Anadolu Tarım Bilim. Derg., 2010,25(S-3):164-169
Anadolu J. Agric. Sci., 2010,25(S-3):164-169

Research
Araştırma

PHYSICAL PROPERTIES OF SODDY- PODZOLIC SOILS UNDER LONG-TERM FIELD EXPERIMENT

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Abstract: The fundamental physical properties of sod-podzolic soils under long-term field experiment were studied. The results showed that these properties have not changed significantly under the influence of nearly 100 years of liming, chemical and organic fertilization. The significant differences of approximation parameters of dependence penetration resistance from soil moisture content indicated that the application of manure increased interparticle contacts within the studied moisture range. This approximation parameters allow to affirm the significant increase interparticle forces by decreasing moisture content in the control and lime treatments compared with the others ones that resulted from the sand fractions increasing in granulometric composition of control treatment soils and aggregation of particles due to the influence of lime (lime treatment).
Key Words: Soil physical properties, Long-term field experiment, Penetration resistance

1. INTRODUCTION

Many soil properties are subjected to changes under conditions of intensive farming. In particular, these changes take place under the impact of mechanical compaction. The creation of a compacted soil layer under the plow horizon affects the soil water regime and the soil aeration. This is accompanied by changes in the soil biota and, often, in the character of the soil organic matter transformation. The application of fertilizers, including organic fertilizers, also affects many soil properties. In particular, relatively stable (conservative) physical properties may be affected, such as the aggregate size distribution, specific surface, etc. (Ditartre and Andreux, 1993; Achmad Rachman et al, 2003).

However, in dependence on the particular farming practices, soil properties, and climatic conditions, these changes may be very different. In some cases, they are clearly manifested. In other cases, they can not be diagnosed by the traditional methods. As shown in a number of works, the long-term application of fertilizers may exert negligible effect on the soil texture and bulk density (Munkholm et al, 2002; Ulrich et al, 2004). Many physical properties of soils are relatively stable, and their minor changes can not be properly estimated by the routine methods. In this context, it is important to develop the methods making it possible to judge unambiguously about changes in the physical properties of soils under the impact of the particular agricultural loads. Our work was aimed at studying a wide range of the physical properties of a soddy-podzolic soil and their changes under the impact of mineral fertilizers, lime, and manure.

2. MATERIAL AND METHODS

Field studies were performed on the plots of the long-term experiment of the Timiryazev Agricultural Academy. This experiment was established by Prof. A.G. Doyarenko in 1912 on a gently inclined surface (1^0 toward the northwest) within the southern margin of the Klin–Dmitrov Ridge. The area of 1.5 ha with a light loamy soddy medium podzolic soil was subdivided into two parts; six rectangular fields were established within each of the parts. Continuous crops (winter rye, potatoes, barley, clover, flax, and clean fallow) have been cultivated on the first part. The second part has been used in rotation (clean fallow–winter rye–potatoes–oats (barley) with clover–clover–flax).

Each field within the part with continuous crops was divided into eleven plots of 100 m^2, on which different variants of fertilization have been tested: control (two plots), N, P, K, NP, NK, PK, NPK, manure, and NPK + manure. Since the fall of 1949, regular liming (once per 6 years) has been practiced on a half (50 m^2) of the plots (Kiryushin, Safonov, 2002).

In April 2008, auger samples were obtained from the layers of 0–10, 10–20, 20–30, and 30–40 cm from the plots with continuous crops; the following trials were tested: control, lime, NPK, and NPK + manure. The soil bulk density was determined in the samples taken by a cylindrical auger (Pol'skii's auger).Particle size distribution analysis was performed in two stages. At the first stage, ground soil was sieved through 1mm and 0.25mm screens to separate coarse soil particles (> 0.25 mm). At the second stage, particle size distribution in the fraction <0.25 mm was determined on a FRITSCH Analysette22 laser diffractometer after the ultrasonic pretreatment. Thus, we obtained data on the content of coarse fractions (>0.25 mm) and on the particle size distribution for finer fractions. This was necessary, because the content of coarse fractions in the analyzed soil was significant and hampered the analysis of particle size distribution curves for fractions <0.25 mm. The soil specific surface was determined by the method of desorption equilibrium above saturated salt solutions and by the method of heat desorption of gases (nitrogen). In the first case, the soil samples (3–5 g) were wetted and stored for two weeks in desiccators above water to reach quasiequilibrium saturation. After this, the samples were placed in desiccators with saturated salt solutions ensuring relative vapor pressures of 0.15, 0.332, 0.55, 0.86, and 0.98. The desorption of water from the samples until the equilibrium state continued for about three months. Then, the samples were dried at 105°C, and their water content was determined. The specific surface was calculated according to the BET method (Shein, Karpachevskii, 2007). The specific surface was also determined by the method of the heat desorption of gases (nitrogen) with the help of a SORBTOMETER device (Shein, 2005; Shein, Karpachevskii, 2007). Aggregate size distribution in the upper horizons (0–10 and 10–20 cm) was determined by the method of dry sifting using a RETSCH device (Retsh GmbH, 2005). The organic carbon content was determined on an automatic analyzer (AH7529) at the temperature of 900–1000°C in the flow of purified oxygen (Shein, Karpachevskii, 2007).

The wetting heat (*WH*, cal/g) was determined on an OX12K calorimeter. It was calculated as follows:

$$WH = \frac{K_k \cdot t_n}{P_d}, \quad (1)$$

where K_k is the heat capacity of the calorimeter, t_n is the real rise in temperature, and P_d is the mass of absolutely dry soil sample (Shein, Karpachevskii, 2007).

The strength of dry aggregates of 3–5 and 5–7 mm in size was determined in 20 replicates with the help of a cone penetrometer developed by P.A. Rebinder:

$$P_m = 1.108 \cdot \frac{F}{h^2}, \quad (2)$$

where F is the load, kg; h is the depth of the cone penetration, cm; and 1.108 is the coefficient for the cone of 30°. According to this method, the penetration resistance (P_m) is measured in kg/cm^2 (Khaidapova, Pestonova, 2007). It was determined for the samples with different contents of water.

3. RESULTS AND DISCUSSION

Data on the major soil physical properties of studied soils are summarized in Table 1. According to the particle size distribution data, the soil has a medium loamy texture; in the surface horizons of the control plot, the soil texture is light loamy. The coarsening of the soil texture (up to the loamy sandy texture) with the high content of coarse (> 0.25 mm) fractions is also observed in the layer of 30–40 cm from the plot treated with NPK fertilizers. It should be noted that particle size distribution curves with two peaks observed in the experimentare typical of the poorly sorted moraine deposits. The specific surface values obtained by the two methods are relatively low and remain stable within the soil profiles, except for the lower part (30–40 cm) of the soils on the control plot and on the plot with NPK and manure, where this index increases. Also, the specific surface determined by the method of the water vapor desorption increases in the soil of the plot with NPK and manure. This may be due to the increased hydrophilicity of organic substances in the soil of this plot and, probably, due to some change in the mineralogical composition of the low soil horizons (Munkholm et al, 2005).

Table 1. Some physical properties of soddy-podzolic soil

Variants	Depth, cm	Granulometric particles content, %			Soil density,	Aggregates 10-0.25 mm,	$C_{org.}$, %	$S_{H2O,}$ m^2/g	S_{N2}, m^2/g	WH, cal/g	Plastic limit,	Liquid limit,
		<0.01 mm	<0.001 mm	>.0.25 mm	g/cm^3	%					%	%
Control	0-10	27,61	3,92	24,64	1,56	71,89	1,04	22,01	2,90	1,68	14,49	19,24
	10-20	28,17	3,90	28,34	1,58	71,71	1,04	20,84	3,26	1,56	15,10	18,16
	20-30	29,27	4,59	34,18	1,80	-	0,65	18,67	3,78	1,37	12,60	15,29
	30-40	34,04	4,98	28,64	1,75	-	0,24	26,20	10,81	1,39	12,33	15,25
Lime	0-10	31,48	4,23	25,30	1,67	76,77	1,20	22,60	2,50	2,18	15,10	19,88
	10-20	29,54	3,95	24,34	1,65	82,58	1,2	21,80	2,50	1,46	15,56	19,43
	20-30	31,34	4,23	25,56	1,88	-	1,05	20,79	2,80	1,46	15,53	20,03
	30-40	25,82	3,41	32,32	1,97	-	0,75	14,10	3,56	1,25	12,61	14,02
NPK	0-10	32,53	4,77	24,88	1,58	72,43	1,16	21,77	3,18	1,44	15,16	19,92
	10-20	31,10	4,26	26,50	1,50	71,92	1,22	17,69	2,92	1,78	14,45	18,96
	20-30	29,13	3,88	35,30	1,67	-	0,67	19,02	3,90	1,47	12,87	16,59
	30-40	17,39	2,42	59,10	1,75	-	0,26	13,75	4,36	0,78	12,95	13,71
NPK +manure	0-10	32,12	4,23	20,26	1,44	81,13	1,77	27,83	2,44	2,20	12,82	26,45
	10-20	31,08	4,20	25,86	1,40	75,10	2,09	31,38	2,44	3,13	21,38	27,22
	20-30	27,42	3,76	29,02	1,75	-	0,57	20,40	3,39	1,23	13,20	17,13
	30-40	35,57	6,55	25,20	1,84	-	0,21	46,66	17,84	2,11	13,30	19,48

Note: $C_{org.}$, - content of soil organic matter, S_{H2O} and S_{N2} – soil specific surface determined by water and nitrogen desorption

An increased water retention capacity of the soil of this plot should also be noted; in particular, this soil is characterized by the increased values of the plastic and liquid limits.It is known that the bulk density determined with the use of Pol'skii's auger is usually somewhat higher, than the bulk density determined with the use of cylindrical rings of Kachinskii. However, the auger method can be applied for comparative assessments of bulk density values in different variants of the experiment. According to our data (Table1), the soil bulk density increases down the soil profile in all the variants. The minimum values are observed in the Ap horizon of the variant with NPK and manure, because the application of manure decreases the soil bulk density in the Ap horizon. The maximum values are observed in the variant with lime application. They are reliably higher than those in the control variant. Increased bulk density values in the variant with lime application were already noted during the survey in 1996–1998; however, it was concluded that the difference between the control variant and the variant with lime were within the experimental error (Kiryushin, Safonov, 2002).The wetting heat varies from 0.78 to 3.13 cal/g; according to this index, the soils are slightly hydrophilic. The maximum values of the wetting heat are in the variant with NPK and manure application, which may be explained by the addition of hydrophilic organic matter. The control variant somewhat differs from other variants by a higher content of coarse particles; the variant with NPK and manure application is characterized by the increased content of the finest particles in the entire profile. The latter circumstance allows us to assume that this phenomenon may be related to the initial textural difference between the plots. However, it is also possible that the increased content of finest particles in this variant is due to the formation of colloidal and fine clay organo-mineral particles in the soil treated with manure.

In general, a comparative analysis of some physical and chemical properties of the upper soil horizons from different variants of the experiment shows that the difference between major physical characteristics of the soil solid phase for different variants is relatively small. The spatial heterogeneity in the distribution of the studied indices within the particular soil profiles and between them is considerable. It can be supposed that a somewhat coarser soil texture at the control variant and an increased content of clay particles in the variant with NPK and manure application are related to the initial heterogeneity in the soil properties rather than to the different agricultural loads on the soils. The degree of changes in the soil physical properties under the impact of different agricultural loads is relatively small. Only the variant with NPK and manure application differs significantly from other variants in a higher content of finest particles and, hence, in a higher water retention capacity at the plastic and liquid limits. Relatively small differences between the major physical properties of soils at different variants of the experiment necessitated the search for other differentiating properties. In particular, the strength of soil aggregates and penetration resistance were studied at different water contents. These characteristics are indicative of the strength of interparticle bonds. As seen from Fig. 2, the strength of airdry aggre gates in the variants with lime and with NPK and manure is higher than that in the control and NPK variants for both studied depths (0–10 and 10–20 cm) and for both aggregate diameter groups (3–5 and 5–7 mm). These data are in agreement with the existing notions about the effect of lime on the mechanical strength of acid soils (Khaidapova, Pestonova, 2007; Khaidapova, Prudnikova, 2002). As for the NPK + manure variant, an increase in the physical strength of the aggregates may be explained by the addition of organic substances. These substances favor the development of coagulation bonds. In the case of soil drying, such bonds may be transformed into stronger mixed and cementing bonds. As a result, the stability of soil micro and macroaggregates in the dry state increases (Boujilla, Gallali, 2008). Thus, the addition of organic fertilizers (manure) not only increased the soil organic matter content (Table 2) but also improved the strength of soil aggregates in the airdry state. Interesting results were also obtained upon penetration resistance (P_w) tests at different soil water contents (W). In this case, the soil is subjected to the compression stress and shear stress. The soil dilatant properties characterizing interaction between the soil particles are clearly manifested. The tests were performed within the soil water range from the liquid limit to the plastic limit.

The results are presented in Fig.1. It is seen that the P_w–W curves for the variant NPK + manure are shifted to the right, i.e., at a given soil water content, the soil resistance to penetration in this variant is higher than in other variants due to the formation of coagulation bonds between the particles. The variant with lime is also characterized by an increased penetration resistance, which is seen from the steep slope of the P_w–W curves. In all the variants, the strength of soil structure (soil resistance to penetration) increases sharply within a relatively narrow range of the soil water contents. This is typical of the soils with an increased content of coarse particles. As seen from Fig. 1, with a decrease in the relative degree of soil moistening, the soil penetration resistance increases most significantly in the variant with lime application; the minimum increase is observed in the variant with NPK and manure application, which is explained by the lubricant action of hydrophilic organic matter in this case. The highest penetration resistance in the limetreated soil is in agreement with earlier published data (Khaidapova, Prudnikova, 2002). The control variant and the variant with NPK occupy an intermediate position. However, the qualitative analysis of the curves does not make it possible to estimate the reliability of the established differences between the soils of different variants. To estimate it, we approximated the obtained curves by the following power equations:

$$P_w = \left(\frac{W}{b2}\right)^{-b1} \quad (3)$$

where P_w is the value of soil resistance to penetration , W is the soil water content, and $b1$ and $b2$ are approximation parameters. The reliability of differences between the approximation parameters obtained for different variants of the experiment was specially evaluated. In this model, parameter $b2$ characterizes the position of the curve relative to the abscissa axis: the higher $b2$, the higher the soil resistance to penetration at the given soil water content (i.e., the stronger interparticle bonds). Parameter $b1$ points to the slope of the curve: the higher $b1$, the steeper the curve, i.e., the more significant changes in the penetration resistance take place with the change in the soil water content. This means that the soil particles come into close contact and display strong internal friction with a decrease in the soil water content.

The results of corresponding calculations and the assessment of reliability of the differences between different variants of the experiment are presented in Table 2.

At all the depths, parameter $b2$ at the variant with NPK and manure is higher than that at other variants, i.e., the corresponding curve lies higher, which is well seen from Fig. 1. Parameter $b1$ is reliably lower for the deep soil layers in this variant, which is seen from the lower steepness of corresponding curves.

Significantly lower values of parameter $b1$ in the variant with NPK and manure point to stronger bonds between the soil particles in this variant and to their relatively small changes within the studied range of soil water contents. This parameter is reliably higher in the control variant and in the variant with lime application, particularly, in the layer of 30–40 cm. This attests to the growing strength of interparticle bonds with a decrease in the soil water content. As noted above, this is typical for the soils with the high content of coarse particles and with the strong aggregation of the particles under the impact of lime application.

Thus, the analysis of the curves showing the dependence of soil physical properties (penetration resistance) on the soil water content makes it possible to obtain information about the reliability of differences in the parameters of the curves and, hence, in the rheological behavior of the soils from different variants of the experiment. Note that routine determinations of the major physical proper ties of the soils did not make it possible to judge about their differences in different variants of the experiment.

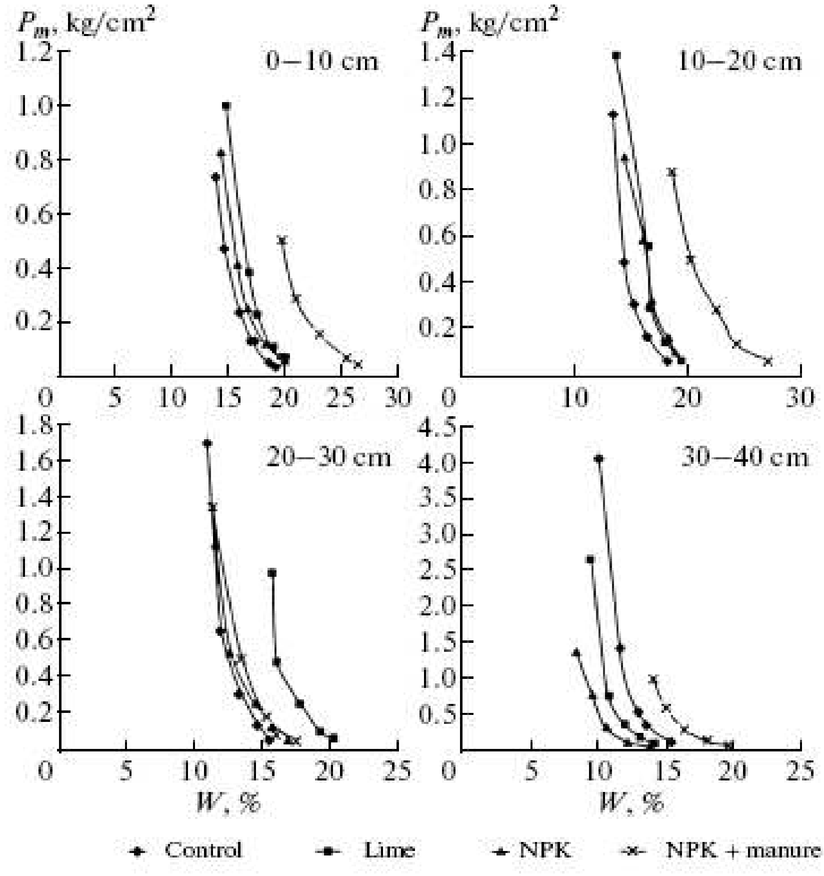

Figure 1. Penetration resistance (P_w, kg/cm^2) as dependent on the soil water content (W,%of dry soil mass) in different experimental variants

Table 2. Assessment of the influence of mineral fertilizers, lime and manure on the changes in soil strength using the power function

Depth 0-10 cm							
Variants		Control		Lime		NPK	
		b1	b2	b1	b2	b1	b2
Lime	b1	8,72					
		9,37					
	b2		13,61*				
			15,04				
NPK	b1	8,72		9,37*			
		8,14		8,14			
	b2		13,61*		15,04*		
			14,23		14,23		
NPK+ manure	b1	8,72		9,37*		8,14	
		7,85		7,85		7,85	
	b2		13,61*		15,04*		14,23*
			18,13		18,13		18,13
Depth 20-30 cm							
Variants		Control		Lime		NPK	
		b1	b2	b1	b2	b1	b2
Lime	b1	10,68					
		13,60					
	b2		11,82*				
			15,57				
NPK	b1	10,68		13,60			
		8,22		8,22			
	b2		11,82		15,57*		
			11,94		11,94		
NPK+ manure	b1	10,68*		13,60		8,22	
		6,93		6,93		6,93	
	b2		11,82*		15,57*		11,94
			12,09		12,09		12,09

Note: Numerators denote the data in columns, and denominators denote the data in rows.
* - Significantly different (with the 0.95 probability) values

4. CONCLUSION

(1) The physical properties of soils, such as particle size distribution, bulk density, specific surface, aggregate size distribution, wetting heat, and penetration resistance as dependent on the soil water content within the range from the liquid limit to the plastic limit were determined in soils of the longterm field experiment at the following plots: control, lime, NPK, and NPK + manure.

(2) It was found that the long-term application of lime, mineral fertilizers, and manure had a minor effect on the main physical properties of the studied soddy-podzolic soils. Only the soil of the plot with NPK and manure application was characterized by a somewhat higher content of finest particles and a higher water retention capacity.

(3) The physico-mechanical properties of the soils (the strength of soil aggregates and the dependence of penetration resistance on the soil water content) were more sensitive and statistically reliable to indicate soil changes under the impact of different treatment systems. These soil properties characterize interparticle bonds and their changes in dependence on the degree of soil moistening, i.e., the rheological behavior of the soils.

(4) The parameters of approximation of the curves showing the dependence of penetration resistance on the soil water content for the NPK + manure variant differed reliably from the analogous parameters for other variants, which pointed to stronger interparticle bonds and their low dependence on the soil water content (within the studied range) in the soil of this variant. Soils of the control variant and the variant with lime application also differed reliably from other soils in the parameter characterizing the increase in the strength of interparticle bonds with a decrease in the soil water content. This can be explained by a some what coarser texture of the soil at the control variant and by a stronger aggregation of the soil particles in the variant with lime application.

5. ACKNOWLEDGEMENT

This study was supported by the Russian Foundation for Basic Research, project Nos. 08-04-00656-a and 09-05-00564-a.

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