Changes of Chemical Soil Properties through Application of Different Tillage Methods

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Summary

In the period from 2005 to 2009 the influence of different tillage methods and timelines on chemical properties of soil during cultivation of maize (*Zea mays L.)* and soybean (*Glycine max*) in crop rotation was researched at testing grounds of Križevci College of Agriculture (N: 46^0 01' 12''; E: 16^0 34' 28''). Almost all researched chemical properties of soil indicated more favourable results with the application of spring and autumn primary tillage with reduced number of secondary tillage interventions. The smallest content of total nitrogen and to plant available potassium in soil was in control method of the most intensive tillage and it was determined at the end of the research. The worst results regarding humus quantity were observed in control tillage method. The applied spring primary soil tillage had unfavourable influence on soil reaction. All tillage methods, except the autumn method of primary tillage and secondary tillage with multi-tiller after a four year period indicated less plant available phosphorus. From the perspective of sustainable management, the application of tillage methods with reduced number of secondary tillage interventions, achieved more favourable results.

Key words

soil tillage, soil chemical properties, sustainable soil management, maize, soybean

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Introduction

The fact that soil tillage as mechanical intervention influences the changes of chemical properties of soil was indicated by Butorac (1999) without intending to diminish the influence of climate conditions and cultivated crops. As stated by the author, the capacity of soil to ensure sufficient amount of nutrients for the cultivated crop depends on several factors: temperature, humidity and soil aeration, soil management methods, quantity and variety of plant available nutrients and the possibility of their absorption, as well as the crop requirements of a specific crop for achieving the planned yield.

Cox et al. (2003) established a negative correlation between the yield of soybean grain and phosphorus and potassium available in the soil, as well as a positive correlation between grain yield and soil reaction. Špoljar et al. (2009) also refer to positive correlations in maize and soybean cultivation in crop rotation between the majority of researched physical and chemical soil properties and achieved grain yield.

Butorac et al. (2006) stated that distribution and quantity of nutrients as well as organic substances depend on the applied soil tillage method. In case of unploughed land, numerous authors to a large extent establish higher quantities of basic nutrients and organic substance in the surface layer (Bauer et al., 2002; Benito and Sombrero, 2006; Gal et al., 2007; Rueda et al., 2007; Mathew et al., 2013).

In case of no-till method in comparison with the conventional soil tillage method Blevins et al. (1983) established lower value of soil reaction in the plough layer. The applied soil tillage methods significantly influence the efficiency of fertilization, development of root system and absorption of nutrients (Qin et al., 2006). The authors predominantly established a large quantity of total nitrogen in the soil with reduced tillage in comparison with the conventional soil tillage method (Papini et al., 2007; Lopez-Fando and Pardo 2009).

This short overview of bibliography indicates the interest of scientists in researching the influence of different soil tillage methods on soil characteristics. However, in Križevci region greater importance is given to the influence of soil tillage methods on yield and grain quality of cultivated crops. As a result, Špoljar et al. (2010) and (2011a) established higher yields of soybean grains with intensive tillage, and higher maize yields with reduced soil tillage. Authors also observed higher protein content in maize and soybean grain with intensive tillage, whereas higher total fat content in soybean grain was established with intensive tillage and total fat content in maize grain was higher with reduced tillage methods.

Therefore, besides the above mentioned, the influence of soil tillage methods on chemical properties of soil was researched in the period from 2005 to 2009 at the testing grounds of Križevci College of Agriculture. It can be assumed that soil tillage methods of lower intensity will result in more favourable condition of the researched parameters in comparison with the control methods of soil tillage.

Materials and methods

In the period from 2005 to 2009 the influence of different tillage methods and timelines on chemical properties of soil was researched at Križevci College of Agriculture (N: 46^0 01' 12''; E: 16^0 34' 28''). Researched soil tillage methods are outlined in Table 1.

Maize was cultivated in 2006 and 2008, and soybean in 2007 and 2009. Fertilization of cultivar was uniform in the research year for all methods of soil tillage. In 2006 the soil was fertilized with 195 kg/ha N, 154 kg/ha P_2O_5 and 231 kg/ha K_2O. Maize received 68 kg/ha of N as supplementary feed. In soybean cultivation fertilization consisted of 163 kg/ha N, 92 kg/ha P_2O_5 and 92 kg/ha K_2O and it was administered in 2007. In 2008 researched methods included fertilization with 221 kg/ha N, 115 kg/ha P_2O_5 and 115 kg/ha K_2O, with 68 kg/ha N administered in the form of supplementary feed. Fertilization with 209 kg/ha N, 138 kg/ha P and 138 kg/ha K_2O was carried out in 2009. Soil sampling for chemical analyses was conducted prior to maize sowing in 2006 and after harvesting the cultivated crops during the research period. Average soil samples were taken for the depth of 0-30 cm for each tillage method in four repetitions.

Soil samples for chemical analyses were administered in line with the ISO 10381-1-2-3. Chemical analyses of soil defined: reaction of soil in 1M KCl (ISO 10390:2005), humus quantity according to Tjurin, plant available potassium and phosphorus measured by AL method and total nitrogen content (ISO 11261:2004). Results of the researched chemical properties of soil were statistically analysed by variance analysis (F test). Average values were tested by LSD test.

Table 1. The investigated soil tillage methods

	Autumn	Spring
A		Primary tillage at 30-35 cm depth with mouldboard plough, additional tillage by multi-tiller (one tillage pass), four-row seeder was used for planting maize and wheat sowing machine for soybean, herbicides according to the type of weed.
B		Primary tillage with mouldboard plough, sowing and herbicides as in variant A, additional tillage by rotary harrow (one tillage pass).
C	Primary tillage at 30-35 cm depth with mouldboard plough	Additional tillage by spike and rotary harrow, sowing and herbicides as in variant A.
D	Primary tillage at 30-35 cm depth with mouldboard plough	Additional tillage by spike harrow and multi-tiller, sowing and herbicides as in variant A.
E	Primary tillage at 30-35 cm depth with mouldboard plough	Additional tillage by spike harrow, disc harrow and multi-tiller, sowing and herbicides as in variant A.

Results and discussion

Figure 1 and 2 indicate average air temperatures and total quantity of precipitation for Križevci area in 2006, 2007, 2008 and 2009 as well as for the multi-annual period from 1927 to 2005.

In Križevci area average monthly air temperatures reach their maximum values in June, July and August. Higher values of the average annual air temperatures were observed in researched years in comparison to the outlined multi-annual average (Figure 1).

In comparison with the multi-annual period, time frames of extreme rain were observed during the research years.

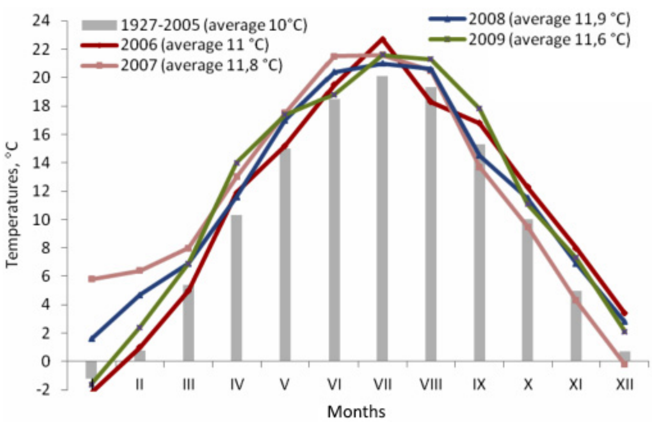

Figure 1. Average monthly and annual air temperature for Križevci

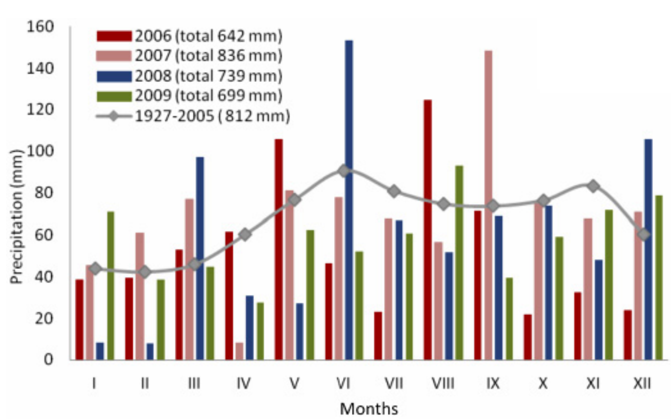

Figure 2. Total monthly and annual values of precipitation for Križevci

The influence of the applied tillage methods and timelines on soil reaction, humus quantity, total nitrogen content, plant available potassium and phosphorus for respective methods in the research period are outlined in Tables 2 to 7.

Statistically justified smaller values of soil reaction were established with methods of primary spring tillage in methods A and B after soybean harvest in 2009 in comparison with the initial state prior to maize sowing in 2006 (Table 2). These changes were not observed with autumn primary tillage methods. Variations of soil reactions were observed in method D, but there were no significant changes in comparison with the results established prior to maize sowing in 2006. In comparison with the initial state in the 0-30 cm tillage layer no changes of soil reaction were established with methods with primary autumn tillage after four years, whereas the methods of primary spring tillage indicated considerable decrease. Soil tillage had the most significant influence on soil reaction, followed by the respective year and mutual interaction of the two. The lowest value of soil reaction observed with spring methods in comparison with autumn methods of primary tillage is the result of different conditions for mineralisation of organic substance and nitrogen nitrification applied in maize and soybean fertilization.

Table 2. Influence of tillage on soil reaction during research

Tillage methods	pH u 1M KCl				
	A	B	C	D	E
Before maize harvesting 2006	5.18a	4.99a	5.44	5.56ab	5.54
After maize harvesting 2006	5.17a	5.02ab	5.47	5.66a	5.69
After soybean harvesting 2007	4.95ab	4.84bc	5.31	5.45bc	5.57
After maize harvesting 2008	4.83b	4.62d	5.26	5.36c	5.44
After soybean harvesting 2009	4.86b	4.77cd	5.27	5.55ab	5.50

The factors: year =15.2; tillage method = 103.6; year x tillage method = 0.73 NS; * values in columns marked with different letters indicate significant fluctuations, $p<0.05$; NS (no significant at $p<0.05$)

For similar reasons Limousin and Tessier (2007) established higher soil reaction on conventional tillage method in comparison with the no-tillage method. Blevins et al. (1983) observed lower values of soil reaction in the plow-layer in no-tillage method in comparison with the conventional tillage method. In addition, Lopez-Fando and Pardo (2009) established higher reaction of soil in the methods where cultivation with paraplough was applied for ten years in comparison with no-till method. Benito and Sombrero (2006) observed no change in soil reaction in the 0-30 cm layer with conventional tillage methods after ten years, whereas they observed significant reduction in cultivation with conservation tillage methods. Increase accumulation of organic residue is one of the possible reasons for soil acidity given by these authors.

Humus quantity in methods A, B, C and D did not change significantly after four years in comparison with the situation prior to maize sowing in 2006. Minor increase in comparison with the initial humus quantity was observed with tillage methods B and D. Contrary to the above, statistically justified smaller humus quantity was observed in control method E with the most intensive tillage soil after maize harvesting in 2008. Based on the results of the research it can be concluded that after four years in comparison with the results prior to maize sowing in 2006 with tillage methods A, B, C and D minor changes regarding humus quantity were observed. It was established that the influence of the respective year on humus quantity was higher than the influence of the tillage methods. The biggest decrease (2.7 g kg^{-1}) was established with the most intensive tillage method (method E), but these differences are not statistically justified with reference to the initial state (Table 3).

Short-term changes in the quantity of organic matter (Liu et al., 2006) depend on environmental conditions, temperature, soil humidity, aeration and quantity of available nutrients. Ellert and Janzen (1999) indicate that higher intensity of tillage methods increases mineralisation, resulting in reduced humus content in soil. Halvorson et al. (2002) whilst cultivating crops in crop rotation, researched the influence of different soil tillage methods on some soil properties and have also observed higher content of organic substance in the soil with reduced soil tillage in comparison with the intensive tillage methods.

It is evident from Table 4 that in all methods, except method D, significant differences in total content of nitrogen in soil were observed. Higher total nitrogen content was to a large extent observed after harvesting with all tillage methods in comparison with the state prior to maize sowing in 2006. Since soybean was cultivated in the last year of research, the observed content of total nitrogen with tillage methods A, B and C was justifiably higher in comparison with the initial state, and those differences were not observed with tillage methods D and E.

Considerably higher nitrogen content in methods with reduced number of secondary tillage interventions could be explained by higher nodulation capacity of nitrogen fixators, which was also observed by Jug et al. (2005) in their earlier research. Whilst cultivating maize and soybean in crop rotation and using conventional tillage Špoljar et al. (2011b) established a considerable increase of humus content and total nitrogen content in soil in most fields where lupine and clover-grass mixture were cultivated. Based on the obtained data, it can be stated that regarding the content of humus and the total nitrogen content in the soil, more favourable results were observed with tillage methods A, B, C and D.

Unfavourable climate conditions during research had a negative impact on chemical properties of the soil. In the control method where primary tillage was administered in the autumn and secondary tillage with disc-harrow and multi-tiller in spring (method E) smaller absorption of plant available phosphorus was observed in maize cultivation in 2006 as well as of potassium for methods where primary tillage was administered in the spring (methods A and B). After maize harvesting in 2006 with reference to the initial state before sowing, an increase of 20.4 kg ha^{-1} and 11.6 kg^{-1} ha of plant available potassium was observed in methods A and B respectively, and an increase of 4.1 kg ha^{-1} of plant available phosphorus was observed in method E. After four years with all tillage methods, except for method D, less plant available phosphorus was observed in comparison with the initial state (Table 5).

Contrary to the above, Lopez Fando and Pardo (2009) established inconsequentially higher content of potassium and phosphorus after five years in the soil layer from 0-30 cm for primary tillage with paraplough in comparison with minimal tillage. Benito and Sombrero (2006) observed less plant available phosphorus and potassium after ten years in soil layer from 0-30 cm with conventional tillage in comparison with minimal tillage, whereas Papini et al. (2007) were unable to establish the influence of varying tillage methods on the amount of plant available phosphorus after six years. It can be concluded that the dynamics of plant available potassium and phosphorus was, besides tillage methods, influenced by other factors as well. Similar was established by Cox et al. (2003).

Table 3. Influence of soil tillage on humus during research

Tillage methods	Humus, g kg^{-1}				
	A	B	C	D	E
Before maize harvesting 2006	23.6	19.1	22.5	20.6	22.9a
After maize harvesting 2006	22.6	21.7	22.6	21.8	22.3a
After soybean harvesting 2007	22.7	18.9	22.3	22.7	22.6a
After maize harvesting 2008	21.7	18.2	21.4	21.3	17.7b
After soybean harvesting 2009	22.5	20.4	20.4	21.1	20.2ab

The factors: year =369.6; tillage method = 17.6; year x tillage method = 15.25;
* values in columns marked with different letters indicate significant fluctuations, $p<0.05$

Table 4. Influence of soil tillage on the total nitrogen content in the soil

Tillage methods	Total N, %				
	A	B	C	D	E
Before maize harvesting 2006	0.10c	0.10b	0.10b	0.10	0.10b
After maize harvesting 2006	0.12ab	0.12a	0.13a	0.11	0.12a
After soybean harvesting 2007	0.13a	0.12a	0.14a	0.12	0.13a
After maize harvesting 2008	0.11bc	0.12a	0.11b	0.11	0.11b
After soybean harvesting 2009	0.13a	0.12a	0.13a	0.12	0.11b

The factors: year =17.8; tillage method = 3.0; year x tillage method = 1.1 NS;
* values in columns marked with different letters indicate significant fluctuations, $p<0.05$; NS (no significant at $p<0.05$)

Table 5. Influence of soil tillage on the content plant available phosphorus in the soil

Tillage methods	P_2O_5, kg ha^{-1}				
	A	B	C	D	E
Before maize harvesting 2006	168.5a	104.0	151.1a	102.3b	118.1
After maize harvesting 2006	111.4b	94.1	117.2b	93.1b	122.2
After soybean harvesting 2007	123.7b	99.2	165.5a	131.2a	121.4
After maize harvesting 2008	115.9b	107.2	135.4a	135.6a	114.3
After soybean harvesting 2009	100.5b	97.3	104.1b	114.7ab	107.8

The factors: year =8.17; tillage method = 5.79; year x tillage method = 3.37;
* values in columns marked with different letters indicate significant fluctuations, $p<0.05$

Table 6. Influence of soil tillage on the content of plant available potassium in the soil

Tillage methods	K_2O, kg ha^{-1}				
	A	B	C	D	E
Before maize harvesting 2006	144.7b	115.2b	232.8a	156.3	159.1a
After maize harvesting 2006	165.1a	126.8ab	178.5abc	154.4	124.6b
After soybean harvesting 2007	149.7ab	114.2b	217.6ab	157.9	113.1bc
After maize harvesting 2008	125,7c	83.3c	149.5c	131.2	98.5c
After soybean harvesting 2009	157.9a	141.7a	157.2bc	135.0	89.4d

The factors: year =9.90; tillage method = 28.5; year x tillage method = 2.80;
* values in columns marked with different letters indicate significant fluctuations, $p<0.05$

Table 7. Maize and soybean grain yield (t ha^{-1}) during research

Tillage methods	t/ha $^{-1}$				
	A	B	C	D	E
Maize (*Zea mays L.*) 2006	10.79ab	12.67a	11.85ab	10.14b	9.93b
Maize (*Zea mays L.*) 2008	10.49b	13.83a	13.53a	13.17a	13.57a
Soybean (*Glycine max*) 2007	1.71c	2.09ab	1.99b	2.00b	2.24a
Soybean (*Glycine max*) 2009	2.96	3.05	2.86	2.99	3.51

* Values within rows indicated by different letters are significantly different (p<0,05)

On the bases of research results it is evident that more favourable results of the researched chemical properties were obtained, except for the soil reaction with spring and autumn primary tillage with reduced number of secondary tillage interventions, methods A, B, C and D in relation to control method of the most intensive tillage method, method E. However, as stated by Kvaternjak (2011), control method of achieved higher yields of soybean grain, whereas the highest yield of maize grain was observed in method with spring primary tillage and secondary tillage with rotary harrow (Table 7).

Contrary to the above Kisić et al. (2002) and Jug et al. (2006) achieved higher yields of maize grain with methods involving very deep ploughing and conventional tillage. Due to poor germination and sprouting, along with low yield of maize and soybean grain achieved at the no-tillage method Kisić et al. (2010) recommend simpler tillage methods adapted to climate conditions, soil type and tillage timelines, and similar was also recommended by Birkas et al. (2008).

From the perspective of sustainable soil management and achieved results of the researched chemical properties, taking into consideration yields of the cultivated crops, there is a possibility to reduce secondary tillage interventions in the researched area, especially with maize cultivation.

Conclusions

After four years of researching chemical soil properties with five different tillage methods in cultivation of maize and soybean in crop rotation it can be concluded that more favourable results were observed with the methods of spring and autumn primary tillage with reduced number of secondary tillage interventions in relation to control method of the most intensive tillage.

At the end of the research a significant reduction of soil reaction was observed with the methods of spring primary tillage, which was not present with the methods of autumn primary tillage.

Significant impact of the applied tillage methods on humus quantity was not observed. In control method of autumn primary tillage and secondary tillage with spike-harrow, disc-harrow and multi-tiller 2.7 g kg^{-1} less humus was observed at the end of the research, but this alteration was not statistically justified.

Cultivation of soybean in crop rotation had a greater impact on the established quantity of total nitrogen than the applied tillage methods. The worst results were observed in the control methods of the most intensive tillage.

In all the methods, except the one involving primary tillage and secondary tillage with multi-tiller (method D), less plant available phosphorus was observed after four years, whereas the methods involving autumn primary tillage indicated less plant available potassium.

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