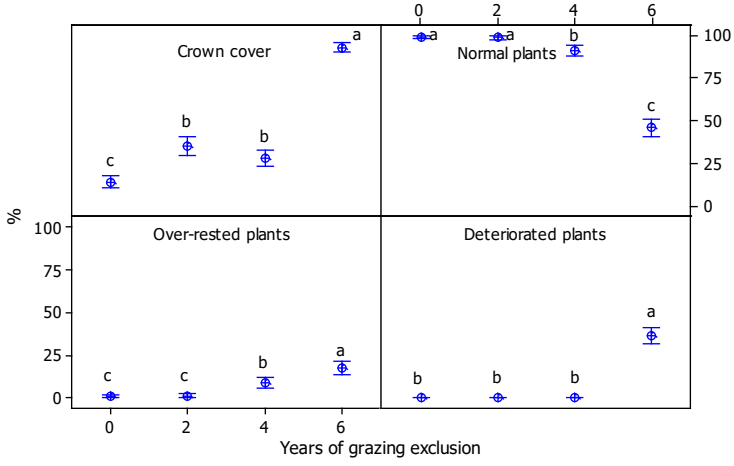

Figure 3. Percentages of crown cover of normal, over-rested and deteriorated plants in the SONP grassland during six years of exclusion. Means with different letters are different according to Tukey's test ($p<0.01$). Bars represent the mean ±1 standard error.

possibly, rainfall also influenced it. In addition, increasing crown cover increases the shaded area and decreases light toward Poaceae growing points, conditions that can inhibit plant growth (Li *et al.*, 2018).

Poaceae make up the most prominent functional plant group in the exclusion area (Figure 2) because it is a grassland ecosystem. In addition, Poaceae, trees and shrubs changed non-significantly during the six years of exclusion. This result agrees with that observed by Molinar *et al.* (2011) in their study on grazing exclusion.

Increasing organic mulch is consistent with results from other studies on grazing exclusion (Zou *et al.* 2016; Bl *et al.* 2018; Li *et al.* 2018; Hou *et al.* 2019). It is known that the increase in organic mulch originates from the accumulation of large quantities of plant material, which is not consumed by herbivores due to grazing exclusion. The accumulation of mulch damages Poaceae that have their growth shoots on the bottom of the plant, and these shoots may remain shaded and physically impeded from growing (Savory 2005). When mulch remains on the plant until the next growing season, almost all perennial grass species are weakened and, in fact, if the accumulation of dead matter persists for several years, the plant may die (Savory 2005).

Soil cover increased 155.08% during the grazing exclusion period due to the increase in basal and organic mulch cover. Organic mulch was the attribute that contributed most to the soil cover (Table 1). However, the basal cover should be the main component of the soil cover, due to the unfavorable effects caused by organic mulch when it accumulates for a long time.

Bare soil cover decreased throughout the exclusion time (Table 1). This result agrees with that observed by Jeo (2005), who identified that the amount of bare soil decreased with the exclusion of grazing. Also, Vermire *et al.* (2018) found less bare soil in exclusions than in areas grazed at 75% utilization.

The percentage of normal plants decreased because these organisms changed to over-rested plants and, in turn, these changed to deteriorated plants during the exclusion time. This trend was more noticeable

after the second year of exclusion (Table 1). The change dynamics of plant form observed in this study agrees with those reported by Savory (2005), who states that over-rested plants contribute old plant material to the mulch and, in turn, change to deteriorated plants due to the effect of the mulch accumulated over several years, which prevents the growth of reproductive shoots.

Grazing exclusion after the second year began to be detrimental for the SONP grassland. In this regard, Weber and Horst (2011) report that some Poaceae in semi-arid areas have evolved with large herbivores. In addition, Poaceae and soil surface require small disturbances to maintain the health of their biotic communities, thus increasing soil organic matter (Savory 2005, Weber and Horst 2011), providing soil-covering mulch, and improving rainfall efficiency (Savory 2005).

CONCLUSIONS

Exclusion of grazing for six years in the SONP grassland increased basal cover, crown cover, organic mulch cover, soil cover, as well as the percentage of over-rested plants and deteriorated plants; also, grazing exclusion decreased bare soil cover and the percentage of normal plants. The increase in organic mulch cover, percentage of over-rested plants and deteriorated plants over six years demonstrates that the SONP grassland is transitioning into a less stable ecological state. The increase in organic mulch cover over six years implies the accumulation of combustible material and represents a potential risk for fires to occur in the SONP grassland.

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