Influence of different tillage systems on soil physical properties and crop yield

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ABSTRACT

An experiment with five different tillage systems and their influence on physical properties of a silty loam soil (Albic Luvisol) was carried in northwest Slavonia in the period of 1997–2000. The compared tillage systems were: 1. conventional tillage (CT), 2. reduced tillage (RT), 3. conservation tillage I (CP), 4. conservation tillage II (CM), 5. no-tillage system (NT). The crop rotation was soybean (*Glycine max* L.) – winter wheat (*Triticum aestivum* L.) – soybean – winter wheat. Differences between tillage systems in bulk density, total porosity, and water holding capacity and air capacity were not significant in winter wheat seasons. In soybean seasons, significant differences between some tillage systems were recorded in bulk density, total porosity, air capacity and soil moisture. The deterioration trend of physical properties was generally increasing in the order CM, CT, CP, NT and RT. The highest yield of soybean in the first experimental year was achieved under CT system and the lowest under CP system. In all other experimental years, the highest yield of winter wheat and soybean was achieved under CM system, while the lowest under RT system.

Keywords: soil physical properties; conventional tillage; conservation tillage systems; winter wheat; soybean

Soil tillage is one of the fundamental agrotechnical operations in agriculture because of its influence on soil properties, environment and crop production in general. To assure normal plant growth, the soil must be in such conditions that roots can have enough air, water and nutrients. Structure of the Ap horizon is largely influenced by soil tillage system and the implements used for tillage (Acharya and Sharma 1994, Pagliai et al. 1995, Lal 1997, Sidiras and Kendristakis 1997). The soil physical properties are connected directly and indirectly with growth of the root system of crops (Logsdon et al. 1987, Sidiras and Kahnt 1988, Azooz et al. 1995, Nasr and Selles 1995, Varsa et al. 1997). At the present time in Central Europe the conventional tillage system dominates. It usually involves mouldboard ploughing and additional secondary tillage to prepare the seedbed (Stroppel 1997). With regard to ecological and economical aspects, the discussion about conventional tillage system, conservation tillage systems and no-tillage system seems to be increasingly important. These nonconventional soil tillage systems are aimed to develop favourable soil conditions and save energy. Many authors examined influence of different tillage systems on the soil physical properties. Kováč and Žák (1999b) found that changes in soil physical properties were induced by different tillage treatments, but the changes were small and insignificant. Some authors pointed out that the tillage treatments affected the soil physical properties, especially when similar tillage system has been practised for a longer period (Jordhal and Karlen 1993, Mielke and Wilhelm 1998). According to Buschiazzo et al. (1998), the influence of tillage system on the soil physical properties was greater in the humid climate area and on loamy soils in comparison to the arid climate and sandy soils. It was determined that the soil physical properties changes affected by different soil tillage treatments could influence yield level of grown crops. Since tillage strongly influences the physical properties of soil, it is important to apply that type of technology that will make it possible to sustain physical properties at a level suitable for normal growth of agricultural crops. Soil physical properties represent a group of properties having a substantial impact on the different physical-chemical and biological processes in soil and hence they should be kept optimal (Lal 1991). For this reason, it is essential to know the soil physical properties not only during the growing season, but also after the harvest of agricultural crops. They may condition the potential of growing crops in crop rotation as well as the choice of the soil tillage method.

There are no recorded data or experiences on the influence of different tillage systems on the soil physical properties in agroclimatic conditions of the region of northwest Slavonia. The general objectives of this experiment were to determine the influence of different tillage system on the soil physical properties and their influence on crop yield within common crop rotation on a silty loam soil, covering a significant area of the region of northwest Slavonia.

MATERIAL AND METHODS

The experiment was performed on an Albic Luvisol (according to FAO Classification 1990) at a location belonging to the agricultural firm Poljoprivreda Suhopolje, located 150 km north-east from Zagreb (45°50 N, 17°26 E). Experimental field consisted of 15 plots, each with length 100 m and width 28 m, organized as randomized blocks with three replications. The soil on the site belongs by its texture to the silty loam (22% clay, 69% silt and 9% sand). The soil is acid with pH 5.6 (measured in water) and pH 4.9 (measured in 1M KCl) with 2.7% organic matter. The climate is semihumid, average annual precipitation of 817 mm and average annual temperature of 11.1°C. Average precipitation and air temperature during experimental period are shown in Table 1.

Five tillage systems and implements, which were included in some system, are as follows:

1. Conventional tillage – plough, disc harrow, seedbed implement (CT)
2. Reduced conventional tillage – plough, seed bed implement (RT)
3. Conservation tillage I – chisel plough, power harrow (CP)
4. Conservation tillage II – chisel plough, multitiller (CM)
5. No-tillage system – no-till planter (NT)

In the season of 1995–1996, this field was in a resting stage. The previous crop in the season of 1994–1995 was winter barley, and the tillage was conventional. In the first year of experiment, primary tillage with mouldboard plough and chisel plough was done on October 14, 1996. Secondary tillage with disc harrow, seedbed implement, power harrow, and multitiller, was done on April 15, 1997. Field was sawn with soybean (*Glycine max* L.), cultivar Gordana, on April 18, 1997. Soybean was harvested on October 06, 1997. In the second year, primary tillage was done on October 23, 1997, and secondary tillage on October 28, 1997. Field was sawn with winter wheat (*Triticum aestivum* L.), variety Manda, on October 30, 1997. Winter wheat was harvested on July 07, 1998. Third year primary tillage was performed on October 25, 1998, and secondary tillage on April 15, 1999. Soybean was sawn May 02, 1999, and harvested on October 21, 1999. Fourth year primary tillage for winter wheat was done on October 23, 1999, and secondary tillage on October 25, 1999. Winter wheat was sawn on October 26, 1999, and harvested on July 03, 2000. Fertilizing and crop protection were uniform for the whole experimental field. Undisturbed soil samples were collected immediately after harvesting from non-traffic zone. Sampling was carried out by sampling cylinders of 100 cm^3 volume by Kopecky method at soil layers 0–5, 15–20, and 30–35 cm, respectively, in three replicates. Soil physical properties were determined as follows: soil texture analysis was carried out by pipette method, while samples were prepared by Na-pyrophosphate, soil bulk density and water holding capacity by Kopecky's cylinders, total porosity was calculated from bulk density and particle density, air capacity was calculated as a difference between total porosity and water holding capacity, and soil moisture content was determined by gravimetric method. The data were analysed using analysis of variance (ANOVA). A Duncan's test was used to compare the mean values when a significant variation was highlighted by ANOVA. The differences were accepted as significant if $P < 0.05$.

RESULTS AND DISCUSSION

This study of the soil physical properties was based on samples taken at the end of the growing season (immediately after harvesting) of the tested crops, soybean and winter wheat. Bulk density is usually used as the most important parameter of the soil physical status. The average bulk density (Bd) for all variants, depths and years was 1.50 $mg.m^{-3}$. The average bulk density for all years and depths per particular tillage systems varied from 1.46 (CM), 1.49 (CT), 1.50 (CP), 1.52 (NT) to 1.53 $mg.m^{-3}$ (RT). A statistically significant difference was recorded only between CM and RT tillage systems. However, analyzing the differences in the average values of all depths between particular tillage systems for each year separately, no significant differences between tillage systems were recorded for winter wheat of both growing seasons (1997 and 1999). For soybeans grown in 1997 (first investiga-

Table 1. Average precipitation and air temperature during growing season of soybean (1997 and 1999), winter wheat (1997/1998 and 1999/2000) and thirty-years average (1965–1994)

Month	Precipitation (mm)					Air temperature (°C)				
	1997	1998	1999	2000	1965–1994	1997	1998	1999	2000	1965–1994
January		89.9	32.0	5.0	47.5		3.3	0.9	–0.7	0.1
February		2.5	85.1	20.3	45.9		6.0	2.0	5.0	1.6
March		57.6	26.6	43.8	65.0		5.4	8.6	7.6	6.4
April	53.4	77.8	92.8	52.4	61.3		12.7	12.5	14.5	11.2
May	81.5	90.0	86.4	55.9	82.1		15.9	17.1	17.8	16.2
June	101.1	62.8	157.9	40.8	102.9		21.5	19.8	18.8	19.0
July	144.7	163.8	135.9		61.6		21.3	21.8		21.8
August	77.6	143.0	83.1		75.0		21.0	20.9		21.2
September	2.3	115.7	48.8		69.9		15.4	18.7		17.2
October	79.2	131.3	44.4		68.6	9.1	12.8	11.5		11.2
November	89.7	93.5	132.3		62.3	5.8	4.1	3.7		5.0
December	97.7	40.2	56.9		75.2	2.9	–2.3	1.7		1.9

Table 2. Soil physical properties after soybean (1997 and 1999) and winter wheat (1998 and 2000) harvesting

Tillage system	Depth (cm)	Soybean 1997					Winter wheat 1998					Soybean 1999					Winter wheat 2000				
		Bd	P	Cw	Ca	Wc	Bd	P	Cw	Ca	Wc	Bd	P	Cw	Ca	Wc	Bd	P	Cw	Ca	Wc
CT	0–5	1.35	48.08	38.12	9.96	20.87	1.45	44.23	37.69	6.54	25.92	1.42	45.38	37.86	7.52	24.83	1.46	43.85	37.55	6.30	21.60
	15–20	1.48	43.08	37.16	5.92	19.35	1.54	40.77	35.83	4.94	25.10	1.47	43.46	36.14	7.32	26.81	1.56	40.00	34.86	5.14	24.74
	30–35	1.45	44.23	37.37	6.86	18.51	1.60	38.46	35.03	3.43	22.12	1.51	41.92	37.30	4.62	25.82	1.58	39.23	36.30	2.93	25.52
	avg	1.43	45.13	37.55	7.58	19.58	1.53	41.15	36.18	4.97	24.38	1.47	43.59	37.10	6.49	25.82	1.53	41.03	36.24	4.79	23.95
RT	0–5	1.47	43.46	36.35	7.11	21.35	1.47	43.46	38.08	5.38	27.22	1.48	43.08	36.28	6.80	26.31	1.46	43.85	38.37	5.48	22.25
	15–20	1.55	40.38	36.11	4.27	19.57	1.57	39.62	35.39	4.23	24.31	1.53	41.15	36.63	4.52	27.52	1.56	40.00	35.26	4.74	24.26
	30–35	1.51	41.92	36.30	5.62	18.42	1.61	38.08	34.96	3.12	21.43	1.54	40.77	35.57	4.20	25.71	1.59	38.85	35.63	3.22	25.85
	avg	1.51	41.92	36.25	5.67	19.78	1.55	40.39	36.14	4.24	24.32	1.52	41.67	36.49	5.17	26.51	1.54	40.90	36.42	4.48	24.12
CP	0–5	1.40	46.15	37.33	8.82	19.97	1.45	44.23	38.26	5.97	27.50	1.43	45.00	37.85	7.15	27.22	1.44	44.62	37.97	6.65	24.50
	15–20	1.51	41.92	37.23	4.69	20.95	1.56	40.00	35.44	4.56	27.11	1.52	41.54	35.87	5.67	30.61	1.56	40.00	34.38	5.62	26.68
	30–35	1.46	43.85	37.26	6.59	18.05	1.59	38.85	35.21	3.64	23.90	1.48	43.08	36.61	6.47	29.24	1.57	39.62	34.69	4.93	27.85
	avg	1.46	43.97	37.27	6.70	19.66	1.53	41.03	36.30	4.72	26.17	1.48	42.21	36.78	6.43	29.02	1.52	41.41	35.68	5.73	26.34
CM	0–5	1.34	48.46	38.03	10.43	22.60	1.44	44.62	37.92	6.70	28.22	1.40	46.15	36.43	9.72	26.35	1.43	45.00	37.90	7.10	24.05
	15–20	1.34	48.46	38.34	10.12	21.80	1.53	41.15	35.33	5.82	27.61	1.43	45.00	36.15	8.85	31.14	1.54	40.77	34.20	6.57	25.90
	30–35	1.38	46.92	39.34	7.58	21.60	1.59	38.85	34.05	4.80	24.13	1.47	43.46	35.52	7.94	29.82	1.57	39.62	34.47	5.15	28.15
	avg	1.35	47.95	38.57	9.38	22.00	1.52	41.54	35.77	5.77	26.65	1.43	44.87	36.03	8.84	29.10	1.51	41.80	35.52	6.27	26.03
NT	0–5	1.31	49.62	38.39	11.23	22.95	1.42	45.38	38.59	6.79	29.12	1.37	47.31	38.11	9.20	28.35	1.42	45.38	38.17	7.21	26.61
	15–20	1.58	39.23	35.06	4.17	23.35	1.57	39.62	35.70	3.92	27.64	1.57	39.62	34.27	5.35	34.27	1.57	39.62	35.52	4.10	28.20
	30–35	1.58	39.23	35.78	3.45	22.20	1.63	37.31	34.68	2.63	26.41	1.57	39.62	35.81	3.81	32.41	1.60	38.46	34.85	3.61	29.52
	avg	1.49	42.69	36.41	6.28	22.83	1.54	40.77	36.32	4.45	27.72	1.50	42.18	36.06	6.12	31.68	1.53	41.15	36.18	4.44	28.11
LSD ($P < 0.05$)		0.089	3.451	3.985	2.827	3.000	0.071	3.318	2.920	2.125	3.301	0.069	3.198	3.640	3.124	3.211	0.075	3.110	3.125	2.325	3.945

Bd = bulk density ($mg.m^{-3}$), P = total porosity (vol. %), Cw = water holding capacity (vol. %), Ca = air capacity (vol. %), Wc = soil moisture (vol. %), avg = average, *LSD* = least significant difference

Table 3. Average yields of winter wheat and soybean (mg.ha^{-1})

Tillage system	Soybean 1997	Winter wheat 1998	Soybean 1999	Winter wheat 2000
CT	3.46	5.75	2.64	5.42
RT	3.09	5.27	2.49	5.22
CP	2.96	5.51	2.57	5.49
CM	3.40	5.89	2.71	5.73
NT	3.26	5.73	2.60	5.62
LSD ($P < 0.05$)	0.36	0.58	0.29	0.52

LSD = least significant difference

tion year), a significant difference was determined between CM and RT, CP or NT systems. For soybeans grown in 1999, a significant difference was determined between CM and RT or NT systems (Table 2). Significant differences in bulk density between different tillage systems were recorded at particular soil depths. The lowest average value for all four years was determined for the depth of 0–5 cm, where it varied from 1.38 (CM) to 1.47 mg.m^{-3} (RT). At the depth of 15–20 cm, it ranged from 1.46 (CM) to 1.57 mg.m^{-3} (NT), while at the depth of 30–35 cm it varied from 1.50 (CM) to 1.60 mg.m^{-3} (NT). According to Lhotský (1991), soil bulk density above 1.50 mg.m^{-3} in the plough horizon on medium heavy soils has a negative effect on the growth and development of agricultural crops and is regarded as the threshold value of adverse soil compaction. Similar results were reported also by Butorac et al. (1992). They recorded the highest soybean yield on Luvisol with the average bulk density of 1.40 mg.m^{-3}, while a much lower yield was obtained with the bulk density of 1.60 mg.m^{-3}. Soils with a high bulk density of the sub-plough horizon have also poor internal drainage and are characterized by reduced root growth, resulting in a substantial yield decrease (Varsa et al. 1997). Under soybeans of both growing seasons, it was only in CM tillage system that no bulk density values above 1.50 mg.m^{-3} were recorded, while in other systems significantly higher values than the given one were recorded at the depths of 15–20 and 30–35 cm. The highest values, as high as 1.58 mg.m^{-3}, were recorded in NT and RT tillage systems. Under winter wheat in both growing seasons, at the depths of 15–20 cm and 30–35 cm in all tillage systems, values higher than the said soil compaction threshold were recorded as well as the highest value at all being 1.63 mg.m^{-3}. Soil bulk density under soybeans grown in 1999 and under winter wheat grown in 1999/2000 was significantly higher than the bulk density under these crops from the initial growing seasons, which confirms the trend of increasing bulk density and soil compaction under the same tillage systems. Similar results on the increase of bulk density compared to the first investigation year were reported also by Kováč and Žák (1999a). For normal growth and development of most agricultural crops, the surface soil layer to the sowing depth should have a bulk density about 1.00 mg.m^{-3}, and the layer in which the seed is sown 1.30–1.45 mg.m^{-3} (Miština and Kováč 1993). However, such conditions were not recorded in our study.

Higher bulk density reduced total porosity and changed the ratio of water holding capacity to air capacity in favour of water holding capacity. The average total porosity (P) for all variants, depths and years was 42.42%. Total porosity for all years and depths per particular tillage systems varied from 44.04% (CM), 42.72% (CT), 42.41% (CP), 41.70% (NT) to 41.22% (RT). Total porosity below 45% on medium heavy soils had a negative effect on plant growth (Lhotský 1991). The average soil water holding capacity (Cw) for all variants, depths and years was 36.46%. Very small differences in average Cw were determined for all four years compared to particular tillage systems, the values ranged from 36.24% (NT) to 36.77% (CT). The recorded differences were not statistically significant. The average soil air capacity (Ca) for all variants, depths and years was 5.95%. The average Ca for all years and depths per particular tillage systems ranges from 4.89% (RT), 5.46% (NT), 5.90% (CP), 5.96% (CT) to 7.57% (CM). Analyzing the differences in average Ca values of all depths between particular tillage systems for each year separately, no significant difference was recorded under winter wheat of both growing seasons. Under soybeans of both growing seasons, a difference in Ca was recorded only between RT and CM. Since air capacity below 10% is a limiting factor for the growth of agricultural crops because it has a substantial impact on yield (Racz 1981), this limit is regarded as the threshold value (Kováč and Žák 1999b).

The average soil moisture content (Wc) for all variants, depths and years was 25.19%. The average moisture for all investigation years and depths per particular tillage systems ranged from 23.43% (CT), 23.68% (RT), 25.30% (CP), 25.95% (CM) to 27.59%(NT). Statistically significant differences were recorded between NT and CT or RT tillage systems. Based on the differences in average moisture values of all depths among particular tillage systems for each year separately, significant differences were recorded for soybeans grown in 1997 between NT and CT, RT or CP systems. Similar results were also obtained for soybeans grown in 1999, where significant differences were recorded between NT and CT or RT, as well as between CT and CM tillage systems. Differences in average moisture values recorded for winter wheat of both growing seasons are significant only between NT and CT or RT tillage systems. The lowest average moisture content of all years per particular tillage systems at the depth of 0–5 cm was determined in CT and at 15–20 and 30–35 cm in RT, while the highest moisture content at all three depths were recorded in NT system. At the depth of 0–5 cm the recorded difference is significant only between NT and CT, at the depths of 15–20 and 30–35 cm between NT and CT or RT tillage systems. Average soil moisture values of all years point to the trend of increased moisture in NT and CM tillage systems compared to CT and RT systems. Statistically significant differences were determined only between NT and CT or RT tillage systems. Grevers et al. (1986) and Lyon et al. (1998) reported similar results.

In general, differences between tillage systems were more obvious in soybean seasons than in winter wheat seasons. The deterioration trend of physical properties could be described as descent from CM, CT, CP and NT to RT tillage systems. Lindstrom and Onstad (1984), and Mielke and Wilhelm (1998) also reported similar results on substantial deterioration of soil physical properties with no-till system, as compared to conventional tillage, as a result of increased bulk density.

The highest yield of soybean in the first experimental year was achieved under CT system and the lowest under CP system. Significantly, lower yield, in comparison with CT system, was achieved under RT and CP systems (Table 3). In other three experimental years, the highest yield of winter wheat and soybean was achieved under CM system, while the lowest under RT system, but the difference was significant only in winter wheat season 1997/1998. It is evident that CM tillage system that produced the most favourable soil physical properties achieved the highest yield, while the most unfavourable soil physical properties and the lowest yield were under the RT system. Further analysis of the soil physical properties influence on the achieved yield showed that bulk density and total porosity significantly influence crop yield. So, between crop yield and bulk density there was a strong reciprocal dependence (–0.558 for soybean and –0.592 for winter wheat), while between crop yield and total porosity there was a strong direct dependence (0.598 for soybean and 0.614 for winter wheat).

CONCLUSIONS

Experiment showed that soil physical properties were influenced by different tillage systems in soybean and winter wheat production on silty loam. The most favourable soil physical properties (the lowest bulk density and the highest total porosity) were recorded under conservation tillage system (CM), while the most unfavourable were under reduced tillage system (RT). Differences between tillage systems were more obvious in soybean seasons. Among monitored soil physical properties, strong reciprocal dependence was found between crop yield and soil bulk density, and strong direct dependence between crop yield and total porosity. The highest crop yields except in the first experimental year were achieved under the CM system, while the lowest under the RT system.

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ABSTRAKT

Vliv různých systémů obdělávání půdy na fyzikální vlastnosti půdy a výnos plodin

V letech 1997 až 2000 jsme v severozápadní Slavonii prováděli pokus s pěti různými systémy obdělávání půdy a jejich vlivem na fyzikální vlastnosti písčitohlinité půdy (ilimerizované půdy). Porovnávali jsme tyto systémy obdělávání půdy: 1. tradiční orba (CT), 2. redukované zpracování půdy (RT), 3. ochranné zpracování půdy I (CP), 4. ochranné zpracování půdy II (CM), 5. bezorebný systém (NT). V osevním postupu jsme pěstovali sóju (*Glycine max* L.) – ozimou pšenici (*Triticum aestivum* L.) – sóju – ozimou pšenici. V letech s ozimou pšenicí jsme nezaznamenali významné rozdíly mezi systémy obdělávání půdy v objemové hmotnosti půdy, celkové pórovitosti půdy, retenci vody v půdě a vzdušné kapacitě půdy. V letech se sójou jsme zjistili významné rozdíly mezi některými systémy obdělávání půdy v objemové hmotnosti, celkové pórovitosti půdy, vzdušné kapacitě půdy a obsahu půdní vláhy. Trend zhoršování fyzikálních vlastností půdy obecně narůstal v pořadí CM, CT, CP, NT a RT. Nejvyšší výnos sóje v prvním pokusném roce byl dosažen v systému CT a nejnižší v systému CP. Ve všech ostatních pokusných letech byl nejvyšší výnos ozimé pšenice a sóje zaznamenán v systému CM a nejnižší v systému RT.

Klíčová slova: fyzikální vlastnosti půdy; tradiční orba; systémy ochranného obdělávání půdy; ozimá pšenice; sója

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