Adaptable tillage – is that a solution for the present climate situation?

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Abstract
The aim of this work was to investigate the critics, connected with the ploughing, in a long-term trial started in 2002, in a Chernozem soil. Besides the ploughing treatment, further treatments were subsoiling, tine tillage, disk tillage and direct drilling. Results revealed occurrence and temporal extension of the plough pan under ploughing treatment. Moreover, the soil structural degradation in the regularly ploughed soil was also proved through high structure deterioration and crust formation following with organic carbon loss trough high CO_2 efflux. At optimum water content ploughing can be less devastating procedure, although long term trial confirm that favourable soil condition is mostly non applicable. Regardless to soil water content, ploughing decline the biota (earthworm) population, but not radical decline in weeds infestation was observed. In the first years of the trial, higher yields were obtained at deeper tillage treatments, including ploughing while after 15 years this trend has changed considering the climate extremes. The aims of adaptation should be supplemented establishing climate tolerable soil condition.
Keywords: soil vulnerability, structure deterioration, adaptable tillage

Introduction

The use of ploughing had started in our region in the end of the years 900s (Milhoffer, 1897). Although, plough constructions changed through time, the damages induced by ploughing remains and, moreover, increased the soil degradation (Birkás, 2008), although other tillage methods appears (Beke, 1922, Birkás et al., 2017), but no radical change occurred. Today, ploughing is used approximately 40% of the arable land in Hungarian and at least 75-77% of the lands in Croatian relation (Đekemati et al., 2016), mostly due to the lack of knowledge of the negative effects of plough on soil. The effects of ploughing on soil can be summed up by own studies (e.g. Gyuricza et al., 2015) and by literature data (Laird and Chang, 2013; Šimon et al., 2009; Tarnawa et al. 2017; Tóth et al., 2017, Bogunović et al., 2018). Negative impact of ploughing on wet soil is the step in formation of the pan layer below edge of tillage. This hardly permeable layer limits water movement, enhancing the drought during a dry season. Similar practice during dry soil enhances the energy consumption, dust formation, hard and large clumps making difficult seeding practice. Soil structure deterioration by ploughing is (Bogunović et al., 2018), minimised in moistened soil, however, organic matter losses occur due to the soil respiration (Birkás et al., 2017). Therefore, tillage alternatives should be researched and implemented in practice for reducing the level of soil degradation and to maintain the soil productivity (Bogunović et al., 2018).

The aim of this research was to investigate the soil physical state under several tillage practices. The questions examined were as follows: occurrence and extension of pan compaction, structure deterioration (dust and crust formation), extension of soil volume causing water loss, limited water content for ploughing, poor earthworm habitat, high CO_2 emission, questions in weed infestation and yield level in harmony with the soil condition.

Materials and methods

A long-term experiment was initiated at the Experimental and Training Farm of the Szent István University, Hatvan, Hungary (47°68' N, 19°60' E, 110 m a.s.l), in 2002. The terrain is flat, while climate is temperate continental with average precipitation of 580 mm (1975-2000). Soil is silty clay loam Endocalcic Chernozems, Loamic (IUSS W. Group WRB, 2015), characterized by adequate humus content (3.12 %) and moderate sensitiveness to compaction. At 0-20 cm depth the sand, silt and clay contents are 10 %, 54 % and 36 %, respectively (Tóth et al., 2017). The soil is categorised as coherent, workable or plastic when its moisture content ranges between, 14.8-18.9, 19.0-23.9, or > 24.0 m/m %, respectively (Csorba et al., 2011). The amount of precipitation in the last eight years is represented in Figure 1.

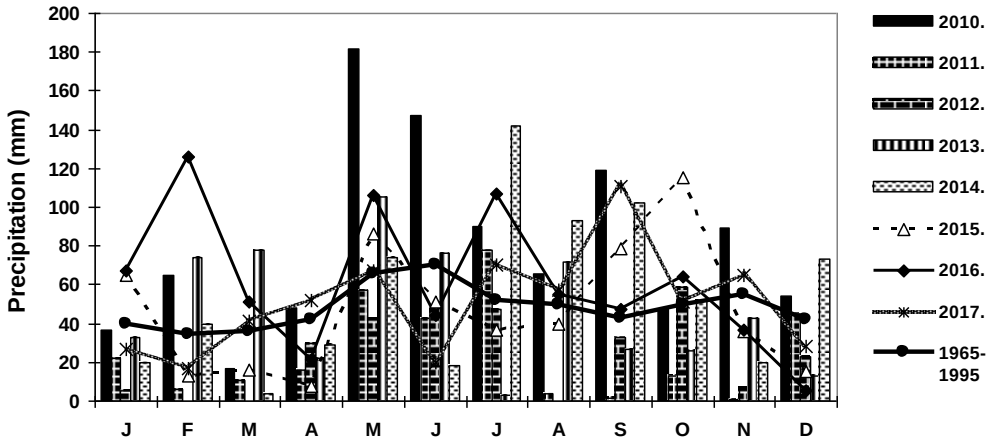

Figure 1 Monthly precipitation (mm) in the last years of investigation (2010-2017) and average of the 30-year period

Experiment was a randomised block design with six treatments in four replicates (Sváb, 1981). Plot size was 13 m x 185 m. Six treatments comprised deep – ≥ 0.300 m (that is loosening, L, ploughing, P, and tine tillage, T) –, and shallow – ≤ 0.22 m, (that is tine tillage, ST and disking, D) – soil disturbance along with direct drilling (DD). One-pass tillage was carried out for cereals, while separate seedbed preparation was applied for wide row crops.

Crop sequence was planned to maintain soil quality and suppress the weeds: white mustard (2002), winter wheat (2002/03), rye (2003/04), pea (2004), winter wheat (2004/05), white mustard (2005), winter wheat (2005/06), phacelia (2006), maize (2007), sunflower (2008), winter wheat (2008/09), white mustard (2009), maize (2010), oat (2011), w. wheat (2011/12), spring barley (2013), sunflower (2014), winter wheat (2014/15), maize (2016) and winter oat (2017).

Crop residues were returned in soil. Post-emergence herbicide was used once in the spring. A direct chemical treatment was applied in five years (2011, 2012, 2013, 2015 and 2017) on cereal stubbles at the end of August.

Sampling was taken in 30-day intervals in each treatment in six repetitions. The soil samples were air-dried and then dry-sieved (60 shakes/min), to determine the aggregate–size distribution. Crumbs in the national soil physics categorisation system are defined as soil aggregates ranging from 0.25 to 10 mm in diameter, of which those falling in the range of 0.25-2.5 mm qualify as small crumbs and <0.25 mm as dusts (Filep, 1999). Soil moisture was measure in situ with the PT-I type gauge (Kapacitiv Kft, Budapest, Hungary) every 30-days. Level of soil water content to determine the suitability for tillage was derived from the basic data collected in 16 years. Penetration resistance was recorded using a handheld Szarvas-type penetrometer (Mobitech, Hungary) having a 1.0 cm^2 cone and a

60° apex, at soil depths of 55 cm at each 5 cm increment, in at least six repetitions. The cover ratios of crusting were measured with a quadrate device with area of 0.25 x 0.25 m. The thickness of the crusts was simultaneously measured. Instrumental measurements were completed with soil profile assessment (with area of 0.5 x 0.5, and to a depth of 45 cm). Results of CO_2 emission were recited from the literature (Bilandžija et al., 2016, Tóth et al., 2017).

Weed surveys were carried out five times in the year that are: 1. in spring, before application of chemical weed control, 2. at flowering (May/June), 3. on the stubble, 4. before primary tillage and before the onset of cold period (November). Weed infestation grade is calculated using the scoring method based on the measurement of the ground coverage of the weeds according to Balázs and Újvárosi (Reisinger, 2001; Kende et al., 2017). Yield was weighed at the time of harvest. Soil deterioration was studied by measuring changes in soil state (extension of pan, ratio of crumb, dust, surface crusting and the number of earthworm).

Statistical analyses. The least significant difference (LSD) at a significance level of $p<0.05$ was used to identify differences between treatment means and completed with the Fisher's adjustment.

Results and discussion

Tillage pan occurrence and extension

During 2002, a compacted layer (2-12 mm) was measured below the upper 28 cm layer. Annual disking (D) and ploughing (P) extend pan layer. However, at the tine tillage (T) and subsoiling (L) penetration resistance was moderate (≤3.2 MPa). The differences, regarding the data compared, are significant ($P<0.01$). The thickness of the pan layer between treatments varied from 2 and 12 mm in 2002 and from 15 and 111 mm in 2017 (Figure 2).

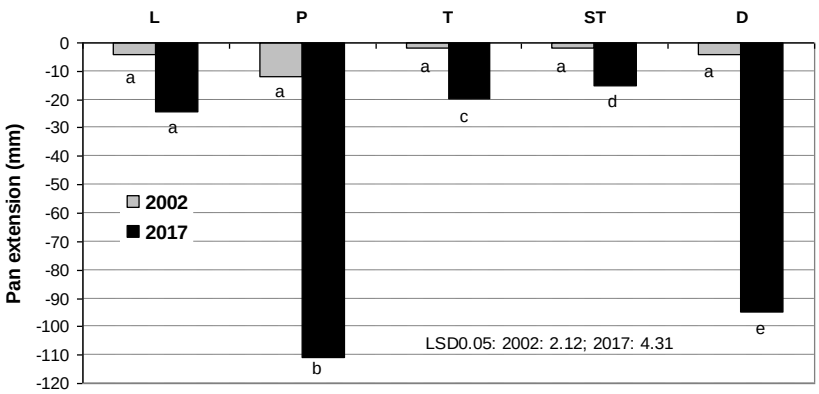

Figure 2 Comparing the tillage pan occurrence in the first (2002) and the 16th (2017) year
Remarks: L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage
Columns designed by the same letter do not differ significantly ($P = 0.01$).

The reason for the differences may originate from the different initial compactness of the soil. Other studies also found the pan forming effect by plough share mainly in wet soil (Đekemati et al., 2016).

Soil structure deterioration and dust formation

In 2002 soil structure was deteriorated, which progressively improved depending on the cultivation treatments. The differences between the treatments are significant ($p<0.0$). The

proportion of crumbs dropped by 4-10% in P treatment (16 years average) in addition to other treatments which is not considerable (e.g. 67 % at the ploughing, and 70-72% at the conservation tillage). The crumb formation was also affected by the soil moisture content in long term (Figure 3).

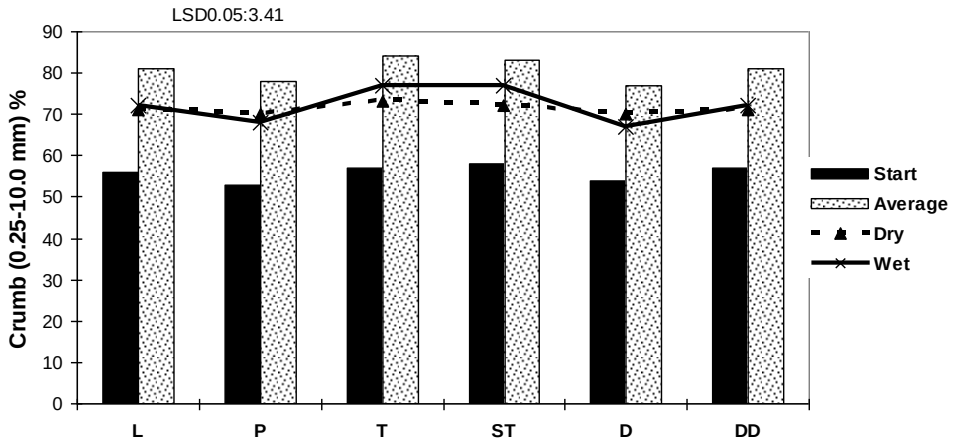

Figure 3 Ratio of crumbs at different soil tillage in the seasons
Remarks: L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage

An important factor is the proportion of dust in the cultivated soil. The ratio of dust in ploughed soil in 16 years is 7.8%, but growth is expected based on the trend (Figure 4). The tendency of the dust ratio at the T treatment shows downward, however that shows upward at the P treatment. The surface cover (at T) reduces the dust formation and the exposure to the climate elements (at P) is increase the dust formation. At present research, structural deterioration is slower than in practice, as ploughing is depending on soil moisture content, so soil exposure to climate elements is lower (Birkás et al., 2017). However, the trend of deterioration deserves attention.

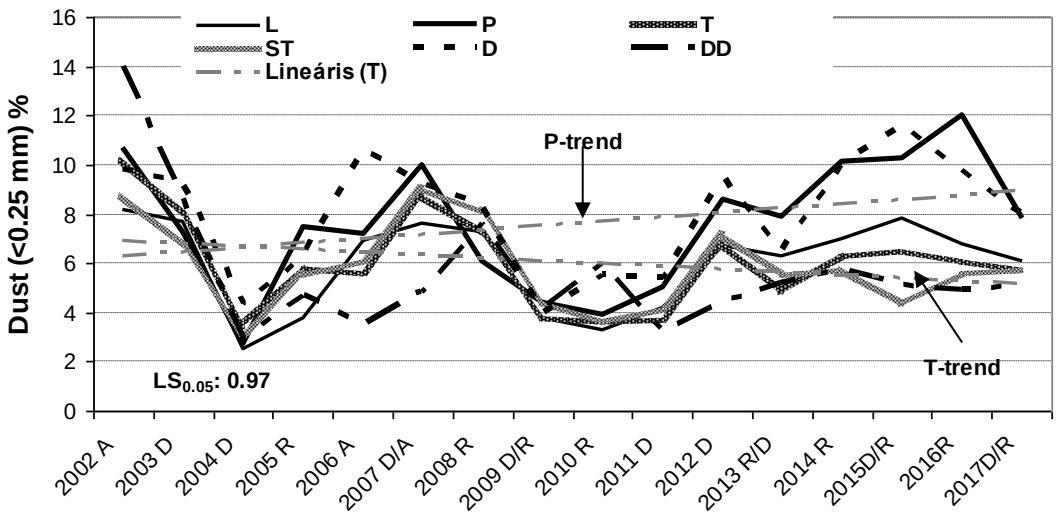

Figure 4 Trend of the dust ratio at different tillage treatments and seasons
Remarks: L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage
A: average, D: dry, R: rainy season

Soil volume extension

The question is how much the volume of cultivated soil grows after soil disturbance, and whether the created state corresponds to the cultivation conditions. The original size of the soil sample was 0.4x0.4x0.4 m (0.064m^3).

Volume of sample (m^3)	Ploughed	Ploughed + levelled	Loosened	Tine
Stubble state	0.064	0.064	0.064	0.064
Following tillage	0.0880	0.741	0.0768	0.0736

After cultivation, the volume of the sample in the ploughed soil was higher that is 0.088, the ploughed and levelled soil was 0.0741, in the loosened soil was 0.0768, and in the tine tilled soil was 0.0736 m^3. Extension of the surface on ploughed soil was 160 mm, on the soil that was ploughed and levelled was 63mm, and on loosened soil that was 45 mm and on tine tilled soil was 31.5 mm. The differences are statistically reliable ($LSD_{0.05}$: 10.2 mm). An important factor is the measure of the soil loosening related to the stubble state. While the seedbed looseness is higher by 30-35% compared to the stubble state, excessive loosening is not desirable at the primary tillage. If ploughing is applied, the smaller degree of soil disturbance may favourable (Birkás, 2010), and this can only be accomplished by use of preparation element.

Limited water content for ploughing

When applying a given cultivation method, soil moisture content is found to be an important factor. Considering the extreme climate conditions, it is preferable to use tillage operations in different humidity ranges (Figure 5). Over the last 3 years (2015-2017) in the experiment, water surplus was dominant in the autumns therefore a new variant, HT had to be included. At the same time, in the growing season, the water shortage was rather typical.

The moisture content of the growing season in average of the 16 years are as follows:

Ploughing	Ploughing-levelled	Loosening	Tine tillage	Disking	Direct drilling
medium	good	very good	very good	good-medium	good-medium

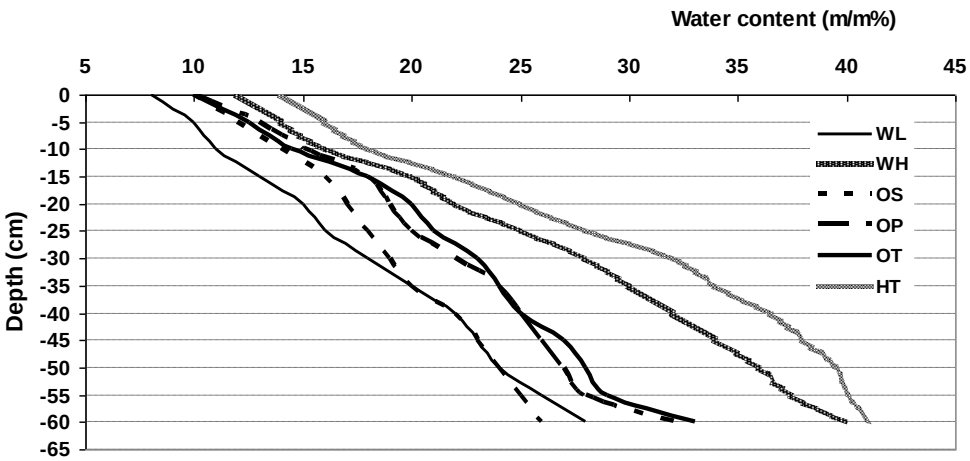

Figure 5 Optimal and less favourable water content for soil tillage interventions on Chernozem soil (Hatvan, 2002-2017)

Remarks: WL: workability, lower water level; WH: workability, highest water level; OS: optimal water content for subsoiling; OP: optimal water content for ploughing; OT: optimal water content for soil tillage; HT: highest water content for tine tillage

In terms of moisture content, good storage and effective moisture retention is considered as favourable. This criterion was performed by subsoiling and tine tillage. At the same time, soil state that was created by plough and packer element was considered also appropriate, which draws attention to change old habits to the new one (Birkás et al., 2017).

Crust formation

The crust area was largest during rainy season and at surface of P and D treatments while the lowest was at the T and DD treatment (Figure 6.). Spatially, crusts occurred at P and D treatments during wide-row crops and also a high density winter crops. The original reason was obviously the dustiness and then the soil siltation. At other treatments we hypothesized that adequate ratio of surface cover gave chance to minimise crust formation. The crusting of the surface is mainly outlined during the sowing and crop emerging period (Gallardo-Carrera et al., 2007), that received less attention in the growing season. As Badorreck et al. (2013) emphasised, the reason for silting and crusting on the soil surface being negative processes and that both impede the movement of moisture, air and heat.

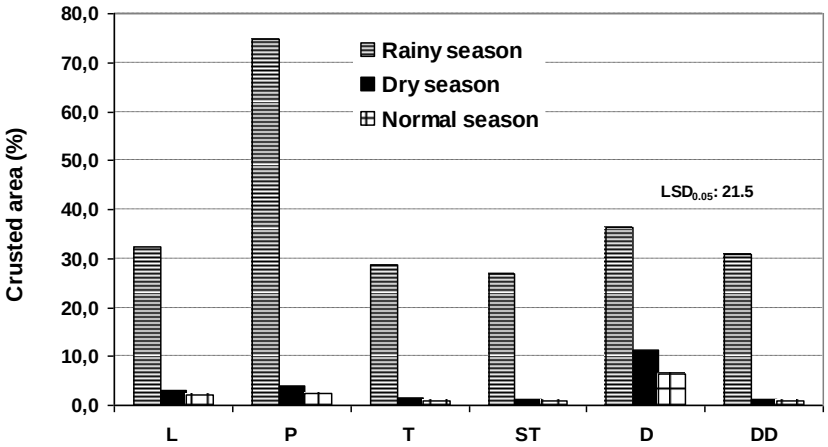

Figure 6 Crusted area in different seasons and in soils disturbed differently (Hatvan, 2003-2017)

Remarks: L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage

Poor habitat for earthworms

The question is, ploughing really gives a bad habitat to earthworms, as the literature data presented (Rothwell et al., 2011, Briones and Schmith, 2017). In our experiment, there were low number of earthworms (Figure 7) in the first year, in the dry years (2011, 2012), in some rainy years (2010, 2016), and in the seasons when a rainy period changed the dry period rapidly (e.g. in 2013). The crops had no influence in the earthworm number. Most of the earthworms were measured in a slightly rainy (2005) and in the average year (e.g. in 2006) and in the years that were free from extremes. Considering the earthworm trend, P treatment decreased the number of earthworms, despite the soil moisture status. In L and D treatments earthworm number fluctuate, while ST soil can be considered as preservatives for earthworm habitats. In the direct drilling treatment – although the number of worms can fluctuate by the season – the increasing number of worms was recognised.

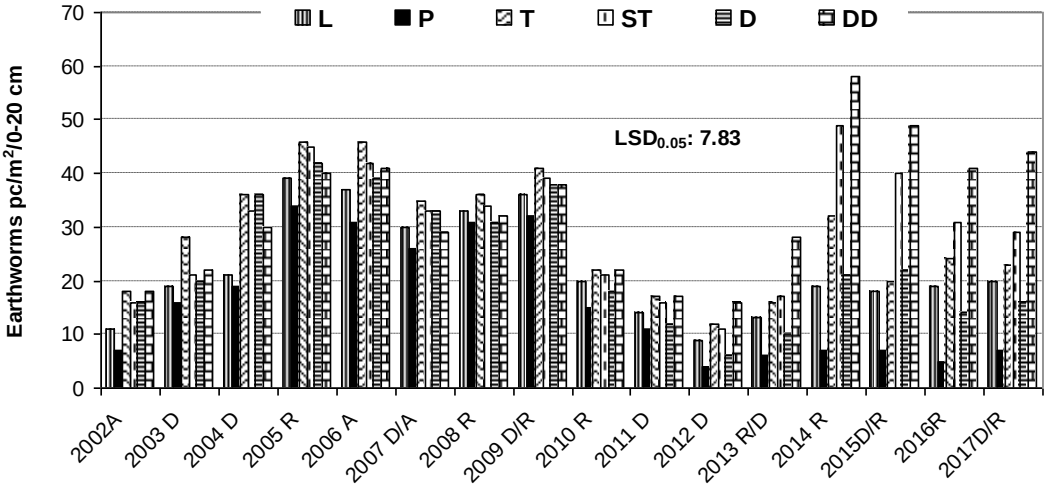

Figure 7 Number of earthworms at different soil disturbance and seasons (Hatvan)
Remarks: L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage. DD: direct drilling

Carbon-dioxide flux

The question is, how increase the ploughing the carbon dioxide emissions. There are data in the literature concerning to state and confirm assumptions. It is fact, that during ploughing, an increase in microbial activity can occur, considering the favourable aeration. Tóth et al. (2017) found that ploughing resulted in higher CO_2 emissions in most cases in the experiment. Ploughing is a soil-inverting primary tillage technique, and the surface layer is in furrows contains holes, and due to this soil CO_2 emission, and the decomposition of organic matters will be increased (Bilandžija et al. 2016). Authors outlined that such circumstances can be avoided by surface levelling simultaneously with ploughing.

Considering the review of the years of data, the following observations can be hoped:

Tillage mode	Ploughing	Ploughing + levelling	Subsoiling	Tine tillage	Disk tillage	Direct drilling
CO_2 emission just at tillage	High	Moderate	Moderate	Low	Moderate	Low
CO_2 emission in the growing season	Moderate, increased after rains	Low/moderate	Moderate	Moderate/low	Low	Low but continuous

Soil disturbance impacts on weed cover

In earlier publications, ploughing was highlighted as a weed control operation (McCloskey et al., 1996, Mohler and Galford, 1997), and this perception has only be changed in less intensely. A plough may invert seeds deeper into the soil and this is a critical point, while larger part of the buried seeds can remain viable in soil for many years (Mas and Verdú, 2003). Initially, the increase in grass weed infestation hindered the introduction of ploughless tillage across Europe (Melander, 1998). There are authors who have highlighted the original reason of the grass weed infestation that is the weed seed accumulating effect of the former soil inversion technique (McCloskey et al. 1996, Colbach et al., 2014). Reducing the weed infestation played great importance in the long-term trial by winter wheat since this crop was grown in six seasons inside of fourteen years (Kende et al., 2017). As it expected, the favourable trend has interrupted by the growing wide row crops in a rainy season (Figure 8). Weed cover slightly decreased by the growing narrow crop

(winter oat) again, which reaffirmed the importance of optimized crop sequence in weed control.

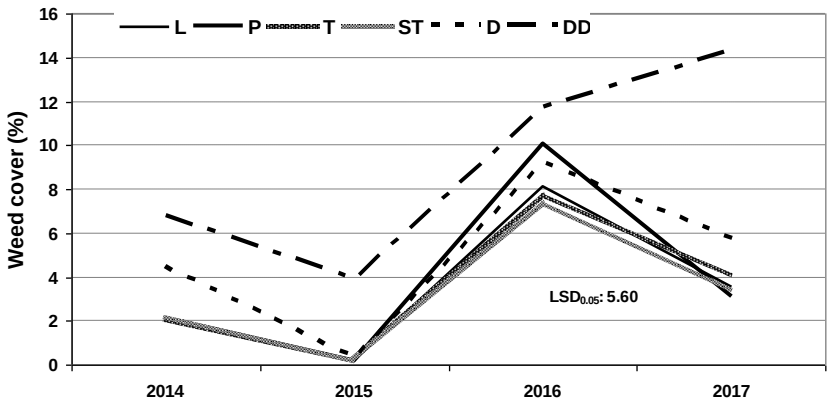

Figure 8. Trend in weed coverage in the last 4 extreme years (Hatvan)
Remarks: L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage. DD: direct drilling

Soil condition and yield level

The question is does the basic method the ploughing for achievement good yields. Results obtained in the long-term trial are presented in Table 1. According to this, best yields were achieved by the loosening and the ploughing with 5x, and by tine tillage with 3x, and the direct drilling 2x inside fourteen years.

Table 1. Crop yields (t/ha) in a long-term trial (Hatvan (2003-2017)

Year, crop	L	P	T	ST	D	DD	$LSD_{0.05}$	Note
2003D W. wheat	**3,45**	3,12	2,99	2,51	2,76	1,10	0,26	start, weed infestation
2004D Dry pea	**1,82**	1,51	0,93	0,80	0,81	0,23	0,09	late sowing, real
2005R W. wheat	5,81	**7,53**	4,67	4,01	4,83	1,81	1,57	real
2006A W. wheat	4,58	**4,59**	3,97	3,07	3,63	1,37	0,60	rain at harvest
2007D/A Silage maize	27,47	**29,63**	26,10	18,93	24,36	25,72	2,80	drought
2008R Sunflower	**4,01**	3,63	3,55	3,5	3,17	3,47	0,24	real
2009D/R W. wheat	5,78	5,60	5,02	5,57	5,48	**6,03**	0,70	extremes
2010R Maize	6,52	**8,34**	7,29	7,13	6,49	6,58	0,50	rainy year
2011D Spring oat	3,56	3,77	**4,31**	3,77	3,84	3,97	0,25	drought
2012D W. wheat	1,61	1,97	3,00	2,01	3,18	**3,84**	0,25	drought
2013R/D S. barley	**3,13**	2,95	3,09	2,47	2,85	2,90	0,22	real
2014R Sunflower	3,13	**3,23**	3,05	3,17	2,67	2,19	0,47	rain at harvest
2015D/R W. wheat	5,76	5,70	5,73	**5,77**	4,71	4,82	0,95	dry season
2016R Maize	8,46	8,37	8,43	**9,33**	7,92	8,05	0,60	rains, hail
2017D/R W. oat	**5,87**	5,70	5,68	5,29	4,50	4,51	0,54	frost, extremes

Remarks: D: dry, A: average, R: rainy year; L: loosening, P: ploughing, T, ST: tine tillage, D: disk tillage. DD: direct drilling

Evaluating the latter extreme seasons, higher crop yields found at soil condition where the soil damages remained minimal, that are at the loosened (L) and the tine tilled (T) soils.

Conclusions

The reality of criticism related to the ploughing was studied in the long-term experimental conditions. The most important findings were:

- The formation and vertical progress of the pan compaction is practically inevitable in a ploughed soil.
- Poor crumb and high dust ratio form in a ploughed soil in general, coupled of the surface crusting.
- Extension of soil volume by ploughing is mostly unfavourable. Levelling the surface can contribute to the water retention in ploughed soils.
- The different moisture range of primary cultivation processes helps to make better choices in extreme climate conditions.
- A ploughed soil – considering the clean surface and the soil inversion – is unfavourable habitat for earthworms.
- The high carbon dioxide emission in a recent ploughed soil can reduce by surface preparation.
- Reducing the weed infestation attributed to ploughing is mostly debatable.
- In extreme climate conditions, higher crop yields found at soil condition where the soil damages remained minimal.

Acknowledgement

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