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LONG-TERM TILLAGE AND CROP SEQUENCE EFFECTS ON MAIZE AND SOYBEAN GRAIN YIELD UNDER EASTERN ROMANIAN DANUBE PLAIN CLIMATE CONDITIONS

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ABSTRACT

Much research around the world has compared the performance of maize (M) and soybean (S) grown under conventional and no tillage systems; however relatively few long-term experiments have been conducted in Eastern Romanian Danube Plain area. In 2012, an experiment was established at Fundulea – Romania, on cambic chernozem soil, testing two tillage treatments [no-tillage (NT) and chisel tillage (CT)], and two crop sequences [soybean (S) and winter wheat (WW) for maize and maize (M) and winter wheat (WW) for soybean]. When compared the two tillage systems, in most experimental years (2012-2017), M as well as S yields were statistically similar. Significant yield increases were determined by higher water amounts of rainfall during vegetation period (from April until August). The smallest yield increase of tillage treatments in NT indicates that CT can be superior to NT as response at higher water amounts of rainfall. WW, as previous crop, had a positive, significant influence on M and S yields. Considering the continuous increasing cost of labor, field equipment and fuel, cultivation of spring crops, as M and S, is preferable within NT system. Additionally, the farmers who adopt the NT practice for spring crops (M and S) can benefit by the economical credit given for preserving the top soil, and possible by the advantages of WW crop rotation.

Keywords: maize, soybean, soil tillage, preceding crops.

INTRODUCTION

Agriculture in the Eastern Romanian Danube Plain is characterized by mouldboard or chisel ploughing and mechanical hoeing that is often thought to lead to land degradation and excessive nutrient losses. To combat this scourge, conservation agriculture (CA) is being promoted through minimum mechanical soil disturbance (i.e. no tillage), permanent soil organic cover and species diversification (FAO, 2018). The effectiveness of CA for controlling excessive water run-off and soil erosion is well documented (Scopel et al., 2004), and it is expected that this contribution can be measured in terms of crop yield. Other benefits associated with CA include reduction in the input costs for crop production and profit maximization (Knowler and Bradshaw, 2007).

Implementing CA in the southern parts of Romania particularly under temperate continental conditions presents challenges different from where CA originated. In temperate continental regions (400-500 mm annual rainfall), success of CA depends on the ability of farmers to retain crop residues and to ensure adequate weed control. Manipulating tillage and mulch management to improve water infiltration and reduce water loss from soil surface in crop fields has potential to substantially improve crop yields and soil conditions. Conventional tillage (CT) practices alter soil structure and increase porosity of the upper layer. This increases the initial water infiltration into the soil, but total infiltration is often decreased by subsoil compaction (Gómez et al., 1999). Cultivated soils may lose a lot of rainfall as run-off and large amounts of soil through erosion (Duley, 1940). Intensive rainfall on bare soil leads to surface sealing and soil compaction, resulting in localized water logging and poor soil infiltration (Castro et al., 2006). The mulch component of CA controls soil erosion by reducing raindrop impact on the soil surface, decreasing the

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water runoff rate and increasing infiltration of rainwater (Barton et al., 2004). Under temperate continental conditions, mulches also play an important role in conservation of soil water through reduced soil evaporation (Scopel et al., 2004). In theory, reduced tillage and surface cover increase soil water available for crop growth by increasing infiltration and by limiting run-off and evaporation losses. However, mulching is not positive in all circumstances; under continuous rainfall, mulches have little effect on soil water status (Unger et al., 1991). Prolonged dry periods may also cause the benefits of mulching to diminish due to continued evaporation (Jalota and Prihar, 1990). Intensive rainfall in mulched fields can cause waterlogging because of reduced evaporation (Araya and Stroosuijder, 2010) leading to reduced soil aeration (Cannell et al., 1985). Interactions between the components of CA and their effects on crop yields are complex and often site-specific and long-term experiments are necessary to provide a better understanding.

Researchers will readily acknowledge that no-till (NT) maize (M) is best adapted to soils that are well drained (Dick et al., 1991). NT is often less likely to result in M yields equal to those with CT (whether mouldboard or chisel ploughing) on fine-textured and (or) poorly drained soils (Opoku et al., 1997). Yet, even then, the long-term advantages of continuous NT to soil structure, plus equipment and labour cost reductions associated with no-till, may still be sufficient reasons to justify maintaining a field in continuous NT through its entire cropping sequence. NT M most likely succeed when planted in rotation with other crops such as soybeans (S) (West et al., 1996) or even winter wheat (WW) (Cociu, 2012). Surface residue placement has also influenced NT M yields following WW (Opoku et al., 1997).

NT S yields are less likely to be lower than those with CT, even on poorly drained soils. Thus, for instance, researchers have generally found few instances of S yield reductions with NT relative CT (West et al., 1996). S yield reductions are most apt to occur if S varieties are susceptible to disease, which is more prevalent in NT (Adee et al., 1994), and if S are planted NT into high residues cover situations in more northern latitudes (Vyn et al., 1998).

Edwards et al. (1988) reported that S yields were increased 6% in a M/WW/S sequence compared with those in a M/S rotation under CT. In contrast, under NT conditions, S yields in a M/WW/S rotation were 19% lower than with M/S rotation.

Much research around the world has compared the performance of M and S grown with CT and NT, but relative few long-term experiments have been conducted in the Southern Plain of Romania, which is under temperate continental conditions, and even fewer have investigated the combined effects of tillage system and crop sequence.

The aim of the present study was to assess the effects of long-term (6 yr.) use of two tillage techniques (NT and CT) on maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] yield performances, within two crop sequence.

MATERIAL AND METHODS

Field experiments were conducted during six growing seasons (2011/12-2016/17) at NARDI Fundulea, which is located at 44°27′45″ latitude and 26°31′35″ longitude, East of Romanian Danube Plain and East of Fundulea town.

The soil is a cambic chernozem formed on loessoide deposits, which is typical for a large area of this plain. Its surface is flat, at 68 m altitude, and with the underground water at 10-12 m depth. Morphologically, the soil has a dusty-argillaceous 0-27 cm horizon, with 36.5% clay, 49.2 mm ha^{-1} permeability and with a compaction of 1.41 g cm^{-3}. It contains high-very high levels of potassium (soluble K=175 ppm), phosphorus (70 ppm), and humus (2.2%). The total nitrogen content is around 0.157, C/N=15.9 and pH=6.7.

Climate is of temperate continental type, with mean annual temperature of 10.9°C and 589 mm rainfall (1960-2017). Long-term rainfall pattern shows most rainfall from May to September with monthly values above 50 mm with the highest amount in June (74 mm). Long-term average temperature and rainfall during the vegetation period of M and S (from April to August) were 10.8°C and 305 mm (1961-2017).

Field management

The experiment was performed in 2011, within a long-term multidisciplinary research platform based on conservation agriculture (CA), initiated in 2010. The experiment was designed as a randomised complete block with split-split plot arrangement in three replications. Tillage systems were main plots, preceding crops represented subplots, fifteen maize hybrids (M) and fifteen soybean cultivars (S) were sub-sub plots. Net sub-sub plot size has 3 m wide by 10 m long. The tillage plots were maintained in the same placement each year, but the subplots for preceding crops and sub-sub plots for maize hybrids and soybean cultivars were re-randomised each year.

The tillage treatments were, as follows: (i) no-tillage (NT) – no soil disturbance was done except for planting; (ii) chisel tillage (CT) – the soil was tilled to a depth of 15 cm with a chisel plough mounted with twisted shanks SG-M 730 (Knoche Maschinenbau GmbH, Bad Nenndorf, Germany). The preceding crop was: (i) soybean (S) and (ii) winter wheat (WW) for maize and (i) maize (M) and (ii) winter wheat (WW) for soybean. Residues of preceding crops were chopped and uniformly spread on soil surface.

M and S were planted with a population of 60,000 and respective 500,000 plants ha^{-1} using a combined planter for seeding and fertilizing of the type Regina (Gaspardo Seminatrici S.p.A., Morsano al Tagliamento, PN, Italy) with four rows and 70 cm row spacing. The size of plots was 30 m^2 at planting. Planting took place in the period of April 15-30. M plots were fertilized at a rate of 120 kg N ha^{-1}, with all N applied surface-banded at the 5 or 6 leaf stage. Appropriate herbicides were used to control weeds as needed. No diseases or insect pest controls were utilized. S experimental plots, of 10 m long and 2.0 wide, were harvested with a Wintersteiger Delta (Wintersteiger AG, Ried, Austria) harvester at beginning of September each year. The experimental M plots were comprised of 2 rows, 10 m long, chosen from the middle of a larger plot. They were hand harvested. Results regarding grain yield are reported at standardized moistures, as follows: 15.5% for M and 12.0% for S.

Statistical analysis

Yield data were analysed using a split-split plot multi-annual analysis of variance. Yields were analysed separately for factors, such as: pre-crops, tillage system and year. The Duncan multiple comparison test at the 0.05 probability level (Steel and Torrie, 1980) was used to make comparisons among treatments. The effect of rainfall on grain yield with different tillage and preceding crops across all experimental years was quantified by second-degree polynomial regression analysis.

RESULTS AND DISCUSSION

Maize and soybean yields after different crops

Maize (M) (*Zea mays* L.) was grown after soybean (S) [*Glycine max* (L.) Merr.] and winter wheat (WW) (*Triticum aestivum* L), and S after M and also WW. M yield variations among years ranged between 4.719 and 13.309 t ha^{-1} after S, and between 4.475 and 12.665 t ha^{-1} after WW. S yields varied between 0.495 and 2.903 t ha^{-1} after M, respectively between 0.516 and 2.841 t ha^{-1} after WW (averages of soil tillage variants) (Table 1).

Table 1. Maize and soybeans yields (t ha^{-1}) as affected by tillage systems [no-tillage (NT) and chisel tillage (CT)], years and preceding crops

Crop		Maize		Soybean		Temperature (°C)	Rainfall (mm)
Preceding crop		Soybean	Wheat	Maize	Wheat	April -August	
Tillage	NT	8.725 b	9.198 a	1.632 b	1.733 a	Mean (1961-2017)	
	CT	8.851 b	8.976 ab	1.770 a	1.768 a	10.8	305
Year	2012	4.719 j	4.475 k	0.495 i	0.516 i	21.6	265
	2013	13.309 a	12.665 b	2.493 c	2.609 b	20.1	381
	2014	9.624 f	9.916 e	1.744 e	1.985 d	18.9	399
	2015	7.741 g	9.569 f	1.280 g	1.388 f	19.9	260
	2016	6.265 i	7.265 h	1.180 h	1.276 g	20.0	295
	2017	11.070 c	10.632 d	2.903 a	2.841 a	19.4	510
ANOVA results	Preceding crop (P)	*		**			
	Tillage (T)	ns		ns			
	Year (Y)	***		***			
	P*T	ns		ns			
	P*Y	***		***			
	T*Y	***		***			

Values with the same letter are not significantly different for the indicated crop, tillage and period ($p<0.05$); ns-not significant; *$p<0.05$; **$p<0.01$; ***$p<0.001$

The "tillage*year" interaction was very significant for M and S. The M yield achieved after S was significantly higher in NT when compared to CT in 2013. Minor differences between tillage systems were recorded in years 2012 and 2016 (when M yield was slightly lower in NT than in CT), and in the years 2014, 2015 and 2017 the yields obtained in NT were significantly lower then those obtained in CT (Figure 1A).

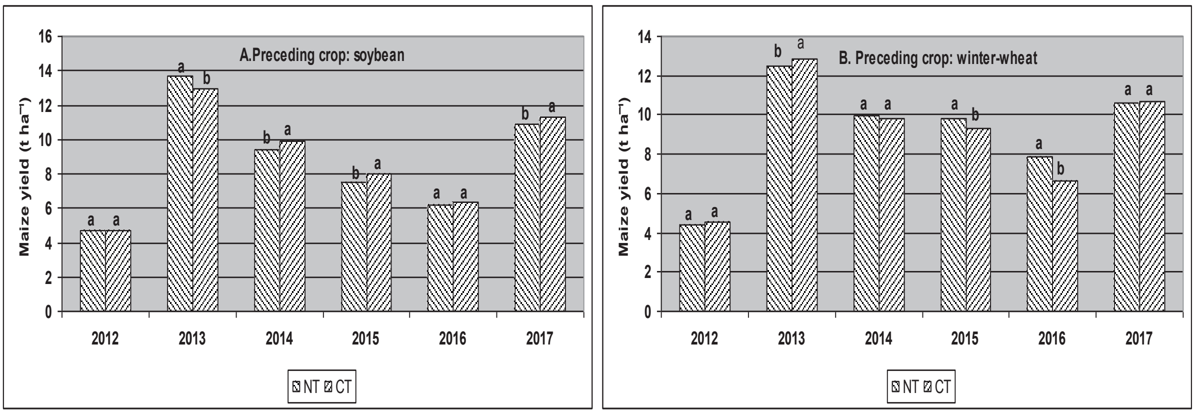

Figure 1. Maize grain yields as affected by tillage system*preceding crop. Tillage systems with the same letter are not significantly different for the indicated period ($p<0.05$)

The M yield achieved after WW was significantly lower in NT compared to CT in 2013. Insignificant differences were recorded in the years 2012 and 2017, when M yields were slightly lower in the NT than in CT, and respectively in 2014, when M yields were slightly higher in the NT than in CT. Significantly higher M yields in NT than CT were obtained in 2015 and 2016 (Figure 1B).

In 2013 and 2017, S yield after M was significantly lower in NT compared to CT, and significantly higher in 2015. Insignificant differences between tillage systems were recorded in 2012, 2014, when S yield was slightly lower in NT than CT, and in 2017, when S yield was slightly higher in NT than CT (Figure 2A).

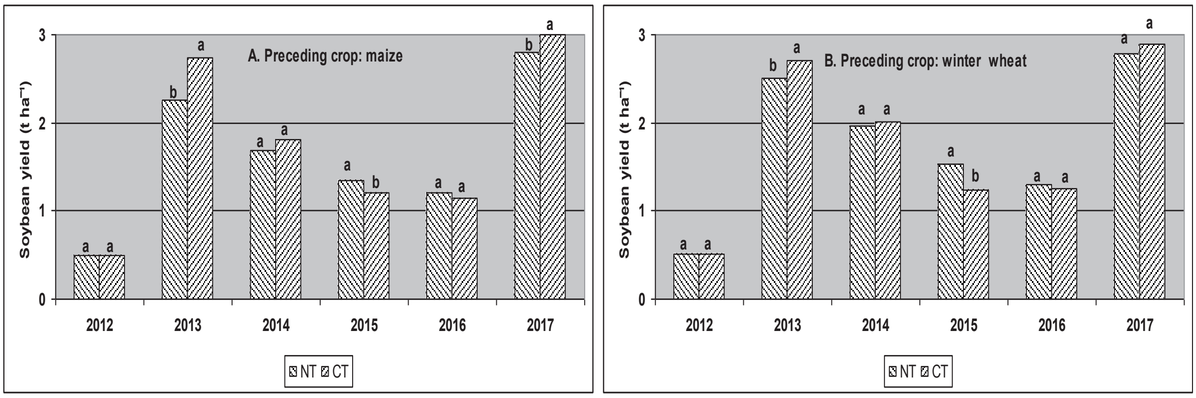

Figure 2. Soybean grain yields as affected by tillage system*preceding crop. Tillage systems with the same letter are not significantly different for the indicated period ($p<0.05$)

In 2013, S yield after WW was significantly lower in NT compared to CT, but significantly higher in 2015. Insignificant differences between tillage systems were recorded in 2012 and 2016, when S yield was slightly higher in NT than CT, respectively in 2014 and 2017, when S production was slightly lower in the NT than CT (Figure 2B).

Yields of M and S after all preceding crops are plotted against rainfall in Figure 3. In the case of M, the yields increased along with the rainfall during vegetation period (from April to August), with higher slope in CT compared to NT, thus indicating the possibility that under larger amounts of rainfall the yields in CT may be expected to be higher than in NT.

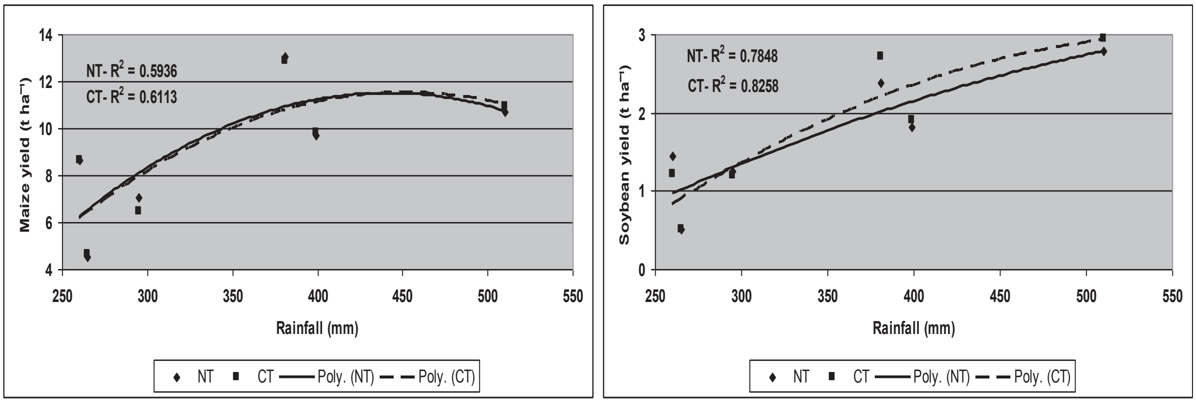

Figure 3. Relationship of maize (M) and soybean (S) grain yields on rainfall (April-August) (M and S yields in all years after all preceding crops. NT-no tillage and CT- chisel tillage)

Only in 2017, M yields after both preceding crops, in CT, was significantly higher than those recorded in the NT, when during vegetation period 510 mm rainfall mean was recorded. In the other years of this study, with mean rainfall in the vegetation period below 510 mm, the M yields obtained in the NT were well compared to those obtained in CT: either significantly higher in 2013 and 2016, equal in 2015 or insignificantly lower in 2012 and 2014.

Based on Figure 3, one can ascertain that the trend of regression curves at M indicates that in reducing the rainfall during vegetation period below 400 mm we can sustain that M yields may be higher in NT because the long-term adoption of the NT may improve soil water storage capacity (Bescansa et al., 2006). The low NT yield during the high rainfall years could be attributed the water-logging that affected nutrient uptake and crop growth (Griffith et al., 1988).

In the case of S, after both preceding crops, the yields increased along with the rainfall during vegetation period (from April to August), with a higher slope in the CT when compared to NT. This indicates the possibility that under larger amounts of rainfall (over 300 mm) the yields in CT should be expected to be higher than in NT. S yield in NT was significantly higher then in CT in year 2015, insignificant higher in 2016, equal in 2012, insignificant lower in 2014 and significant lower in 2013 and 2017.

Preceding crops effect on maize and soybean yields

M and S were cultivated during six experimental years, in two rotations (M after S and WW, respectively S after M and WW), so, the effects of preceding crops on yields could be evaluated each year (Table 1).

The M outputs were significantly higher after S in 2012, 2013 and 2017, and after WW in 2014, 2015 and 2016. In Figure 4, it can be seen that under rainfall below 380 mm the higher M outputs are recorded after WW, and more than 380 mm after S.

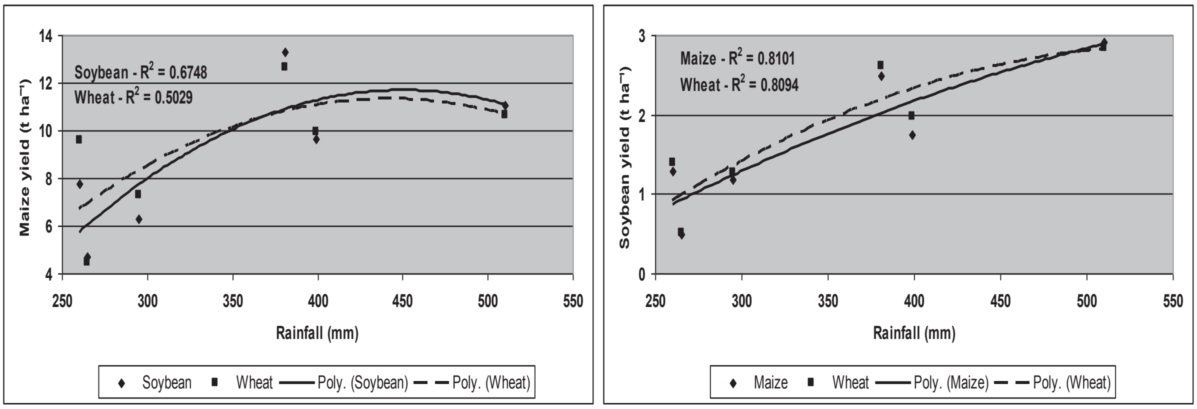

Figure 4. Relationship of maize (M) and soybean (S) grain yields on rainfall (April-August)
(M and S yields in all years after tillage systems)

In 2013, 2014, 2015 and 2016, S yields were significantly higher after WW, and after M in 2017. In 2012 the yields after the two preceding crops were equal. Data presented in Figure 4 show that under rainfall below 500 mm, S yield is superior after WW.

CONCLUSIONS

The results of this experiment, carried out within 6 years on a cambic chernozem under the conditions of the Eastern Romanian Danube Plain, show that in M crop, the NT system achieved an average yield of 0.5% higher than the CT system, and the rotation with WW, although did not have significant positive effects, resulted in an average yield of 3.4% higher than that obtained in the S rotation. In the S-crop, the CT system provided a insignificantly higher average yield by 2.9% compared to the system NT and the rotation with WW resulted in an average yield with 5.1% superior to that obtained in the rotation with M.

Considering the continuous increasing cost of labour, field equipment and fuel, cultivation of spring crops, as M and S, is preferable within NT system. Additionally, the farmers who adopt the NT practice for spring crops (M and S) can benefit by the economical credit given for preserving the top soil (superficial soil layer), and possible by the advantages of winter wheat crop rotation.

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