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Relationships between Some Soil Quality Indicators in Different Agricultural Soils from Varamin, Iran

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ABSTRACT

Soil quality is a necessary indicator of land management. Different indices are applied to evaluate farming systems, soil types and land uses based on soil quality. The slope of retention curve at its inflection point has been defined as soil physical quality index (Si) but the relationships between Si and penetration resistance (PR), the least limiting water range (LLWR), and available water content (AWC) have not been studied yet. In this study, I) the effects of soil physical properties on Si index and PR, and II) the relationships between Si index and PR, LLWR, and AWC were investigated. Seventy undisturbed soil samples were collected and the slope at inflection point for soil retention curve as a soil physical quality index (Si) was determined in each sample using soil retention curve data. Furthermore, PR was measured in soil surface, and LLWR and AWC were calculated. The results showed that the correlations between PR and water content, Electrical conductivity (ECe), SAR, and Si index were significant at P<0.01, whereas its correlations with bulk density (ρb), and organic matter (OM) were significant at P<0.05. There was also a negative correlation found between AWC and PR (P<0.01). In addition, a positive correlation between Si and LLWR, and a negative correlation between PR and LLWR among soil samples (P<0.01) were found to exist. Therefore, the Si index provides a tool that can be used to compare different soils or the effects of different management practices on soil physical properties.

Keywords: Available water content, Least limiting water range, Penetration resistance, Soil physical quality index.

INTRODUCTION

Soil quality developed as a specific concept during the decade of the 1990s, and it is an outcome of holistic approach to soil management and sustainable land use systems (Karlen et al., 2001). It is a necessary indicator of land management sustainability and depends on a large number of physical, chemical and biological soil properties. Characterization of soil quality requires a selection of the indicators most sensitive to changes in management practices (Elliott, 1994). Arshad and Coen (1992) suggested that soil depth to a root restricting layer, available water holding capacity, bulk density or penetration resistance, hydraulic conductivity, aggregate stability, soil organic matter content, nutrient availability, pH, and electrical conductivity are generally sensitive to management practices, thus they can be used as soil quality indicators. The least limiting water range (LLWR) has been proposed as an index of soil physical quality for crop growth (Da Silva et al., 1994, Betz. et. al., 1998). The LLWR has been validated as a

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soil physical quality indicator for a wide variety of soils, crops, and management systems (Da Silva et al., 1994; Wu et al., 2003).

Under semi-arid conditions where moisture is limited for crop production, soil physical parameters such as texture, bulk density, aggregate size distribution and aggregate stability can be used to characterize constraints on the water availability and root growth (Noellemeyer et al 2006). Noellemeyer et al (2006) showed that the clay + silt contents of the rangeland soils affected the values of soil quality parameters. Sparling and Schipper (2002) found seven key properties (pH, total Carbon and Nitrogen, mineralizable N, Olsen P, bulk density and macro porosity) as a minimum data set to study the soil quality. Shukla et al (2006) concluded that soil organic carbon should be considered as an important parameter in soil quality. According to their study, soil organic carbon, bulk density, water stable aggregates and cumulative infiltration varied with management practices, should be considered as dynamic soil quality indicators.

Since pore size and configuration of soil affect its water retention curve, Dexter (2004) showed that the slope of water retention curve at inflection point (Si) can reflect the different aspects of soil quality such as infiltration, hard-setting, compaction, organic matter contents, aeration, and root growth, etc. He defined the slope of retention curve as a soil physical quality index. Soil physical quality index is an estimation of soil micro-structure which may directly control many of the principal soil physical properties and it can be easily measured from retention curve. The value of Si = 0.035 was defined as the boundary between good and poor soil physical condition by Dexter (2004). The following categories of Si index have been suggested: Si < 0.020, very poor; 0.020 < Si < 0.035, poor; Si > 0.035, good. Some sands may have a poor structure, and large values of Si index. However, it seems that some sands may be exceptions (Dexter 2004) and in spite of unsuitable structure in sandy soils, they may have high values of Si index due to macro porosity. It has been suggested that those values could be useful for contours on maps showing areas within which soil physical properties may be considered as being good or poor. Changes in the land cover of such areas with time could be used as an indication of the increment or decrement of degraded areas. Therefore, the Si index could be a valuable index in the quantification of soil physical degradation or amelioration, and it can be used in the assessment of the physical quality of global soil resources.

Penetration resistance (PR) is one of the important parameters of soil quality. Penetration resistance decreases by the increase in water content (Ayers and Perumpral, 1982). Faure and Da Mata (1994) found that when soil was close to saturation point, the penetration resistance was very low or near zero. Penetration resistance increases with increment of cementation as a result of cementing factors such as carbonates, hydrous silicates, and Fe oxides (Puppala et al., 1995). Lowery and Schular (1994) showed that when soil compaction increased, the penetration resistance and bulk density increased.

Because the relationship between Si index and other soil physical quality indices and also the relationship between Si index and PR, LLWR, and available water (AWC) have not been studied, we conducted this research to study: I) the relationships between different soil physical properties and Si index, and II) the relationships between different soil physical indicators and indices, i.e., Si index, PR, LLWR, and AWC.

MATERIALS AND METHODS

Site Description

This study was carried out in agricultural fields in the south-east of Tehran province, Iran. The sampling sites were located in

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Varamin (from 35° 24′ 46.07″ to 35° 02′ 41.65″ east longitudes and from 51° 33′ 49.92″ to 51° 47′ 02.66″ north latitudes). The climate of the region is semi-arid type with mean annual temperature and precipitation of 18°C and 150 mm, respectively (Moravvej et. al., 2004). The soil is classified as Xeric Haplocalcid (Moravvej et. al., 2004) with a particle size distribution consisting of 372.6 gkg^{-1} clay, 347.8 gkg^{-1} silt and 282.5 gkg^{-1} sand. Soil texture includes Clay Loam (31 samples), Clay (22 samples), Loam (6 samples), Sandy clay loam (5 samples), silty clay loam (3 samples), and silty clay (3 samples). Winter wheat is cultivated in the studied region. We searched for soils with a wide range of physical and chemical properties to compare the soil physical indicators. Therefore, this location was selected.

Soil Sampling and Analysis

Soil sampling was done as a systematic sample in three replications for each sample. A total of 70 undisturbed soil samples (5-cm diam. by 5-cm length) were collected in November 2006. The disturbed soil samples were also collected from the same surface layer to measure physical and chemical properties. Some chemical properties of soil samples were measured after air drying and passing the disturbed soil samples through a 2-mm sieve. Soil texture was determined using the hydrometer method (Gee and Bauder, 1986), organic matter was determined by wet oxidation with dichromate, total $CaCO_3$ equivalent (CCE) was determined from the weight loss in 2 g of sample treated with 6 M HCl, and pH was measured in 1:2.5 soil: water suspension. Na^+ in the aliquot of soil suspension was measured by Flame photometry. EDTA titration was used for the determination of Ca^{2+} and Mg^{2+}. In this method, the aliquot was adjusted to pH 10 by adding ammonium hydroxide-ammonium chloride buffer. Ten drops of EBT indicator were added. Titration was made with EDTA to the end point indicated by the color change of EBT from wine-red to pure blue (Page et. al., 1982).

Electrical conductivity (ECe) was measured in the saturated paste extract and the sodium adsorption ratio was calculated as ($SAR=Na^+/\ [(Ca^{2+}+Mg^{2+})/2]^{0.5}$, where Na^+, Ca^{2+}, and Mg^{2+} refer to the ionic concentrations in $mmol_c\ L^{-1}$).

Undisturbed soil samples were used to measure bulk density (Blake and Hartge; 1986) and to obtain the retention curve. Water content of soil was measured at 0, 15, 25, and 55 cm H_2O suctions by hanging water column, and at 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, and 10 bar pressure heads by pressure plate (Klute, 1986). Si index was determined in all soil samples by using the moisture retention curve data. Soil texture, bulk density and moisture retention curve data were used as input data in RETC 6.0 software (Van Genuchten, 1990) and the parameters of Van Genuchten (1980) equation (n, θ_r, α) were predicted. Then Si index was calculated as follows (Dexter 2004):

$$S_i = -n\left(\theta_{sat} - \theta_{res}\right)\left[1+\frac{1}{m}\right]^{-(1+m)} \quad (1)$$

If *m=1-1/n* is applied:

$$S_i = -n\left(\theta_{sat} - \theta_{res}\right)\left[\frac{2n-1}{n-1}\right]^{\left(\frac{1}{n}-2\right)} \quad (2)$$

where n and α (empirical parameters), and θ_{res} (residual water content (gg^{-1})) are obtained by RETC software but θ_{sat} (saturated water content (gg^{-1})) was measured. Since the Si index is always negative, the modulus of Si index was used in this paper.

The penetration resistance of soil surface (0-5 cm depth) was measured by a cone penetrometer with 6.29 cm^2 base area in the field. Wu et al. (2003) used the undisturbed soil cores (5 cm (diameter) × 5 cm (height)) to measure water retention characteristics and mechanical resistance. Simultaneously, soil samples were collected to determine the moisture content of the soil layer by oven

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drying. The LLWR was determined for each sample by the procedure of Da Silva et al. (1994). The soil water content at the critical limits of the matric potential, soil resistance and air filled porosity were obtained considering field capacity (θ_{fc}) to be the soil water content at h = -0.01 MPa. For the permanent wilting point (θ_{wp}) we considered soil water content at h = -1.5 MPa, for penetration resistance (θ_{pr}) we used the 2.0 MPa value, and for air filled porosity (θ_{afp}) we used the value of 10%. The θ_{pr} was obtained by Eq. (3).

$$\Pr = a\theta^{b}\rho_{s}^{c} \quad (3)$$

where a, b, and c are constants, ρ_s is the particle density (assumed to be 2.65 gcm^{-3}) and Pr is the soil penetration resistance (MPa). The LLWR is the difference between the upper and the lower limits. The upper limit is the drier θ of either θ_{fc} or θ_{afp} whereas the lower limit is the wetter θ of either θ_{wp} or θ_{pr} (Tormena et al., 1999; DA Silva et. al., 1994; Betz et. al., 1998).

Statistical Analyses

The variables under study were subjected to a descriptive statistical study and tested in terms of their normality prior to their processing using Pearson correlation analysis. The analyses were performed using SPSS 12 Windows (2003).

RESULT AND DISCUSSION

The average, standard deviation, and coefficient of variation of some soil properties were calculated in all soil samples (Table 1). Based on Dexter (2004) theory, the studied soil samples had suitable physical and structural properties for agriculture practices, because the Si index of soil samples was greater than 0.035. The results also showed that the penetration resistance varied from 0.05 to 0.34 MPa. Therefore the studied soil samples were suitable at surface layer (0-5cm depth) for plant growth based on Taylor et al. (1966) suggestion. They reported that when the penetration resistance in root zone was more than 2 MPa, it limited the root and seeding growth of plants and crop yield decreased significantly. Groenevelt et al (2001) found that soil samples with penetration resistance more than 2.5 MPa limited the root growth. Since the penetration resistance of all soil samples was low but Si index was high, the soils were found to have no limiting physical properties. However, although the penetration resistance and Si index may be restricting factors to root growth, they are not limiting properties for plant growth at surface layer (0-5 cm depth). Wu et al. (2003) determined the nonlimiting water range (NLWR) for plant growth in undisturbed soil cores (5 cm (diameter) × 5

Table 1. Some statistic parameters of soil properties (n=70).

Soil properties	Minimum	Maximum	Average	St. D. [a]	C. V. [b]
Clay (%)	12.24	56.00	37.26	8.43	22.63
Silt (%)	13.12	51.72	34.78	8.09	23.27
Sand (%)	9.00	59.04	28.25	9.70	34.34
OM (%)	0.97	4.52	2.13	0.74	34.74
Bulk density (gcm^{-3})	1.16	1.64	1.46	0.10	6.82
EC (dS/m)	0.58	34.30	4.46	4.87	109.14
SAR	0.15	40.28	7.97	8.66	108.60
$CaCO_3$ (%)	5.67	20.20	12.63	3.75	29.69
Soil Moisture (cm^3cm^{-3})	0.06	0.20	0.13	0.03	23.31
Si index	0.074	0.210	0.137	0.030	21.82
PR (MPa)	0.05	0.34	0.18	0.06	32.39
LLWR (cm^3cm^{-3})	0.24	0.40	0.33	0.04	11.43
AWC (cm^3cm^{-3})	0.15	0.47	0.22	0.06	28.58

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cm (height)) and concluded that the NLWR of soil surface was not significantly affected by the various agricultural management practices.

The relation between Penetration Resistance and Soil Properties

The results of statistical analysis showed that there was a significant correlation between penetration resistance and some soil properties such as soil moisture, electrical conductivity (ECe), sodium absorption ratio (SAR), bulk density, organic matter content, and Si Index. According to Table 2, by increasing the bulk density, the penetration resistance also increased, but by increasing the soil moisture, the penetration resistance was reduced. Physical processes can affect soil strength. When a soil dries, fine particles (clay and silt) find new configurations and create connections and bridges between sand particles. These bridges pull the particles towards each other by decreasing water content. As result of this, the soil strength increases. Franzmeier et al. (1996) found that the increase in soil strength is not only due to cemented agents; rather, matric potential also affects the soil strength and increases it when water content decreases. Ayers and Perumpral (1982) also found a negative relationship between penetration resistance and soil moisture content. Lowery and Schular (1994) showed that when soil is compacted, the penetration resistance and bulk density are increased. Based on Utseta and Cid (2001), the penetration resistance in ferralosols was highly influenced by soil moisture content. These results show that by increasing the bulk density or decreasing the moisture content, the cohesive force that holds the particles together is increased. By increasing the bulk density the internal friction between soil particles increases too which can further increase soil strength and penetration resistance.

There was a negative correlation between penetration resistance and organic matter content. Organic matter content causes improvement and stability of soil structure and therefore decreases the penetration resistance. Different researchers emphasized the effect of organic matter on penetration resistance reduction. Chan (1995) reported that the hard-setting had a significant relation with organic carbon, so that the soil strength increased at lower depths where organic carbon was less. Watts and Dexter (1997) observed the decrement of shear resistance with the increase in organic matter in a fine silt loam soil.

There was a significant negative correlation between Si index and PR ($r = -0.593$; $P<0.01$) (Table 2). The relationship between Si index and PR has not been studied, but some indirect researches reflect this trend. For example, Mullins et al. (1990) found that degradation of aggregates during the wetting caused hard-setting. They believed that during the wetting, most of macro-pores (> 0.06 mm in diameter) decreased and their resistance increased after the soil was dried. It is known that decreases in macro-pores cause decreases in Si, whereas the penetration resistance increases.

There were positive correlations between penetration resistance and ECe and SAR. Sudduth et al. (2002) found a similar

Table 2. The correlation coefficient (r) between penetration resistance and some soil properties (n=70).

Soil Properties	Correlation coefficient (r)	Soil Properties	Correlation coefficient (r)
Clay percent	0.131^{ns}	Organic matter	-0.304^{*}
Silt percent	-0.009^{ns}	Lime percent	-0.057^{ns}
Sand percent	-0.077^{ns}	SAR	0.408^{**}
Bulk density	0.272^{*}	EC_e	0.330^{**}
Si Index	-0.593^{**}	Soil moisture (cm^3cm^{-3})	-0.584^{**}
LLWR(cm^3cm^{-3})	-0.573^{**}	Available water (cm^3cm^{-3})	-0.603^{**}

**: significant at P<0.01, *: significant at P<0.05, ^{ns}: none-significant

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relationship between ECe and PR. Mullins et al. (1990) and Franzmeier et al. (1996) observed that hard-setting soils in some depths had a higher clay content, pH, and exchangeable sodium. Dexter and Chan (1991) cited that some cations such as sodium cause clay dispersion, and as a result, maximum penetration resistance in dry soils. According to Table 1, the averages of ECe and SAR in 70 soil samples are 4.46 dSm^{-1} and 7.97, respectively. Thus, it seems that the increase in Na^+ in soil solution results in ECe increase, and therefore increasing the electrical conductivity creates a matrix that is more difficult to penetrate. Results indicated that the cohesive force that holds the particles together is lower in low salinity and sodicity soil. However, the average penetration resistance values did not exceed the critical 2 MPa value. Thus, penetration resistance is not a limiting factor within the soil water content range from the wilting point to field capacity.

The relationship between penetration resistance and the least limiting water range (LLWR) was also studied. The least limiting water range is the range of water content in which the limiting factors of plant growth such as soil moisture potential, aeration, and mechanical resistance to root growth are minimum (DA Silva et al., 1994; Tormena et al., 1999). The incorporation of soil aeration, penetration resistance, and matric potential for plant growth are considered as the least limiting water range. The LLWR is more sensitive than available water to variations in soil structure which is determined based on dry bulk density (DA Silva et al., 1994).

Results showed that there was a negative correlation between PR and the LLWR ($P<0.01$) (Table 2). The LLWR is regarded as an index of soil structure for crop yield (DA Silva et al., 1994), therefore negative correlation between PR and the LLWR is reasonable and agree with the results of DA Silva et al. (1994), and Tormena et al., (1999). Furthermore, the correlation between Si index and the LLWR was positive (Table 2). Dexter (2004) introduced Si index as a structure quality index and DA Silva et al. (1994) and Tormena et al. (1999) reported the LLWR as a parameter of quality index. Therefore correlation between Si and the LLWR is reasonable. Available water had a negative correlation with PR at $P<0.01$ (Table 2). With increasing PR, the soil structure is degraded and porosity is decreased and as a result of this, available water is decreased as well.

The Relation between Si Index and Soil Properties

The results showed that the Si index had a significant correlation with organic matter, SAR, LLWR, AW, and PR at $P<0.01$ and with clay content, bulk density, and ECe at $P<0.05$. In addition, the relationship between Si index and clay content, bulk density, SAR, ECe, and PR was negative whereas its relation with organic matter, LLWR, and AW was positive (Table3). Dexter (2004) and Emami et al (2008) found that Si index decreased with increasing clay content. An increase in clay content causes the ratio of textural to structural pores to increase, thereby decreasing the slope of retention curve at inflection point (Si index). In compacted soils, the preferential loss of the

Table 3. The correlation coefficient (r) between Si index and some soil properties (n=70).

Soil Properties	Correlation coefficient (r)	Soil Properties	Correlation coefficient (r)
Clay percent	-0.265^{*}	Organic matter	0.364^{**}
Silt percent	0.118^{ns}	Lime percent	0.211^{ns}
Sand percent	0.069^{ns}	SAR	-0.356^{**}
Bulk density	-0.239^{*}	EC_e	-0.272^{*}
PR	-0.593^{**}	θ_s (cm^3cm^{-3})	0.391^{**}
LLWR(cm^3cm^{-3})	0.542^{**}	Available water (cm^3cm^{-3})	0.523^{**}

**: significant at $P<0.01$, *: significant at $P<0.05$, ^{ns}: none-significant

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largest pores has the effect of changing pore size distribution and hence the water retention characteristics. Based on the results of our research, with increasing bulk density, Si index decreased (Table 3). Dexter (2004) studied the effect of compaction on Si index and concluded that the value of Si index decreased with increasing density. The high sodium absorption ratio (SAR) **c**auses degradation of soil structure, thereby decreasing Si index. Dexter (2004) studied different values of exchangeable sodium percentage (ESP) and found that the Si index decreases with increasing the ESP. Our results showed that there was a positive relation between organic matter and Si index. The organic matter helps to improve aggregate stability and structure formation, so that with increasing organic matter, Si index increases. The use of systems of land management that lead to greater contents of organic matter in soils also results in higher values of soil physical quality as measured by Si index (Dexter 2004). Emami et al. (2008) also reported similar results in their research. In addition, Si index had a positive relation with the LLWR and AW.

As cited earlier, the LLWR is regarded as an index of soil structure for crop yield (DA Silva et al., 1994), and we demonstrated that there is a positive correlation between Si index and the LLWR. Available water had a positive correlation with Si index at $P<0.01$ as well (Table 3). With increasing Si index, soil structure was formed and its stability and porosity increased, resulting in an increase in available water.

CONCLUSION

In order to assess soil quality or sustainability, the slope of retention curve at its inflection point, penetration resistance, the least limiting water range, and available water content were determined. The relationships between Si index and PR, LLWR, AWC, and soil physical properties were studied. Significant correlations between Si index and soil physical properties and other soil physical indicators i.e., PR, LLWR, and AWC demonstrated that Si index can be considered as an index of soil physical quality. Si index is a measure of soil micro-structure that controls many key soil properties. The Si index provides a tool that can be used to compare different soils or the effects of different management practices on soil physical properties.

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رابطه بین بعضی از شاخص‌های کیفیت خاک در خاک‌های مختلف کشاورزی منطقه ورامین، ایران

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چکیده

کیفیت خاک یکی از شاخص‌های ضروری برای مدیریت اراضی است. شاخص‌های مختلفی برای ارزیابی کیفیت خاک سیستم‌های زراعی، نوع خاک و کاربری اراضی ارائه شده اند. شیب منحنی رطوبتی در نقطه عطف آن (Si) به‌عنوان شاخص کیفیت فیزیکی خاک تعریف شده است و تاکنون رابطه بین شاخص کیفیت فیزیکی خاک (Si) با مقاومت فروری (PR)، دامنه رطوبت با کمترین محدودیت (LLWR) و مقدار آب قابل استفاده گیاه (AWC) بررسی نشده است. در این تحقیق ۱) تاثیر ویژگی‌های فیزیکی خاک بر PR و شاخص Si و۲) رابطه بین شاخص Si و LLWR، PR و AWCبررسی شد. بدین منظور ۷۰ نمونه خاک دست‌نخورده جمع‌آوری و شاخص Si برای هر نمونه با استفاده از داده‌های منحنی رطوبتی تعیین شد. علاوه بر این PR در خاک سطحی اندازه‌گیری و LLWR و AWC نیز برای هر نمونه محاسبه شدند. نتایج نشان داد که همبستگی PR با مقدار آب، هدایت الکتریکی عصاره اشباع خاک (ECe)، نسبت جذب سدیم (SAR) و شاخص Si در سطح یک درصد معنی‌دار بود، اما همبستگی آن با جرم مخصوص ظاهری (ρb) و ماده آلی (OM) در سطح پنج درصد معنی‌دار بود. همچنین رابطه منفی بین PR با AWC مشاهده شد ($P<0.01$). علاوه بر این همبستگی مثبت بین شاخص Si وLLWR و همبستگی منفی بین PR و LLWR در خاک‌های مورد مطالعه نشان داده شد ($P<0.01$). بنابراین شاخص Si ابزاری را برای مقایسه خاک‌های مختلف یا تاثیر عملیات مدیریتی مختلف بر ویژگی‌های فیزیکی خاک فراهم می‌کند.

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