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The Effect of 15 Years of Direct Drilling Application: Part I - S Index and Carbon Sequestration

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Abstract: In Poland, West Pomeranian province, (53 19′ 38″N, 14 57′ 34″E) the impact of two soil tillage systems, CC – conventional cultivation (ploughing), and DD - direct-drilling, on the bulk density, moisture, water retention characteristic, and S index of soil properties on horizon sequences (layers): 1 - 0-10, 2 - 10-20, 3 - 20-30 cm were compared.
On good-rye-soil-suitability-complex of soil, with texture of light loamy sand, with 13% of silt-and-clay content, and 1.3% of humus in topsoil the tillage systems has been executed from 1994 y.
Using the S index as an indicator of soil quality and condition gives information that a good physical condition and good structural quality were found after long time application of DD. More over the carbon average content in top layer (0-30 cm) of soil horizon after DD cultivation was measured on 32.4 ± 4.32 t per hectare. The estimated value of C content, in DD plot, was higher (+1.8 t) compared to conventional cultivation plot (CC). The analysis of data showed that the no-till system (DD) can be recommended, in Poland's weather conditions (year precipitation - 530 mm), to sandy soils cultivation.
Key words: tillage systems, no-till, direct drilling, moldboard ploughing, S index, carbon sequestration, water retention characteristics

INTRODUCTION

The changes of physical, chemical and biological properties of soil are significantly dependant on tillage system applied. The effects of compaction after tillage on crop yield have been studied in many countries (Dzienia and Wereszczaka 1993, Lal 1994, Lindstrom and Voorhees, 1994, Kotorowa and Kovać 1999, Dzienia et. al. 2001). Reduced tillage, especially direct-drilling has received much attention as a mean of soil conservation and reducing tillage costs. On sandy soil condition, Dzienia and Wereszczaka (1999), described the root development under different tillage systems

Direct-drilling system offer numerous benefits that intensive tillage systems cannot match. This system reduce labour requirement, machinery wears and save time and fuel consumption, improve long-term soil productivity and surface water quality. Reduced soil erosion, improved water infiltration and decreased soil compaction. On the other side the intensive soil tillage accelerates organic matter mineralization and converts plant residues in carbon dioxide, which is liberated to the atmosphere causing the green house effect and global warming (CTIC, 1996).

Tillage systems have a direct impact on chemical and physical properties of soil, especially on the carbon sequestering potential (Smith 1997 a, b, Lal 1999 a, Smith et al., 2000 a). The average stock of soil carbon, calculated for non organic soil in European Union, was less then 5% (about 53 $t \cdot C \cdot ha^{-1}$) for 0-30 cm depth (Smith et al., 2001 b). Whilst agricultural soils tilled every few years may contain more carbon than the same soils cultivated every year (Smith 1997 a, b).

In agricultural cropping systems the larger part of the carbon is stored in the soil. Evaluation of current and new management practices for carbon sequestration should focus on input and output of soil organic carbon. Referring to Article 3.4. of the Kyoto Protocol, a carbon sequestration in agricultural soil is desirable and suitable. Because of changes of land use and management from traditional in different ways like non-food crop production (rapeseed or maize) the carbon sequestration will be decreasing.

The moisture of soil suitable for tillage practices is the key point in seed bed preparation processes.

The optimum water content for tillage was found to be equal to the water content at the inflection point of the water retention curve, as fitted with the van Genunchten (1980) equation (Dexter and Bird, 2001, Dexter et al., 2005). Some other work on the optimum water content for tillage has used the soil Plastic Limit (PL). Arvidsson and Bolenius (2006) found with a Swedish soil that tillage at 0,75 PL produced a greater proportion of small aggregates than tillage at 0,91 PL. Keller et al. (2007) made tillage experiments in the field on four different Swedish soils. In relation to PL, they showed that 0,7 PL gave the best prediction of the optimum water content for tillage.

The Index S – theory is based on the concept of the structural stage of soil as quantified by water retention data by slope of the water retention curve at its inflection point. Soil physical parameter S can be considered as an index of the soil physical quality (Dexter 2004 a, b, c, Dexter and Czyż 2007). Values of the S can be used to give information about the size distribution of aggregates or clods produced by tillage as shown by Dexter and Birkas (2004) and Keller et al. (2007). Independently, three main properties: physical, chemical, and biological can describe soil quality, and fertility. There is a close conjunction between quality of soil and S index (Niedzwiecki et al., 2008, Pecio and Niedzwiecki 2008, Pranagal et al., 2008). The measurement of selected properties of soil takes a lot of time, and consume much energy. Searching for environmentally friendly measurements Dexter proposed an opportunity for saving natural resources and recommended S index for characteristic of structure quality. The S index provides a graduation that can be applied easily in order compare different soils or the effect of different soil physical condition and impact of soil management practices.

There is a need to look at actual data from long term field experiments with tillage systems to establishing a crop management strategies, which are aimed at saving arable land for future generation,

The paper shows results of a long – term application of direct drilling and its impact on some indices of physical condition and structure quality of sandy soil.

MATERIALS AND METHODS

In years 1994-2008 a field experiment was carried out in West Pomeranian region of Poland (53 19′ 38″N, 14 57′ 34″E) on good-rye-soil-suitability-complex of soil with texture of light loamy sand, with 13% of silt-and-clay content, and 1.3% of humus in topsoil. The trial included two plots where conventional cultivation (CC) and direct drilling (DD) have been applied since 1994 in crop rotation with 50% of cereals.

The research aimed at defining the impact of two soil tillage systems, i.e. CC – conventional cultivation (ploughing), and DD - direct-drilling, on the bulk density, moisture, and water retention characteristic, and S index of soil properties on horizon sequences (layers): 1 - 0-10, 2 - 10-20, 3 - 20-30 cm. Additionally the organic carbon content has been measured at the same layers.

In 2008 post-harvest bulk density and other physical properties of soil in compared layers were defined after the harvest of winter wheat from five sites of each plots. Soil samples were taken to a steel cylinders of 100 cm3 from 0 down to 30 cm.

Procedure for soil water retention characteristics measurements:

Water retention characteristics of the soil were measured using conventional methods at water potential of -10, -20, -40, -80, 100 hPa on a sand-table apparatus, and at -500, -2000, -4000, -8000, -15000 hPa on ceramic pressure plate extractors.

The water retention curves were fitted to the van Genuchten (1980) equation (1):

$$\theta = (\theta s - \theta r)\,[1 + (\alpha h)^{n}]^{-m} + \theta r \qquad (1)$$

with the Mualem (1976) restriction: $m = 1-1/n$

where:

θs – water content at saturation [$kg \cdot kg^{-1}$],

θr – residual water content [$kg \cdot kg^{-1}$],

h – pressure head [hPa],

α - adjustable scaling factor [hPa^{-1}],

n – adjustable shape factor.

Index of soil physical quality S was defined by Dexter (2004 a, b, c). It is equal to the slope of the soil water retention curve at its inflection point (Eq. 2). The equation was derived by Dexter (2004a,b,c) from Eq. 1.

$$S = -n \cdot (\theta s - \theta r) \cdot \left[\frac{2n-1}{n-1}\right]^{\left[\frac{1}{n}-2\right]} \quad (2)$$

The carbon content in the top layer of the soil has been measured according to standard Tiurin method.

The results were analysed statistically with a variance analysis; the significance of differences between the mean values was evaluated with the Student test, and Statgraph ® was used.

RESULTS

In the soil taken from object where ploughing have been applied from 1994 y., (CC - traditional tillage) average values of the water content of individual layers of the ploughing zone (1- 0-10, 2 10-20 and 3 - 20-30 cm) were estimated (tab. 1.).

In soil layer 1, 2, 3 for pF value = 2.0 the content of the water were respectively 0.116, 0.121, 0.114 kg.kg-1 of water, however for value pF = 4,2, adequately 0.033, 0.035 and 0.033 kg.kg-1.

Soil management practices performed during the study modified the water content of the top soil layer (0-30). Differences of gravimetric water content were counted in individual layers of soil taken from ploughed object (CC) and from object where direct drilling was applied (tab. 2).

Table 1. The gravimetric water content under traditional, conventional tillage system (CC) at Ap - level (mean values kg·kg^{-1})

Value of pF	Ap level (cm)		
	0-10	10-20	20-30
1.0	0.237	0.225	0.236
1.6	0.201	0.198	0.192
1.9	0.127	0.139	0.128
2.0	**0.116**	**0.121**	**0.114**
2.7	0.096	0.104	0.078
3.3	0.057	0.063	0.055
3.6	0.041	0.042	0.039
3.9	0.035	0.038	0.033
4.2	**0.033**	**0.035**	**0.033**

Independently from the compared layers, the higher content of water in soil was affirmed for lower values the pF (up to 1.6 pF) on ploughed object (CC). The compared values shows at lower value of pF the higher holding capacity for storing of easily accessible water for plants after conventional cultivation tillage (CC) application. Comparison of water content at higher pF (pF=>1.9) values gives different results. Differences can prove better moisture of soil, where the ploughing was not executed (DD).

Table 2. The difference of gravimetric water content under direct drilling and traditional, conventional tillage system (DD-CC), in Ap - level (mean values kg·kg^{-1})

Value of pF	Ap level (cm)		
	0-10	**10-20**	**20-30**
1.0	-0.030	-0.032	-0.053
1.6	-0.015	-0.026	-0.034
1.9	0.009	0.007	0.000
2.0	0.004	0.009	0.011
2.7	0.017	0.014	0.027
3.3	0.010	0.002	0.008
3.6	0.007	0.006	0.008
3.9	0.002	0.000	0.001
4.2	0.002	-0.002	-0.002

The shaping of the curves of water content for three layers of sandy soil taken from DD objects were presented on fig.1, 2, and 3.

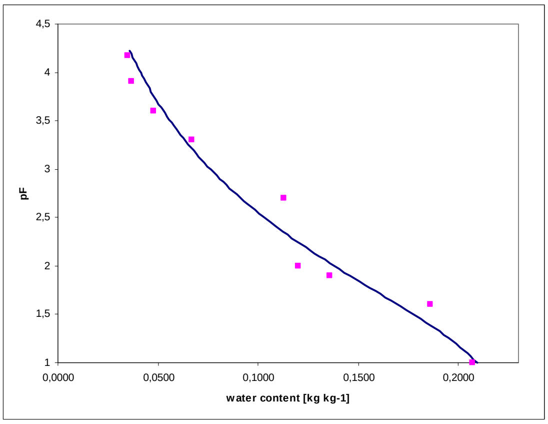

Fig. 1. The gravimetric water content under direct drilling system – DD at Ap - level 0-10 cm

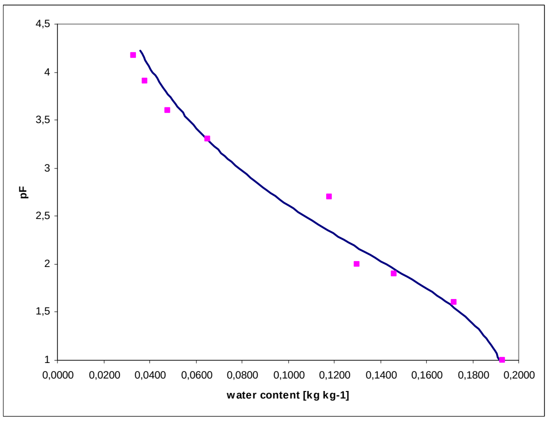

Fig. 2. The gravimetric water content under direct drilling system – DD at Ap - level 20-30 cm

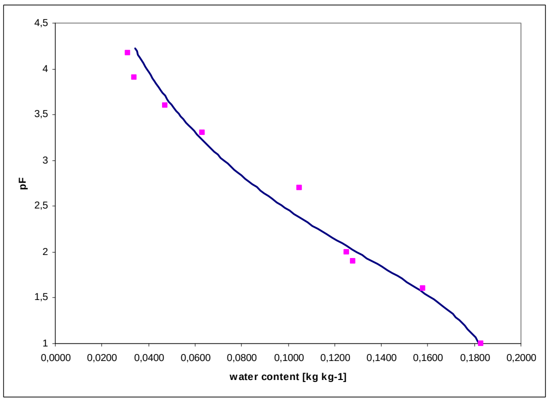

Fig. 3. The gravimetric water content under direct drilling system – DD at Ap - level 20-30 cm

At first sight, as though the dependence between S and root growth is entirely consistent. Root growth is logically expected to be positively correlated with S. It is clear, that in most soils larger values of S indicate soil type that is more suitable for root development (Dexter. 2004 a). At value approximately S=0.035 estimated by Dexter as a limit between soils with good and poor soil structural quality (S<0.02 very poor soil physical condition in the field).

The estimation of S Index by measurement and description of water retention curve was based on the Dexter (2004 a) theory. The S values of the compared soils taken from different tillage systems were estimated (fig. 4). It was found that S values were higher on the conventional cultivation (CC) compared to direct drilling (DD) in all layers of ploughing zone.

After 15 years no-till system (DD) application, in the first horizon level (0-10 cm) the S value was 0.035, and in the second one (10-20 cm) and in the third layer (20-30 cm) lower than 0.035 but much higher then 0.02. Described results shows good physical condition and structural quality in the field with direct drilling.

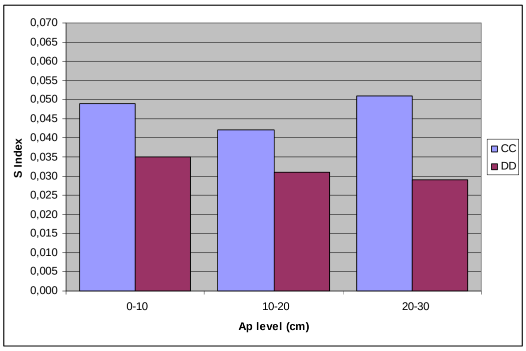

Fig. 4. The changing S Index value after tillage systems application (Ap level 0-30 cm)

In case of this field experiment it was not found, either confirmed conclusion of Dexter (2004 a) that the use of land management systems caused greater content of organic matter in the soil resulting in higher values of physical quality as measured by S.

The trouble free measurements of carbon sequestration changes in moldboard ploughing soils should be useful to fill the restrictions of greenhouse gases, expressed in carbon dioxide equivalent. The direct drilling performed continuously, increases soil reservoir of carbon and should be recommended as a mean for reduction of CO2 concentration and emission. Comparing to traditional tillage (CC) the no-till system (DD) gives advantage in storage of surplus of carbon. Also, application of this system is a reason to encourage for lobbing to subsidies farmers reducing greenhouse gas emission.

Adopting the no-till farming system by farmers is supposed to be a profitable change of land management.

The analysis of variance of the C organic content shows no differences between medium values of C org. depended on tillage system on Ap level (0- 30 cm)

The average value define for individual studied layers of soil, indicates that content of organic carbon have not differ essentially (Fig. 5). However, deciding sketches show clear tendency of organic carbon sequestration on objects where direct drilling (DD) has been applied from 1994, compared to conventional cultivation - traditional tillage (CC).

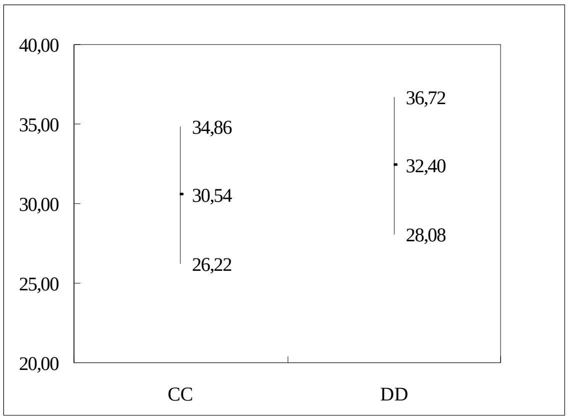

Fig. 5. The analysis of variance content of C organic dependant on tillage system on Ap level (0-30 cm, t·ha^{-1})

Analysis of data shown on Fig. 6, indicates that average content of carbon in top layer (0-30 cm) of soil found in direct drilling system (DD) was higher by 1.87 t per one hectare, compared to conventional cultivation (CC), and as it was measured on 32.4 t per hectare ± 4.32 t, with 95% of confidence level for averages.

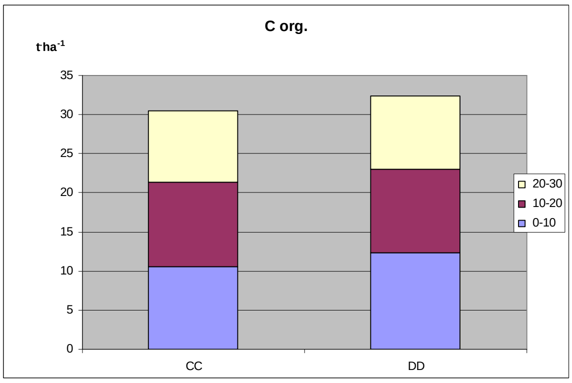

Fig. 6. The total content of C organic dependant on tillage system at Ap level (0-30 cm, t·ha^{-1})

CONCLUSSIONS

1. In soil layers 1: 0-10. 2: 10-20, and 3: 20-30 cm for pF value = 2.0 carried out resp 0.116, 0.121, 0.114 kg.kg-1 of water, however for value pF = 4.2, adequately 0.033, 0.035 and 0.033 kg.kg-1

2. No matter at which compared layers, should the higher content of water in soil was affirmed near lower values the pF (up to 1.6 pF) on ploughed object (CC), and at higher values of the pF (pF=>1.9) on no-till object (DD).

3. The S index value equal in the first level (0-10 cm), and then lower by 0.035 in the second one (10-20), and third one (20-30 cm), shows good physical condition and structural quality in the field where direct drilling was applied.

4. The average content of carbon in the soil top layer (0-30 cm), was found higher in no-till - direct drilling system (DD) by 1.87 t per one hectare, compared to conventional cultivation (CC) and it was measured on 32.4 t ± 4.32 t per hectare.

5. Adopting the no-till system by farmers is suggested to be the a profitable change of land management especially from point of view CO2 emission restriction.

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