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LONG-TERM TILLAGE AND CROP SEQUENCE EFFECTS ON WINTER WHEAT AND TRITICALE GRAIN YIELD UNDER EASTERN ROMANIAN DANUBE PLAIN CLIMATE CONDITIONS

Alexandru I. Cociu

National Agricultural Research and Development Institute Fundulea, 915200 Fundulea, Călăraşi County, Romania
E-mail: acociu2000@yahoo.com

ABSTRACT

Many researches around the world have compared the performance of winter wheat (WW) and triticale (T) grown under conventional and no tillage systems; however, relatively few long-term experiments have been conducted under Eastern Romanian Danube Plain area. An experiment was established in 2012 in Fundulea on a cambic chernozem with two tillage treatments [no-tillage (NT) and chisel tillage (CT)] and two crop sequences [soybean (S) -WW/T and maize (M) – WW/T)]. WW and T yields were generally at similar levels with both tillage systems in most years between 2012 and 2017. Yields increased with higher amounts of rainfall during the vegetation period (from October until June) with the smallest increase among tillage treatments in NT. This indicates that CT can be superior to NT regarding yield at superior amounts of rainfall. Preceding crops did not considerably influence WW and T yields.

Keywords: winter wheat, triticale, soil tillage, preceding crops.

INTRODUCTION

There is increasing worldwide interest in soil conservation systems due to their economic and environmental benefits. Economic benefits of no-tillage (NT) systems may arise from lower drought susceptibility due to higher plant-available soil water content, resulting in more stable yields and savings of labour and fuel. Ecological benefits include an increase of soil organic carbon, biotic activity, soil porosity, agro-ecological diversity, less erosion and lower carbon emissions (due to less fuel consumption) (Derpsch et al., 2010). NT establishment of winter wheat (using a direct drilling machine with disc coulters) on a chernozem could reduce fuel consumption and work time by more than 25% compared to CT (i.e. using a chisel plough) and subsequent seeding (using a vibro roller and a seeding machine) (Cociu, 2010).

Soil tillage influences soil chemical characteristics and nutrient distribution (e.g. of phosphorus and potassium) in the soil (Neugschwandtner et al., 2014) and soil physical characteristics like bulk density, pore volume and pore size distribution, infiltration, soil water supply, aggregate stability and penetration resistance (Cociu, 2011). Residues on the soil surface play an important role in soil water conservation in NT (Lampurlanés and Cantero-Martínez, 2006). A disadvantage of NT is higher weed infestation compared with ploughing (Gruber et al., 2012).

Crop yields in NT were observed to be within five percent of those obtained by CT in experiments from several European countries (Soane et al., 2012) with soil, crop and weather factors exerting important influences. For winter wheat (WW) yields, contrasting results have been reported for yields of tillage systems with additional factors such as crop rotation (López-Bellido et al., 1996) and climatic conditions influencing the relation. WW yields under temperate conditions in Austria (Liebhard, 1995) and south-western Germany (Gruber et al., 2012) were lower in NT than in CT mainly due to impaired crop emergence. Under cool and humid conditions in Switzerland, no yield difference of WW between tillage systems were reported by Anken et al. (2004), whereas Rieger et al. (2008) observed slightly

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lower WW yields with NT than with CT, mainly due to both lower ear density and thousand kernel weight. Under Mediterranean dry land conditions of Spain and Italy, variability of tillage effects due to climatic conditions was observed with higher WW yields with NT when drought stress occurred and higher yields with CT when water availability was adequate (López-Bellido et al., 1996; Amato et al., 2013).

Many researches around the world have compared the performance of cereal crops grown with CT and NT, but relative few long-term experiments have been conducted in the southern parts of Romania 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 winter wheat (*Triticum aestivum* L.) and triticale (x *Triticosecale* Witt.) yields within two crop sequences [soybean-winter wheat (triticale) and maize-winter wheat (triticale)] under Eastern Romanian Danube Plain conditions.

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 both Romanian Danube Plain and 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 vegetation period of WW and T (from October to June) were 7.5°C and 416 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, ten winter wheat cultivars (WW) and five triticale cultivars (T) 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 winter wheat and triticale cultivars were re-randomised each year.

The tillage treatments were, as follows: (i) no-tillage (NT) – no soil disturbance was done except for drilling; (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) maize (M). Residues of preceding crops were chopped and uniformly spread on soil surface.

Certified seed was planted with the twenty-four row TUME Nova Combi 3000 (Noka-Tume Oy, Turenky, Finland) seed drill with 12.5 cm row spacing with a rate of 500 viable grains per square meter. The size of plots was 30 m² at sowing and 20 m² at harvesting. Seeding took place from mid to late October each year. Plots were harvested with Wintersteiger Delta (Wintersteiger AG, Ried, Austria) harvester at beginning of July each year. Results regarding grain yield are reported at the 14% standard moisture.

Common conservation agriculture practice was used – fertilization for high yields according to soil analysis (nitrogen and phosphor fertilizers, 30 and 80 kg a.i.ha^{-1} respectively, were applied simultaneously with seeding, and a dose of 90 kg a.i.ha^{-1} nitrogen fertilizer was added by spreading in spring), herbicides (trifensulfuron-metil + tribenuron-metil and fluroxipir-meptil) and fungicides (tebuconazol) were applied once before first inter-node formation.

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 linear regression analysis.

RESULTS AND DISCUSSION

Winter wheat and triticale yields after different crops

WW and T were grown after S [*Glycine max* (L.) Merr.] and M (*Zea mays* L.). Yield variations recorded between years were between 4.518 and 7.081 t ha^{-1} after S respectively between 4.380 and 7.364 t ha^{-1} after M for WW and between 5.168 and 8.732 t ha^{-1} after S respectively between 5.086 and 8.556 t ha^{-1} after M for T (averages of variants of soil tillage's) (Table 1). The tillage * year interaction was insignificant for WW cultivated after S and M and very significant for T cultivated after S and M. The WW yield achieved after S was significantly lower in the NT compared to CT in 2017. This year's rainfall was very abundant during the growing season, 121 mm above the multiannual average. Minor differences between tillage systems were recorded during 2012-2016 (when WW yield was slightly lower in NT than in CT). During these years, the rainfall recorded during the vegetation period was lower than that registered in 2017 (Figure 1A). WW yield after M was significantly lower in NT than in CT in 2015 and 2016, in the other years, the yield was slightly lower in NT than CT (Figure 1B).

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

Crop		Winter wheat		Triticale		Temperature (°C)	Rainfall (mm)
Preceding crop		Soybean	Maize	Soybean	Maize	October-June	
Tillage	NT	5.561 a	5.595 a	6.533 bc	6.432 c	Mean (1961-2017)	
	CT	5.811 a	5.882 a	6.852 a	6.694 ab	7.5	416
Year	2012	4.518 f	4.380 f	5.168 e	5.086 e	7.6	392
	2013	7.081 b	7.364 a	8.732 a	8.556 a	8.6	531
	2014	5.394 e	5.525 de	6.401 cd	6.348 cd	8.8	484
	2015	5.627 d	5.593 de	6.327 cd	6.287 cd	8.2	514
	2016	6.044 c	5.417 de	7.270 b	6.503 cd	9.3	480
	2017	5.453 de	6.150 c	6.255 d	6.598 c	7.6	537
ANOVA results	Pre-crop (P)	ns		ns			
	Tillage (T)	ns		**			
	Year (Y)	***		***			
	P*T	ns		ns			
	P*Y	***		***			
	T*Y	ns		***			

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 T yield after S was significantly lower in the NT compared to CT in the years 2012, 2015 and 2017. Minor differences between soil systems were recorded in the years 2013 and 2014 (when T-yields were slightly higher in NT than in CT) and 2016 (when yield of T in NT was slightly lower than CT) (Figure 2A).

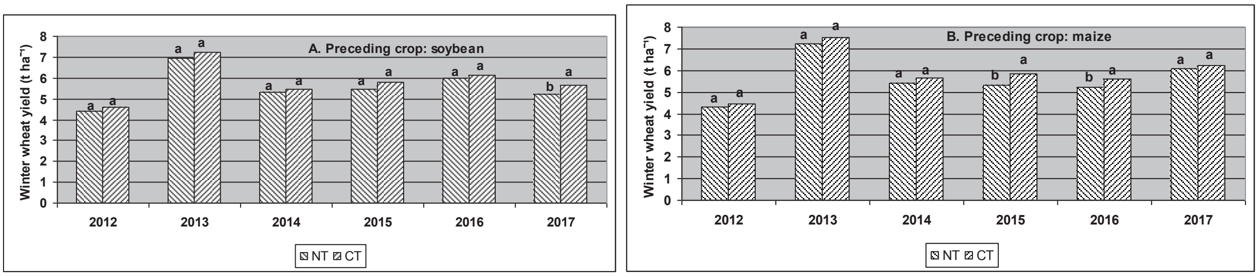


Figure 1. Winter wheat grain yields as affected by tillage system * preceding crop.
Tillage systems with the same letter are not significantly different for the indicated period ($p<0.05$)

The yield of T after M was significantly lower in the NT compared to CT in the years 2012 and 2016, in the other years the yield was slightly lower in the NT compared to CT (2013, 2015 and 2017) or slightly higher in the NT compared to CT (2014) (Figure 2B).

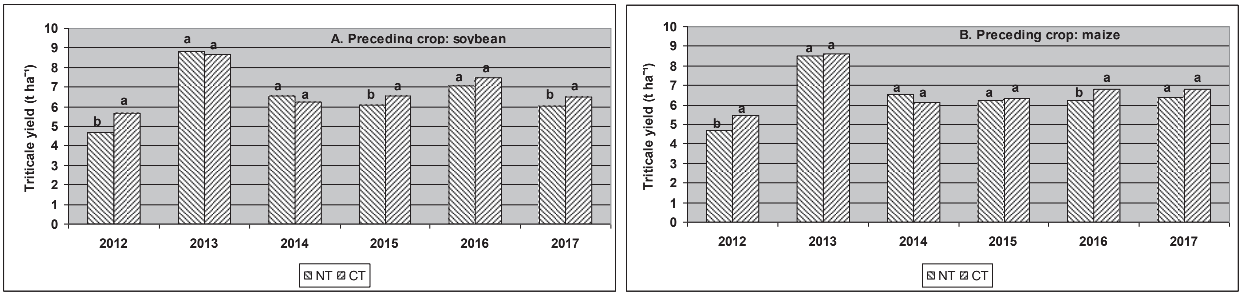


Figure 2. Triticale grain yields as affected by tillage system * preceding crop.
Tillage systems with the same letter are not significantly different for the indicated period ($p<0.05$)

Yields of WW and T after all preceding crops are plotted against rainfall in Figure 3. WW yields increased with the rainfall during vegetation period (from October to June) with higher slope in the CT compared to NT, indicating the possibility that under larger amounts of rainfall the yields in CT be higher than in NT.

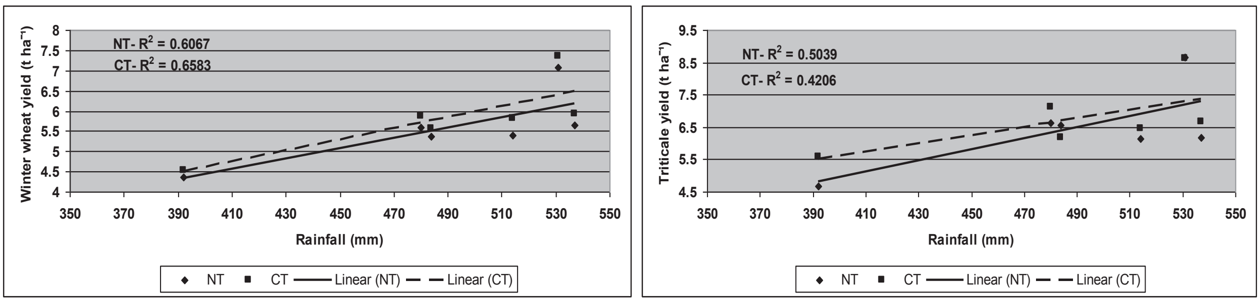


Figure 3. Regressions of winter wheat (WW) and triticale (T) grain yields on rainfall (October-June)
(WW and T yields in all years after all pre-crops). NT – no tillage and CT – chisel tillage

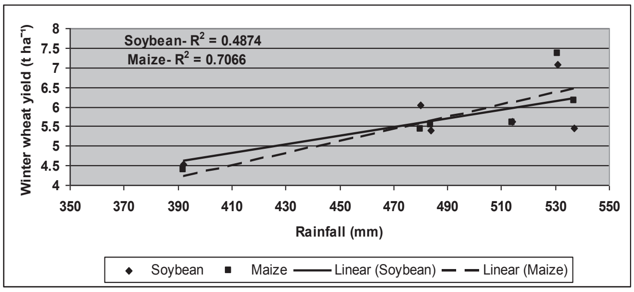
WW yields after both preceding crops in CT were significantly higher than those recorded in the NT in the years 2013 and 2017, when, during vegetation period, rainfall over 530 mm were recorded. In the other years of the study, with rainfall, during vegetation period, below 530 mm, NT yields were insignificantly lower than those recorded in CT. Our results obtained under the Eastern Romanian Danube Plain partially confirm the statement by Soane et al. (2012) that there is a reduction in the reliability of crop yields with NT especially in wet seasons. Based on Figure 3, the trend of regression lines at WW indicated that we could sustain the observations made by Amato et al. (2013) that

WW yields may be higher in NT under drought conditions, as the long-term adoption of the NT may improve soil water storage capacity (Bescansa et al., 2006).

In Triticale, after both preceding crops, the yields increased with the rainfall during vegetation period (from October to June) with a higher slope in the NT compared to the CT, indicating the possibility that under larger amounts of rainfall (over 550 mm) the yields in NT be higher than in CT. T yield in CT was significantly higher than in the NT in the years 2012, 2016 and 2017, while in 2014, the average T yield was significantly higher in the NT. In the other years of study, T yield in NT was insignificantly lower than in CT.

Preceding crops effects on winter wheat and triticale yields

WW and T were cultivated during six experimental years in both rotations, so, the effects of preceding crops on yields could be evaluated each year (Table 1). Yields of WW and T after all tillage systems are plotted against rainfall in Figure 4. The WW outputs were significantly higher after M in 2013 and 2017 and after S in 2016. In the other years, WW yields were insignificantly different. Figure 4 shows that under low rainfall conditions, below 480 mm, higher WW outputs were recorded after S and more than 480 mm after M.



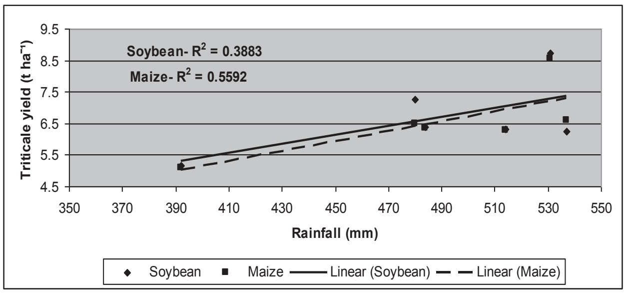


Figure 4. Regressions of winter wheat (WW) and triticale (T) grain yields on rainfall (October-June) (WW and T yields in all years after all tillage systems). S – soybean and M – maize

T yields were significantly higher after S in 2016 and after M in 2017. In the other years, T yields were insignificantly different. Figure 4 shows that under rainfall below 590 mm, higher T yield were recorded after S. Larger yields after S, at both WW and T, could be explained by the conservation of soil nitrogen by legumes and the transfer of nitrogen-bound biologically by crop residues to the subsequent crop (Chalk, 1998; Kaul, 2004), but their relative importance varies depending on climatic conditions (Amato et al., 2013).

CONCLUSIONS

The results of this experiment, carried out within 6 years on a cambic chernozem under the conditions of the Eastern Romanian Danube Plain, showed that in WW crop, the CT system achieved an average yield of 4.8% higher than the NT system, and the rotation with M, although did not have significant positive effects, resulted in an average yield of 0.9% higher than that obtained in the S rotation. In the T-crop, the CT system provided a significantly higher average yield by 4.5% compared to the system NT and the rotation with S resulted in an average yield with 2.0% superior to that obtained in the rotation with M.

The recent economic impact of increasing costs for machinery, labour and fuel favours the cultivation of winter cereals (WW and T) under the NT system and has provided the incentive for more farmers to switch to it. Additional incentives that favour the use of the NT winter small grain (WW and T) system includes an economical credit for topsoil conservation and potential benefits for rotation of corn and soybean crops.

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