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Effects of slope aspect, grazing, and sampling position on the soil penetration resistance curve

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ABSTRACT

The slope aspect, grazing intensity, and vegetation canopy are factors that affect the physical and mechanical properties of soil. However, their effects on the soil penetration resistance (PR) curve are unclear. Thus, we investigated the effects of northern and southern slope aspects, the grazing intensity (free and controlled grazing, and livestock exclusion), and the sampling position (beneath and between canopy) on the PR curve and bulk density in the Gonbad paired watershed in Hamedan, Iran. At the end of the grazing season, we collected and analyzed seven undisturbed samples (total = 252) and one disturbed soil sample (total = 36) from each experimental unit. The soil PR was measured at different suctions. We fitted the To and Kay (2005) and Stock and Downes (2008) models to the PR data. The effects of treatments on the bulk density, PR curve and its model coefficients, and PR were analyzed at different suctions. The slope aspect had the greatest impact on the soil bulk density and PR at suctions of 30 and 1500 kPa. The Stock and Downes (2008) model coefficients, which represent the degree of change in the PR relative to the moisture content, were affected mostly by the sampling position. Southern aspects had higher overall PR curves than northern aspects due to their lower soil organic matter contents and more coarse fragments. The overall PR curve increased with the grazing intensity. There were interactions between the effects of the three factors on the PR curve and all affected the PR.

1. Introduction

Soil resistance is one of the most dynamic mechanical properties of soil and it is important for plant growth and soil biological activities (Tahmasbi et al., 2008). Penetration resistance (PR) is a suitable indicator for identifying changes in soil resistance to penetration over a period and for assessing the effects of soil resistance to root development (O'Sullivan, 1992). Increasing resistance to root penetration leads to reduced root growth and root morphological changes, and thus the green parts of plants are affected (Young et al., 1997). Measurements of tensile forces (applied energy) using agricultural equipment, as well as soil trafficability and root growth are difficult and expensive, but the PR can be used as an alternative indicator to assess these properties (Dexter et al., 2007). Indeed, Bayat et al. (2008) and Mahboubi et al. (1993) considered the effects of different tillage systems on soil compaction using the PR index.

The properties of seedbed soil such as the physical state of the soil structure are important for seed germination, root growth and development, and crop production (Aluko and Koolen, 2001).

The soil PR is a suitable variable for understanding the physical and mechanical condition of a seedbed due to its high sensitivity to changes in the physical properties of soil (Castrignano et al., 2002). Thus, the PR can be used as an indicator to assess the effects of various factors such as tillage practices, swelling and shrinkage, wetting and drying, freezing and thawing cycles, and compaction on the soil structure (Soane and van Ouwerkerk, 1994). The soil PR may be related to many soil properties, such as the soil type, amorphous oxides, soil organic matter content, soil solution chemistry, soil moisture content, bulk density, and clay mineralogy (Gerard, 1965).

The relationship between the soil PR and the matric potential or soil moisture content is known as the PR curve (To and Kay, 2005). The soil PR decreases as the soil moisture content increases, as well as with increasing soil bulk density (Koolen and Kuipers, 2012). In certain soils, the variations in the PR relative to the soil bulk density and moisture content are not linear (Marshall et al., 1996). Stock and Downes (2008) fitted the basic soil water retention curve model of van Genuchten to the data measured for a PR curve and obtained model parameters with high accuracy. They concluded that shape of the PR curve is sigmoidal relative to water suction. The maximum PR value was observed under 10^2–10^5 hPa matric suction and the curve was almost a straight line

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with a very low slope gradient at higher matric suctions (Stock and Downes, 2008).

da Silva and Kay (1997) found that the PR depends on the soil clay content and bulk density. Stock and Downes (2008) and Gao et al. (2012) studied the effects of different soil organic matter contents on decreases in the PR. Grunwald et al. (2001) reported that the soil bulk density is the most effective factor for predicting the PR, followed by the soil moisture content. All of the factors that affect the PR and PR curve are also influenced by the grazing intensity and duration, as well as the slope parameters and vegetation. For example, the soil bulk density is a sensitive factor that responds immediately to livestock trampling and compaction by hooves (Kolahchi, 2005).

Thus, Proffitt et al. (1995) studied the effects of sheep trampling and grazing practices on the physical properties of soil. Ahmad et al. (2009) showed that the compaction of soil decreased when treated with low intensity grazing, where the soil bulk density decreased and the porosity increased.

The slope aspect is one of the main factors that determine soil diversity in semiarid regions. Many studies have investigated the effects of the slope aspect on soil properties, such as the soil type (Begum et al., 2010), clay content (Stotzky et al., 1997), amorphous oxides content (Kirschbaum, 1995), soil organic matter content (Begum et al., 2010), soil solution chemistry (Zhang et al., 2012), soil moisture content (Broxton et al., 2009), soil bulk density (Salehi et al., 2008), porosity (Geroy et al., 2011), and clay mineralogy (Miura et al., 1988).

The soil PR is changed by differences in soil suction. The change in this factor with suction, which comprises the PR curve, represents the extent of changes in the soil strength properties with changes in suction. The soil PR curve can be described by different models, such as the Stock and Downes (2008) model (Stock and Downes, 2008). The parameters in the PR curve model quantify the sensitivity of the soil strength and they can be used as an index for studying root growth with changes in suction. The coefficients of the PR curve model reflect the strength properties of soil and possibly the effects of many factors on soil behavior, such as the slope, tillage practices, and vegetation. Many studies have investigated the PR values for agricultural soils, but none have quantified and discussed the effects of factors such as the slope aspect, grazing intensity, and sampling position on the soil PR curve shape and model parameters in rangeland soils. Thus, in this study, we investigated the effect of different factors such as the slope aspect, grazing intensity, and sampling position (beneath and between the canopy of plants) on the soil PR at suctions of 30 and 1500 kPa, as well as on the soil PR curve model coefficients.

2. Methods and materials

2.1. Study area and sampling

The study was conducted in the Gonbad paired-watershed located at 48° 41′ 05″ E to 48° 43′ 40″ E and 34° 41′ 16″ N to 34° 42′ 31″ N, 28 km southwest of the city of Hamedan, Iran. A map showing the study area and sampling locations is provided in Fig. 1. The average annual rainfall and temperature in this area are 304.2 mm and 9.5 °C, respectively. The mean elevation is 2300 m above sea level. In order to collect soil samples, we selected three locations with different grazing intensities and practices as well as different slope aspects in the paired watershed. The grazing intensities comprised: free grazing plots (G1) with no limit on the time or number of livestock grazing, so overgrazing occurred; controlled grazing plots (G2), which were only open to livestock grazing for one month at the end of the grazing season; and livestock exclusion plots (G3), which comprised fenced areas where grazing had been prevented since 2002. The northern and southern aspects were dominant and most of the grazing plots were located on these aspects, so northern (A1) and southern (A2) aspects were selected for sampling. The main vegetation type comprised shrub with a patchy distribution pattern. In order to determine the effects of this vegetation pattern on the soil properties, soil samples were taken from beneath (P1) and between (bare soil) (P2) the vegetation canopy. Soil samples were collected in November at the end of the grazing season. The study area contained hilly slopes with a slope between 12° and 25°. All of the samples were taken from the backslope positions with almost the same slope degree and almost in line with an identical elevation. The study area had different slope degrees and positions, so we had to minimize the effects of these factors on the soil properties. However, it was not possible to consider geostatistical factors when deciding where to collect the soil samples. Moreover, the active soil erosion in the study area comprised interrill erosion. The study was conducted on steep rangeland and thus different parts of the slopes, such as shoulders, backslopes, and footslopes, were subjected to different types of water erosion and sedimentation processes. To avoid the effects of slope position (which is a different problem), the current study was designed so all soil samples were collected from backslope positions. In total, 36 disturbed and 252 (from 36 points, with seven samples at each point) undisturbed soil samples were collected using core cylinders with a diameter of 5.1 cm and height of 4.5 cm from the 0 to 10 cm soil depth.

2.2. Laboratory measurements

The impacts of the slope aspect, grazing factor, and sampling position on the soil bulk density, PR curve, PR at 30 and 1500 kPa matric suctions, and the parameters of the PR curve models (the PR curve represents the changes in the soil PR versus water content and/or matric suction) were evaluated using a completely randomized design as a factorial test with three replicates.

The soil texture was measured based on Stock's law using the hydrometer method (Gee and Bauder, 1986). Bulk density was measured with the cylinder method (Blake and Hartge, 1986). Organic matter was measured using the wet oxidation method (Walkley and Black, 1934).

The soil PR is a highly variable parameter and many measurements are required to obtain a reliable value (Lapen et al., 2001; O'Sullivan, 1992). To measure the soil PR curve, one undisturbed soil sample was selected randomly from seven undisturbed soil samples collected at each sampling point and placed in a sand box at suction of 6 kPa. After equilibration, the PR was measured using this sample to obtain the PR at a matric suction of 6 kPa, and its water content was then measured. Undisturbed samples 2 to 7 were then selected randomly from the seven undisturbed soil samples from each sampling point and placed in the pressure plate apparatus at matric suctions of 30, 100, 200, 400, 800, and 1500 kPa. After equilibrating, they were used to measure the PR and water content at these matric suctions.

The gravel content is an important factor that affects the PR value, where the PR increases with the gravel content (Hamblin, 1986). In addition, the variance in the PR value increases with the gravel content (Campbell and O'Sullivan, 1991). Thus, the PR is a highly variable soil property (Lapen et al., 2001; O'Sullivan, 1992) and the number of readings should be increased to improve the accuracy when measuring highly variable soil properties (Davies et al., 1973, 1993). In this study, in order to increase the accuracy of the PR measurements, the force measurement were obtained twice by inserting the cone into each soil core sample at a rate of 1 mm/min and readings were acquired at depths of 0.5, 1, 1.5, 2, 2.5, and 3 cm. To measure the PR, a laboratory needle penetrometer manufactured in Iran was attached to a force transducer on the loading frame of a California Bearing Ratio device. The diameter of the cone base was 2 mm and the cone angle was 30°. The outlier readings (possibly due to the penetrometer cone contacting gravel particles) were omitted. The PR value for each soil sample was the average of about 12 readings, excluding outlier data, thereby obtaining a reliable measurement. The mean of the forces at the measured points in each soil sample is: