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EFFECTS OF LONG-TERM USE OF APPLE ORCHARDS ON SOME ASPECTS OF SOIL PHYSICAL QUALITY

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Abstract. The study reported here was aimed at the estimation of the effects of over 15-years of cultivation of apple trees on the physical status of soil in orchards situated on various soils. The study was conducted on soils with silty particle size distributions (a Haplic Chernozem developed from loess, a Haplic Luvisol developed from loess (1), a Haplic Luvisol (non-uniform), developed from silt (2), and a Fluvic Cambisol developed from silty formations). The determinations included the particle size distribution and the density of the soils, solid phase density, total porosity (*TP*), field water capacity (*FC*). In addition, the quality of the air-water relations was analysed, determining the values of *FC/TP* ratio. The study showed that the values of the parameters under analysis were affected by the soil type, genetic horizon, soil layer, and also by the intensity of orchard care. Long-term maintenance of herbicide belts had a fairly beneficial effect on the physical status of the soils under study. A slight compaction of soil was noted (in comparison with the normal consolidation system of weakly-compacted one) as well as very good water properties. It is predicted that, only at the state of field saturation of the soil with water, conditions occurred that inhibited gas exchange between the soil and the atmosphere.

Keywords: multi-year orchard cultivations, apple tree, physical properties of soil

INTRODUCTION

Apple trees are the most common type of fruit tree grown in orchards in Poland. An intensive development of fruit-farming, mainly apple orchards, took place after 2000, when the process of replacing short-trunk production orchards with dwarf tree orchards was begun, at the same time increasing tree density per area unit from 1600 to 3000 per 1ha (Makosz 2014). For over a dozen years there has also been an increase in the area of apple tree cultivation, and in the level of mechanisation of the treatments performed. The level and quality of orchard production are significantly affected by soil and weather conditions, and by the method of orchard care. In modern pomology the conventional cultivation treatments such as ploughing, cultivator tillage or harrowing are applied only at the time of soil preparation for new plantings (Glover *et al*. 2000, Forge *et al*. 2003, Mika 2010). In the course of subsequent orchard use mechanical tillage has been totally abandoned in favour of other agricultural treatments such as the use of herbicides. Also typical is multi-year application of uniform fertilisation and repeated care treatments in orchards (Glover *et al.* 2000, van Dijck and van Asch 2002, Mika 2010).

In the past soil maintenance systems in orchards were undergoing changes. After the Second World War standard trunk orchards were dominant, where ploughing was applied on practically the entire orchard area (Pieniążek 2000). Later on, with the introduction of short-trunk trees, narrow belts of turf grass were used, and black fallow with cover crops for green manure in the inter-rows. In the sixties, triazine herbicides came into common use, replacing the turf grass belts with belts of herbicide fallow. The standard method of orchard soil care in the nineties of the last century was the maintenance of herbicide fallow in the rows of trees and turfgrass in the inter-rows. That system ensured favourable conditions for plant growth and development, eliminating weed competition, especially in tree rows (Lipecki 1998, Pieniążek 2000).

Out of care for the environment, towards the end of the past century new methods of orchard soil care were developed, conforming to the requirements of environmental protection. Among other things, it was recommended to apply soil mulching in tree rows, using organic (straw, sawdust, bark) or synthetic materials (polyethylene foil, polypropylene unwoven fabric), to maintain narrow strips of herbicide fallow, black mechanical fallow, permanent grass over the whole area, or to maintain grass only in the inter-rows (Lipecki 1998, Stojanowska 1998).

A method of soil care commonly applied in recent years in orchards is the maintenance of narrow belts of herbicide fallow in tree rows and grass in the inter-rows.

Chemical weed control in orchards is the cheapest and the easiest way of soil care in tree rows. This method, as a relatively inexpensive one, ensures weed elimination for a longer period of time. Under herbicide fallow tree roots can grow without hindrance, which allows full utilisation of mineral fertilisation. The soil displays a slower depletion of humus and a more stable structure than soil under mechanical fallow. Soil pores are not destroyed and this ensures soil air exchange and water filtration (VandenBygaart *et al.* 2000, Emerson and McGarry 2003, Eynard *et al*. 2004).

Turfgrass maintenance in an orchard consists in permanent sod formation on soil surface between tree rows. That is usually applied after several years from orchard establishment. It consists in sowing seeds of a mixture of poorly growing grasses, with low water and nutrient requirements, in the inter-rows. The benefits of that treatment result from increased influx of organic matter to the soil, increased humus content in the soil, formation of stable aggregate structure in the soil, allowing tractor traffic, and from the protection against water and air erosion of the soil (Hogue and Nielsen 1987). A shortcoming of permanent turf grass on the soil surface in orchards is the strong competition to trees in the availability of water and nitrogen. This often causes the necessity of irrigation and supplemental fertilisation with nitrogen. In young orchards, where the competition is more intense, it is not recommended to use turf grass (Link 1997, Bielińska 1999).

Proper soil status is determined by a combination of its suitable physical, physicochemical, chemical and biological properties. The relations among those soil properties determine soil quality (Karlen *et al.* 1997, 2003, Carter 2002).

Soil is a significant part of natural resources, and therefore its rational use is an important element of sustainable development (Andrews *et al.* 2003, Schjønning *et al.* 2004). Soil quality is becoming the main element in land management strategy as it affects the living conditions of all organisms, including humans (Arshad and Martin 2002).

The primary objective of the study was to determine the effect of long-term apple tree cultivation on the physical propoerties of soil in orchards situated in four different mesoregions of the Lublin Region. The study was conducted on soils with silt particle size distributions (a Haplic Chernozem developed from loess, a Haplic Luvisol developed from loess (1), a Haplic Luvisol (non-uniform), developed from silt (2), and a Fluvic Cambisol developed from silty formations). The scope of the study comprised the determination of the basic soil quality parameters such as particle size distribution, compaction, air-water relations. The evaluation of the soils under study was performed on the basis of comparison of the results obtained with the accepted reference values for the selected properties.

MATERIAL AND METHODS

The study was conducted in four apple orchards. The orchards selected for the study were short-trunk semi-dwarf apple trees orchards (c.v. Idared on M26 rootstock) with over 15-years period of intensive use. The objects selected were situated within various physical-geographic units of the Lublin Region (4 mesoregions), included in the Wołyń Upland and the Lublin Upland (Kondracki 2000) (Tab. 1).

The soils used were from the good wheat complex, with silt particle size distribution. With regard to typology (IUSS Working Group WRB 2006) they are characteristic of the mesoregions and occupy a majority of their surface areas (Turski *et al.* 1993, Turski and Słowińska-Jurkiewicz 1994). The land relief of all of the experimental sites was essentially flat. The measurement sites were situated on elevated areas.

Table 1. Geographic situation of research objects

Research objects	Geographic coordinates
Haplic Chernozem developed from loess	50° 35' 05" N
Sokalska Ridge	23° 54' 19" E
Haplic Luvisol developed from loess (1)	51° 20' 51" N
Nałęczowski Plateau	22° 16' 46" E
Haplic Luvisol, (non-uniform, developed from silt (2)	50° 58' 31" N
Giełczewska Prominenc	22° 46' 11" E
Fluvic Cambisol developed from silt formations	51° 10' 15" N
Małopolski Water Gap of the Vistula	21° 50' 39" E

The cultivation system in the orchards was traditional, with herbicide belt and turf strip. The herbicide fallow was maintained in the tree rows with the use of herbicides from the group of aminophosphonates (glyphosate). The orchards were fertilised mainly with nitrogen, in the form of ammonium nitrate (34%), every year at the dose of 100 kg N ha^{-1}. Pesticides and agents for tree disease control were applied in conformance with the recommendations of the program of protection of apple orchards (Mika 2010).

Soil samples for analysis were taken from the herbicide belts. The samples were taken from layers of 0-10 cm and 10-20 cm, isolated from the arable-humus (Ap) or humus (Ah) horizons. In addition, samples were also collected from outside of the immediate reach of working elements of agricultural machines and implements, from soil layer situated below 35 cm. That encompassed the following genetic horizons of the soils: Ah2 in Haplic Chernozem, Bt in Haplic Luvisol, and AC in the case of Fluvic Cambisol. To determine the physical status of the soil, samples with undisturbed structure (Polish Committee for Standardisation 2001) were taken, in ten replicates, into metal cylinders with volume of 100 cm^3, from the layers of 2-7 cm, 12-17 cm and 35-40 cm. The samples were used to determine the field water capacity (Klute 1986). Soil samples (approx. 1 kg) for the determination of the remaining physical soil properties were taken separately. Analyses and measurements performed:

– granularity of the soils was determined on the basis of assays of particle size distributions with the sedimentation-areometric method of Bouyoucos as modified by Casagrande and Prószyński (Polish Society of Soil Science (PSSS) 2009),

– particle density (*PD*) – with the pycnometric method; Mg m^{-3},

– bulk density (*BD*) – with the gravimetric method, on the basis of the ratio of the mass of soil dried at 105°C to the initial soil volume of 100 cm^3; Mg m^{-3},

– total porosity (*TP*) was calculated on the basis of results of particle density (*PD*) and bulk density (*BD*), $TP = 1-BD/PD$; m^3 m^{-3},

– field water capacity (*FC*) was calculated from the ratio of the volume of water contained in the soil at the potential of −15.5 kPa to the soil volume (m^3 m^{-3}), In addition, analysis of the quality of the air-water relations of the soil was performed determining the values of *FC/TP* ratio (Skopp *et al.* 1990, Olness *et al.* 1998, Reynolds *et al.* 2008).

Statistical evaluation of the results was conducted with the use of analysis of variance (two-way ANOVA – object-soil × soil layer). All pairs of means were compared with the use of the Tukey's method and the honestly significant difference test (HSD). The statistical evaluation was conducted assuming the significance level of 0.05.

RESULTS AND DISCUSSION

The distribution of soil particle size fractions obtained in this study permitted the classification of the soils studied into suitable particle size groups and subgroups (Polish Society of Soil Science (PSSS) 2009). It was found that among all soil samples analysed all were classified in the silt group (tab. 2). The studied soils were classified in the following particle size subgroups: in 6 cases it was clay silt (SiL) and also in 6 cases loamy silt (SiL).

Table 2. Granularity of soils under study – particle size distribution (%)

Studied soils	Horizon	Layer cm	Particle size fraction			Particle size subgroup granulometryczna (PSSS 2009)
			2.0-0.05 mm	0.05-0.002 mm	<0.002 mm	
Haplic Chernozem	Ap	0-10	13	74	13	SiL - pyi
developed from	Ap	10-20	14	71	15	SiL - pyi
loess	Ah	>35	13	70	17	SiL - pyi
Haplic Luvisol (1)	Ap	0-10	14	72	14	SiL - pyi
Developed from	Ap	10-20	17	68	15	SiL - pyi
loess	Bt1	>35	17	66	17	SiL - pyi
Haplic Luvisol (2)	Ap	0-10	22	73	5	SiL - pyg
(non-uniform),	Ap	10-20	21	73	6	SiL - pyg
developed from silt	Bt1	>35	20	72	8	SiL - pyg
Fluvic Cambisol	Ap	0-10	43	52	5	SiL - pyg
developed from silt	Ap	10-20	40	51	9	SiL - pyg
formations	AC	>35	40	52	8	SiL - pyg

The Haplic Chernozem and Haplic Luvisol (1) were characterised by highly similar granularity. They contained 13-17% of the coarsest fraction (sand, 2.0-0.05 mm), 66-74% of the silt fraction (0.05-0.002 mm), and 13-17% of the finest fraction – clay (< 0.002 mm). Whereas, Haplic Luvisol (2) and, especially, Fluvic Cambisol were considerably more sandy. The content of the sand fraction in those soils varied from 20 to 43%, that of the silt fraction from 51 to 73%, and that of the clay fraction from 5 to 9% (Tab. 2).

Table 3. Selected physical properties of the soils under study

Studied soils	Horizon	Layer	*PD*	*BD*	*TP*	*FC*	*FC/TP*
		cm	Mg m^{-3}		m^3·m^{-3}		
Haplic Chernozem developed from loess	Ap	0-10	2.58 a	1.27 ab	0.509 bcd	0.386 bc	0.76 abc
	Ap	10-20	2.59 ab	1.37 ab	0.471 ab	0.385 bc	0.82 bc
	Ah	>35	2.61 abc	1.31 ab	0.498 abc	0.372 bc	0.75 abc
Haplic Luvisol (1) developed from loess	Ap	0-10	2.60 abc	1.13 a	0.565 d	0.338 abc	0.60 a
	Ap	10-20	2.64 cd	1.35 ab	0.489 abc	0.374 bc	0.76 abc
	Bt1	>35	2.66 d	1.40 ab	0.474 ab	0.386 bc	0.82 bc
Haplic Luvisol (2) (non-uniform), developed from silt	Ap	0-10	2.63 cd	1.43 b	0.455 ab	0.353 bc	0.78 bc
	Ap	10-20	2.65 cd	1.47 b	0.444 ab	0.356 bc	0.80 bc
	Bt1	>35	2.65 cd	1.43 b	0.461 ab	0.340 abc	0.74 abc
Fluvic Cambisol developed from silt formations	Ap	0-10	2.62 bc	1.35 ab	0.484 ab	0.325 abc	0.67 ab
	Ap	10-20	2.64 cd	1.49 b	0.436 a	0.302 ab	0.69 abc
	AC	>35	2.65 cd	1.50 b	0.435 a	0.275 a	0.63 ab

Explanations: *PD* – particle density, *BD* – bulk density, *TP* – total porosity, *FC* – field water capacity. Different letters (a, b, c) mean; statistically significant differences (P ≥0.05) (object-soil × soil layer) according to the Tukey's honestly significant difference test (HSD)

The differences noted in the granularity of the soils can be considered as small, resulting most likely from the origin of the soils (Turski *et al.* 1993, Konecka-Betley 2009), with probably no anthropogenic influence caused by intensive long-term use (Turski and Słowińska-Jurkiewicz 1994). The different nature of the Fluvic Cambisol in terms of its granularity results, as in the case of the chernozem and the Haplic Luvisols, from its pedogenesis, and especially from the character and run of the process of sedimentation on alluvial material. That material was periodically deposited on the flood plain by high water levels characterised by diverse values, dynamics, and times of sedimentation (Pranagal and Ligęza 2009).

The results of *PD* attained values typical for the soils under study (tab. 3). They varied only slightly, mainly with regard to the soil type, genetic horizon, and soil layer. The values of that soil property increased every time with the depth at which the analysed genetic horizons and soil layers were situated (0-10, 10-20 and > 35 cm). The lowest values of particle density were characteristic of the surface layer of the soils (0-10 cm), especially in horizon Ap of the chernozem (2.58 Mg m^{-3}). That was most probably due to the greater content of organic matter in those layers (Pranagal 2009). Wojtasik (1989, 1995) also emphasised in his studies the importance of the relation between the humus content of soil and the value of its density.

According to certain authors (Ślusarczyk 1979, Pabin *et al.* 1998) the bulk density of the soil analysed in this study falls within the range of optimum values for arable mineral soils. The low, and fairly uniform within the pedon, mean value of *BD* of the chernozem developed from loess (Tab. 3) was an obvious example of the relation between bulk density and organic matter content (Wojtasik 1989, 1995, Mendoza *et al.* 2008). During the period of measurements the chernozem was characterised by a normally compact structure (layer of 0-10 cm) and weakly compacted (layers of 10-20 cm and > 35 cm) (Święcicki *et al.* 1972). However, for the achievement of maximum yields its *BD*, as indicated by Olness *et al.* (1998) and Drewry *et al*. (2008), was too high as it could have caused an inhibition of gas exchange between the soil and the atmosphere (Carter 1988, McQueen and Shepherd 2002). The Haplic Luvisol (1) developed from loess (Tab. 3) was characterised primarily by a weakly compacted structure (10-20 cm and <35 cm) and normally compact (0-10 cm) (Święcicki *et al.* 1972), and as in the case of the chernozem one could expect the occurrence of interference in the aeration of that soil (Carter 1988, McQueen and Shepherd 2002). The incomplete Haplic Luvisol (2) developed from silt was similar, in terms of its compaction structure (Święcicki *et al.* 1972), to the loess-derived Haplic Luvisol (weakly compacted structure), though its compaction was higher. Also in that soil there could be limitations in soil air movement and plant yields (Carter 1988, McQueen and Shepherd 2002, Drewry *et al.* 2008). The Vistula Fluvic Cambisol (Tab. 3) had a weakly compacted structure (Święcicki *et al.* 1972). The level of compaction of the Fluvic Cambisol, in the opinion of many authors (McQueen and Shepherd 2002, Drewry *et al.* 2008, Reynolds *et al.* 2008), could also be a factor limiting its productivity.

Total porosity of not less than 0.500 m^3 m^{-3} is the condition that has to be fulfilled to ensure soil air-water relations favourable for plants (Thompson and Troeh 1978, Kowda 1984). However, that condition is often insufficient as proper relations between the two antagonistic phases of soil, the liquid and the gaseous, are determined also by a suitably developed pore structure (Skopp *et al.* 1990, Cockroft and Olsson 1997, Olness *et al.* 1998, Walczak *et al.* 2002, Reynolds *et al.* 2008).

TP of the chernozem was generally very close to the value of 0.500 m^3 m^{-3}, and varied within the range of 0.471-0.509 m^3 m^{-3} (Tab. 3). Similar results were noted also in the case of the Haplic Luvisol (1), for which total porosity assumed values in the range of 0.474-0.565 m^3 m^{-3} (Tab. 3). Whereas, in the case of the incomplete Haplic Luvisol (2) (Tab. 3) a greater compaction of soil mass was observed, as its total porosity varied from 0.444 to 0.461 m^3 m^{-3} and was distinctly different than the reference values (Thompson and Troeh 1978, Kowda 1984). The Fluvic Cambisol had the smallest volume of free spaces among the soils studied, as its total porosity was in the range of 0.435-0.484 m^3 m^{-3} (Tab. 3). The *FC/TP* index defines the expected value in the relations between soil moisture and aeration. Skopp *et al*. (1990) and Olness *et al.* (1998) are of the opinion that the best for plants air-water relations in soil are those when the ratio of field water capacity to total porosity *FC/TP* = 0.66. This means that 66% of soil pores should be filled with water, and 34% - with air. A similar view was presented also by Reynolds *et al.*

(2008) who indicated that the optimum is met when *FC/TP* falls within the range of 0.60-0.70. According to those authors (Reynolds *et al.* 2008), field water capacity *FC* should assume values in the range of 0.300-0.350 m^3 m^{-3}.

The Haplic Chernozem was characterised by the highest average field water capacity (Tab. 3), and the results obtained assumed values in the range of 0.372-0.386 m^3 m^{-3}. According to the classification of Walczak *et al.* (2002), it should be considered as high, and according to Reynolds *et al.* (2008), it is higher than the optimum range (0.300-0.350 m^3 m^{-3}). Only slightly lower values of the property in question, *FC*, were noted in the case of both Haplic Luvisols (Tab. 3). *FC* of Haplic Luvisol (1) developed from loess assumed values in the range of 0.338-0.386 m^3 m^{-3} and, as in the case of the chernozem, the *FC* was high (Walczak *et al.* 2002) and usually higher relative to the reference values determined by Reynolds *et al.* (2008). Measurements of field water capacity (*FC*) in the incomplete Haplic Luvisol (2) (Tab. 3) indicated high values of that property (Walczak *et al.* 2002), very close to the optimum (Reynolds *et al.* 2008), as they fell within the range of 0.340-0.356 m^3 m^{-3}.

The Fluvic Cambisol was characterised by the lowest field water capacity (Tab. 3). Compared to the other soils, the mean *FC* for that soil was the lowest, with values in the range of 0.275-0.325 m^3 m^{-3}. According to Walczak *et al.* (2002), it should be considered as high for layers of 0-10 cm and 10-20 cm, and as medium in the case of the deepest layer (< 35cm). According to Reynolds *et al.* (2008), *FC* for the surface layers (0-10 and 10-20 cm) attained the optimum, while in the case of the layer < 35 cm it was lower than the recommended level.

The results of FC/TP were notably different than the optimum (FC/TP = 0.66) given by Skopp *et al*. (1990) and Olness *et al*. (1998). In the case of the Haplic Chernozem and the Haplic Luvisols the values were most often distinctly higher than 0.70. The Fluvic Cambisol was characterised by values of the FC/TP ratio that were close to the optimum range (Reynolds *et al.* 2008). The values of FC/TP indicated very good water conditions in the Haplic Chernozem and the Haplic Luvisols, but at a state indicating sporadic inhibition of aeration (Tab. 3).

CONCLUSIONS

The estimation of the selected physical properties of soils in apple orchards after an at least 15-years period of use revealed that the changes in the properties analysed depended on the soil type and genetic horizon, and also on the intensity of soil care treatments. The maintenance of herbicide belts in the apple orchards had a fairly beneficial effect on the physical status of the soils under study. A certain slight compaction of the soil was noted (normally compact or weakly compacted structure), as well as very good water-air properties (*FC* > 0.300 m^3 m^{-3}).

Periodically, only at the state of field saturation of soil with water, conditions inhibiting gas exchange between the soil and the atmosphere may occur (*FC/TP* > 0.70). Statistical analysis permitted the statement that significant differences (HSD) were noted both for comparisons between the soils and genetic horizons.

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WPŁYW WIELOLETNIEGO UŻYTKOWANIA SADÓW JABŁONIOWYCH NA NIEKTÓRE ASPEKTY FIZYCZNEJ JAKOŚCI GLEBY

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S t r e s z c z e n i e**.** Przeprowadzone badania miały na celu ocenę wpływu ponad 15-letniej uprawy jabłoni na stan fizyczny gleby w sadach położonych na różnych glebach, w czterech wybranych mezoregionach Lubelszczyzny. Badania zostały przeprowadzone na glebach o pyłowym składzie granulometrycznym (Haplic Chernozem wytworzony z lessu, Haplic Luvisol wytworzona z lessu (1), Haplic Luvisol niecałkowita wytworzona z pyłu (2), Fluvic Cambisol wytworzona z utworów pyłowych). Określono uziarnienie i gęstość gleb, gęstość stałej fazy, porowatość ogólną (*TP*), polową pojemność wodną (*FC*) oraz przeprowadzono analizę jakości stosunków powietrzno-wodnych, wyznaczając wartości ilorazu *FC/TP*. W wyniku przeprowadzonych badań stwierdzono, że na wielkość analizowanych parametrów miały wpływ: typ gleby, poziom genetyczny, warstwa gleby, jak również intensywność pielęgnacji sadu. Wieloletnie utrzymanie pasów herbicydowych względnie korzystnie kształtowało stan fizyczny badanych gleb. Obserwowano niewielkie zagęszczenie gleby (w porównaniu z układem normalnie zwięzłym lub słabo zbitym) i bardzo dobre właściwości wodne. Przewiduje się, że jedynie w stanie polowego wysycenia gleby wodą będą występowały warunki utrudniające wymianę gazową między glebą a atmosferą.

S ł o w a k l u c z o w e: wieloletnie uprawy sadownicze, jabłoń, fizyczne właściwości gleby