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Soil erosion and runoff in different vegetation patches from semiarid Central Mexico

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ABSTRACT

Vegetation patches in arid and semiarid areas are important in the regulation of surface hydrological processes. Canopy and ground covers developed in these fertility islands are a natural cushion against the impact energy of rainfall. Also, greater levels of organic matter improve the soil physicochemical properties, promoting infiltration and reducing runoff and soil erosion in comparison with the open spaces between them. During the 2006 rainy season, four USLE-type plots were installed around representative vegetation patches with predominant individual species of Huisache (*Acacia sp*), Mesquite (*Prosopis sp*), Prickly Pear or Nopal (*Opuntia sp*) and Cardon (*Opuntia imbricata*), to evaluate soil erosion and runoff, in semiarid Central Mexico. A comparative bare surface condition (Control) was also evaluated. Vegetative canopy and ground cover were computed using digital images. Selected soil parameters were determined. Soil erosion was different for the studied vegetation conditions, decreasing as canopy and ground cover increased. There were not significant differences in runoff and soil erosion between the Control and *O. imbricata* surfaces. Runoff was reduced by 87%, 87% and 98% and soil loss by 97%, 93%, and 99% for *Acacia farnesiana*, *Prosopis laevigata* and *Opuntia sp*, respectively, as compared to the Control. Soil surface physical conditions were different between the low vegetation cover conditions (Control and *O. imbricata* surfaces) and the greater vegetation cover conditions (*A. farnesiana*, *P. laevigata* and *Opuntia sp*), indicating a positive effect of vegetation patches on the regulation of surface hydrological processes.

1. Introduction

Drylands, defined according to the World Atlas of Desertification (UNEP, 1992) as areas with a ratio of average annual precipitation (P) to potential evapotranspiration (PET) of less than 0.65, occupy approximately 40% (54 million km^2) of the total land area worldwide (Slaymaker and Spencer, 1998), including 24% of the American Continent (Sivakumar, 2007). In Mexico, arid and semiarid lands cover approximately 40% of the country's total area (Villa, 1981), mostly located in the north-central region.

Regardless of geographical location, arid and semiarid areas are characterized by specific vegetation and climatic conditions. Vegetation in drylands includes plants with mechanisms of resistance and/or adaptation to water stress, such as cactus, mesquites, bushes, etc. (Valles-Septién et al., 1998; Nobel, 1998). Spatial distribution patterns of vegetation in those areas are mostly identified as patches or strips of shrubs and grasses (Aguiar et al., 1992; Aguiar and Sala 1994; Facelli and Temby, 2002), often called fertility or hydrologic islands (Moro et al., 1997; Rango et al., 2006).

Climatically, arid lands are characterized by extreme temperature conditions (D'Odorico and Porporato, 2006) and torrential precipitation events with short duration and high intensity (Wei et al., 2007), which causes low infiltration and consequently water erosion and great amounts of runoff (Rango et al., 2006). All of these processes are regulated by the terrain and the overall vegetation cover (Ridolfi et al., 2008). These ecosystems are generally fragile and often susceptible to desertification (UNCCD, 2004).

Vegetation plays an important role in the regulation of hydrological processes and changes in soil properties because of the destructive forces of rainfall that cause erosion (Wei et al., 2007) and soil sealing and crusting (Regüés and Torri, 2002). In the fertility islands, erosion and surface sealing can be significantly reduced relative to bare soil as a result of canopy cover protection and improvement of soil physical, chemical and biological properties (Casermeiro et al., 2004).

In systems where perennial plants form a discontinuous cover, such as savannas and shrublands, the presence of canopy alters the micro-environment in ways that influence the activity of soil microbes (Hopmans, 2006). Scattered shrubs in arid lands are important in structuring the annual plant community. The distributions of patches may take

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the form of spots or bands between bare surfaces (Aguiar et al., 1992; Aguiar and Sala, 1994; Rango et al., 2006). This spatial heterogeneity can result in a patchwork of microenvironments that can have both facilitative and inhibitory effects on the annual plant communities associated with the dominant perennial plant species (Facelli and Temby, 2002), which influences hydrological surface processes.

Most past studies have been focused on determining the influence of semiarid patches of vegetation on localized soil physical, chemical and biological properties (Puigdefábregas, 2005; Bautista et al., 2007). Only a few studies are related to hydrological processes in the fertility islands, and even fewer on the interaction among vegetation cover, soil physical conditions and the surface hydrological processes of soil erosion and runoff (Chen et al., 2007; Bautista et al., 2007).

The aim of this study was to evaluate soil erosion and runoff under different representative dryland vegetation patches as related to soil physical conditions and canopy/ground cover, as compared to open-space areas, where soil physical and hydrological properties are believed to be different.

2. Materials and methods

2.1. Study site

The study site is located at the Santo Domingo Ranch in the municipality of Cadereyta, Queretaro, Mexico (Fig. 1) at 99° 46″ 46′ W, 20° 43″ 49′ N and 2069 m altitude. Mean annual temperature in the site is 16.7 °C and mean annual precipitation approximately 480 mm, as reported by INEGI (1996). Vegetation is dominated by Huisache (*Acacia farnesiana* (L. Willd)), Mesquite (*Prosopis laevigata* (Humb. et Bonpl. ex Willd)), Cardon (*Opuntia imbricata*) and Nopal (*Opuntia sp*) (Mastachi-Loza et al., 2010). The dominant soil is a Pellic Vertisol associated with a Haplic Phaeozem, according to the FAO Soil Classification system (INEGI, 1984).

2.2. Erosion and runoff measurements

Modified USLE-type circular plots were used for runoff and soil erosion measurements. The plots were built around the vegetation of interest using concrete blocks along the perimeter of the canopy projection, and inserted 10 cm into the ground to isolate surface and subsurface water flows. A metal-sheet plot end was placed at the bottom of the slope to convey runoff into a 10-cm PVC pipe which, in turn, delivered water and sediment into a collection system consisting of a series of two 200-L containers (Fig. 2). The second container collected the excess of the first using a connecting 4-cm tubing pipe.

In addition to the plots under the vegetation patch, a Control plot similar in shape and slope, but without vegetation and under continuous tillage to avoid crusting and weed development, was established according to the specifications of Renard et al. (1997) in order to determined the relative soil loss attributed to the vegetation island effect.

Runoff and sediment samples and measurements were taken after each rainfall event. Runoff was determined by measuring the water stage in the container and then translating it into volume using the corresponding geometric equations. A representative 1-L runoff/sediment sample was taken by mixing vigorously and homogeneously and filing the plastic bottle from the bottom up to obtain an integrated sample. The sample was then taken to the laboratory for gravimetric processing. First, the sample was flocculated with a saturated solution of aluminum sulphate, then the excess water was decanted before the solids were oven-dried at a temperature of 105 °C until constant weight was achieved. Calculations of runoff in mm and erosion rate in ton ha^{-1} were obtained for each event.

Rainfall durations, depths, and intensities were monitored using a Vaisala WXT510 sensor (Vaisala Weather Transmitter WXT510) with a CR1000 datalogger. Kinetic energy and the USLE-type rainfall erosivity index were determined using the equations proposed by Foster et al. (1982) and Wischmeier and Smith (1978). Runoff coefficients for each rainfall event were calculated as the ratio of runoff to rainfall.

2.3. Vegetation measurements

Representative individuals of *O. imbricata*, *A. farnesiana*, *P. laevigata* and *Opuntia sp*, and their ground and/or surrounding vegetation were studied. Total individual plant height and height of the trunk from the ground to the first branch bifurcation were measured using a

Fig. 1. Study site.