Soil Compaction Alleviation as a Solution in the Climate Stress Mitigation

Márta BIRKÁS[1], Danijel JUG[2], Attila STINGLI[1], Tibor KALMÁR[1], András SZEMŐK[1]
[1]Szent István University Gödöllő, Hungary,
[2]J. J. Strossmayer University Osijek, Croatia
Birkas.Marta@mkk.szie.hu

Abstract: Tillage-induced soil compaction has often occurred in the Pannonian region. This form of compaction occurs on arable lands both in Hungary (1.82 million ha) and in Croatia (0.97 million ha) having negative impacts on crop production. In this study the tillage-induced compaction is discussed as an indicator of climate stress on arable fields. The research is based on soil condition monitoring and measuring that was started 32 years ago and on short and long-term experiments assessing the compaction impacts on the crops. The survey comprised 1870 monitoring places and 38 experimental plots. The following points were chosen for monitoring: 1. Root zone state (to a depth of 0-50 cm). 2. Occurrence of compacted layer (indicating the risk). 3. Extension of the compacted layer (indicating the degree of damage). 4. Long term effects of tillage (deterioration or improvement). 5. Tillage-induced drought and water-logging damage impacts on yield loss. The formation and location of compaction provided information concerning the depth, the method and the type of tillage applied, along with the expected risk for crop production under extreme climate conditions. The main objectives of the study are: 1. Occurrence and the extent of tillage-pan compaction in soils. 2. Consequences on water management in each of the years covered by the experiments. 3. Soil quality consequences. 4. Alleviation of pan-compaction by mechanical and biological methods. Long-term assessing has convincingly proven a correlation between tillage-pan compaction and the degree of climate stress. In view of the findings trends in soil tillage can be grouped into the following categories: climate damage mitigating and climate-stress increasing ones.
Key words: tillage-induced compaction, alleviation, climate stress, mitigation

INTRODUCTION

Research findings show that agricultural activities have contributed to climate change and that at the same time agriculture is one of the sectors adversely affected by climate damage (*Neményi, 2008*). *Várallyay* (*2008*), emphasised, that possibilities in agriculture are limited particularly by unexpected and long spells of unusually hot or cold weather. Although combinations of certain climate phenomena (e.g. too high ambient air temperature coupled with water shortage) cause severe losses in cropping, those seeking to identify the causes for the losses tend to narrow their quest to the main causes of the damage. Attention to this shortcoming has been drawn by findings of soil state monitoring. The authors assume that the extent of climate-induced damage and losses may be affected by the presence or absence of a thick compacted layer in the soil impeding the infiltration of precipitation in the soil and the storage of water, leading to waterlogging in a season of abundant precipitation, and similarly impeding the rising of soil moisture from deeper layers to the root zone, resulting in increased drought damage in drier seasons (*Birkás et al., 2008*). According to *Tursic et al.* (*2008*) a 'thick compacted layer' builds up in the root zone as a consequence of poor tillage practices, primarily as a result of the farmer failing to vary the depth of intervention over several years. Tillage-induced soil compaction and compaction in general (*Soane and Ouwerkerk, 1994*), is the subject of research across the world. One relatively recently adopted approach to studying compaction involves modelling the build-up of compact layers (*Krümmelbein et al., 2008*). Some of the researchers have referred to relationships between compaction and the extent of climate damage to date (cf. *Lipiec and Simota, 1994; Kvaternjak, et al., 2008*). Research (cf. *Canarache, 1991; Birkás, 2000, Gyuricza, 2000*) findings show that compaction limits crop rooting depth, water and nutrient uptake and consequently growth above the ground. Effective protection against certain serious climate phenomena is known to be a difficult and costly undertaking however, alleviation factors affecting the extent of damage, like compaction, may bring about positive results even in a shorter run. The first and foremost task in this aspect in the Pannonian region is changing tillage patterns, replacing interventions causing compaction with practices preventing soil damage.

MATERIAL AND METHODS

This paper based on soil condition monitoring and measuring that started 32 years ago in Hungary by Department of Soil Management at Szent István University Gödöllő (Birkás, 2000, Birkás et al., 2004), and in Croatia in the last decade by Department of Crop Production at Strossmayer University in Osijek (Jug et al., 2007). The objective of soil condition monitoring is to see whether there is harmful compaction in the top 40-60 cm soil layer, and if compaction occurs, to identify its depth and thickness. One supplementary task is to assess impacts on soil quality, water transports and on crops during dry and wet periods. Soil condition parameters were measured first with the aid of soil probes, penetrometers and in some cases pit tests. The studies were carried out in fields under the following crops between 1976 and 2001: winter wheat (2800 ha), maize (4090 ha), sugar beet (550 ha), sunflower (1340 ha); pea (370 ha), and others (alfalfa, tomato, winter and spring barley, 570 ha), total 9720 ha, between 2002 and 2007: winter wheat (1197 ha), maize (1195 ha), sugar beet (507 ha), sunflower (717 ha), w. oil-seed rape (715 ha), others (alfalfa, tomato, w. barley, pea, 359 ha), total: 4690 ha. Winter oilseed rape fields were involved with a view to the use of the crop for the purposes of the energy industry and to the size of the area used for producing oilseed rape. Dry spells were observed in both the eighties and the nineties but the latest ones (2000, 2003, 2007) have become particularly important as a consequence of the global climate change. Demonstrating the relationships between the tillage-induced soil compaction and the extent of climate damage was taken on as a particular challenge.

Tillage systems based on ploughing (P), loosening (L), shallow disking (D) or tillage with cultivator (C), leaving a mulch on the soil surface and direct drilling (DD) have been studied for years to date in long term cropping experiments (Hungary: Hatvan, Croatia: Cancici, Knezevo regions). Among these variants ploughing and disking lead to pan development, loosening alleviates pan compaction, while the use of cultivators and direct drilling preserve the soil structure. However, in the case of the last two variants soil settlement may occur, while in the case of the first two variants it is possible to delay pan forming. A crop sensitive to the soil state (maize) and crops less sensitive to soil state (winter wheat, rye and sunflower) were grown in the experiments. During recent years the experiments were supplemented by studying relationships between soil quality and climate effects. The experiments are set up, the tillage variants are arranged and the soil state parameters and crop responses are measured at each of the three locations of the project in accordance with the relevant standards and regulations (Birkás et al., 2004, Jug et al., 2007; Kvaternjak, et al., 2008, Birkás, 2008; Birkás et al., 2008, Mesic, et al., 2008).

In this paper the relationship between the depth of the layer where tillage-induced soil compaction occurs, the extent of the compacted layer and losses caused by climate effects are discussed. The effects of compaction on soil quality are also discussed and references to the effectiveness of methods of alleviation are also made in this paper.

RESULTS and DISCUSSION

Occurrence and the extent of tillage-pan compaction in soils

The first step of assessing the damage was to categorise the thickness of the compacted layer. The various categories of damage were set out on the basis of the findings of the monitoring programme: 0-10 mm compacted layer: slight, 10-20 mm: medium, 30-50 mm: serious, 50-100 mm: very serious. A total of 1.82 million hectares in Hungary and 0.97 million hectares (35 %) in Croatia falls in the slight compaction category. This includes areas where pan development and structure improvement alternate from year to year. Soils damaged by medium compaction account for 40-45 %, seriously compacted soils account for 10-15 %, while very seriously compacted soils account for 5 % of the total area affected by soil compaction. A certain part of the soils damaged by compaction of a medium degree turn into seriously compacted soils, while part of the seriously compacted soils can be turned into soils damaged by compaction of a medium degree by insufficient improvement interventions. Conclusions from the most frequently encountered soil state variants (Table 1) can be drawn concerning tillage patterns and likely cropping risks. Climate risk is the smallest in the case of soils loosened to a depth of at least 40 cm and, if properly carried out, loosening has a positive impact on the soil and most crops (*Birkás et al., 2004, Birkás and Kisic et al., 2008*).

A 28-32 cm loosened top soil layer is created by deep ploughing in the autumn before spring-sown crops and since at that time of the year the soil contains more water than the optimum level for ploughing, puddling and smearing cannot be avoided. As has been pointed out by Tursic, et al. (2008), soil loosened to a depth of 28-32 cm provides adequate circumstances for the growth but this advantage is lost after repeating this tillage variant over 2-3 years. Plough pan compaction at a depth of 22-26 cm qualifies as a climate damage aggravating factor on account of the shallower loosened layer. Severe damage is to be expected in a year of extreme weather conditions on soils where the disk pan has formed at a depth of about 18 cm. As a consequence of repeated compaction stress impacts, a number of compacted layers can develop in the soil adding to the soil climate-sensitiveness. As *Birkás and Kisic, et al.* (*2008*) pointed that during the growing season, as a result of the regular soaking-over of the loosened layer the yield reducing impact of the tillage pan is not as severe. As the farmer does not recognise that the condition of his soil is short of adequate, he does not see the need for improving it.

Table 1 .Subsoil compaction observed on 14.410 ha of land during five examination periods (1976-2007; *Birkás, Kisic, et al., 2008*)

Location of the compacted layers (cm)	Examination periods					Degree of climate damage
	1976-1987	1988-1990	1991-1997	1998-2001	2002-2007	
	Percentage of observed land area					
Below 60	14	4	1	0	11	no/low
Below 40	22	12	6	2	21	no/low
At the depth of 28-32	44	47	42	36	30	low/moderate
At the depth of 22-26	14	22	23	14	21	moderate/great
At the depth of 18-22	6	10	16	22	12	great
2-3 compacted layers below 16	0	5	12	26	5	greatest
Examined area (ha)	2420	2860	2580	1860	4690	

Consequences on water management in each of the years covered by the experiments

The relationship between soil moisture deficit and yield loss in our experiment is shown in Figure 1.

The optimum soil moisture contracting entity on the soil in this region (Calcic Chernozem) in the top 60 cm layer is 22 w/w %, to which we compared the average of 12 measurements per year, per treatment. Before the experiment the typical cropping pattern applied in the area was resulting in losing soil moisture, which in the 1st and the 2nd year of our experiment – despite the fact that there was no pan compaction in the soil –, could be identified in both the percentage of soil moisture and the yield. The results of moisture conservation tillage are also reflected by the modest deficit.

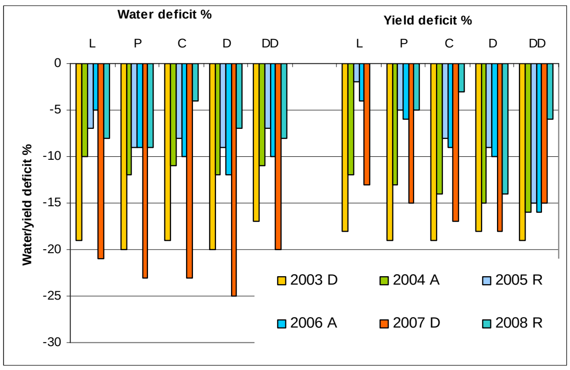

Figure 1. Ratio of moisture to yield loss in the case of different soil state variants (Hatvan, 2003-2008).
Legend: A: average, D: dry, R: rainy season. Optimal average water level on the given soil: 22 %, w/w. Optimal yield level t ha^{-1}: w. wheat (2003): 5.62; green rye (2004): 16.95; w. wheat (2005): 6.75; green maize (2007): 35.6; sunflower (2008): 3,70; Soil conditioning plants: 2004: pea, 2005: mustard, 2006: phacelia. LSD 0.05 water deficit: 3.11 %; yield deficit: 4.09%

The production of crops alleviating pan compaction (mustard, phacelia) has been found to have favourable impacts from the aspect of the soil condition but slightly unfavourable from the aspect of soil moisture. As a result of the improvement in the level of soil moisture the shortfall from the optimum yield level in the 3rd and the 4th years did not exceed 6 % in the case of a deeper loosened root zone (L, P) and 10 % in the case of a shallower loosened layer (C, D) (P<0.01 %). Soil moisture was adequate under direct drilling (DD), which was not reflected by the yield, probably as a consequence of soil settlement. For this reason, the soil was loosened by slitting in the autumn of 2006. Year 2007 was one of severe droughts across Europe. In our case the soil moisture deficit was related to the soil state, e.g. the DD variant without seeding-pan was more water conserving and this was also reflected by the smaller loss of yield. In year 2007 every tillage variant was characterised by balanced soil moisture conditions. In soil damaged by disk pan (D) and in soil damaged by plough pan (P) the yield of sunflower fell short of the optimum level by 14 % and by 5 %, respectively. The loss was smaller on settled but pan-free soils (DD, C) and more than the optimum amount was harvested on fields of soil best suited or taking in and storing water (L). This and other phenomena experienced during the trial show that conventional principles such as that sunflower is not so exacting in regard to the looseness of the soil – given its strong root system – or that winter wheat can be produced by shallow tillage, do not apply to today's crop variants and hybrids. The soil moisture experiments prove – as has been noted by Lukács et al., 2007 – that in a dry season compaction in the root zone leads to indirect water deficit and to relative water surplus in a rainy period.

Soil quality consequences

In the concerning soil compaction literature (cf. Soane and Ouwerkerk, 1994, Kirby, 2007) one finds numerous references to tillage-induced soil quality degradation (platy structure, habitat degradation, impeded water transport etc.). The soil moisture content at the time of tillage is known to have an impact on the effectiveness and impacts of tillage itself, so tillage can cause or aggravate or even alleviate damage. Examples are shown here on the basis of our experiments between 1997 and 1999 involving maize (Figure 2). The treatments included typical variants applied in the region, some of them known as tillage pan creating (P, D/D) others as tillage pan alleviating (P/D, D/P, L+D).

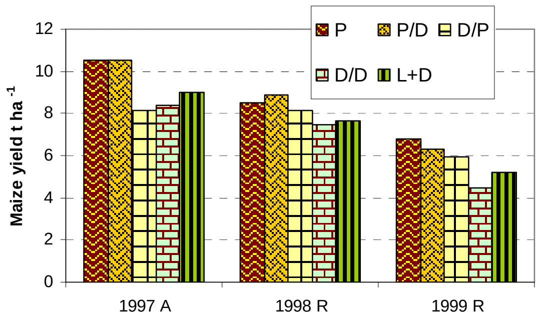

Figure 2. Influence of soil tillage on maize yield on lessive-pseudogley soil at Cacinci site (1997-1999).
Legend: A: average, R: rainy season. P: ploughing, DD: deeper and shallower disking, P/D and D/P: ploughing alternates disking, L+D: loosening + disking. LSD 0.05: 1997: 0.87; 1998: 0.98; 1999: 0.44 (P<0.05)

Maize has special requirements concerning the state of the soil (Jug, et al., 2006), it needs deeply loosened soil but it also produces adequate yields in soils without tillage pans even if the soil is short of the optimum depth of an adequately loosened layer. In our experiments the state of the soil and the yield both matched the treatments and the average weather conditions in 1997. In the next year when precipitation was more abundant, the lower yield was explained by the deterioration of the state of the soil, which was alleviated to some extent by the good water supply. In 1998 primary tillage was carried out on too wet fields and the D/D tillage which is rather a pan-inducing approach, had a definitely negative impact on the yield. Loosening was not effective and disk re-compacted the soil. The only reason the ploughed soil was slightly better because the plough pan occurred relatively deeper in the soil, thus the root zone was also deeper in the case of the L+D intervention. This example – along with experience built up during monitoring – highlight the increased sensitiveness of the soil to damage and to the impeding of crops' water uptake (cf. Várallyai, 2008) again. As has been pointed out by Neményi (2008), one of the negative consequences of the deterioration of the soil quality is increased climate damage, while mitigating climate damage requires good soil quality.

The tasks have been defined primarily for the Pannonian region, as follows: 1) Awareness of the state of the soil: knowledge of the depth of the loosened soil layer enables the farmer to draw conclusions concerning the likely damage and loss (minor, medium, great) in a season of extreme weather conditions and to draw lessons concerning future growing seasons. 2) Eliminating or preventing the compacted layers impeding water transport is a fundamental prerequisite for alleviating climate stress. Water that cannot seep into the soil will never be utilised by crops. 3) In the case of compaction, eliminating the compacted layer impeding water transports in the soil with the aid of a suitable tillage technique (loosening in some form). 4) Creating little surface through which water can be lost, at any time of the year, without compaction stress. 5) Covering the surface with chopped residues to protect soil and soil moisture and to alleviate climate stress. 6) Since humus colloids store more water than do clay minerals, preserving the soil organic carbon contents is crucial in the course of any type of tillage and in any season. 7) Degraded soils are more exposed to climate stress, therefore protecting the soil structure is the right approach in the course of any tillage intervention and in any season. 8) In choosing the deepest – primary – tillage method within the tillage system preventing and alleviating damage should be the most important consideration. 9) The frequent occurrence of climate extremes call for preventing damage and for using tools causing smaller damage in over-wet or over-dry soils. 10) In the case of regular irrigation particular attention is to be paid to maintaining the soil water storage capacity.

Alleviation of pan-compaction by mechanical and biological methods

In assessing the risk of compaction natural (soil, precipitation) and farming (soil management, tillage) factors are taken into account. Soils are categorised as follows: 1) Sensitive, where the soil is highly prone to compaction when humid or wet, the duration of loosening interventions is short and the production of crops of rooting systems loosening the soil poorly. 2) Moderately sensitive where the soil is adequately prone to settle when humid or wet, the effects of loosening are moderately lasting by growing crops having loosening root systems (rape, mustard, oilseed radish). 3) Soils that are not or only slightly sensitive are only slightly prone to settle regardless of soil moisture content and loosening interventions last for 2-4 growing seasons.

The impacts of precipitation: 1) Where it exceeds the multi-year average by at least 50 %, there is an increased risk of compaction, in this case more serious to apply pan-inducing tools (such as disks, ploughs). 2) In the case of average precipitation there is an average risk of compaction setting in, pan-inducing tools, however, should not be applied. 3) When precipitation is below 50 % of the multi-year average (dry seasons) there is a smaller risk of compaction and there is a good opportunity for loosening compacted layers.

The impacts of land use: 1) Detrimental, where the cropping technology results in the appearance and/or aggravation of compaction and no soil state improvement takes place; in this case there is a high risk of serious climate damage. 2) Neutral, if the overall effect of the applied cropping technology has no negative or positive impact on the soil's condition; in this case the risk of the climate damage is high in drought or rainy periods. 3) Preserving, where all interventions are aimed at preventing compaction, where defects are improved and where crops with rooting systems loosening the soil are also grown; in this case there is probable climate damage but its risk is low.

The impacts of tillage: 1) Detrimental, where the soil structure is heavily deformed, tillage pan is formed or it is aggravated; in this case there is a high likelihood of the occurrence of climate damage. 2) Neutral, where tillage pan may be formed but can be easily eliminated; in this case the occurrence of climate damage is small or moderate. 3) Soil preserving, when no tillage pan is induced, the soil state is preserved or improved and the level of climate damage is likely to be low.

CONCLUSIONS

The following conclusions have been drawn from our tillage and soils state experiments as well as from a broad range of soil state monitoring activities: 1. Tillage implements can be assigned to pan-inducing, soil preserving and compaction-alleviating categories according to their effects on the soil. 2. A new approach should be taken to tillage interventions (ploughing) conventionally applied in the Pannonian region on wet fields, on account of their typical pan-inducing and compaction-aggravating effects. 3. In terms of crop response, plough pans are not as harmful as are disk pans in that plough pans allow the soil to store more water and thereby enable a longer period during which crops can tolerate drought. 4. Most of the available data concerning crops' tillage depth requirements do not apply to new crop varieties and hybrids. 5. Tillage systems can be assigned to preserving-improving and deteriorating categories in terms of their impacts on the quality of the soil. This is closely linked to the likely losses, in regard to which versions alleviating and versions aggravating damage can be distinguished.

ACKNOWLEDGEMENTS

This paper presents results of research programmes supported by OTKA-49.049, NTTIJM08, HR-32/2008, and Ministry of Science, Education and Sports of the Republic of Croatia; our thanks to the farms (Józsefmajor, Mezőhegyes, Belvárgyula, Szentgál), and "Belje" - farm "Knezevo".

REFERENCES

Birkás, M., 2000. Soil compaction situation in Hungary; Consequences and possibilities of the alleviation. DSc Theses, Gödöllő (in Hungarian)

Birkás, M., 2008. Scientific measurement methods in soil tillage experiments. Gödöllő (in press)

Birkás, M., M. Jolánkai, C. Gyuricza, A. Percze, 2004. Tillage effects on compaction, earthworms and other soil quality indicators in Hungary. Soil & Tillage Res. 78 (2): 185-196.

Birkás, M., A. Stingli, A. Szemők, T. Kalmár, L. Bottlik, 2008. Soil condition and plant interrelations in dry years. Cereal Research Comm. 36 (Suppl): 15-18.

Birkás, M., I. Kisic, L. Bottlik, M. Jolánkai, M. Mesic, T. Kalmár, 2008. Subsoil compaction as a climate damage indicator. EUROSOIL Congress, 25-29 August, Wien. Abstracts (Eds. Blum, W. H. et al.) pp. 33

Canarache, A. 1991. Factors and indices regarding excessive compactness of agricultural soils. Soil & Till. Res. 19 (2-3): 145-164.

Gyuricza, C. 2000. Evaluation of some physical and biological effects in sustainable and conventional tillage. PhD Theses, Gödöllő (in Hungarian)

Jug, D., Stipesevic, B., Zugec, I., Horvat, D., Josipovic, M. 2006. Reduced soil tillage systems for crop rotations improving nutritional value of grain crops. Cereal Res. Comm., 34 (1): 521-524.

Jug, D., B. Stipesevic, I. Jug, D. Samota, V. Vukadinovic, 2007. Influence of different soil tillage systems on yield of maize. Cereal Research Comm., 35 (2): 557-560.

Kirby, M., 2007. Whither soil compaction research? Soil & Till. Res. 93 (2): 472-475.

Krümmelbein, J., S. Peth, R. Horn, 2008. Determination of pre-compression stress of a variously grazed steppe soil under static and cyclic loading. Soil & Tillage Res. 99 (2): 139-148.

Kvaternjak I., I. Kisic, M. Birkás, K. Sajko, I. Simunic, 2008. Soil tillage as influenced by climate change. Cereal Research Comm., 36 (Suppl): 1203-1206.

Lipiec, J., C. Simota, 1994. Role of soil and climate factors in influencing crop responses to soil compaction in Central and Eastern Europe. In: Soil compaction in crop production. Soane, B.D., C. Van Ouwerkerk (eds.), Elsevier Sci., 365-389.

Lukács A., G. Pártay, C. Farkas, 2008. Studying the soil – water – plant relationships on winter wheat grown in undisturbed soil columns. Cereal Research Comm., 36 (Suppl): 479-482.

Mesic, M., I. Simunic, F. Basic, I. Vukovic, A. Jurisic, 2008. Soil type influence on drainage discharge and yield of soybean. Cereal Res. Comm. 36 (Suppl): 1207-1210.

Neményi, M. 2008. Limiting factors of precision farming - soil compaction and precipitation. Cereal Res. Comm., 36 (Suppl): 1859-1962.

Tursic, I., S. Husnjak, Z. Zalac, 2008. Soil compaction as one of the causes of lower tobacco yields in the republic of Croatia. Cereal Res. Comm. 36 (Suppl): 687-690.

Soane, B. D., C. Van Ouwerkerk, 1994. Soil compaction in crop production, Elsevier Sci., pp. 627-642.

Várallyay, G., 2008. Extreme soil moisture regime as limiting factor of the plants' water uptake. Cereal Research Comm., 36 (Suppl): 3-5.