J.Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 9 (4): 173 – 181 , 2018

Soil Shrinkage, Sealing Index and Hydro-Physical Properties of Vertisols as Influenced by Long-Term Cultivation Systems in Northern Egypt

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ABSTRACT

Soil shrinkage and sealing index are important for understanding water and solute transport in soils. Effects of long-term cultivation systems on the soil shrinkage, sealing and hydro-physical properties of Vertisols in Kafr El-Sheikh Governorate, Northern Egypt were studied. The cultivation systems were fruit trees (FT), field crops (FC), vegetables crops (VC), and non-cultivated soil (NC). Forty eight samples were collected from sixteen soil profiles (three layers: 0-30, 30-60 and 60-100 cm) from different locations. The studied parameters included coefficient of linear extensibility (COLE), shrinkage ratio (SR), potential linear extensibility (PLE), soil sealing index (SI), bulk density (BD), penetration resistance (PR), saturated hydraulic conductivity (Ks) and soil water content (SWC). Long-term cultivation improved soil shrinkage, sealing and hydro-physical properties. Soil organic matter (SOM) and silt + clay contents increased in VC and FC compared with FT and NC systems in all layers ($p < 0.05$). The BD and PR decreased in all systems, and in VC and FC systems it was prominent compared with NC system. Ks and SWC increased ($p <0.05$) under VC and FC than in NC system. Low COLE, SR and PLE occurred in all systems particularly in VC and FC system. The VC and FC reduced shrinkage hazards, while high COLE, SR and PLE occurred in NC, indicating shrinkage hazards. The SI was significantly ($p <0.05$) affected by cultivation systems and sealing was low in soils of VC, FC and FT than NC. Each of COLE, SR and PLE showed a negative correlation ($p < 0.01$) with SOM, but a positive one with BD and PR ($p < 0.01$). Each of COLE and SR ($p < 0.05$) and PLE ($p < 0.01$) showed negative correlations with SWC and Ks. SI showed a negative correlation with each of COLE, SR, BD and PR ($p < 0.01$) and PLE ($p < 0.05$), and a positive one with SWC and Ks ($p < 0.05$). VC and FC improved the soil shrinkage, sealing index and hydro-physical properties of Vertisols.

Keywords: Shrinkage properties; Sealing index; Hydro-physical properties; Cultivation systems; Vertisols

INTRODUCTION

Egypt is located in arid and sub arid region, where it's the climate is characterized by hot dry summer and mild winter (Fayed and Rateb, 2013). The alluvial soils of the Nile Delta are characterized by cracks under dry conditions (Ghabour *et al.* 2002). Soil texture varies from silty clay loam, clay loam to clay. Soil structure varies from granular in the surface layers to blocky in the subsurface layers with distinct slickensides (Kotb *et al.* 2005).Vertisols are large shrinkage soils (Pal *et al.* 2012), and the magnitude of the shrinkage is largely determined by the amount and nature of the clay contents (Brierley *et al.* 2011). Vertisols have poor physical properties including wide deep cracks, high bulk density, low hydraulic conductivity and narrow range of moisture for field operation (Ghabour *et al.* 2002). Low soil organic matter in Vertisols is one of the major reasons for the deterioration of soil health resulting in low and unsustainable productivity of crop (Onweremaadu *et al.* 2007; Moustakas, 2012; Ito and Azam, 2013).

Cultivation systems and management practices can change soil properties (Fayed and Rateb, 2013). Proper land use and management improve soil characteristic, reducing its degradation and achieving agricultural sustainability (Kalhoro *et al.* 2017). Humberto *et al.* (2009) who concluded that cultivation systems affected soil hydro-physical properties after 33 years of cultivation system. Singh *et al.* (2009) reported changes in soil organic carbon and bulk density after a period of 30 years of field crops. After 16 years of planting decreases in soil bulk density and increases in porosity and soil aggregates were reported by Shreenivas *et al.* (2010) and Kalhoro *et al.* (2017). Cultivation systems affect soil quality, water holding capacity, hydraulic properties, bulk density, porosity, penetrability, aggregation and soil shrinkage properties (Horel *et al.* 2015).

Soil shrinkage is caused when loss of moisture in soil decreases its height by subsidence (Dorner *et al.* 2013). During evaporation, shrinkage can be divided into various phases (Bronswijk, 1991): The first; structural shrinkage, when loss of water due to draining of macropores is larger than the volume changes, so that the soil structure behaves stable. Normal shrinkage (also known as proportional shrinkage), is where the volume change caused by shrinkage is proportional to water loss (Flowers and Lal, 1999). Residual shrinkage is when loss of water volume is greater than the total decrease in volume. In the final phase, zero shrinkage, the volume does not decrease any further and a small amount of water evaporates (Moei, 2016).

Shrinkage which accompanies a reduction in water content is an important soil property affecting the economics of the irrigation water, especially in Vertisols in north Egypt (Ghabour *et al.* 2002). Swelling and shrinkage which accompany wetting and drying is important, since it is by this process that soils, particularly clay soils, are physically reconditioned (Huang *et al.* 2011 and Zaffar *et al.* 2014). In arable soils, cracking may be either beneficial in promoting aeration to plant roots; increasing the capability of the soil to absorb water, and to exchange gases with the atmosphere, or harmful in cutting plant root and allowing extreme drying (Moustakas, 2012). Subsequent wetting cause's soil to swell because of entrapped air and heterogeneous nature of the wetting process and this causes larger structural units of the soil mass to break apart (Ito and Azam, 2013). This increases porosity and improves soil tilth. Therefore, evaluation of factors governing soil shrinkage is useful in assessing arable sustainability (Stewart, *et al.* 2016).

Dynamics soil of shrinkage is essential for prediction of water and solute transport (Lu *et al.* 2014). The coefficient of linear extensibility (COLE) is the dimensional length change of a soil body between two moisture contents. Most soils change volume with change in water content. COLE is used to measure the shrink-swell capacity of soil (Malik *et al.* 2017). Shrinkage ratio (SR) is the ratio of a given volume change to the corresponding change in water content. Potential linear extensibility (PLE) represents the integration of coefficient of linear extensibility for one meter of soil (Lu *et al.* 2014). Soil sealing index (SI) controls water movement and retention and determine the amount of water stored in soil (Barthes and Roose, 2002). Soil properties affecting soil sealing are texture, organic matter and structure (Udom and Kamalu, 2016). Soil properties like bulk density (BD), penetration resistance (PR), saturated hydraulic conductivity (Ks) and soil water content (SWC) are widely used as soil quality indicators for the assessment of agricultural systems and soil physical degradation (Fernandez-Galvez *et al.* 2012 and Moncada *et al.* 2014). The current study aims at assessing the long-term effect of cultivation systems (fruit trees, field crops and vegetables crops) on soil shrinkage properties, sealing index and hydro-physical properties of Vertisols in Northern Egypt.

MATERIALS AND METHODS

1. Study Site:

The study area is located in Kafr El-Sheikh Governorate at the Northern Egypt (Longitudes 30° 28′ 0″ to 30° 50′ 0″ E and latitudes 31° 00′ 0″ and 31° 30′ 0″ N). It covers 1335.17 km^2 (about 133517 ha). The climate is arid to semi-arid with hot dry summer, mild winter, high evaporation and moderately to high relative humidity. The maximum temperature is 36°C and the minimum temperature is 16°C with an average of 25°C. Mean annual rainfall is 135 to 255 mm. Wind is generally western and north westerly. The average annual wind speed is 12 km/h. Agriculture depends mainly on surface irrigation with River Nile water (Fig.1).

2. Cultivation Systems:

The studied cultivation systems included: fruit trees (FT), i.e. orange, fig, lemon and guava for the last 20 years; field crops (FC), i.e. wheat, clover, maize, cotton, rice and sugar beet for the more than 20 years; vegetable crops (VC), i.e. carrots, onion, eggplant, pepper, tomato, and potato for the more than 20 years and non-cultivated soils (NC), this soil have no cultivation and has not been undergone any tillage for the last 13 years (bare soils since 2005).

3. Soil Sampling and Measurements:

Sixteen soil profiles were dug in the studied area; each cultivation system was represented by four profiles. A total of 48 soil samples were collected from three layers; surface (0 to 30 cm), subsurface (30 to 60 cm), and deep (60 to 100 cm). For soil shrinkage properties the soil were sampled by metal cylinders (Fig. 2) which with bottoms having small holes. During transport, the cylinders with their soils were sealed airproof to avoid evaporation; the subsequently saturated from the bottom by soaking in a tray filled with water with a level just below the top of the soil. After the soil was dried by oven, the volume was measured regularly (Huang *et al.* 2011).

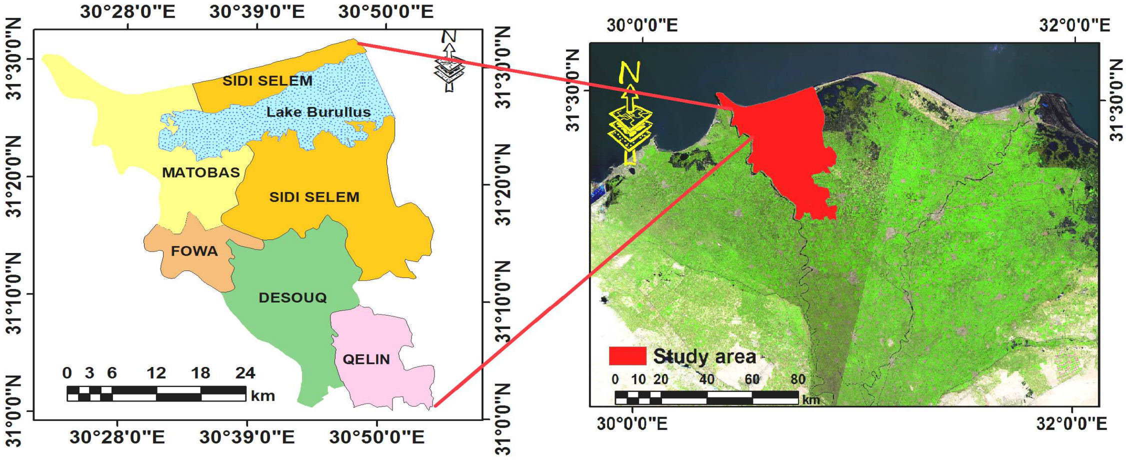

Fig. 1. Geographical location of the studied area

Fig. 2. A metal cylinder used for measure soil shrinkage

Measurement of coefficient of linear extensibility (COLE) was according to the following equation:

$$COLE = \left(\frac{Vm}{Vd} \right)^{1/3} - 1$$

Where: Vm **is the volume of saturation and** Vd **is the volume of drying**

COLE of < 0.03 is low, 0.03 - 0.06 is moderate, 0.06 - 0.09 is high and > 0.09 is very high (Parker *et al*. 1982).

Shrinkage ratio (SR) was obtained using the equation used by Liu and Eveet (1984) as follows:

$$SR = \frac{(\Delta v / vo)}{(\Delta \omega / \omega o)}$$

Where: ΔV **is the soil volume change (cm^3),** Vo **is the volume of oven - dried soil (cm^3),** $\Delta \omega$ **is the change in water content (gm) and** ωo **is the weight of oven - dried soil (gm).**

Potential linear extensibility (PLE) with COLE as shrinkage index of layer (0 to 100 cm) was obtained using the method of Reeve *et al*. (1980) as follows:

$$PLE_m\ (cm) = (COLE)_1\ (H_1) + (COLE)_2\ (H_2) + (COLE)_3\ (H_3) + ...$$

Where: ***PLE*** **is the sum of** ***COLE*** **values for successive layers from, the surface, to 1.0 meter depth, and** H_n **are the thickness of those layers in cm.**

Soil sealing index (*SI*) was determined using the Van der Watt and Claasens method (1990) as follows:

$$SI = \frac{SOM}{C+S} \times 100$$

Where: SOM **is the soil organic matter (%),** C **is the clay content (%), and** S **is the silt content (%).**

The SI value ≤ 5% is of high crusting or sealing risk, while 9% is low sealing risk and 7% is a threshold.

Saturated hydraulic conductivity (*Ks*) was calculated by rearranging Darcy's equation for constant head condition as below (Klute, 1986);

$$Ks = \frac{V \times L}{A \times T \times H}$$

Where V **is the volume of water collected at steady state (mL),** L **is the length of the soil sample (cm),** A **is the cross sectional area (cm^2),** T **is the time (h) and** H **is the hydraulic head difference (cm).**

Soil water content (SWC) was calculated as (Klute, 1986);

$$SWC = \frac{Mw - Md}{Md}$$

Where; Mw **is mass of wet soil and** Md **is mass of dry soil.**

Soil bulk density (BD) was determined on undisturbed soil samples using a steel cylinder of 100 cm^3 volume (Nimmo and Perkins, 2002). Soil penetration resistance (PR) was measured by penetrometer, and readings were taken when soil was at field water capacity. Soil PR is expressed in kg/cm^2 and converted to MPa where 100 kg/cm^2 = 9.80 MPa (Quang *et al*. 2012).

Particle size distribution was determined by the pipette method (Kroetsch and Wang, 2007). Soil organic matter was determined by the Walkley and Black method (Nelson and Sommers, 1996).

4. Statistical analysis:

Data were all statistically analyzed using analysis of variance (ANOVA) at a 0.05 level. Pearson's correlation coefficient was applied and significant differences among data were determined at $p < 0.05$ and $p < 0.01$. The statistical analysis was conducted using SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

1. Soil organic matter and texture:

Results in Table (1) show that cultivation systems had a significant effect on SOM (P < 0.05) in all layers, and the highest values related to soils of VC. In the surface layer (0-30 cm), increases of 56.43, 31.12 and 12.59% were in VC, FC and FT, respectively compared with NC. In the subsurface layer, the corresponding increases were 77.47, 51.81 and 11.22% for VC, FC and TC, respectively. Pronounced increases were in the VC in the deep layers, where SOM increase was 2.54 folds compared with NC. For the FC and TC, the corresponding increases were 1.98 and 1.62 folds, respectively. Generally, SOM at surface layer was higher than at subsurface and deep layers. This may be due to manure application in VC than in FC and FT. Plant residues accumulation is higher in soils cultivated with vegetables than other soils (John *et al.* 2005). High content of fine fractions in soils cultivated with vegetables favors organic matter accumulation (Brock *et al.* 2011; Fayed and Rateb, 2013; Udom and Kamalu, 2016).

Table 1. Soil organic matter (SOM) and soil texture with cultivation systems

Soil layers (cm)	Cultivation Systems	SOM g kg^{-1}	Sand %	Silt %	Clay %	Silt+ Clay %	Texture (USDA)
Surface layer (0-30 cm)	FT	22.90bc	28.70a	38.20ab	33.10b	71.30b	Clay loam
	FC	26.67b	25.55b	41.50a	32.95b	74.45a	Clay loam
	VC	31.80a	23.14bc	41.43a	35.43ab	76.86a	Clay loam
	NC	20.34c	30.81a	30.67c	38.52a	69.19c	Clay loam
	Mean	25.42	27.05	37.95	35.00	72.95	-
Subsurface layer (30- 60 cm)	FT	11.70b	27.65ab	35.92ab	36.43bc	72.35b	Clay loam
	FC	15.97a	20.58b	30.78b	48.64a	79.42a	Clay
	VC	18.67a	19.52c	40.94a	39.54ab	80.48a	Silty clay loam
	NC	10.52bc	30.54a	29.65c	39.81ab	69.46c	Clay loam
	Mean	14.21	24.57	34.32	41.10	75.42	-
Deep layer (60- 100 cm)	FT	9.70b	26.44b	44.65a	28.91c	73.56b	Clay loam
	FC	11.87ab	28.41a	20.14c	51.45a	71.59b	Clay
	VC	15.21a	22.58c	35.59ab	41.83b	77.42a	Clay
	NC	5.98c	30.76a	30.01b	39.23b	69.24bc	Clay loam
	Mean	10.69	27.04	32.59	40.35	73.56	-

Note: FT is fruit trees, FC is field crops, VC is vegetables crops and NC is non-cultivated soil. Values followed by the same letter within a column in dictate no significant difference at 0.05 level

Long-term of cultivation systems had varying ($p < 0.05$) effects on soil texture as shown in Table 1. Silt + clay content were higher in the soil VC than other soil FC and FT in all soil layers ($p < 0.05$). The average silt + clay content were significantly higher in the subsurface than the surface and deep layers. The subsurface layer (30- 60 cm) has highest clay content compared with the surface or deep layer. Soil was fine through the entire layers with high clay and silt contents. Texture ranges from clay, silty clay loam and clay loam, and variations were relatively slight (Udom and Kamalu, 2016), probably due to migration of fine particles from surface layer to the subsurface layers (Risikesh *et al*. 2011). Soils VC and FC have higher content of fine particles than FT in the surface layer; probably due to application of organic manure for vegetables (Kalhoro *et al*. 2017).

2. Soil bulk density and penetration resistance:

The BD was lower ($p < 0.05$) in VC soil than NC soil in all layers (Table 2). In surface layer, the BD decreased in soils of VC and FC by 14.38% and 11.51%, respectively when compared with NC. The BD decreased in VC soil in subsurface layer (14.48%) than soil of FC (8.96 %) and soil of FT (6.89 %). At deep layer, BD in the NC soil was 1.52 Mg m^{-3} and in FT soil it was 1.46 Mg m^{-3} greater than in FC soil (1.44 Mg m^{-3}) or VC soil (1.39 Mg m^{-3}). The BD at surface and subsurface layers was lower than in deep layer. The VC soils have lower bulk density than the FT and NC soils. The PR was affected by cultivation systems ($p < 0.05$) and the lowest values were in VC and FC soils. In the surface layer, comparison with NC soil, show that in VC soil PR was lower by 30.28%, and FC soil was lower by 22.86%. In the depth 30-60 cm, the lowest PR of 1.92 MPa was in VC soil and 2.13MPa in FC soil and 2.29 MPa in FT soil. The average soil PR was lower in the surface layer than subsurface layers. Highest PR was in NC soil, followed by FT, FC and VC soils. Soil BD and PR are affected by soil texture, organic matter and cultivation practices (Saha and Kukal, 2015). The low BD and PR in surface layers may be a result of plowing effect, as well as the relatively high organic matter content (Lu *et al*. 2014).

Table 2. Soil bulk density (BD), penetration resistance (PR), saturated hydraulic conductivity (Ks) and soil water content (SWC) with cultivation systems

Soil layers (cm)	Cultivation Systems	BD Mg m^{-3}	PR MPa	Ks cm/h	SWC g g^{-1}
Surface layer (0-30 cm)	FT	1.24b	1.47b	0.51b	0.32ab
	FC	1.23b	1.35bc	0.65ab	0.33a
	VC	1.19c	1.22c	0.73a	0.35a
	NC	1.39a	1.75a	0.43c	0.29b
	Mean	1.26	1.44	0.58	0.32
Subsurface layer (30- 60 cm)	FT	1.35b	2.29b	0.45bc	0.30b
	FC	1.32bc	2.13c	0.53b	0.32ab
	VC	1.24c	1.92c	0.62a	0.34a
	NC	1.45a	2.40a	0.40c	0.27c
	Mean	1.34	2.18	0.50	0.30
Deep layer (60- 100 cm)	FT	1. 46ab	2.56b	0.43b	0.29b
	FC	1.44b	2.44bc	0.50a	0.30ab
	VC	1.39c	2.35c	0.53a	0.32a
	NC	1.52a	2.85a	0.38c	0.24c
	Mean	1.45	2.55	0.46	0.28

Note: FT is fruit trees, FC is field crops, VC is vegetables crops and NC is non-cultivated soil. Values followed by the same letter within a column in dictate no significant difference at 0.05 level

3. Soil saturated hydraulic conductivity and water content:

Saturated hydraulic conductivity (Ks) was higher in VC than in NC soil ($p < 0.05$). The Ks was higher in the surface layer than subsurface and deep layers (Table 2). The highest Ks (0.73 cm/ h) occurred in the surface layer of VC soils. In the subsurface layer, there was a 55% increase in VC soil than in NC soil; relative higher values for FC and FT were 32.5 % and 12.5%, respectively. Values in VC in deep layer, was also higher. Soil water content (SWC) was significantly ($p < 0.05$) affected by cultivation systems, and the highest value was in VC soil (Table 2). The SWC in VC soil in surface layer was 0.35 g g^{-1} than in FC soil (0.33 g g^{-1}) and FT soil (0.32 g g^{-1}) compared with NC soil (0.29 g g^{-1}). In the subsurface layer, VC showed higher (25.9 %) than NC soil, while in FC soil SWC was higher (18.5 %). The VC and FC soils showed high SWC at the 60-100 cm depth. The SWC was higher in the 0- 30 cm than in 30-60 cm and 60-100cm. Therefore surface layers of VC soil showed higher Ks and SWC values compared with FC and FT soils. Such an increase in Ks and SWC may be a result of plowing as well as organic matter (Udom and Nuga, 2014; Saha and Kukal, 2015).

4. Soil sealing index:

The soils in general showed a high crusting or sealing risk in all cultivation systems (Van der Watt and Classens, 1990). This is due to the low organic matter content (Udom and Adesodun, 2016; Udom and Kamalu, 2016). Soil sealing index (SI) was affected by cultivation systems ($p < 0.05$). The SI was lower in VC soil than in NC soil (Fig. 3). In surface layer, SI was lower in VC and FC soils (37.5% and 22.2%, respectively) compared with NC soil. The SI was decreased in VC soil in subsurface layer (33.3%), compared with FC soil (16%). In deep layer, SI was higher in the NC and FT than in FC and VC.

5. Soil shrinkage properties:

Coefficient of linear extensibility (COLE) was significantly ($p < 0.05$) affected by cultivation systems

(Fig. 4) and values were lower in VC soil, compared with NC soil. In the surface layer, COLE was lower in VC soil (29.16%) than NC soil. FC lower values were also in (26.38 %), and FT (22.22 %). The COLE values in subsurface layer were lower in VC (0.061) than FC (0.064) and soil FT (0.069) compared with NC (0.085). The VC and FC soils also showed low values in 60-100 cm. The COLE was lower in the 0-30 cm than in the 30-60 cm and 60-100cm. According to Parker *et al.* (1982), COLE was moderate in cultivated soils, compared with the non- cultivated soil. Subsurface soil COLE was high in cultivation systems, as in Fig. 4. In the deep layer, COLE was high in cultivation systems.

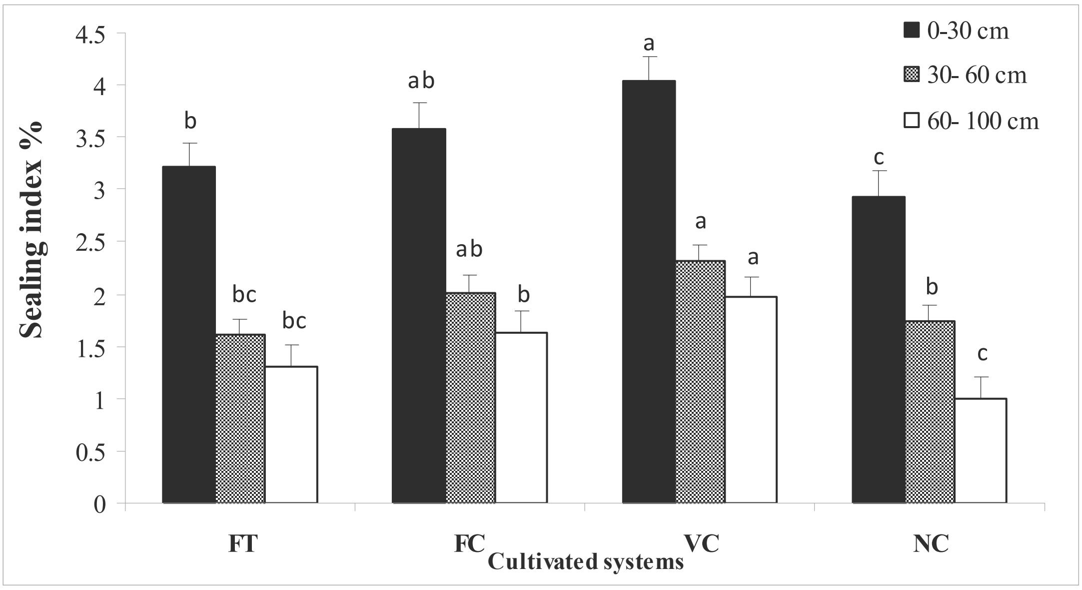

Fig. 3. Soil sealing index (SI) with cultivation systems (FT is fruit trees, FC is field crops, VC is vegetables crops and NC is non-cultivated soil). Vertical bars indicate mean ±1 standard error.

Shrinkage ratio (SR) was lower in the VC than other FC and FT soils (Fig. 5). The SR was lower in VC soil in surface layer (1.130) than FC (1.134) and soil FT soils (1.137) compared with NC soil (1.140). In subsurface layer, the VC and FC soils showed lower in SR, compared with NC. The average SR was lower in the surface layer (1.135) than subsurface layer (1.147) and deep layer (1.163). The potential linear extensibility (PLE) was significantly affected by cultivation systems ($p < 0.05$) and the lowest was in soils VC and FC (Fig. 6). High values in NC soil (8.67) and FT soil (7.03) than FC (6.63) and VC (6.28). The PLE was low in soil VC in all layers.

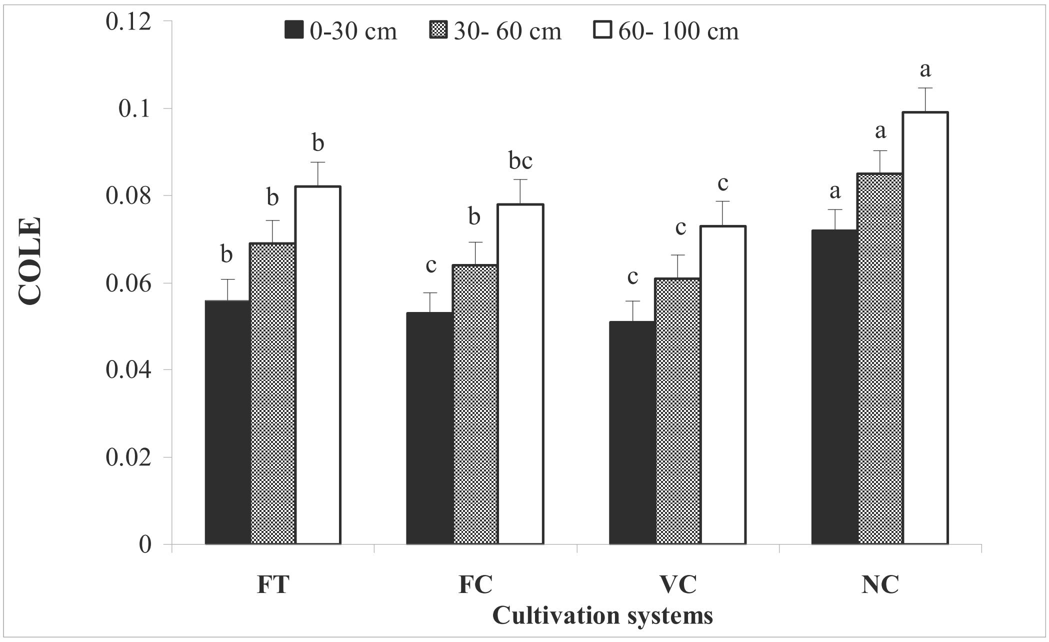

Fig. 4. Coefficient of linear extensibility (COLE) with cultivation systems (FT is fruit trees, FC is field crops, VC is vegetables crops and NC is non-cultivated soil). Vertical bars indicate mean ±1 standard error

The COLE, SR and PLE are important for agriculture, plant root penetration and behavior with cultivation systems (Hemmat *et al.* 2010; Aksakal *et al.* 2013). The high values of COLE, SR and PLE were in

NC soil indicating shrinkage hazards. The VC and FC soils had low shrinkage hazards by altering the total volume reduction associated with clay content or change in clay minerals responsible for the COLE, SR and PLE (Lu *et al*. 2014 ; Malik *et al*. 2017). Organic matter improves linear shrinkage of clayey soil (Manukaji, 2013; Abd El Halim and El Baroudy, 2014).

Roots are affected by cracking, thus they are affected by COLE, SR and PLE. Plant roots may have large effects on COLE, SR and PLE rates throughout which they occur. COLE, SR and PLE may change depending on the cropping pattern (Mitchell and Genuchten, 1991). Battikhi and Suleiman (1999) found that tillage decreases soil shrinkage properties in Vertisols. Because of restrictions on shrinkage imposed by factors such as climate, crops, ground water and moisture release characteristics of soils, soils with a high PLE may not behave very differently to soils with a much lower potential. The reduction in the COLE, SR and PLE in cultivated soil (VC, FC and FT) represented the reduction of shrinkage in the Vertisols and was probably due to two processes in cultivated soils. The first process includes the interchanging of swelling clay with non-swelling materials content. The second one involved resistance in the swelling which depends on the clay-carbon contact and effective clay-carbon particles contact as described by Lu *et al*. (2014). Low COLE, SR and PLE in cultivated soils is a required property in case of Vertisols to avoid formation of bigger cracks which affect the root formation leading to erosion and high water evaporation (Malik *et al*. 2017).

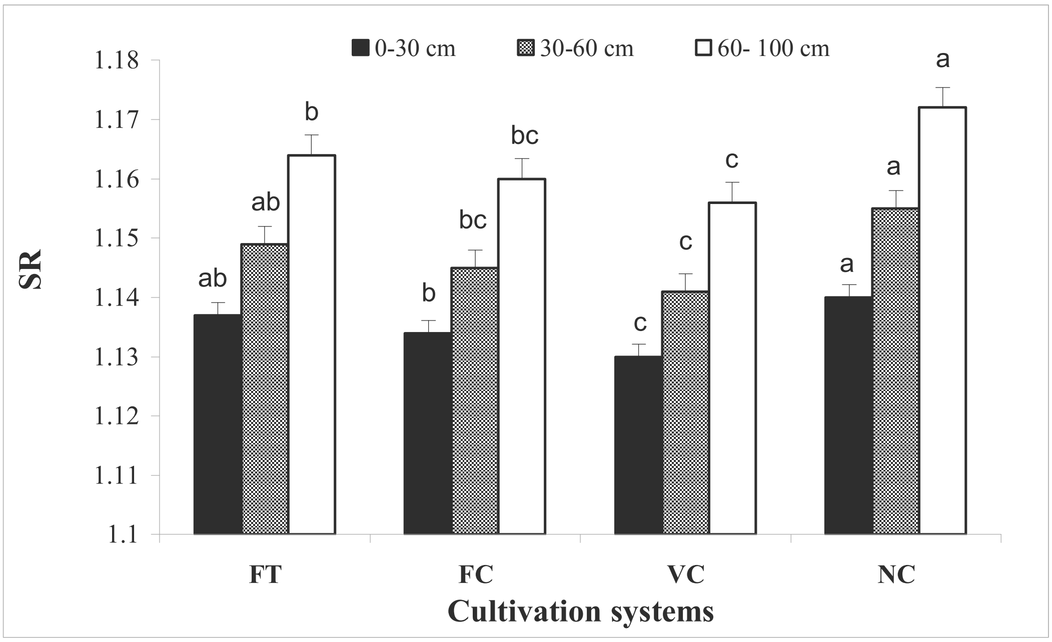

Fig. 5. Shrinkage ratio (SR) with cultivation systems (FT is fruit trees, FC is field crops, VC is vegetables crops and NC is non-cultivated soil). Vertical bars indicate mean ±1 standard error

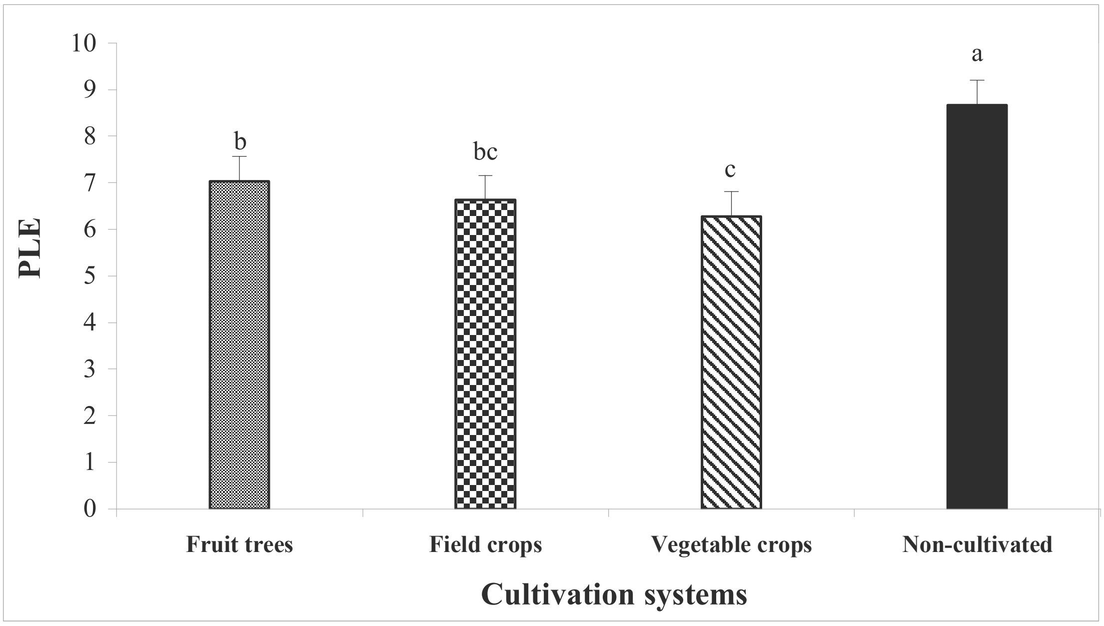

Fig. 6. Potential linear extensibility (PLE) with cultivation systems. Vertical bars indicate mean ±1 standard error

6. Relationships among soil shrinkage, sealing index and hydro-physical properties:

A highly significant correlation ($p < 0.01$) occurred among the SOM and COLE, SR, PLE, SI, BD, PR, Ks and SWC (Table 3). The COLE, SR and PLE showed a negative correlation ($p < 0.01$) with SOM, but a positive correlation with BD and PR ($p < 0.01$), which indicate that organic matter caused a decrease in COLE, SR and PLE. There was also a significant COLE and SR ($p < 0.05$) and PLE ($p < 0.01$) negative correlation with SWC and Ks. On the other hand, soil SI showed negative correlations with COLE and SR ($p < 0.01$) and PLE ($p < 0.05$). There were negative correlations between SI, and BD and PR ($p < 0.01$), but positive correlations with SWC and Ks ($p < 0.05$), and SOM ($p < 0.01$). High organic matter content reduces soil sealing. There was also significant BD ($p < 0.01$) negative correlation with SWC, Ks and SOM and a positive correlation with soil PR ($p < 0.01$). On the other hand, soil PR showed negative correlation with SWC and Ks ($p < 0.05$), and SOM ($p < 0.01$), which indicate that organic matter decreased BD and PR and improved soil structure. The SWC and Ks showed a positive correlation ($p < 0.01$) with SOM, which indicates that organic matter increased SWC and KS and improved soil water flow. The stability of soil shrinkage is associated with the composition of soil organic matter, tillage practices and microbial activities (living and dead organisms, decomposable soil organic matter, and dead plant materials) in cultivated soils compared with non-cultivated soil (Malik *et al*. 2017; Kalhoro *et al*. 2017) .

Table 3. Pearson's correlation among soil organic matter, shrinkage, sealing index and hydro-physical properties

	COLE	SR	PLE	SI	BD	PR	SWC	Ks
COLE	1.00							
SR	0.82**	1.00						
PLE	0.89**	0.86**	1.00					
SI	-0.87**	-0.82**	-0.78*	1.00				
BD	0.88**	0.82**	0.88**	-0.83**	1.00			
PR	0.81**	0.86**	0.87**	-0.88**	0.82**	1.00		
SWC	-0.79*	-0.79*	-0.85**	0.71*	-0.90**	-0.72*	1.00	
Ks	-0.75*	-0.74*	-0.80**	0.76*	-0.84**	-0.76*	0.89**	1.00
SOM	-0.89**	-0.85**	-0.81**	0.88**	-0.88**	-0.87**	0.80**	0.84**

Note: **Significant $p < 0.01$ and *Significant $p < 0.05$; COLE, coefficient of linear extensibility; SR, shrinkage ratio; PLE, potential linear extensibility; SI, sealing index; BD, bulk density; PR, penetration resistance ; Ks, saturated hydraulic conductivity , SWC, soil water content and SOM, soil organic matter.

CONCLUSION

The soils of VC and FC systems showed improvements in soil shrinkage, sealing index and hydro-physical properties of Vertisols. Highly significant effects on saturated hydraulic conductivity and soil water content were observed in VC and FC soils thus improved of soil water flow. Low bulk density and penetration resistance in VC and FC soils were associated with low soil compaction. In VC and FC soils showed low COLE, SR and PLE were low. The VC, FC and FT soils showed low sealing index, thence low sealing risk. Correlations indicated that all the properties, *i.e.,* COLE, SR, PLE, SI, BD, PR, Ks, SWC and SOM were significantly correlated with each other. Generally, COLE, SR, PLE, SI, BD, PR, Ks and SWC parameters of Vertisols were improved by cultivation systems, particularly soils cultivated with vegetables and field crops.

ACKNOWLEDGEMENT

The author expresses his grateful to Prof. Dr. Ali Abdel Salam, Soil and Water Department, Faculty of Agriculture, Benha University, Egypt for his valuable comments.

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انكماش التربة ودليل التلاصق والخواص الهيدروفيزيائية لأراضي Vertisols متأثرة بنظم الزراعة طويلة الأجل في شمال مصر

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انكماش التربة ودليل التلاصق مهمان لفهم نقل الماء والمذيبات في التربة. الهدف من الدراسة معرفة تأثير نظم الزراعة طويلة الأجل على انكماش التربة ، دليل التلاصق والخواص الهيدروفيزيائية لأراضي Vertisols. نظم الزراعة عبارة عن أشجار الفاكهة ، والمحاصيل الحقلية ، ومحاصيل الخضروات والتربة غير المزروعة (أرض بور). تم أخذ 48 عينة من 16 قطاعا ارضيا (ثلاث طبقات: السطحية من صفر الي 30 سم ، التحت سطحية من 30 الي 60 سم ، و العميقة من 60الي 100 سم) من مواقع مختلفة في محافظة كفر الشيخ ، شمال مصر. تمت دراسة مؤشرات الانكماش و التلاصق والخواص الهيدروفيزيائية (معامل التمدد الطولي ، نسبة الانكماش ، التمدد الخطي المحتمل ، دليل التلاصق ، الكثافة الظاهرية ، مقاومة الاختراق، التوصيل الهيدرولكي المشبع والمحتوى المائي للتربة). أظهرت النتائج أن نظم الزراعة على المدى الطويل حسنت من انكماش التربة ، دليل التلاصق والخواص الهيدروفيزيائية. زاد محتوي المادة العضوية و الطين + السلت في أنظمة زراعة الخضروات والمحاصيل الحقلية بالمقارنة بالنظم الاخري في جميع الطبقات . أنخفضت الكثافة الظاهرية ومقاومة الاختراق وزاد التوصيل الهيدرولكي المشبع والمحتوى المائي للتربة مع نظم الزراعة. حدث انخفاض في مؤشرات الأنكماش في جميع النظم ولا سيما أنظمة زراعة الخضروات والمحاصيل الحقلية اللذان قلل من الانكماش بالمقارنة بالتربة الغير مزروعة التي تشير إلى مخاطر الانكماش .كان دليل التلاصق معنوياً ومتأثراً بنظم الزراعة وكان تلاصق التربة منخفضا مع نظم الزراعة . وقد أوضح الارتباط أن جميع الخصائص ترتبط ارتباطًا وثيقًا ببعضها البعض. عموما نظم زراعة الخضروات والمحاصيل الحقلية حسنت من انكماش التربة ، دليل التلاصق والخواص الهيدروفيزيائية لأراضي Vertisols.