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Assessment spatial variability of soil penetration resistance in sugarcane ratoon fields (Case study amir kabir sugarcane agro-industry, Khuzestan, Iran)

Abdollah Omrani[1], Mohamad Javad Shiekhdavoodi[1], Mahmoud Shomeili[2], Mohamad Javad Afzali[3]
[1]Agricultural Mechanization Engineering And Mechanics Engineering of Agricultural Machinery and Mechanization Department, Agricultural Faculty, Shahid Chamran University, Ahvaz, Iran.
[2]Manager of Agronomy in Iranian Sugarcane Research and Training Institute, Khuzestan, Iran.
[3]Expert of Research Center in Agriculture and Natural Resources, Technical Research of Agriculture section, Khuzestan, Iran.

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ABSTRACT

Sugarcane is one of the most important major economic plants under cultivation in Iran. Heavy equipment and the intensive use of machinery can cause to soil compaction in sugarcane fields. In order to studying quantity of compaction in soil depth in two ages of ratoon 3rd and 6th, cone penetrometer was used for soil resistance measurements was conducted in 45 km south of Khuzestan province Amir kabir Agro-industry (31º03´N, 48º14´E) which has total area 12000 hectare which most of time 9500 hectare is under cultivation. Values were determined by using variograms maps of variable produced by kriging technique. Geostatistical software (GS+5.1, 2001; Gamma Design Software) was used to construct semivariograms and spatial structure analysis for variables fields. results showed differences were found both in soil depth and percentage of soil penetrometer resistance values ≥ 2 MPa and results shows differences between 61-80cm soil depth in furrows of 3rd and 6th ratoon are very obvious than 0-61cm of soil depth. In 61-80 cm of soil depth resistance in both ratoon field have increased and usage of mechanical loosening techniques subsoiling to remove soil compaction is necessary. In general combination of geostatics data with primary analysis can assist agricultural mechanization studies field and scientists through a previous identification of degraded zones within the field (e.g. block kriging) and management methods involved in slightly areas.

Introduction

Population growth and increase need to more utilization of resources such as fertilizer, water, soil, energy, machinery, manpower and other inputs lead to use them more than last era for earn more production. Sugarcane is one of the most important economic plants under cultivation in Iran. In addition two oldest Agro-Industries in Iran are Haft-Tapeh and Karoon. The sugarcane by products institute development projects took place in the area of 120000 hectare of virgin lands of Khuzestan province aimed for establishing new septet sugarcane Agro-Industry (Moazzen Rezamahalleh et al, 2012) and about case study that is Amir Kabir Agro-Industry, has total area 12000 hectare which most of time 9500 hectare is under cultivation. In the past, the use of manual labor for sugarcane production was popular due to low labor costs. However, nowadays, mechanization in sugarcane farming is becoming more important due to the ever increasing demand for sugarcane together with the problem of a labor shortage. Intensive farming of crops and animals has spread all over the world; the machinery needed to undertake timely and rapid tillage has become larger and heavier, and the more frequent use of this machinery has led to an increase in soil compaction (Poesse, 1992). Soil compaction is described as decreasing porosity or increasing dry bulk density (BD) as a result of firm-pack soil particles (Kilic et al, 2000). Heavy equipment and the intensive use of machinery can cause damage to the soil structure, which is of concern as the structure affects the ability of a soil to hold and conduct water, nutrients and air that are necessary for plant root activity, with sustained damage eventually reducing yields. Soil compaction as a result of mechanization (in different farm operation likes to tillage, planting, intercultural, harvesting and transporting cane) must be considered as one of the negative consequences of sugarcane production. Usaborisut and Niyamapa (2010) reported soil compaction affected the height and diameter of sugarcane and yield of sugarcane reduced by 22.9% in plots that compacted with 15 tractor passages when compared with the control plot. Recent changes in agricultural practices (such as increased number of operation and larger equipment) have made soil compaction more common. Most yield limiting compaction is caused by wheel traffic from heavy machinery used into sugarcane farm operations, often when operations are conduct on wet soils. Hamza and Anderson (2005) reviews and classify factors which effecting on soil compaction respectively 1.influence of soil water content on soil compaction, 2.mechanized farm operations and soil compaction (axle load as a source of soil compaction, effects of wheels and tires on soil compaction, number of passes), 3.trampling and soil compaction.

Due to attention to using fully mechanized cultivation in the septet sugarcane Agro-industry, this method of cultivation has been rejected in about 84000 hectares and a new method has been developed and used since 1984(Naseri et al, 2007). This new method of cultivation is fully mechanized. However, it is well known that in mechanized agriculture, soil compaction also

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Tele:
E-mail addresses: Ab.omrani1@gmail.com

reduces crop yields (Lindstrom and Voorh ees, 1994). Therefore, it was necessary that a system of cultivation with minimum soil compaction be developed. In the new cultivation method, sugarcane is planted in two rows inside the furrows spaced at 1.83 m. The space between the two rows in each furrow is 0.45 m. When the sugarcane stalk height reaches about 0.5 m, the furrow is replaced with the hill. As a result, sugarcane growth zone is on the hill and inside the furrow specialized for irrigation and the necessary traffic (Naseri et al, 2007) (Fig. 1).

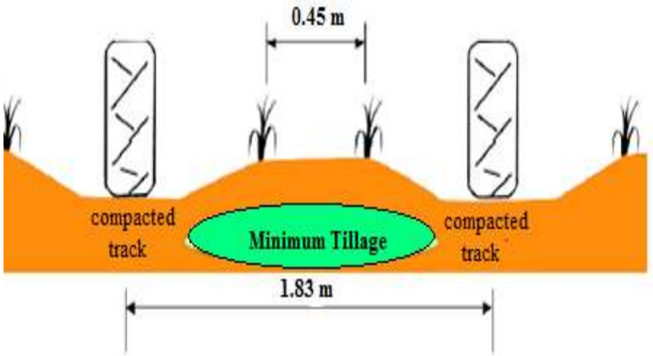

Figure 1. A schematic track width of vehicles and crop row spacing in a sugarcane fields

Geostatistics provides a set of statistical tools for incorporating the spatial and temporal coordinates of observations in data processing, allowing for description and modeling of spatial patterns, prediction at other locations without sampling, and assessment of the uncertainty attached to these predictions. The soil properties vary along the field and cannot be measured everywhere. Thus, the understanding of spatial variability of soil properties will allow better management of soil and crop in the field (Al-Omran et al, 2004). Applications of the Theory of Regionalized Variables (Geostatistics) and its multiple methods have signified important advances for quantifying spatial attributes of soil compaction at several observational scales. A main practical importance of the spatial variability analysis is associated with the opportunity of identifying degraded regions within the agricultural field. This can help scientists, engineers or farm managers to develop appropriate strategies of soil management and to develop site specific agricultural practices (Pe´rez et al, 2010).

Spatial variability analysis can also include, among others, soil texture, bulk density, pH, penetrometer resistance and water content as these soil properties can be affected considerably by soil compaction (Kilic¸ et al, 2000).

Material and methods

Description of study area

This field study was conducted in Amir kabir Agro-industry (31º03´N, 48º14´E) 45 km south of Khuzestan province, Figure 2 shows the location of the field study in Iran, Khuzestan province and Amir Kabir sugarcane Agro-industry. This region has a mean annual rainfall of about 147.1 mm, air temperature is 25 C, soil temperature at 50 cm depth is 21.2^{o} C and Average elevation is 7m above sea level.

Field experiment: This research has been carried out in two fields with different cultivation ages as follows: (i) the first field was under the third year of cultivation (ratoon 3); (ii) the second field was under the sixth year of cultivation (ratoon 6) and these fields were harvested at 15% soil moisture content. Both fields have been applied conventional tillage forming from moldboard plough about 20 cm depth), cultivator (about 15 cm depth) and disc harrow (about 10 cm depth) for a long a period of time.

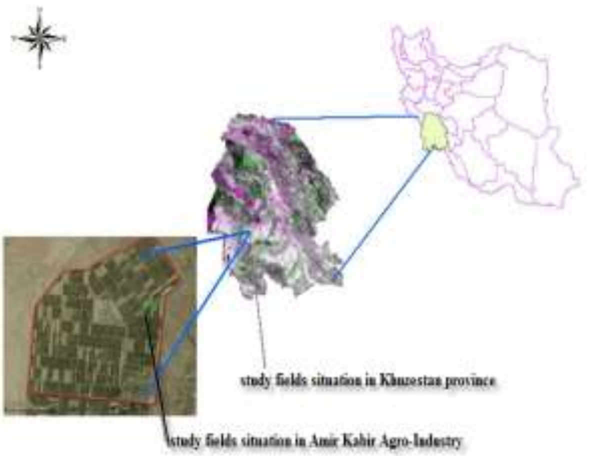

Figure 2. Location of the study fields in south of Ahvaz, Khuzestan province, Iran

Table 1 shows some selected physical and chemical characteristics of the studied area. The site has been under sugarcane (*Saccharum officinarum sp*.) monoculture during the last 14 years which can produce yield decline due to soil properties degradation. Each sugarcane field represents a rectangular of approximately 25 ha (250 m width × 1000 m long). Sugarcane is harvested from November to March each year by using the Case IH-Austoft series 7000 harvesters. Photograph (Fig. 3) shows the sugarcane 3rd ratoon field (during soil sampling and measurement penetration resistance) and approximately 6 days after irrigation.

Table 1. Some characteristics of the studied soil

Soil characteristics	Mean	CV (%)
Clay (%)	41.2	12.1
Silt (%)	40.2	11.6
Sand (%)	18.5	39.4
pH	7.86	1.26
O.M. (%)	1.01	47.6

n= 75 soil sample each case

Seventy five diffrent soil samples were collected (approximately 1 kg each one) within 30×60m grid. Seventy five sub-samples (approximately 50 g each sub sample) were bagged in aluminum containers and weighted for soil moisture determinations (gravimetric method) after oven-drying at 105^{o} C. each soil sample was extracted from 31-60 cm soil depth using an auger. Also Barzegar et al (2005) reported that long term sugarcane cultivation altered soil physical properties. Aggregate stability and macro pore proportions decreased and bulk density increased at a depth of 30-60 cm of sugarcane cultivated soils. At the laboratory, collected soil samples were air dried for 2 weeks, ground and passed through a 2.0 mm sieve. The soil pH values were determined in H_2O using the potentiometric method and organic carbon (OC) by Walkley & Black method (OM=1.724×OC).

Figure 3. Applying the penetrometer instrument in study fields

Statistical and geostatistical analyses

Data analyses for each grid were done in four Steps: (i) normality test (ii) distribution were described with classical statistics (standard deviation and coefficient of variation C.V), (iii) correlation between Penetrometer resistance were determined, (iv) for each variables range, nugget and RSS values were determined by using variograms maps of variable produced by kriging technique. Geostatistical software (GS+5.1, 2001; Gamma Design Software) was used to construct semivariograms and spatial structure analysis for variables. Semi variance is defined as the half of estimated square difference between sample values in a given distance (lag) (Kilic et al, 2004).

Model selection for semivariograms was done on the basis of regression (r^2) and visual fitting. Nugget variance that was expressed as the percent of total semivariance was used to define for spatial dependency of soil variables. If the rate was equal or lower than 25%, variables were accepted as strongly dependent and if the rate between 25 and 75%, variables were moderately dependent and if the rate was higher than 75%, variables were weak dependent (Cambardella et al., 1994). When the slope of semivariogram was close to zero, since the nugget rate was not considered, it was accepted that the variables were random (no spatial dependency) Cambardella and Karlen, 1999).

Penetrometer resistance, soil property measurements and global positioning system

Soil resistance data were collected at the vertexes of regular squared grids. In 3rd and 6th ratoon we used a 30 × 30 = 297 point's (for 3rd ratoon) and 54 points (for 6th ratoon) grid with sampling interval L = 30 m and 9 points in each furrow and because inter-row spacing is main route of harvester wheels and accompanying trucks or tractors. An electronic penetrometer (EijkelkampTM 06.15.SA soil compaction meter, Giesbeek, the Netherlands)[1] some specific characteristics of this instrument are: operational temperature 0-50° C in depth resolution = 1 cm, in depth range 0-80 cm, and cone index range = 0-10 MPa. Cone penetrometer readings were taken at three different depths from the furrow in 3rd ratoon and 6th ratoon field (0-30, 31-60 and 61-80 cm). Cone index is measured with a soil cone penetrometer which is defined by ASAE Standard S313.3 (a) and ASAE Standard EP542 (b). These documents provide details on the construction and use of the soil cone penetrometer. The unit is composed of a 30 cone connected to a rod. A handle on the upper end is used to force the cone into the soil. Some method of measuring insertion force is included with the unit. Cone index is defined by the insertion force divided by the cross-sectional area of the base of the cone. The standard set of cone Penetrometer has a cone with 30° tip angle a standard cone base area (1 cm^2) and shaft diameter (8mm). Penetrometer resistance measurements were made pushing vertically the penetrometer to the soil at an approximated speed of 2cm/s (Eijkelkamp, 2007). As the pressures exceed 2 MPa, root growth has been shown to be restricted to varying degrees (Raper, 2005). We used the MONTANA™ [2] 600 series GPS to record precise location of cone penetrometer in both fields. When we going into row space and take a soil sample and record penetrometer resistance data mark waypoint to determinate accurate location in field map and using coordinate system data in GS^+ software.

Result and Discussion

Table 2 shows the descriptive statistics of soil penetrometer resistance in both ratoon fields. Minimum, maximum and mean values increased with soil depth in 3rd and 6th sugarcane ratoon fields but the largest estimates were found in 6th ratoon field (except maximum value in 31-60 cm depth that in 3rd ratoon more than 6th ratoon).

Figs. 4 and 5 show the spatial distribution of soil penetrometer resistance in 3rd and 6th sugarcane ratoon fields. In both cases each data distribution was previously converted into a regular XYZ matrix (Z representing soil penetration resistance data). Both figures are linked to table 3. As different authors have stated different extreme values for soil compaction, we used 2MPa as a threshold for separating compacted from un-compacted soil. One can note the dominance of cone index value smaller than 2MPa 3rd ratoon field for 0-30, 31-60 and 61-80 cm soil depth (fig. 4). It is also evident from table 3 and figs 4 and 5 that percentage of mechanical impedance values ≥ 2 MPa increased with soil depth in both ratoon ages. However after in 6th ratoon field the total percentage of penetrometer resistance data ≥ 2 MPa was 36.6% as compared to only 20% in 3rd ratoon field. One can also note from fig. 5 different spatial patterns of soil penetrometer resistance values as compared to those presented in fig. 4. Furthermore, inspection of both figures reveals some sort of spatial organization where spatial structures seem to be random-like fields.

Table 2. Descriptive statistics of soil penetrometer resistance for sugarcane 3rd and 6th ratoon field

Soil depth (cm)	Mean(MPa)	Min. (MPa)	Max. (MPa)	S.D.[a]	C.V.[b] (%)
3rd ratoon field					
0-30	0.94	0.27	2.13	0.347	37.2
31-60	1.61	0.41	4	0.596	36.8
61-80	2.17	0.95	4.09	0.588	27
6th ratoon field					
0-30	1.56	0.78	2.4	0.652	41.6
31-60	2.02	1.24	2.82	0.595	29.4
61-80	2.5	1.19	4.27	0.872	34.8

[a] Standard Deviation

[b] Coefficient of Variation

Table 3. Percentage of soil penetrometer resistance values ≥ 2 MPa.

Soil depth(cm)	3rd ratoon field (%)	6th ratoon field (%)
0-30	2.6	31.11
31-60	13.55	46.66
61-80	64	68.88
Total	20	36.6

Table 4 show results of semivariance in Isotropic variogram model for all depth of soil in both ratoon age fields Geostatistical software (GS+5.1, 2001; Gamma Design Software) was used to construct semivariograms and spatial structure analysis for variables. Model selection for semivariograms was done on the basis of regression (r^2) and visual fitting.

Conclusions

With soil penetrometer index and measuring in two ages of sugarcane ratoon field's differences were found both in soil depth and percentage of soil penetrometer resistance values ≥ 2 MPa and results shows differences between 61-80cm soil depth in furrows of 3rd and 6th ratoon are very obvious than 0-61cm of soil depth.

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[1] Trade name mention is only for scientific purpose not for product endorsement.

Table 4. Semivariance (Isotropic variogram model) for sugarcane 3rd and 6th ratoon fields

Soil depth (cm)	Model	Nugget (Co)	Sill(Co+C)	Range(m) (A0)	RSS	r^2
3rd ratoon field						
0-30	Linear to sill	0.11530	0.23160	610.9000	7.882×10^{-4}	0.606
31-60	Linear	0.13215	0.14560	245.9311	7.235×10^{-4}	0.553
61-80	exponential	0.062600	0.125300	610.9000	1.629×10^{-4}	0.519
0-80	Linear	0.073764	0.075109	246.2994	7.259×10^{-4}	0.005
6th ratoon field						
0-30	Gaussian	0.15000	0.47100	26.8100	6.936×10^{-4}	0.766
31-60	Exponential	0.075900	0.152800	30.9900	6.393×10^{-4}	0.249
61-80	Exponential	0.10060	0.20220	30.9900	4.102×10^{-3}	0.050
0-80	Spherical	0.051400	0.107800	29.3500	1.647×10^{-3}	0.312

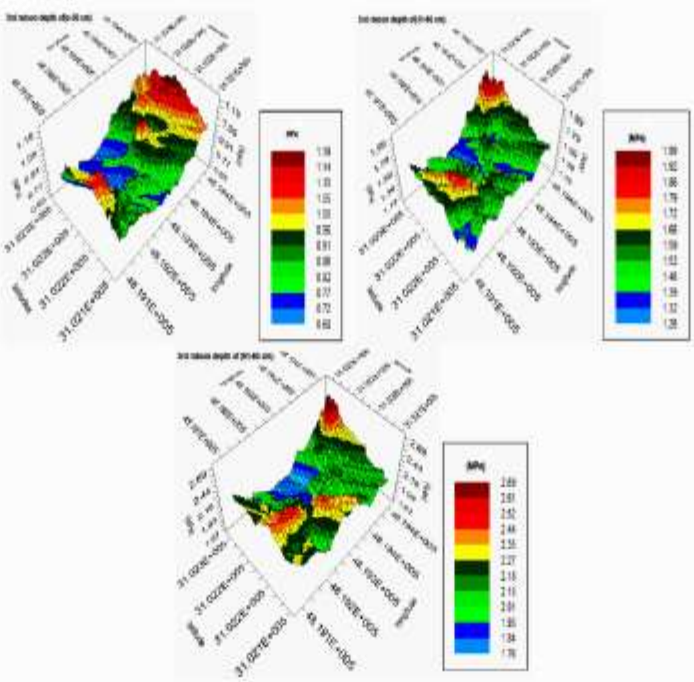

Figure 4. Spatial distribution of soil penetration resistance in different depth of 3rd ratoon field

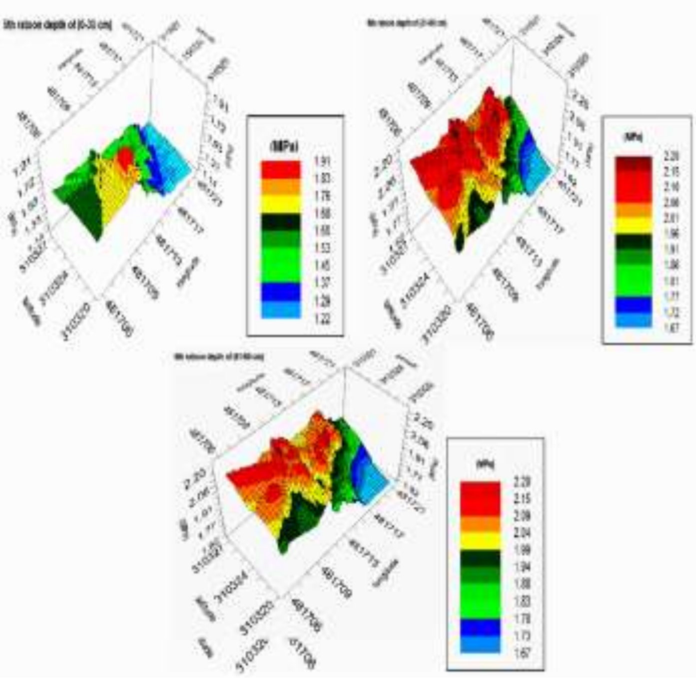

Figure 5. Spatial distribution of soil penetration resistance in different depth of 6th ratoon field.

In 61-80 cm of soil depth resistance in both ratoon field have increased and usage of mechanical loosening techniques subsoiling to remove soil compaction is necessary. Also compare with Barzegar et al (2005) report, we found depth of compaction is different and now locate in 61-80 cm layer of soil depth. In general combination of geostatics data with primary analysis can assist agricultural mechanization studies field and scientists through a previous identification of degraded zones within the field (e.g. block kriging) and management methods involved in slightly areas are precise and by accurate determine degraded zone we can produce a layer and use in precision agriculture and improve production yield of sugarcane farms.

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