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Effect of Traditional, Reduced and Zero-Tillage for Winter Wheat on Soil Physical Properties

E.A. CZYŻ[1,2,3], A. R. DEXTER[1,3,4]
[1]Department of Soil Science, Erosion and Land Conservation, Institute of Soil Science and Plant Cultivation - National Research Institute (IUNG-PIB), ul. Czartoryskich 8, 24-100 Puławy, Poland
ewac@iung.pulawy.pl
[2] University of Rzeszów, Faculty of Biology and Agriculture, Aleja Rejtana 16c, 35-959 Rzeszów, Poland
[3] Unité de Science du Sol, INRA Orléans, Ardon, 45160 Olivet, France
[4] Le Studium Institute of Advanced Studies, 45071 Orléans, France

Abstract: The aim of this research was to determine the effects of different tillage systems on the soil physical properties: bulk density, water content, stability and soil physical quality. Analyses were performed on long-term field experiment on a farm in Rogów, Poland on a silt soil (5% clay, 81% silt, 14% sand and 1.56% organic matter). Winter wheat was grown in three systems: 1) traditional tillage (TT) with straw incorporation based on mouldboard ploughing (to 25 cm depth) and traditional soil management equipment, 2) reduced tillage (RT) with surface mulching based on soil crushing-loosening equipment and a rigid-tine cultivator (to 10 cm depth), and 3) zero-tillage (NT) with surface mulching and direct sowing. Soil physical properties were measured on samples collected from the field throughout the growing season. These included: particle size distribution, soil water content and bulk density. Soil stability was measured in terms of the content of readily-dispersible clay (RDC) in the soil samples. From water retention curves, an index of soil physical quality (*S index*) was calculated.
The effect of the tillage systems on the values of the physical properties was significant. RT and NT increased water content and bulk density in the top layer in comparison with TT. RT and NT reduced the amount of RDC and therefore increased soil stability, especially in the top layer in comparison with TT. RT and NT decreased the *S index* after the first year in comparison with TT. After 6 years, the RT and NT plots showed some improvement in soil stability.
Key words: Tillage: traditional, reduced and zero-tillage systems, Soil water content, Soil bulk density, Soil stability in water, Readily-dispersible clay *(RDC),* Soil physical quality (*S index*).

INTRODUCTION

In Poland and other countries, there is growing interest in developing systems of reduced tillage with mulching (conservation tillage) as an alternative technology to traditional tillage to protect the environment whilst producing good conditions for plant growth. Conservation tillage protects the sub-soil against compaction and erosion by water. It can reduce run-off throughout the year (Dexter et al, 2004) reduce evaporative losses and can increase infiltration and can also increase the stability of the soil through increased organic matter content and increased biological activity. Reduced tillage has effects on soil physical properties: bulk density, water content, soil stability (Czyż et al., 2008; Gaţe et al., 2005; Gaţe et al., 2006a; Gaţe et al., 2006b) and soil physical quality (Dexter, 2004). We are looking for soil physical conditions that give good plant production whilst at the same time protecting the environment. The aim of the research was to compare three different tillage systems (traditional, reduced and no-tillage systems) on some soil physical properties.

MATERIALS and METHODS

2.1. Soils and treatments

Field experiments were done in 2003-2008 on a private farm at Rogów, in the Lubelskie voivodeship of Poland (Latitude = 50° 48′N, Longitude = 23° 29′E, elevation = 230 m a.s.l.) on a silt loam soil that had been formed on loess, 60 km east from Lublin.

A long-term field experiment with three tillage treatments was established in the autumn of 2002 (Czyż and Dexter, 2008). The soil is a silty loam formed on loess, which is typical in this region and considered to be sensitive to erosion and compaction. The annual precipitation is 585 mm on average with 365 mm within the growing season.

Winter wheat was grown in three systems: 1) traditional tillage (TT) with straw incorporation (chopped wheat straw) based on mouldboard plough (with depth 25 cm) and traditional soil management equipment, 2) reduced tillage (RT) with surface mulching based on soil crushing-loosening equipment and a rigid-tine cultivator (to 10 cm depth), and 3) zero-tillage (NT) with surface mulching and direct sowing. Soil physical properties were measured on samples collected from the field throughout the growing season.

The soil was tilled in October 2002 and sampled four times in the vegetation period of each of the years 2003-2008. Winter wheat was sown in October and harvested in August. The long-term tillage experiment was set up in 2002 on 1 ha experimental plots with three replicates.

2.2 Soil physical analyses

Particle size distribution and organic matter measurements

The particle size distributions of the soils studied were determined by Casagrande's aerometric method modified by Prószyński (Lityński et al., 1976). The organic matter content of the soils was measured by wet oxidation by the Tiurin method (Ostrowska et al., 1991). Maps of organic matter content (%) and clay content (%) of the arable layer (calculated using the correlation gridding method) at 2003 at Rogów are shown in Figs 1 and 2.

From each tillage treatment at the farm Rogów, undisturbed soil cores of 100 cm^3 volume were collected at times (August and October) in 2003, 2004, 2005, and 2008. In the case of the Rogów soil, samples were taken from the 0-5, 5-10, 10-15, 20-25, 30-35 cm layers in 4 replicates, representing the cultivated layer, the pan and the non-tilled layers, respectively.

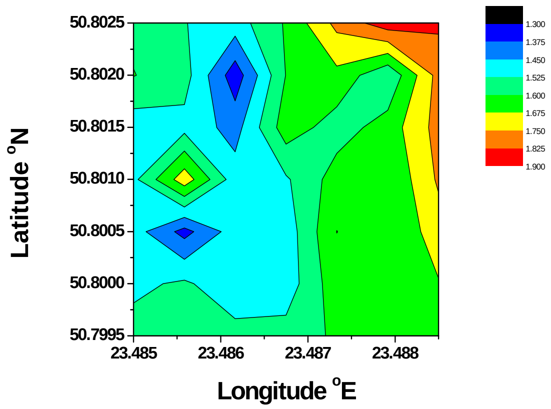

Fig. 1. Map of organic matter content (%) of the arable layer (calculated using the correlation gridding method) at 2003 at Rogów.

Soil bulk density (ρ) and water content (w) by oven-drying

Soil water content and bulk density were measured using 100 cm^3 cylinder samples (after drying at 105ºC for 24 hours). For the above, four replicates were collected from each of the following depths: 0-5, 5-10, 10-15, 20-25 and 30-35 cm.

The water contents were measured gravimetrically by drying the samples at 105 °C until no changes in their weight were observed. Bulk density was calculated from dry soil weights (105 °C, 48h) and the volume of undisturbed samples.

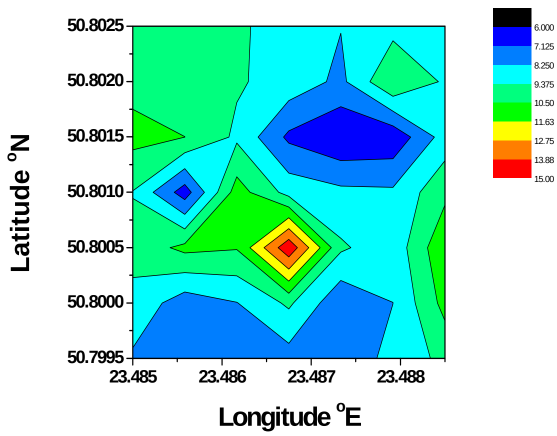

Fig. 2. Map of clay content (%) of the arable layer (calculated using the correlation gridding method) at 2003 at Rogów

For determination of dry bulk density, ρ (Mg m^{-3}), and soil water content volumetrically, θ (%, m^3 m^{-3} or %,vol.), and gravimetrically, w (kg kg^{-1}), soil samples collected from the field were used. The soil samples were collected from soil pits which were dug in the field under different treatments at Rogów. For the above, four replicates were collected from each of the following depths: 0-5, 5-10, 10-15, 20-25, 30-35 cm. The depth of sampling was selected to coincide with the depths of layers corresponding with the different tillage practices. Undisturbed soil cores were taken by pushing stainless steel cylinders of 100 mL vertically into the soil using a hammer, and for each layer and location 4 replications were sampled. The cylinders were then closed with stainless steel end caps and were placed in polythene bags to prevent water loss. Dry bulk density and water content of the soils were measured in the laboratory by weighing the soil samples before and after drying at 105°C in the oven for 48 hours. The determinations were done immediately after returning from the field so that further water loss was avoided. The soil water content values were then calculated firstly as % volume using the following equation:

$$\theta = \frac{(\mathrm{mw} + \mathrm{t}) - (\mathrm{md} + \mathrm{t})}{100} \quad (1)$$

where: θ = volumetric water content (vol. %),

m_w = wet soil mass (g),

m_d = dry soil mass (g), and

t = tare of cylinder (g).

Note that Eq. (1) assumes that the density of water, ρ_w = 1.00 g mL^{-1}.

Then dry bulk density (ρ) was calculated using the following equation:

$$\rho = \frac{m_d}{100} \quad (2)$$

where: ρ is dry bulk density (Mg m^{-3}), and the other terms are as described above.

Gravimetric water content (w) of the soils was then calculated as:

$$w = \left(\frac{\rho_w}{\rho}\right)\frac{\theta}{100} \quad (3)$$

where: w is the gravimetric water content of the soils (kg kg^{-1}), and the other terms are as described above.

2.3 Determination of soil stability

Soil stability was measured by a turbidimetric method using samples from 5-10, 15-20 and 30-35 cm depths. Soil stability was measured in terms of the content of readily-dispersible clay (RDC) in the soil samples. The turbidimeter was a Hach model 2100AN as described in Czyż and Dexter (2008). The method used for determination of readily-dispersible clay, RDC (NTU/(g $L)^{-1}$) and RDC (g (100g $soil)^{-1}$), is that described by Czyż et al., (2002); Dexter and Czyż (2000), and is rather similar to that described by Kay and Dexter (1990); Watts and Dexter (1997) and but was adapted for Polish sandy soils.

Turbidity values are linearly proportional to the concentration of colloids (clay) in suspension (Dexter and Czyż, 2000). The turbidimeter readings were expressed as NTU (Nephelometric Turbidity Units) and were normalized by dividing by the concentration of the original soil in the water to give NTU/(g L^{-1}). The mass of soil was corrected to dry mass for this calculation. Ten replicates were used for each tillage system and depth at each place.

We also considered the proportions of the soil clay content that are readily dispersible. We did this by using high energy inputs (30 mins of intense stirring) to disperse all the clay followed by 18 hours of sedimentation and measurement of turbidity (as described above) to obtain the normalized turbidity, T (NTU/(gL^{-1})), due to the total clay. We then calculated a factor, K, as follows:

$$K = \left[\frac{C}{T}\right] \quad (4)$$

where C is the total clay content (%) as measured in the particle size analysis. K is a calibration factor that relates turbidity measurements to amounts of clay in suspension. K may be expected to be different for different soils because of differences in clay mineralogy (Czyż and Dexter, 2008).

2.4 Determination of S values

For estimation S values – soil physical quality, we measured water retention on undisturbed cylinder samples. Cylinder samples were wetted from below to saturation and then drained to water suctions, h, of 10, 20, 40, 80, 250 hPa. For suctions of 500, 1000, 2000, 4000, 8000 and 15000 hPa. The measurements were made on crumbled soil fragments. The water contents, θ, were measured gravimetrically. The mean water contents for every value of suction were then fitted to the van Genuchten (1980) equation using RETC (van Genuchten et al., 1991). The Mualem restriction, assuming the relationship m = 1–(1/n) between the van Genuchten parameters n and m was applied.

From the fitted van Genuchten equation, we calculated the water content at the inflection point, θ_{INFL}, as (Dexter and Bird, 2001)

$$\theta_{INFL} = (\theta_{sat} - \theta_{res})\left[1 + \frac{1}{m}\right]^{-m} + \theta_{res} \qquad (5)$$

where θ_{sat} and θ_{res} are the gravimetric water content at saturation and the residual water content, respectively, and m is a shape parameter. θ_{INFL}, can be used as an estimate of the optimum soil water content for tillage.

The slope of the water retention curves at the inflection point, S, was calculated according to Dexter (2004a)

$$S = -n(\theta_{sat} - \theta_{res})\left[1 + \frac{1}{m}\right]^{-(1+m)} \qquad (6)$$

where m and n are shape parameters.

The S values were compared between the different tillage systems. The relationship between S and soil bulk density is significant. As shown by Dexter (2006), values of S can be used to predict a range of other properties including: hydraulic conductivity, clod production during tillage, soil strength and root growth. S is also related to the stability of soil in water as measured by the content of readily-dispersible clay (Gaţe, et al., 2006).

The examples presented above show that the S index is a useful addition to the range of approaches available to soil and tillage scientists. Use of the S index enables us to identify soil management practices for sustainable agriculture and for environmental protection.

RESULTS and DISCUSSION

The effect of tillage system on soil bulk density was different in the 6 years studied. The reduced tillage system had higher soil bulk density than traditional tillage at all depths measured (Figs. 3-5). Effects of different tillage on soil bulk density after 6 years of tillage are shown in Fig. 6.

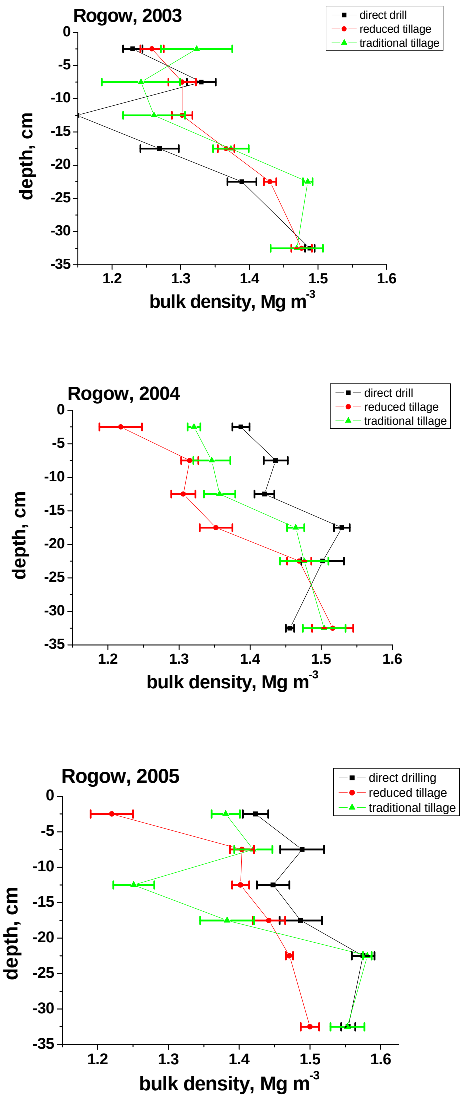

Fig. 3. Effects of different tillage systems on soil bulk density -Graph of bulk densities (error bars show ±s.e.)

The results with the soil bulk density showed similar trends to those obtained with these two soils observed in earlier research by Czyż, 2005a. In this reference, the effects of different soil tillage systems on physical properties of heavy soil in a three-year field experiment were presented. The soil physical properties (soil bulk density, water content) in the 0–25 cm layer in the three different

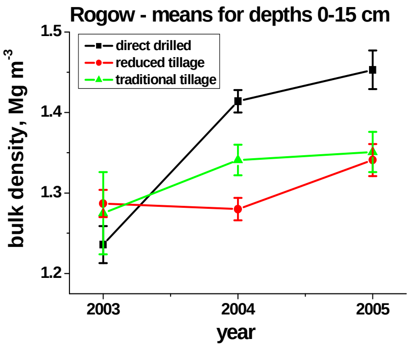

Fig.4. Effects of different tillage systems on mean soil bulk densities in the 0-15 cm layer. Graph of bulk densities (error bars show ±s.e.)

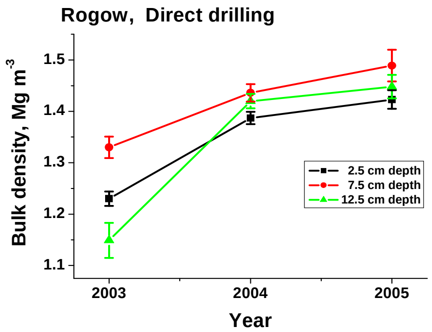

Fig. 5. Trends in bulk density on direct-drilled plot - Graph of bulk densities (error bars show ±s.e.)

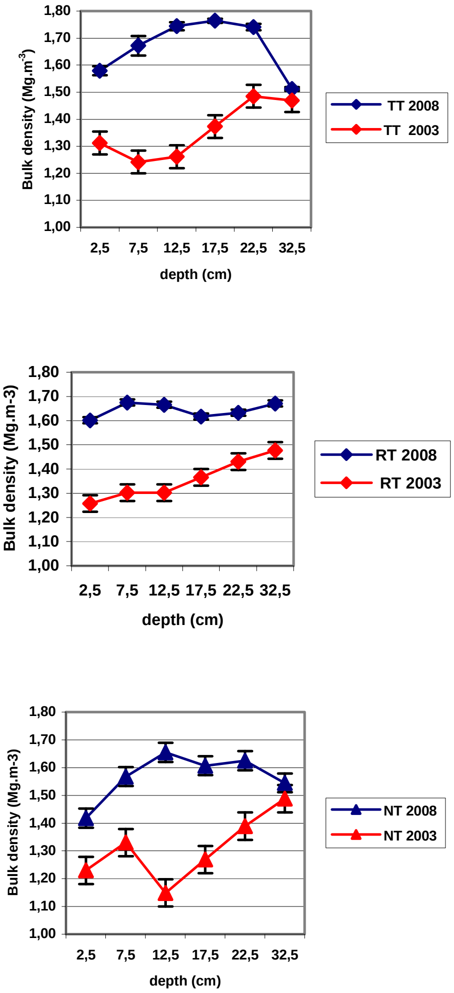

Fig. 6. Comparison of the effects of different tillage practices on soil bulk density after 6 years - Graph of bulk densities (error bars show ±s.e.)

tillage systems: traditional (ploughing), reduced tillage and direct sowing. The value of soil bulk density, mean of three years, was highest with direct drilling (1.58 Mg.m^{-3}), lower with reduced tillage (1.39 Mg.m^{-3}), and the lowest with conventional (ploughing) tillage (1.24 Mg.m^{-3}). Pranagal et al., 2005. presented results after 7 years of use of different tillage systems (traditional, reduced and direct drilling). Differences in bulk density were not significant with the loamy and loamy silt soils at the 0-10 cm depth. However, bulk density was greater in the 10-20 cm layer of loamy silt soils with direct drilling in comparison with traditional and reduced tillage systems.

Several authors have shown an increase in soil bulk density with reduced tillage or no- tillage system in comparison with the traditional tillage (plough) system. Some authors have shown in their experiments that such is the case with their soils (e.g. Fabrizzi et al., 2005; Moreno et al., 1997). However, some researchers have not found significant differences in bulk density between tillage treatments (Ferreras et al., 2000).

The effect of tillage system on soil water content was different in two soils studied. At Rogów, the reduced tillage system had higher soil water contents than traditional tillage at all depths measures (Fig. 7).

The results shown effects tillage systems on soil physical quality, values S at 5-10 cm depth after three years different tillage systems (Fig. 8). The relationship between the index of physical quality, S, and the content of readily-dispersible clay (Fig. 9) has been published earlier by Gaţe et al. (2004). The boundary between good and poor physical quality (S = 0.035) and between poor and very poor (S = 0.020) of the soils was suggested by Dexter, 2004.- from presentation at paper Gaţe et al., 2004. Values of S that were measured on samples collected in the years 2003 and 2004 mainly followed the regression lines obtained for S values measured on samples collected in the previous year, except for the S values from Rogów that were well above the regression lines. At this location, the factor that had more significant effects on the dispersibility of clay minerals was the field water content of the soil samples. In 2003, the values of RDC were obtained on soil samples having around 0.10 kg kg^{-1} water content, whereas the values of RDC in the year 2004 were obtained on soil samples having around 0.24 kg kg^{-1} water content. Although the silt loam soils from Rogów had quite good physical condition as quantified by the S index, higher water contents at the time of collection of the soil samples led to the release of more dispersible clay in the year 2004.

Soils with high contents of readily-dispersible clay in the presence of water may experience the collapse of their structures. The importance played by water in weakening the bonds between particles that constitute the structure with the consequent loss of the inter-aggregate pores and soil homogenization has been discussed by Czyż et al. (2002). Problems associated with clay dispersion include: anaerobic soil that is unsuitable for plant root growth, reduced infiltration of water with associated risk of run-off, flooding and erosion (Dexter and Czyż, 2000). The importance of primary binding agents in stabilizing soil structure has been emphasized by Kay, 1990.

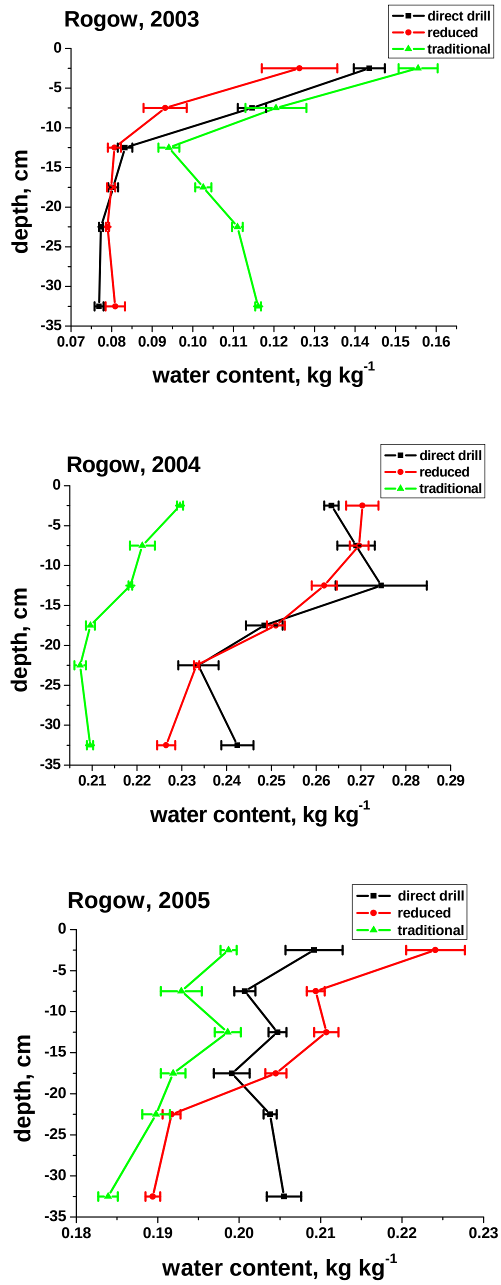

Fig.7. Effects tillage systems on soil water content - Graph of water contents (error bars show ±s.e.)

Readily-dispersible clay is also related to soil strength. A soil with a high content of readily-dispersible clay will be weaker when wet and stronger when dry than a soil with a low content of readily-dispersible clay. Reduced tillage decreased the quantity of readily-dispersible clay (RDC) and therefore increased soil stability, especially in the top layer 5 – 10 cm in both soils in comparison with traditional tillage (Czyż and Dexter, 2008).

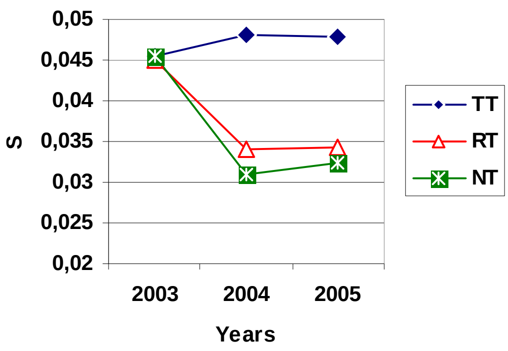

Fig. 8. Effects tillage systems on soil physical quality, values S at 5-10 cm depth after tree years different tillage systems

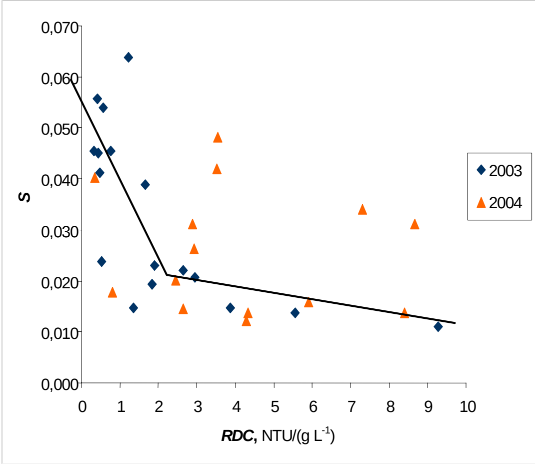

Fig. 9. Relationship between the index of physical quality, S, and the content of readily-dispersible clay (Gaţe et al., 2004).

CONCLUSIONS

On the basis of 6 years of research we concluded that:

1) reduced tillage increased water content throughout the whole soil profile,
2) reduced tillage increased bulk density in soil in the 2–8 cm depth layer in comparison with traditional tillage,
3) reduced tillage decreased readily-dispersible clay (RDC) and therefore increased soil stability, especially in the top layer in comparison with traditional tillage,
4) reduced tillage and zero-tillage decreased soil physical quality in the 0-15 cm depth in comparison with traditional tillage.

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