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Strategies for Re-vegetation of Degraded Arid Rangelands in Zacatecas, México

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ABSTRACT

Seed bed conditions play an important role in revegetation of degraded arid rangelands, where type of seedbed may favor the recovery (re-vegetation) of the rangeland by means of increasing quantity of vegetation cover, density of perennial and annual plants, forage production and yearly relative re-vegetation rate. In this two year (1999 & 2000) research work, the behavior of grasses on a degraded arid rangeland was analyzed in a field. Animal trampling and sowing *Bouteloua curtipendula* and *B. gracilis* seeds plus mulching by maintaining a substantial amount of plant residues (branches of native brushes: *Larrea tridentata*, *Acacia constricta & Mimosa biuncifera*) were the best strategies for revegetation and establishment of both the species in degraded arid rangelands under no grazing. Modification of seedbed through treatments as applied to this degraded arid rangeland might not increase forage production enough to justify these strategies when conditions of extreme drought (i.e., rainfall of 76 mm in 1999) were encountered.

Key Words: Animal trampling; Mulching; Grass seeding; Vegetative cover; Forage production; Principal components analysis

INTRODUCTION

One half of the earth's land is arid or semi-arid in climate on all continents. Human populations and the intensity of development are increasing rapidly in many of these regions, placing more demands on goods and services and changing the way that people interact with the unique diversity of desert systems. Past management actions and climatic fluctuations have caused degradation or desertification of many of these rangelands. One sixth of the world's population is affected by desertification and 73% of drylands in North America are degraded (UNEP, 1992).

The potential exists for future dramatic shifts under directional changes in climate and as a result of shifts in land use and management practices. These changes may result in further desertification on some sites and remediation on others (Schlesinger *et al.*, 1990; Herrick *et al.*, 1997; Havstad *et al.*, 2000). Because deserts are among the most temporally and spatially heterogeneous systems in the world, achieving management goals and predicting future conditions and dynamics is challenging. Rangelands in arid lands are really complex systems and thus characterized by extreme temporal variability on short time scales (both within & between years) as well as for longer time periods.

The stability of arid rangeland ecosystems is poorly buffered against changing drivers and changes typically exhibit significant time lags and 'pulse- reserve' responses (Noy-Meir, 1973). Short, intense rain and wind events combined with high topographic and soil variation result in heterogeneous patches and landscape units that are spatially connected through the redistribution of soil's minerals, water, seeds and nutrients across the landscape. Interactions between grazing animals and landscape dynamics provide further challenges to management decisions and predictions about future dynamics.

In México, semi and arid rangelands throughout the 'Chihuahua desert' provide forage for livestock production, habitat for native flora and fauna, watersheds for rural agriculture and urban uses, invasion sites for exotic species, sources of non-renewable minerals, open areas for recreation and biochemical systems that globally interact with other terrestrial and atmospheric systems. These rangelands are in a variety of conditions, from degraded to fully functional and managed by a number of different individuals (ranchers) and institutions with different objectives (Bravo-Espinoza *et al*., 2006). Significant changes in these landscapes have occurred over at least the past century that are related to, but not completely dependent upon, excessive grazing pressure by domestic herbivores, in particular cattle during the last four decades. Large-scale conversion of perennial grasslands to shrub lands has resulted in rangelands with lower quality and quantity of forage and greater susceptibility to wind and water erosion (Schlesinger *et al*., 1999). Then, this process of rangeland degradation is accompanied by soil erosion (Bravo-Espinoza *et al*., 2006) and biodiversity loss due to diminished quality and quantity of available soil water.

We carried out a field essay with the aim of analyzing a two years behavior of native grass on a degraded arid rangeland under the hypothesis that type of seedbed could be favoring the recovery (revegetation) of the rangeland by means of increasing quantity of vegetation cover, density of perennial and annual plants, forage production and yearly relative revegetation rate.

MATERIALS AND METHODS

Description of the experimental site. The experimental plot is located into the 'Chihuahua Desert Biotic Province' (Dice, 1945), at the northeast of Zacatecas state within of the 'Villa de Cos' municipality, near to kilometer 80.5 of the federal road from Zacatecas city to Saltillo city. It is within 'El Halcón' Ranch. The plot mean altitude is 2050 msnm (CNA, 2000).

The vegetation community displays a low number of desirable species and a high density of undesirable species such as *Larrea tridentata*, *Acacia constricta* and *Mimosa biuncifera*, among others. The vegetation is classified as desert xerophytic shrub (COTECOCA, 1982) having important forage herbaceous species like *Leptochloa dubia, Buchloe dactyloides, Setaria geniculata, Chloris virgata,* etc. Also, there are important species of foraging brushes such as *Atriplex canescens, Dalea bicolor, Buddleja scordioides, Opuntia leucotricha, O. rastrera* and *O. cantabrigensis*.

The soil texture is sandy loam and soil is classified as 'xerosol'. Climate is classified as BW (Köeppen, 1962). The annual mean of temperature is 17.5°C and the long-term (1960-2000) yearly mean of precipitation is 357.8 mm, being February the driest month and June the moistest one (CNA, 2000). The 'Villa de Cos' meteorological station registered annual rainfall was of 76 and 134 mm for 1999 and 2000, respectively. It means that annual precipitation in our study was below the long-term average for both years.

Experimental design and data. After selection of the experimental plot, six treatments were chosen and randomly distributed in the field inside four consecutive blocks separated each from other by 100 m. Applied treatments or strategies with the aim of modify soil physical properties (seedbed) playing an important role in the establishment and growth of rangeland plants (Chaichi *et al*., 2005) are the following:

1. TE = Traditional exclusion. It was made by only fencing the area of the experimental units receiving this treatment.
2. S = Conventional seedling. It consisted of removing all plants (rod wedding & rod brushing) from the fenced experimental units; afterward, sowing was performed by using *Bouteloua curtipendula* and *B. gracilis* seeds (8 Kg ha^{-1} each species), manually dispersed and then soil covered by utilizing surface tillage passing an agricultural tool with discs.
3. M = Mulching. This treatment was performed by maintaining a substantial amount of plant residues (branches of native brushes: *L. tridentata*, *A. constricta & M. biuncifera*) on soil of the fenced experimental units with the aims of conserving soil water and possibly improve the soil nutrient status (Pease *et al*., 2006).
4. HD = Handling disturbance. This treatment was applied in the fenced experimental units by disturbing surface soil using a pick.
5. AT = Animal trampling and seedling. It consisted of sowing *B. curtipendula* and *B. gracilis* seeds (8 Kg seed of each species ha^{-1}), manually dispersed; afterward, one 400 kg weighted-cow was introduced in the fenced experimental units, during 24 h., because it has been demonstrated that animal trampling can remove crusting developed on soil when strong humidity alternates with drought and helping litter and seeds to be mixed with soil particles (Anonymous, 2007).
6. AT + M = Animal trampling and seedling plus mulching. This treatment was the sum of actions involved in treatments 3 and 5.

On 7th, May 1999, all treatments were applied in 25 m^2 (5 x 5 m) experimental units. The experiment plot was maintained with no animal grazing during the two years of the study. On 25th, November 1999 and 2000, field work was realized in order to obtain data for the following variables:

1. VC = Vegetation cover. It is measured as the area covered by vegetation per surface unit. It was expressed in percentage (%).
2. TDP = Total density of plants. It identifies the number of plants per squared meter (Plants m^{-2}).
3. FP = Total production of forage. It denotes the quantity of forage produced each year expressed in grams of dry matter per squared meter (g DM m^{-2}).
4. TDPP = Total density of perennial plants. It identifies the number of perennial plants per squared meter (Plants m^{-2}).
5. TDAP = Total density of annual plants. It denotes the number of annual plants per squared meter (Plants m^{-2}).
6. YRRR = Yearly relative revegetation rate. It means the percentage of increasing vegetation cover at yearly level (%).

Data Analyses

Analyses of variance. An analysis of variance was performed for each of six measured variables in years 1999 and 2000. To test significant difference among their means, least squared difference procedure (p = 0.05) was considered.

Principal components analysis. Principal components analysis (PCA) was used as an ordination tool (Sneath & Sokal, 1973), to reveal relationships among variables and treatments within each PC structure (Valdez-Cepeda *et al*., 1996; Gutiérrez-Acosta *et al*., 2001). Each PC is defined by a linear combination of the original variable values. These combinations are the eigenvectors of the PC's. The first PC (PC1) will account for the maximum variance among all variables values that can be attributed to a single axis. Each succeeding PC will account for a progressively smaller percentage of the remaining variance. It is expected that the first two or three PC's often account for a large portion of the variance for each trait. Thus, PCA simplifies the original 'n' dimensional scatter plot by enabling the observations to be plotted on a reduced number of orthogonal axes, while minimizing the loss of information. A measure of the similarities among treatments can be inferred from the spatial proximity of the observations represented in the orthogonal space defined by each couple of PC's.

PCA was performed using Multi-Variate Statistical Package, version 3.12 (Kovach Computing Services, 2001). In the analysis, the means of all six treatments were used to compute a correlation matrix from which standardized PC loadings and scores were extracted.

Interpretation of the PC's was aided by inspection of the factor loading matrix. This is a matrix of correlations or loadings between the PC's and the original variables values. The correlations between some of the variables and the components generally became high or low; the interpretation of the PC's could be then easier.

RESULTS AND DISCUSSION

Analyses of variance. Treatments had no statistically different impact on vegetation cover for 1999, while for 2000 there were significant differences among treatments (Table I). These results could be attributed to the extreme below-average annual precipitation (76 versus 357.8 mm) in 1999 and the possibility of inadequate levels soil water availability and therefore, plant growth (Pease *et al*., 2006). However, in 2000, AT + M and S treatments promoted the vegetation cover in a better way than all other four treatments; for instance, three-fold and two-fold of TE strategy, respectively although rainfall (134 mm) for that year was also below-average annual precipitation (357.8 mm). When effects of each of the six treatments are compared between years, it is appreciated that vegetation cover is statistically higher in 2000 than in 1999 for all treatments excepting M. It might be meaning scarce rainfall (within the range from 79 to 134 mm) is not enough to promote adequate levels of plant growth when maintaining a substantial amount of plant residues (branches of native brushes, *Larrea tridentata*, *Acacia constricta* & *Mimosa biuncifera*) in arid rangelands; however, it promotes high vegetation cover (almost 33% in Table I) when applied in combination with animal trampling (AT + M) revealing a synergic effect, explained probably by the important positive role of mixing litter and grass seeds with soil particles, as pointed out by Anonymous (2007).

There were statistical differences among treatments for TDP in both years and between years for S, HD and AT + M strategies (Table I). It is remarkable that AT + M effect (33 & 78% in Table I) on this variable was better than those from other treatments in both years. Additionally, it is interesting to point out that AT had minimum effects on TDP, which is appreciated by means of the lowest value for each of both years (23 & 49% for 1999 & 2000, respectively).

Forage production was not statistically different among treatments, as applied in arid rangelands, nor between years due probably to rainfall critically below-average annual precipitation as can be appreciated by analyzing FP-1999 and FP-2000 in Table I. However, there appears yearly rainfall of 134 mm (2000) is enough to promote treatment effects (Table I), in terms of FP, higher than when annual rainfall is scarce (76 mm in 1999). In 2000, AT + M strategy had a FP of 49 g DM m^{-2}, a quantity higher than those associated to other rangeland revegetation treatments.

All six treatments had no different effects on TDPP in each of both years nor among years; however, did they on TDAP (Table I). By this way, AT + M effect was statistically different from those associated to other rangeland revegetation treatments when this variable (TDAP-1999 & TDAP-2000) is taken into account in the comparison. It is remarkable AT + M and M strategies were the best treatments for rangeland revegetation under extreme drought (rainfall of 76 mm in 1999) conditions in order to promote high TDAP (Table I). Furthermore, all treatment effects were statistically different between years (Table I). These results suggest TDAP is more sensitive to short time (two-year time scale) rainfall changes than TDPP does.

YRRR also showed statistical different treatment means conforming clusters of treatments, being remarkable AT + M strategy was the best treatment for rangeland revegetation in both years (Table I). TE, AT + M and S effects were statistically different between years (Table I).

As can be seen in Table I, AT + M resulted to be the best treatment when VC-2000, TDP-1999, TDP-2000, TDAP-1999, TDAP-2000, YRRR-1999 and YRRR-2000. This result agrees with findings of Valentine (1989) and Winkel and Roundy (1991) who indicated that soil compaction due to animal trampling has a positive effect on some grass and forbs germination. This agreement could be associated to our experimental units were no grazed during two years of duration of the field experiment. Additionally,

Table I. Means of the studied variables and comparison among treatments through least squared difference (LSD)

Treatment	VC-1999 (%)	VC-2000 (%)		TDP-1999 (Plants m^{-2})		TDP-2000 (Plants m^{-2})		FP-1999 (g DM m^{-2})	FP-2000 (g DM m^{-2})
TE	5.91	10.05	b*	24.97	b	59.19	b	7.50	14.06
S	6.24	20.33	ab*	28.26	b	89.39	ab*	12.34	27.73
M	8.51	14.55	b	52.66	ab	73.35	ab	22.01	43.56
HD	7.98	15.29	b*	43.09	ab	96.65	ab*	18.82	27.76
AT	3.71	11.27	b*	23.18	b	49.02	b	8.48	21.32
AT+M	13.63	32.81	a*	78.21	a	130.43	a**	35.58	49.38

	TDPP-1999 (Plants m^{-2})	TDPP-2000 (Plants m^{-2})	TDAP-1999 (Plants m^{-2})		TDAP-2000 (Plants m^{-2})		YRRR-1999 (%)		YRRR-2000 (%)	
TE	24.94	22.59	0.00	c	36.26	bc**	0.32	bc	1.13	b**
S	28.88	21.46	0.00	c	68.89	ab**	0.83	bc	3.15	ab*
M	30.28	28.61	21.34	b	45.47	abc*	0.73	bc	2.15	b
HD	43.87	36.35	0.00	c	58.16	abc**	1.04	b	1.91	b
AT	23.18	22.50	0.00	c	26.27	c**	0.23	c	1.46	b
AT+M	33.60	39.90	44.90	a	90.92	a**	2.02	a	5.60	a*

TE=Traditional exclusion; S=Seedling; M=Mulching; HD=Handling disturbance; AT=Animal trampling; AT+M=Animal trampling plus Mulching
VC=Vegetation cover; TDP=Total density of plants; FP=Total production of forage; TDPP=Total density of perennial plants; TDAP=Total density of annual plants; YRRR=Yearly relative re-vegetation rate.
Different letters in the same column indicate significant differences at $p \leq 0.05$
* and ** in the same row indicate significant differences at p=0.01 and p=0.05, respectively, for each variable

our results are reinforced by Chaichi *et al*. (2005) findings who recommend that in order to improve vegetation cover in the moderately grazed area, the rangeland needs to have restricted grazing by livestock for at least three years before it is managed with a more moderate stocking density that is in accordance with the rangeland's capacity to produce; and in the heavily grazed area, the vegetation cover needs to be improved by the seeding and establishment of high quality rangeland plants, which needs to be totally prohibited from grazing livestock long enough for plants to become well established and reproduced through natural regeneration. As a matter of fact, animal trampling had a positive effect on establishment of *B. curtipendula* and *B. gracilis* in this arid rangeland case of study, as reported by Winkel and Roundy (1991) for some different range species in other rangelands. However, animal trampling negative effects are expected when rangeland is under heavy grazing conditions (Chaichi *et al*., 2005; Saravi *et al.*, 2005; Anonymous, 2007).

Climatic variation in two years of conducting the experiment had no significant effect on forage production and total density of perennial plants (Table I). It could be, in part, explained by taking into account these perrenial plants existed before the severe change in yearly rainfall were happened in both years, On the other hand, probably sowed species did not have enough time to show its productive potential. In general, VC, TDP, FP, TDAP and YRRR increased in 2000, because of the better climatic conditions, that is, these variable positive behaviors are probably due to more available moisture and better growing season.

Principal components analysis. From the PCA, it was considered that the first two PC's were sufficient to summarize the variation of the original data. They accounted for 86.5% of the variance for means of six variables measured over two years (1999 & 2000): PC1, 74%; and PC2, 12% (Table II). Therefore, only 13.5% of total variation remains unexplained by this two PC's.

Table II. Principal components Eigenvalues and explained variance

	PC 1	PC 2
Eigenvalues	8.92	1.45
Percentage of explained variance	74.35	12.14
Cumulative percentage of explained variance	75.35	86.50

Table III. Principal components analysis variables' loadings

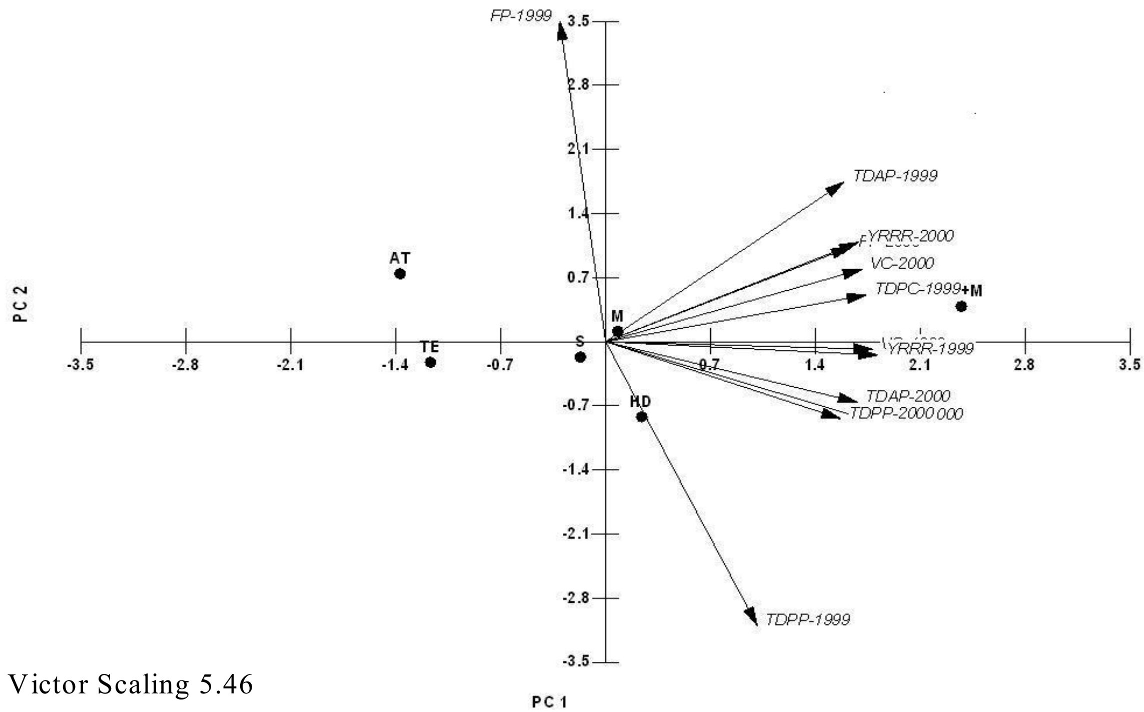
Variable and year	PC1	PC2
VC-1999	**0.326**	-0.015
VC-2000	**0.313**	0.145
TDP-1999	**0.318**	0.093
TDP-2000	**0.321**	-0.156
FP-1999	**-0.056**	0.640
FP-2000	**0.299**	0.190
TDPP-1999	**0.184**	-0.566
TDPP-2000	**0.286**	-0.154
TDAP-1999	**0.291**	0.319
TDAP-2000	**0.307**	-0.121
YRRR-1999	**0.332**	-0.027
YRRR-2000	**0.308**	0.199

Important variables' loadings in each PC structure are in boldface
VC=Vegetation cover; TDP=Total density of plants; FP=Total production of forage; TDPP=Total density of perennial plants; TDAP=Total density of annual plants; YRRR=Yearly relative re-vegetation rate

The first component (PC1) is really a composite character, which is the combination of all six variables, except FP-1999, measured in both years, that captures maximal variation (74%) in the data set (Table III). As can be appreciated, all these variables are positively inter-correlated. Its structure reveals that, in 1999, forage production was not inter-correlated with any other variable, because it was low due probably to the scarce rainfall (76 mm) that year.

On other hand, the second component (PC2) was highly correlated with a lower number of variables when compared with PC1 (Table III). The positively correlated

Fig. 1. Position of six treatments, and six variables measured in 1999 and 2000 on the orthogonal plane defined by the first two principal components (PC's). Treatments: TE=Traditional exclusion; S=Seedling; M=Mulching; HD=Handling disturbance; AT=Animal trampling; and AT+M=Animal trampling plus Mulching. Variables: VC=Vegetation cover; TDP=Total density of plants; FP=Total production of forage; TDPP=Total density of perennial plants; TDAP=Total density of annual plants; and YRRR=Yearly relative re-vegetation rate



variables with PC2 are VC-2000, FP-1999, FP-2000, TDAP-1999 and YRRR-2000; whereas these negatively correlated with same component are TDP-2000, TDPP-1999, TDPP-2000 and TDAP-2000. Structure of PC2 suggests that positively correlated variables with PC2 are positively inter-correlated between them as well as those negatively correlated with PC2; however, they are negatively inter-correlated between them when each couple is formed with variables from different group. There is interesting to point out several important ecological traits when high absolute values of loadings (Table III) are considered. For instance, in the driest year (1999), an increasing of total production of forage (loading = 0.64 for FP) could be associated to a decrease of total density of perennial plants (loading = –0.566 for TDPP). This situation is corroborated by examining Fig. 1, where can be clearly appreciated that FP-1999 and TDPP-1999 arrows are in closely opposite directions.

When the first two PC's account for a high percentage of the total variation, as in the present study case, a plot of PC1 versus PC2 can be a useful way of looking for clusters. Initial examination of that plot (Fig. 1) suggests an obvious pattern. There is a visual indication of the relationships among all the six treatments and six variables measured in both years. All variables, excepting FP-1999 and TDPP-1999, are positively correlated with AT + M treatment on the right region of the orthogonal plane defined by the two first PC's. This graph indicates that AT + M treatment is the best strategy for revegetating this type of degraded arid rangelands when the response is measured trough these six variables. Unfortunately, soil properties were not evaluated in this study, thus our results must be taken with caution, because animal trampling in turn reduces soil infiltration capacity and leads to accelerated runoff and soil erosion in rangelands under grazing conditions, as pointed out by Butler (2002), Chaichi *et al*. (2005) and Saravi *et al*. (2005).

Fig. 1 allows us to assure that this rangeland is characterized by extreme temporal variability on two-year time scale, as measured in forage production terms. It deserves to be pointed out that in 1999, the driest year, there appears AT could be the best strategy for forage production. Moreover, results suggest that all six treatments as applied to this degraded arid rangeland might not increase forage production enough to justify several treatments when conditions of extreme drought (rainfall of 76 mm in 1999) are encountered. This late appreciation agrees with that reported by Pease *et al*. (2006) for semidesert grass-shrub rangelands.

CONCLUSION

Animal trampling and sowing *Bouteloua curtipendula* and *B. gracilis* seeds (8 Kg seed of each species ha^{-1}) plus mulching by maintaining a substantial amount of plant residues (branches of native brushes: *L. tridentata*, *A. constricta & M. biuncifera*) treatment was the best strategy for revegetation and establishment of *B. curtipendula* and *B. gracilis* in degraded arid rangelands under no grazing conditions. This animal trampling and sowing plus mulching strategy positive effect was also elucidated by means of increases of vegetation cover, total density of plants, forage production, total density of annual plants and yearly relative vegetation rate from an extreme severe dry year (1999 with 76 mm of rainfall) to a year (2000) with below-average annual precipitation (137 versus 357.8 mm).

Climatic variation in two years of conducting the experiment had no significant effect on forage production and total density of perennial plants. It could be explained by taking into account these perennial plants existed before the severe change in yearly rainfall were happened in both years and that sowed grass species had not enough time to show its foraging potential.

Arid rangeland of the present study case is characterized by extreme temporal variability on two-year time scale, as measured in vegetation cover, total density of plants, forage production, total density of annual plants and yearly relative revegetation rate terms. It deserves to be remarked, for instance, that an increasing of total production of forage could be associated to a decrease of total density of perennial plants in extreme dry years.

Modification of seedbed through treatments as applied to this degraded arid rangeland might not increase forage production enough to justify these strategies when conditions of extreme drought (i.e., rainfall of 76 mm in 1999) are encountered.

Finally, we recommend degraded arid rangelands be totally prohibited from grazing livestock long enough for plants to become well established and reproduced through improving revegetation by means of animal trampling and sowing *Bouteloua curtipendula* and *B. gracilis* seeds (8 Kg seed of each species ha^{-1}) plus mulching by maintaining a substantial amount of plant residues (branches of native brushes: *L. tridentata*, *A. constricta & M. biuncifera*).

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