Soil porosity affected by cattle trampling in highland agriculture of Northern Mexico

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Abstract
The impact of agriculture practices on soil porosity is shown for high grassland of the Nazas River (Northern Mexico). The image analysis method applied to a non perturbed soil monoliths let's compares soil porosity between areas of well conserved grassland and areas degraded because of overgrazing and cattle trampling. Results show that soil porosity is reduced up to 32 % in degraded areas characterized by round and vesicular micro-porosity. On the contrary well conserved grassland areas show higher porosity (up to 43 %) dominated by macro pores (bigger than 2mm^2 with an irregular shape) associated with grass roots abundance. This paper determines the hydrological consequences of studied surfaces in terms of infiltration and run off in the watershed.

Key Words
Soil porosity, image analysis, watershed hydrology

Introduction
Soil surface porosity is important for water infiltration and runoff toward shallow or deep soil levels (Gonzalez-Barrios *et al.* 2008). Flow dynamics in soil are realized into porous media having different sizes, shapes and distributions within soil profile. Soil porosity can be measured with microscopic tools on thin sections (González-Cervantes *et al.* 2004; Maragos *et al.* 2004; Mooney *et al.* 2007). The aim of this paper is to quantify the soil porosity (from 0 to 15 cm depth) with image analysis. Two soil surfaces were studied in relation with highland agriculture practices in the Nazas river watershed (Northern Mexico) that is one of the most important rainfall capture area in Northern arid of Mexico.

Methods
The study zone is located in the upper watershed of the Nazas river (Durango, Mexico) corresponding to a highland volcanic area of the Sierra Madre Occidental extended on 18321 km^2 with an altitude between 1600 and 3200 meters above the sea level (Figure 1).

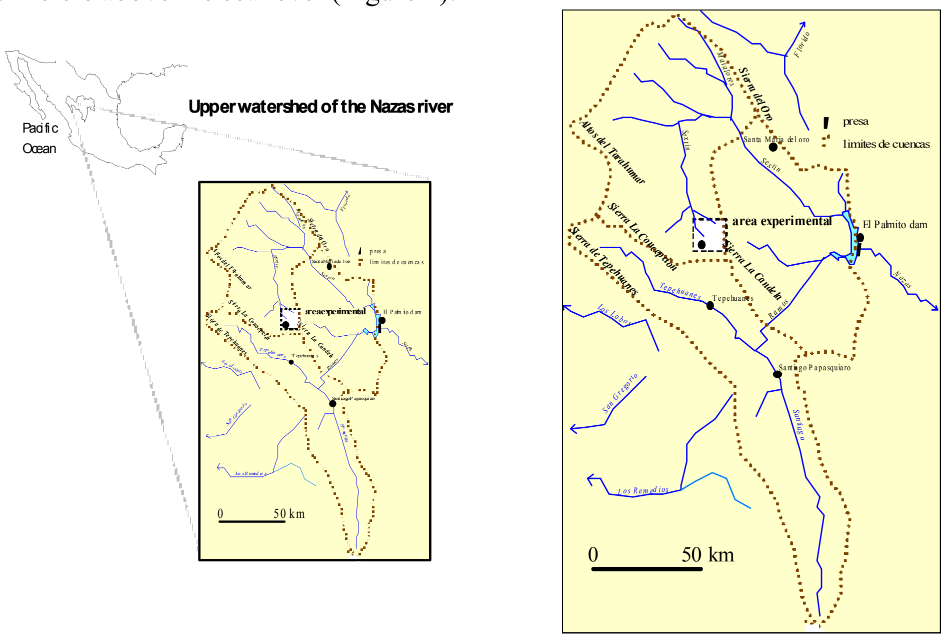

Figure 1. The study zone

Climate is from semiarid to sub-humid with temperature average between 15.9°C and 13.3°C; rainfall average are from 500 to 900mm respectively. Rainfall precipitation produces a great amount of hydrological runoff (up to 1200 million m^3) towards the great regional dam "Lázaro Cardenas" in order to supply water for irrigated lands of the bottom (Comarca Lagunera) region (Descroix *et al.* 2004).

Two soil surfaces related to highland agriculture where selected for analyzing soil porosity. They have the following characteristics:
1) Soil surface on well conserved (good state) grassland, with a vegetal cover from 75 to 100 % dominated by "navajita" grass (*Bouteloa gracilis*) with a Mull humus level (Duchaufour 1995) of 1cm thick formed by grass residue moderately incorporated into the sandy loam texture soil "chromic Cambisol" (FAO 1998).
2) Soil surface on degraded grassland, with a vegetal cover from 0 to 25 % dominated by "navajita" grass (*Bouteloa gracilis*) overgrazed and over trampled by bovine cattle that gives to the surface a mineral almost bare appearance on a sandy loam textured "chromic Cambisol".
Both surfaces corresponding to the same kind of geological features; chromic Cambisol developed from tertiary volcanic rock (Riolythe-Ignimbrite). Each surface was sampled from 0 to 15cm depth in order to measure physicochemical measurements (bulk density, organic matter, and total carbonate content) and were taken with non perturbed monoliths (15x15x15cm) in order to characterize the soil porosity by the Vergière method (Bourrier 1965). In laboratory conditions the six monoliths were dehydrated with acetone replacement and were impregnated with polyester resin (Scot-Bader Crystic) with added fluorescent pigment (Uvitex) that is sensitive to ultraviolet light (Murphy *et al.* 1977) Monoliths were cut at four depth levels (2, 3, 12 and 13 cm) and polished in order to take digital photos with white and UV light for the image analysis process.
Digital images were taken with an Olympus camera with an optical sensor (CCD) of 4.1 mega pixel. Two spatial scales were used for this proposes: M1 scale (scenes of 127 x 95 mm) with a pixel size of 56 µm, and M2 scale (scenes of 13 x 10 mm) with a pixel size of 6 µm. Digital images were binary transformed with the Image analyze program (Pro Plus® v4.5 Media Cybernetics, Maryland, USA).
The total soil porosity in monoliths was calculated from bulk density measurements (*ρd*)

$$\eta = 1 - (\rho d / \rho r) \quad (1)$$

Where: η is total porosity (in percent), ρd is bulk density and ρr is real density (2.65 g cm^3) according to literature.
Pores characteristics were defined according with size and shape parameters. Pore size is expressed by the section area of each image (Equation 2). This parameter was grouped into three classes for each scale (Table 1)

$$T = 4\pi \,(area) \quad (2)$$

Where: *T* is the pore size (in square millimeters), and area is the pore section surface according with Coster and Chermant (1985).

Pore shape is calculated by the longing index (*Ia*) according with the area and the pore section on image scene and according with equation 3 (Hallaire *et al.* 1997). This was grouped into three pore shape classes (Table 2)

$$F = (perimeter)^2 / 4\pi \,(area) \quad (3)$$

Table 1. Pore size classification.

Size	Scale M1 Pore Class	Scale M2 Pore Class
Small	T3: < 2 mm^2	T6: <0.02 mm^2
Medium	T2: 2 to 10mm^2	T5: 0.02 to 0.1mm^2
Large	T1: >10 mm^2	T4: > 0.1 mm^2

Results

Table 3 shows the soil physicochemical characteristics in each surface. There are a little difference between the sand content (higher) and in the loam and clay contents (lower) of degraded grassland surface. On the contrary there are significant differences in organic matter content (OM) and bulk density values (Da) between both surfaces. Total carbonate content is low for both surfaces The OM and bulk density values are indicators of the soil's pore volume, nevertheless they do not give information about the size and shape of soil porosity. Digital image treatment quantify the size and shape of soil porosity.

Table 2. Pores shape classification.

Shape	Longing index
Round	< 5
Elongated	5 a 7
Irregular	> 10

Table 3. Soil physicochemical characteristics (from 0 to15 cm depth).

Studied surface	Sand	Loam	Clay	Texture	OM	Bulk Density	Tot Carbonate
	------------ % -----------				%	g/cm³	(%)
1. Good state grassland	68	14	18	Sandy loam	6.2	1.50	3.80
2. Degraded grassland	82	6	12	Sandy loam	1.4	1.80	5.97

Binary images from four depth levels are showed on Figure 2. A preliminary analysis of the porous media in each profile indicates a high relative abundance of soil porosity (dark areas) in the good state grassland surface. Figure 3 shows the soil porosity profile based on bulk density combined with image analysis.

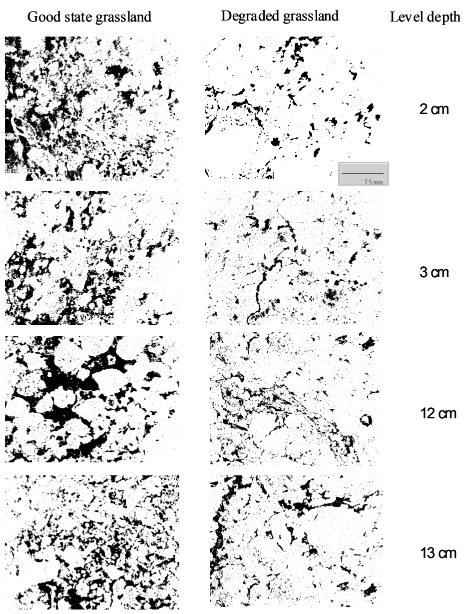

Figure 2. Soil porosity at M2 scale (13x10 mm scene size)

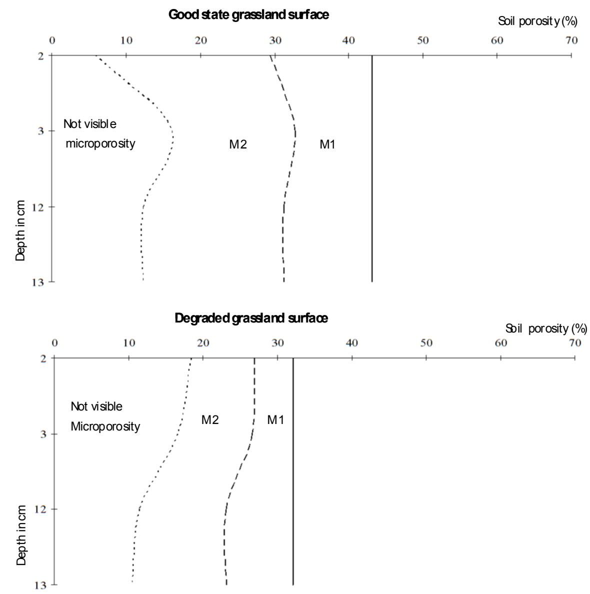

Figure 3. Soil porosity distribution in studied surfaces

The total soil porosity of good state grassland surface is larger than for degraded grassland (43 % versus 32 % respectively) and show a distribution of macro pores (M1 scale) with a rank from 10 to 13 % and a distribution of micro pores (M2 scale) with a rank from 16 to 23 %. On the contrary the degraded grassland surface shows a very dominant micro porosity from 0 to 3 cm depth; soil macro porosity is very reduced at the same level (5 % on M1 scale) but it increases (to 10 %) at 12 and 13 cm levels, with decreasing of cattle trampling influence. The frequency distribution of pores size and shape are shown in Figure 4. The histograms show six vertical bars corresponding to a six pore size classes (from T1 to T6 according to Table 1) and a subdivision into three pore shape classes (round, elongated and irregular). The good state grassland surface show higher percentages of large pores (T1 and T4 classes). Macro-porosity tends to disappear for the degraded grassland surface (T1 and T2 classes) that is dominated by smaller pores (T3 and T6 classes). The small pore class T3 (smaller than $2mm^2$) shows a similar proportion in all the soil profiles of good state grassland. For both studied surfaces, round and irregular pores are dominant over elongated shape pores that are present in a lower proportion. Irregular pores are mainly in T1, T2 and T4 classes representing larger size pores. Round pores are dominant in T3, T5 and T6 classes corresponding to smaller pore sizes. Elongated pores are more frequent in T3, T4 and T5 classes. In conclusion, the studied surfaces have differences in terms of total soil porosity as well as pore size and shape. These differences certainly affect water and air flux within the soil of the watershed that is important to quantify.

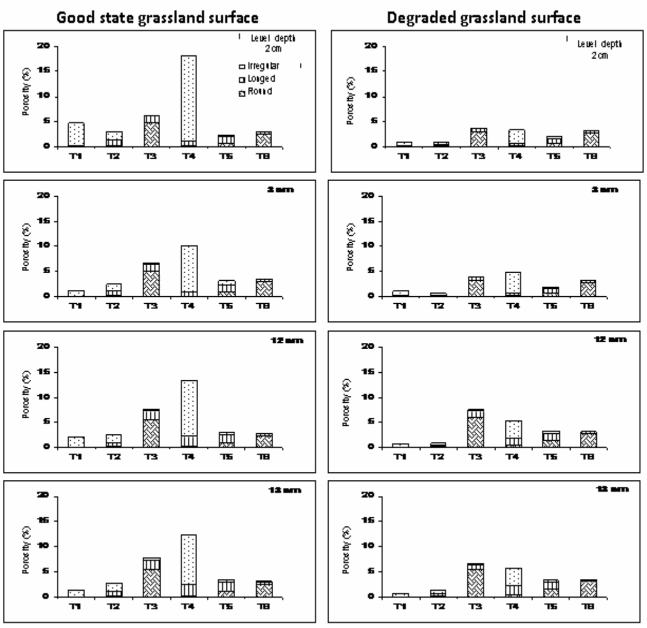

Figure 4. Size and shape of soil pore classes

Conclusions

The studied grassland surfaces have different porous media that could be related to their condition: good state grassland surface has a dominance of macroporosity characterized by irregular pores in relation to the importance of grass roots penetrating the soil surface and causing good aeration and water circulation. In contrast, degraded grassland surface shows a reduced pore volume dominated by round micropores that reveal physical compaction (by cattle trampling). The image analysis applied in this study shows clearly the qualitative and quantitative differences of soil porosity between two kinds of soil surface that are related to land use intensity in highland agriculture of Northern Mexico.

Physical degradation of soil surface observed here reveals the necessity managing about agriculture practices in highlands specially cattle grazing intensity. The hydrological repercussions of increasing degraded areas can be easy imagined. A stronger control of agriculture practices must be encouraged in order to keep this important zone in good condition.

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