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Original Article

Spatial Distribution of Soil Penetration Resistance in Sugarcane Ratoon Fields (Case Study: Amir Kabir Sugarcane Agro-Industry, Ahvaz, 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. An on-farm experiment was conducted in 45 km south of Khuzestan province Amir Kabir Agro-industry to assess implications of alleviating soil compaction in wheel tracks under the zonal tillage production system. In order to studying quantity of compaction in soil depth layers in two ages of ratoon 3rd and 6th, cone penetrometer was used for soil resistance measurement. 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 semi variograms 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 0-60cm soil depth in furrows of 3rd and 6th ratoon are very obvious than 61-80cm of soil depth. In 31-60 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 Knowledge on the spatial distribution of the penetration resistance can be helpful in identifying zones with soil compaction (strength) problems and development management options that minimize crop production risks and the harmful impact of traffic on the environment.

Keywords: Penetration Resistance, Spatial Variability, Sugarcane Ratoon Fields

INTRODUCTION

Sugarcane is one of the most important industrial crops in the world and has been allocated more than 100,000 hectare surface of land to the Khuzestan province of Iran. Soils dedicated to sugarcane production usually affected by multiple factors. Two important factors are monoculture and use of heavy machinery for sugarcane harvesting [1]. Use of machinery with heavy axle loads and their wheel traffic are found to affect soil physical, chemical and biological properties of cane fields depending on the prevailing climatic conditions in various field crops. In the mechanized sugarcane (Saccharum spp.) production, effects of soil compaction and subsequent yield decline have been well documented elsewhere [2, 3, 4].

Since Sugarcane is one of the most important major economic plants under cultivation in Iran. In addition haft-tapeh and Karoon the oldest agro-industries in Iran, the sugarcane by products development project took place in the area of 84000 ha virgin land of Khuzestan province for establishing new septet sugarcane agro-industry [5], and about casestudy that is Amir Kabir Agro-industry, has total area 12000 hectare. 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 [6]. The sugarcane crop in Iran is wholly mechanically harvested by harvesters. This new method of cultivation is fully mechanized. However, it is well known that in mechanized agriculture, soil compaction also reduces crop yields [7]. Therefore, it was necessary that a system of cultivation with minimum soil compaction be developed. In the new cultivation

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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 [6] (Fig. 1).

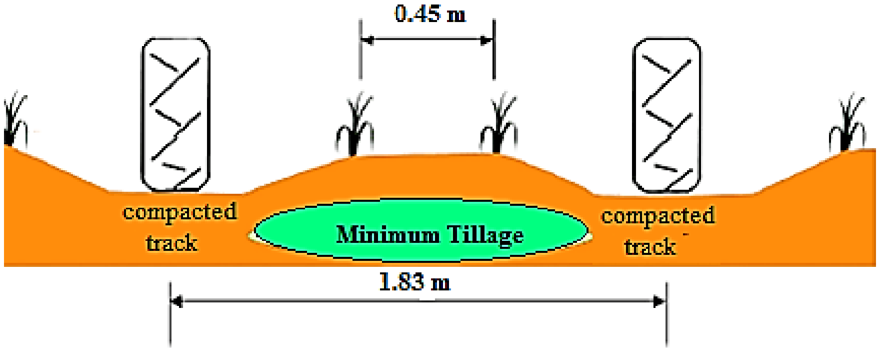

Figure1. Relation between track width of vehicles and crop row spacing

In recent decades, the weight of agricultural machines has increased in order to meet the demands of modern agriculture. This ever-increasing weight of agricultural machines causes stress penetration to deeper soil layers [8]. To compound the effects of axle load on soil compaction, harvesting is done under wet conditions, which leads to wheel slip with greater potential for soil compaction [6]. Soil compaction by vehicular traffic is an integral part of the soil management system and progressively more challenging problem for crop production and environment Increasing size of agricultural machinery is a significant reason of induced soil compaction and decline of soil structure, surface crust resistance, traffic ability and draft requirements and root growth. This property can be easily and rapidly measured and therefore penetration resistance (PR) is widely used to evaluate the effects of changes in soil pore and aggregate structure [9].

This study was undertaken to assess changes in soil cone resistance after three and six years (or in 3rd and 6th ratoon) sugarcane field and take a site specific management by result maps. 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 [10]. 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 [11]. 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 [12].

MATERIALS AND METHODS

Description of study area

This field study was conducted in 45 km south of Khuzestan province Amir Kabir Agro-industry (31º03´N, 48º14´E), 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.

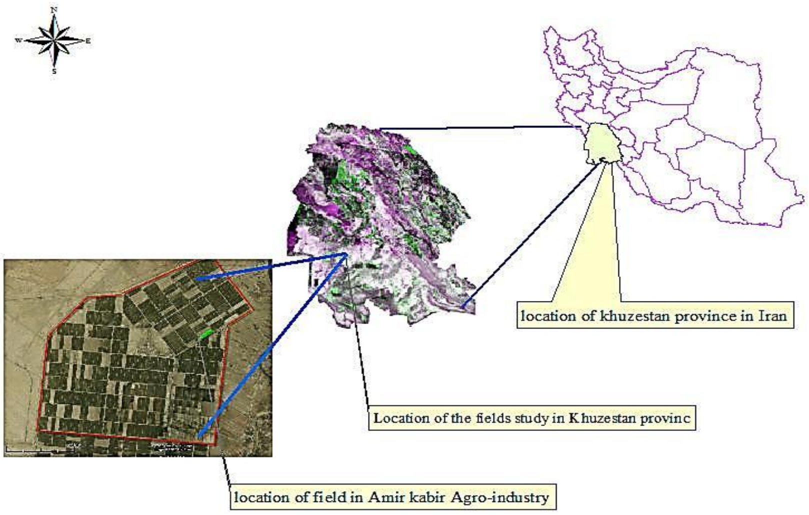

Figure 2. Location of the fields study in south of Ahwaz, Khuzestan province, Iran

Field experiment: This research has been carried out in three 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% moisture. 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.

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 in Iran. Photograph (Fig. 3) shows the sugarcane 3rd ratoon field (during soil sampling & 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 distributed 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. reported that long term sugarcane cultivation altered soil physical properties [13]. 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, undistributed soil samples were air dried for 2 weeks, ground and passed through a 2 mm sieve. The soil pH values were determined in H_2O using the potentiometric method and organic carbon (OC) by Walkley andBlack method (OM=1.724×OC), [14].

Figure 3. Photograph of studied sugarcane ratoon field

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 nugget ratio values were determined by using variograms maps of variable produced by kriging technique. Geostatistical software (GS+5.1, 2001; Gamma Design Software), [15] 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) [12].

Model selection for semi variograms was done on the basis of regression (r^2) and visual fitting. Nugget variance that was expressed as the percent of total semi variance 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 [16]. When the slope of semi variogram was close to zero, since the nugget rate was not considered, it was accepted that the variables were random (no spatial dependency) [17]. Spherical semi variogram was used in geostatistical calculation carried out foe evaluation of spatial autocorrelation [18]. The following parameters were calculated:

Nugget (C_0) – semivariance when the distance between the points is vanishing and corresponds to the variability of values in the point that is not clarified by the spatial structure; Sill ($C+C_0$) – indicates the maximum semi variance, this is the maximum height of semivariogram curve; Nugget and sill ratio ($C_0/C+ C_0$) – indicates the spatial dependence of penetration resistance (MPa) on the distance; Range (A) – distance between the points at which the spatial dependence occurs; Regression coefficient (r_2) – indicates how well the model fits the semivariogram data. The regression coefficient close to 1, the semi variogram model matches better; Residual sum of square (RSS) – indicates how well the model fits the variogram data; the lower the residual sum of squares, the better the model fits. Geostatistical software [15] (GS+5.1, 2001; Gamma Design Software) was used for interpolation and drawing the digital maps and computing Variograms.

Penetrometer resistance, soil property measurements and global positioning system

Soil cone resistance was used as an indicator of soil compaction due to speed and ease of measurement. Cone index has two main advantages over bulk density measurements. First, they are easier to obtain requiring significantly reduced time to quantify the entire soil profile. Second, cone index measurements can be compared across soil types much easier than bulk density measurements [19]. Some researchers have found that cone index is more sensitive to increased vehicle traffic than bulk density [20]. Soil resistance data were collected at the vertexes of regular squared grids. In 3rd ratoon and 6th 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 [21] (EijkelkampTM 06.15.SA soil compaction meter, Giesbeek, the Netherlands)* some specific characteristics of this instrument are: operational temperature 0-50o 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) [22] and ASAE Standard EP542 (b) [23]. 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 30o 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 $2cm.s^{-1}$ [21]. As the pressures exceed 2 MPa, root growth has been shown to be restricted to varying degrees [19]. We used the MONTANATM 600 series GPS to record precise location of cone penetrometer in both fields. When we going into row space, 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.

RESULTS

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 4 show results of semi variance 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.

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*- Trade name mention is only for scientific purpose not for product endorsement.

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

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. Semi variance (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

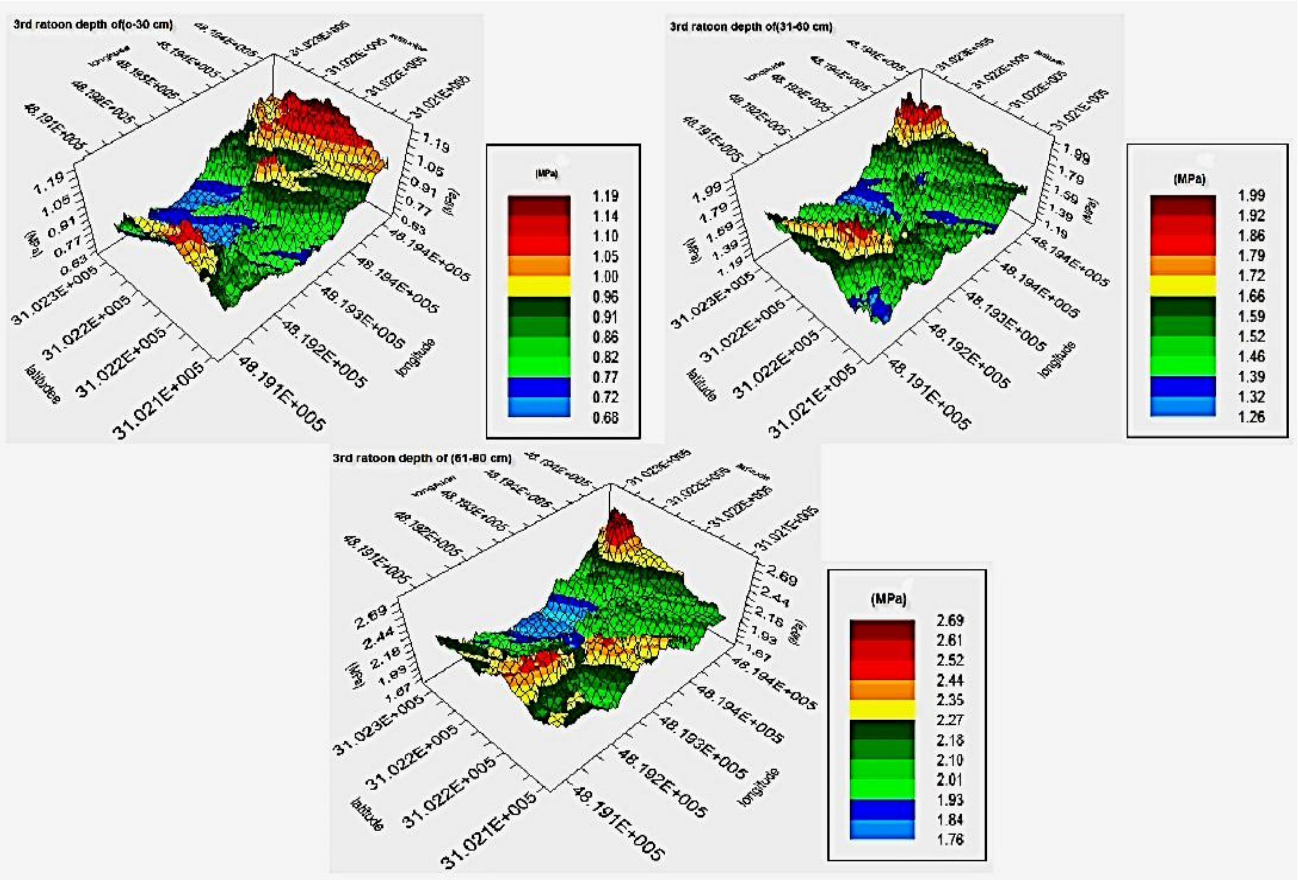

Figure 4. Spatial distribution of soil penetration resistance in different depth of 3rd ratoon field

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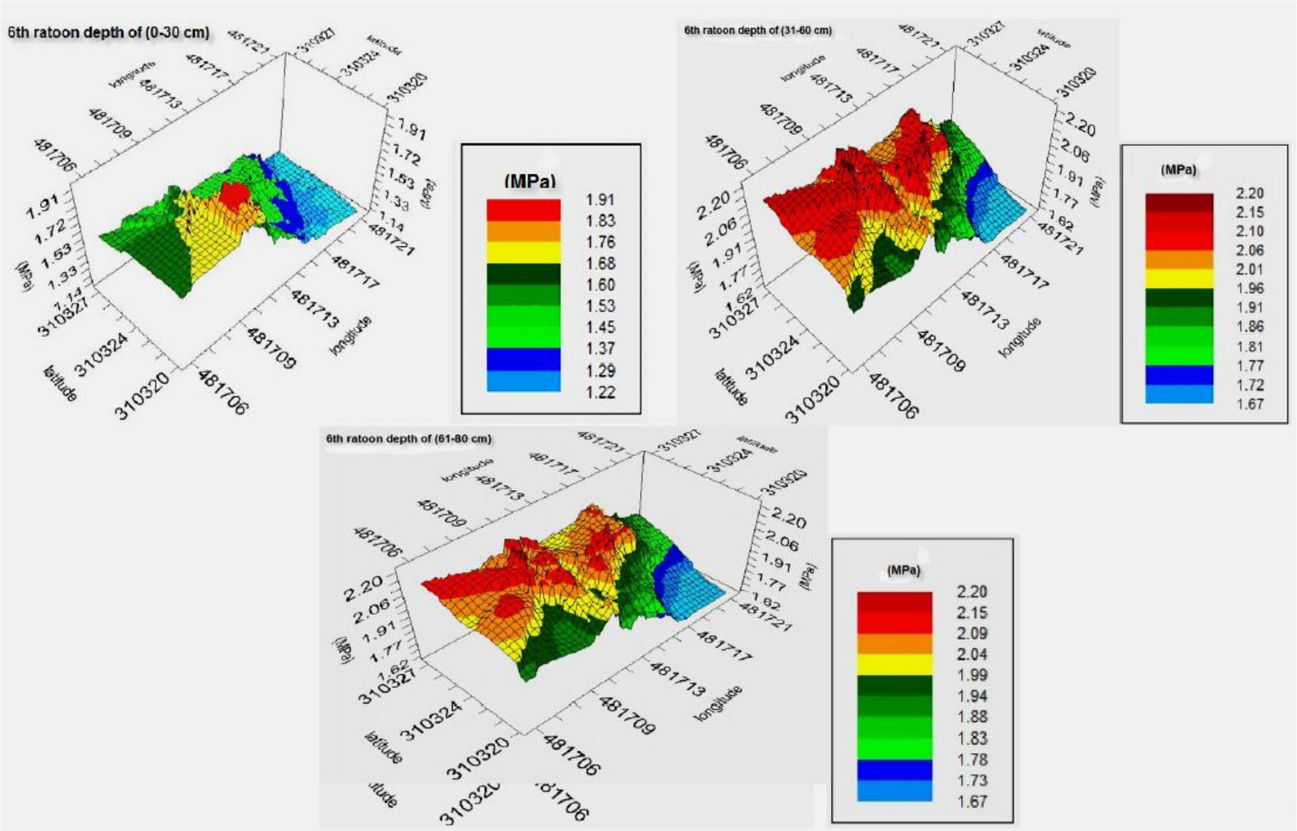

Figure 5. Spatial distribution of soil penetration resistance in different depth of 6th ratoon field

DISCUSSION

Spatial variability of penetration resistance as affected by traffic intensity and associated compaction level analyzed in horizontal and vertical planes using semivariograms and fractal dimension. Isotropy was observed in spatial distribution of penetration resistance. Fractal dimension for penetration resistance can be a useful indicator of increasing compaction level due to traffic intensity, whereas that from the horizontal planes can indicates any traffic events.

Naseri et al. [6] report the harvesting traffic can result in negatively change in soil conditions, but sub soiling can treat the soil compaction and improve soil physical properties. Knowledge on the spatial distribution of the penetration resistance can be helpful in identifying zones with soil compaction (strength) problems and development management options that minimize crop production risks and the harmful impact of traffic on the environment. 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 0-60cm soil depth in furrows of 3rd and 6th ratoon are very obvious than 61-80cm of soil depth. In 31-60 cm of soil depth resistance in both ratoon field have increased and usage of mechanical loosening techniques sub soiling 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 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.

Suggestions:

- Matching sugarcane row spacing with equipment track width will minimize changes in soil properties under the crop row.
- Soil penetration resistance contours can provide a useful visual presentation of soil compaction throughout the soil profile so each agro industry may use it in periodical season.
- Soil compaction resulting from vehicle traffic may not be able to be completely eliminated, but it can be controlled and reduced through intelligent management of vehicle traffic.

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