Time-Dependent Changes in Distribution Patterns of Soil Penetration Resistance in a Rangeland under Overgrazing

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ABSTRACT
Soil penetration resistance as an indication of soil compaction affects on soil infiltration and runoff. Overgrazed rangelands are under severe erosion risk because of compaction. The objective of this study was to determine changes in soil penetration resistance with time in a high altitude rangeland. A 5 ha rangeland (200x250 m) was transected with 25 m intervals, and soil penetration resistance was measured at every 5 m in each transect for 20 cm surface soil layer in three different time periods (15th of July, August and September). Undisturbed soil samples were taken for determining soil bulk density and soil moisture-penetration calibration tests, and these samples also were used to obtain fundamental soil characteristics. Exponential semivariogram models were fit to explain spatial variance in soil penetration resistance values. Distribution patterns of soil penetration resistance were defined using kriging values produced by the punctual kriging. Results indicated that soil penetration resistance was higher than the critical penetration resistance (3 MPa) for root growth in all measurement points. The mean soil penetration resistance increased about 9 % in August as compared with July and it was more or less constant in the following month. There were good agreements among the distribution patterns of soil penetration resistance obtained for different time periods.
Key Words: *penetration resistance, spatial variability, overgrazing, rangeland.*

INTRODUCTION

Overgrazing is one of the main factors causing range degradation by leading erosion, reducing biodiversity, and altering soil properties (Özgül & Öztaş, 2004). Zhao et al. (2007) reported that grazing decreased soil water content and soil organic C, but increased bulk density and shear strength. Greenwood (1997) compared hydraulic conductivity, bulk density and soil strength in grazed and ungrazed pastures and found statistically significant differences among the measured properties between two sites.

Soil compaction due to animal trampling is one of the factors responsible for the degradation of the physical quality of soils under pasture (da Silva et al., 2003). Warren et al. (1986) reported that trampling animals caused soil deformation by exerting high ground contact pressures under their hooves. The soil compaction caused by cattle grazing generally leads to reduction of porosity and water infiltration rates (Dadkhah and Gifford, 1981), impeded root growth, and increased losses of nitrogen due to runoff and erosion (Wood et al., 1989).

Spatial variability patterns of soil properties within an agricultural field or a pasture are useful tools for making effective management practices, defining relations among soil properties and also for evaluating disruptive factors affecting on these properties. Imhoff et al. (2000) used penetration resistance (PR) for determining spatial variability in soil properties induced by animal trampling in grazing systems, and emphasized the usefullness of PR curves for the evaluation of the physical quality of soils under pasture.

The objective of this study was to determine changes in soil penetration resistance with time in a high altitude rangeland under uncontrolled grazing.

MATERIAL and METHODS

The study area is located in a high altitude of the Palandoken Mountains. A 5 ha rangeland (200x250 m) was transected with 25 m intervals, and soil penetration resistance was measured at every 5 m in each transect for 20 cm surface soil layer in three different time periods (15^{th} of July, August and September). About 400 cattles were grazed in the research site during the whole grazing season.

Undisturbed soil samples were taken for determining soil bulk density and soil moisture-penetration calibration tests, and these samples also were used to obtain soil physical and chemical properties. Particle size fraction was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986), soil reaction using a glass electrote pH-meter (McLean, 1982), $CaCO_3$ by the Scheibler calcimeter (Nelson, 1982), organic matter by the Smith-Weldon method (Nelson and Sommers, 1982), electrical conductivity using a conductivity meter in saturation extract (Rhoades, 1982a), cation exchange capacity by the ammonium acetate method (Rhoades, 1982b), and aggregate stability using a Yoder type wet sieving analysis (Kemper and Rosenau 1986). Penetration resistance was measured using an Eijkelkamp type hand penetrometer (Herrick and Jones 2002).

Three undisturbed soil cores (30 cm in diameter and 30 cm in depth) were also taken for penetration resistance (PR) moisture calibration test. Soil cores were saturated and PR measurements were taken with approximately 5 days intervals and soil moisture content was determined at the time of PR measurements in laboratory.

Penetration resistance measurements were standardized for moisture changes using the relationship given in Figure 1.

$$\mathbf{PR_a = PR_o \exp((x-0,1)/0,716)}$$

in where;

PR_a : Adjusted penetration resistance, (kPa)

PR_o : Measured penetration resistance, (kPa)

X : Moisture content at measurement taken, (kg/kg)

0.1 : Selected moisture content for standardization, (0.1 kg/kg)

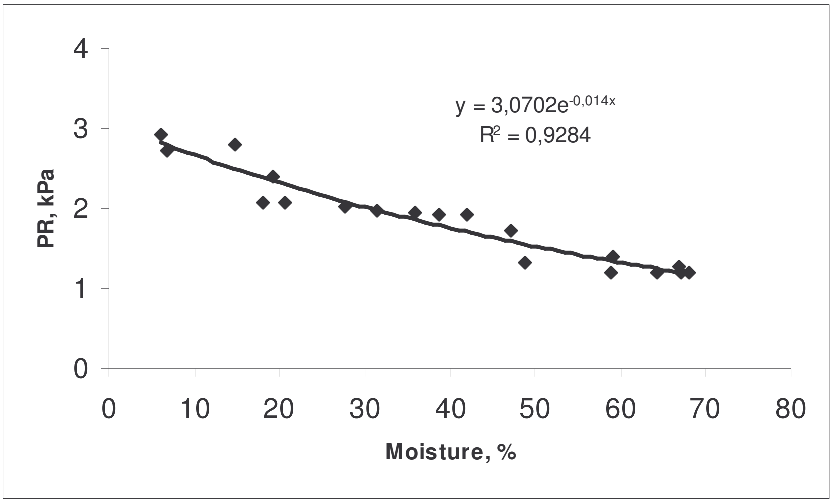

Figure 1. Relationship between soil moisture and penetration resistance for the soil studied.

Semivariogram and punctual kriging analyses were performed for preparing the distribution patterns of spatial variability of penetration resistance within the study field using GS+ geostatistical software.

RESULTS and DISCUSSION

Some physical and chemical properties of soil in the rangeland site were given in Table 1. The soil in the study site is loamy-textured, containing, on the average, 6.7 % organic matter and 0.2 % $CaC0_3$. Although the bulk density in the early grazing period was 0.88 g cm^{-3}, it slightly increased with increasing animal trampling due to compaction in August and decreased in September because of autum rainfall. The average soil wet aggregate stability (WAS) was 96 %. Although it decreased slightly in August as compared to the July, there was no significant differences among the WAS values.

Table 1. Some physical and chemical properties of soil in the study site.

Soil property	Time of sampling		
	June 15th	August 15th	September 15th
Sand, %	43.52		
Silt, %	33.54		
Clay, %	22.94		
Textural class	Loamy (L)		
Bulk density, g cm^{-3}	0.88	0.93	0.82
pH (1:2.5)	5.60	5.85	5.72
Organic matter, %	6.37	6.65	7.08
EC, dS cm^{-1}	450		
$CaCO_3$, %	0.21	0.20	0.20
Wet aggregate stability, %	95.88	94.52	97.71
Cation Exchange capacity, cmol kg^{-1}	38.6		

Spatial Variability Patterns of PR with Time

Descriptive statistics of the data are given in Table 2. The mean penetration resistance was 3.88, 4.21 and 4.16 MPa for July, August and September measurements, respectively. There was statistically significant increase (9%) in the PR measurements between the July and August values, but it was almost constant in September. The coefficient of variation of PR measurements was considerable low (5.16, 3.33 and 3.73 % for July, August and September, respectively) in all time periods, but it was the highest in July. This result indicated that the variability of PR get almost constant with grazing after July.

Table 2. Descriptive statistics for PR (MPa) measurements.

Minimum	Maximum	Mean	Standard deviation	Skewness	Kurtosis
July 15th					
3.41	4.47	3.88	0.20	-0.14	-0.34
August 15th					
3.63	4.54	4.21	0.14	-0.62	1.65
September 15th					
3.70	4.52	4.16	0.02	-0.37	-0.15

The experimental semivariograms were developed for different directions at the angles of 0^0, 45^0, 90^0, and 135^0 for soil penetration resistance values to determine directional variability within the research site. There were no distinct differences among the structures of the directional semivariogram models. Therefore, isotropy was assumed and a uni-directional semivariogram was fitted for characterizing spatial variability. Exponential semivariogram models were fit to explain spatial variance in soil penetration resistance values. The best fit model for the last period of grazing was only given here because of limited pages, (Figure 2). The range of influence was 122 m. This means that PR measurements within a circle area with a diameter of 122 m are correlated to each other.

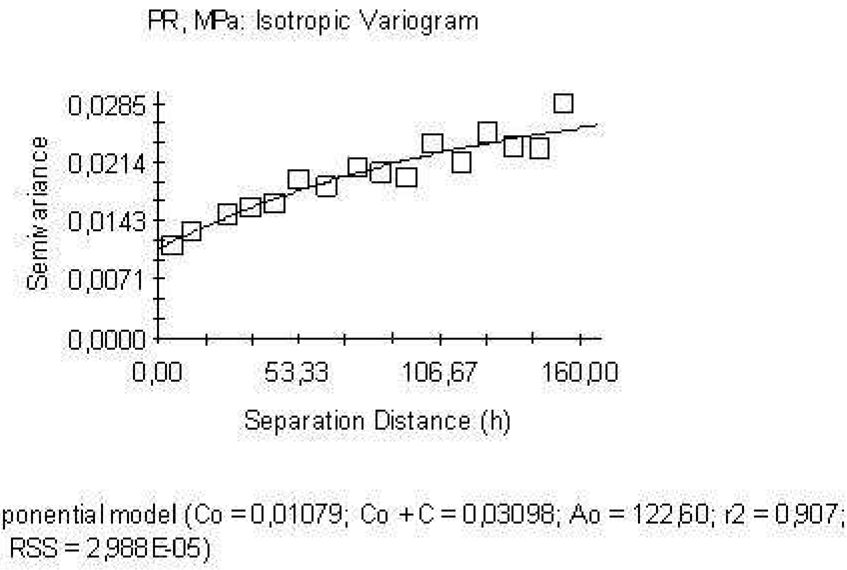

Figure 2. Semivariogram model fitted to explain variability in PR measurements (September).

Punctual kriging procedure was applied for estimating penetration resistance values at unsampled points with 1 m intervals using 6 to 10 measured values. The kriged estimation values were mapped to produce spatial variability patterns of PR in three different measurement periods (Figure 3). The patterns of variation in soil penetration resistance showed remarkable differences in different measurement periods. In July, higher PR values (>4.2 MPa) were recorded only in several points within the rangeland area, and total area with PR value of 4.0 MPa or more was only 14 % of the whole research area. However, in August the PR value was higher than 4.0 MPa in almost whole area (99.2 %). The rate of the most severe compacted area with PR value more than 4.2 MPa within the whole site was 65 %. On the other hand, in September the rate of the most severe compacted area with PR value more than 4.2 MPa within the whole site decreased down to 42 % and the rate of relatively less compacted area with PR value lower than 4.0 MPa within the whole site was almost 10 %. These results clearly indicated that grazing caused significant soil compaction during summer period, but autum rainfalls helped to slightly lower PR values in September. As reported by the Zhao et al. (2007) soil compaction induced by animal trampling inclined to a homogeneous spatial distribution of penetration values.

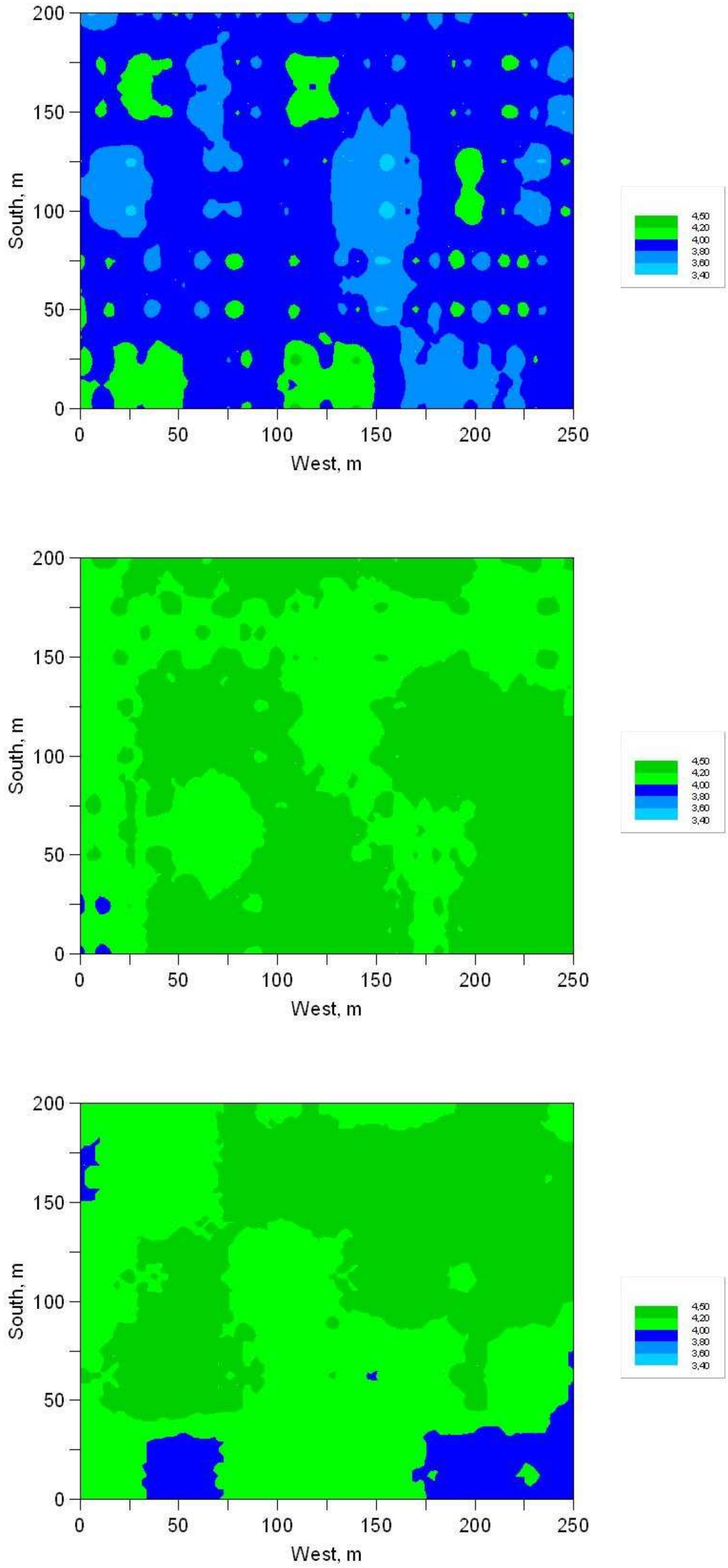

Figure 3. Spatial distribution patterns of PR in different time periods.
(from top to bottom; July, August and September).

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