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SOIL CONSERVATION TILLAGE IN CROP PRODUCTION

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Summary: *In our region most classical authors held that the primary aim of cultivating soil was to meet crops requirements. In the late 19th century rendering the soil's fertile layer suitable for crop growing was considered to provide a good standing place for plants. The word suitable usually applied to the soil physical state, its favourably loose structure that was to be developed to the required depth. However, it was recognised by some authors back in the late 1800s already, that creating soil condition assumed to be required by plants may even damage the soil, what with the frequent traffic involved in the process. In other words, taking a crop oriented approach will rather do damage than good. In a regime of tillage focusing on conservation the need for protecting the soil is not subordinated to crops demands. Primarily importance is to create a soil condition required by crops takes a lot less energy and causes much less mechanical damage in a soil whose good structure and condition has been carefully preserved. In the second decade of the new millennium the primary goal of tillage is to create and maintain favourable interaction between soil conservation and cropping. The aim of soil conservation and environmental protection should realise depending on the effectiveness of the EU and national soil conservation endeavours and efforts and its duration should be determined by the extent to which such practices are adopted across the farming community.*

Key words: *adaptability, soil remedying, water conservation, Pannonian region*

INTRODUCTION

Classical authors emphasised the importance of creating a good site for plants, that of improving the soil fertile layer to make it suitable for cropping (Birkás et al., 1989). In the physical approach tillage was regarded as playing its most important role in controlling soil processes. Consequently the period of several centuries dominated by this approach is referred to as the era of crop oriented tillage (Cannell, 1985). The over-estimation of the importance of crop requirements resulted in damaging the soils, which inevitably led to the recognition, in the mid-1960s, of the need for protecting soils quality hence that was the beginning of the era of soil oriented tillage (Bartalos et al., 1995). Any crop requirements can be met by a soil kept in a good physical and biological condition by soil preserving tillage, with the added benefits of causing less damage and cutting costs. Since the first years of the climate change, as the new trends have raised concern, tillage must be turned into a climate focused effort with the aim of reducing climate-induced losses through improving soil quality (Birkás, 2011).

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The various trends of tillage (minimum, reduced, soil conservation) and endeavours (e.g. energy saving, sustaining) can be distinguished in the basis of their aims (Hayes, 1982a,b; Birkás et al, 1989; Edwards et al., 1990). Since the first energy crisis (mid-1970s), the endeavours to reduce tillage have been motivated by a variety of factors. During the next years reduced tillage under the pressure of economic constraints was practised on several hectares in the region promoting physical and biological degradation of the soils (ECAF, 1999; Jug et al., 2010). It had to be made aware that is no possible to adopt techniques of energy saving tillage without improving the condition of the soils. Further challenge was that the methods developed far from this region adapting to the local soil and farming conditions (Birkás and Mesić, 2012; Jug et al., 2006).

Tillage results in changes in the soil state and in its environment. Such changes can be identified at any given point in time as well as over a longer period of time. It is a crucial question whether tillage carried out 'in the crop's interest' has effects improving, maintaining or deteriorating the soil's structure, water regime and biological activity. The main problem of the ploughing systems is not the soil inversion (however this action is often deteriorates soil quality), but the realisation in the regional sites. Partly to mitigate damage caused by the climate change the plough is probably going to be used less frequently in this region in the future (Bašić et al., 2010; Birkás, 2012). From crops responses and from findings of soil state assessments and studies it has been concluded that tillage without inverting is not disadvantageous to cropping and particularly to environmental protection (Kisić et al., 2010; Birkás et al., 2013). The ploughless systems, on the one hand, are based on soil loosening (by tine or by subsoiler) and on shallow intervention (by disk or rotavator). On the other hand, the variants which can realise in soils are adequately applied to the different site conditions (Birkás, 2010). Namely, subsoiler and tine can be used in the entire surface or in strips, and tine tillage is also applied shallowly (~10-15 cm) or deeply (~30-35 cm) adopting to the production goals. At the same time, further tillage and sowing technologies have circumspectly been tested since the 1980s e.g. till and plant system for green manure plants, strip-till and plant for wide row crops, ridge-till and plant in sloped sites etc. (Jug and Birkás et al., 2010). It is noteworthy that the first trials of direct drilling in this region were conducted and investigated in the beginning of the 1960s (Birkás et al., 2008). Nowadays this system is often used as a studying variant in the regional soil tillage experiments. The most important questions in adoption of any new tillage and sowing systems are the adaptability to the cropping requirements and site conditions, the yield certainty, good trainability and reasonable investment level (Spoljar et al., 2011). A further important question is the suitability of the new systems to the extreme climate conditions are increasingly afflicted soil in the region (Gajić-Čapka, 2009; Jug et al., 2007; Pospišil et al., 2011, Smutný et al., 2013; Szalai and Lakatos, 2013; Várallyay, 2011).

The aim of this paper is to present and evaluate the main variants of the soil tillage and sowing systems that are tested and/or applied in the region and to indicate their impacts on soils condition.

MATERIALS AND METHODS

This paper is based on works reviewing the subject (Bartalos et al., 1995; Bašić et al., 2010, Birkás et al., 1989; Birkás and Kisić et al., 2013, Jolánkai et al., 2013; Jug et al., 2009, 2010, Kisić et al., 2010; Šeremešić et al., 2011; Sabo et al., 2006, 2007) and on stating in long term experiments underway in the countries as well as on the conclusions drawn from them (Birkás, 2010, 2012; Jug and Sabo, 2010, Kalmár et al., 2013).

RESULTS

Tillage trends, time and place of the development, the appearance and realisation of the new systems in the Pannonian region are listed in Table 1. The need for applying new tillage systems is delayed in the region relative to the time of the development. However, the practice was also unprepared to accommodate to the new tillage modes in the 1970s. The goals of the minimum tillage have often been misunderstood from the beginning until now. Most of the doubts have obviously emerged against no-till systems. However, further methods and technique of the conservation trends have gradually took root in the regional cultivation practice.

Table 1. Soil tillage trends, objectives and realisation in the Pannonian region

Trends, *systems*	Time and place of developing	Aims of the system	In the Pannonian region	
			appearance	realisation
Minimum tillage	1950s (USA)	cutting tillage depth, passes and costs	mid-1970s	reduced constraint e.g. disk tillage
Reduced tillage	1960s (USA)	cutting tillage passes and costs	mid/end-1970s	tool/element combination
Conservation tillage	1960s (USA)	effectual soil preserving by surface cover (≥30 %) after sowing	end-1980s, first years of the 2000s	surface cover after stubble tillage and after some types of primary tillage
no-till	1950s (USA)	soil and water preserving by minimised soil disturbance	from the 1960s	problems in the first years limited the interests
mulch-till	1980s (USA)	soil and water preserving by whole surface disturbance and by fair surface cover	mid-1980s, first years of the 2000s	good: by tine, by loosening, risky: by disking
ridge-till	1980s (USA)	soil and water preserving in sloped fields	1990s	in experiments only
strip-till – 1st	1970s (USA)	clean sowing strips, covered inter rows – reducing tillage intervention and costs; improved by satellite guidance and automatic positioning	1990s	tepid interest
strip-till – 2nd	2000s (USA)		2010s	field trials with hope of the extending
Climate mitigating	mid-1990s (Europe)	all systems are adaptable to site and climate conditions	first years of the 2000s	step by step, however time presses

Main advantages and considerations of the relative new tillage systems are summarised in Table 2. The main reason of the adaptability should be the compliance with the site and local conditions.

Table 2. Experiences in soil conservation solutions in the Pannonian region

System/method	Crops sown *Situation*	Main advantages	Main considerations	First adoption
Mulch-till by subsoiling	Oilseed rape, wide-row crops	Deep rooting, less climate dependence	Same diseases, greater weed infestation in the first years	- mid 1980s - from the 2000s
Mull-till by tine	All crops	Soil structure preserving and improvement, less dependence on soil water content	Same diseases, greater weed infestation in the first years	- mid 1980s - from the 2000s
Much-till by disk	Mostly winter cereals	Saving time and energy	Shallow loosened layer, higher climate dependence	- from the 1980s
Till-plant	Green manure crops/ oilseed rape	Saving time and energy	State of the root zone	- from the 2010s
No-till	Mostly w. cereals, secondary crops	Saving time and energy	Continuous: long-term soil conversion; occasional: soil water content	- 1960s, 1990s - 2010s
Strip-till	Mostly wide-row crops	Loosened soil to the depth of 27 cm, saving time and energy	Uncrushed maize stalks (good habitat to E. corn borer)	- from the 2010s
Composting tillage	All crops	Soil structure preserving and improvement	Depth of the loosened layer	-from the 2010 (Slovenia)
Twin-row sowing	Oilseed rape, wide-row crops	Deep rooting (in subsoiled soil only)	Misunderstanding the crop root development and placement	- Kolbai, 1956, Hungary - 2010s (USA)
Seedbed preparation and plant	All narrow-row crops	Water conservation for germination	Over-wet soil condition	-mid 1990s
Surface cover of undisturbed soil (2-3 months)	Stubble state after cereals	Best water conservation in dry season	Risks at autumnal sowing	- 2010s
Improved ploughing	Spring sown crops	Inverting and surface levelling	Pan compaction	- mid 1980s -1990s

A tillage system based on mulch-till by subsoiling is an indispensable element of modern intensive crop production on account of the benefit of improving the soil state and in maintaining the stability and reliability of cropping. Any crop may be grown after soil remedying, though crops requiring high quality soil in deeper layers. By applying additional elements improves the penetration of the soil. Forming and consolidating of surface the soil's improved state may last longer. Combining seedbed preparation with plant is to reduce soil disturbance and at the same time to cut costs. Sowing in a separate pass may be necessitated by the time of seeding, the state of the soil or the lack of a machine that can sow the seeds in soil under mulch cover.

The system based on the use of mulch-till by tine offers the benefit of sparing the soil structure before crops sown. In the year following subsoiling it may use for maintaining the favourable soil conditions. This method is also recommended for gently trans-mixing the upper (0-30 cm) layer of soil after application of 3-4-year strip-till. It causes little – and easily remedied – damage in wet soils. The mulch-till by tine may be a part of modern low intensity and mid-tech land use mode on account of its favourable environmental impact. In a dry year loss of moisture can be reduced by less soil disturbance, gentle crumbling and leaving adequate surface cover.

Mulch-till by disk may be applied in the year following one during which deep ripping or ploughing was carried out, or if disking is resorted to partly in order to chop crop residues. Disking should not be applied in successive years. The system should only be applied if the soil deeper layers are in a good condition, and the soil should be dry or a little humid. Composting tillage shows similar advantages and risks.

Using a till-plant is one of the modes of low intensity farming. A deeper soil disturbance may be resorted to in a year following the sallow tillage. Strip-till is applied in the mid-tech farming for maintaining good soil state as involves few tillage passes. By covering between rows with residues this technique meets the expectations in weed free fields. Loosening variant of strip-till may be applied if the aim is to improve the soil condition.

No-till is a mode of the low-intensity farming and offers benefits and entails risks. Being a special cropping method entailing minimised soil disturbance whose application requires modern machinery, a frequently updated technology adapted to the site, the year and the crop concerned and sound expertise. On soils of degraded structure the yields will decline in the first years after adopting the no-till. The risks of applying this particular system may be reduced when the soil physical, biological and chemical parameters have been harmonised.

Twin-row – 55+22 cm row spacing – sowing was developed for optimizing the use of light, water, and nutrients by crops. Special twin-row planter put the seeds in a precise alternating diamond pattern, and distance between plants is also optimised (25.1-29.5 cm). A forced machine selling and method' adoption are really overshadowed the original and possible advantages.

Seedbed preparation and sowing in a single tillage pass in a soil after primary tillage of the depth and mode meeting the crop requirements and adapted to the site conditions, involving or without ploughing and then finishing the surface of the soil with the aid of a combined machine assembled for this purpose.

Improved ploughing-based systems should be applied periodically or for the purposes of crop protection, if the soil is in a condition that is highly suitable for inverting, in combination with secondary tillage. Seedbed preparation and plant in one go reduces tillage costs and improves the environmental impacts of ploughing.

It may outline that the first step in the process of adaptation in conservation tillage involves recognition of the risks – wrong practices/habits, poor soil quality, extreme climate phenomena etc. – and an urge for improvement, while the second step involves improvement or conservation of the quality of the soil, in harmony with ecological conditions, mechanisation and the farming and management conditions. Twelve factors are selected to present the fundamental requirements of the conservation soil tillage (Bašić et al., 2010; Birkás and Mesić, 2012): (1) Avoiding the farming and tillage-induced soil damages, that are occurrence and extension of soil compaction, soil structure degradation, water and wind erosion, high CO_2 emission, and organic material loss. (2) Maintaining soil moisture transport by improving the water infiltration and storage in wet periods and decreasing the moisture loss in dry and average seasons. (3) Preserving organic material of the soil to increase the water-holding capacity, the structure stability, the loading capacity and the workability and to decrease the soil compactibility and vulnerability. (4) Managing stubble residues by application of harvest and tillage techniques leaving mulch cover. Cover the surface after harvest, as long as possible to remedy soil structure and to preserve soil moisture and to mitigate heat and rain stress outside the growing season. (5) Recycling stubble residues to the soil with the passing of the critical period for the sake of the soil organic matter improvement, promoting the favourable biological activity in soils thus improving the soil workability trough the mellowing processes. (6) Utilizing the possible machinery – tractor, mass of tool, running gear, working speed, energetic relation between tractor and tool, state and construction of tillage tool – and arable site factors to reduce the energy consumption thus to decrease the environmental load. (7) Minimising the soil loading stress from stubble to sowing phase. (8) Applying optimal crop sequence to reduce fertilizer needs and to improve soil biological activity through the crops effect on soil condition. (9) Particular attention is to be paid to maintaining the soil infiltration and storage capacity and the soil aggregation on irrigated soils. (10) Applying tools without pan-creation in any tillage procedures, particularly in wet soils. (11) Assessing the possible risks cautiously prior to establishment of the new tillage and sowing systems. Soil condition assessment will have greater importance before tillage interventions, in the crop stands and after sowing. (12) Selecting the most adaptable soil conservation methods are conformed to the site and crop production requirements.

DISCUSSION

Tillage results in changes in the soil state and in its environment (Jug and Stipešević et al., 2006, 2007). Such changes can be identified at this moment as well as over a longer period of time. It is a crucial question whether tillage carried out ‘in the crops interest’ has effects improving, maintaining or deteriorating the soil’s structure, bearing capacity and biological activity (Birkás et al., 2008; Nikolić et al., 2002).

The development of tillage systems in our region, respect for tillage in general, its position in the system of cropping, the efforts made at conserving the soil along with the acceptance of new approaches, have always been substantially affected by traditions (Birkás et al., 2008). They noted that the foreign trends – e.g. the American Campbell’s dry farming boom between 1905 and 1912 or the German Bippart’s ‘anti-plough’ movement in the 1920s – had little impact on the common tillage practices in this region. The practice of ploughing to depths exceeding 25 cm was increasingly widely adopted in response to the encouragement of sugar bet production (from 1860 on). The standards of soil tillage declined in the wake of the two world wars, as a consequence of distribution of land and as a result of the privatisation of land as well. Farmers failed to recognise the importance of the relevant findings of soil tillage research but they were quick to respond to changes in the economic conditions. Economising under the force of necessity has always been a typical response to periods of economic difficulties but the over-tillage of soils cannot be linked directly to any particular time period (Birkás et al., 1989; Jug et al., 2010; Pejićet al., 2013). Farmers’ attitude with respect to rationalising tillage could, in retrospect, be explained by shortage of capital. At the same time the former aversion to the new methods has also lasted despite of the symptoms in soil deterioration that are originated from the long-term traditional tillage (Kovačević and Lazić, 2012). Authors, cited above, have often outlined that adopting new techniques in this region can not be introduced without remedying the condition of the soils.

Soil protection has been a key subject of research for decades now, and the results achieved so far are taken into account in the development and application of cultivation practices (Jug and Jug et al., 2007; Spoljar et al. 2011). The practical solutions applied in protecting soils are just as varied as are the types of damage affecting soils across the world. The first results came from the work of North-American researchers. Covering the soil was found to be an effective approach to control dust storms on the Great Plains in the 1930s (Allen and Fenster, 1986). The approach referred to as ‘minimum tillage’, which was developed in the 1960s, should be regarded as something of a detour, as the objective of soil conservation ranked second to the priorities of reducing tillage operations and costs (Schertz, 1988). The year of change was 1977, and the new concept is called ‘soil conservation’ tillage, a method that retains protective amounts of residues on the surface throughout the year. Schertz quotes the definition adopted by the authorities in 1983, conservation is any tillage and planting system in which at least 30 % of the soil surface is covered by plant residue after planting to reduce soil erosion by water.

Crop residues – that can be seen in the foregoing – are considered a possible material for soil conservation. Stubble residues have come under the limelight again, though unfortunately at a time when they have come to be used as a source of ‘bio-energy’ (Lal, 2009). Surface protection during the summer is indisputably important in the Pannonian region (Kalmár et al., 2013). Climate-induced damage is observed increasingly frequent outside the growing season in the region. The amount of rain in the summer has been decreasing but rain storms have been growing increasingly frequent and are becoming more devastating. Soils deprived of their protective straw are increasingly exposed to summer climate stress (Jolánkai et al., 2013; Várallyay, 2013). The soil needs to be kept in place and at the same time efforts must be made to alleviate heat and rain stress and to reduce the loss of water (Birkás, 2011; Turk and Mihelič, 2013; Várallyay, 2013). Mulched green manure and chemically treated weeds and volunteers may also provide a protective cover besides crop residues on soils. Two of classic authors (Manninger and Kemenesy) were encouraged first (in the 1930s) to use mulch covering the soil (Birkás et al., 2008). The training of mulch-tillage was laid down 34 years ago by the studying of the soil in fields after harvest (Kalmár et al., 2013). Progress was clearly facilitated by the introduction of flat plate disks and mulch-cultivator tools (Rádics and Jóri, 2010). Where the crop residue is left on the soil surface the level of protection is first affected by the ratio of the cover, and later by the mode and quality of stubble tillage. Kalmár et al. (2013) cited Schertz (1988) that soil conserving tillage is characterised by an at least 30 % cover ratio after sowing, and they recommended a higher – 45-55 % – ratio by evenly chopped straw for surface cover after summer harvest.

Different methods of the soil protection have been and are being conducted in areas exposed to erosion by water or wind, in parallel with no-till experiments (Kisić et al., 2003; Soane et al., 2012). According to Soane et al., no-till systems are not applied in Europe as extensively as they could be. At the same time, there is growing interest in other soil conservation techniques e.g. till-plant, mulch-till, and strip-till (Jug et al., 2010), to some extent perhaps as a consequence of the increasingly climate threats. Shifts in the timing and the gradual lengthening of periods that are critical from the aspect of soil conservation are also considered to have been caused by extreme weather patterns.

CONCLUSION

There have been considerable changes in tillage practice in the Pannonian region over the past decades from over-disturbing tillage systems to the adaptable some conservative solutions. The main tasks are to provide scientific proof of the benefits of soil conservation and to stabilize crop yield level and to disseminate various tillage techniques that are suitable for achieving these aims, as widely as possible in the farming community.

REFERENCES

ALLEN, R. R., FENSTER C.R.: Stubble-mulch equipment for soil and water conservation in the Great Plains. J. Soil and Water Conservation, 41(1): 11-16, 1986.

BARTALOS, T., LAL, R., NÉMETH, T.: Conservation tillage for sustaining soil and water quality. Akaprint, Budapest, p. 293, 1995.

BAŠIĆ, F., KISIĆ, I., MESIĆ, M.: Framework of climate change- and soil type-oriented tillage and land management in Croatia. Proc. of the 1st Internat. Sci. Symp. on Soil Tillage – Open Approach (Jug, I., Vukadinovic, V., eds.) Osijek, 9-11 Sept., 2010. pp. 29-49.

BIRKÁS, M., ANTOS, G., NEMÉNYI M., SZEMŐK, A.: Environmentally-sound adaptable tillage. Akadémiai Kiadó, Budapest, p. 353, 2008

BIRKÁS, M.: Long-term experiments aimed at improving tillage practices. Acta Agr. Hung. 58(Suppl 1): 75-81, 2010.

BIRKÁS, M.: 2011. Tillage, impacts on soil and environment. In: Encyclopedia of Agrophysics. (Glinski, J., Horabik, J., and Lipiec, J., eds.). Springer, Dordrecht, pp. 903-906, 2011.

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

BIRKÁS, M., ANTAL, J., DOROGI, I.: Conventional and reduced tillage in Hungary – A review. Soil and Tillage Res., 13(3): 233-252, 1989.

BIRKÁS, M., MESIĆ, M.: Impact of tillage and fertilization on probable climate threats in Hungary and Croatia, soil vulnerability and protection. Hungarian – Croatian Intergovernmental S&T Cooperation 2010–2011. Szent István Egyetemi Kiadó, Gödöllő, p. 186, 2012.

BIRKÁS, M., KISIĆ, I., JUG, D., SMUTNÝ, V.: 2013. Soil management to adaptation and mitigation of climate threats. Proc. of 2nd Internat. Conference on Soil and Crop Management: Adaptation and Mitigation of Climate Change (Vukadinović, V. and Đurđevic, B., eds), Osijek, Croatia, 26-28 Sept., 2013, pp. 14-24.

BOTTLIK, L., CSORBA, SZ., GYURICZA, CS., KENDE, Z., BIRKÁS. M.: Climate challenges and solutions in soil tillage. Applied Ecology and Env. Research. 12(1): 13-23, 2014.

CANNELL, R.Q.: Reduced tillage in north-west Europe – A review. Soil and Tillage Res., 5: 129-177, 1985

ECAF: Conservation Agriculture in Europe: Environmental, economic and EU policy perspectives. European Conservation Agricultural Federation, Brussels, p. 14, 1999.

EDWARDS, C.A., LAL, R., MADDEN, P., MILLER, R.H, HOUSE, G.: Sustainable Agricultural systems. Soil and Water Conservation Society, Ankeny, Iowa, p. 696, 1990.

GAJIĆ-ČAPKA, M.: Global Climate Change – Observed Climate Change in Croatia – Precipitation. In: Fifth National Communication of the Republic of Croatia under the United Nation Framework Convention on the Climate Change. Ministry of Environmental Protection, Physical Planning and Construction, pp. 137-143, 2009.

HAYES, W.A.: Minimum tillage farming. No-Till Farmer, Inc., Brookfield, Wisconsin, p. 167, 1982a.

HAYES, W.A.: No-till farming. No-Till Farmer, Inc., Brookfield, Wisconsin, p. 202, 1982b.

JOLÁNKAI, M., BALLA, I., PÓSA, B., TARNAWA, Á., BIRKÁS, M.: Annual precipitation impacts on the quantity and quality manifestation of wheat and maize yield. Acta Hydrologica Slovaca, 14(2): 446-450, 2013.

JUG, D., BIRKÁS, M., ŠEREMEŠIĆ, S., STIPEŠEVIĆ, B., JUG, I., ŽUGEĆ, I., DJALOVIĆ, I.: Status and perspective of soil tillage in South-East Europe. Proceedings of the 1st International Sci. Symposium on Soil Tillage – Open Approach (Jug, I., Vukadinović, V., eds.) Osijek, Croatia, 9-11 Sept, 2010. pp. 50-64.

JUG, D., JUG, I., KOVAČEVIĆ, V., STIPEŠEVIĆ, B., ŠOŠTARIĆ, J. Soil tillage impacts on nutritional status of wheat. Cereal Res., Comm., 35(2): 555-558, 2007.

JUG, D., SABO, M., JUG, I., STIPEŠEVIĆ, B., STOŠIĆ, M. Effect of different tillage systems on the yield and yield components of soybean [Glycine max (L.) Merr.] Acta Agr. Hung., 58(1): 65-72, 2010.

JUG, D., STIPEŠEVIĆ, B., ZUGEĆ, I. Effects of conventional and reduced tillage systems in winter wheat – soybean crop rotation on crops biomass development. Cereal Res. Comm., 34: 1137-1143, 2006.
JUG, D., STIPEŠEVIĆ, B., JUG, I., SAMOTA, D., VUKADINOVIĆ, V. Influence of different soil tillage systems on yield of maize. Cereal Res., Comm., 35(2): 559-562, 2007.
JUG, D., STOŠIĆ, M., BIRKÁS, M., DUMANOVIĆ, D., SIMIĆ, M., VUKADINOVIĆ, V., STIPEŠEVIĆ, B., JUG, I.: Soil trafficking analysis for different reduced soil tillage systems. Proceedings of 2nd International Conference on Agriculture in nature and environment protection (Jug, D. and Sorić, R., eds.), Vukovar, Croatia, 4-6 June, 2009. pp. 51-59.
KALMÁR, T., BOTTLIK, L., KISIĆ I., GYURICZA, C., BIRKÁS, M.: Soil protecting effect of the surface cover in extreme summer periods. Plant, Soil and Env., 59 (9): 404-409, 2013.
KISIĆ, I., BAŠIĆ, F., NESTROY, O., MESIĆ, M., BUTORAC, A.: Soil erosion under different tillage methods in central Croatia. Die Bodenkultur, 53(4): 197-204, 2003.
KISIĆ, I., BAŠIĆ, F., BIRKAS, M., JURIŠIĆ, A., BIĆANIĆ, V.: Crop yield and plant density under different tillage systems. Agriculturae Conspectus Scientificus, 75(1): 1-7, 2010.
KOLBAI, K. A gödöllői ikersoros kukoricatermesztés. MTA Agrártudományok Oszt. közleményei, 9 (4): 371-375, 1956.
KOVAČEVIĆ, D., LAZIĆ, B.: Modern trends in the development of agriculture and demands on plant breeding and soil management. Genetika, 44(1): 201-216, 2012.
LAL, R.: Soil quality impacts of residue removal for bioethanol production. Soil and Tillage Research, 102: 233–241, 2009.
NIKOLIĆ, R., SAVIN, L., FURMAN, T., GLIGORIĆ, R., TOMIĆ, M.: Research of problems of the soil compaction. Tractors and power machines, 7(1): 5-13, 2002.
PEJIĆ, B., KRESOVIĆ, B., TAPANAROVA, A., GAJIĆ, B., MAČKIĆ, K.: Effects of water stress on water use and yield of maize**.** Contemporary Agriculture, 62(1-2): 35-45, 2013.
POSPIŠIL, M., BRČIĆ, M., HUSNJAK, S.: Suitability of soil and climate for oilseed rape production in the Republic of Croatia. Agr. Conspectus Scientificus, 76(1): 35-39, 2011.
RÁDICS, J., JÓRI, J. I.: Development of 3E tillage system and machinery to challenge climate change impacts. Periodica polytechnica-mechanical engineering, 54: 49-56, 2010.
SABO, M., JUG, D., UGARČIĆ-HARDI, Ž.: Effect of reduced tillage on wheat quality traits. Acta Alimentaria, 35(3): 269–279, 2006.
SABO, M., JUG, D., JUG, I.: Effect of reduced tillage on quality traits of soybean [*Glycine max* (L.) MERR.] Acta Agronomica Hungarica, 55(1): 1-6, 2007.
SCHERTZ, D. L.: Conservation tillage: An analyis of acreage projections in the United States. J. Soil and Water Conservation, 43: 256-258, 1988.
ŠEREMEŠIĆ, S., MILOŠEV, D., DJALOVIĆ, I., ZERENSKI, T., NINKOV, J.: Management of soil organic carbon in maintaining soil productivity and yield stability of winter wheat. Plant Soil and Environment, 57(5): 201-206, 2011.
SMUTNÝ, V., NEUDERT, L., LUKAS, V., DRYŠLOVÁ, T., HOUŠŤ, M.: The effect of different soil tillage on yield of maize and the impact on soil environment. Növénytermelés, 62 (Suppl.): 17-20, 2013.
SOANE, B.D., BALL, B.C., ARVIDSSON, J., BASCH, G., MORENO, F., ROGER-ESTRADE, J.: No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. Soil and Tillage Research, 118: 66–87, 2012.
SPOLJAR, A., KISIC, I., BIRKÁS, M., GUNJACA, J., KVATERNJAK, I.: Influence of crop rotation, liming and green manuring on soil properties and yields. J. of Environmental Protection and Ecology, 12: 54-69, 2011.
SZALAI, S., LAKATOS, M.: Precipitation climatology of the carpathian region and its effects on the agriculture. Növénytermelés, 62(Suppl.): 315-318, 2013.
TURK, A., MIHELIČ, R. Wheat straw decomposition, N-mineralization and microbial biomass after 5 years of conservation tillage in Gleysol field. Acta agriculturae Slovenica, 101 (1): 69-75, 2013.
VÁRALLYAY, G.: Water-dependent land use and soil management in the Carpathian basin. Növénytermelés, 60(Suppl.): 297-300, 2011.
VÁRALLYAY, G.: Soil moisture regime as an important factor of soil fertility. Növénytermelés, 62(Suppl.): 307-310, 2013.

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