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THE INFLUENCE OF VARIOUS MEANS OF TILLAGE SIMPLIFIED MODIFICATION ON SELECTED PHYSICAL AND WATER PROPERTIES OF THE ARABLE-HUMUS HORIZON IN A MINERAL SOIL**

Abstract. This paper presents the results of testing studies of the basic values of physical and water properties of the humus horizon in a typical black earth where three variants of simplified tillage were implemented. The state of a three-phase system of soil after fourteen years of no-tillage cultivation was compared with the variant of single deep plowing and plowing with manure fertilization. The following properties were marked: texture, specific and bulk density, porosity, moisture, maximal hygroscopic capacity, saturated hydraulic conductivity, water binding potential, total (TAW) and easily (RAW) available water, drainage porosity. It was acknowledged that the systems of most of the physical and water properties in the investigated combinations were very similar. There was no evidence of negative changes of key physical properties in the soil after the 14-year long no-tillage cultivation when compared with the variant of single traditional tillage rotation. Some minor differences were found within hydraulic and water properties and total carbon, however, they cannot practically deteriorate the agrotechnical state of a humus horizon and cannot have a negative effect in the field environment. It was affirmed that within a three-phase soil system, the no-tillage cultivation provides plants with almost identical conditions of growth and development as the systems with the tillage rotation.

Systems of tillage simplifications, used in Poland on a small scale, raise a lot of controversy. Some resources inform about the lack of differences in the amount of obtained crop between simplified and traditional tillage [23], others show their decrease by about 11–15% [7, 30]. The observed differences are

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often referred to as insignificant [1, 3, 26]. Numerous researchers have observed a significant decrease of crops when direct seeding was implemented [2, 4, 5, 6, 15, 16, 19, 25, 34]. However, they point to the fact that the decrease of crops is compensated by significantly low costs of production. On the other hand, many publications inform about the growth of crops after the implementation of no-tillage cultivation systems [9, 11 ,31]. The impact of tillage simplifications on soil properties, especially in its humus horizon, is also a widely discussed issue. Numerous authors claim that the long term use of simplifications leads to unfavorable changes especially within the physical properties and report the increase of soil density with the simultaneous decrease of its porosity [8, 18, 22, 25]. Notwithstanding, Dubas *et al*. [7] do not notice any differences between the porosity of soils under the plowing cultivation and no-tillage cultivation. Literature often contains conflicting information. An interesting concept was presented by Orzech *et al*. [24] and Pabin *et al*. [25]. They claim that a single application of tillage in a rotation of the long term direct seeding boosts the parameters mentioned above. This paper presents long-term studies of such solutions.

MATERIALS AND METHODS

The research was conducted in October 2012 in Swadzim near Poznań in the experimental area of The Research and Didactics Centre of the Poznań University of Life Sciences. The soil cover of the object was represented by the soil subtype of typical black earths (Haplic Phaeozems) [28]. They covered three planes where a multi-year monoculture tillage of corn was conducted. Variant C reflected the state of the soil after 14 years of no-tillage cultivation. In the other two variants (A and B), single deep ploughing (30 cm, variant B) was done after twelve years of such tillage; in the case of variant A, manure was also implemented in a dose 40 t ha^{-1}. After these operations, corn monoculture in direct seeding was continued on all planes. After two years (fourteen from the beginning of experience), soil samples (of the disturbed and non-disturbed structure) were taken from humus horizons – at the depths of 0–7 cm and 15–20 cm. The following measurements were made: texture of soil with Bouyoucos' method in Prószyński's modification [29], specific density with picnometric method [32], soil bulk density with Nitzsch's vessels of 100 cm^3. Porosity was marked on the basis of the density indications, moisture – with the oven-dry method [21], maximal hygroscopic capacity was measured in a vacuum chamber in the vacuum of 0.8 atm in the presence of a saturated solution of K_2SO_4 [21]. The saturated hydraulic conductivity was measured using the method of a constant pressure decrease [14], the soil's water binding potential - with the method of Richards' pressure chambers [13], total (TAW) and easily (RAW) available water was measured on the basis of pF designations, effective (drainage) porosity, i.e. the sum of soil macro- and mezopores hereinafter referred to as drainage porosity, was defined as the difference between total porosity and moisture corresponding with the field water capacity (marked at the potential of -10 kPa, which corresponds with the value at pF=2.0) and the molecular capacity of pores of the diameter larger than 30 µm. Total carbon and total nitrogen were marked with the Vario-Max analyzer. All published results are average values of five replications.

RESULTS AND DISCUSSION

The texture of the soils was balanced so it did not affect the presented results as an additional variable. All the examined epipedons showed a grain-size distribution of loamy sands [27] which corresponded with the granulometric subgroup of loamy sand according to FAO [10], provided they contained 1% clay and 15–17% silt (Table1).

TABLE 1. THE TEXTURE OF THE INVESTIGATED SOILS

Treat-ment*	Depth (m)	Percentage content of fraction on diameter (mm)					Texture acc. to:	
		2.0–0.05	0.05–0.02	0.02–0.005	0.005–0.002	< 0.002	PTG	FAO
A	0.00–0.07	82	8	9	0	1	pg*	LS
	0.15–0.20	83	7	9	0	1	pg	LS
B	0.00–0.07	84	7	8	0	1	pg	LS
	0.15–0.20	84	6	9	0	1	pg	LS
C	0.00–0.07	82	9	8	0	1	pg	LS
	0.15–0.20	83	8	8	0	1	pg	LS

* For explanation see Materials and Methods.

The specific density was stable and equaled 2.63 Mg m^{-3} in the horizons of 0–7 cm and 2.64 Mg m^{-3} at the depths of 10–20 cm. Its values depended on the balanced composition of the soil's solid phase gently modified with a slightly higher content of total carbon in the surface horizons (Table 2).

The bulk density oscillated between 1.61 Mg m^{-3} (tillage, depths of 7 cm) and 1.76 Mg m^{-3} (manure + tillage, depths of 7 cm). The values of density in direct seeding were between the values of the two variants of plough cultivation (1.69–1.74 Mg m^{-3}) (Table 2). The values of soil density grew along with the depth (by 0.05–0.08 Mg m^{-3}) with an exception of the combination where manure had been used – here its decrease along with the depth was observed (by 0.06 Mg m^{-3}). It may be explained with a probable, uneven distribution of this fertilizer within the two examined horizons. Also in this combination, the values of density were the highest. The negative decrease of density was not observed in the long term non-tillage cultivation (Table 2). This observation did not confirm the claims of other authors [8, 18, 22, 25]. It is noteworthy that the differences in the soil density between each combination were minor and practically insignificant from an agrotechnical point of view. This was confirmed by the remarks of Pabin *et al*. [25] and Orzech *et al*. [24].

TABLE 2. BASIC PHYSICAL PROPERTIES

Treatment	Depth (karbon)	Total C (g kg^{-1})	Specific density (Mg m^{-3})	Bulk density (M m^{-3})	Porosity	
					Total (%v/v)	Drainage (%v/v)
A	0.00–0.07	8.37	2.63	1.76	33.08	15.86
	0.15–0.20	7.65	2.64	1.70	35.61	20.31
B	0.00–0.07	8.70	2.63	1.61	38.78	21.05
	0.15–0.20	7.90	2.64	1.69	35.98	19.46
C	0.00–0.07	7.61	2.63	1.69	35.74	19.44
	0.15–0.20	7.25	2.64	1.74	34.09	18.95

The lowest total porosity was observed in combination A at the depth of 0–7 cm (33.08%), whereas the highest – both in the surface horizon (38.78%) and at the depth of 20 cm (35.98%) – in combination B. At a balanced specific density, the size and distribution of the presented values may be treated as the reverse of the discussed soil density. It may also be ascertained that the values of porosity marked in the late autumn were low but stable and slightly differentiated irrespective of the tillage system (Table 2). Radecki and Opic [30] also claim that the rejection of mechanical tillage does not reduce the soil porosity which, according to the authors, is connected with the growth of the soil fauna population. Furthermore, within the drainage porosity, the results were very similar and oscillated between the values of approximately 16 and 21% (Table 2).

Natural moisture was very balanced. Its values in surface horizons in combination A (20.05%) and combination B (21.55%) were only slightly higher than the ones marked in the samples with non-tillage cultivation (18.07% vol.). Capacity moisture at the depth of 20 cm was consistently lower by 2–3 % in all combinations. These results confirm the notions of Włodek *et al*. [35]. However, the proved negative difference in the soil moisture content was very minor (Table 3). The observations of other authors were not confirmed by this study [12, 20, 30].

TABLE 3. BASIC WATER PROPERTIES

Treat-ment	Depth (m)	Moisture		Hygroscopic water		Maximum hygroscopic water		Saturated hydraulic conductivity
		(% m/m)	(%v/v)	(% m/m)	(%v/v)	(% m/m)	(%v/v)	(µm s^{-1})
A	0.00-0.07	11.42	20.05	0.7478	1.3142	2.1734	3.8197	17.22
	0.15-0.20	10.49	17.86	0.6002	1.0227	2.0384	3.4732	20.41
B	0.00-0.07	13.38	21.55	0.6286	1.0132	2.1366	3.4441	29.42
	0.15-0.20	10.28	17.33	0.6743	1.1369	2.2004	3.7098	10.03
C	0.00-0.07	10.70	18.07	1.3083	2.2127	1.9794	3.3476	27.89
	0.15-0.20	9.63	16.79	0.6280	1.0950	2.0421	3.5608	20.20

Hygroscopic moisture (H) showed very similar values (1.0132–1.3142% vol.) within combinations A and B. This parameter reached its highest value in the combination with direct seeding (2.2127% vol.). The value of maximal hygroscopic capacity within combinations A and B (MH) were usually slightly lower (by about 0.3–0,6 %) than in the case of direct seeding (Table 3). All the marked values of H and MH were highly equalized; they depended on the content of the clay fraction and the rather undifferentiated content of total carbon (7.25–8.70 g kg^{-1} of soil), whereas the tillage system did not influence them at all (Table 3).

The saturated hydraulic conductivity in the examined soils oscillated between about 10.03 µm s^{-1} and 29.42 µm s^{-1}. The differences between combinations A and C at the depth of 20 cm were minor and amounted to 20.41 µm s^{-1} and 20.20 µm s^{-1}, respectively. Furthermore, insignificant differences were observed between their Ks (17.22 µm s^{-1} and 27.89 µm s^{-1}) in their surface horizons. Between combinations B and C, a small differentiation at the level of 1.53 µm s^{-1} was observed in their surface horizons. All the defined Ks values were characteristic of the texture subgroup of loamy sands and fitted the range given by various authors for deposits and soils of a similar origin and grain-size distribution [17, 36]. From the perspective of soil hydraulics, the spread of the results (from 10.03 µm s^{-1} to 29.42 µm s^{-1}) practically proves no differentiation of the saturated hydraulic conductivity within each combination and at the same time indicates almost the same water conductivity abilities in the examined soils (Table 3).

The maximum water capacity (pF=0.0) of the investigated soils remained at the level from 31.67 to 36.04% v/v. Its values were 1.5 to 2% lower, respectively, than the total porosity present in each sample. It stems from the lack of methodological possibility of ideal deaeration of the capacity samples in laboratory conditions. The field water capacity (pF=2.0), similar to all the other marked capacities, was slightly higher (by about 1–2%) in the surface horizons than the capacity found at the depth of 20 cm and fitted the range from 16.30 (direct seeding) to 17.73% (tillage). The corresponding values were consistently lower by about 2–3% at pF=2.5. The values of moisture marked for field capacity (pF 2.0) were similar to those presented by Ślusarczyk [**33**] for soil deposits of a similar grain-size distribution and the content of humus. The limit of production water (pF=3.7) oscillated between the values of 9.50 (direct seeding) and 12.04% (tillage) in the surface horizons, and 8.35 (tillage + manure) and 9.28% (direct seeding) at the depth of 20 cm. The wilting point (pF=4.2) was almost undifferentiated. Having considered all combinations and depths of the sample collection, its values were between 4.98 and 5.52%. The moisture at pF=4.5 was similarly balanced (from 3.34 to 3.81%). From a practical point of view, there were no differences in this regard. Nevertheless, from a theoretical point of view, it ought to be mentioned that most of the described characteristic points of the water desorption curve reached the lowest values in the combinations with direct seeding. The differences between absolute values were very small and practically insignificant for agrotechnics (Table 4).

TABLE 4. SOIL WATER POTENTIALS AND THE POTENTIAL AND TOTAL AVAILABLE WATER

Treatment	Depth (m)	Water capacity at pF (%v/v)						Total available water (%v/v)	Easily available water (%v/v)
		0.0	2.0	2.5	3.7	4.2	4.5	pF 2.0–4.2	pF 2.0–3.7
A	0.00-0.07	31.67	17.22	15.16	10.41	5.52	3.81	11.70	6.81
	0.15-0.20	32.82	15.30	12.70	8.35	5.01	3.47	10.29	6.95
B	0.00-0.07	36.04	17.73	15.14	12.04	5.70	3.44	12.03	5.69
	0.15-0.20	34.75	16.52	13.09	8.78	4.98	3.70	11.54	7.74
C	0.00-0.07	33.36	16.30	14.14	9.50	5.22	3.34	11.08	6.80
	0.15-0.20	32.17	15.14	12.89	9.28	5.00	3.56	10.14	5.86

With highly equalized values and a similar system of constant parameters, the water-soil figures of total (TAW) and easily (RAW) available water must be similar, as well. In the surface horizons, TAW oscillated between 11.08 (direct seeding) and 12.03% (tillage) with RAW between 5.69 (tillage) and 6.81% (manure + tillage). At the depth of 20 cm, these values were slightly lower: TAW – from 10.14 (direct seeding) to 11.54% (tillage) and RAW – from 5.86 (direct seeding) to 7.74% (tillage) (Table4). The values did not differ much and were similar to those presented by Ślusarczyk [33] for soil deposits of a similar grain-size distribution and humus content.

CONCLUSIONS

1. This research has shown that the systems of almost all physical and water properties of the investigated tillage combinations were very similar.

2. No negative changes of key physical properties of soil after 14 years of no-tillage cultivation were found when compared to the variant with a single rotation of traditional tillage.

3. Furthermore, no deterioration affected the density and porosity, which are parameters crucial for a three-phase system.

4. Minor changes were observed within the water and hydraulic properties and total carbon content. These, however, cannot have any practical impact on the deterioration of the agrotechnical state of the humus horizon and cannot act negatively in the field conditions.

5. It was also found that within the quality of the soil's three-phase system, the no-tillage cultivation provided the plants with almost identical conditions for growth and development as the systems with the single tillage rotation.

Issues connected with tillage simplifications need to be continuously and thoroughly investigated and discussed, and conclusions and recommendations for agricultural practice will still be difficult and risky. According to the present state of research, it appears that, even as far as in the USA, the classical no-tillage cultivation will become more and more popular considering the vast areas and often very diverse character of the soil's solid phase (frequently appearing mono-fractional silt deposits). In Polish conditions, considering the soils formed from differentiated postglacial deposits, this tillage system will always be controversial. Based on what numerous researchers report, its alternating variant with periodical implementation of the traditional tillage may be considered. However, it does not appear necessary based on the conclusions of this paper.

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WPŁYW RÓŻNYCH SPOSOBÓW MODYFIKACJI UPROSZCZONEJ UPRAWY ROLI NA WYBRANE WŁAŚCIWOŚCI FIZYCZNE I WODNE POZIOMU ORNO-PRÓCHNICZNEGO GLEBY MINERALNEJ

W pracy przedstawiono wyniki badań testujących wartości podstawowych właściwości fizycznych i wodnych poziomu próchnicznego czarnej ziemi typowej, na której zastosowano 3 warianty uproszczonej uprawy roli. Porównano stan układu trójfazowego gleby po 14 latach uprawy zerowej z wariantami stosującymi jednorazową głęboką orkę oraz orkę wraz z nawożeniem obornikiem. Oznaczono następujące właściwości: skład granulometryczny, gęstość fazy stałej, gęstość gleby, porowatość, wilgotność, maksymalną pojemność higroskopową, współczynnik filtracji, potencjały wiązania wody przez glebę, potencjalną (PRU) i efektywną (ERU) retencję użyteczną, porowatość drenażową. Stwierdzono, że układ niemal wszystkich właściwości fizycznych i wodnych był w rozpatrywanych kombinacjach uprawowych bardzo podobny. Nie stwierdzono negatywnych zmian kluczowych właściwości fizycznych gleby uprawianej przez 14 lat bez orki, w stosunku do wariantów stosujących jednorazową rotację uprawy tradycyjnej. W obrębie właściwości wodnych i hydraulicznych oraz w przypadku zawartości węgla ogólnego stwierdzono nieznaczne różnice, które jednak nie mogą mieć praktycznego wpływu na pogorszenie się stanu agrotechnicznego poziomu próchnicznego i nie mogą negatywnie skutkować w warunkach polowych. Stwierdzono, że w zakresie jakości układu trójfazowego gleby, uprawa zerowa zapewnia roślinom uprawnym niemal identyczne warunki wzrostu i rozwoju, jak systemy z rotacyjnym udziałem orki.