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TILLAGE INDUCED SOIL COMPACTION CONSEQUENCES IN THE PANNONIAN REGION

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Abstract

This paper is based on soil condition monitoring and measuring that was started 35 years ago and on soil tillage trials modelling and checking the extension of compaction in the soil. The survey comprised 2018 monitoring places on 17280 hectares and on 45 experimental plots. A total of seven typical versions of tillage-induced compaction were identified: 1) favourable to a depth of 60 cm; 2) favourable to a depth of 40 cm; 3) compaction at the depth of 28-32 cm; 4) compaction at the depth of 22-26 cm; 5) compaction at 18-22 cm; two compact layers below 16 cm; 7) three compact layers below 16 cm. The following points were chosen for monitoring: (i) Root zone state. (ii) Occurrence of compacted layer. (iii) Extension of the compacted layer. Accordingly, soil loosened to a depth of 35 – 40 cm qualifies as suitable, soil loosened to 28 – 32 cm is rated as adequate, while soil loosened only to a depth of 16–20 cm is conditionally adequate or inadequate. The depth of the loosened layer is the same as the depth of the layer suitable for water storage. The evaluation of data led to the establishment of four categories: modest damage is to be expected if there is a compacted layer of up to 10 mm in the soil, while if the thickness of the compacted layer is 10–30 mm, 30–50 mm or 50–100 mm, medium, heavy and severe damage should be expected. Serious damage is caused by compaction near the surface.

Keywords: tillage, compaction, pan, monitoring, rooting depth, climate

Introduction

Tillage-induced compaction has been caused by man ever since the first forms of agricultural production appeared (Van Ouwerkerk and Soane, 1994). This type of soil degradation occurs in the wide range of soils and climates and a typical phenomenon of the industrialized and poorly developed agriculture. Concern over the extent of land affected by soil compaction is widespread; it was recorded as affecting some 33 million hectares in Europe (Van den Akker et al., 2003). In the Carpathian basin tillage-induced compaction affected increasingly large areas during last decades (Table 1) as a result of deteriorating general economical conditions and a decline observed in tillage culture itself (Filipovic et al., 2006, Tursic et al, 2008, Birkás and Jolánkai et al., 2004). Types of tillage-induced soil compaction can be grouped according to the depth of occurrence (e.g. in top layer, or in the subsoil) – or by cause (disk pan or plough pan compaction). In both of the latter two ones compaction is caused by operating the tillage implement in the same depth over and over again, in humid or wet soil. Plough pan forms in the ploughed layer, depending on the most frequent ploughing depth (anywhere between 22 and 35 cm, Birkás and Kisic et al., 2009). Disk pan forms underneath the most frequent disking depth (between 12 and 20 cm, Birkás, 2000). The detrimental consequences of tillage-induced soil compaction have been identified by a number of regional researchers (e.g. Kisic, 2008, Neményi et al., 2008, Birkás and Kisic et al, 2009, Birkás and Stingli et al., 2009, Jurisic et al., 2011). Useful information found in selected (Ouwerkerk and Soane, 1994,

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Horn et al., 2000), and reviewed papers (Hamza and Anderson, 2005, Batey, 2009) as well. The adversely consequences of tillage-induced soil compaction include structure deformation, intensification of anaerobiosis, breakdown of useful biological processes including decomposition of stubble residues.

Table 1 Percentage of total agricultural land affected by human-induced soil degradation in selected countries* (from Birkás et al., 2008)

Selected countries	Agricultural land area (1000 ha)	Soil compaction	Temporary drought/water-logging effects	Wind erosion	Water erosion
		As a percentage of the total agricultural land			
Bulgaria	5 725	47	40/35	15	43
Croatia	3 220	25-35	35/25	10	35
Czech Republic	3 674	40-50	31/27	10	52
Hungary	5 585	30-35	27/23	24	39
Poland	16 136	20-25	16/24	27.6	28.5
Romania	14 714	54	48/26	2.6	43
Serbia	5 109	?	35/30	13	33
Slovakia	2 437	26.5	no data	6.2	43.3

*Data from BASIC (2003), BIELEK (2003); DUMITRU et al (2002), JANEČEK (2003), KOZÁK (2003), KISIC (2007), LIPIEC (2007), SZEWRANSKI, et al. (2003), Source Ministry of Agriculture and Forestry, Agrostatistics Directorate, Sofia (from "Agroclimatic resources in Bulgaria for field crop cultivation under irrigated and rain-fed conditions"), VUPOP, 2007: Výročná správa Výskumného ústavu pôdoznalectva a ochrany pôdy Bratislava za rok 2006, Bratislava, VUPOP, State of the environment report, SR 2001, Kobza et al. (2005). Completed: www.unserboden.at/files/dlt2011, Dragicevic S. et al., 2011. Natural Hazard Assessment for Land-use Planning in Serbia *Int. J. Environ. Res., 5(2):371-380.*

Tillage of compacted soil – regardless of its moisture content – takes an increased energy input and the increment is to be booked as a loss (Nikolic et al., 2002). From the aspect of crop production restricted water infiltration and storage as well as the blocking of the water transport from deeper soil layers towards the root zone, are some of the most unpleasant consequences of soil compaction. Moreover, compaction in the root zone causes an indirect water shortage substantially reducing plant growth and yield in a dry period (as heat stress). According to Birkás (2011) climate stress is temporary damage to soils (and plants) caused by an extended period of extreme heat or by heavy and excessive rains, while climate threat is a permanent damage to soil. Climate risk is the expected or likely defects in the soil quality and/or state along with likely consequences of soil disturbance. At the same time water stagnation may occur above severe compacted tillage pans during wet periods as (water-logging stress). As authors outlined, tillage-induced compaction has a complex impact on plants, restricts the depth of root growth, water and nutrient uptake and the plant biomass above the ground (Jug et al., 2007, Kvaternjak et al., 2008, Birkás et al., 2008). Moreover, plant protection consequences were also found on compacted fields (Tursic et al., 2008). Soil compaction has been discussed in a large number of publications, however doubts of the effectiveness has also been increased. Kirby (2007) peculiarly noted, while much compaction research is aimed at the farming, information is also required at a broader level. Not as expected, relative few papers refer to the possible relations between tillage-induced soil compaction and soil susceptibility to climate extremes or between the occurrence and extension of the compact layer and the likely climate damage.

Material and method

This paper is based on soil condition monitoring and measuring that was started 35 years ago in Hungary (Birkás et al., 2004), and 20 years ago in Croatia (Jug et al., 2007, Sabo et al., 2007, Kisic, 2008; Mesic et al., 2008). Soil condition monitoring is aimed to assess whether there is harmful compaction in the top 60 cm layer of the soil, and if there is, at what depth it is to be found and how extensive the damage is. Preliminary soil condition measurements were carried out with the aid of soil probes, followed by actual measurements with the aid of penetration resistance. Measurements were taken and studies were conducted in soils under the following crops between 1976 and 2010: winter wheat (4560,5 ha), maize (5915,5 ha), sugar beet (1108 ha), sunflower (2436,5 ha), winter oil-seed rape (1592,5), and others (alfalfa, tomato, barley, soybean, mustard, 1667 ha), total 17280 ha. The involvement of rape fields was necessitated by the utilisation of this crop for the purposes of the energy sector.

Conventional and soil condition improving tillage variants at each of the production sites involved in the long term tillage experiments. Tillage impacts can also be grouped according to the depth of loosened layer in soil, that is loosened to the depth of 35-40 cm, loosened to the depth of 20 cm (no pan layer), and pan compaction occurred below 15 (disk pan) or below 30 cm (plough pan). Crops that are best suited to the given production sites are grown in the trials, e.g. winter wheat, maize and soybeans or sunflower and mustard. The studies were extended to studying relations between soil quality and climate effects. The monitoring and measuring of the soil condition parameters and the crops responses were taken in accordance with the relevant standards and regulations (Jug et al, 2007, Kisic, 2008, Farkas, et al., 2009, Birkás Kisic et al., 2009).

This paper discusses the following aspects: 1) Presenting tillage-induced soil compaction data from field assessment in Hungary, 2) Studying the occurrence, position (depth) and the thickness of tillage-induced soil compaction, 3) Impact of precipitation surplus on compacted and on adequately loosened soils. The authors present measurements and findings that may be also applied as indicators in the relevant models.

Results and discussion

Tillage induced soil compaction in Hungary

The most frequently variants of soil compaction resulting from inadequate tillage practices have been regularly assessed in fields of soils of different physical types – sandy loam, loam, clayey loam, clay and heavy clay, in terms of clay content: 26-30, 40-60, 60-70, and 80-85%, respectively – since 1976. This 35-year period has been divided into six phases by tillage mode and soil condition: 1976-1987: a phase of *development*, 1988-1990: a phase in which development *ground to a halt*, 1991-1997: a phase of *decline*, 1997-2001: a phase of *transition*, 2002-2007: a phase of *a new beginning*, and 2008-2010: a phase of the *climatic challenges*. A total of 7 typical versions of compaction caused by wrong tillage practices were identified: 1) favourable to a depth of 60 cm; 2) favourable to a depth of 40 cm; 3) compaction at the depth of 28-32 cm; 4) compaction at the depth of 22-26 cm; 5) compaction at 18-22 cm; two compact layers below 16 cm; 7) three compact layers below 16 cm (Table 2). The categorisation is necessitated by the different effects of the different soil state versions. No similar categorisation has been encountered in other publications so far. The condition described by numerous authors (e.g. Hamza and Anderson, 2005; Van Ouwerkerk and Soane, 1994) was categorised as ‘compact’. In a compact layer the soil’s bulk density was up to 1.59-1.61 t m^{-3} while its penetration resistance – when moist – exceeded 3.0 MPa. The so-called ‘favourable looseness’ (bulk density not exceeding 1.38-1.48 t m^{-3} and 2.5-2.8 MPa penetration resistance) was characteristic to soils loosened to a depth of 60, 40, 28, 22, 18 or 16 cm only to such depths. In this paper, evaluation of the trend is more important. During the sixth period (2008 to 2010) soils were well-loosened to a depth of at least 40 cm on 35% of the area. Area of the well-loosened soils was lowest between the 2nd and the 4th periods reflecting the omission of the soil condition improving tillage.

Table 2 Tillage induced soil compaction observed on 17,280 ha of land during five examination periods in Hungary (1976-2010)

Location of subsoil compaction	Examination periods					
	1st 1976-1987	**2nd 1988-1990**	**3rd 1991-1997**	**4th 1998-2001**	**5th 2002-2007**	**6th 2008-2010**
	Percentage of observed land area					
Below 60 cm	14	4	1	0	11	9
Below 40 cm	22	12	6	2	21	26
At the depth of 28-32 cm	44	47	42	36	30	34
At the depth of 22-26 cm	14	22	23	14	21	16
At the depth of 18-22 cm	6	10	16	22	12	10
2 compacted layers below 16 cm	0	3	7	14	5	5
3 compacted layers below 16 cm	0	2	5	12	0	0
Examined area (ha)	2420	2860	2580	1860	4690	2870

The percentage of soils compacted at a depth of 28 to 32 cm (below the typical deep ploughing zone in the region) did not change significantly during the first three periods (1976 to 1997), but it did decrease from 44 to 34 % for the latest period (2008 to 2010). Nowadays, however a loosened layer, to a depth of 28-32 cm can be created not only by plough but also by cultivator constructed for pan-alleviating tillage. The percentage of soils compacted at the depth of 22 to 26 cm has been fluctuated during the periods. Previously this was the typical depth of the medium-deep ploughing, and recently this depth can be created by cultivator, too. The percentage of soils compacted at a depth of 18 to 22 cm (i.e. below the depth of conventional disking), increased 6 to 22% during the 25 years, reflecting the more frequent use of the shallow disk tillage. Compaction is occurred below 16 cm was found primarily in fields where are preferred disking as a means of primary tillage and in fields of those choosing conventional disk for secondary tillage after ploughing. In the 6th period, 10 % of the assessed soils were deteriorated by disk pan compaction, and this proportion can be referred to the whole practice. The occurrence of two or three compacted layers within the same profile, indicate the expansion of subsoil compaction during the third and especially in the fourth period. These soil condition types are especially serious for winter oilseed rape, but affected all crops within many fields. We found greatest climate-induced soil deterioration and in the fields representing two or three compact layers in the soil profile. Earlier it was not possible to definitely establish that loosened state of the top 60 or 40 cm is a pre-requisite for mitigating susceptibility to climate stress or damage for we found different results in the drought periods. Looseness to a depth of 40 cm was mostly favourable than looseness only in the top 28 cm layer, i.e. looseness to a depth of 40 cm may be taken as an indicator. However a loosened state to the depth of 30-32 cm for lack of pan compaction has really guaranteed the lower climate stress of soils. We also found that a deeper loosened layer had a more effective climate damage mitigating impact in soils of higher clay contents. No deepening of the cultivated layer at all in a no till variant, at the same time that is competitive in comparison to any other type of tillage is characteristic of soils not damaged by compacted pan formation.

The occurrence, position (depth) and thickness of tillage-induced soil compaction

The depth of the loosened state (the state of the top 60 cm soil layer) shows whether there is any compact layer in the root zone blocking water transports. The following has been concluded from crop and yield assessments and evaluations between 2000 and 2010 at a total of 2018 sites:

- 35-40 cm: good climate damage mitigation, little (hardly or non identifiable) loss,
- 28-32 cm: medium or good climate damage mitigation, little (identifiable) loss,
- 22-25 cm: moderate climate damage mitigation, medium loss,
- 16-20 cm: little climate damage mitigation, great loss,
- 10-12 cm: very little climate damage mitigation, severe loss.

The negative effects entailed by the location (depth) of the compact layer were not affected by the soil properties or clay content: the closer the compact layer was to the surface, the more susceptible the soil and the crop was. Accordingly, this feature is indicative not only of the soil quality but also as a climate indicator. The shallower the layer in which roots could grow and expand the less favourable the conditions were. Compaction between 16 and 20 cm was found primarily in fields where preferred conventional disking as a means of primary tillage and in fields used disk for secondary tillage after ploughing. So the assumption that cereals, including wheat need only shallow tillage should be re-considered, since these crops suffered heat stress sooner in soils compacted at the depth of 16 cm during dry periods than in soils where compaction occurred in layers deeper down. We found that in some periods the soil's top 10-20 cm layer is regularly (weekly, once every 10 days) soaked through, and the loss in the yields of shallow rooting cereals is fairly modest (10-15 %), so no one is looking for the causes. A field with a shallow loosened layer is not suitable for growing rapes, for instance. The active root zone depth – that is at least 32-40 cm – will be required both for weathering summer drought and for precipitation surplus as well (Figure 1).

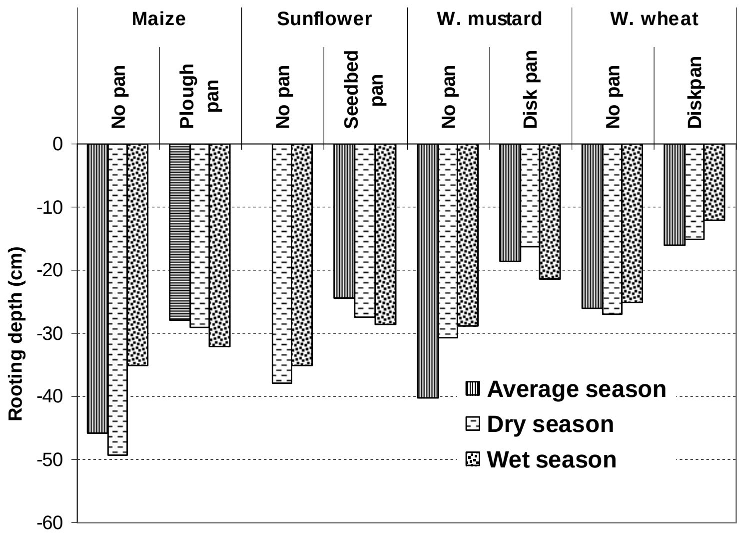

Figure 1 Rooting depths (cm) of crops in experimental conditions (2002-2010)

Right in the first years of the monitoring programme was found that the thickness of the compact layer may be – in relation to the soil water transports – an important indicator. Because it impedes water transport in the soil – from which conclusions can be drawn with regard to the expected risks and possible damage. The following categories are distinguished in terms of the correlation between the thickness of the compacted layer and soil damage:

- 0-10 mm compact layer: slight damage,
- 10-30 mm: medium damage,
- 30-50 mm: heavy damage,
- 50-100 mm: severe damage.

Some slight damage (0-10 mm) may be caused in a humid soil even during seedbed preparation, or medium damage (10-30 mm) may occur in a wet soil during primary tillage as well as during seedbed preparation. The latter occurs more frequently in soils under spring-sown crops. Heavy (30-50 mm) and severe (60-100 mm) damage appears after an extended period of tillage to the same depth while the criteria of workability are ignored. Authors (Chen and Tessier, 1997, Nikolic et al., 2002 Hamza and Anderson, 2005) have found that initial tillage-induced soil compaction is substantially affected by the soil moisture and clay content, the machines weight and the smearing, and pressing effects of the tillage implements. The repeated pressure and of so-called tillage pan forming elements (Birkás et al., 2008) – plough share, conventional disk plate – in the same dept over and over again result in increasing the thickness of the compact layer. A medium degree of damage (10-30 mm compact layer) has developed to the severe one in a rainy growing season.

Impact of precipitation surplus on adequately loosened soils

According to the continuous soil condition studies the following types of soil state damage were observed and proven by measurements: settlement (in the wake of steady rains), aggravation of compaction (as dust and clay colloids are washed down), and structure degradation as a result of steady rainfalls. Under adverse climate conditions (as in 2010) however, even soils that are moderately sensitive to settling, become endangered. The early rains had the greatest settling impact on bare ploughed or disked (slightly covered) soils. In the maize growing season a total of 646 mm of rains had been recorded, and the compacting impact of which – considering wide row crop – had also been detected. Dust rata has continuously been decreased in the surface layer until mid-summer. However, dust ratio has simultaneously increased at the depth of the ploughed and of the disked layer, compacting the soil state.

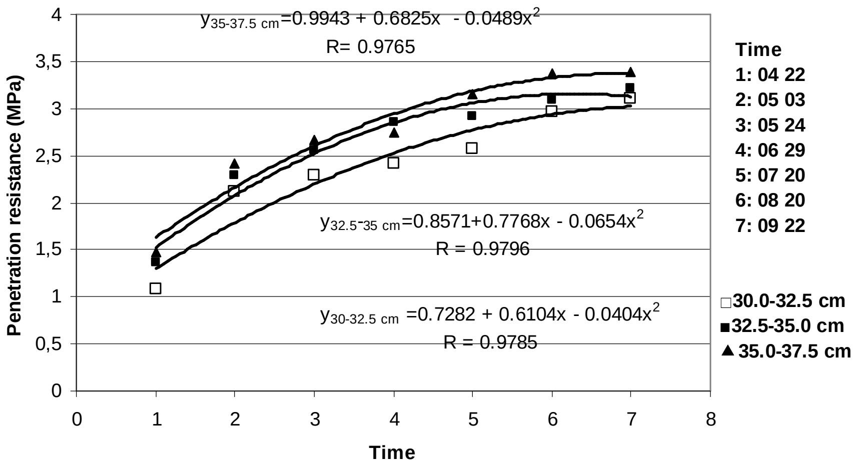

Figure 2 Changing in penetration resistance values in three layers of a ploughed soil (2010)

Soil state was more important in three layers in the ploughed soil (30.0-32.5; 32.5-35.0; and 35.0-37.5 cm) which occurred nearest to the former plough pan (Figure 2). Values of the correlation coefficient of the polynomial curves are high (>0.9700). Evaluation of the compacted layer occurred above 35 cm impacts on the lower (35.0-37.5 cm) layer compaction gave an interesting result. We found that the modifying of the upper (30.0-32.5 cm) layer affected 5.5 times greater the state of the 35.0-37.5 layer then the state of the layer at the depth of 32.5-35.0 cm. The washed dust probably contributes in the extension of the plough pan compaction. A similar phenomenon was found in the disk tilled variant (Figure 3), where values of the correlation coefficient were also high (>0.9600).

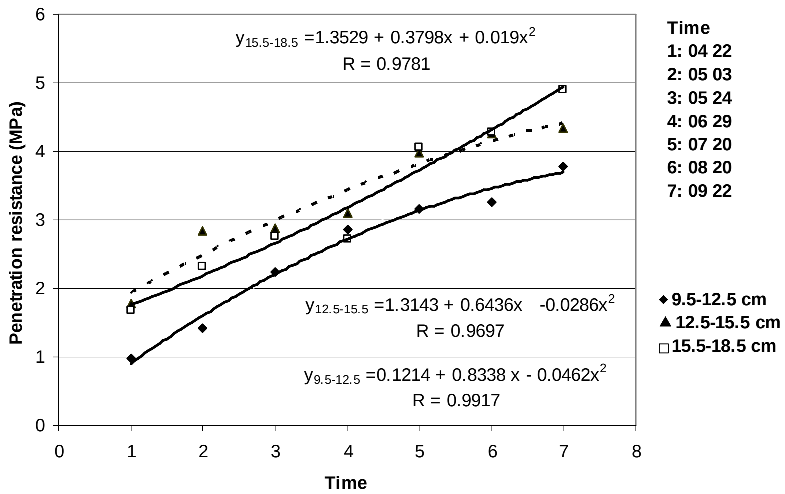

Figure 3 Changing in penetration resistance values in three bottom layers of a disked soil (2010)

We found that the state of the former disk pan, occurred at the depth of 15.5-18.5 cm has really worsened due to dust sediment from the upper layers to the pan layer. On the basis of this finding a climate-induced worsening factor is to add to the tillage-induced compaction threat. As Kalmár et al. (2011) suggested, new climate conditions underscore the need for eliminating compact layers in arable soils.

Conclusion

A total of seven typical versions of tillage-induced compaction caused by wrong practices were identified and discussed. The formation and location of compacted layers provided real information regarding the depth, method and type of tillage being used, and moreover the expected risk for agri-environment. Some compaction-related factors, such as the depth of the loosened zone, the thickness of the compact layer and the occurrence of severe damage may be used as climate damage indicators. Regional tillage practice fall into two main groups: those having climate damage mitigating and those having climate damage aggravating effects. Frequency occurrence of the extreme rainfall, longer dry periods and shorter rainy periods suggests tillage technique keeping arable soils free of tillage-induced soil compaction, maintaining soils water infiltration and storing capacity.

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