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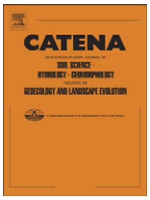

Spatial variability in soil compaction properties associated with field traffic operations

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ABSTRACT

Current agricultural practices using heavy machinery are associated with soil compaction.
This study was carried out to determine the effects of field traffic operations on the changes in spatial variability of soil aggregate stability (AS), bulk density (BD), total porosity (TP), penetration resistance (PR) and volumetric moisture content (VMC) in the various soil depths as indicators of soil compaction. Soil samples to determine AS, BD and VMC were collected and field measurements of PR at 0–10, 10–20 and 20–30 cm depths were taken, respectively from geo-referenced intersections with 25 × 20 m intervals before and after traffic operations. Total porosity was calculated using bulk and particle density values. Both disturbed and undisturbed soil samples were taken from each depth (0–10, 10–20 and 20–30 cm) of the intersection points of the grid system, before and after traffic operations. As a total 360 soil samples were taken. Kriging analysis was performed to create spatial variability distribution maps of AS, BD, TP, PR and VMC with 1 × 1 m intervals within the field. Results showed that the AS, BD, TP, PR and VMC were significantly influenced by traffic operation and depth. More significant effects on the AS, BD, TP, PR and VMC were produced at the 0–10 cm depth than at the 10–20 and 20–30 cm depths. For 0–10, 10–20, and 20–30 cm depths, while BD increased in the rates of 14.5, 5.3 and 6.7% it caused a decrease in TP at the rates of 12.1, 5.5 and 6.6%, respectively. Averaged across depth, while the initial AS was 54.1% it decreased to 41.9% with traffic operation. Averaged across depth, the BD (8.6%), PR (43.3%) and VMC (12.7%) increased, with an associated decrease in AS (22.6%) and TP (8.9%) after traffic operation, as compared to their initial values measured before traffic operation. Spatial distribution patterns of AS, BD, TP, PR and VMC values following traffic operation showed significant differences compared to those values of before traffic operation. Among the indicators of compaction, the AS and PR was greatly affected by the traffic operations as compared to BD, TP and VMC. Knowledge on the spatial distribution can be used for development management options that minimize production risks and the harmful impact of traffic.

1. Introduction

Soil management practices are closely associated with ecosystem services. However, traditional high-intensive agricultural practices which use heavy machineries for tillage, planting and harvesting are often associated with soil structural degradation, increased compaction and reduced soil productivity (Soane and van Ouwerkerk, 1994). In addition, more energy is needed for tilling the compacted soil, which is responsible for higher farming costs (Horn et al., 1995; Whalley et al., 1995). The increasing use of heavy machines causes stress penetration to deeper soil depths and, consequently, results in deeper soil compaction than reported previously (Keller et al., 2007; Zink et al., 2010).

Several studies have been reported on the transitional and long-term effects of wheel traffic of agricultural machinery on soil compaction and crop yields (Liepiec et al., 1991; Ohu and Folorunso, 1989). It is reported that agricultural machines responsible for soil compaction reduce macroporosity and restrict aeration and the gaseous movement system in soil–plant–air continuum (Aksakal and Oztas, 2010; Botta et al., 2010; Hamza and Anderson, 2005). This preferential loss of larger pores can potentially change important soil hydrological functions related to water infiltration and water holding capacity and drainage (Botta et al., 2010; Brais, 2001; Horn et al., 1995; Soane et al., 1981). Soil compaction also reduces saturated hydraulic conductivity and may trigger accelerated surface runoff and water erosion (Horn et al., 1995). The increased mechanical resistance by compaction affects plant root growth and distribution, restricts water and nutrient uptake and decreases crop growth and yields (Dorner et al., 2010; Unger and Kaspar, 1994).

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Soil compaction characteristics are dependent on the relationship between applied stress and the response of volumetric parameters such as strain, void ratio or porosity (Chaplain et al., 2011; Dorner et al., 2010). The degree of soil compaction also depends on the texture, antecedent moisture content, load and tire dimension, inflation pressure and slip, forward speed and the number of repeated machinery passes (Dauda and Samari, 2002; Oni and Adeoti, 1986). Among the soil physical properties that are considered sensitive indicators to evaluate compaction are aggregate stability (AS), bulk density (BD), total porosity (TP), strength or penetration resistance (PR) and moisture content (VMC) (Barik et al., 2011; Hamza and Anderson, 2003; Panayiotopoulos et al., 1994; Soane and van Ouwerkerk, 1994).

Spatial variability in soil properties that are associated with compaction within an agricultural field can be used as tools to define relationships among soil properties, evaluate disruptive factors affecting these properties and recommend appropriate management practices to sustain soil productivity.

To study soil variability, two main statistical approaches can be used, which are different in the way that data is analyzed. Classical statistics requires the validity of some basic hypotheses, such as the independence between observations, due to the randomness of variations from one place to another. In contrast, geostatistics, based on the theory of regionalized variables, enables the interpretation of results based on the structure of their natural variability, taking into consideration spatial dependence within the sample space. The analysis of dependence is based on the structure of the semivariogram, which demonstrates the existence of spatial dependence (Goovaerts, 1997; Junior et al., 2006). Geostatistics is increasingly used in the assessment of spatial variability in soil science.

Geostatistics is concerned with detecting, estimating and mapping the spatial patterns of regional variables and is centered on the modeling and interpretation of the semivariogram. This instrument distinguishes variation in measurements separated by given distances (Goovaerts, 1997; Isaaks and Srivastava, 1989; Rossi et al., 1992). Semivariogram models provide the necessary information for kriging, which is a method for interpolating data at unsampled points. Semivariograms have proven to be an excellent method of exploring the structure of spatial variation in agricultural soils.

Soil properties have often been reported to show a strong spatial dependence (Lophaven et al., 2006; Shouse et al., 1995). Spatial dependence is commonly characterized and quantified by geostatistical methods such as autocorrelation and variogram analysis. Such spatial analysis is necessary to perform sound interpolation when producing contour maps and to simultaneously provide an estimate of the variance of the interpolated values (Goovaerts, 1998). Kriging, which is an interpolation procedure, which provides best linear and unbiased estimation, has been universally applied in the environmental sciences to analyze spatial variability and to resolve site specific problems (Buttafuocoa et al., 2005; Cassel and Nelson, 1985; Famiglietti et al., 1998; Gerke et al., 2001; Goovaerts and Sonnet, 1993; Junior et al., 2006; Western et al., 1998).

Geostatistical techniques are commonly used tools for determining spatial variability distribution in soil properties. Aksakal and Oztas (2010) used geostatistical techniques to measure changes in spatial distribution patterns of PR within a silage-corn field following the use of harvesting equipment. Imhoff et al. (2000) used PR to determine the spatial variability in soil properties induced by plants and animal trampling in grazing systems. Other studies reported that spatial variability of BD and PR is affected by agricultural management practices (Gomez et al., 2005; Warrick and Nielsen, 1980). However, limited studies were conducted to evaluate the agricultural machinery effects on spatial distribution of soil aggregate stability.

Although compaction is regarded as one of the management problems caused by traditional agriculture, it is the most difficult type of soil degradation to locate and rationalize, because as it is invisible, cumulative and persistent (Horn et al., 1995). However, the changes in AS, BD, TP, PR and VMC resulting from traffic operations are dynamic and often show a wide range of spatial variability in response to management practices (Gomez et al., 2005; Mielke and Wilhelm, 1998; Warrick and Nielsen, 1980). Therefore, measuring the horizontal and vertical spatial distribution of these properties may help to identify field areas where soil compaction is a problem to sustain for crop productivity.

The current research focuses on the spatial dependence of soil compaction indicators before and after field traffic. Although many investigations have dealt with soil ecosystems, conclusions aiming at the development of sustainable management strategies are difficult to derive from those studies. It is reasoned that spatial autocorrelation/variation of soil compaction related parameters is usually ignored. This paper serves to close this gap by performing a combined analysis of soil compaction indicators (aggregate stability, bulk density, total porosity, penetration resistance and moisture content) as well as their spatial variation. Therefore, our objective is to investigate the effect of field traffic operations on the changes in spatial variability of soil aggregate stability, bulk density, total porosity, penetration resistance and volumetric moisture content in the various soil depths as indicators of soil compaction.

2. Materials and methods

2.1. Study area

This study was conducted at the Ataturk University Research Farm (~7 ha) in the Erzurum Plain (39° 10′ to 40° 57′ N latitude and 41° 15′ to 42° 30′ E longitude at 1850 m above mean sea level) located north of the Palandoken Mountains, Erzurum, Turkey. The study area covers one ha of land (125 × 80 m) under conventionally-tilled corn silage. The territory of the experiment has only a slight slope (<2%), so no runoff was noticed during the study. The area is dominated by a continental climate, the winter is long and harsh and the summer is short and hot. The coldest month average temperature is −8.6 °C, the warmest month temperature is 19.6 °C, with the lowest temperature of −35 °C and the highest temperature of 35 °C. Average annual rainfall is approximately 450 ± 30 mm. Highest rainfall occurs in the spring and winter months. According to soil taxonomy (Soil Survey Staff., 2006), soil in the study area formed on alluvial parent material and classified as Typic Fluvaquent great soil group.

2.2. Experiment

The study area was transected with 25 × 20 m intervals (Fig. 1). A New Holland TD 65D marked 2650 kg tractor, a TURKAY T-MSM marked 450 kg slag machine and a trailer with an empty weight of 1500 kg and with a capacity of 4000 kg were used in slagging. The trailer was loaded with 2350 to 2550 kg cut corn depending on moisture contents during

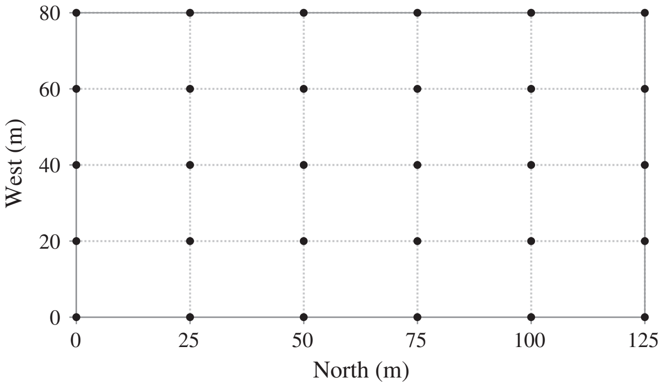

Fig. 1. Layout of soil sampling locations.