Soil Tillage Responses to the Climate Threats – Revaluation of the Classic Theories

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Summary

Prevention and alleviation of the climate induced damages by soil management is a great challenge in our regional agriculture nowadays. This study fulfils two aims. In the first aim ploughing was evaluated by fifteen factors in wet and dry soils. The evaluation related mainly to quality of the disturbed layer of soil, and the impact of ploughing on moisture transport and the weed infestation. In addition, the reasonability of twelve classic theories related to ploughing under the present climate conditions were reviewed. The main conclusion of this review is that the inverting practice requires impartial revaluation both in national and regional relation. The second aim was comparing the effects of tillage treatments on soil condition in the past seven extreme seasons. In a long-term experiment six treatments comprised deep – ≥ 0.30 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). The rank reflects the suitability of each treatment for soil preservation in the extreme circumstances. After all, soil tillage adaptability to wet soil condition were (from adequate to the unsuitable) as follows: ST>T=L>DD>P>D. Rank of the treatments slightly modified in dry soil, i.e.: ST>DD>T>L>D>P.

Key words

Pannonian region, climate consequences, ploughing, ploughless tillage

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Introduction

Weather extremes occurred in Pannonian region even 100-150 years ago (Milhoffer, 1897). Gyárfás (1925) cited meteorological data in his book and outlined that 83 years were dry and 84 years were wet between years 930-1876. However, the number of so-called average years exceeded the number of extreme years five times. In the meantime, weather induced phenomena have increased over past 150 years (Láng et al., 2007; Jolánkai et al., 2016; Szalai and Lakatos, 2013). Although the weather was always changeable, the severe global threats have been occurring all over the world in the last decades. For this reason, more attention could be drawn from the end of the 1980s to an analysis of the effects of climate change, reducing risk factors and discussing the solutions (IPCC, 2007; Sakalli, 2017). Agriculture is a sector that highly exposed to the weather conditions, and is one of the possible factors influencing the climate change (Láng et al., 2007; Spinoni et al., 2015). Authors refer to soil sensitivity to the climate damages appointing that soil exposure has intensified by the inappropriate land use (Birkás, 2008; Dexter et al., 2008; Sakalli, 2017; Várallyay, 2015). The criticisms of ploughing have often been arisen for years, and it grew stronger nowadays considering its contribution to the climate change. The ploughing has dutifully applied in the Pannonian region for centuries (Birkás et al., 1989), despite of the negative consequences that discussed in European and the worldwide context (Lal et al., 2007; Törő et al., 2017; Vukadinović et al., 2014). The main disadvantages of the ploughing, according to literature data are limited depth of the loosened layer, the humus and water loss and soil structure deterioration (Birkás et al., 2017a; Lal et al., 2007; Rubinić and Husnjak, 2016). Ploughmen do not want to recognize these damages despite the fact they are to face the negative consequences of their practice in extreme seasons. Ploughmen have regrettably remained indifferent to the sustainability ideas up to now (Birkás et al., 2017b; Jug et al., 2015). Ploughing causes damage in both dry and wet soils (Đekemati et al., 2016; Jug et al., 2017). Changing the attitude to the ploughing practice seems to be really urgent considering the impacts of the extreme climate phenomena on ploughed soils. The two extremes of the climate – too wet or too dry – require applying another cultivation method that may cause less damage in the soil. This concept is rather new in the theory and practice of Hungarian and regional soil tillage practice (Đekemati et al., 2016; Gyuricza et al., 2015; Jug et al. 2017). According to Várallyay (2015) the impact of cultivation processes on wet and dry soils can be evaluated through the results of direct and indirect changes. The ultimate result is the achievement of the smallest and easily remediable damages that can be investigated by impartial soil condition tests.

Some of the papers mentioned have answered the primary question of soil tillage role in the regional climate damage' mitigation solutions. Considering this, two main aims were specified in this work. The first aim was to review some of the classical cultivation theories associated with ploughing in the present climate conditions. The second aim was to evaluate and rank the soil conditions that are characterized by different tillage treatments in dry and wet seasons.

Material and methods

The first task comprised of a critical assessment of ploughing by fifteen factors in wet and dry soils. The evaluation related mainly to the quality of the disturbed layer, and the impact of ploughing on moisture transport and weed infestation (Table 1). The evaluation relied on data from publications, results from the experiment and soil state monitoring that were obtained from four districts (foot of Mátra hill, South-Zemplén, SE Békés and South-Baranya, Figure 1). One of the districts (4.) reaches across the border to Northern Slavonia. In addition, the reasonability of twelve classic theories (Table 2) related to ploughing under the present climate conditions were reviewed.

In the second task, soil conditions, evolved from different soil tillage methods, were evaluated and ranked by sixteen factors in dry and wet seasons. These factors are listed in the left columns of Table 3-4. The evaluation depended on the results of the long-term field experiment (Figure 2) underway since 2002 on the Experimental and Training Farm of the Szent István University, near town, Hatvan, Hungary (47°68' N, 19 °60' E, 130 m a.s.l), 60 km NE of Budapest. Soil is classified as Chernozems with chernic horizon and silty clay texture (WRB 2015), with a humus content of 3.12 % and sand, silt and clay contents of the top 200 mm layer of 23 %, 42 % and 35 %, respectively (Csorba et al., 2011). The soil is categorised as dry, humid or wet 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 precipitation was measured at the weather station of the training farm. The multi-year average of the precipitation is 580 mm. The annual amount of precipitation was found to be similar to the long-term average in two years. However, the distribution showed extremes during the 7-year period (Figure 3).

In accordance with the primary plan, the experimental area was selected in a field where soil had already been degraded (Kende et al., 2017). This degraded soil offered an opportunity for soil quality improvement by applying adaptable tillage systems. Six treatments comprised deep – ≥ 0.30 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). The experiment was arranged in a randomised block design with four replicates. This study covers the most important findings experienced in the last seven extreme years. Crop sequence in the given seven years – 2010-2016 – was as follows: maize, spring oat, winter wheat, sunflower, winter wheat and maize. The slightly higher proportion of cereals was justified for conservation of organic matter.

Instrumental measurements were also required for soil condition tests. Soil moisture measurements were taken with the PT-I type gauge (Kapacitív Kkt, Budapest, Hungary), and that was repeated in the required intervals. Penetration resistance recorded using a handheld Szarvas-type penetrometer having a 1.0 cm^2 cone and a 60° apex, at soil depths of 0.6 m at each 0,05 m increment, in at least six repetitions. Samples for assessing aggregate size distribution were taken just after climate phenomenon in each treatment in six repetitions. The soil samples were air dried and then they were gently sieved (60 shakes/min). The grades measured were <0.25, 0.25–2.5, 2.5–10, and >10 mm. The ratio of silting and 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 the soil profile assessment (with an area of 0.5 x 0.5, and to a depth of 0.5 m). Visual soil state monitoring was also an important additional activity. Citing the papers published earlier concerning soil condition measurements were also inevitable (e.g. Birkás, 2010, Birkás et al., 2012, 2013, 2015, Birkás and Đekemati et al., 2017b, Birkás, Mesić and Smutný, 2015). Among the cited literature are – in accordance with the objective of this study and the numerous soil quality problems in the region – dominated the publications by local authors.

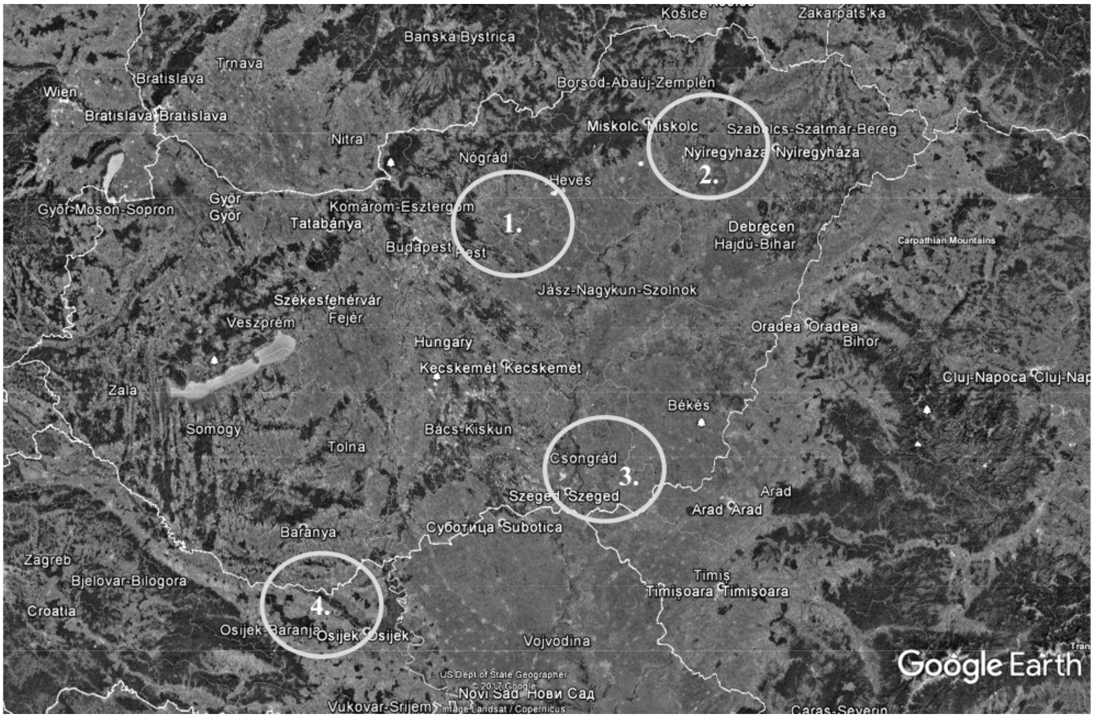

Figure 1. District for soil condition monitoring

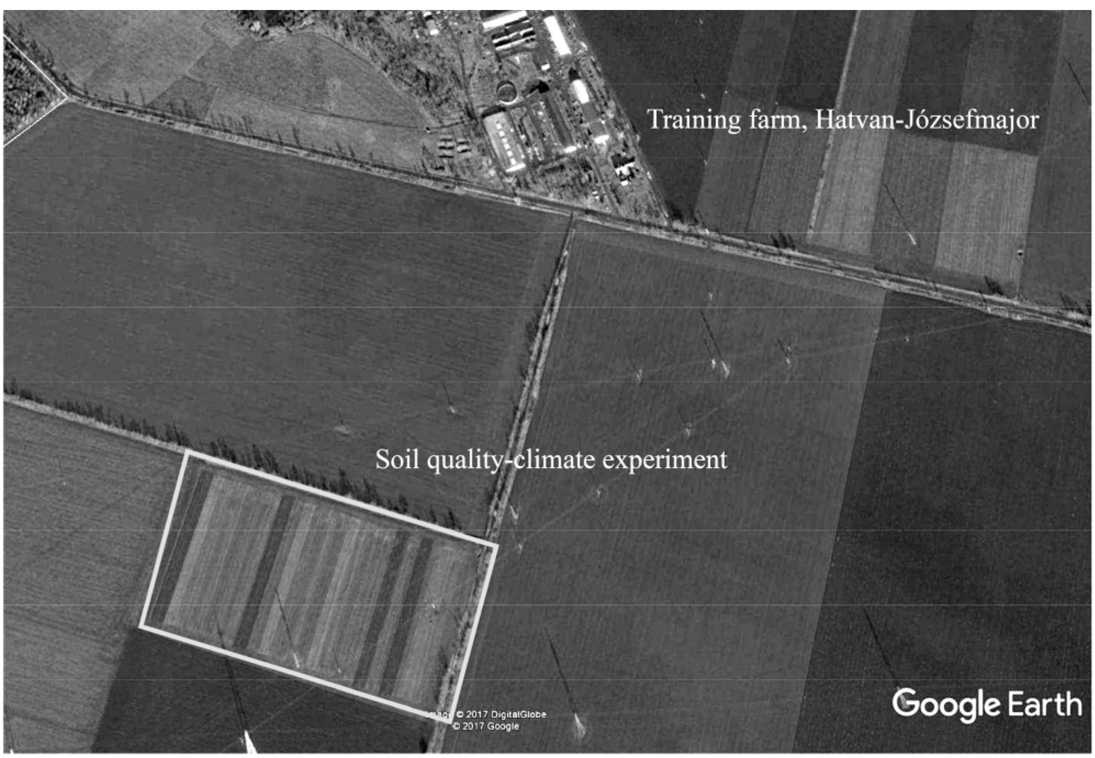

Figure 2. View of experiment on Google Earth (10/7/2013)

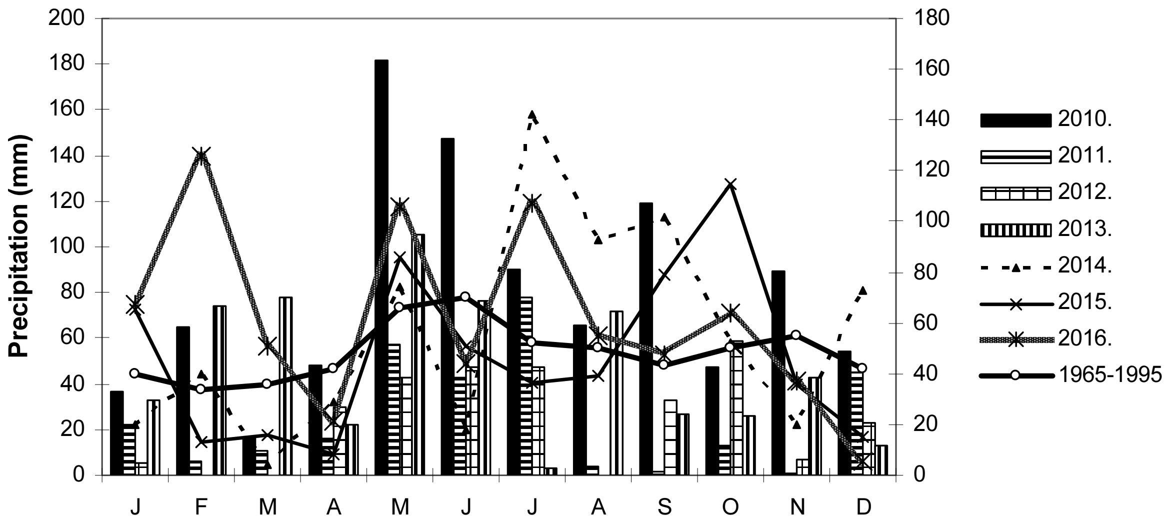

Figure 3. Monthly cumulative precipitation amounts for the seven experimental years and for the 30-year period (1965-1995)

Results and discussion

The reasonability of classic theories associated with ploughing in the present

Impacts of ploughing on wet and dry soils were evaluated by fifteen factors (Table 1). The results obtained in the long-term experiment gave new considerations in the appreciation of ploughing. The possible depth of the loosened layer created by ploughing is often limited regarding the probability of the plough pan creation. However, the depth of ploughing surpasses the depth that creates by disk tillage and therefore gives better soil condition for crop rooting in any season (Birkás et al., 2015).

The effect of ploughing on the soil is mostly unfavourable, but it is particularly critical at the two extremes of moisture content (Lal et al., 2007). The first major damage in wet soils is the pan creation just below the ploughed layer. We found, that pan layer has unfavourably extended for seasons, even in moist soils and severely limited the root growing into the deeper soil layers.

Further aggravating factor is the settling of the ploughed layer. In one respect, ploughing creates an overly loosened state related to the seedbed requirement and at the same time, the inverted, clean surface has become more sensitive to the climate elements. As Birkás and Đekemati et al., (2017a) stated, the typical reason for the new ploughing is to force the alleviation of the unfavourably settled state. Authors underlined, that the occurrence of the pan compaction was minimal during dry seasons. However, the pan layer that had formed previously had become stable.

The second major damage is producing large clods (≥ 50 mm) by ploughing in both types of seasons, and the diameter of the clods may exceed 500 mm or more. Formation of bacon-like clumps by plough seems also quite frequent in wet autumnal period. Unfortunately, these types of ploughed surface is still accepted by small farms, in this region, without respect to the negative results. Considering the high proportion of clods, the ratio of the crumbs (diameter is 0.25-10.0 mm) is quite low, and within this particle size, small crumbs (diameter is 0.25-2.5 mm) are dominant.

The third major damage is the deterioration of soil structure in ploughed soils. The size of big clods slightly reduces in ploughed soils after wintering, however a high amount of dusts (≥ 55 % in a

Table 1. Assessment of the ploughing in wet and dry soil condition

Factors	Wet soil	Dry soil
Optimal looseness for rooting	doubtful	doubtful
Compact state below tilled layer	formed/extended	remained
Settling	high	moderated
Creating ≥ 50 mm particles	typical (bacon-like)	typical (lumps)
Crumb ratio	low	low
Dust ratio (by ploughing)	low	high
Dust ratio (after wintering)	high	high
Dust sedimentation from the surface	high	moderated
Results of clean surface	siltation	pulverisation
Decomposition of stubble residues	very poor	very poor
Earthworm activity	moderated	very poor
CO_2 emission	very poor /high	increasing
Impacts on water transport	limited infiltration (plough pan)	water loss
Impacts on weed infestation	moderated emergence	poor emergence
Deterioration of soil quality	very heavy	very heavy

Table 2. Reviewing the classic ideas of ploughing

Factors	Classic theories	Comments
Aim of tillage (ploughing)	Fulfilling soil state demand of crops	Other tools create less damages
Summer tillage	A plough creates clean surface	Soil exposes to heat and strong rain stress
Clods in summer are advantageous	Large clods disintegrate in time	Soil loses water, and biological activity declines
Weed emergence in summer ploughed soil	Less weeds are favourable	Poor weed emergence – seed bank of soil is remained
Preparation of cloddy soil	Conventional disk is adaptable after soil leaking	A disk creates compact pan in a ploughed soil
Autumnal ploughing	Let it deep with large surface (catch water and snow)	Soil losses water both in autumn and winter
Winter ploughing	Applying in soil covered by snow without damages	Snow unsuitable to prevent pan compaction
Damages in soil creating in autumn/winter	Frost will remedy any damages	Pan that pressed into soil is invisible – belief that is no
Frost impact	Favourable – large clods is crumbled	Frost dust is dust and that removable by wind and sediment by rainwater
Catching the snow	A cloddy (ploughed) soil is adaptable	A large surface my catch the snow but it evaporates more water after melting
Surface preparation in spring	A simple leveller is beneficial	It is late intervention following water loss in winter
Spring ploughing	Advantageous regarding soil inversion	Soil losses more water than hoped

unit area) are formed on the surface (Đekemati et al., 2016). Dust is undesirable in the soil surface in the spring, as the wind removes small particles, and in addition dust sediments to the deeper layer of soil by rainwater. Over-estimation of the frost effect seems unfortunate, and the damage is more serious related to the beliefs. In our experiment, a levelled and covered surface had only been suitable for mitigating the dust formation during winter period. Considering the extreme climate, a clean soil surface after ploughing is found to be undesirable because of the dust formation, and later on the siltation and the crust formation. Otherwise, less dust (≤0.25 mm) developed by ploughing in wet soils, but besides the large clumps plenty of dusts occurred in dry soils.

The fourth major damage that was related to ploughing was the limited decomposition of raw organic matter. Ploughing was found to be critical due to high CO_2 emissions (Bilandzija et al., 2016; Gelybó et al., 2016). Birkás et al. (2011) and Szabó (2008) noted that decomposition process is rather limited in wet soil considering the airiness state. However, dry soil condition had also lowered biological activity. This is yet another reason why tillage adapted to the soil's physical and biological state, combining organic matter preserving tillage should be introduced in the soils found in the Pannonian region.

The earthworm count was an important factor in addition to monitoring soil state changes in the experiments. Ojha and Deepa (2014) outlined that both too wet and over dried soil were unfavourable habitat for earthworms. Moreover, the ploughed soil itself was by far the worst habitat (Birkás et al., 2010).

The fifth major damage is the adverse effect of ploughing on soil moisture transport. In wet weather, rainwater infiltrates to the ploughed layer, but the plough pan limits leakage into the deeper layers. During dry season, a large and cloddy surface was found to be the primary water-loss factor (Kende et al., 2017).

The sixth major damage is overestimating the effect of ploughing on weed infestation (Kende et al., 2017). A belief that poor emergence of the weeds may be advantageous during dry seasons, although in this case no chance for effectual weed control. Soil inversion was stated to be the best weed control technique (Gruber et al., 2012; Percze, 2002). There are statements in favour of ploughing in terms of killing and burying the weeds, destroying emerged weed seedlings and restricting the new seed production (Boström, 1999). A plough may invert seeds deeper into the soil where germination conditions are limited and seed dormancy becomes longer. This seems to be a critical point, while larger part of the buried seeds can remain viable in the soil for many years and only an insignificant proportion of the weed seed bank may be stimulated to germinate by ploughing (Ozpinar, 2006). The role of the ploughing in weed control seems to have slightly been changed by findings of recent trials (Han et al., 2013). Ploughing was to be found beneficial only if the regularly tilled layer contains no or less weed seeds. Kende et al. (2017) outlined that weed seeds inverted to the bottom of ploughed layer may be considered as the potential source of the infection.

The test result of the reliabilities of the twelve important classical theories related to ploughing is shown in Table 2.

Based on the classic theories, the aim of tillage comprised expectations that could be fulfilled by ploughing (Gyárfás, 1925). At that time, protection of the soil did not receive similar priority, as it is perceived in our days (Bašić, 2013; Birkás, 2011). The plough, a hundred years ago was only the tool for summer cultivation after cereals' harvest. Although the mode of the stubble tillage had significantly changed, the popularity of summer ploughing has remained until now. Poor germination of the weed seeds was believed to be one of the advantages of the cloddy surface produced by ploughing. In this way, weed management was postponed to the period after sowing. The fact is, the size of the large clods had been visibly reduced by the alternation of the higher and lower temperature in the day and night. The facts differ from the belief that is, the fragmentation of clods might have adequately occurred, but in the meantime the biological activity of the soil has ceased and the decomposition of stubble residues that inverted in the soil has completely stopped.

The importance of the autumnal primary tillage has lasted until recent decades. However, the percentage of ploughed soil between the possible modes is even higher than it would have been accepted (Đekemati et al., 2016). The cloddy surface as result of ploughing is still accounted for the goal to catch the rainwater and the snow. In this relation, as Đekemati et al. (2016) outlined, a ploughing often conserves less water in relation to the subsoiling or the deep tine tillage. The amount of snow has continuously decreased, so the reference to catch the snow seems disputable. Considering milder weather, winter ploughing has also become more frequent, believing the damage might be remedied by the frost. As Đekemati et al. (2016) reported, the crumbling effect of the frost or alternating temperature could only be detectable on the surface of the clods. Impact of the friability extended to the depth of 10-20 mm in the surface layer, and a higher ratio of the new particles were dust.

It has to be highlighted that the physical and biological deterioration of soils are in close connection with the ploughing practice. The short-term result (inverting the weed seeds), despite the deterioration of the soil structure and water loss, seems more preferable related to the ploughless methods that have already proved long-term soil quality improvement (Birkás et al., 2013; Kende et al., 2017).

Evaluation and rank of soil condition characterizing tillage treatments in dry and wet seasons

Table 3 presents the most important soil condition factors and their changes in adverse wet and dry soil conditions.

The soil condition changes listed in Table 3 were summarised by the results of the soil state monitoring performed in four districts of Hungary (cf. Figure 1). Thereafter, these sixteen factors were used to rank the six soil tillage treatments applied in the last seven years in the long-term experiment (Table 4).

It is clear that more damage may occur by tillage in wet soils, and somewhat less in the dry seasons and the remedying takes longer in both cases (Birkás and Đekemati et al., 2017a). The depth of the loosened layer important for water infiltration and root growth corresponded to the depth of cultivation for treatments where a compact state had developed at the bottom of disturbed layer that is at the plough (Vukadinović et al., 2014) and the disk. Both plough and disk pan compaction have been occurring in the soil since the beginning of the experiment in two treatments (P and D), and this phenomenon became particularly severe in wet seasons. The effects of the tools on the soil structure and the extent of damage was, however, fortunately different. A strip pressure (ST, T, L) in wet soil was found to be moderate related to the damage that extended to the entire soil profile (P and D). During the wet season, the depth of cultivation that reached or surpassed at least 250 mm (L, T, P) was reasonable to achieve adequate depth for rooting. Bottlik et al. (2014) observed that the degree of the soil settlement significantly depended on soil quality (mainly humus content) and the intensity, duration and repetition of rainfalls. The level of the settlement was stronger in the upper 0-150 mm layer of deeper cultivated (P, L) and the uncovered soil (P, D). The settled state at the direct drilling treatment (DD) has stabilised during the extreme seasons. Larger clods (≥50 mm) that needed reduction for seedbed occurred in all treatments and in both extreme seasons except at the direct drilling (DD). Large clods in ploughed soil often exceeded the size of 150-500 mm. Dry or kneaded large clods often formed in soils were already adversely settled (Bottlik et al., 2014). Both levels of settling and the clod formation were luckily different in the treatments (Table 4.).

The proportion of crumbs in the cultivated layer may be an important indicator of soil quality. As Stefanovits (1994) wrote, approximately 75 % of crumbs are considered optimal, however, this ratio can increase to as much as 80% by the adoption of the soil conservation tillage. Higher crumb ratios were found in the treatments (ST, T, L, DD) where physical damages remained at low degree both in dry and wet soil.

As described above, a high ratio of dust accumulating in the surface layer is a rather undesirable phenomenon. The ratio of dust was highest in ploughed soil (P) after wintering, and in addition in dry period, due to clean and uncovered surface. Siltation, and later on, the crust formation became serious in soils that included more dust in the disturbed layer (P and D). Várallyay (2015) outlined that the dust, formed in the top layer sediments by rainwater to the nearest compact pan, simultaneously with the colloids, then these small particles are assembled, thus the compact layer that occurred previously would considerably thicken. Birkás and Đekemati et al. (2017) noted that the shape and the exposure of the soil surface indicate the potential danger of the weather elements.

Removing the stubble residues from the fields in accordance with the classic theory made the soil tillage performance easier after harvest (Gyárfás, 1925). This attitude has luckily been changed in the last three decades. Kalmár et al. (2013) observed optimal crumb formation and water preservation at 45-55 % of surface cover in their

Table 3. Changes in soil condition factors in wet and dry soil

Factors	Changes in wet soil	Changes in dry soil
Optimal looseness for rooting	Short duration	Limited (after plough, disk)
Water infiltration and store	Limited (after plough, disk)	Water loss occurred
Compact state below tilled layer	By plough, disk	Moderated danger
Settling	Real danger	Moderated danger
Creating ≥ 50 mm particles	Related to the tools (worst by plough)	Changing by tools (worst by plough)
Crumb preservation	By soil preserving tools	By soil preserving tools
Dust formation (by tillage)	Less danger	Considerable danger (mostly by plough, disk)
Dust ratio (after wintering)	At clean and cloddy surface	At clean and cloddy surface
Dust sedimentation from the surface	Main reason: dusts in tilled layer	Mostly in ploughed, disked soil
Surface extension	Main reason: clean surface	Main reason: clean surface
Siltation/crust formation	Main reason: clean surface	Main reason: clean surface
Decomposition of stubble residues	Kneading limits decomposition	Limited decomposition
Earthworm activity	Related to the tools (worst by plough)	After soil drying is poor
CO_2 emission	Related to the soil disturbance	After soil drying is poor
Impacts on weed infestation	Related to the tools	Related to the tools
Deterioration of soil quality	Related to the tools (worst by plough, disk)	Related to the tools (worst by plough)

Table 4. Impacts of tillage treatments on soil condition and the rank in wet and dry soil

Factors	Rank in wet soil	Rank in dry
Optimal looseness for rooting	L>T>ST>P>DD>D	L>T>ST>P>D>DD
Water infiltration and store	L>T>ST>P>DD>D	L>T>ST>P>D>DD
Compact state below tilled layer	D>P>L>T>ST>DD	D>P>ST>T>DD>L
Settling	P>L>D>T>ST>DD	P>D>L>T>ST>DD
Creating ≥ 50 mm particles	P>L>T>D>ST>DD	P>L>D>T>ST>DD
Crumb formation	ST>T>DD>L>P>D	ST=T>L>DD>P>D
Dust formation (by tillage)	P>D>L>T>ST>DD	P>D>L>T>ST>DD
Dust ratio (after wintering)	P>L>T>D>ST>DD	P>L>T>ST>D>DD
Dust sedimentation from the surface	P>D>L>T>ST>DD	P>D>L>T>ST>DD
Surface extension	P>D>L>T>ST>DD	P>L>T>D>ST>DD
Siltation/crust formation	P>D>L>T>DD>ST	P>D>L>T>ST>DD
Decomposition of stubble residues	T>L>ST>D>P>DD	ST>T>L>D>DD>P
Earthworm activity	DD>ST>T>L>D>P	DD>ST>T>D>L>P
CO_2 emission	P>L>T>DD>ST>D	D>DD>P>L>T>ST
Impacts on weed infestation	DD>D>ST>T>L>P	DD>D>ST>T>L>P
Deterioration of soil quality	D>P>L>DD>T>ST	P>D>L>T>DD>ST

Legend: L: loosening (0.4 – 0.45 m), P: ploughing (0.28-0.32 m), T: tine tillage (0.22-0.25 m), ST: tine tillage (0.18-0.22 m), D: disking (0.12-0.16 m), DD: direct drilling (soil disturbing by sowing).

stubble experiment. In addition, the serious effect of heat and rain stress had effectively mitigated at the higher coverage ratio (85-100 %). The benefits of stubble residues are at least triple, that is, they are the most important source of humus (Rubinić and Husnjak, 2016), the most important soil surface protection material, and ultimately, food for earthworms in agricultural soils (Birkás et al., 2010; Ojha and Deepa, 2014). The stubble residues in soil decomposed harmoniously in the slightly damaged soils (T, ST, L), but it was limited in soils kneaded or over-dried by plough (P). The optimal distribution of the well-chopped stubble residues in the disturbed layer (T, ST, L) was found more favourable to the earthworm activity than the inversion of residues by plough (P) to the bottom of the ploughed layer. Jug et al. (2008) stated that the earthworm activity reduced by over disturbance of soil and/or the lack of crop residues. At the same time despite the undisturbed soil condition, and the physical phenomena (plate structure) a well-covered soil (DD) proved to be a better habitat to earthworms than ploughed soil.

Measuring the CO_2 emissions of differently disturbed soils is a popular research topic nowadays. In our case, the results correspond to the data from other literature (e.g. Bilandžija et al., 2017; Gelybó et al., 2016) that states a rough (P) or a deep (L) soil disturbance increase CO_2 emissions.

However, in the case of gentle disturbance (ST) or shallow cultivation (D), the rate of the emission remains low. The level of emission at the direct drilling treatment (DD) was quite low, but continuous due to wetter soil and the exposure of stubble residues to the microbial decomposition.

Cultivation treatments have a particular effect on weed infestation. On the one hand it was possible to justify the decreasing effect of ploughing on weed emergence (Boström, 1999; Gruber et al., 2012) although it had a short-term positive effect and for that there was no literature reference (Kende et al., 2017). A greater degree of weed infestation was found at the ploughless treatments in the first six years of the experiment, in accordance with the favourable soil condition that stimulated the weed emergence. At the same time, it was more informative to produce a wide-row plant in a rainy season when weed infestation increased again.

We may note that the ploughing treatment proved to provide better observations than the regional practice, both in work quality and water conservation, although it has accomplished poorer results compared to the tine tillage or subsoiling.

Conclusions

Protection of soils requires revision of a number of cultivation practices in order to alleviate the adverse effects of the extreme climate. Reviewing the classic theories of ploughing, we found that the hopes of the users rather than the real consequences were compiled in them. Ploughing-related damages have a real impact on the deterioration of soil quality over the past centuries. The formation and worsening of the plough pan is often unknown by ploughman considering the lack of soil condition tests. Due to the inversion of stubble residues, soil surface becomes unprotected against climate phenomena and in addition, the decomposition of residues hindered due to uneven distribution in the ploughed layer. Ploughing has reasonable effect on weed infestation in short term due to the inversion process but it is adverse in the long-term considering the accumulation of viable weed seeds in the soil. Since ploughing was found unsuitable to the current weather conditions, it seemed necessary to find other solutions adaptable to climate extremes. From the beginning of the experiment, an important aim was to limit the degree of soil deterioration. This aim was met for some treatments (tine tillage, direct drilling, loosening) and for others (ploughing, disking) hardly fulfilled. Only the treatment considered acceptable which has resulted in easily remedying damages that occurred during the last seven extreme seasons.

In conclusion, soil tillage adaptability to wet soil condition were (from adequate to the unsuitable) as follows: ST>T=L>DD>P>D. Rank of the treatments has been slightly modified in dry soil, i.e.: ST>DD>T>L>D>P.

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