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SOIL PHYSICAL DEGRADATION OF RANGELANDS UNDER CONTINUOUS GRAZING AT THE ZACATECAS, MEXICO HIGHLANDS

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SUMMARY - The objective of the study was to assess soil changes due to continuous (CG) and rotational (RG) grazing systems with small ruminants on structural, hydrological and soil organic matter content as well as soil losses and runoff. The study was carried out in a rangeland site (53 ha) located in the ejido Panuco, Zacatecas, Mexico, during 2002 to 2005. The average rainfall of the site is 400 mm and soil is mainly sandy. Soil measurements were performed in the study area and the surroundings. The continuous trampling on the CG area had negatively affected soil characteristics and some changes in structural variables with respect to RG were found. Changes in CG were for bulk density (1.53 Vs 1.41), increase penetration soil resistance (17.06 Vs 15.3 Jcm^{-1}), more porosity on RG (4 to 5%), and also smaller radii pore size (534-550µ vs. 578-592 µ). There were no differences for the hydrological variables such as sorptivity (0.54–0.6 vs. 0.71-0.76cm $min^{-1/2}$), infiltration (7.1-7.6 vs. 9.7-10.7cm h^{-1}) and surface roughness (1.03-1.21 vs. 1.23-1.37 dimensionless), between CG and RG, respectively. Also, there were no differences between organic matter content and humic acids. With respect to soil losses and runoff, their values were systematically higher for the CG system under the native vegetation conditions studied ($P<0.01$). CG leads to a continuous physical degradation of rangelands. By contrast, RG effects are associated to increments in the soil water storage, which may be the starting point for stopping soil degradation and eventually improve rangeland condition.

Key words: Penetration soil resistance, Radii pore size, Bulk density, Infiltration rate, Sorptivity, Surface roughness, water erosion.

RESUME- *L'objectif de l'étude, a été d'évaluer les changements du sol avec des indicateurs structurels, hydrologiques, contenu de matière organique, érosion hydrique et pertes par ruissellement, dus au pâturage continu (CG.) et au pâturage de rotation (RG) avec des petits ruminants. L'étude a été effectuée dans une praire (53 ha), situé dans l'ejido Panuco, de l´état de Zacatecas au Mexique, pendant les années 2002 au 2005. Les précipitations moyennes sont de 400 mm et le sol est principalement sableux. Le piétine continu sur le sol avec CG a affecte négativement les caractéristiques du sol et on a trouvé. Les changements en CG se sont pressentes sur la densité apparente du sol (1.53 contre 1.41* Kg/m^3*), la résistance de sol a la pénétration á augmente considérablement (17.06 contre 15.3* Jcm^{-1}*), on a trouvé plus de porosité en RG (4 au 5%), et aussi une plus petite taille du rayon du pore (534 – 550 µ contre 578-592 µ). Il n'y a pas eu aucune différence pour les variables hydrologiques, tell quelles que le sorptivité (0.54-0.6 contre 0.71-0.76 cm* $min^{-1/2}$*), l'infiltration (7.1-7.6 contre 9.7 -10.7cm* h^{-1}*) et la rugosité superficielle (1.03 - 1.21 contre 1.23-1.37 sans aucune dimension), pour CG. et RG, respectivement. En outre, il n'y pas eu aucune différence entre le contenu de matière organique et des acides humiques. En ce qui concerne les pertes du sol et ruissellement, leurs valeurs ont été systématiquement hautes pour le système de CG sous les conditions de végétation étudiés (*$P<0.01$*). Le CG. mène à une dégradation physique continue des terrains.*

Mots clés: *Résistance du sol a la pénétration, taille de rayon du pore, densité apparente, vitesse d'infiltration, Sorptivité, rugosité superficielle, érosion hydrique.*

INTRODUCTION

Soil degradation is defined by the UNCED (1992) as “the process that reduce the soils capacity to produce goods and services”. After the Rome convention about soils degradation, in 1974 (FAO, 1980), six types of degradation were defined: water and wind erosion; biologic degradation, which is associated to organic matter and fertility reduction; chemical degradation, that is associated to acidification and toxicity; excess of salts and sodium accumulation; and soil physical degradation, which refers to adverse changes on soil properties such as porosity, soil permeability, bulk density and structural stability (FAO, 1980). Soil physical degradation affects agricultural lands, where the excessive use of machinery lead to negative effects, and rangelands, where physical degradation is mainly due to overgrazing. The negative effect of physical degradation is worst when is associated to more degradation types, increasing runoff and water erosion, biological degradation by effect of organic matter reduction and less vegetation cover, which may increase the desertification risk.

In Mexico, more than 65% of the surface dedicated to agricultural and rangeland uses are under continuous degradation, especially those under a communal regime. There are two types of land ownership in Mexico, private and communal. The communal type was organized in Ejidos, which gave legal land ownership to peasants after the Mexican Revolution. A portion of the land was assigned to each family for crop production and the rest of the area was assigned for communal use mainly for livestock grazing. Agricultural activities are rain fed based with low crop yields and under practices that exacerbate land and natural resource degradation. Most Livestock production systems are raised under the ejido tenure. Nearly 50% of the ejidos involve ranges suffering from systematic degradation due to overgrazing.

Grazing modify soil physical, chemical and biological properties; consequently, processes associated to hydrology, nutrients cycles and rangelands vegetation growth are also modified (Whisenant, 1999, Beukes and Cowling, 2003, Tate *et al.,* 2004). For instance, some authors (Gifford and Hawkins, 1978, Wood *et al.,* 1978, Blackburn, 1983) have indicated that the rangelands rational use induces vegetation recovery after a grazing or harvest period and promotes higher soil water storage by improving the soil infiltration. Other studies (Blackburn, 1983, Blackburn, 1984) have shown the positive or negative effects of using several grazing intensities, stopping grazing or temporal grazing exclusion, on the water erosion values in rangelands. Besides, grazing effects on soil conditions may be different for each vegetation type (Blackburn *et al.,* 1982), and the processes that occurs in each site depends on the vegetation community type (Pierson *et al.,* 2002) and management. Rotational grazing system promotes vegetation cover recovery and soil conditions improvement through the temporal exclusion of a single pasture, meanwhile the rest of pastures are being grazed. The resting and use periods are distributed in time and space and then, gradually, a recovery stage is achieved, due to the carrying capacity reduction (Holechek *et al.*1995, Wood and Blackburn, 1984). In studies carried out in semiarid areas (Wood and Blackburn, 1984, McGinty *et al.,* 1979, Wood and Blackburn, 1981a, Wood and Blackburn, 1981b), where some grazing systems were tested, it was shown that rotational grazing systems helped to improve water infiltration rate and reduced water erosion compared against high intensity – low frequency system, continuous grazing and continuous grazing with a moderate animal pressure. Also, rotational grazing system improved soil condition by increasing the organic matter content and soil aggregates stability (Wood and Blackburn, 1984).

The rangelands recovery starting by the reduction of the physical soil degradation has an additional advantage. Rangelands are located in the middle part of the watershed and its role as recharge sites has been recognized, by increasing water storage in rangelands also increase the aquifer recharge, which may help to control the aquifer disequilibrium by over-extraction of irrigation water in the watershed lower parts.

The study objective was to evaluate the soil physical degradation by means of changes due to two grazing systems (continuous and rotational) with small ruminants on soil structural and hydrological variables and organic matter content.

MATERIALS AND METHODS

Study area description.

The study was carried out in a 53 ha rangelands area, located in 22º 54' N and 102º 33' W with 2,285 masl. The annual precipitation is about 400 mm. According to COTECOCA (1980) classification system, the vegetation is medium thorny bush with the predominant vegetation being "native range, cactus - thorny shrub". Grassland predominates in some areas and cactus in others. The former contains mostly gramineas (*Bouteloua curtipendula, Bouteloua gracilis (HBK)* Lag*, Aristida spp, Lycurus phleoides* HBK), while the latter is represented by a large number of wild cacti (*Opuntia Leucotricha* D.C., *Opuntia streptocantha* Lem*, Opuntia Rastrera* Weber*, Opuntia hyptiacantha* Weber, *Opuntia megacantha* Salm-Dick and *Opuntia pachona* Griffiths). The thorny bush vegetation is composed of bushes and some annual plants (*Acacia farnesiana* (L) Willd, *Prosopis laevigata (*Willd) M.C. Johnston, *Mimosa biuncifera* Benth and *Dalea bicolor*). The studied area is a micro-watershed, with a main stream which is a tertiary affluent with intermittent flow of water. Soils are mainly sandy (63-87%) with pH slightly alkaline (pH ~ 7.8), low nutrients content and organic matter (0.1-2.7%) and salts. According to the WRB (2006) classification soil are mainly Leptosols and Castanozems in lower proportion and have a petro-calcic horizon with variable depth (Serna y Echavarría, 2002).

Grazing system

The rotational grazing (RG) system was established in 2002. The site was excluded to grazing during five years (1995-2000) and reopen to continuous grazing the following two years, then, site was excluded and handled as RG, with four divisions. The carrying capacity was determined based on 1.5 kg dry matter/day/animal needs, leaving 25% of the vegetation aerial yield. Grazing was applied one month in each season. Instead of using the four months average carrying capacity for each pasture, which was estimated in 151 goats or sheep, a higher number was used and 250 small ruminants were managed without forage limitations, due to an increment in the rain mean during 2002 and 2003.

Continuous grazing (CG) treatment was applied in the surrounding area of the excluded site. The carrying capacity was not controlled because CG represents the traditional management and goat raisers have a variable flock size. However, there is an informal distribution of the rangelands users and based on observations of the grazing routes was determined that only four herds used to graze that part of the terrain, with at least one herd using the area and with 200 to 300 goats and sheep grazing every day. The CG is considered as the control. Several soil indicators were used to evaluate the grazing effect on soil degradation. Indicators were organized as structural, hydrologic, biological and water erosion as the main indicator, which integrates the degradation effect.

Soil physical degradation

Structural soil Indicators

The indicators used were bulk density, porosity, pore radii, soil compaction and texture, which were determined in both CG and RG systems. Bulk density (BD) was measured with the cylinder method (Blake, 1965), by using metal rings of 12 cm of diameter and 6 cm of height. Bulk density was determined in the RG by sampling five transects where 51 samples were collected during 2002 and 10 samples in 2005. In the CG five transects were sampled and 20 samples were collected in 2002 and 10 samples in 2005. Each transect had variable length with sampling points located each 500 m separated between them. Bulk density was estimated according to Brady and Weil (2000) procedure.

Porosity and pore radii were determined at the end of the study. In order to do that two undisturbed soil samples were collected by transect, both back slope and foot slope, which are contrasting physiographic positions. Five transects for each grazing system were sampled with a total of ten samples by system. Undisturbed samples were sampled with metal funnels of 12 cm diameter and 6 cm height and a 3.175 mm outlet. Funnels were introduced into the soil to avoid soil disruption. Porosity distribution was determined with the Vomocil (1965) technique, which is a procedure to obtain pairs of data of soil water content and pressure or matrix potential, which is, released such amount of water. The pore radii was estimated with the Brady y Weil (2000) equation; $\boldsymbol{r = 0.149\ cm^2/\Psi_m}$, where r is the pore radii, $0.149\ cm^2$ is a constant of the capillarity equation and Ψ_m is the matrix potential (cm). A bivariate distribution that includes pore radii associated to water content was used to calculate moments (mean, variance, skewness and kurtosis), where the mean was the moment of interest.

The soil texture was determined with the Bouyoucos hydrometer method (Pulido and Del Valle, 2001). The soil compaction, which is reported as soil penetration resistance, was measured with a penetrometer (Davidson, 1965). Measurements were performed in five transects in each treatment where 51 and 20 samples were collected in RG and CG, respectively. Each sampling point was represented by the five measures mean. Eight measurements were done from March 2002 to November 2005. The depth values were transformed to force units' trough the following formula (Herrick y Jones, 2002):

$$F = \frac{(n_i)(m)(g)(h)}{d_i} \tag{1}$$

Where F is the energy that oppose to penetration into soil measured in Joules cm^{-1}; n_i is the number of hammer strikes; m is the weight in kg; g is the fall speed by gravity effect (9.81 m seg^{-2}); h is the height of hammer fall in m; and d_i is the distance of penetration in m.

Soil hydrologic indicators

The soil hydrologic indicators were sorptivity (S) (Fuentes, 1989), cumulated infiltration after 60 minutes of test (I_{60}), final infiltration rate (I_f) and surface roughness. Indicators were evaluated at the end of the study period, sampling in the same way as for radii pore and porosity determination already described.

The indicators S, I_{60} *y* I_f were estimated from infiltration tests (Bertrand, 1965) using a hydraulic head ranging from 4 to 3 cm. The inner cylinder is 25 cm diameter and the external cylinder is 40 cm. The last one is used to build a hydraulic barrier, which produces a one-dimensional flow. Each cylinder was introduced 6 cm into the soil. Readings of water height were fixed in one cm, recording the lapse of time to infiltrate it. Immediately after infiltration, a volume of water enough to recover the amount of water infiltrated was applied in the inner cylinder. Measurements were performed for each sampling site. Field data were converted to infiltration rate (cm h^{-1}) and infiltrated partial and total depths (cm). Data collected in the first 15 minutes of the test were used to estimate S, following the Sharma *et al.* (1980) method. Volumetric soil water content ($m^3\ m^{-3}$) was determined at the beginning of the test.

The soil surface roughness determination was made with a 20 needles point frame (Kincaid and Williams, 1966). This determination represents the standard deviation of heights located above or below a parallel plane of the soil surface (Pierson *et al.,* 2002). Two samplings were made by transect in two physiographic positions.

Biologic degradation Indicators

Soil Organic Matter content and humic acids

The soil organic matter content (percent based in total soil weight) and its differentiation in humic acids and humins, were determined in laboratory following the Schnitzer (1982) methods. Indicators were evaluated at the end of the study period, sampling in the same way as in the radii pore and porosity determination already described.

Water erosion, runoff and Vegetation Cover factor (C) of the universal soil loss equation (USLE)

The soil losses (water erosion) were recorded since the study starting in the RG area, but only were measured for both grazing systems in 2004 and 2005. Runoff plots with collectors and storage recipients were used to collect water and soil sediments. Dimensions of runoff plots were 3 X 22 m (Wischmeier and Smith, 1978). Plots were installed in two vegetation conditions, which were a high density of native cactus pear with a mean density of 2000 plants/ha and thorny bush vegetation as a second condition with a mean density of 1200 plants/ha. An additional runoff plot was always kept without vegetation by using herbicides, and no mechanical control of erosion was established. This plot gave potential erosion water data or maximum soil losses, which was used to estimate the C factor of USLE. The records of rainfall were obtained with three rain gages distributed in the study area. The magnitude of rainfall (mm) and the runoff volume (m^3 $ha^{-1)}$ of each of the runoff plots were registered for each event. Also and aliquot (one litter of water) was taken for each plot in order to determine in the laboratory the suspended sediments (g l^{-1}). The separation of the suspended sediments of each aliquot was done by filtering, using No. 2 Whatman filter paper. Erosion was determined by multiplying the sediments by the total runoff (kg ha^{-1}).

Statistical analysis

For pairs of samples coming from both grazing systems, a t-test was done. Analysis was made with SAS program (1992). For the mean estimation of a bi-variate function of water content and pore radii the CALMOM program was used (Skopp, 1986). For water erosion and runoff data a combined variance analysis was performed, year was used as the first factor and vegetation condition as the second one. Because of the erosion data behave as log normal distribution, data were transformed to natural logarithm (Giordanengo *et al.,* 2003). Analysis was performed by SAS program (1992).

RESULTS AND DISCUSION

Soil structural variables

The mean BD values for grazing systems studied are shown in Fig. 1. At the beginning of the study period (2002), mean values of BD were the same in both systems ($P>0.05$). By contrast, at the end of the study, four years later (2005), the mean values of BD were different ($P<0.05$), due to a BD value increment in the CG treatment while the RG values were the same as 2002. BD increment was ~0.12 g cm^{-3} (Fig. 1).

The mean values of the soil resistance for both grazing systems studied are shown in Fig. 2 The soil resistance data behaved as the BD data; for both systems, at the beginning of the study, mean values were not different ($P>0.05$). After that point, data became different ($P>0.05$) between grazing systems (15.3 vs. 17.06 J cm^{-1}, RG and CG, respectively). The CG system increased soil resistance along the length of the study. Both increments, BD and soil resistance values are associated to a diminishment in total porosity and matrix potential values less negatives (Warkentin, 1971).

The *Table 1* shows the pore radii mean values, percentage of porosity and content of sand in the places of RG and CG sampled in two physiographic positions through the study area. Soils located in the back slope where the CG was practiced, shown a greater pore radii mean ($P>0.05$) than the soils located in the same physiographic position where the RG was carried out. By the contrary, porosity showed greater values in places with small size of pore ($P>0.05$) than the soils located in the back slope. For soils located in the foot slope, there was no difference between the mean porosity values and pore radii between RG and CG.

In general, the greater pore size values were associated to values with reduced values of porosity and they were located in places dedicated to CG (*Table 1*). The mean sand content in the study area showed little variation. Nevertheless, on foot slope soils, the area where CG was practiced showed a mean value of sand content significantly greater ($P>0.05$) than the soil where RG was used. This explains the greater pore size values in this topographical position.

A change in BD values in CG indicated that under this treatment, soil weight per unit of surface increased. This change leads to a soil porosity reduction and consequently a reduction in soil water storage and greater soil resistance (Fig. 2). BD values between 1.1 and 1.5 g cm^{-3} has little influence in soil water suction, but values greater than 1.5 to 1.7 g cm^{-3} lead to lower values of the soil water suction (Warkentin, 1971).

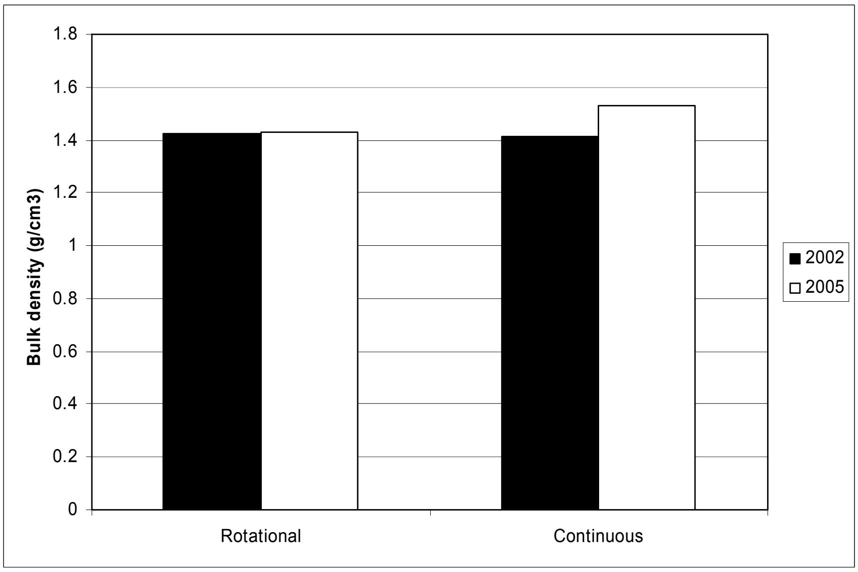

Fig. 1. Mean values of soil bulk density under rotational (RG) and continuous grazing (CG) in Zacatecas, Mexico

A characteristic due to animal trampling is compaction of the soil surface layer. It has been reported that increasing stocking rate and grazing time in the pasture, the continuous trampling destroys slowly the soil aggregates, which at the same time, leads to a more soil surface compaction and increments soil surface BD (Warren *et al.,* 1986a, Tate *et al.,* 2004), reducing infiltration rate and soil water storage, and increasing soil water erosion (Warren *et al.,* 1986b). Such information can explain why, in this experiment, continuous trampling of a high stocking rate applied along the year induced the increment in BD values and resistance to penetration. However, it is also not rejected that additionally to the RG treatment, a previous period of exclusion (from 1995 to 2000) might have had an influence to produce minor values of BD and resistance to penetration than the RG treatment.

With respect to the pore radii mean values, they were inversely associated with soil porosity. Therefore minor pore size is associated to higher values of porosity (*Table 1*). Higher ability to water storage indicates that a great ability to soil water storage rely on micro - pores and mesopores (Skopp, 1998a). Differences in porosity between grazing systems were from a range between 4 to 5 % of soil water stored (volume based) for back slope and foot slope, respectively. This represents higher soil water content in saturation as a result of the RG management (*Table 1*). Even when no measurements of soil water content were made, the soil water storage might increase in proportion to the increment of soil water saturation values. Because of the total porosity represents the maximum water storage in soil (Skopp, 1998b), there was a higher storage capacity in RG than in CG. At the same time, there was a significant difference among pore size, porosity and sand content by physiographic position (*Table 1*). That can be explained by differences in the soil drainage system for each position. Even though, back slope soils are exposed to a more intense erosion process, they have a more mature drainage system, while soils located at the foot slope are mainly build by soil accumulation, which make more difficult to develop a drainage system (Skopp, 2000). The prominence of micro - pores and mesopores, a better soil water storage capacity and less sand content, are characteristics of a better drainage system, which require time for establishment, and represent *in situ* soil development, such as the back slope soils. In the soils built by accumulation as the foot slope, the improvement of the structural characteristics of soil depends on a less intensity of degradation or compaction processes, besides; it needs more time for changing (*Table 1*).

The group of studied indicators shows a continuous change process as the physical degradation of rangelands in sites under CG. Also, the actual and potential capacity to produce biomass for animal species has been reduced. This last was shown for this study site in a parallel study (Echavarría *et al.,* 2006).

Table 1. Radii pore, porosity and soil sand content for continuous and rotational grazing. Pánuco Zacatecas, México.

Indicators	Back slope		Foot slope	
	RG	CG	RG	CG
Radii pore (10^{-3}mm)	534b ± 30	578a ± 22	550a ± 34	592^a ± 52
Porosity (%)	0.47a ± 0.03	0.42b ± 0.02	0.45a ± 0.03	0.41a ± 0.05
Sand content (%)	55.9a ± 6.0	57.1a ± 8.6	54.4b ± 3.7	70.5a ± 6.2

Means with the same letter were not significantly different ($P<0.05$).

Soil hydrologic indicators

The mean values of soil roughness and infiltration associated to grazing treatments for two physiographic positions are shown in *Table 2*. Soil roughness showed systematically higher values in the back slope than foot slope for RG. Values of I_{60}, I_f , and S were also higher in RG than in CG. In all cases, mean values were not different ($P<0.05$) neither, between grazing treatments, nor physiographic positions.

According to Fuentes (1989) "sorptivity represents the soil capacity to absorb water due to capillarity forces in certain soil water content". That implies a strong dependence of infiltration with pore size.

The higher values of sorptivity and infiltration and lower mean values of pore size were located in the back slope of RG (*Table 2*). By contrast, lower values of sorptivity and infiltration, and higher values of pore size were located in the foot slope of CG. An ideal pore distribution includes similar amounts of micro, meso and macro - pores (Skopp, 1998a). Higher values of porosity indicates a bigger amount of water at saturation level, however, higher mean pore size values are not necessarily associated to high porosity values (*Table 1*) and may be an indication of lack of symmetry of distribution curve around the mean value and shows mean values to the right side of the curve, which can reduce the soil ability to store water. In this case, high values of sorptivity and infiltration are influenced by the pore size distribution where mean pore size was lower. Besides, this characteristic was found in the back slope of RG treatment, where a pore net connected between them has been developed naturally, which allows a better water drainage. The opposite behavior was found in the foot slope of CG treatment, where a pore net interconnected has not been developed.

Biologic degradation Indicators

The results of organic matter and humic acids determination in grazing systems are shown in Fig. 3 The organic matter values were not different ($P>0.05$) among grazing systems. The humic acids in CG were higher than RG, but the difference was not significant ($P>0.05$). That tendency indicates an accumulation of vegetation, which is more degradable. By contrast, in RG area, there was an accumulation of vegetation, which is more difficult to be degraded. In the case of RG, part of the vegetation is not consumed by animals, which allow them reaching plant maturity. That kind of material when is deposited on soil is degraded slowly. Although results indicated both treatments were not different ($P<0.05$), the presence of plant material in RG, which is uneasy to degrade, lead to a slow mineralization (Sparks, 1995). As long as that organic matter stays into the soil, it will keep some favorable characteristics (unchanged BD, less penetration soil resistance and better soil water storage) and, consequently, a more sustainable rangeland resource.

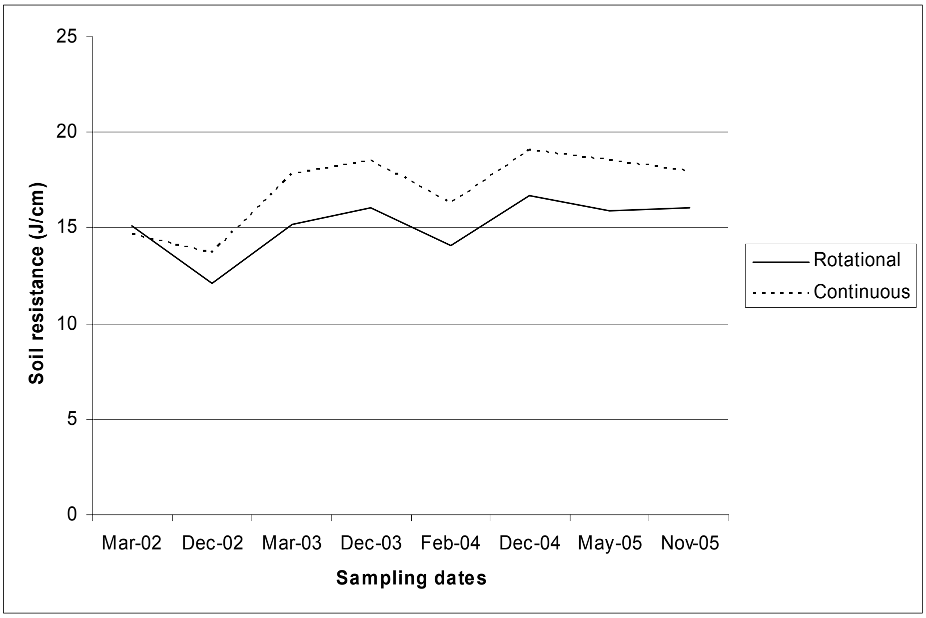

Fig. 2. Soil penetration resistance for continuous and rotational grazing. Pánuco Zacatecas, Mexico.

Table 2. Infiltration indicators and surface roughness for continuous and rotacional grazing. Pánuco Zacatecas, México.

Indicador	Back slope §		Foot slope §	
	RG	CG	RG	CG
Cumulated infiltration in 60 minutes (cm)	10.4 ± 2.8	8.0 ± 2.1	11.2 ± 3.7	7.9 ± 1.3
Sorptivity (cm $min^{-1/2}$)	0.71 ± 0.16	0.60 ± 0.09	0.78 ± 0.29	0.54 ± 0.06
Final infiltration rate (cm h^{-1})	9.7 ± 2.8	7.1 ± 2.1	10.7 ± 3.4	7.6 ± 1.5
Surface roughness (adimensional)	1.37 ± 0.48	1.21 ± 0.88	1.23 ± 0.035	1.03 ± 0.81

§:Mean values are not statistically different.

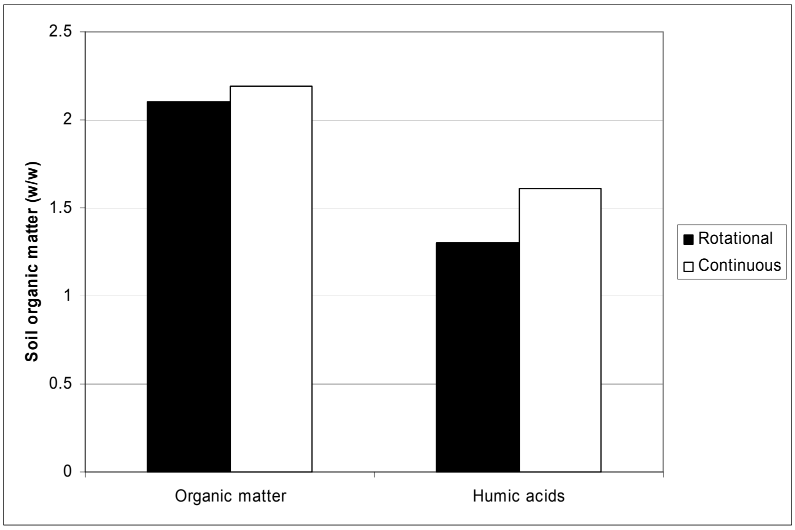

Fig. 3. Organic matter and humic acids content continuous and rotational grazing. Pánuco Zacatecas, Mexico.

Water Erosion, Runoff and factor C of USLE

Soil losses, runoff and C factor of the USLE for both grazing systems are shown in *Table 3*. During 2004, water erosion values in RG under two vegetation conditions (cactus pear with high density and spiny shrubs with medium cover) showed the lowest values (less than 5 kg ha^{-1}). In contrast the CG values were slightly higher in both vegetation conditions (30 y 357 kg ha^{-1}, respectively). In both cases differences were significant ($P<0.01$). In the 2005 year, the difference in water erosion values was higher ($P<0.01$), maintaining low values in RG and higher values (263 kg ha^{-1} year^{-1} and 477 kg ha^{-1} year^{-1}), in the treatment CG. There was no difference among years ($P>0.05$). The annual runoff was influenced directly by the magnitude of the annual rainfall, with more runoff in 2004 than in 2005 (*Table 3*). The spiny shrubs with medium cover condition in CG yielded more runoff than in RG for both years ($P>0.05$). The vegetation condition with the highest density does not showed differences ($P<0.05$). In general, the water erosion values measured were lower than the maximum permissible erosion loss, which shall be lower than 2 Ton ha^{-1} year^{-1}. Those low water erosion values are associated with the degradation level that had occurred before these measurements were done. In a separated morphologic study (not included here), it was detected that all measurements were made on C-horizons, where in the past there were A and B-horizons, and by the effect of degradation they were lost.

In some cases an incipient A horizon is being formed over the C horizon. With such degradation level plus the good soil cover used in runoff plots, the water erosion values were reduced, underestimating the real degradation level induced by water erosion.

With respect to the C factor values, which are a parameter that explains the effect of vegetation cover in the USLE, they were low for RG and high for CG. The values found allow using the USLE for erosion prediction and determining the effect of water erosion in CG and RG conditions. Also, they can be used for GIS modeling, where the effect of both treatments can be estimated to the rest of the ejido rangelands (2500 ha). Also, they can be used to induce the adoption of technology and to suggest the use of a grazing system as the RG. Finally, there is a need of soil morphological studies to characterize degradation levels, which will give a better understanding of technological intervention effects on different soils, and to determine the management level according to these degradation levels.

Table 3. Soil losses by water erosion, runoff and vegetation cover factor (C) of the USLE for for continuous and rotational grazing. Pánuco Zacatecas, México.

Vegetacion condition	Erosion (kg/ha/año)		Runoff (m^3/ha/año)		*C* Factor	
	RG	CG	RG	CG	RG	CG
	Year 2004§ (Annual rain = 485 mm)					
Spiny shrubs with medium cover	4.72a	356.9b	76.7a	346.1b	0.0059	0.45
Cactus pear with high density	4.43a	30.7b	37.4a	23.4a	0.0059	0.038
	Year 2005$^{¥}$ (Annual rain = 269 mm)					
Spiny shrubs with medium cover	2.4^{a}	477.1b	12.0a	200.1b	0.0011	0.208
Cactus pear with high density	6.2^{a}	263.2b	20.0a	21.5a	0.0027	0.115

[§] During 2004, potential erosion was 790.8 kg/ha/año and maximum runoff was 816.7 m^3/ha/año.
[¥] During 2005, potential erosion was 2283.5 kg/ha/año and maximum runoff was 661.7 m^3/ha/año.
Means with the same letter were not significantly different ($P<0.05$).

CONCLUSIONS

1. Physical degradation of the rangeland under continuous grazing is a permanent process on Zacatecas rangelands.
2. Value increments in bulk density; penetration soil resistance and pore radii along with decrements of porosity are indicators of soil physical degradation.
3. Changes in soil physical characteristics in continuous grazing reduced soil infiltration and promoted an increase in soil erosion and runoff.
4. In Zacatecas, temporal exclusion of rangelands before establishment of a rotational grazing system may help to reduce degradation process and could be the beginning of a sustainable management of soil rangeland resource.

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