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MAIZE YIELD AND ITS STABILITY AS AFFECTED BY TILLAGE AND CROP RESIDUE MANAGEMENT IN THE EASTERN ROMANIAN DANUBE PLAIN

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ABSTRACT

Rainfed crop management systems need to be optimized to provide more resilient options in order to cope with projected climatic scenarios, which forecast a decrease in mean precipitation and more frequent extreme drought periods in the Eastern Romanian Danube Plain. This research, carried out in the period of 2011-2014, had as main purpose the determination of influence of tillage practices and residue management on rainfall use efficiency, maize yield and its stability, in order to evaluate the advantages of conservation agriculture (CA) in the time of stabilization of direct seeding effects, in comparison with traditional chisel tillage. The maize grain yields are presented for each crop management practices, as follows: (1) chisel tillage, retained crop residues being chopped and incorporated (ciz); (2) zero tillage, retained crop residue chopped and kept on the field in short flat condition (rvt); (3) zero tillage, crop residues kept on the field in short root-anchored condition (1/2rva), and (4) zero tillage, crop residues kept on the field in tall root-anchored condition (1/1rva). In 2012, a year with prolonged drought during vegetative growth, yield differences between zero tillage with short root-anchored residue retention (1/2rva) and chisel tillage with residue incorporation (ciz) were positive, up to 840 kg ha^{-1}. On average over 2011-2014, conservation agriculture (CA) practices had a yield advantage over traditional chisel tillage practice. Zero tillage with residue retention used rainfall more efficiently, suggesting that it is a more resilient agronomic system than traditional (conventional) practices involving chisel tillage with residue incorporation.

Key words: conservation agriculture, crop residues, zero-tillage, yield stability.

INTRODUCTION

Water is a limiting factor for the world's economy, because of its decreasing quality and changes in distribution. With global warming, an increase in aridity is predicted for some areas in some model scenarios, which estimated that drought would persist in critical agricultural regions of Europe, especially in the southern regions, as well as in eastern North America. It is projected that these regions will suffer from increased dryness, heat, water shortages, resulting in reduced production (Schwartz and Randall, 2003). The projected mean precipitation decrease will be accompanied by more frequent dry extremes in all seasons (Christensen et al., 2007). Evaluations of the impact of global weather changes in Romania emphasize that aridity would increase, especially during the crop growing season, in the southern parts of Romania (Marica and Busuioc, 2004). In the light of these predictions, there is a need to develop resilient crop management systems that are able to cope with both heavy rainfall events and prolonged drought. The basis of conservation agriculture (CA) are supported by three principles: (1) minimal soil movement, (2) retention of rational amounts of residue cover, and (3) economically viable crop rotations, which together should lead to reductions in management costs and to increased profitability (Hoobs et al., 2008). The techniques to apply the principles of conservation agriculture will vary with bio-physical and system management conditions and farmer circumstances (Verhulst et al., 2010). Conservation agriculture can improve water infiltration in comparison with conventional tillage and zero tillage with residue removal (Verhulst et al., 2010). In the case of CA, the residue cover prevents aggregate breakdown and thus crust

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formation, which is caused by direct raindrop impact, as well as by rapid wetting and drying of soils (Le Bissonnais, 1996). In addition, the residue cover slows down runoff, giving the water more time to infiltrate.

Reports on the effect of tillage practice and residue management on maize (*Zea mays* L.) yields are variable. Thierfelder and Wall (2009) reported that, depending on the season, maize yields were equal or higher using conservation agriculture practices compared to conventional tillage in Zambia and Zimbabwe. In the Argentine Pampas, maize yields were lower with zero or reduced tillage than with mould-board tillage without nitrogen fertilizer, but yield differences disappeared when fertilizer was applied (Alvarez and Steinbach, 2009). Pedersen and Lauer (2003) reported that zero tillage decreased maize yield compared to chisel ploughing in some rotations, but increased or maintained yield in others.

A complex experiment started to be carried out in 2010, at a multidisciplinary research platform within NARDI Fundulea, in order to investigate the long term effects of the practices as soil tillage/seeding, crop rotation and vegetal residue management on the performances of winter wheat – maize – soybean system, in rain fed conditions. Further on, the research taking place in the period of 2011-2014 had the purpose of determining the influence of tillage practices and residue management on rainfall use efficiency, maize yield and yield stability, in order to evaluate the advantages of conservation agriculture (CA) in the time of stabilization of direct seeding effects, once again - in comparison with traditional chisel tillage.

MATERIAL AND METHODS

Experimental soil and climatic conditions

This rain fed, long-term experiment was located in a NARDI Fundulea research field, situated at 44º27’45” latitude and 26º31’35” 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 presents an Ap 0-27 cm horizon, dusty-argillaceous, 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 is around 0.157, C/N=15.9 and pH=6.7. Climate is of temperate continental type, with a 50 year multiannual mean temperature of 10.7°C and 580 mm precipitations.

Table 1. Yearly weather data of 2011-2014 crop cycles and the average of 1960-2014 at NARDI Fundulea zone

Month	Rainfall (mm)					Potential evapotranspiration (mm)				
	2011	2012	2013	2014	1960-2014	2011	2012	2013	2014	1960-2014
April	29	35	39	83	45	34	54	49	40	39
May	77	160	97	101	62	67	77	83	68	71
June	102	21	127	136	75	141	112	101	88	95
July	59	2	96	52	71	115	141	111	110	108
August	30	48	22	27	49	111	124	115	116	104
September	14	49	91	37	50	95	86	70	78	73
Rainfall mean April-Sept.	311	315	472	436	352					

The total rainfall during 2011 growing season (April-September) was 311 mm, lower than the long-term average of 352 mm, but it was well distributed (Table 1). The growing season started with good precipitations: 77 mm in May and 102 mm in June. It was followed by a relatively dry three month period (July, August and

September), with sub long-term averages of 59, 30 and 14 mm, respectively, and potential evapotranspiration values (calculated by the Thornthwaite, 1948 method) of 115, 111 and 95 mm, respectively. In 2012, the total rainfall during the growing season was 315 mm (Table 1). It was similar to that of 2011, but precipitation distribution was very different. In 2011, drought was mainly confined to August and September, while in June and July of 2012 there was an extended very dry period, with rainfalls lower than long-term average, of 21 mm and 2 mm, respectively, and potential evapotranspirations of 112 and 141 mm. In 2013 and 2014 the rainfall totalled 472 mm and 436 mm, respectively, which were higher than the long-term average, of 352 mm. Their distribution was more favourable to the crop in 2013 then 2014. While in 2013 the only drier month was August, in 2014 the drought installed, as in 2011, in July and lasted up to the end of the vegetation season.

Research information

The study described in this paper was conducted as part of a long-term complex trial. In 2010, at the end of summer, one month after a rainy period, the entire experimental plot was treated with a broad-spectrum contact herbicide, than it was seeded with winter wheat (Cociu, 2011). Individual plots were of size of 6.0 m by 10.0 m. Maize and soybean were planted with a population of 60,000 and respective 500,000 plants ha^{-1}, on 70 cm apart rows, and winter wheat with 500 seeds $m^{-2,}$ on 12.5 cm apart rows. The winter wheat and maize plots were fertilized at a rate of 120 kg N ha^{-1}, with all N applied to wheat (broadcast) at the 1st node growth stage, and to maize (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. Winter wheat planting took place in the period of October 10-20, and for maize and soybean - April 15-30. Experimental design was 4x4 Latin Square. The 12 treatments combined: wheat-maize-soybean rotations, tillage/ planting methods, and residue management practices. Experimental treatments included: 1) chisel tillage, retained crop residues being chopped and incorporated (ciz); 2) zero tillage, retained crop residue chopped and kept on the field in short flat condition (rvt); 3) zero tillage, crop residues kept on the field in short root-anchored condition, maize stubble until below ear and 25 cm wheat stubble (1/2rva), and 4) zero tillage, crop residues kept on the field in tall root-anchored condition, all maize and wheat residue (1/1rva). Ears were hand harvested in the two central rows of each plot, dried and shelled. Dry weights were recorded. For rainfall use efficiency evaluation, grain yield was divided by growing season rainfall (April - September) and expressed in kg grain yield per m^3 rain.

Yield data were analyzed using ANOVA for randomized complete block design, with tillage-residue management system as a split-plot on year. The significant differences were separated by Duncan's new multiple range test. Significant differences were accepted at $P<0.05$ (Steel and Torrie, 1980). Yield stability was assessed by two methods. First, the CV of yields over time was calculated for each plot and the CVs were then analyzed like the yield data. Second, stability analysis was performed as in Raun et al. (1993). Treatment means for each year were regressed linearly against annual yields (averaged over all considered treatments). The annual mean yield reflects the overall growing conditions for each year, which includes temperature, rainfall and pest pressure. Regressing treatment yields on the annual mean yield allows one to evaluate the relative response of the treatments under the range of growing conditions that occurred (Raun et al., 1993). Linear slopes of treatment yields on the annual mean yield were compared among the four tillage-residue management system, using the tests for equality of slopes of several regression lines described by Sokal and Rohlf (1995) (at $P<0.05$).

RESULTS AND DISCUSSION

Maize yields varied greatly over years, with averages ranging from 5.77 t ha^{-1} in 2012 to 10.80 t ha^{-1} in 2013. The mean yield of the period of 2011-2014 was higher, but not statistical significant, in the variant zero tillage with residue retention, flat or anchored, in comparison with chisel tillage with residue incorporation (ciz). The highest mean yield was registered for variant zero tillage with tall root-anchored residue retention (1/1rva): 9.38 t ha^{-1}, higher with 0.2%, 1.0% and 2.3%, respectively, compared to the variants zero tillage with short root-anchored residue retention (1/2rva), zero tillage with short flat residue retention (rvt) and chisel tillage with residue incorporation (ciz): Table 2.

In 2011, maize yields were different, but not significantly, varying between 9.70 t ha^{-1} and 10.70 t ha^{-1} limits which were recorded for the variants zero tillage with root-anchored residue retention (1/2rva and 1/1rva). In 2012, the highest yield was obtained within the variant zero tillage with short root-anchored residue retention (1/2rva): 6.24 t ha^{-1}, higher with 4.2%, 14.7% and 15.6%, respectively, when compared to those of the variants zero tillage with short flat residue retention (rvt), zero tillage with tall root-anchored residue retention (1/1rva) and ciz, but the differences were not significant.

Table 2. Effect of tillage practice and crop residue management on maize yields (t ha^{-1}) for 2011, 2012, 2013, 2014 and average yields 2011-2014, in the long-term sustainability trial, at NARDI Fundulea

Management practice	2011	2012	2013	2014	2011-2014
ciz*	9.97 (1.30) a	5.40 (0.33) a	10.69 (0.70) a	10.62 (0.58) a	9.17 (0.46) a
rvt	10.19 (1.07) a	5.99 (0.27) a	10.27 (0.43) a	10.70 (0.34) a	9.29 (0.40) a
1/2rva	9.70 (1.43) a	6.24 (0.23) a	11.40 (1.46) a	10.11 (0.65) a	9.36 (0.45) a
1/1rva	10.70 (0.81) a	5.44 (0.86) a	10.84 (0.31) a	10.53 (0.71) a	9.38 (0.50) a

*ciz - chisel tillage, retained crop residues being chopped and incorporated; rvt - zero tillage, retained crop residue chopped and kept on the field in short flat condition; 1/2rva - zero tillage, crop residues kept on the field in short-root anchored condition, maize stubble until below ear and 25 cm wheat stubble; 1/1rva - zero tillage, crop residues kept on the field in tall root-anchored condition, all maize and wheat residue. Standard error is given in the parentheses. Management practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

Similarly, in 2013, the best yield, but not significantly higher, was again registered at the variant zero tillage with short root-anchored residue retention (1/2rva): 11.4 t ha^{-1}, higher with 5.2%, 6.6% and respectively 11.0% than those of the variants zero tillage with tall root-anchored residue retention (1/1rva), chisel tillage with residue incorporation (ciz) and zero tillage with short flat residue retention (rvt). In 2014, yields were similar in all applied practices, between 10.11 and 10.70 t ha^{-1}.

Table 3. Stability analysis of maize grain yield (2011-2014) in the long-term sustainability trial, at NARDI Fundulea

Management practice	CV (%) over time	Regression of treatment means vs. year means		
		Slope	Intercept	R^2
ciz	28.5 (1.40) a	1.1035	-0.8855	0.9893
rvt	24.3(1.66) b	0.9240	0.6945	0.9810
1/2rva	25.6 (2.13) ab	0.9061	0.9359	0.9482
1/1rva	28.5 (4.32) a	1.0685	-0.7670	0.9975

CV coefficient of variation of grain yields over time (2011-2014). Standard error is given in parentheses.
Management practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

The coefficient of variation (CV) over time was significantly higher for practices with chisel tillage with residue incorporation (ciz) than for practices with zero tillage with short flat residue retention (rvt). Its value was lower for zero tillage with short flat residue retention (rvt) and zero tillage with short root-anchored residue retention (1/2rva) than for all the other practices studied (Table 3). The regression lines of treatment mean vs. annual mean differed among tillage-residue management systems. The test for equality of slopes of linear regressions (Figure 1) did not reveal significant differences in stability between treatments: $F_s = 2.18 < F_{0.05\ [3,\ 8]} = 4.07$. So, we conclude that the four groups were sampled from populations of equal slopes.

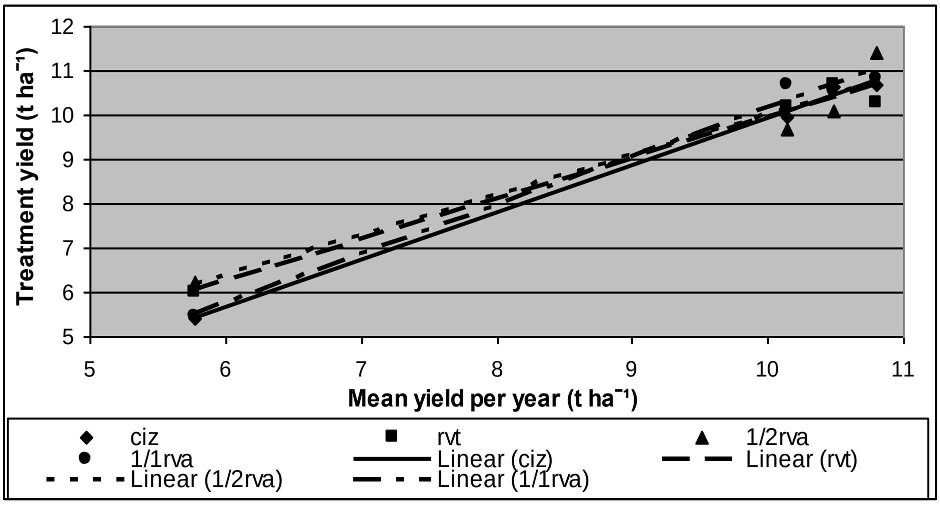

Figure 1. Linear regressions for agronomic treatment maize grain yield on the annual average maize grain yield from 2011 to 2014, in NARDI Fundulea long-term sustainability trial

Zero tillage with short root-anchored residue retention (1/2rva) seemed to have the most stable (smallest slope) and the highest yield (Figure 1, Table 3), whereas chisel tillage with residue incorporation had the steepest slope and thus providing most variable yield.

Average rainfall use efficiency in 2011, 2012, 2013 and 2014 was 3.57, 2.49, 2.79 3.18 kg m^{-3}, respectively (Table 4). In 2011, average rainfall use efficiency was comprised between 3.77 kg m^{-3} registered for zero tillage with tall root-anchored residue retention (1/1rva) and 3.42 kg m^{-3} for chisel tillage with residue incorporation (ciz). In 2012, 2013 and 2014 the rainfall use efficiency was the lowest for chisel tillage with residue incorporation (ciz): 2.33 kg m^{-3} in 2012, 2.66 kg m^{-3} in 2013 and 3.06 kg m^{-3} in 2014, and the highest for zero tillage with short root-anchored residue retention (1/2rva): 2.69 kg m^{-3} in 2012, 2.95 kg m^{-3} in 2013 and 3.24 kg m^{-3} in 2014. The long-term average rainfall use efficiency was 3.12 kg m^{-3} for zero tillage with short root-anchored residue retention (1/2rva), 3.03 kg m^{-3} for zero-tillage with tall root-anchored residue retention (1/1rva), 3.02 kg m^{-3} for zero tillage with short flat residue retention (rvt), and 2.87 kg m^{-3} for chisel tillage with residue incorporation (cis).

Rainfall in Easter Romanian Danube Plain is erratic and water shortage can occur at any time during the growing season.

In 2011, the soil water reserve, accumulated from the abundant rainfall during tasseling and silking favoured a very good grain fill in all treatments. Only a small advantage of zero tillage with tall root-anchored residue retention (1/1rva) was noticed. In 2012, the drought installed in June and continued during the whole tasseling and silking period. When it began raining again, at the middle of August, it was too late for maize crop to recover. This year, zero tillage with short root-anchored residue retention (1/2rva) showed a small advantage. In 2013 and 2014, years rich in precipitations, the maize grain yields registered for all treatments were quite similar, with higher but not significant advantage of the variant zero tillage with short root-anchored residue retention (1/2rva), in 2013, and in 2014 of the variant zero tillage with short flat residue retention (rvt): Table 2.

Table 4. Effect of tillage practice and crop residue management on rainfall water productivity (kg m^{-3}) recorded in 2011, 2012, 2013, 2014, and averaged over 2011-2014, in the long-term sustainability trial, Fundulea

Management practice	2011	2012	2013	2014	2011-2014
ciz*	3.42 (0.46) a	2.33 (0.14) a	2.66 (0.18) a	3.06 (0.18) a	2.87 (0.16) a
rvt	3.51(0.38) a	2.58 (0.12) a	2.77 (0.11) a	3.21 (0.10) a	3.02 (0.14) a
1/2rva	3.59 (0.50) a	2.69 (0.10) a	2.95 (0.38) a	3.24 (0.20) a	3.12 (0.14) a
1/1rva	3.77 (0.29) a	2.35 (0.37) a	2.81 (0.08) a	3.19 (0.22) a	3.03 (0.19) a

*ciz - chisel tillage, retained crop residues being chopped and incorporated; rvt - zero tillage, retained crop residue chopped and kept on the field in short flat condition; 1/2rva - zero tillage, crop residues kept on the field in short-root anchored condition, maize stubble until below ear and 25 cm wheat stubble; 1/1rva - zero tillage, crop residues kept on the field in tall root-anchored condition, all maize and wheat residue. Standard error is given in the parentheses. Management practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

Data recorded in 2012 (with a dry summer) showed that conservation agriculture (CA) practices result in a more resilient system than applying chisel tillage with residue incorporation (conventional tillage). This assertion is confirmed by the reduced CV values reported for CA-based practices. In the regression analysis, the yield advantage in CA-based practices seemed to be larger in adverse conditions (years with low average yields) than in years with high yields, but this could not be confirmed by the difference in slope of the regression lines. Considering the average yield advantage, CA seems to be more important than a differential yield response to adverse conditions. Additionally, the CA practices reduced costs compared to practices involving conventional tillage resulting in differences in returns over variable costs that were even more marked than the field differences (Sayre et al., 2006). In years with prolonged drought periods during vegetation, such as 2012, rainfall was used more efficiently in CA-based variants than when conventional tillage was practiced (Table 4). Thierfelder and Wall (2009) reported rainfall use efficiency values of 0.22 to 1.13 kg m^{-3} for maize in Zambia and Zimbabwe, with higher values for conservation agriculture than for conventional ploughing, in certain sites and years.

CONCLUSIONS

In the stabilization period of CA, rainfall was used by maize crop more efficiently in zero tillage with residue retention (flat or anchored) than in the case of chisel tillage with residue incorporation (conventional tillage). Yields were statistically similar in the three conservation practices under study (zero tillage with short flat or with full or partial anchored residue retention), suggesting that removing part of the vegetal residue can be a sustainable solution when there is a competition for this residue. Incorporating residue by tillage, as is done in conventional tillage, was less efficient in terms of soil and water conservation than keeping residue on the soil surface. The conservation agriculture (CA) based practices resulted in a more resilient agronomic system than chisel tillage with residue incorporation, especially where irrigation was not available.

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