J. Agric. Sci. Technol. (2005) Vol. 7: 59-68

Long Term Sugarcane Cultivation Effects on Physical Properties of Fine Textured Soils

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ABSTRACT

Long term sugarcane cultivation can alter soil physical properties. The objective of this study was to determine the effects of 38 years of sugarcane (*Sacchrum officinarum* L.) cultivation on the physical properties of fine textured soils (Haplustepts and Calciustepts) in southwestern Iran. Six paired soil profiles (three pairs in each soil type) were dug along parallel transects (100 m apart) in a side-by-side comparison of areas cultivated and uncultivated with sugarcane. Composite and undisturbed soil samples from 0-30, 30-60 and 60-90 cm layers were taken for physical and chemical analysis. The results of this study revealed that long term sugarcane cultivation resulted in a higher bulk density, lower structural stability, and an increased proportion of fine pores. The decreased number of macropores together with decreased structural stability indicated the formation of a dense compacted layer at 30-60 cm in sugarcane cultivated soils.

Keywords: Sugarcane, Subsoil compaction, Thin section, Pore size distribution, Water characteristics curve.

INTRODUCTION

Commercial irrigated sugarcane cultivation in Khuzestan province in southwest Iran commenced in the late 1950's. Over the last 38 years, the annual cane yield has ranged from 50 to 110 Mg ha^{-1}. The use of heavy machinery during planting, harvesting and transporting operations in fine textured soils has led to the concern that subsoil compaction may decline long term productivity.

Hadas (1994) reviewed the theoretical analysis and experimental data on soil compaction under high axel load. He stated that subsoil compaction occurred under specific conditions, namely wet, homogenous, and deep soil under high contact pressure. Axel loads exceeding 90 kN m^{-3} increased subsoil compaction (Salire *et al.,* 1994). Subsoil compaction can cause serious root restriction (Tardieu, 1994; Westermann and Sojka, 1996; Håkansson *et al.,* 1996) and the loss of both transmission and water storage pores. These changes result in lower water infiltration due to the loss of transmission pores and higher soil water caused by the loss of storage pores (Soane *et al.,* 1982; Gupta *et al.,* 1987; Hadas, 1994; Lipiec *et al.,* 1998), that may consequently reduce nutrition uptake and crop yield (Hammel, 1994; Westermann and Sojka, 1996; Håkansson *et al.,* 1996; Grath and Arvidsson, 1997). Torres *et al.* (1990) reported a decrease in sugarcane rooting depth and crop yield as a result of subsoil compaction.

Different parameters and methods are used to characterize soil compactibility, suchas dry bulk density, vane shear strength, pore size distribution, gas and water diffusion,

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and morphological analysis (Hadas, 1994). Micromorphological studies were extensively used to characterize soil deformation (Jager *et al.,* 1983; Koppi *et al.,* 1992). Jager *et al.* (1983) indicated that macropores and mesopores were less frequent in plough pans as compared with other soil layers, whereas micropores were more common. However, little information is available on the micromorphology of compacted subsoil layers, particularly under sugarcane cultivation. In this paper, changes in soil physical properties related to compaction behavior of sugarcane cultivated soils (Haft-Tapeh) were identified and compared with nearby uncultivated soils.

METHODS AND MATERIALS

Soil Sampling and Analysis

This research was conducted on a commercial sugarcane plantation in Haft-Tapeh (32° 04´ N, 48° 21´ E), southwestern Iran. Prior to the planting of sugarcane in 1959, the site was under a wheat (*Triticum* sp.) base system. The area has a unimodal rainfall with a dry season from May to November and a rainy season from November to April. The mean annual rainfall of the area studied is 270 mm. Evaporation (Class A open pan) is about 2700 mm yr^{-1}. The mean annual temperature is 31.6° C. The soils are pedologically young and have been developed on transported sediments.

Six paired soil profiles (three in each soil type) were dug along parallel transects (100 m apart) in a side-by-side comparison of areas cultivated and uncultivated with sugarcane. The transects crossed two soil families: fine, mixed, hyperthermic Haplustepts and fine loamy, mixed, hyperthermic Calciustepts (Table 1). The uncultivated soils exist between the main drain and access road. These soils have not been cultivated for about four decades.

Twenty-four undisturbed soil cores were taken from 30-60 and 60-90 cm layers of soil profiles at farms 101, 102 and 103 (hereafter referred to as I, II and III, respectively) of the Haft-Tapeh sugarcane complex. Undisturbed soil samples were not taken from 0-30 cm because of heavy disturbance of this layer during plantation. The water content at sampling time (October, 1998) varied from 60% to 80% of the field capacity. The undisturbed soil samples were used to determine dry bulk density, water characteristic curves and structural stability. The water characteristics curves were determined on a pressure membrane apparatus, using three intact cores taken from each soil layer. Three measurements were made in each intact core. The pressures used were 10, 30, 50, 100, 1000 and 1500 kPa. The pore size distribution was calculated using the water characteristics curves (Jury and Horton, 2004) and the structural stability of 2-4 mm aggregates was determined by a method outlined in Barzegar *et al.* (1996). The aggregates were oven dried for 72 hours at 50° C. Five grams of the aggregates were then shaken with distilled water (25 mL) for

Table 1. Classification of soils (Soil Survey Staff, 1998; FAO/UNSCO, 1998).

Soil type	Family	Subgroup	FAO/UNSCO
$I_{SC}{}^{a}$	Fine, mixed, hyperthermic	Calciustepts	Calcic Cambisol
$I_{UC}{}^{b}$	Fine loamy, mixed, hyperthermic	Haploustepts	Utric Cambisol
II_{SC}	Fine loamy, mixed, hyperthermic	Haploustepts	Utric Cambisol
II_{UC}	Fine loamy, mixed, hyperthermic	Calciustepts	Calcic Cambisol
III_{SC}	Fine, mixed, hyperthermic	Haploustepts	Calcic Cambisol
III_{UC}	Fine loamy, mixed, hyperthermic	Haploustepts	Calcic Cambisol

[a] SC, sugarcane cultivated soils; [b] UC, uncultivated soils

5 minutes on an end-over-end shaker. The suspension was passed through sieves of 250µm with three additional washes of 50 mL of distilled water. The particles remaining on the sieves were oven dried at 105° C and weighed. The sand content of the macro aggregates (> 250µm) was also determined.

Composite soil samples from 0-30, 30-60 and 60-90 cm of each soil profile were used to measure chemical properties and particle size distribution. Organic matter content was determined by the dichromate oxidation method (Nelson and Sommers, 1982). The cation exchange capacity (CEC) was measured by a Na-saturation procedure (Rhoades, 1982a). Electrical conductivity of the saturation extract (ECe) and the pH of the saturated paste of soils were measured (Rhoades, 1982b). Particle size distribution was determined by the pipette method (Gee and Bauder, 1986).

Thin Sections

Thirty two samples were taken from 30-60 and 60-90 cm of paired profiles (four samples from each). Thin sections for study under a polarizing-light microscope were then prepared (Murphy, 1986). Undisturbed samples were impregnated with a polyester resin-acetone mixture under a partial vacuum. The resin permeated into the soil and set hard in about 48 hours. The surface was removed with a hard and soft grinder to expose a fresh, flat surface of resin-impregnated mixture. The samples were then sliced, smoothed and mounted on glass. The mounted blocks were also thinned and smoothed with a diamond-edge saw, lapping machine and corundum powder to reach a thickness of 25 to 30µm. The central faces of the 100mm×100mm area were photographed using a 35-mm camera fitted with a macrolens. Image analysis was carried out using a special program (Image tool) and various soil structural characteristics were evaluated. Although image analysis was used to analyze a two-dimensional picture, this process provides useful information about the complexity of pore patterns in soils, which could not be obtained with other methods, such as mercury intrusion, water retention, and nitrogen sorption (Bullock *et al.,* 1985). Thin sections were described using the manual written by Bullock *et al.* (1985).

Statistical Analysis

Student's *t* test was used for a paired comparison of cultivated and uncultivated soil samples. Least Significant Difference (LSD) values were calculated to compare pairs of mean values at either 5% or 1% levels of probability. The statistical analysis was performed using the SAS statistical package (SAS Institute, 1988).

RESULTS AND DISCUSSION

Physical and Chemical Properties of Soils

The physical and chemical characteristics of the soils are presented in Table 2. The soils under sugarcane (except the surface layer of soil II) had a higher clay ($P<0.05$) and lower sand ($P<0.05$) content compared to uncultivated soils. The differences in particle size could be due to deep tillage and subsoiling use for sugarcane cultivation. The organic carbon content of 0-30 cm of sugarcane cultivated soils was more than that of uncultivated soils ($P<0.01$); for other layers the difference was not significant. The cation exchange capacity (CEC) of sugarcane cultivated soils was higher at 0-30 and 30-60 cm than in uncultivated soils ($P<0.01$) due to differences in both organic matter and clay contents. Sugarcane cultivated soils had lower electrical conductivity and pH values as compared to uncultivated soils ($P<0.01$). Excess leaching of salts in sugarcane cultivated soils resulted in lower soil electrical conductivity. In salt-affected soils, leaching excess salts increases the pH of soils (Barzegar, 2000).

The bulk density of the 30-60 cm layer of sugarcane cultivated soils was higher than that of uncultivated soils ($P<0.01$). No difference was found among the bulk densities of the 60-90 cm layers. Heavy duty machinery and increasing numbers of passage of agricultural machinery over the long term result in subsoil compaction (Soane *et al.,* 1982; Håkansson *et al.,* 1996). However, the bulk density of the 0-30 cm layer of sugarcane cultivated soils was lower than that of uncultivated soils ($P<0.05$). This might be due to either cane residuals left after harvesting or soil disturbance after cultivation. Barzegar *et al.* (2000) investigated the influence of different amounts of sugarcane residue and soil water content on soil compactibility at different energy input levels. They indicated that sugarcane residue was effective in reducing soil compactibility at various soil water contents and compaction levels. These results differ from those reported by Hartemink (1998). He compared the physical and chemical properties of soils

Table 2. Physical and chemical characteristics of selected soil layers.

Soil type	Depth (cm)	Sand	Silt	Clay	O.C^{a}	BD^{b} (Mg m^{-3})	CEC^{c} (Cmol kg^{-1})	ECe^{d} (dS m^{-1})	pH
		(g kg^{-1})							
${}^{I}SC^{e}$	0-30	150	450	400	10.0	1.35	16.5	0.8	8.0
${}^{I}UC^{f}$	0-30	230	460	310	5.0	1.41	12.0	16.1	7.2
SL^{g}		*	ns	*	**	*	**	**	**
${}^{I}SC$	30-60	170	430	400	5.0	1.60	16.0	0.7	8.1
${}^{I}UC$	30-60	285	443	272	3.7	1.42	12.5	5.7	7.6
SL		**	ns	**	ns	**	**	**	**
${}^{I}SC$	60-90	160	490	350	3.5	1.50	14.0	0.5	8.0
${}^{I}UC$	60-90	270	455	275	2.0	1.50	12.3	7.1	7.6
SL		**	ns	*	ns	ns	ns	**	*
${}^{II}SC$	0-30	240	490	270	8.2	1.36	12.0	0.6	8.0
${}^{II}UC$	0-30	210	470	320	5.0	1.40	12.3	10.1	7.4
SL		ns	ns	ns	*	ns	ns	**	**
${}^{II}SC$	30-60	170	500	330	4.0	1.55	14.0	0.5	8.1
${}^{II}UC$	30-60	250	440	310	2.5	1.40	13.5	6.5	7.6
SL		*	*	ns	ns	**	ns	**	**
${}^{II}SC$	60-90	200	450	350	3.8	1.45	14.0	0.5	8.1
${}^{II}UC$	60-90	350	400	250	1.0	1.50	11.0	6.0	7.6
SL		*	*	**	*	ns	*	**	**
${}^{III}SC$	0-30	240	430	330	7.1	1.35	14.2	0.7	8.0
${}^{III}UC$	0-30	220	475	305	5.4	1.35	13.0	27.5	7.3
SL		ns	ns	ns	ns	ns	ns	**	**
${}^{III}SC$	30-60	120	485	395	4.5	1.60	16.0	0.5	8.1
${}^{III}UC$	30-60	320	509	171	3.4	1.42	9.5	13.8	7.6
SL		**	ns	**	ns	**	**	**	**
${}^{III}SC$	60-90	50	590	360	4.0	1.51	15.2	0.5	8.1
${}^{III}UC$	60-90	350	400	250	3.0	1.42	10.5	13.0	7.8
SL		**	**	**	ns	ns	**	**	ns

[a] O.C, organic carbon; [b]BD, bulk density; [c]CEC, cation exchange capacity; [d] ECe, electrical conductivity of saturated extract; [e]SC, sugarcane cultivated soil; *f* UC, uncultivated soils; [g] SL, significant level, ns not significant, * significant at 5%, and ** significant at 1%.

(Eutric and Mollic Fluvisols and Eutric Vertisols) with an average annual rainfall of 2000 mm under sugarcane and grassland, and indicated no significant differences between either the bulk density or infiltration rate of grassland and sugarcane rows. However, the interrow had a significantly higher bulk density and lower infiltration rate due to wheeled traffic. He also reported a decline in soil pH from 6.5 to 5.8 in sugarcane cultivated soils.

Pore Size Distribution

Figure 1 shows the water characteristics curves of soils. Water content at saturation of soils under sugarcane was about 10% higher than that of uncultivated soils. The decrease in soil matric potential from 0 (saturation) to -33 kPa (field capacity) was very gradual in the 30-60 cm layer of uncultivated soils compared to sugarcane cultivated soils, indicating the presence of large voids with different diameters. The differences were small in the 60-90 cm layer, indicating fewer effects of compaction on this layer. The reductions in the wet range (from 0 to -33 kPa) were similar in both sugarcane cultivated and uncultivated soils although the absolute values of water content at given water potential were different.

The pore size distribution calculated using water characteristics curves is illustrated in Figure 2. Results indicated a lower percentage of macropores (>9.3 µm diameter) in sugarcane cultivated soils. Pores with diameter of 9.3 to 29 µm in uncultivated soils were greater than sugarcane cultivated soils. The reduction in macroporosity suggests a reduction in aeration and water use efficiency. Few to common fine redoximorphic features in the 30-60 cm layer of sugarcane cultivated soils (revealed by studying the thin sections; Figure not shown) was also the result of different hydraulic conductivities

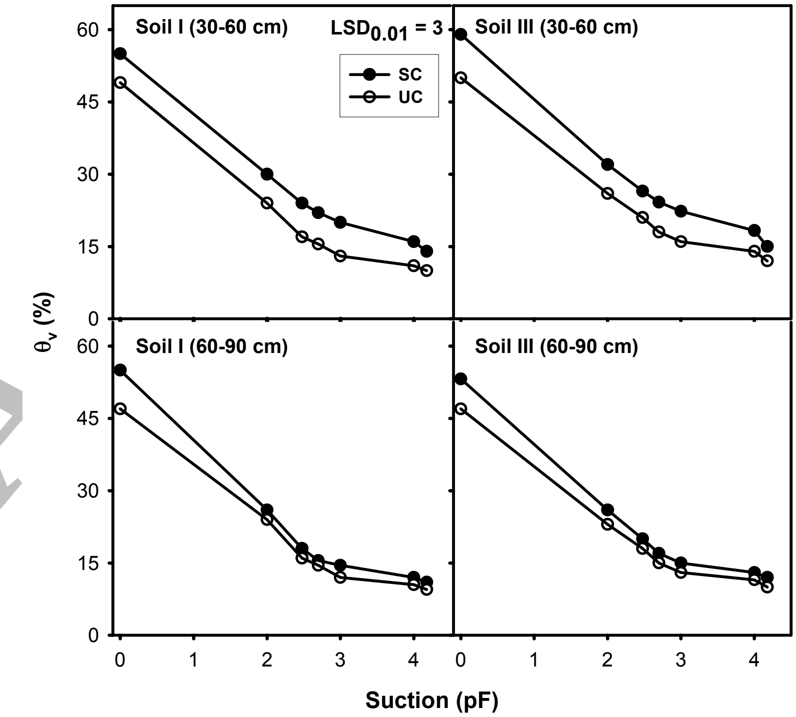

Figure 1. Water characteristics curves of 30-60 and 60-90 cm layers of sugarcane cultivated (SC) and uncultivated (UC) soils.

caused by changes in the void distribution pattern. These features have not been observed on similar layers of uncultivated soils. Kooistra *et al.* (1992) investigated the influence of deep tillage and compaction on soil structure and reported similar results.

The proportion of different pore shapes is presented in Table 3. The percentages of channel, chamber and vughy pores were generally greater in the 30-60 cm layer than in the 60-90 cm layer, probably due to the higher biological activity. The same trend was observed for sugarcane cultivated sols. Overall, the number of channel, chamber and Vughy pores were higher in sugarcane cultivated soils as compared to uncultivated soils (P<0.01). The percentage of vesicle and packing voids were similar in both sugarcane cultivated and uncultivated soils. The results of quantitative measurements of pore shapes (Table 3) combined with pore size distribution (Figure 2) showed a decline in macropores in the subsoil (30-60 cm) layers of sugarcane cultivated soils (P<0.01).

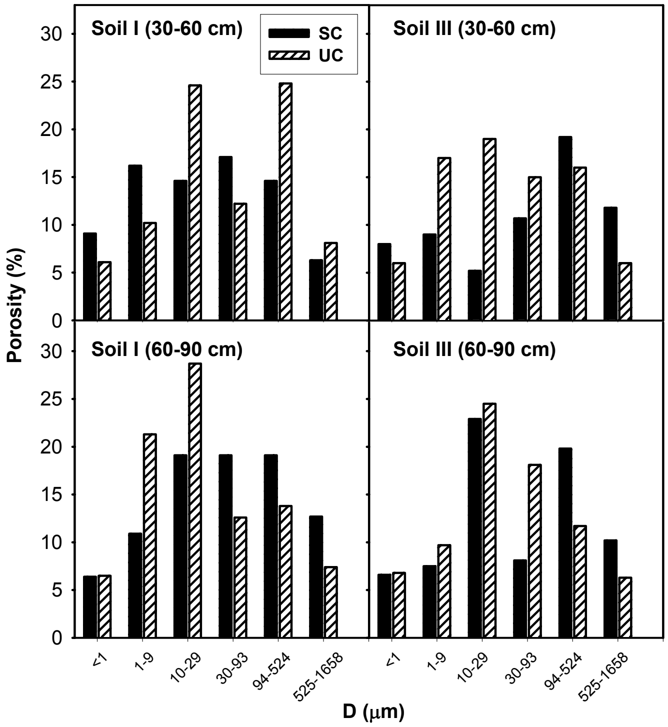

Figure 2. Pore size distribution of soils calculated from the water characteristics curves.

Structural Stability

The macroaggregate (>250 μm) stability of soil layers is given in Table 4. Generally, the proportion of macroaggregates in the 30-60 cm layer of sugarcane cultivated soils was relatively lower compared to uncultivated soils. However, in the topsoil of sugarcane cultivated soils, the water stable macraggregate stability was greater than in uncultivated soils. This can be due to both the higher clay and organic matter content of these soils.

Table 3. The percentage of different types of pores calculated using the thin sections.

Soil type	Depth (cm)	Channels	Chambers	Vughs	Planes	Vesicles	Packing voids
				(%)			
I_{SC}[a]	30-60	42	35	10	5	3	5
I_{UC}[b]	30-60	26	25	25	14	5	5
SL[c]		**	**	**	**	ns	ns
I_{SC}	60-90	42	40	5	6	3	4
I_{UC}	60-90	25	30	20	15	5	5
SL		**	**	**	**	ns	ns
III_{SC}	30-60	35	35	15	5	5	5
III_{UC}	30-60	25	20	35	15	2	3
SL		**	**	**	**	ns	ns
III_{SC}	60-90	50	10	10	20	5	5
III_{UC}	60-90	25	20	30	15	5	5
SL		**	**	**	**	ns	ns

[a] SC, sugarcane cultivated soil; [b] UC, uncultivated soils; [c] SL, significant level; [ns] not significant; [*] significant at 5% and [**] significant at 1%

All the attributes measured, including bulk density, water characteristics curve and macroaggrate stability revealed that soil structural stability in the 30-60 cm layer of sugarcane cultivated soils was decreased. Cumulative heavy traffic for planting, harvesting and transporting sugarcane in the last 38 years has led to subsoil compaction at a depth of 30-60cm. There are a number of possible reasons for the formation of compacted subsoil at the Haft-Tapeh. The harvesting season of sugarcane in Khuzestan province lasts from September to March. This period is the rainy season of this area. Heavy machinery traffic on sugarcane cultivated soils with the optimum water content for compaction will result in soil compaction. Barzegar *et al.* (2000) investigated the compactibility of sugarcane cultivated soils and reported that soil water content near the plastic limit results in a favorable conditions for soil compaction. The compactibility of soils is also dependent on the weight, contact area and speed of agricultural machinery (Soane *et al*., 1982; Soane and van Ouwerkerk, 1994). The weight of the agricultural machinery used for sugarcane production at Haft-Tapeh including transporters, trucks and vanguards are 18.3, 20, 43.5 Mg, respectively. The contact areas of these are 35.61, 7.46 and 12.93 m^{-2}, respectively. The heavy weight and low contact area of vanguards would be one the main reason for soil compaction. The other reason for the formation of a compacted subsurface layer in sugarcane cultivated soils might be the low organic matter content of these soils. Most of the sugarcane crops are harvested after pre-harvesting burning. This will reduce the amount of residue left on soils after harvesting. Compaction of the plough layer of sugarcane cultivated soils can be alleviated by restricting heavy machinery traffic at a water content less than 0.8 of the plastic limit, and incorporating sugarcane residue at a rate of 27 Mg ha^{-1} (Barzegar *et al.,* 2000). Crop residues with very low decomposition rates not only increase the C:N ratio (Oades, 1984) but also may interfere with common agricultural practices and the movement of irrigation water in furrows. Barzegar *et al.* (2002) indicated that the C:N of composting bagasse (C:N of 25) was almost one fifth of sugarcane residue (C:N of 135). A number

Table 4. Water stable macroaggregates (>250 µm; MA) of sugarcane cultivated (SC) and uncultivated (UC) soils.

Soil type	Depth (cm)	MA_{SC}[a]	MA_{UC}[b]	[c] Significance level
		%		
I	0-30	40	32	**
	30-60	28	29	ns
	60-90	32	25	**
II	0-30	29	35	ns
	30-60	25	30	*
	60-90	30	25	ns
III	0-30	40	34	*
	30-60	25	29	*
	60-90	30	20	**

[a] SC, sugarcane cultivated soil; [b] UC, uncultivated soils; [c] ns, not significant; * significant at 5% and ** significant at 1%

of studies have illustrated that organic matter increased soil structural stability (Kay, 1990; Barzegar *et al.,* 2002), water holding capacity at higher soil water potential (i.e. between 0 to -100 kPa), soil porosity and the infiltration rate (Barzegar *et al.,* 2002) and decreased soil compactibility (Barzegar *et al.,* 2000). Viator *et al.* (2002) recommended subsoil rather than within-row application of compost as the preferred practice for sugarcane production in heavy textured soils.

CONCLUSION

Results indicated that long term sugarcane cultivation altered soil physical properties. Aggregate stability and macropore proportions decreased and bulk density increased at a depth of 30-60 cm of sugarcane cultivated soils. An aquic condition was likely developed at the compacted subsurface layer of sugarcane cultivated soils as revealed by redoxiomorphic features.

ACKNOWLEDGEMENTS

We are grateful to Professor Alfred E. Hartemink of the International Soil Reference and Information Center (ISRIC), The Netherlands, and three anonymous reviewers for their comments.

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اثرات طولاني مدت كشت نيشكر بر خصوصيات فيزيكي خاكهاي ريزبافت

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چكيده

كشت طولاني مدت نيشكر مي‌تواند باعث تغييرات عمده‌اي در خصوصيات فيزيكي خاكها شود. هدف از انجام اين تحقيق بررسي اثر 38 سال كشت نيشكر (*Saccharum officinarum*) برخصوصيات فيزيكي خاكهاي ريزبافت (هاپل يوستپت و كلسي يوستپت) در جنوب غرب ايران مي‌باشد. شش پروفيل دوتايي (سه زوج پروفيل در هر تيپ خاك) در مزارع كشت نيشكر و در خاكهاي كشت نشده, به موازات هم در طول ترانسكت‌هئي به فاصله 100 متر حف گرديد. از اعماق 0-30 , 30-60 و 60-90 سانتيمتري اين پروفيل‌ها نمونه‌هاي مخلوط و دست‌نخورده جهت آزمايشات فيزيكي, شيميايي و ميكرومرفولوژيكي تهيه گرديد. نتايج اين تحقيق نشان داد كه كشت طولاني مدت نيشكر باعث افزايش جرم مخصوص ظاهري, كاهش پايداري ساختمان و افزايش خلل و فرج ريز خاك گرديده است. كاهش خلل و فرج درشت بهمراه كاهش پايداري ساختمان خاك نشان از تشكيل لايه فشرده و متراكم درعمق 30-60 سانتيمتري خاكهاي تحت كشت نيشكر دارد.