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SOIL PROPERTIES, WINTER WHEAT YIELD, ITS COMPONENTS AND ECONOMIC EFFICIENCY WHEN DIFFERENT TILLAGE SYSTEMS ARE APPLIED

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ABSTRACT

This research was aimed to identify the most suitable tillage systems for sustainable winter wheat (*Triticum aestivum* L.) yield levels, with best economic efficiency, assuring at the same time high quality soil physical and mechanical properties. The field experiments were carried out at Fundulea on a cambic chernozem soil type. Four tillage systems were tested to determine their influence on soil water content, soil macro-aggregates, resistance to soil penetration, wheat grain yield and its components, and crop economic efficiency. The following tillage systems were studied: traditional, with moldboard plough (TS); chisel plough tillage – primary tillage executed with chisel implement type without furrow over throwing (CS); disc/sweep tillage, providing a combined effect of vegetal remnants chopped with disc implements along with soil work with arrow type tools, without furrow over throwing (DS); No till (NT) – without any tillage work. In comparison with TS variant, soil conservation tillage systems (SCTS), as CS, DS and NT, increased the soil water content, recorded at seeding time, with 0.8%, 3.9%, and 4.1%, respectively. Soil water content, recorded at harvest time for CS and NT variants was 1.3% and 2.5% higher than in the case of TS ($P<0.05$). The NT variant significantly improved the soil structure by increasing the percentage of macro-aggregates of >2mm with 5.5%, and the mean weighted diameter of soil particles resulted by dry sieving, with 5.5% and 10%, respectively. Yield components recorded for soil conservation tillage systems (CS, DS, and NT) did not differ significantly from those evaluated for traditional system (TS), but the superior values of 1000 kernels weight and spike density suggest that these components contributed more to higher yields, obtained with SCTS, than grain weight per spike, number of grain per spike, and number of grains per square meter. With regards to economic efficiency, the outputs of all tested SCTS were significantly greater than the TS. The present study, revealing important advantages of soil conservation tillage systems over the traditional one, revealing the improvement of soil physical and mechanical properties, higher winter wheat yield levels and higher crop economic efficiency, invites farmers from South Plain of Romania to adopt soon these new progressive systems.

Key words: soil conservation tillage system, soil water content, soil structure, cone index, grain yield and its components.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is grown on a very important acreage of South Plain of Romania, being one of the main cereal crops. Generally, the traditional or conventional tillage system includes plough with moldboard at 20-25 cm depth. This basic soil work, used many years in a row, may affect the soil stability and fertility, increasing water evaporation and pulverization degree of soil superficial layers, so reducing the resistance to wind and water erosion (Lal, 1991). Picu (2005) demonstrated that the reduction of soil degradation and better water storage in this zone can be achieved using conservation tillage systems with surface maintenance of vegetal remnants. Baker et al. (2002), appreciated that minimum 30% of soil surface need to be covered with vegetal material, resulted from secondary production of the previous crop, in order to consider that no till, reduced till, strip or billon till applied have a specific soil conservation target.

In Romania, the interest in other soil tillage methods, as alternative to the traditional system, raised after the energetic crisis manifested in the year 1973. The main objective of the related research was to increase the agronomic and energetic input efficiency of primary soil work, by reducing the ploughing depth and adopting different

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efficiency of primary soil work, by reducing the ploughing depth and adopting different versions of minimum till systems. Winter wheat proved to respond with better results than other crops to minimum tillage (Picu et al., 1979; Sin et al., 1986). Considering these research results, the disc till extended gradually as an alternative option, replacing the traditional plough, especially in dry falls and after late harvests. The alternation of superficial soil work with traditional plough gave the best results in most agricultural zones. After 1990, different field equipments for direct seeding in non-worked land were introduced in Romania. Based on certain positive research results, the replacement of traditional plough practice with direct seeding in non-worked land was recommended (Ionita et al., 1999). The research on soil work of that time did not deal with the utilization of vegetal remnants as a mean of soil protection.

Soil conservation tillage systems (SCTS) with vegetal remnants maintenance on ground surface assumes: higher economic and energetic efficiency, superior water capitalization, reduction of soil erosion and nutrients losses, and maintenance or increase of carbon content in superior soil layers.

The present research had as main objective the comparison of traditional soil work with different variants of SCTS, estimating at the same time the importance of soil loosening at the arable horizon depth. We were looking to see what would be the advantages or disadvantages of replacing the traditional plough with moldboard (plus disc) with conservative systems, on soil properties, winter wheat crop productivity input and output, in the South Plain of Romania.

MATERIAL AND METHODS

This research was carried out at the National Agricultural Research Institute Fundulea (NARDI), located at 44º 27’ 45” latitude and 26º 31’ 35” longitude, on the eastern side of South Plain of Romania, in agricultural years 2007/2008, 2008/2009, and 2009/2010. The climate is of temperate-continental type, with 50 year averages of 10.7ºC mean temperature, and 580 mm annual precipitation.

Total precipitation varied considerable in the experimental years, as follows: in 2007/2008 it was of 470.4 mm, with 109.3 mm lower than the multiannual average; in 2008/2009, it was of 662.4 mm, with 17.3 mm less than normal; and in 2009/2010 it was of 623.1 mm, with 43.1 mm over normal. The year mean temperature fluctuated less, as follows: in 2007-2008 and 2009-2010 it was of 11.5ºC, and in 2008-2009 it was of 12ºC. These meteorological data were recorded at the local station, situated at 250 m from the respective experimental field.

Soil is of a cambic chernozem type, formed on loessoide deposits, with plane surface, of 68 m altitude from the sea level, and with table water at 10-12 m. As morphology, it is constituted by a horizon Ap 0-27 cm (clay loam – powdery, with 36.5% clay, 49.2 mm/ha permeability), and a horizon Apb 27-41 cm (clay loam with 37.3% clay, settled 1.41 g/cm^3). The macro-element contents are average to high: mobile K = 175 ppm, mobile P = 76 ppm, total N = 0.157, C/N = 15.9. Humus content of arable horizon is 3.4%, and pH is 7.5.

The experimental field was previously cultivated with mustard and soybean for getting a good uniformity. The previous crop was soybean in each experimental year. The experimental design was the split plot, lied out in randomized complete bloc design, in three replications. The main plots were represented by sub-soiling or not sub-soiling, and the subplots were the tillage systems. Each replication contained 8 plots: 2 gradation of sub-soiling*4 of tillage systems. The plot size was of 6*10 m.

The following tillage systems were applied: (1) traditional, with moldboard plough (TS); (2) chisel plough tillage – primary tillage executed with chisel implement type without furrow overthrowing (CS); (3) disc/sweep tillage – it has a combined effect of residues breaking up by the discs along with the primary tillage performed by sweeps, without furrow over throwing (DS); (4) No till (NT) – not any tillage work. The effect of different tillage systems was estimated on plots with deep sub-soiling and plots without deep sub-soiling, executed once - only when this research was initiated (summer of 2007). The previous soybean crop residue (the so called secondary product) was chopped and uniformly spread on the respective plot during its harvest. In no till variants, total weed control was assured by Glyphosate (0.9 kg ha^{-1}) application in the period between previous crop harvest and seeding the experiment.

The winter wheat cultivar used was Boema. The planter was TUME Nova Combi (Noka-Tume Oy, Turenky, Finland), which is a combined machine for seeding and fertilizer application on a large diversity of land configurations, with wheels for controlling the seeding depth, which in our case was of 4 cm. Planting dates were: 10.17.2007, 10.17.2008, 10.12.2009, and harvest dates: 07.20.2008, 07.08.2009, 07.15.2020. Seeding rate on all plots was of 215 kg ha^{-1}. In all three years, all experiments were placed on large plots on which the same soil tillage was applied, having soybean as previous crop. Fertilizer of 12:52:0 (150 kg ha^{-1}) was applied in strips, simultaneously with planting, and the nitrogen fertilizer (90 kg N ha^{-1}) by spreading, in spring. 2.4-D herbicide (0.6 kg ha^{-1}) was sprayed before first internodes formation. Grain yield was calculated at the standard 14% moisture.

Each year, soil moisture was measured gravimetrically, at planting and harvest time, on the depth of 0-90 cm, in 30 cm layers. The soil samples were harvested with a tubular proof stick and weighed immediately and after being dried at 105ºC. For soil moisture calculation the following formula was utilized: SM(%) = [moist soil weight(g)/dry soil weight(g) – 1]*100, where SM (%) is the gravimetric moisture. Soil water content (reserve) was expressed using the formula SM (mm) = 10*H*SBD*SM(%), where H is the soil depth (m), SBD is the volumetric weight mean on the considered H (t m^{-3}).

For soil structure evaluation, samples were harvested after winter wheat harvest in 2010, with a small spade to avoid the sample compaction and disturbance and to assure a minimum wall area referred to the volume, in order to diminish the risk of compaction. After the larger clods (>5 cm) were gently smashed, the soil samples were kept two weeks at room temperature for drying. Afterwards, they were passed through an 8 mm sieve. A subsample of 200 g was sifted 1 minute, using 5 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm sieves. The amount of soil left on each sieve was weighed, and the mean weight diameter (mm) of dry sieved soil was calculated as:

$$MWDds = \sum_{i=1}^{n} X_i \times WSA_i$$

where X is the mean diameter of each size fraction (i), WSA is the proportion of total sample weight recovered in the size fraction after sieving (i) and (n) is the number of size fractions (Kemper and Chepil, 1965). Soil resistance to penetration (considered in this paper similar to con index) was measured in 2010 after winter wheat crop harvest, with a penetrometer with con (Eijkelkamp, Giesbeek, The Netherlands), having the base diameter of 15.96 mm and the top angle of 60º. The measurements were performed on each 5 cm soil layer throughout the 0-30cm depth.

Experimental plots were harvested with a Wintersteiger Delta combine (Wintersteiger AG, Ried, Austria), of 2 m work front, and the length of each harvested plot was 10 m. The grain yield components (1000 grain weight, grain weight per spike, number of grain per spike) were determined by harvesting 30 plants, chosen randomly, from each plot. Other yield characteristics, such as harvest index, number of grains per m² were also estimated.

Work time and fuel consumption were evaluated per total for all replications of each variant. Fuel consumption was estimated after each work executed on each replication and variant by completing fuel tank with a graduated cylinder.

The efficiency of the tillage systems was estimated on the basis of technical-economical parameters of the utilized equipment (Cociu, 2010) and the grain yield means obtained over the three experimental years.

Duncan multiple comparison test, at the level of P≤0.05, was used to make comparisons among variants (Steel and Torrie, 1980). Analysis of variance (ANOVA) was performed with the data of soil physical properties, winter wheat grain yield and its components.

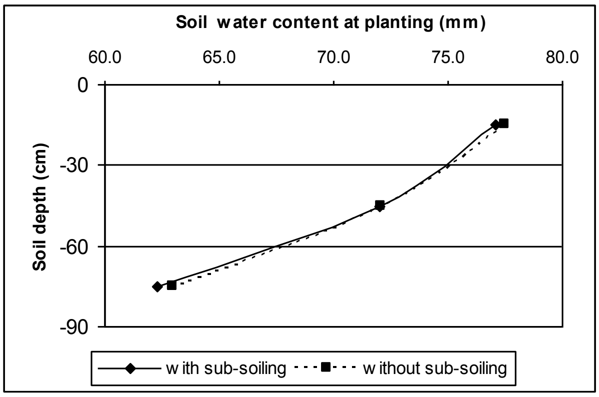
RESULTS

Influence of deep soil loosening and tillage systems on soil water content

Deep soil loosening did not influence significantly the water content of 0-90 cm soil layer, when evaluated at planting (Figure 1), and at harvest time (Figure 2).

Soil water content for sub-soiling variant at planting time was 211.4 mm, being 0.6% less than that without sub-soiling. At harvest time, soil water content for sub-soiling variant was 1.2% higher than without sub-soiling (208.0 mm).

In the three soil layers, 0-30, 30-60, 60-90 cm, water content at planting time was higher without sub-soiling than in sub-soiling variant: 77.5 mm, 72.1 mm, and 63.0 mm, comparing with 77.1 mm, 72.0 mm, and 63.3 mm, respectively, but the differences were not statistically significant. At harvest time, the differences were also not significant.

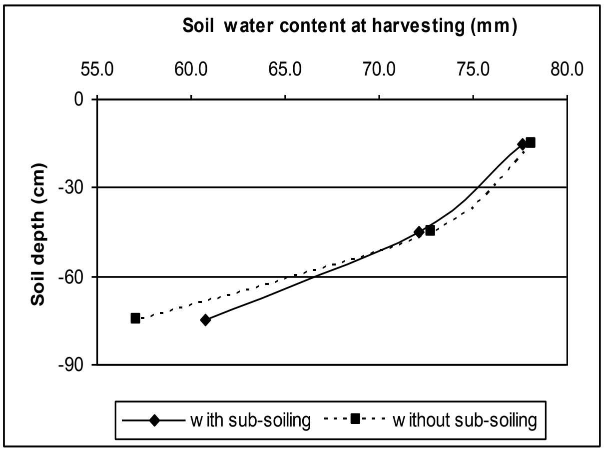


Soil depth (cm)	With sub-soiling	Without sub-soiling
0-30	77.1a	77.5a
30-60	72.0a	72.1a
60-90	62.3b	63.0a

Number followed by different letters are significantly different at P<0.05.

Figure 1. Influence of deep soil loosening and soil depth on soil water content (mm) at winter wheat planting time. Fundulea, 2008-2010

Higher values were recorded without sub-soiling, at 0-30 and 30-60 cm layers: 78.1 mm and 72.8 mm, comparing to 77.6 mm and 72.1 mm. At 60-90 cm layer, higher water content was registered for sub-soiling variant: 60.8 mm against 57.1 mm.



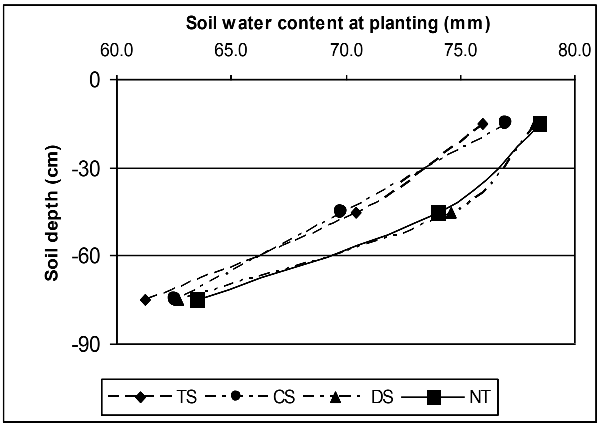
Soil depth (cm)	With sub-soiling	Without sub-soiling
0-30	77.6a	78.1a
30-60	72.1a	72.8a
60-90	60.8b	57.1c

Number followed by different letters are significantly different at P<0.05.

Figure 2. Influence of deep soil loosening and soil depth on soil water content (mm) at winter wheat harvest time. Fundulea, 2008-2010

Tillage systems had a significant influence on soil water content, considering the 3 year means, at 0-90 cm soil layer. At planting time (Figure 3), the highest values were registered for NT and DS variants, 216.1 mm and 215.6 mm, respectively, but the difference between them was not significant. Soil water contents recorded for CS and TS were significantly lower than for NT: 209.4 mm and 207.6 mm, respectively.

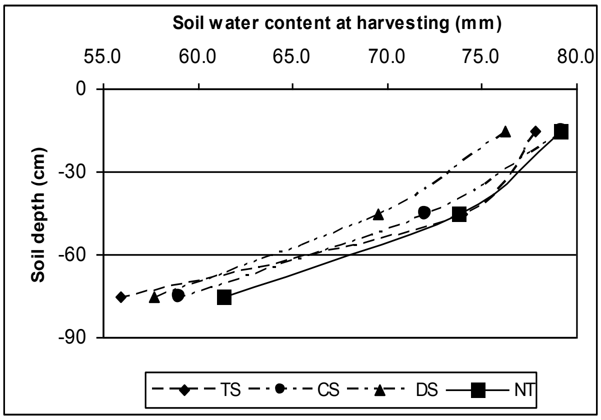
The influence of tillage systems at 0-30 cm layer was not significant, the values ranging between 76.0 mm for TS and 78.5 mm for NT. A significant influence (P<0.05) was identified at 30-60 cm layer, with 74.1 mm for DS and 74.6 mm for NT, values which are significantly higher than 69.8 mm for CS and 70.4 mm for TS. At the level of 60-90 cm layer, it looks that the tillage systems had not a significant effect on soil water content, the recorded values being between 61.2 mm for TS and 63.6 mm for NT.



Soil depth (cm)	TS	CS	DS	NT
0-30	76.0a	77.0a	78.3a	78.5a
30-60	70.4b	69.8b	74.6a	74.1a
60-90	61.2a	62.6a	62.7a	63.6a

Number followed by different letters are significantly different at P<0.05.

Figure 3. Influence of tillage system and soil depth on soil water content (mm) at winter wheat planting time. Fundulea, 2008-2010



Soil depth (cm)	TS	CS	DS	NT
0-30	77.8a	79.2a	76.2a	79.1a
30-60	74.0a	72.0abc	69.5c	73.8ab
60-90	55.9a	59.0a	57.7a	61.3a

Number followed by different letters are significantly different at P<0.05

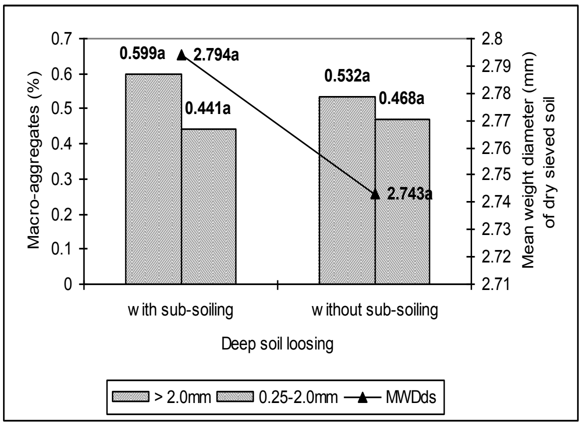
Figure 4. Influence of tillage system and soil depth on soil water content (mm) at winter wheat harvest time. Fundulea, 2008-2010

At harvest the highest soil water content values were recorded for NT and CS 212.8 mm and 210.3 mm, respectively (Figure 4). The values for TS (207.6 mm) and DS (202.3) were significantly lower than for NT. In 0-30 cm layer, soil water content was not significantly affected by tillage systems, the values ranging between 76.2 mm for DS and 79.2 mm for NT). At 30-60 cm layer, this influence was also not significant. The highest value was 74.0 mm for NT, which was not significantly different from those recorded for TS (73.8 mm) and CS (72.0 mm). The lowest value was for DS (69.5 mm), being significantly different. Considering the 60-90 cm layer, the tillage systems did not affect significantly soil water content (values ranging between 55.9 and 61.3 mm).

Influence of deep soil loosening and tillage systems on soil structure

Deep soil loosening did not influenced significantly the distribution of macro-aggregates, of >2.0 mm and of those between 0.25 and 2.0 mm, as well as the mean weight diameter of dry sieved soil (Figure 5).

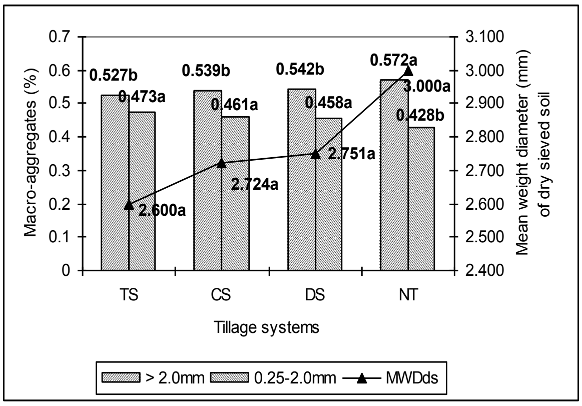
After three years from applying deep soil loosening work, the >2.0 mm macro-aggregate content was with 12.6% higher in the plots with deep loosening work than in those without deep loosening, but the 0.25-2.0 mm macro-aggregate content was with 16.7% lower in the plots with deep loosening work than in those without deep loosening. Mean weight diameter of dry sieved soil was not significantly affected by soil deep loosening, the difference being of only 1.9%.



Number followed by the same letters are not significantly different at P<0.05.

Figure 5. Influence of deep soil loosening on soil aggregates distribution and weighted mean diameter of dry sieved soil

The experimented tillage systems, influenced significantly (P<0.05) the aggregates distribution and not significantly the mean weight diameter of dry sieved soil, after three years of stationary application (Figure 6). The highest value (0.572 percentage units) of >2.0 mm macro-aggregate, recorded for NT, was significantly different from those for DS (0.542), CS (0.537), and TS (0.527). The 0.25-2.0 mm macro-aggregate content was of 0.428 percentage units for NT, significantly smaller than those registered for DS (0.458), CS (0.461), and TS (0.473). Mean weight diameter of dry sieved soil had values between 2.6 mm for TS, and 3.0 mm for NT.



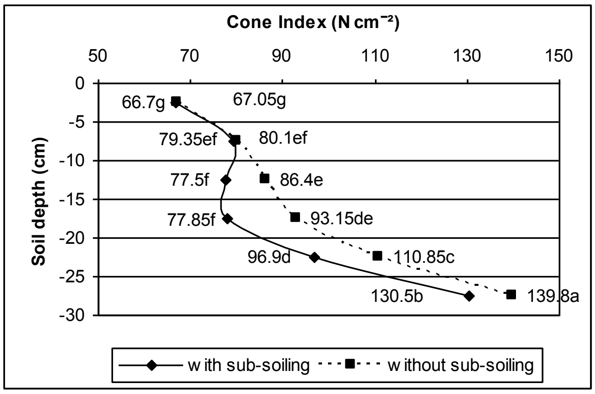
Number followed by different letters are significantly different at P<0.05.

Figure 6. Influence of tillage system on soil aggregates distribution and mean weight diameter of dry sieved soil

Influence of deep soil loosening and tillage systems on soil mechanical properties

After three years from the deep soil loosening work, soil resistance to penetration, expressed as cone index, showed to be significantly (P<0.05) influenced by this work, in the 0-30 cm layer. A higher value, of 96.2 N cm^{-2}, was recorded for non deep loosening, when compared to 88.1 N cm^{-2}, recorded for deep loosening.

Cone index value raised along with the soil depth. In 0-30 cm layer, values between 66.7 N cm^{-2} and 130.5 N cm^{-2} for deep soil loosening, and 67.05 N cm^{-2} and 139.8 N cm^{-2} for non deep soil loosening variant were registered (Figure 7).

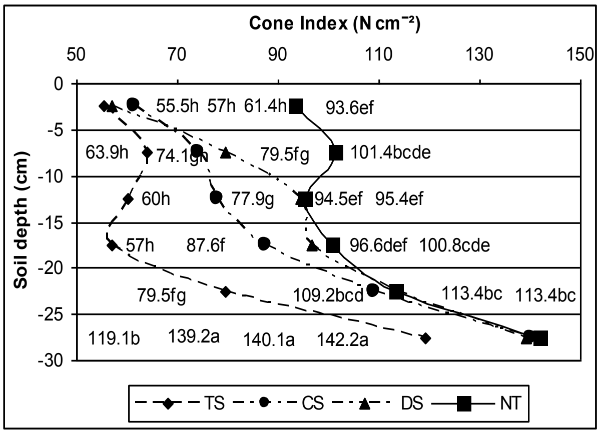


Number followed by different letters are significantly different at P<0.05.

Figure 7. Influence of deep soil loosening and soil depth on cone index (N cm^{-2})

After three years of stationary application, tillage systems affected very significantly (P<0.001) soil resistance to penetration. The highest value, of 107.8 N cm^{-2}, was recorded for NT. The values for CS (91.717 N cm^{-2}) and DS (96.700 N cm^{-2}) were smaller, but not statistically different. For TS, the value of 72.500 N cm^{-2}, was significantly lower.

The results presented in figure 8 suggest a tendency of higher cone index values for the CS, DS and NT, in comparison with TS, in 0-30 cm layer. Cone index values for NT were significantly higher (P<0.05%) than for TS in each depth layer. The cone index was significantly higher for DS in the 5-10 layer, and for CS in 10-15 cm layer. The cone index in the 25-30 cm layer was <1.2 MPa for TS, >1.2 MPa for CS, <1.4 Mpa for DS, and >1.4 Mpa for NT.



Number followed by different letters are significantly different at P<0.05.

Figure 8. Influence of tillage system and soil depth on cone index (N cm^{-2})

Influence of deep soil loosening and tillage systems on winter wheat grain yield and its components

The deep soil loosening work did not affect significantly the winter wheat grain yield. A yield of 5508 ha^{-1} was obtained applying deep loosening, with only 2% higher than without deep loosening. Data presented in table 1 show that deep loosening did not significantly influence grain yield components.

Table 1. Grain yield and yield components of winter wheat grown under different deep soil loosening treatments. Fundulea, 2008-2010

Treatment	Yield (kg ha^{-1})	Grain weight per spike (g)	Harvest index	Number of grains per spike	Number of grain per square meter	Spikes per square meter (no.)	Thousand kernels weight (g)
With sub-soiling	5508a	1.32a	0.468a	32.50a	16277a	501a	42.24a
Without sub-soiling	5393a	1.28a	0.479a	32.46a	16711a	519a	42.00a

Means within columns followed by the same letter are not significantly different at $P<0.05$.

On average for the three experimental years, the highest winter wheat grain yield (5642 kg ha^{-}) was obtained with NT, with 3.0%, 3.8% and 6.8% higher than with DS, TS, and CS, respectively (Table 2). The differences among variants were not statistically significant, but some of them look quantitatively important.

Table 2. Grain yield and yield components of winter wheat grown under different tillage treatments. Fundulea 2008-2010

Treatment	Yield (kg ha^{-1})	Grain weight per spike (g)	Harvest index	Number of grains per spike	Number of grain per square meter	Spikes per square meter (no.)	Thousand kernels weight (g)
TS	5442a	1.34a	0.481a	33.89a	16108a	479a	41.79a
CS	5282a	1.35a	0.480a	33.58a	16568a	494a	42.16a
DS	5473a	1.31a	0.477a	32.35a	15963a	494a	42.37a
NT	5642a	1.19a	0.457a	30.10a	17264a	573a	42.17a

Means within colums followed by the same letter are not significantly different at $P<0.05$.

The tillage systems did not affect significantly the yield components, but in some cases they seemed to determine important quantitative differences.

For example, Harvest index (0.481) with TS was with 0.2% higher than with CS; 0.8% higher than with DS, and 5.0% higher than with NT. Number of grains per spike was also the greatest with TS, and lower with 0.9% with CS, 4.5% with DS and 11% with NT. Number of grain per square meter had the lowest value with DS (15963), which was 1.4% lower than with TS, 3.8% lower than with CS and 8.2% lower than with NT. Spike per square meter had the lowest value with TS (479), being with 3% lower than with CS and DS, and 19.6% lower than with NT. The values of thousand kernels weight increased from 41.79 g with TS: with 0.8% with CS, 0.9% with NT, and 1.4% with DS.

Influence of tillage systems on the main technical-economic indicators of the winter wheat crop

The results presented in table 3 reveal important economic advantages of SCTS, compared to TS.

Tabelul 3. Main technical-economic parameters of the tillage systems tested for winter wheat at Fundulea, 2008-2010

Specification	Units	TS	CS	DS	NT
Labor consumption	hours/t	1.083 a	0.876 b	0.798 c	0.460 d
Fuel consumption	l/t	12.93 a	9.83 b	9.21 c	5.04 d
Expenses for mechanical work	lei/t	160.0 a	140.2 b	134.2 b	88.9 c
Net income + subsidy/ 1000 lei variabile expenses	lei	519.2 d	585.5 c	628.1 b	659.2 a
Net income + subsidy/ 1000 lei total expenses	lei	479.6 d	539.0 c	577.7 b	607.9 a
Production cost/tone	lei	359.3 a	338.5 b	328.1 bc	322.0 c

Means within rows followed by the different letters are significantly different at P<0.05.

The work time recorded for TS (1083 hours/tone) was reduced with 0.207 hours with CS, with 0,285 hours with DS and with 0,623 with NT. All differences were significant. Fuel consumption and the cost of mechanized work per tone of product were reduced significantly. The net income + subsidy per 1000 lei of variable expenses increased considerably, from 519.2 lei with TS, to 585.5 lei with CS, 628.1 lei with DS, and 659.2 lei with NT. The net income per 1000 lei total expenses increased from 479.6 lei with TS to 539.0 lei with CS, 577.7 lei with DS, and 607.9 lei with NT. All differences were significant and quantitatively important. The cost per one tone of product decreased significantly, from 359.3 lei with TS, to 322.0 lei with NT.

DISCUSSION

Deep soil loosening did not influence significantly the soil water content in the layer of 0-90cm (Figures 1 and 2). In comparison with TS, the NT variant increased significantly ($P<0.05$) soil water content, in the 0-90 cm layer, with 4% when recorded at seeding time and 2.5% at harvest. DS variant increased it with 3.8% at seeding and CS with 1.3% at harvest. These soil water content differences were mostly due to differences in the extent of infiltrated water and water runoff. NT, DS, and CS variants maintained the soybean vegetal remnants on the ground surface, preventing the water runoff and evaporation, and improving water infiltration from precipitations (Johnson et al., 1984). At seeding time, when the ground was not covered by vegetation, the water runoff was greater on the plots without vegetal remnants on surface, which resulted in lower water soil content with TS variant, in comparison with the conservative systems. Higher water content values at both seeding and harvest times were registered for NT, DS, and CS, when compared to TS (Figures 3 and 4). As a result, winter wheat crop had better water supply during the vegetative cycle with conservative tillage systems than with the traditional one.

Deep soil loosening did not influence the distribution of soil aggregates and weighted mean diameter of dry sieved soil, the differences between the values for deep loosening and non deep loosening being small and not significant (Figure 5). After three years of application of the same tillage system, the percentage of large (>2.0 mm) macro-aggregate increased significantly ($P<0.05$) with NT, in comparison with TS, and the percentage of small (0.25-2.0 mm) increased significantly with TS against NT (Figure 6). Similar results were reported by Wright and Hons (2004). The reduced soil aggregation condition in TS is a direct effect of aggregate breaking down by the active plough organs and of the impact of precipitations on the surfaces which are not protected by vegetal remnants. The percentage of large (>2.0 mm) macro-aggregate represents the most important element for the evaluation of influence of the tillage system on soil aggregation condition, because it exercises a strong influence on the mean weight diameter (MWD). This is a more comprehensive index of soil aggregation (Lichter et al., 2008). We can see that NT, with the retention of vegetal remnants on the ground surface, did improve soil aggregation comparing with ST, where the vegetal mass was incorporated within soil. This looks like of an additional advantage of NT.

Deep soil loosening affected significantly ($P<0.05$) the con index (N cm^{-2}), in 0-30 cm layer. Without deep loosening, this parameter was with 9.2% higher than with deep loosening. If in 0-10 cm layer the differences between the two variants were not significant, in 10-30 cm layer they became significant (Figure 7). The difference was mainly due to a more pronounced soil compaction in the case of no deep loosening. Cone index with TS, in 0-30 cm layer, was significantly ($P<0.05$) smaller than with CS, DS, and NT, with 21.0%, 25.0%, and 32.7%, respectively. In none of experimented tillage systems, in 0-30 cm layer, the cone index did not exceed 2.0 MPa, the value over which the root growth is considered completely inhibited. In 20-30 cm layer, the recorded cone index was over 1.0 MPa, value, over which the root growth is reduced (Taylor et al., 1966). The difference between soil resistance with NT and TS, in 0-30 cm layer, was of 0.35 MPa. Hammel (1995) concluded that soil resistance in 5-25 cm layer, with NT variant was with 1.0 MPa higher than with TS, regardless the crop rotation. Greater soil penetration resistance realized with NT than with other tillage systems, especially conservative ones, were also reported in other previous studies (Hill, 1990; Busscher and Sojka, 1987).

Deep soil loosening did not significantly influence the winter wheat grain yield and any of its components under this study (Table 1). The mean yields over three years obtained with NT and DS were higher than that recorded for TS (Table 2). Even if this difference was not significant, it was quite important quantitatively. These results agree with those reported by Tessier et al. (1990). The grain yield differences correlated positively with the differences registered for the yield components, as the number of spikes per square meter; and thousand kernels weight. A possible explanation may be that NT assures a better plant growth, by facilitating greater soil water storage, and stimulates a faster root development towards the deeper water reserve, due to a spongier (macro-pore) condition facilitating the penetration.

Table 3 shows that the highest output was obtained with NT. The specific consumptions of mechanized work and fuel were most reduced with NT; for mechanized work with 57.5% less than with TS, with 47.5% less than with CS and with 45.3% less than with DS. For fuel this reduction was of: 61.0%, 48.7%, and 45.3%, respectively. The differences among treatments were statistically significant ($P<0.05$). The expenses of mechanical work with NT variant were significantly reduced when compared to the other tillage systems, between 33.8% and 44.4%. Net income + subsidy per 1000 lei of variable expenses and net income + subsidy/1000 lei total expenses were significantly higher with NT variant than with the other tillage systems, with 5.0% to 27.0% and 5.2% to 26.8%, respectively. Production cost per one tone of product was also less, with 1.9% - 10.4%.

CONCLUSIONS

This research makes evident that the periodical deep soil loosing influences significantly soil resistance to penetration, by decreasing its compactness. The experimented tillage systems affected significantly soil water content, soil structural condition, soil resistance to penetration, and the economical efficiency of winter wheat crop in a continental climate, which is characterized by frequent drought during grain formation period. So, no till (NT) system, which assumes the maintenance of vegetal remnants on ground surface, corresponds better to this type of environment than the traditional system (TS), with which the previous crop remnants are incorporated into soil. This study shows clearly that, for winter wheat, NT assures higher and more efficient grain yield than TS. Consequently, this tillage system is recommended to be adopted in the Southern zone of Romania. Requiring lower inputs, this system should be also considered one of the means for mitigating the effects of global warming.

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