Original scientific paper

Soil management to adaptation and mitigation of climate threats

Márta Birkás[1], Ivica Kisić[2], Danijel Jug[3], Vladimír Smutný[4]

[1]Szent István University, Gödöllő, Hungary (Birkas.Marta@mkk.szie.hu)
[2]University of Zagreb, Faculty of Agriculture, Croatia
[3]J.J. Strossmayer University Osijek, Faculty of Agriculture, Croatia
[4]Mendel University in Brno, Faculty of Agronomy, Czech Republic

Abstract
The possible relations between main climate factors and soil state defects have received great attention in the recent years. These factors that are light, temperature, precipitation, and wind have positive and negative impacts on soils. We consider it our duty to assess the main consequences of moisture surplus and water shortage in soils. The third goal of this paper was presenting the combined effect of the climate induced and the tillage induced damages on soil condition. While crop production is one of the sectors adversely affected by climate damage, so steps to prevent and alleviate the deterioration of soils are also drawn up. Five of the important solutions are as follows: 1. Cover the surface to alleviate both the rain and the heat stress mainly in summer. 2. Create surface to be adaptable to water infiltration and water retention. 3. Prevent the pan compaction formation in soils and keep the soil in well-loosened state. 4. Prevent the situations may lead to clod (and dust, crust) formation and use crumb conserving tillage tools. 5. Manage the stubble residues rationally; residue cover is primary in surface preservation, secondly, the residues are basic source of soil organic matter, and also, food of the earthworms.

Key words: soil, climate, tillage, moisture surplus, water shortage

Introduction

Various climate extremes, for instance drought stress, water deficit or water-logging, hail storms etc. have been afflicted the soils of the Pannonian region in the last decade. One of the fundamental causes of climate damage is extreme shortage or abundance of precipitation, i.e. too dry or too wet soil. As Szalai and Lakatos (2013) noted, the tendencies in the precipitation sums, the number of precipitation events with threshold values, especially the more intense rain events shows tendencies having serious effects on the available water amount and the surface water balance. From the aspect of cropping the damage caused by the underlying factor is also affected by the site parameters, the actual soil fertility, nutrient supply and water regime (Várallyay, 2013). Research findings show that agricultural activities have contributed to climate change and that at the same time (Jolánkai et al., 2013). Soil is an environmental element labelled by a variable state and quality, renewed or degraded (Várallyay, 2011). This renewal capability of the soil can be maintained by continuous treatment carefully aligned to the prevailing circumstances. Therefore the primary task of tillage is to maintain favourable soil quality and fertility and to prevent climate sensitiveness. The state of soils – mainly has there been a compact layer in it limiting moisture transport from deeper layers to the root zone or its movement down to be stored in deeper layers – is another modifying factor in the degree of the climate stress. Moreover, the unreasonable insistence on applying habitual tillage practices has really increased vulnerability of soils (Várallyay, 2013). These phenomena may relate to both site and soil. As authors (Birkás et al., 2011a, Vach et al., 2013; Kalmár et al., 2013) has already stressed, to maintain good soil quality may reduce the effects of climatic extremes at reasonable cost. Although the climate situation is rather grave today, there is a wide variety of solutions for soil stress-alleviation and for climate stress mitigation.

Materials and methods

The problem referred to in this paper was studied in long-term trials those have been underway since 2002 in a field of the Experimental and Training Farm of the Szent István University, located in the micro-region of the town Hatvan (47^{o}41'N, 19^{o}36'E, 136 m a.s.l.). The research site is flat and the soil – Chernic Calcic Chernozem soil by WRB (2006) with a clay loam texture – is moderately sensitive to compaction (Csorba et al., 2011, 2012). Soil assessment was extended to the surrounding area of an approx. 10 km radius with similar type of soil. In this site the long-term annual precipitation is 580 mm. The various years' precipitation figures are as follows: average (2002, 2006), dry (2004: -101 mm, 2011: -283 mm, 2012: -286 mm) and rainy (2005: +125 mm, 2008: +152 mm, 2010 +371 mm). Years 2007 and 2009 were dry in the growing seasons. The continuous soil state studies were comprised the possible soil state variants, e.g. shallow and deep, good and bad soil tillage, pan free and pan presence in soil, clean and covered (0, 15, 25, 35, 55, 65 %) surface, cloddy and levelled surface etc. which gave chance to learn more about soils sensitivity to the climate stresses (Kalmár et al. 2011). Colleagues, from Croatia and from Czech Republic, have followed with attention these experiments (Spoljar et al., 2011; Birkás et al., 2010). The measurements were taken and evaluated in accordance with the applicable standards (Csorba et al., 2011); Soil Sampling Protocol, JRC, 2010).

This study is the summary of a series of articles and conference papers published in the last decade. The following subjects are discussed below: 1) Listing the impacts of climate factors on soils condition. 2) Evaluating the main consequences of moisture surplus and water shortage in soils. 3) Presenting the combined effect of the climate and the tillage induced damages. 4) Listing the prevention and the alleviation modes of soil deterioration.

Results and discussion

Listing the impacts of climate factors on soils condition

Assessing climate factors – light, temperature, precipitation and precipitation forms (raindrops, downpour, hail-storm, hoar, rime, snow), and wind – impacts on soil condition, more negative and less positive impacts were found (Table 1). Temperature of soil may regulate – warming or cooling – a by ratio of the surface cover. A clean surface is found to be beneficial in early spring achieving a sufficient temperature for sowing. However, the bare surface may often disadvantageous during the later phases of the season. Amount and distribution of precipitation in the growing season are the key factors both in improvement and in deterioration of the soil state. The crumb formation, the silt- and crust-free state, the harmonic water infiltration and storage in soils are known to be favourable impacts of the optimal water supply. However, water surplus in soils caused by extra amount of rain or downpours deteriorate crumbs in soil surface, remove soil particles and contribute surface water-loggings. Unfortunately, most of the harmful precipitation phenomena are occurred incalculably. In this case the most important solution is to be decreasing of the soil damage. I our long-term soil state assessment stubble residues were found as the possible surface preserving matter. Residues are known to be usually more reflective than bare soil, reduce solar radiation, heat and rain stress and thus water and wind erosion (Shen et al., 2012). Hail-storm hit both the crops and the soils hard. The soils that had been silted by hails became severely crusty. The soils sensitiveness (high, moderate or low, Várallyay, 2011) is one of the key factors in the damaging of the soils. In soils that had been found to be sensitive and moderately sensitive, the unfavourable precipitation patterns aggravated the damage (Birkás et al., 2011a).

Table 1: Impacts of climate factors on soils condition

Climate factors	Positive impacts	Negative impacts
Light	Photosynthetic green and purple bacteria and algae	*Connected with heat*: strong photochemical UV radiation kills microbes
Temperature	*Moderated warm* beneficial both on soil and living creatures	*High*: over-warming, drying, killing beneficial living creatures, Soil shrinking and cracking
	Frost: killing pests and diseases in surface layer (?)	*Frost*: dust formation on the surface
Precipitation	*Soaking rain* and moderated amount; dew in summer	*Lack*: soil drying, over drying
		Extra: crumb deterioration, silting (later crusting), dust leaching, water erosion
		Freezing rain: causing airless condition
Raindrops	*Moderated*: alleviating crusts	*Strong*: crumb explosion, crumb collapse
Downpour	-	Leaching, out-washing, gullying, soil removing, water-logging
Hail storm	-	Crumb deterioration, settling
Hoar/rime	-	Cooling
Snow	*Beneficial cover*, water source, moderating frost effects	Soil settling, Iced crust on the surface
Wind	*Breeze*: temperature moderating	*Warm wind in summer*: soil desiccation
		Wind-storm: soil removing/depositing, erosion

Evaluating the main consequences of moisture surplus and water shortage in soils

Problems are often caused the quantity of precipitation and also the extremes of its distribution, sometimes up to 150-160 mm rain may fall in a matter of 4-6 days. The soils are fully saturated by water and the existing crumbs in the surface layer are soaked, collapsed and silted. The rising of the groundwater table caused heavy damage by water-loggings. However, surface run-off and the stagnation of water on the surface depends on the soil mechanical composition and structure, on the soil original moisture content, the surface condition, the soil water permeability and conductivity and on the quantity and intensity of the precipitation The most exposed situation can be assessed in the degraded soil and bare surface variants (Birkás, 2011). As we found, the former dust ratio had significantly decreased in the tilled, and it had increased in the bottom layer from early season till the end season. At the same time the former compact layer had also been extended, probably been caused by the dust leaching from the tilled layer. The rain stress proved to be moderate on soils kept in good state in long-term, however the difference between minimum and maximum values were lasted. As Birkás et al. (2013) noted, the long term soil conservation and the effectual surface cover have really been mitigated the rain and water surplus damages. Both assessed factors, namely surface silting, silt-film formation, crusting, crumb reduction, dust leaching, compaction occurrence, and settling showed lowest degree of damage in the well-managed soils. The hailing destroys not only the field vegetation but the uncovered soils as well. Due to the hard hit of the hail, the depth of the loosened layer may decrease by 9-22 %, related to the soils condition. As Várallyay (2013) noted, the soils sensitiveness (high, moderate or low) is known one of the key factors in the soil settling. A moderated settling and less crumb deterioration and a relatively rapid regeneration were assessed on soils maintaining the organic matter continuously. This finding is similar to that observed Tóth et al. (2013) in their long-term filed trials. On the other hand, soils that had been cultivated unreasonably, found to be more sensitive to the climatic phenomena including hail-stones.

The further extreme is the drought that is the long-term precipitation deficiency. The drought is often occurred in soil when moisture level has gradually been reduced and the root system can not intake the bound water (Szász, 1997). Soil is severely shrinking, deeply cracking, and breaking plant roots. The negative consequences of the long-term dry period worsened by heat stress are the soil desiccation, the increasing water deficit, the crumb degradation, strong clod formation by the soil disturbance, and declining of the soil biological life. We found the compact pan layer occurred in soil close to the surface a drought-increasing factor. 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 (Birkás et al., 2011b).

Table 2: The drought stress impact on soils condition (2011, 2012)

Phenomenon	Situation on heavy soils*		Situation on loamy soils**	
	Clean surface	Covered surface (55%)	Clean surface	Covered surface (55%)
Surface crusting (%)	45-65±5.0	5.5-8.5±1.0	15-25±5.0	2.5-4.5±1.0
Cracking (depth ≥ 10 cm, nr m^{-2})	3-7±2.0	0-2±1.0	2-3±1.0	0-1
Crumb reduction (%)	45-65±5.0	15-25±2.5	20-30±2.5	5-10±1.5
Water loss mm day^{-1} (dry summer)	4.5-5.8±0.4	1.6-2.2±0.2	4.2-6.2±0.2	1.4-1.9±0.2
Increasing penetration resistance (%)	68-88±10.0	26-38±8.0	52-68±9.2	21-32±5.4
Prone to clod formation	very strong	medium	strong	slight
Earthworms (0-20 cm) nr m^{-2}	0	5-7±5.0	2-5±2.0	10-20±5.0

*n= 310; clay content 55-75 %, and/or silt content: 25-40 %, Fluvisols, Gleysols; **n=345, clay content 35-50 %, Chernozem;

The drought induced problems occurred both in the experimental fields, and in the region has really been offered new research challenges. A peculiar finding of the long-term soil condition assessment is worthy more attention. The negative influence of the water surplus in soils can really be proved in the increase of the soils' drought stress. Tracing soil state deterioration back to the rain stress has prolonged for the next two dry seasons. In Table 2 six types of soil state damage are selected and evaluated on the bases of the measurements. Considering the degree of phenomena, appreciable differences appeared between heavy and loamy soils, and the preserving effect of the clean and the covered surface. A bare surface through both water loss and crumb deterioration is greatly exposed to the crusting and cracking processes. The soil penetration resistance increase is also affected by great water loss which contributes similarly to the strong clod formation. According to Birkás et al. (2012), a sufficient ratio of the surface cover may veritably decrease the degree of the drought damage. Considering the possible extremes, we outline, that a larger – minimum 45 %, or more – cover ratio correspond to the soil conservation requirements in the dry summer period. The unprofessional soil tillage, as an aggravating factor of the drought stress is mainly unacknowledged in the tillage practice.

The combined effect of the climate and the tillage induced damages

Due to long-term soil state assessments, a close coherence was found between climate and the technology induced damages (Figure 1).

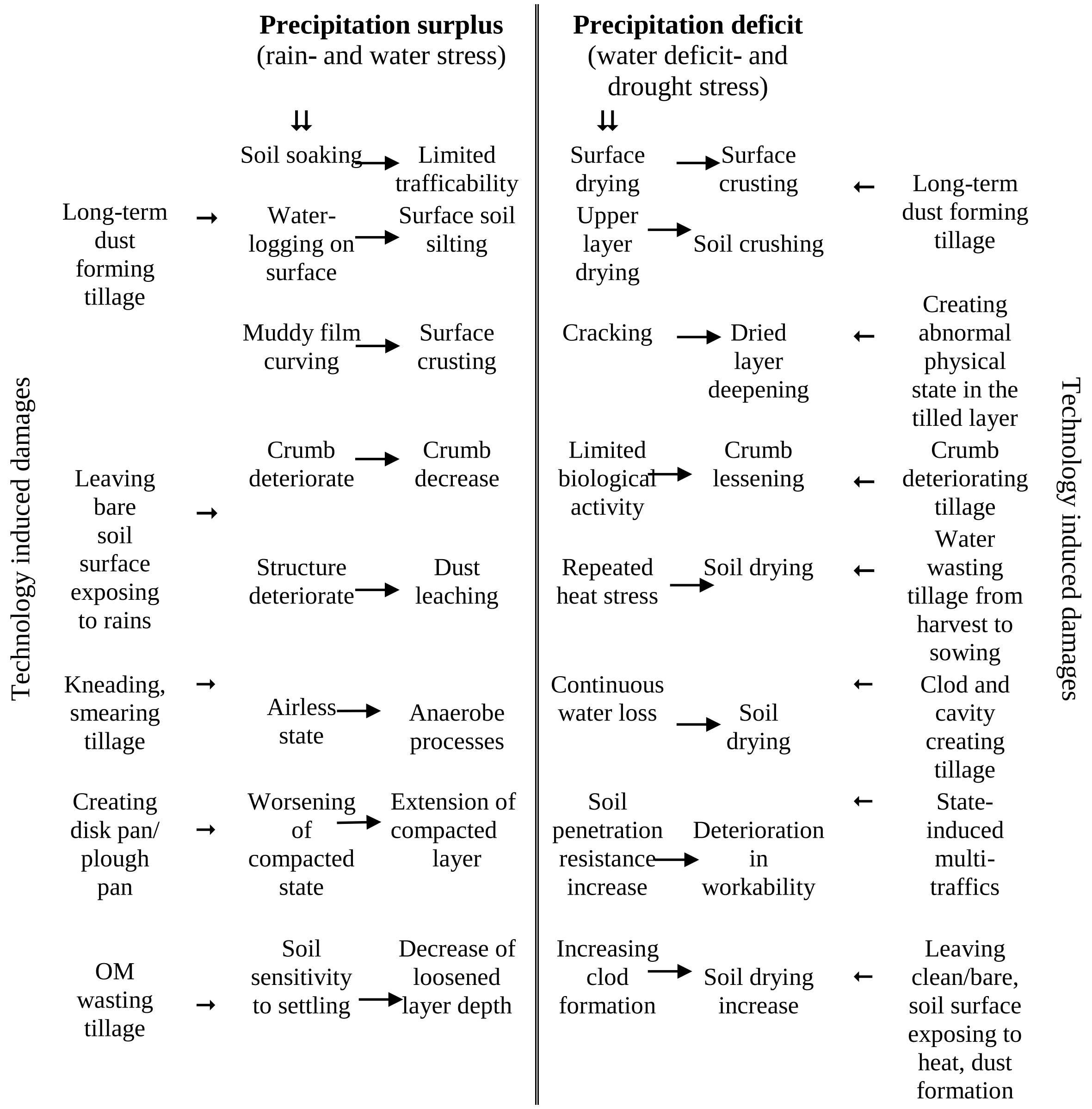

Figure 1: Influence of climate and faming induced damages on soil condition

In wet periods traffics' loading, pan-compaction creating and extending, soil smearing and kneading, and crumb deterioration are found to be frequent types of the tillage induced damage. There are serious indirect consequences of these phenomena that are the water stagnation on the surface, and/or on the pan layer, dust leaching to the nearest compact layer and extending the former pan.

In the course of the summer period – from mid-July till end of August, or, sometimes till mid-September – typical tillage defects have really been increased the soils' exposure to the climatic threats. The most frequent tillage defects are as follows: 1) leaving bare soil surface after harvest, 2) creating large, cloddy, water wasting surface after deep and rough tillage interventions, 3) leaving cloddy state, full of cavities in the tilled layer, 4) forming dusty structure during clod breaking. 5) over-pressing the tilled soil layer during clod breaking operations. Surveying the coherence between tillage induced and climate induced damages both in wet and dry seasons two or three levels of the problems may indicate, that is unacceptable, tolerable from time to time, and tolerable rate (presented in a conference paper at Vukovar, in May, 2013, see Birkás et al., 2013).

Findings and recommendations for prevention and alleviation modes of soil deterioration

The extreme weather conditions afflicted the agricultural activity requires professional competence and specialists are to elaborate the concrete and adaptable mitigation techniques. While the number of the extreme climatic and water transport conditions show upward tendency, the key issues of the mitigation cover both soil quality improvement and conservation of the water and organic material content in soils and alleviation of the soils sensitivity to the climate extremes. The new findings summarised by our research staff are as follows:

(1) Identification of the different effects on soil of the water-logging caused by natural factors and stagnant water saturation caused by wrong tillage practices.
(2) Pulverising of soils' structure in the top layer by frosts in ploughed fields left them in cloddy state.
(3) Proving the silting of bare soil surface in the wake of repeated rain stress, in the case of >17.5 % surface dust and small crumb (<2.5 mm fraction) content.
(4) Demonstrating the leaching of dust (<0.25 mm fraction) formed by mechanical impacts and by natural processes in the surface and top layer, in the case of frequent heavy rains.
(5) Proving the aggravation of compaction as a consequence of the dust and clay colloids leaching in a rainy season.
(6) Observing the impact of the leaching of dust and mineral colloids magnifying consistency phenomena, e.g. swelling, then slow and later rapid desiccation, shrinking and capping.
(7) Identification of the decrease in the depth of the of loosened layer in chernozem, forest and gley soils depending on organic matter content, in rainy periods (in 90-120 days).
(8) In the case of bare soil surface, decrease (by 63.1 – 81.5 %) in the ratio of crumbs in the top soil layer between seedbed preparation and the development of complete coverage by vegetation.
(9) Demonstration of a certain special stratification of the soil after tillage carried out when the soil moisture content was not suitable for tillage (autumn of 2010, spring of 2011): relatively loosened layer 0-250 mm (after ploughing), 0-120 mm (after disking) with puddled, compacted tillage pan (50-300 mm) underneath, below which the soil is settled and wet.
(10) The unavailability of the moisture content of the deeper soil layers if wrong tillage has resulted in a thick (50-300 mm) compact layer over them; appearance of heavy drought damage (with at least 22.5 % – most often twice as heavy – yield loss).
(11) Demonstrated the limited rooting depth in soils degraded by tillage pan forming (spring and early summer in 2011); which improved only a little after abundant rains (July 2011). The few roots that actually penetrated the compact layer proved the gravity of the situation again.
(12) Different fraction sizes in the layer loosened by breaking up the tillage pan (at least 45 % >100 mm), a lot of cavities appeared between the clods which could not be remedied by one pass with a soil compacting tool. The moisture rising towards the surface from

deeper layers condensed in the cavities and failed to reach the surface pressed by rollers; this is considered to have caused the uneven emergence of rape seedlings.

Considering the results achieved in Hungarian relation – on 2 million hectares –, we may conclude that there are number of mitigation techniques which can effectively be used in our arable fields in the future. The most important principles are listed below (Table 3). The prevention and remediation methods should be demonstrated and trained for land users; that can be a new major challenge for us who know more accurately the cause of the troubles, so the solutions, too.

Table 3: Mitigation tillage techniques in rainy and droughty seasons

Mitigation tillage techniques in rainy seasons	Mitigation tillage techniques in droughty seasons
• Creating and maintaining soil condition suitable for water surplus intake.	• Creating and maintaining a loosened state promoting water transport from the deeper layers to the root zone.
• Prevention of surface silting: revising and neglecting the overrated practice e.g. sowing into dust.	• Creating water retaining surface in the critical periods. • Increasing water retention ability of soil by organic matter adding.
• Preventing clod formation as the preceding phase of the pulverisation: a) tilling the soil at workable state, b) neglecting tillage tools creating clods.	• Prevention of clod and dust formation in the critical periods.
• Extension of the loosened state duration by OM recycling and using carbon conserving tillage.	• Extension of the loosened state duration by OM recycling and using carbon conserving tillage.
• Preventing soil compaction aggravation: as leaching dust disperses in a deeper layer in soil being a pan-free state (where is no pan, there is no dust filter).	• Re-loosening pan layers occurred in wet seasons.
• Prevention of swelling and shrinking: limiting surface silting and quick drying by surface cover (at least 50 %).	• Avoiding surface crusting and cracking by adaptable surface preservation (covering by 50 %).
• Prevention of crusting and crust thickening by increasing soil resistance (or decreasing soil sensitivity) with long-term OM recycling and surface covering.	• Avoiding dust formation in winter (as frost effect) by leaving smaller surface for wintering.
• Soil structure improvement by OM and carbon conserving, and crumb preventing tillage.	• Maintaining crumb forming ability by OM recycling, surface covering and crumb preventing tillage.
• Assessing soil condition critically in and out of growing season	• Assessing soil condition critically in and out of growing season.

We may outline again that an effective mitigation of the climate extremes can only be realised in a frame of the long-term national and regional program.

Acknowledgement

Research was supported/subsidized by the TÁMOP-4.2.A-11/1/KONV and by the following agricultural business: GAK Training Farm, at Józsefmajor, Agroszen Kft, Belvárdgyulai Mg.

Zrt, Bóly Zrt, Dalmand Zrt, Kvernaland Group Hungária Kft, Mezőhegyesi Ménesbirtok Zrt, Szerencsi Mg. Zrt., P.P. Orahovica d.d., Róna Kft., TerraCoop Kft, Väderstad Kft.

References

Birkás, M. (2011): Tillage, impacts on soil and environment. In. Encyclopedia of Agrophysics. Eds. Glinski J; Horabik J; Lipiec J. Springer Dordrecht, pp. 903-906, p.1028, ISBN: 978-90-481-3584-4 e-ISBN 978-90-481-3585-1

Birkás M. (2012): Challenges faced by the practice of soil tillage in Hungary and in the Pannonian region. In: Birkás M. (ed.): Soil-School. What to learn from and what to teach about soils. Szent István Egyetemi Kiadó, Gödöllő, pp. 432-451.

Birkás, M., Kisic, I., Jug, D., Smutny, V. (2010): The impacts of surface mulch-cover and soil preserving tillage on the renewal of the top soil layer. Agriculture in nature and environment protection. 3rd Internat. Scientific/professional conf., Vukovar, 31st May-2nd June, 2010. Proc. (Eds. Jug, D., Soric, R.), pp. 21-27. ISBN: 978-953-7693-00-8

Birkás M., Kisic, I., Jug, D., Smutny, V. (2011a): Remedying water-logged soils by means of adaptable tillage. Agriculture in nature and environment protection. 4th Internat. Scientific/professional conf., Vukovar, 1-3 June, 2011. Proc&Abstracts (Eds. Stipesevic, B., Soric, R.), pp. 11-22. Glas Slavonije d.d. Osijek, ISBN: 978-953-7693-01-5

Birkás, M., Kisic, I., Jug, D., Jolánkai, M., Kakuszi, Z. (2011b): Tillage-induced soil compaction consequences in the Pannonian region. International Sci. Symposium on Agriculture. Agrosym, Jahorina, 2011. November 10-12, 2011, Bosnia. Conf. Proc. (Eds. Kovacevic D. et al.), pp. 9-16. UDK 631.51:631.48(497.113)

Birkás, M., Kisic, I., Jug, D., Bottlik, L., Pósa, B. 2012. Soil phenomena and soil tillage defects in the past two years – A scientific approach. 5th Internat. Scientific/professional conf., Agriculture in nature and environment protection, Vukovar, 4-6 June, 2012. Proceedings &Abstracts (Eds. Stipesevic, B., Soric, R.), Glas Slavonije d.d.Osijek, pp.11-23. ISBN: 978-953-7858-01-8

Birkás, M., Stipešević, B., Sallai, A., Pósa B., Dezsény Z. 2013. Soil reactions on climate extremes – Preserving and mitigating solutions. 6th Internat. Scientific/professional conf., Agriculture in nature and environment protection, Vukovar, 27-29 May, 2013. Proceedings &Abstracts (Eds. Soric, R., Jug I.), Glas Slavonije d.d.Osijek, in press

Csorba Sz., Farkas Cs., Birkás M. (2011): Kétpórusú víztartóképesség-függvény a talajművelés-hatás kimutatásában. Agrokémia és Talajtan, 60: 2. 335-342.

Csorba Sz., Farkas Cs., Birkás M. (2012): An analysis of the water retention capacity function of a soil of a heterogeneous pore structure in soil conserving tillage systems. Növénytermelés, 61: Suppl. 251-254.

Jolánkai M., Nyárai H. F., Kassai M. K.. et al. (2013): A water stress assessment survey based on the evaportranspiration balance of major field crop species.Növénytermelés, 62: Suppl. 351-354.

Kalmár T., Csorba S., Szemők A., Birkás, M. (2011): The adoption of the rain-stress mitigating methods in a damaged arable soil. Növénytermelés, 60: Suppl. 321-324.

Kalmár T., Pósa B., Sallai A., Csorba Sz., Birkás M. (2013): Soil quality problems induced by extreme climate conditions. Növénytermelés, 62. Suppl. 209-212.

Nikolic, R., Savin, L., Furman, T., Gligoric, R., Tomic, M. (2002): Research of problems of the soil compaction. Tractors and power machines, 7. (1): 5-13.

Shen, J.Y., Zhao D.D., Han H.F., Zhou X.B., Li Q.Q. (2012): Effects of straw mulching on water consumption characteristics and yield of different types of summer maize plants. Plant, Soil and Environment, 58:161-166

Soil Sampling Protocol, JRC (2010): http://eusoils.jrc.ec.europa.eu/soil_sampling/index.html

Spoljar A., Kisic, I., Birkás, M., Gunjaca, J., Kvaternjak, I. (2011): Influence of crop rotation, liming and green manuring on soil properties and yields. J. of Environmental Protection and Ecology 12: 54-69.

Szalai S., Lakatos M. (2013): Precipitation climatology of the carpathian region and its effects on the agriculture. Növénytermelés, 62: Suppl. 315-318.

Szász G. (1997): Agrometeorology for agricultural water management. In: Szász G., Tőkei L. (eds.) Meteorology. Mezőgazda Kiadó, Budapest, 411-452. (In Hungarian)

Tóth Z., Dunai A., Jolánkai P., Kismányoky T. (2013): Organic fertilizers and soil fertility (Results of a long-term field experiment) Növénytermelés, 62. Suppl. 269-272.

Vach M., Javurek, M., Strasil, Z. (2013): Positive effects of long-term use of conservation tillage treatments on soil fertility. Növénytermelés, 62: Suppl. 289-292.

Várallyay G. (2011): Water-dependent land use and soil management in the Carpathian basin. Növénytermelés, 60: Suppl. 297-300.

Várallyay G. (2013): Soil moisture regime as an important factor of soil fertility. Növénytermelés, 62: Suppl. 307-310.