Effect of Tillage Systems in Physical Properties of a Clay Loam Soil under Oats

Karen Denisse Ordoñez-Morales¹, Martin Cadena-Zapata²*, Alejandro Zermeño-Gonzalez³
Santos Campos-Magaña⁴

¹ Postgraduate student, Production Systems Engineering Program. Universidad Autónoma Agraria Antonio Narro. Calzada Antonio Narro 1923 Saltillo, Coahuila, México; mome190512@gmail.com
² Agricultural Machinery Department UAAAN Saltillo, Coahuila, Mexico; martincadenaz@gmail.com
³ Irrigation and Drainage Department UAAAN, Saltillo, Coahuila, Mexico; azermenog@hotmail.com
⁴ Agricultural Machinery Department UAAAN Saltillo, Coahuila, Mexico; camposmsg@hotmail.com

* Correspondence: martincadenaz@gmail.com; Tel.: +52-844-4110323

Received: date; Accepted: date; Published: date

Abstract: Conservation tillage contributes to preserve the soil, but to promote those practices in new areas it is necessary to generate local information to achieve the best results. The objective was to study the effect of No Tillage (NT), Vertical Tillage (VT) and Conventional Tillage (CT) in physical soil properties of a clay loam and in the yield of oats (Avena sativa L.) in a semiarid area of Mexico. From 2013 to 2016 an experiment was established in random block designs with the three tillage systems as treatments; Soil core samples were taken to calculate bulk density (Bd); total porosity (TP) was calculated from Bd and particle density; field saturated hydraulic conductivity (Ks) was measured by the auger hole method with the Guelph permeameter. Crop yield was quantified as dry matter. Results show that there were increases and decreases within a range of 1.21 g cm⁻³ to 1.39 g cm⁻³ for BD, 45% to 55%, for TP, 4.29 mm h⁻¹ to 13.61 mm h⁻¹ for Ks; there were not significant differences in those variables among the treatments at each season. The yield was significantly different only in the 2015 season for NT. Tillage systems had not significant effect in soil physical properties.

Keywords: tillage systems; bulk density; porosity; hydraulic conductivity; oats; semiarid region

1. Introduction

The inadequate practices for some crop production systems in Mexico are causing soil degradation by erosion and compaction [1]. An increase in soil density could lead to degradation by compaction; when this occurs there is a problem for agricultural productivity [2].

The soil has a crucial role in agroecosystems; among the most important functions are capture, storage and regulation of water [3]. To preserve the resources such as soil, water and biodiversity, the practices for crop production used in the agroecosystems should be oriented for resource conservation [4].

A high soil density is related to compaction [5] and therefore the decrease in porosity. Those affect the hydraulic conductivity, which is an important factor to predict the water flow and solute transport in the soil; the information in this factor is used to evaluate management alternatives of soil-water-crop [6].

The aim of tillage in crop production is to produce favorable physical conditions for seed germination and plant growth [7]. However, an intensive soil tillage could lead to degradation of soil structure, which will result in low moisture availability for plants [8].

To promote the capture and conservation of water in agricultural systems in arid and semiarid regions, the tillage conservation practices are a feasible option; those contribute to avoid soil degradation by compaction [9, 10]. A great diversity of values on soil density and hydraulic
conducted in the laboratory and in the field. From those, a great variety of results has been produced when comparing the effects of traditional tillage and conservation tillage in the physical and hydraulic properties of the soils [11, 12].

In some cases, conservation tillage effects are high bulk density values in the surface, low infiltration rates and less crop yield compared with conventional tillage [13, 14]. On the other hand, a site managed with no tillage for nine years, resulted in a decrease of the bulk density and a significant increase of infiltration capacity [15].

In other studies, bulk density increased significantly after 12 years of no tillage [16]. Soil physical properties also change strongly in one growing season; bulk density increased 15% to 20% from its initial value in a growing season of maize and the hydraulic conductivity decreased 3 to 6 times according to the soil layer and was negatively correlated to the bulk density [17]. Over a period of eleven years, bulk density in a no tillage system increased only 10% in depth of 0 to cm compared to conventional tillage [18].

Root growth is severely restricted by bulk densities in a range of 1.4 to 1.6 g cm$^{-3}$ [19]. However, this not always happens, a great root density of wheat was obtained in a compacted soil (1.5 g cm$^{-3}$) rather than in a loose soil (1.1 g cm$^{-3}$), this was due better contact between the soil and roots; also root diameter was greater in the condition of high bulk density [20]. In a different crop, the root growth of tomatoes was bigger in a clay loam soil with bulk densities of 1.5 to 1.6 g cm$^{-3}$ [21].

In relation to the hydraulic properties of the soils, it is well known that the variability of the hydraulic conductivity in space and time is not fully understood [22]. The hydraulic properties of the soils are subjects to temporal changes in response to tillage and natural factors such as rainfall, increase and decrease of biological activity, root development and cycle of drying and wetting [23].

Results in hydraulic conductivity depend on the management and spatial variability of the soil; also depends in the technique to take the data [24]. The rate of hydraulic conductivity was three times higher after subsoiling and chiseling compared to no tillage in a semiarid environment [25]. After seven years of conventional tillage and no tillage in a temperate climate, the hydraulic conductivity was from 12% to 62% lower in the no tillage treatment [26].

The conservation tillage practices as new techniques to be introduced in a particular region, should be carefully managed in order to have the best results according to particular soils and climates [27]. It is necessary to have more research to determine the effects of the conservation practices on the physical and hydraulic properties in different soil and agro ecological conditions [28, 29].

Conservation tillage is being promoted in Mexico but there is scarce information about the results of these practices in the arid and semiarid areas of the country. The objective of this research was to quantify the effects of three tillage systems on the bulk density, total porosity and field saturated hydraulic conductivity of a clay loam soil and its implication in the fodder yield of oats. The hypothesis is that conservation tillage practices improve the physical condition of the soil and have a positive effect on crop yield.

2. Materials and Methods

The study was conducted in the crop seasons of 2013, 2014, 2015 and 2016 at the experimental station of Universidad Autonoma Agraria Antonio Narro, Saltillo, Coahuila, Mexico. The site is located at 25° 23' 42” N and 100° 59' 57” W, at an altitude of 1743 m above sea level. The climate is semiarid with an average annual temperature of 16.9 °C, the mean annual rainfall 435 mm, and annual evaporation 1956 mm. The soil is a clay loam (34.1% clay, 33.4% silt and 32.5% sand) with a 2.09% of organic matter.

The experimental setup was random blocks; In January at the beginning of each growing season, the tillage treatments were performed in plots of 12 m x 40 m and replicated three times. The crop established was forage oats (Avena sativa L.) under irrigation. The statistical analysis of the data was made using the R software making comparisons between means of treatments with the Tukey test ($\alpha$ ≤ 0.05).
2.1. The tillage treatments were as follows:

Conventional tillage (CT) is the reference tillage system in the region; the sequence of tillage operations in this system is disk plowing, disk harrowing and planting.

The other treatments were conservation tillage systems leaving at least 30% of mulch cover. Vertical Tillage (VT), the sequence of tillage operations is chisel plowing, disk harrowing and planting. No Tillage (NT), the only tillage operation is direct planting.

Measurements of the variables studied: In April each year, the crop was harvested as forage and the following variables were measured.

2.2. Bulk Density

At each treatment, undisturbed core samples were taken carefully in the soil profile from 0 to 20 cm at intervals of 5 cm. The core sampling was made using cylinders of 50 mm diameter and 50 mm long. Samples were processed according to procedures described in [5, 30]. Soil bulk density was calculated as follows:

\[ Bd = \frac{M}{V} \]  

Where:
- \( Bd \) = bulk density (g cm\(^{-3} \))
- \( M \) = mass of the dry soil sample (g)
- \( V \) = volume of sample (cm\(^3 \))

2.3. Total porosity

It was calculated from the values of bulk density and particle density. The latter was determined with the method of picnometry [31]. Total porosity was calculated as follows:

\[ TP = (1 - \frac{Bd}{Pd}) \times 100 \]  

Where:
- \( TP \) = Total Porosity (%)
- \( Bd \) = bulk density (g cm\(^{-3} \))
- \( Pd \) = particle density (g cm\(^{-3} \))

2.4. Saturated hydraulic conductivity

The in-situ determination of the field-saturated hydraulic conductivity (mm h\(^{-1} \)) was determined by the auger-hole method, using The Guelph Permeameter [32].

2.5. Crop yield

A frame (0.25 X 0.25 m) was placed in the soil, the matter in the center of it was cut, weighed as green fodder, and then dehydrated at a temperature of 70°C for 72 hours until depletion of moisture and so its weight was constant to obtain the yield of the dry fodder. This was taken as the dry matter weight of the crop to calculate yield per hectare [33].

3. Results and Discussion

3.1. Effects in bulk density

In table 1, it could be seen that there are no significant differences in bulk densities each year among the tillage systems at the different layers in the soil profile.

There is not a clear tendency of increase or decrease in bulk density for any treatment in the years observed. This has been also found in other studies; according to [34, 35] the soil bulk density could change on time but not necessarily in a consistent tendency, from one year to another it could increase or decrease due to several factors such as volume and intensity of rainfall, drying and wetting of soil, land position and crop type among others.
Table 1. Bulk density from 2013 to 2016 in the soil profile for each tillage system

<table>
<thead>
<tr>
<th>Year</th>
<th>Tillage System</th>
<th>0 to 5 (gr cm$^{-3}$)</th>
<th>5 to 10 (gr cm$^{-3}$)</th>
<th>10 to 15 (gr cm$^{-3}$)</th>
<th>15 to 20 (gr cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>NT</td>
<td>1.28 a</td>
<td>1.29 a</td>
<td>1.33 a</td>
<td>1.31 a</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>1.24 a</td>
<td>1.25 a</td>
<td>1.27 a</td>
<td>1.26 a</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>1.28 a</td>
<td>1.31 a</td>
<td>1.32 a</td>
<td>1.27 a</td>
</tr>
<tr>
<td>2014</td>
<td>NT</td>
<td>1.43 a</td>
<td>1.35 a</td>
<td>1.36 a</td>
<td>1.41 a</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>1.34 a</td>
<td>1.38 a</td>
<td>1.36 a</td>
<td>1.39 a</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>1.36 a</td>
<td>1.31 a</td>
<td>1.38 a</td>
<td>1.36 a</td>
</tr>
<tr>
<td>2015</td>
<td>NT</td>
<td>1.33 a</td>
<td>1.37 a</td>
<td>1.39 a</td>
<td>1.39 a</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>1.36 a</td>
<td>1.35 a</td>
<td>1.41 a</td>
<td>1.42 a</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>1.36 a</td>
<td>1.44 a</td>
<td>1.36 a</td>
<td>1.33 a</td>
</tr>
<tr>
<td>2016</td>
<td>NT</td>
<td>1.26 a</td>
<td>1.22 a</td>
<td>1.22 a</td>
<td>1.22 a</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>1.26 a</td>
<td>1.24 a</td>
<td>1.23 a</td>
<td>1.23 a</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>1.21 a</td>
<td>1.21 a</td>
<td>1.21 a</td>
<td>1.20 a</td>
</tr>
</tbody>
</table>

Means with the same letter in a column in the same year are not significantly different (Tukey $\alpha \leq 0.05$).

In Figure 1, are shown the mean values of the bulk density in the soil profile from zero to 20 cm; the increase and decrease of the values from one year to another are in a range from 1.21 g cm$^{-3}$ to 1.39 g cm$^{-3}$. These values fall in a range considered normal for clay loam soils as it is the soil under study [36, 37]. Bulk density values less or equal to 1.40 g cm$^{-3}$ are considered normal for clay loam soils [38].

![Figure 1](image_url)
cm\(^{-3}\)). In the same study, in the surface layer (0 to 5 cm) there were not significant differences among systems [41].

Even in long periods, not always, there are changes; in a study in a silty clay loam under no tillage, moldboard plow, disk tandem and chisel plow for 35 years, there were not significant differences in bulk density between the tillage treatments at any depth in a soil profile from 0 to 30 cm [42].

In Figures 2, 3 and 4 it is observed the changes in bulk density in 2014, 2015 and 2016 having as a reference the values of 2013. Changes are in percentage and for 2014 and 2015 are in increases in all the treatments in the range from 1 to 13% for all the soil depths. NT presents in 2014 the highest increase in the surface layer and VT in the bottom layer in 2015. These increments are quite small compared to those obtained after eight weeks since the cultivations in a loamy sand soil where increments in bulk density of 48% for no tillage and 55% for plow tillage were reported [43]. Those increments in the same season were believed to be due to high rainfall intensity and wetting and drying cycles.

![Figure 2](image2.png)

**Figure 2.** Increases in percentage of values of bulk density in 2014 compared to 2013.

![Figure 3](image3.png)

**Figure 3.** Increases in percentage of values of bulk density in 2015 compared to 2013.
After three years the changes in the values of bulk density were decrements compared to those measured in 2013, except for the treatment of VT in the surface from 0 to 5 cm depth, it was a small increment. The range of decrease in bulk density is from 0.5% to 8.8% (Figure 4).

**Figure 4.** Increases and decreases in percentage of the values of bulk density in 2016 compared to 2013.

From the results, there are not significant differences at each year on values of bulk density among tillage treatments. The increases and decreases during the four-year experiment should be due to other causes as rainfall, drying and wetting as it has been documented in other results (40, 43).

### 3.2. Effects in total porosity

In Figure 5, it is presented the variations in the values of total porosity in the top layer of the soil profile; in the Figure 6 are the variations for the bottom layer in the time of study for each tillage system. For all the depths in 2013 and 2016 total porosity fluctuates between 50% to 55%, for the intermediate years 2014 and 2016 between 45% to 50%; same tendency was found for the layers from 5 cm to 15 cm, not shown here. The variations of total porosity are linked to the values of bulk density so, values are lower in 2014 and 2015 when bulk density increased in reference to 2013.

**Figure 5.** Total porosity in the surface layer from 0 to 5 cm through the years for the different tillage systems.

Means with same letter in the same year are not significantly different (Tukey α ≤ 0.05)
Means with same letter in the same year are not significantly different (Tukey α ≤ 0.05)

In general, the results of total porosity in this study for all tillage systems are in a range of 45% to 55%. Soil pores could occupy from 30% to 70% of the volume depending on many factors [45] and a soil with a 40% of total porosity is considered extremely porous [46]. Considering these references, the porosities calculated in this study are in normal range of agricultural soils.

The results in this study are similar to others; total porosities from 46.6% to 51.4% at a soil depth of 0 to 10 cm were measured in a study during three years with a wheat crop under conventional tillage and reduced tillage [47]. In other research, after 13 years of conventional tillage and no tillage, total porosities were 47.9% and 50.17% respectively at a depth of 0 to 10 cm. Those values of porosity had not a significant difference between treatments [16].

3.3. Effects in hydraulic conductivity

There are not significant differences among the tillage treatments in the values of saturated hydraulic conductivity in a same year. From the values presented in Figure 7, hydraulic conductivity in the period fall in a range of 3.6 mm h⁻¹ to 36 mm h⁻¹ which is classified as moderately high [48].
Some authors consider a range of 0.36 mm h\(^{-1}\) to 360 mm h\(^{-1}\) as acceptable values of saturated hydraulic conductivity for agricultural soils [49]. The hydraulic conductivity values obtained in this research are within this range. Other study considers an ideal range of hydraulic conductivity for agricultural soils from 18 mm h\(^{-1}\) to 180 mm h\(^{-1}\); in this case the values found in this work are just below of this range [50].

In Figure 8, it can be seen the changes of the saturated hydraulic conductivity having as a reference the values of 2013. The highest increments were in 2014 in the order CT> NT> VT, almost no changes were registered in 2015; decrements very similar are observed in 2016. The increments and decrements are in a range from 0.04 mm h\(^{-1}\) to 6.43 mm h\(^{-1}\); those are relatively small. This is the reason of not resulting statistically significant differences among treatments.

Our results agree with other studies. There were not significant differences in the mean values of hydraulic conductivity in the profile of a sandy loam soil at four different depths; soil Ks averaged across four years and four layers was not affected by tillage [39].

Other authors have found that the hydraulic properties of soil are highly variable within a season and across the years for different soils. Values increase / decrease show different trends [51].

3.3. Effects in crop yield

Figure 9 presents the dry matter yield of the oats crop (Avena sativa L.) There are no significant differences in yield among tillage systems in the seasons of 2013, 2014 and 2016. The yield in the NT system in 2015 is significantly lower than CT and VT; in that year there were problems with the crop planting because many seeds were left without proper soil cover due to heavy rate of mulch, this caused failures and a lower plant density in the NT treatment.
The impact of no tillage agriculture in crop yield are variable, for most crops in the first two years the yields are lower than those under conventional tillage. After two or three years from no tillage implementation, yields start to be comparable to those crops under conventional tillage [52].

In our study, apart from the problem of crop establishment in 2015 that had a negative impact in yield of NT; yields of CT and VT had a tendency to decrease compared to the yields in 2013, meanwhile NT had a yield in 2014 and 2016 very similar to that in 2013.

In other study, yield results of wheat grain with no significant differences between treatments of conventional tillage with mulch and no mulch compared to reduced tillage with mulch are reported in a three-year research in a silt loam soil [47]. However, significantly reduced yield was obtained in reduced tillage without mulch; the result was related to significant lower total porosity and high bulk density compared to the other treatments.

4. Conclusions

In the conditions of our study, tillage systems had not effect in the soil physical variables. During the four years of the study, the values of bulk density had not significant differences among tillage systems at any depth in the soil profile.

Since total porosity is inversely related to bulk density, the changes in this variable were also not significant among tillage practices; values of total porosity were around 50% of the total volume of the soil, which are normal for an agricultural soil.

Hydraulic conductivity varies also from year to year but do not had significant differences among the tillage systems. Values of hydraulic conductivity were always within a range classified as moderately high.

Dry matter yield of oats had not significant differences among tillage treatments in 2013, 2014 and 2016. In 2015 there was a significantly low yield in NT; it was due to high density of the crop.

**Author Contributions:** conceptualization, Martin Cadena-Zapata, Santos Campos-Magaña; methodology, Martin Cadena-Zapata, Alejandro Zermeño-Gonzalez; validation, Karen Denisse Ordoñez-Morales, Alejandro Zermeño-Gonzalez, Martin Cadena-Zapata; formal analysis, Karen Denisse Ordoñez-Morales, Martin Cadena-Zapata; investigation, Karen Denisse Ordoñez-Morales, Alejandro Zermeño-Gonzalez, Martin Cadena-Zapata; data curation, Martin Cadena-Zapata, Karen Denisse Ordoñez-Morales; writing—original draft preparation, Karen Denisse Ordoñez-Morales; writing—review and editing, Martin Cadena-Zapata, Santos Campos-Magaña, Alejandro Zermeño-Gonzalez.

**Funding:** Universidad Autonoma Agraria Antonio Narro, grant number 2167, internally funded this research

**Acknowledgments:** We acknowledge the technical staff of the Agricultural Machinery Department of UAAAN for the support given in the fieldwork.
Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References


Agriculture 2019, 9, x FOR PEER REVIEW

375 38. Soil Quality Institute. Soil Compaction: Detection, Prevention, and Alleviation. National Resources
376 Conservation Service. USDA. Soil Quality – Agronomy Technical Note No. 17, Soil Quality Institute, 411 S.
377 Donahue Dr. Auburn, AL 36832 USA. 2003. 7p.
378 39. Jabro, J.D.; Iversen, W.M.; Stevens, W.A.; Evans, R.G.; Mikha, M.M.; Allen B.L. Physical and hydraulic
379 properties of a sandy loam soil under zero, shallow and deep tillage practices. Soil & Tillage Research
382 Vitti, C.; Rossi, R.; Rana, G. Short-term effects of conversion to no-tillage on respiration and chemical -
383 physical properties of the soil: a case study in a wheat cropping system in semi-dry environment. Italian
386 on soil organic carbon and selected physical properties of a clay loam in southwestern Ontario. Soil &
389 hydraulic properties. Soil and Tillage Research 2017, 170: 38-42. doi:10.1016/j.still.2017.03.001
389 43. Osunbitan, J.A.; Oyedele, D.J.; Adekulu, K.O. Tillage effects on bulk density, hydraulic conductivity and
390 strength of a loamy sand soil in southwestern Nigeria. Soil & Tillage Research 2005, 82: 57-64,
391 doi:10.1016/j.still.2004.05.007
392 44. Martinez, E.; Fuentes J.P.; Silva, P.; Valle, S.; Acevedo, E. Soil physical properties and wheat root growth as
393 affected by no tillage and conventional tillage systems in a Mediterranean environment of Chile. Soil &
398 Sustainable Land Management - Environmental Protection- A Soil Physical Approach. Advances in
400 47. Glab, T.; Kulib, B. Effect of mulch and tillage system on soil porosity under wheat (triticum aestivum). Soil
407 50. Reynolds, W.D; Yang, X. M.; Drury, C. F.; Zhang, T. Q.; Tan, C.S. Effects of selected conditioners and tillage
409 51. Jirku, V., Kodešová, R., Nikodem, A., Můhlnárová, M., Žigová, A. Temporal variability of structure and
410 hydraulic properties of topsoil of three soil types. Geoderma 2013, 204–205: 43-58,
411 doi:10.1016/j.geoderma.2013.03.024
413 Six, J.; Venterea, R.T.; van Kessel, C. When does no-till yield more? A global meta-analysis. Field Crops
415 © 2019 by the authors. Submitted for possible open access publication under the terms
416 and conditions of the Creative Commons Attribution (CC BY) license
417 (http://creativecommons.org/licenses/by/4.0/).