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LONG-TERM EFFECTS OF TILLAGE SYSTEMS ON WINTER WHEAT, MAIZE AND SOYBEAN GRAIN YIELD AND YIELD STABILITY UNDER RAINFED CONDITIONS IN THE EASTERN ROMANIAN DANUBE PLAIN

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ABSTRACT

Tillage plays a key role in cropping system sustainability, due to its impact on soil properties, crop yields, economic returns, labour, and energy requirements. The objective of this research was to evaluate the effects of sub-soiling and tillage systems (two conservation tillage practices vs. the conventional tillage), under rain fed conditions, on the yield and its stability of winter wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.]. This long-term field experiment was initiated in 2007 and based on 3-yr crop rotation. Rainfall use efficiency of each crop was also evaluated. The 8-yr (2007-2015) average of winter wheat grain yield for no-tillage variant was with 1.37 % higher than that recorded for the conventional tillage, plough tillage (5.91 vs. 5.83 t ha^{-1}). Differences between tillage systems were significant in 4 out of the 8 seasons and were small when rainfall deficit occurred during the grain filling period. The 8-yr average grain yield for no-tillage maize cropping was with 5.29 % higher than that registered for conventional tillage - plough tillage (9.16 vs. 8.70 t ha^{-1}). Difference between tillage systems were significant in 3 out of the 8 seasons and were small when rainfall deficit occurred during the grain filling period. The 8-yr average grain yield for soybean was significantly lower when no-tillage was applied as compared with conventional tillage (2.02 vs. 2.18 t ha^{-1}), but differences between tillage systems were small and not significant in 6 out of the 8 seasons. In comparison to wheat and maize, no-tillage soybean had higher weed pressure.

Key words: conservation tillage, conventional tillage, yield stability, rainfall use efficiency.

INTRODUCTION

Knowledge of specific crop responses to tillage and surface crop residues as affected by climate changes is necessary in selection of appropriate tillage systems for improved crop production. During the second half of the 20th century, many energy-consuming agricultural practices were adopted as part of the modern scientific approach to achieve higher yields. Mouldboard plough-based soil cultivation, in particular, becomes very common. Nevertheless, continuous soil disturbance through cultivation and particularly through soil inversion has lead to the degradation of soil structure, soil compaction, and decreased levels of organic matter in its useful layer. This, in turn, has caused a wide range of negative environmental impacts, including soil degradation, water and wind erosion, increased carbon emissions released due to the use of high energy-consuming machinery, and an overall reduction in beneficial soil organisms and mammals. Climate change has also exacerbated the problems of degradation and variability as rainfall events have become more erratic with a greater frequency of storms (Osborn et al., 2000).

Conservation tillage is a widely used term to characterize the development of new crop production technologies that are normally associated with some degree of tillage reductions, for both pre-plant as well as in-season mechanical weed control operations that may result in some level of crop residue retention on the soil surface. The definition of conservation tillage does not specify any particular optimum level of tillage, but it does stipulate that the residue coverage on the soil surface should be at least 30% (Jarecki and Lal, 2003). Conservation tillage – an assortment of reduced tillage practices such as chisel ploughing and no tillage – reduces soil erosion and also production costs, while maintaining or increasing productivity. Chisel ploughing offers the advantage of breaking up soil similar to the way done by mouldboard

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plough, without inverting the soil. This practice is particularly important in compacted soils. No tillage creates minimal soil disturbance by using machinery only to chop down residues and then to cut a slit in the soil where the seed is injected and then covered over. In this case, herbicide application is needed to control weeds.

Hansen (1996) defined production sustainability as the ability of a system to maintain the high productivity level, despite major disturbances such as intensive stress or large perturbation. It is worth to mention also the Raun et al. (1993) assertion that long-term experiments are very important for designing cropping systems with high and stable yields and low production risk.

The objective of this research was to evaluate the effect of sub-soiling and tillage practice (conservation vs. conventional tillage) on rainfall use efficiency, grain yield and yield stability, in a long-term experiment, initiated at the National Agricultural Research and Development Institute Fundulea (NARDI Fundulea) in 2007, for winter wheat, maize and soybean, in rotation.

MATERIALS AND METHODS

Experimental soil and climatic conditions

This rain fed long-term experiment was carried out in a NARDI Fundulea research field, situated 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 cernozem 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 a 55 year multi-annual mean temperature of 10.8°C and 584 mm precipitations.

Precipitation amounts fallen in the cold season (October – March) varied largely, between 164.8 mm in cycle 2013/14 and 385.5 mm in 2014/15 (Table 1). In comparison with the multi-annual mean, precipitation deficits were recorded for the seasons: 2007/08 (32.3 mm), 2008/09 (18.7 mm), 2010/11 (18.5 mm), 2011/12 (55.3 mm) and 2013/14 (67.5 mm), and the excess for 2009/10 (55.3 mm), 2012/13 (36.5 mm) and 2014/15 (153.2 mm).

Total precipitation during vegetation period (April – September) of 2008 was substantially under the multi-annual. This vegetation period started well, with April and May rich in precipitations, but it was followed by a dry June – August period. Potential evapotranspiration during these three months, calculated by the method of Thornthwaite (1948), was close to the average value. In 2009, the precipitation amount during the vegetation period was quite similar to the multi-annual value, but with a very different distribution: the dry April – May period was followed by a very wet June – July one. August and September were drier again. Potential evapotranspiration during June – August was higher than the average values. The total precipitation of 2010 vegetation season was close to the multi-annual amount, with a distribution more or less like that of 2009. Potential evapotranspiration recorded for August was much higher than the average. The total rainfall during 2011 growing season was lower than the long-term average, but it was well distributed. May and June came with good precipitations. This period was followed by a relatively dry three month period. Potential evapotranspiration recorded for June had much higher value than the average one. In 2012, the total rainfall during the growing season was similar to that of 2011, but precipitation distribution was very different. In 2011, the drought was mainly confined to August and September, while in June and July of 2012 there was an extended very dry period, with rainfall lower than long-term average. Potential evapotranspiration was high, especially in July. In 2013 and 2014 the total rainfall amounts were higher than the long-term average. Their distribution was more favourable to the crops under this study. While in 2013, the only drier month was August in 2014 the drought installed in July and lasted up to the end of the vegetation season, as in 2011. The precipitations registered in the vegetation period of 2015 was close to the multi-annual value, but distributed very differently. April was rich in precipitations, but the amount registered in May, June and July was well under the multi-annual value. In August and September, the precipitations were in excess. Potential evapotranspiration was very elevated in July.

Table 1. Average values of rainfall and potential water evaporation data, registered at NARDI Fundulea during 2007-2015 crop cycles

Month	Rainfall (mm)								
	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	1960-2015
October	46.2	25.9	60.1	47.0	27.0	30.8	67.0	56.7	**40.5**
November	52.7	27.5	19.1	9.0	1.5	9.4	20.7	59.1	**42.2**
December	62.4	33.2	54.9	92.5	28.1	87.9	0.2	119.4	**46.3**
January	15.0	69.2	45.4	43.7	73.5	49.2	37.1	30.8	**34.5**
February	2.3	25.5	69.8	16.5	42.2	52.5	1.7	40.8	**31.7**
March	21.4	32.3	38.3	5.1	4.8	39.0	38.1	78.7	**37.1**
April	61.6	22.1	41.8	28.9	35.1	38.5	82.8	46.9	**44.6**
May	59.9	35.8	31.2	76.8	159.5	97.1	100.6	30.0	**61.5**
June	30.6	103.6	104.5	102.4	20.7	126.7	136.2	51.9	**74.1**
July	57.5	119.5	95.0	59.0	2.0	96.1	52.1	36.8	**70.1**
August	1.6	24.6	34.4	29.7	47.8	22.2	27.3	94.4	**50.2**
September	59.2	43.2	28.6	13.8	49.1	91.4	37.0	89.3	**50.3**
Rainfall Oct.- Sept.	**470.4**	**562.4**	**623.1**	**524.4**	**491.3**	**740.8**	**600.8**	**734.8**	**583.1**
Potential evapotranspiration (mm)									
March	29	18	14	13	15	14	30	18	**16**
April	55	47	49	39	60	56	47	44	**49**
May	87	93	92	82	94	103	86	98	**92**
June	131	130	129	176	140	129	114	125	**124**
July	137	142	138	139	170	135	134	151	**134**
August	140	127	143	125	139	131	131	131	**121**
September	72	83	81	96	87	72	81	90	**79**

RESULTS

Winter wheat yields and rainfall use efficiency

Winter wheat yields varied greatly over years under not sub-soiling practice, with averages ranging from 4.63 t ha^{-1} in 2012 to 7.63 t ha^{-1} in 2013 (Table 2). The mean yield over 2008-2015 period recorded for the no tillage variant was higher but not statistically significant.

In 2008, the mean yield of the plough tillage variant was significantly higher than the yields registered for no tillage and chisel tillage. In 2009, the mean yields of the three soil work variants were not significantly different. In 2010, the yields obtained by applying plough tillage, chisel tillage and no tillage were almost similar. In 2011, the mean yield of the no tillage variant was significantly higher than the other two variants. In 2012, the best yield was obtained also with no tillage, but without significant differences. The best yield recorded in 2013 was by using chisel tillage, being significantly superior to no tillage and plough tillage variants. In 2014, like in 2012, the highest yield was of no tillage variant, but it was not significantly better than those obtained with plough and chisel tillage systems. In 2015, plough tillage was significantly more effective than the other two variants.

Table 2. Effect of tillage system in not sub-soiling conditions on winter wheat yield (t ha^{-1} at 14% H_2O), registered during 2008-2015 period in the long-term sustainability trial at NARDI Fundulea

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	5.37a	5.12a	6.79a	5.60b	4.51a	7.22c	5.53a	6.53a	5.83a
Chisel	4.73b	5.02a	6.75a	5.84b	4.52a	7.96a	5.55a	5.99c	5.80a
No till	4.98b	4.94a	6.25a	6.47a	4.86a	7.69b	5.83a	6.27b	5.91a

Tillage practices with the same letter are not significantly different for the indicated crop and period (P<0.05).

Over the eight experimental years, sub-soiling practice, in comparison with not sub-soiling, did not provide a significantly better yield, the difference being of only 0.11 t ha^{-1} (Tables 2 and 3). In sub-soiling conditions, the best yield registered in 2008 was with plough tillage application, significantly higher than with chisel tillage, but statistically equal to that of no tillage (Table 3). In 2009 and 2010, the yields of the three soil work variants under study were almost similar.

Table 3. Effect of sub-soiling and tillage system on winter wheat yield (t ha^{-1} at 14% H_2O), registered during 2008-2015 period in the long-term sustainability trial at NARDI Fundulea

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	5.48a	5.35a	6.86a	5.89b	4.88a	7.28b	5.78a	6.48a	6.00a
Chisel	4.63b	5.27a	6.85a	5.71b	4.69a	8.12a	5.11a	6.17a	5.82a
No till	5.12ab	5.45a	6.30a	6.28a	4.90a	7.89a	5.77a	6.37a	6.01a

Tillage practices with the same letter are not significantly different for the indicated crop and period (P<0.05).

In 2012, the yields were quite low and almost similar for the three tillage variants. In 2013, which was a very good year for the crop, the best yield was registered for the chisel tillage (8.12 t ha^{-1}), but statistically similar to that of no tillage variant. In 2014 and 2015, the yields of the three soil work systems were again statistically similar.

The regression analysis did not reveal significant differences in stability between treatments: the hypothesis of equality of slopes was not rejected (P>0.05). Sub-soiling practice seems to determine the most stable (milder slope) yields and higher in comparison with those obtained with no sub-soiling (Figure 1).

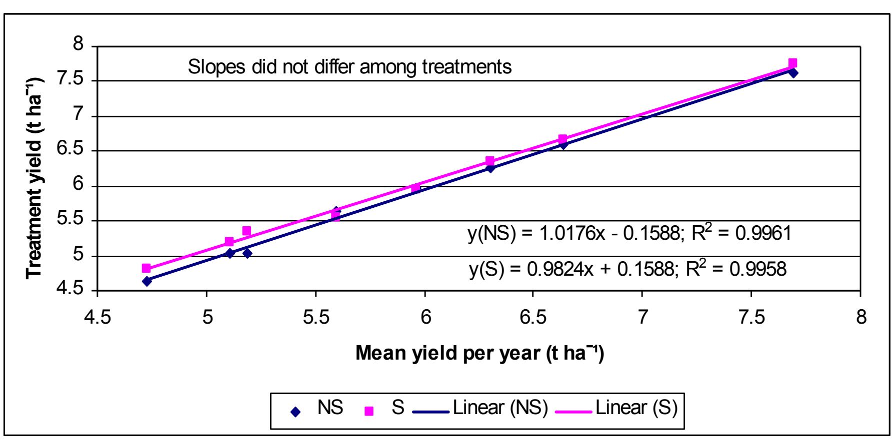

Figure 1. Linear regressions of winter wheat yield for sub-soiling treatments on the annual mean yield, recorded in 2008 to 2015 period, in the NARDI Fundulea long-term sustainability trial

The regression lines of treatment mean vs. annual mean differed among tillage systems without sub-soiling practices: the hypothesis of coincidence was rejected by the F-test ($P<0.05$). It looks like that plough tillage contributes to more stable yields (milder slope), but not significantly, than the no tillage with which superior yields were obtained (Figure 2).

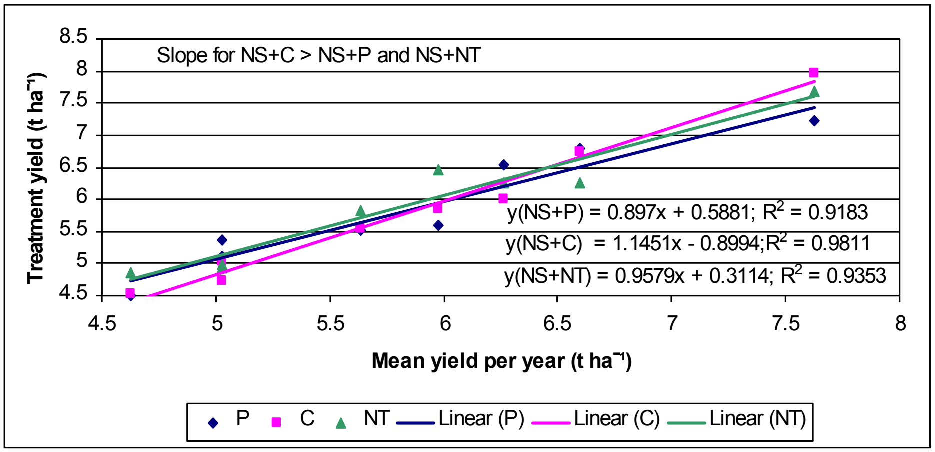

Figure 2. Linear regressions of winter wheat yield for tillage treatments on the annual 2008-2015 average Yield, in the NARDI Fundulea long-term sustainability trial

The regression lines of treatment mean vs. annual mean differed among tillage systems with sub-soiling practice: the hypothesis of coincidence was rejected by the F-test ($P<0.05$). Plough tillage with sub-soiling seemed to have the most stable (milder slope), but lower yields (Figure 3).

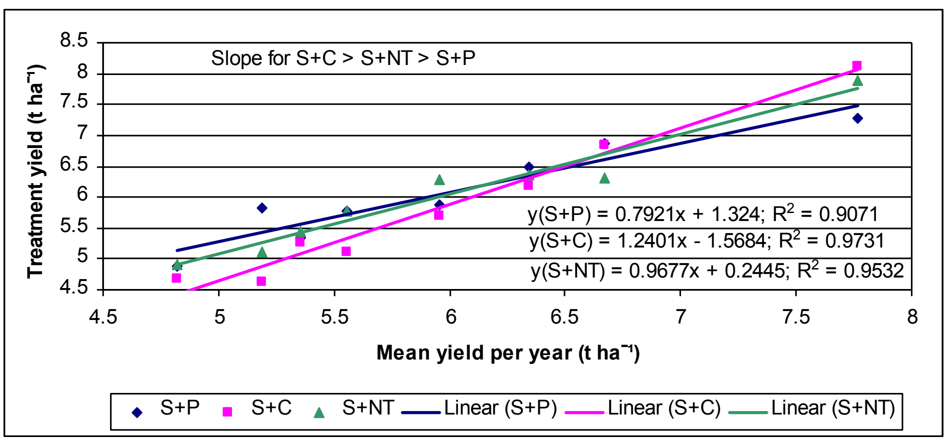

Figure 3. Linear regressions of winter wheat yield for sub-soiling and tillage systems on the annual means, registered during 2008-2015 period in the NARDI Fundulea long-term sustainability trial

In 2009 and 2010, rainfall use efficiency had the lowest values for no tillage, but superior values of this variant over the other two were registered in most the remaining years, making the 2008-2015 averages of all variants almost equal, with amounts between 13.5 and 13.8 kg $ha^{-1}mm^{-1}$ (Table 4). Sub-soiling, as averaged over eight experimental years, determined a small, not significant, increase of rainfall water productivity (0.183 kg $ha^{-1}mm^{-1}$) as compared with not sub-soiling (Tables 4 and 5).

From data presented in Table 5, it can be seen that sub-soiling and tillage system did not influence, over all, significantly the rainfall water efficiency for this crop.

Table 4. Effect of tillage system in not sub-soiling conditions on rainfall water productivity of winter wheat yield ($kg\ ha^{-1}mm^{-1}$), during 2008-2015 period, recorded in NARDI Fundulea long-term sustainability trial

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	15.1a	13.8a	14.1a	14.4b	12.4a	15.3c	11.9a	12.1a	13.6a
Chisel	13.3b	13.6a	14.0a	15.0b	12.3a	16.9a	11.9a	11.1c	13.5a
No till	13.8b	13.4a	13.0a	16.6a	13.3a	16.3b	12.5a	11.6b	13.8a

Tillage practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

Table 5. Effect of sub-soiling and tillage system on rainfall water productivity of winter wheat yield - $kg\ ha^{-1}mm^{-1}$, during 2008-2015, recorded in NARDI Fundulea long-term sustainability trial

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	15.4a	14.5a	14.2a	15.1b	13.4a	15.5b	12.5a	12.0a	14.1a
Chisel	13.0b	14.3a	14.2a	14.6b	12.8a	17.3a	11.0a	11.5a	13.6a
No till	14.4ab	14.7a	13.0a	16.1a	13.4a	16.7a	12.4a	11.8a	14.1a

Tillage practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

Maize yields and rainfall use efficiency

In the eight experimental years, maize yields varied greatly in not sub-soiling conditions, with averages ranging from 4.58 $t\ ha^{-1}$ in 2012 to 12.11 $t\ ha^{-1}$ in 2013 (Table 6). The 2008-2015 mean yield of not tillage variant was higher showing significant differences from the other two variants. In 2008, 2009, 2011, 2013 and 2015, the yields recorded for the three tillage systems were almost equal. A significant yield advantage of applying no tillage practice was identified in 2010. Sub-soiling, on average over the eight experimental years, contributed to increasing maize yield with only 0.193 $t\ ha^{-1}$, in comparison with not sub-soiling practice (Tables 6 and 7). From the data presented in Table 7 we can see that the mean yields were statistically similar for the three tillage systems, in most years as well as for the whole 2008-2015 period. More frequently, higher values were registered for the no tillage variant.

Table 6. Effect of tillage system in not sub-soiling conditions on maize yields ($t\ ha^{-1}$ at 15.5% H_2O), registered during 2008-2015 period in the long-term sustainability trial at NARDI Fundulea

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	6.28a	10.98a	9.97b	8.05a	4.33b	12.74a	8.42b	8.87a	8.70c
Chisel	6.34a	11.63a	10.65ab	8.62a	4.79a	11.71a	9.36a	8.55a	8.96b
No till	6.02a	11.88a	11.53a	9.45a	4.63a	11.89a	9.14a	8.71a	9.16a

Tillage practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

*Table 7.*Effect of sub-soiling and tillage system on maize yields ($t\ ha^{-1}$ at 15.5% H_2O, registered during 2008-2015 period in the long-term sustainability trial at NARDI Fundulea

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	6.52a	11.19a	9.97b	8.34a	3.88b	12.45a	9.61a	9.46a	8.93a
Chisel	5.85a	11.99a	10.46b	9.02a	4.37a	12.28a	9.78a	9.43a	9.15a
No till	6.17a	12.14a	11.83a	8.85a	4.53a	12.41a	9.31a	9.34a	9.32a

Tillage practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

The regression analysis did not reveal significant differences in stability between treatments: the hypothesis of equality of slopes was not rejected (P>0.05). Not sub-soiling seemed to have the most stable (milder slope) yields, but with lower values than those recorded for the sub-soiling variant (Figure 4).

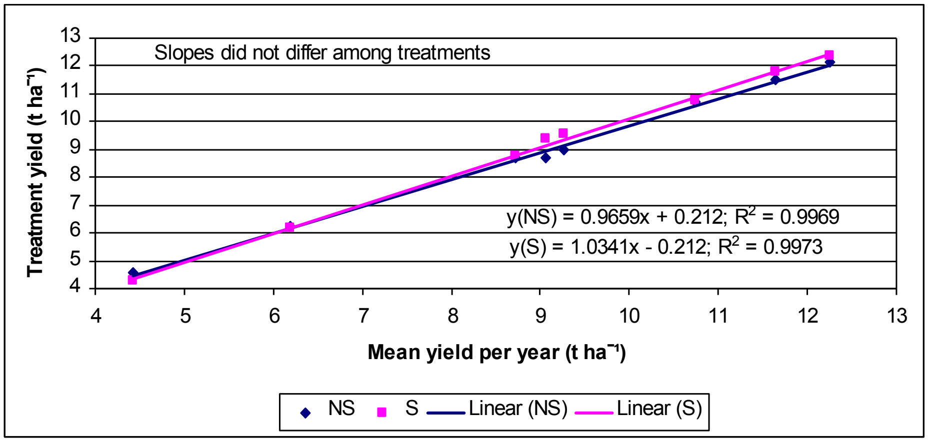

Figure 4. Linear regressions of maize grain yield for sub-soiling treatments on the annual mean maize grain yield of 2008-2015 period, recorded in NARDI Fundulea long-term sustainability trial

The regression lines of treatment mean vs. annual mean did not differ among tillage systems without sub-soiling practices: the hypothesis of coincidence was not rejected by the F-test (P>0.05). Chisel tillage looks like having the most stable (milder slope) yields, but with lower values than those recorded for the no tillage variant (Figure 5).

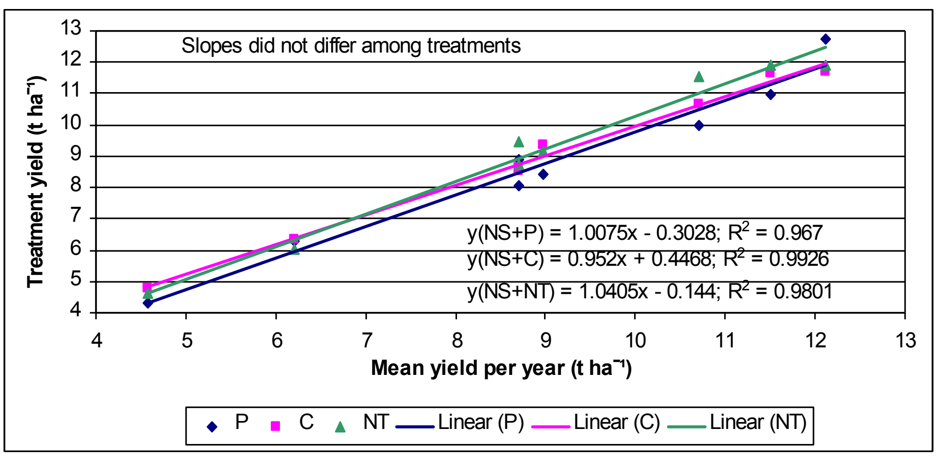

Figure 5. Linear regressions of maize grain yield for tillage treatments on the annual average maize grain yield of 2008-2015 period, recorded in NARDI Fundulea long-term sustainability trial

The regression lines in sub-soiling conditions of treatment mean vs. annual mean did not differ among tillage system: the hypothesis of coincidence was not rejected by the F-test (P>0.05). Plough tillage with sub-soiling seemed to determine the most stable (milder slope), but with lower, yields (Figure 6).

From data presented in Table 8, it can be seen that, on average over 2008-2015 period, the best rainfall water efficiency, was calculated for no tillage, with significant differences from the other two tillage systems, but in most years the values of all three variants were quite similar.

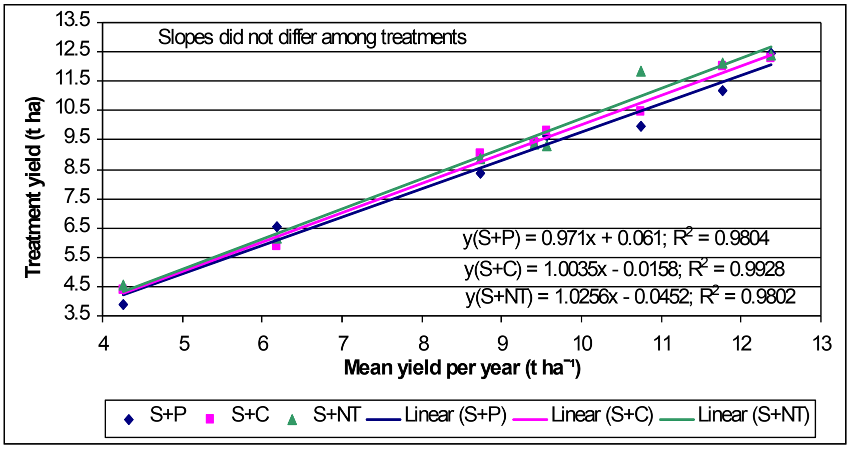

Figure 6. Linear regressions of maize yield for sub-soiling and tillage treatments on the annual mean maize grain yield, recorded in 2008-2015 period at NARDI Fundulea long-term sustainability trial

Table 8. Effect of tillage system in not sub-soiling conditions on rainfall water productivity (maize yield, kg $ha^{-1}mm^{-1}$), during 2008-2015 period, recorded in NARDI Fundulea long-term sustainability trial

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	19.6a	32.9a	36.9a	28.4a	16.6b	37.2a	25.5b	40.5a	29.7c
Chisel	19.8a	34.9a	39.4a	30.4a	18.4a	34.2a	28.3a	39.1a	30.6b
No till	18.8a	35.6a	42.7a	33.3a	17.7a	34.7a	27.7ab	39.8a	31.3a

Tillage practices with the same letter are not significantly different for the indicated crop and period (P<0.05).

In sub-soiling conditions (Table 9), the rainfall water efficiency of this crop was not influenced significantly by the tillage systems in most years and over 2008-2015 period.

Table 9. Effect of sub-soiling and tillage system on rainfall water productivity (maize yield, kg $ha^{-1}mm^{-1}$), during 2008-2015, recorded in NARDI Fundulea long-term sustainability trial

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	20.4a	33.5a	36.9a	29.4a	14.9a	36.3a	29.1a	43.2a	30.5a
Chisel	18.3a	35.9a	38.7b	31.8a	16.7a	35.9a	29.6a	43.1a	31.3a
No till	19.3a	36.4a	43.8a	31.2a	17.3a	36.2a	28.2a	42.7a	31.9a

Tillage practices with the same letter are not significantly different for the indicated crop and period (P<0.05).

Soybean yields and rainfall use efficiency

In not sub-soiling conditions, soybean yields varied greatly over the experimental years, with averages ranging from 0.812 t ha^{-1} in 2012 and 3.337 t ha^{-1} in 2010 (Table 10). The years 2010 and 2013 were very favourable for this crop and 2008, 2014, 2015, and especially 2012, were less suitable for it, mainly due to the lack of precipitations during the vegetation period. The yields recorded for the three tillage systems were statistically similar in six years, as well for as for the entire experimental period. Sub-soiling did not come with an important soybean yield increase over the whole eight year period, being of only 59 kg ha^{-1}, when compared to the not sub-soiling practice, for which an average of 2.085 t ha^{-1} was calculated (Tables 10 and 11). From the data of Table 11 we can see that, in sub-soiling conditions, the three tillage systems did not have a significant impact on soybean yields in most experimental years, as well as on the 2008-2015 averages.

Table 10. Effect of tillage system in not sub-soiling conditions on soybean yields (t ha^{-1} at 12% H_2O), registered during 2008-2015 period in the long-term sustainability trial at NARDI Fundulea

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	1.55a	2.59a	3.46a	2.46a	0.92a	3.30a	1.42a	1.72a	2.18a
Chisel	1.03b	2.46a	3.22a	2.49a	0.75c	3.46a	1.37a	1.64a	2.05a
No till	1.35a	2.42a	3.33a	2.69a	0.77b	2.71a	1.37a	1.51a	2.02a

Tillage practices with the same letter are not significantly different for the indicated crop and period (P<0.05).

Table 11. Effect of sub-soiling and tillage system on soybean yields (t ha^{-1} at 12% H_2O), registered during 2008-2015 period in the long-term sustainability trial at NARDI Fundulea

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	1.62a	2.64a	3.62a	2.53a	0.89a	3.37a	1.48a	1.63a	2.22a
Chisel	1.05b	2.71a	3.13a	2.66a	0.75c	3.49a	1.39a	1.50a	2.08a
No till	1.32ab	2.68a	3.46a	2.70a	0.78b	2.92a	1.51a	1.63a	2.12a

Tillage practices with the same letter are not significantly different for the indicated crop and period (P<0.05).

The regression analysis presented in Figure 7, did not reveal significant differences regarding soybean yield stability between the two treatments: the hypothesis of equality of slopes was not rejected (P>0.05). Not sub-soiling practice seemed to favour a little more stable (milder slope) yields.

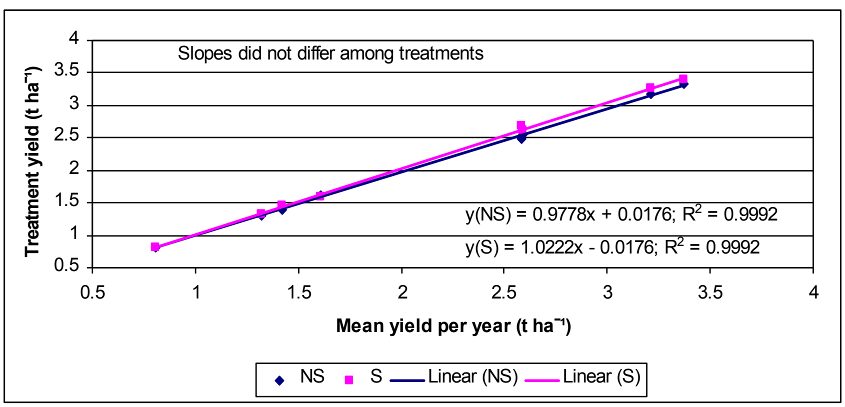

Figure 7. Linear regressions of soybean yield for sub-soiling treatments on the annual mean yields, recorded from 2008 to 2015, in the NARDI Fundulea long-term sustainability trial

The regression lines of treatment mean vs. annual mean of soybean yields did not differ among tillage systems in not sub-soiling conditions: the hypothesis of coincidence was not rejected by the F-test (P>0.05). No tillage variant determined more stable yields (smallest slope) than the other two tillage systems, but with no significant differences (Figure 8).

The regression lines of treatment mean vs. annual mean did not differ significantly among tillage systems with sub-soiling application: the hypothesis of coincidence was not rejected by the F-test (P>0.05). No tillage with sub-soiling practice seemed to produce more stable yields (smallest slope), but at a little lower levels (Figure 9).

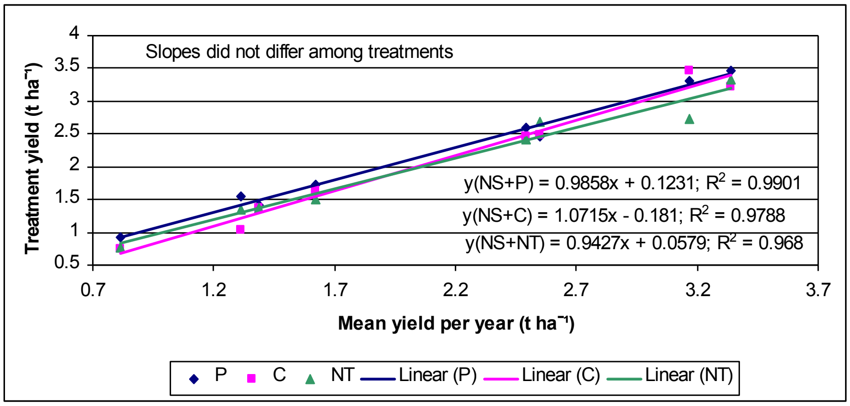

Figure 8. Linear regressions of soybean yield for tillage treatments in not sub-soiling conditions, on the annual mean yields, recorded from 2008 to 2015, in NARDI Fundulea long-term sustainability trial

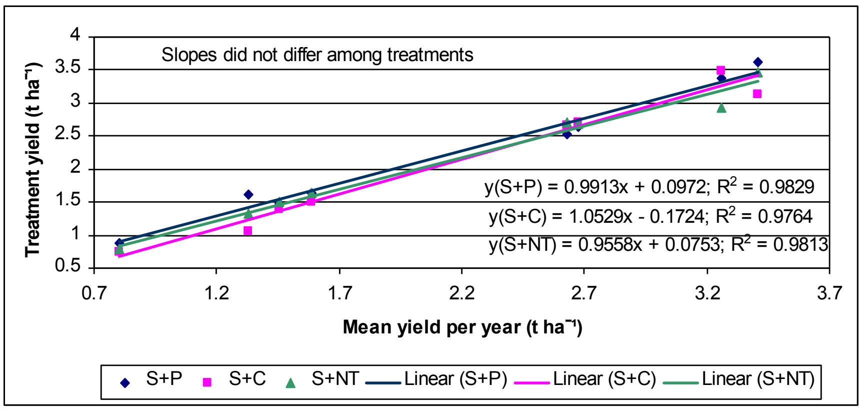

Figure 9. Linear regressions of soybean yield for sub-soiling and tillage treatment on the annual average soybean grain yield from 2008 to 2015, in NARDI Fundulea long-term sustainability trial

No significant effect of the three tillage systems on rainfall water productivity of soybean were recorded in six experimental years, and also when 2008-2015 averages were considered (Table 12).

Data presented in Table 13 show that the effects of tillage system, in sub-soiling conditions, on rainfall water soybean productivity was almost similar to those registered in not sub-soiling conditions. No significant differences among the tillage variants were detected in most experimental years and among the 2008-2015 averages.

Table 12. Effect of tillage system in not sub-soiling conditions on rainfall water productivity (soybean yield, kg ha^{-1}mm^{-1}), during 2008-2015 period, recorded in NARDI Fundulea long-term sustainability trial

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	4.2a	7.9a	12.8a	8.7a	4.0a	9.6a	4.7a	6.3a	7.3a
Chisel	2.8b	7.5a	11.9a	8.8a	3.3b	10.1a	4.6a	6.0a	6.9a
No till	3.7a	7.4a	12.4a	9.5a	3.3b	8.0a	4.6a	5.5a	6.8a

Table 13. Effect of tillage system in sub-soiling conditions on rainfall water soybean productivity (kg ha^{-1}mm^{-1}), during 2008-2015 period, recorded in NARDI Fundulea long-term sustainability trial

Tillage system	2008	2009	2010	2011	2012	2013	2014	2015	2008-2015
Plough	4.4a	8.0a	13.4a	8.9a	3.9a	9.8a	4.9a	6.0a	7.4a
Chisel	2.9b	8.2a	11.6a	9.4a	3.2c	10.2a	4.6a	5.4a	6.9a
No till	3.6ab	8.1a	12.8a	9.5a	3.4b	8.5a	5.0a	6.0a	7.1a

Tillage practices with the same letter are not significantly different for the indicated crop and period ($P<0.05$).

DISCUSSION

Rainfall in Easter Romanian Danube Plain is erratic and water shortage can occur at any time during the vegetative season. In 2008, very dry year (Table 1), the average yields of the three crops under study were quite low. Data presented in Table 2 and Table 3 show that for winter wheat, in both not sub-soiling and sub-soiling conditions, the best variant was plough tillage. In regards with maize, not significant differences among tillage variants were registered, a little higher yield being obtained with chisel tillage in not sub-soiling conditions (Table 6), and with plough tillage in sub-soiling conditions (Table 7). For soybean, significant higher yields were obtained with plough tillage, in both not sub-soiling conditions (Table 10) and sub-soiling conditions (Table 11). The year 2009 was better as precipitations, but still drier than normal (Table 1), with a modest winter wheat mean yield. The maize and soybean yield levels were superior due to the rains during the grain formation period (June and July). For winter wheat, in both not sub-soiling and sub-soiling conditions, there were not significant differences among tillage variants (Table 2 and Table 3). Regarding maize, there were not significant yield differences among tillage variants, higher values being recorded for no tillage system (Table 6 and Table 7). For soybean, a yield gain, but not significant, was registered for plough tillage in not sub-soiling conditions (Table 10), and for chisel sub-soiling conditions (Table 11). The year 2010, rich in precipitations (Table 1), was characterized by high average yields of all three crops. Winter wheat yields registered for all tillage variants were almost similar (Table 2 and Table 3). For maize (Table 6 and Table 7), no tillage variant came with a yield advantage but not significant, and for soybean (Table 10 and Table 11), plough tillage produced an yield increase but also not significant. The year 2011, like 2009, had a reduced total precipitation amount (Table 1) however the good rains of May and June contributed to getting reasonable average yields of all three crops. For winter wheat, no tillage variant assured significant positive differences in both, not sub-soiling and sub-soiling conditions (Table 2 and Table 3). The maize yield differences among tillage variants were not significant; however no tillage came with a certain increase in not sub-soiling conditions (Table 6), and chisel tillage with sub-soiling practice (Table 7). The soybean yields of all tillage variants were almost similar, with a not significant yield increase provided by no tillage (Table 10 and Table 11). The year 2012, as 2008, was characterized by a severe lack of precipitations (Table 1), especially in June and July. In August, when rains started to take place, it was too late for maize and soybean crops to recuperate their yield formation process. For winter wheat, no tillage gave a yield advantage but not statistically significant, in both not sub-soiling (Table 2) and sub-soiling (Table 3) conditions. As concerns maize, the differences among variants were small and not significant within not sub-soiling (Table 6), and in sub-soiling conditions. The best, significantly higher yield was recorded for no tillage practice (Table 7). For soybean, small but significant positive differences were registered for plough tillage variant, in both not sub-soiling (Table 10) and sub-soiling conditions (Table 11). The best yields of the three crops under study were achieved in 2013, which was the richest year in precipitations among the eight experimental years (Table 1). Regarding winter wheat, the highest yields, with significant differences were registered for the chisel tillage, in not sub-soiling (Table 2) as well as sub-soiling (Table 3) conditions. No significant yield differences among tillage systems were calculated for maize, but higher values being recorded for plough tillage variant (Table 6 and Table 7). From data presented in Table 10 and Table 11 it can be seen that there were also no significant soybean yield differences among tillage systems, the highest ones being obtained with chisel tillage (Table 10 and Table 11). In 2014, year with a normal regime of precipitations (Table 1), average to good mean yields of all three crops were obtained. The winter wheat yields recorded with all three tillage practices were statistically similar, a small advantage having the no tillage (Table 2 and Table 3). In the case of maize, a significantly lower yield was recorded for plough tillage in not sub-soiling conditions (Table 6). With sub-soiling, the yields of the three tillage variants were statistically similar (Table 7). For soybean, the yields of all tillage variants were quite close, without significant differences (Table 10 and Table 11). The year 2015, like 2013, was rich in precipitations, but with not very good monthly distribution for the three crops. For winter wheat, plough tillage was more favourable, but did not produce significant differences over the other two tillage systems (Table 2 and Table 3). Similar results were registered for maize (Table 6 and Table 7) and for soybean (Table 10 and Table 11). The regression lines of Figure 2 indicate that in adverse conditions (years with lower yields) winter wheat, in not sub-soiling conditions, performs better with the chisel tillage, and in years with higher yields - with no tillage practice. In sub-soiling conditions (Figure 3), in years with lower yields, the regression lines show that plough tillage is more beneficial while in years with higher yields no tillage system is better. In regards with maize crop (Figure 5 and Figure 6), higher yields were obtained applying chisel and no tillage systems, in both not sub-soiling and sub-soiling conditions. For soybean, the conventional (plough) tillage gave the best results (Figure 8 and Figure 9).

Conservation tillage practices, besides contributing to higher yields in a series of cropping conditions, are coming with reduced costs compared to practices of conventional tillage, resulting in differences in returns over variable costs that were even more marked than the yield differences (Sayre et al., 2006). In 2012, characterized by a severe drought during vegetation period, the water from precipitations was used more efficiently by winter wheat when no tillage (conservation tillage) was practiced, especially in not sub-soiling conditions (Table 4). For this crop, in Spain, López-Bellido et al. (2007) did not find significant yield differences among tillage systems, reporting values between 9.2 and 9.3 kg ha^{-1} mm^{-1}. For maize crop, in 2012 and over the period of 2008-2015, chisel and no tillage (again conservation tillage) gave the best results in this respect (Table 8 and Table 9). In other agriculture conditions, as those of Zambia and Zimbabwe, Thierfelder and Wall (2009) reported rainfall use efficiency values of 2.2 to 11.3 kg ha^{-1} mm^{-}, with significant higher values for conservation tillage system than for conventional ploughing, in certain sites and years. For soybean, plough tillage (conventional tillage) looks more appropriate in both not sub-soiling (Table 12) and sub-soiling (Table 13) conditions.

CONCLUSIONS

Conservation tillage systems can be an important part of a sustainable agricultural system providing benefits for the farmers in terms of labour and fuel consumption; however, yield variability may discourage and slow down its adoption. Similar levels of winter wheat, maize and soybean productivity can be achieved with the three tillage systems under study in this research, if well managed. Winter wheat yields practicing conservation tillage were almost similar to the yield obtained when plough tillage was applied. Maize yields were higher by applying conservation tillage than with plough (conventional) tillage. In this experiment, conventional tillage, as plough tillage, looks more beneficial for soybean. Sub-soiling influenced positively (significantly in most cases) the maize and soybean yields and less winter wheat yield. Rainfall use efficiency showed a similar tendency to that of the yield, for all three crops.

REFERENCES

Hansen, J.W., 1996. *Is agricultural sustainability a useful concept?* Agr. Syst., 50: 117-143

Jarecki, M. K., and Lal, R., 2003. *Crop management for soil carbon sequestration*. Crit. Rev. Plant Sci., 22: 471-502.

López-Bellido, J.R., López-Bellido, L., Benítez-Vega, J., and López-Bellido, J.F., 2007. *Tillage system, preceding crop, and nitrogen fertilizer in wheat crop: II.water utilization.* Agron. J., 99: 66-72.

Osborn Timothy, J., and Jones Philip, D., 2000. *Air flow influences on local climate: observed United Kingdom climate variations. Atmos.* Sci. Lett., 1 (1), 62-74.

Raun, W.R., Barreto, H.J., Westerman, R.L., 1993. *Use of stability analysis for long-term soil fertility experiments*. Agron. J., 85: 159-167.

Sayre, K.D., Govaerts, B., Martinez, A., Mezzalama, M., Martineza, M., 2006. *Comparison of alternative conservation agriculture technologies for rain fed production in the highlands of Central Mexico.* In: Proceedings of the 17th Conference of the International Soil Tillage Research Organization, Kiel, Germany, August 28th – September 3rd 2006.

Sokal, R.R., Rohlf, F.J., 1995. *Biometry, the principles and practice of statistics in biological research*. 3rd ed. W.H.Freeman and Company, New York.

Steel, R.G.D., Torrie, J.H., 1980. *Principles and procedures of statistics*. McGraw-Hill Publishing Company, New York.

Thierfelder, C., Wall, P.C., 2009. *Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe*. Soil Tillage Res., 105: 217-227.

Thornthwaite, C.W., 1948. *An approach toward a rational classification of climate*. The Geographical Rev., 38 (1):55-94.