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THE INFLUENCE OF CONSERVATIVE TILLAGE SYSTEMS ON PHYSICO-CHEMICAL PROPERTIES AND YIELD UNDER A CAMBIC CHERNOZEM FROM NORTHEASTERN PART OF ROMANIA

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ABSTRACT

The long-term experiment was carried out during 2005-2018, with samples collected on the experimental farm of the University of Agricultural Sciences and Veterinary Medicine in the city of Iasi (47º07` N latitude, 27º30` E longitude). The soil under investigation is classified as Cambic Chernozem (WRB) with a clay-loamy texture. Initial physical characteristics of the soil on 0-20 cm depth were: bulk density 1.33 g.cm^{-3}, pH (1:2.5) 6.23, clay 364.2 g.kg^{-1}, silt 263.2 g.kg^{-1}, loam 372.6 g.kg^{-1}, humus 2.95%. In the last 5 years a continuous maize cropping system was used. The tillage treatments included: (1) No-till: direct drilling in untilled soil with a disc drill without previous removal of residues, using a FABIMAG FG01 seeder (NT); (2) a reduced system using a chisel at 22-25 cm depth, after harvest without overturning the furrow (RT); (3) moldboard ploughing after harvest to a soil depth of 28-30 cm (CT). The crumbled and loosened soil was turned over and thereby residues were fully incorporated into the soil. After the harvest of pre-crop, stubble breaking (disking to the depth 10 cm) was used. Seedbed preparation was applied using a compactor after chisel and conventional tillage. In spring the weeds were suppressed by total herbicides before seeding. Crop-specific fertilization was performed according to good agricultural practice. Combine harvest was performed in October (between 5th and 28th) using a Wintersteiger Delta Plot Combine. Tillage systems affected soil penetration resistance (PR) under maize crop only for certain soil depths. At 0-5 cm depth, the highest value (0.78 MPa) was recorded on no-till system, whilst in the case of the other two variants the values ranged from 0.56 to 0.61 MPa. In CT variant at 30-40 cm, we noticed a compacted layer (2.54 MPa) indicating the existence of hardpan.

Keywords: conservative agriculture, no-tillage, soil physical properties.

INTRODUCTION

Soil tillage can change the chemical, physical, and biological properties of the soil, whereby plant, development and yield are influenced. Using conservative tillage systems as a substitute for plow-based methods of seedbed preparation, may provide a sustainable way for using soil resources. Choosing the proper tillage system for conserving the soil humidity is important in increasing yields and reducing the consequences of drought events which are going to become more frequent. Soil tillage is an important agricultural activity because of its impact on crop production and soil properties (Chatterjee et al, 2009; Chivenge et al., 2007). In the last decades, all over the world, the tillage systems for soil conservation have been extended on a large scale, being an attractive alternative to the conventional practices (Smart et al, 1999; Bran et al., 2008). Extreme climatic events like drought are becoming common and have more impact in rain-fed agriculture. Farmers respond to such events by adopting drought mitigations strategies (Fleury et al., 2010). Research on the yields obtained in different tillage systems are contradictory. While some have found that no-till and reduced tillage provide higher yield compared with the conventional tillage (Francis et al., 1987; Hodgson et al., 1989; Lal et al., 1989; Aslam et al., 1999) others contradict the previous

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assertion (O'Sullivan et al.; 1982; Beyaert et al., 2002; Dam et al., 2005).

MATERIAL AND METHODS

The long-term experiment was carried out during 2005-2018, with samples collected on the experimental farm of the University of Agricultural Sciences and Veterinary Medicine in the city of Iasi (47º07` N latitude, 27º30` E longitude), but this paper will cover only the 2016-2018 agricultural years. The soil under investigation is classified as Cambic Chernozem (WRB) with a clay-loamy texture.

The soil texture was analyzed using pipette method. Initial physical characteristics of the soil on 0-20 cm depth were: bulk density 1.33 $g.cm^{-3}$, pH (1:2.5) 6.23, clay 364.2 $g.kg^{-1}$, silt 263.2 $g.kg^{-1}$, loam 372.6 $g.kg^{-1}$, humus 2.95%.

This work was divided in two chapters. In the first chapter the objective was to evaluate some physical parameters of Cambic Chernozem submitted to different tillage practices. The second chapter aimed to study the impact of tillage on maize yield *(Zea mays* L.). In the last 5 years a continuous maize cropping system was used. The tillage treatments included: (1) No-till (NT): direct drilling in untilled soil with a disc drill without previous removal of residues, using a FABIMAG FG01 seeder (NT); (2) a reduced system using a chisel at 22-25 cm depth, after harvest without overturning the furrow (RT); (3) moldboard ploughing after harvest to a soil depth of 28-30 cm (CT). In conservative variants (V_1 and V_2), the previous maize crop residue, so called secondary product, was threshed and uniformly spread during its harvest on plots.

The experimental area has an annual average temperature of 9.4ºC and precipitations of 587 mm. The experiment was a "split plot" design with three replicates. Soil bulk density was determined on an oven-dry basis by the core method (Blake and Hartge, 1986). For determination of the bulk density core samples were collected from layers of 0-10 cm, 10-20 cm and 20-30 cm, right couple of day before maize harvesting.

The penetration resistance of the soils was determined using a digital penetrologger (Eijkelkamp Equipment, Model 0615-01 Eijkelkamp, Giesbeek, The Netherlands) which had a cone angle of 30º and a base area of 1 cm^2. It was carefully inserted into the soil profiles in 1 cm increments from the surface to a depth of 50 cm by the same person following a rain event that satisfied the field capacity of the soils and avoiding wheel tracks. 10 parallel records were made in each plot and averaged for statistical analysis. Cone index data were digitized into the computer at 5 cm-depth intervals.

For water stable aggregates (WSA), the procedure of Kemper and Rosenau (1986) was used. Soil samples were taken randomly from different places of the selected field. Four grams of 1-2 mm air-dried aggregates were placed into sieves and wetted with enough distilled water to cover soil when the sieve was at the bottom of its stroke.

The sieves were allowed to raise and low 1.3 cm, 35 times/min for 3 min (Eijkelkamp - Wet Sieving Apparatus). The remained material (stable aggregates) in the sieve was dispersed with 2 g/l NaOH. The wet aggregation was calculated as the ratio of stable aggregates weight to total sample weight corrected for sand (USDA, 1998). All analyses were done in three replications. Dynamics of precipitation and air temperature during the growth period of maize from 2016 to 2018 are presented in Figure 1 and 2.

Meteorological data to calculate monthly rainfall and mean temperature were obtained from the local meteorological station.

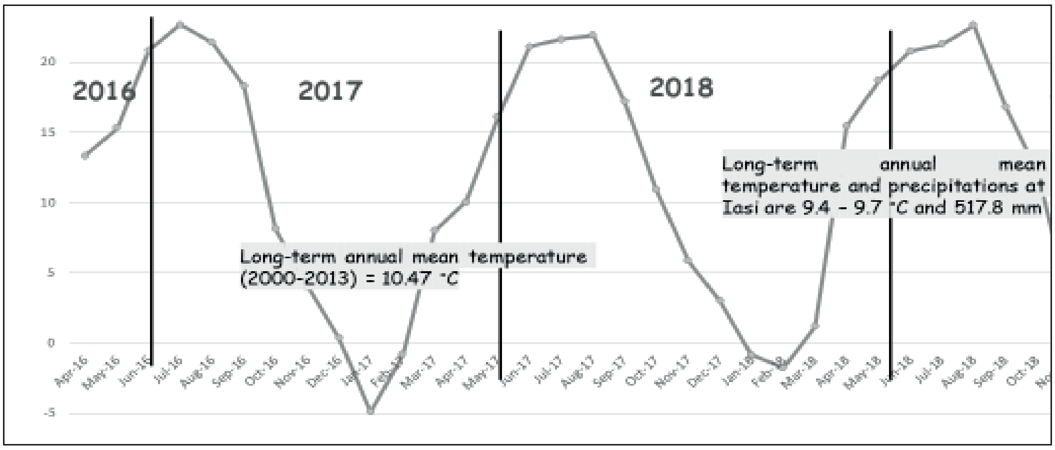

Figure 1. Climatic pattern during the study period - Air temperature at the Experimental site (average 2016-2018)

The experimental site received a total rainfall between 587.2 mm and 751.8 mm during 2018 and 2017, respectively (Figure 2).

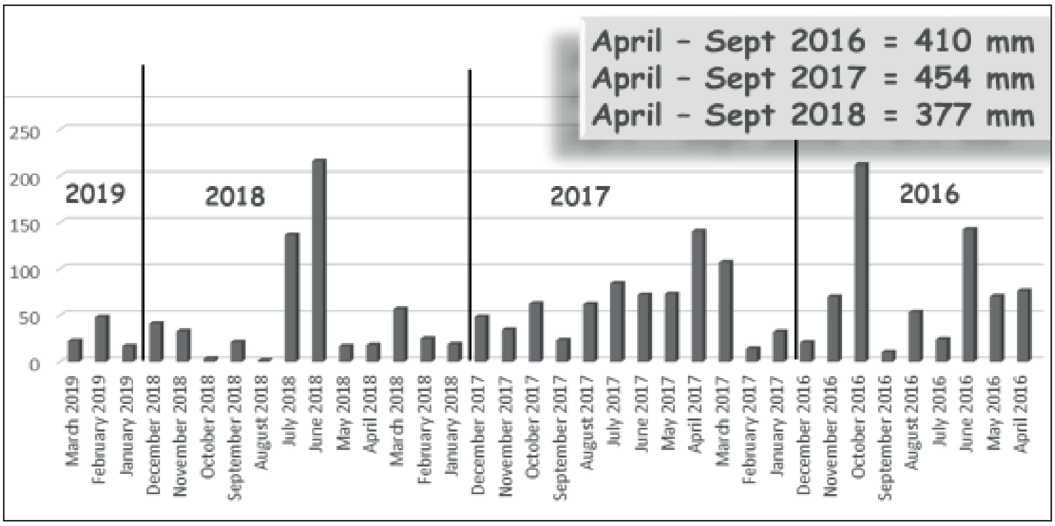

Figure 2. Climatic pattern during the study period - Rainfall distribution 2016-2018

Although there was poor rain during the time of sowing in April - May 2018, there was an increase afterwards as the cropping season progressed.

Soil water permeability is the property of the soil pore system allowing fluid to flow through. The Hauben water permeameter apparatus is a laboratory test method for establishing the coefficient of permeability or hydrologic conductance of water (vertically) through an undisturbed water-saturated soil sample. Soil moisture was determinate by gravimetric method.

Maize (P9241 hybrid) was sown between 20 April - 4 May, for a target population of 7 plants m^{-2}, drilled in 70 cm-spaced rows, with a 4.2 m-wide Fabimag FG-01 No-till Planter pulled by a Valtra 200 HP tractor and with a SPC 6 for conventional variants.

For maize yield, combine harvest was performed in October (between 5th and 28th) using a Wintersteiger Delta Plot Combine (Austria). Grain yield was adjusted to the constant moisture of 15 %.

The ANOVA procedure was used to evaluate the significance for the split plot design in three replicates. Treatment means were separated by the least significance difference (LSD) test and all significant differences were reported at 5%, 1% and

0.1% levels to find out differences among individual treatments.

RESULTS AND DISCUSSION

The aim of this study was to evaluate the influence of conventional and conservative tillage systems on maize yield and soil physical properties in the pedoclimatic conditions of the Moldavian Plain. One of the main objectives for the soil tillage system was to create an optimal physicochemical state of the soil and to preserve this state over the whole vegetation time.

The soil of the experimental site is a clay-loam Cambic Chernozem with soil humus content of 2.95% and pH of 6.23 in 0-18 cm. The initial characteristics of the soil used in this study are presented in Table 1.

Table 1. Chemical and physical properties of selected soil

Chemical properties / Depth (cm)	pH	Humus (%)	Nt (%)	P_{AL} (mg/kg)	K_{AL} (mg/kg)
0-18	6.23	2.95	0.181	64	178
18-30	6.35	2.83	0.166	59	182
30-43	6.75	2.66	0.145	13	182
43-67	6.97	1.83	0.104	14	174
67-88	7.23	1.18	0.082	20	162
88-105	8.39	0.83	0.062	1	134
105-130	8.60	0.59	0.050	0.3	120

Table 2. The influence of tillage on soil chemical properties (2016)

Treatment	Depth	pH	Humus (%)	Nt (%)	P_{AL} ($mg.kg^{-1}$)	K_{AL} ($mg.kg^{-1}$)
No-till	0-10 cm	6.10	3.96	0.235	68	306
	10-20 cm	7.00	3.60	0.198	19	191
Chisel	0-10 cm	6.54	3.54	0.209	65	218
	10-20 cm	6.68	3.30	0.169	24	193
Plough 30 cm	0-10 cm	7.00	3.24	0.171	16	203
	10-20 cm	7.01	3.12	0.163	15	200

The soil water dynamics is presented in Figure 3, 4, 5. Soil moisture (SM) is a basic requirement for plant growth and development. Traditional methods of measuring soil humidity, including the gravimetric method by drying and weighing soil samples, provide a measurement of the collected sample and can generate accurate point measurements, but they are local measurements.

The production of maize and economic income in farms depends mostly on the rainfall and the distribution of rainfall during the growing season.

Among the tillage treatments, no-till had the highest water content at the soil surface (Figure 3), mulching improving the soil humidity. In contrast, in plots with plough at 30 cm treatment, at the same soil depth, the water content was minimum (Figure 5). This was mostly due to the lowest temperature in no-till during the vegetation period on the surface of the soil influenced by the straw-mulching regime. At the maturity stage, in June, soil water storage increased in all three treatments.

Water content differences among dates of measurement depended on how thoroughly each rain wetted the profile.

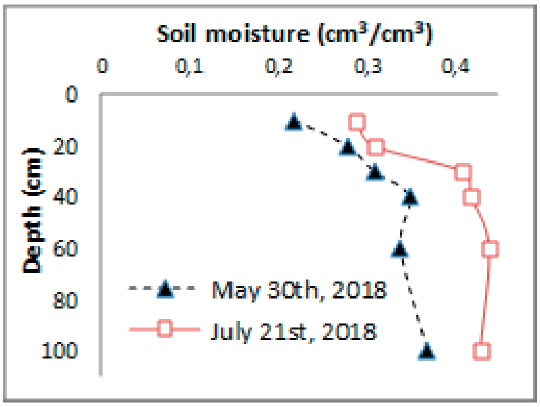

Figure 3. Dynamics of soil water content under No-tillage

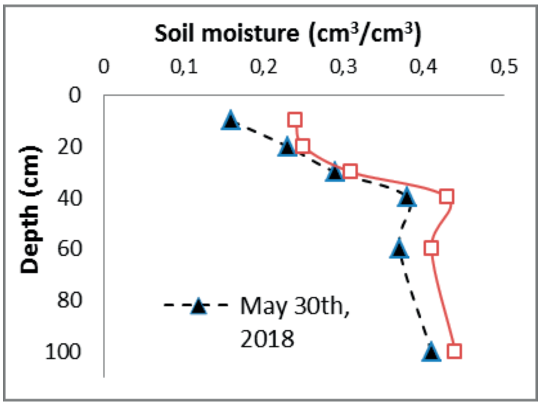

Figure 4. Dynamics of soil water content under Chisel

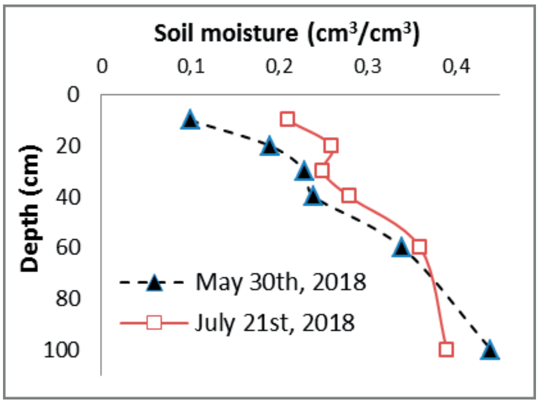

Figure 5. Dynamics of soil water content under Plough 30 cm

Table 3. Bulk Density (g.cm^{-3})

System	Depth (cm)	Year		
		2016	**2017**	**2018**
No-till	0-10	1.36	1.39	1.30
	10-20	1.52	1.54	1.47
	20-30	1.55	1.57	1.49
	Mean	**1.48 x**	**1.50 x**	**1.42 o**
Chisel	0-10	1.30	1.31	1.28
	10-20	1.39	1.41	1.38
	20-30	1.46	1.48	1.47
	Mean	**1.38 ns**	**1.40 ns**	**1.38 oo**
Plough 30 cm (control)	0-10	1.33	1.36	1.35
	10-20	1.45	1.44	1.52
	20-30	1.44	1.48	1.55
	Mean	**1.41**	**1.43**	**1.47**
	LSD 5% =	0.06	0.05	0.05
	LSD 1% =	0.10	0.08	0.09
	LSD 0.1% =	0.19	15.1	0.16

Analyzing soil bulk density (BD) in maize (*Zea mays* L.), in 2016 this indicator had the lowest value on V_2 – Chisel, at 0-10 cm depth (1.30 $g.cm^{-3}$).

The values increased on 10-20 cm layers, on all treatments, recording the greatest intensity in the No-till variant (1.52 $g.cm^{-3}$). Analyzing the 20-30 cm layers we observed that the highest values were provided also by V_3 – No-till (1.55 $g.cm^{-3}$) (Table 3). In 2018 the average values on 0-30 cm were lower in both no-till and chisel compared with V_3 – the control treatment.

Results showed larger densities in the approximate depth of 0-10 cm in 2018, in plough at 30 cm variant; the root evaluation, even visually, it is a good indicative of the soil physical condition and the bulk density and penetration resistance, if appraised with moisture near field capacity, and are good indicators of the soil suitability for plant development.

Carman (1997) found that bulk density was higher in moldboard plow followed by disc harrow twice than stubble cultivator followed by a disc harrow in 0-10 cm soil depth.

Most of the soil compaction in intensive agriculture is caused by external load on soil from farm machinery or livestock. This causes considerable damage to the structure of the tilled soil and the subsoil, and consequently to crop production, soil workability and the environment (Defossez and Richard, 2002).

Penetrometer resistance is widely measured because it provides an easy and rapid method of assessing soil strength. The penetration resistance (Pr) of the soil varied with the method of tillage operations. Pr in the soil for all the three tillage treatments increased with depth and from sowing to harvesting. Several researchers have reported that Pr is reduced in conventional tillage compared to reduced tillage (Sidiras et al., 2000).

The penetration resistance of the soil varied significantly with the method of tillage operations. Under maize, soil penetration across years was generally affected by tillage intensity. Penetration resistance was significantly lower in the 0-30 cm depths under Plough and Chisel than NT, coinciding with the tilled depth (about 25-30 cm). Tillage created a loose soil structure in the affected soil depth. Consequently, these lower values of PR were observed only in the tilled zone.

Detailed analysis for each year showed some significant differences: e.g. for the year 2018 penetration resistance in 30-50 cm depth was higher at CT than at NT. Below 35 cm no differences were found between RD and NT.

Penetration resistance under NT showed a uniform distribution in depth; however, under CT it increased considerably under 30 cm.

However, Ehlers et al. (1983) observed that despite having greater PR and bulk density values under NT, plant roots can grow within bio-pores and cracks in the soil. This seems to be the case at our site, where differences between maize yield under NT compared with CT where not very high.

The soils' saturated hydraulic conductivity in 0-10 cm (Table 4) was highest under NT (a mean of 2.4 x 10^{-2} cm/s) and lowest under CT (1.9 x 10^{-2} cm/s).

Macropore proportion is generally a small fraction of the total soil volume, but its contribution to soil hydraulic conductivity is extremely high. Macropores crated by earthworms and plant roots decomposed can be preserved under no-till soil, while conventional tillage tends to destroy the continuity of macropores in the topsoil thereby reducing movement of water from the soil surface to the macropores (Green et al., 2003).

Table 4. Effects of tillage on Hydraulic Conductivity (Ks) - September 2017

Treatment / Depth (cm)	No-till Ks (cm/s)	Plough at 30 cm Ks (cm/s)
0-10	2.4 x 10^{-2}	1.9x 10^{-2}
10-20	0.9 x 10^{-2}	5.4 x 10^{-2}
20-30	2.0 x 10^{-3}	6.1 x 10^{-2}

Aggregate stability was only measured on a smaller soil fraction as this particle size is usually responsible for sealing the soil. By studying soil aggregate stability, it is possible to quantify whether a certain tillage system is ameliorating the soil properties and the land capability for agriculture. A good soil structure is essential in fertility increment and plant growth. The tillage systems significantly affected the WSA in all three years. As expected, the no-till system caused the greatest proportion of water stable aggregates. The highest values were obtained under NT system, in 2016, 2017 and also in 2018 (Figure 6).

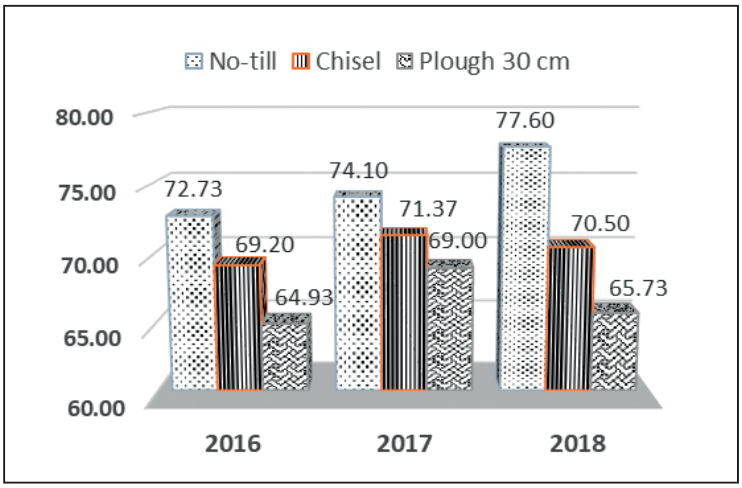

Figure 6. Water stable aggregates (0-30 cm)

Annual maize yield averages varied between 6810 kg. ha^{-1} and 7885 kg. ha^{-1} in 2016, between 7207 kg. ha^{-1} and 8108 kg. ha^{-1} in 2017 and between 6614 kg. ha^{-1} and 7208 kg. ha^{-1} in 2018 (Table 5).

Table 5. Maize yield during 2016-2018

Treatment \ Year	2016 (kg. ha^{-1})	2017 (kg. ha^{-1})	2018 (kg. ha^{-1})
V_1 - No-till	6810 (oo)	7850 (ns)	6614 (o)
V_2 - Chisel	7208 (o)	7206 (oo)	7208 (ns)
V_3 - Plough 30 cm (control)	7885	8108	7020
LSD 5 % =	450.6	356.1	298.9
LSD 1 % =	747.3	590.5	495.7
LSD 0.1 % =	1395.7	1102.8	925.8

A bigger yield increase was found under plough at 30 cm treatment pattern in 2016 and 2017. The positive effect on yield production brought by deeper tillage was clear in these two years. The severe drought in April and May of 2018 resulted in poor yield of maize under CT.

CONCLUSIONS

Generally, our results confirmed the hypothesis that reduced tillage would improve physical properties of the soil.

Tillage systems significantly affected the maize yield. In the conditions of Moldavian plain, the highest yield was recorded in the control treatment, plough at 30 cm and fertilized, followed by conservation tillage - chisel. Depending on specific climatic condition of every year, the results indicated that minimum tillage using chisel plow in fall, but also no-till treatment can be considered as a substitute to conventional moldboard plowing without considerable reduction in terms of crop productivity.

When we must choose a proper tillage system, not only the immediate arguments should be considered, like the highest yield, but also the long-term view in order to ensure productivity and profitability and to be environmentally friendly and to conserve soil and water resources.

Experiments on the determination of yield are difficult to compare because of differences in each experimental period, soil types and different climatic regime. Regarding the yields, significant differences were observed in 2016 in V_1 and V_2 tillage systems, in 2017 in V_2 (chisel) and in 2018 in no-till system. These results support the fact that in maize, increasing tillage depth results in higher yields. Crops roots growth can be depressed when soil bulk density reaches 1.6 $g.cm^{-3}$ and Pr overpasses a threshold of 2.5-3.0 MPa.

These limits were generally not exceeded in our experiment, between 2016-2018. Introduction of water-conserving tillage practices are assumed to be an important adaptation measure.

Maintaining effective preservation and use of natural rainfall is the best solution to improving maize production and water use efficiency in this part of Romania. Generally, our results for maize confirmed the hypothesis that reduced tillage and no-till would improve physical soil properties.

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