2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Change of soil hardness and soil properties due to tile drainage in the Red River Valley of the North

Xinhua Jia

North Dakota State University, 1221 Albrecht Blvd. PO Box 5626, Fargo, ND 58105.

Thomas F. Scherer

North Dakota State University, 1221 Albrecht Blvd. PO Box 5626, Fargo, ND 58105.

Thomas M. DeSutter

North Dakota State University, 214 Walster Hall, Fargo, ND 58105.

Dean D. Steele

North Dakota State University, 1221 Albrecht Blvd. PO Box 5626, Fargo, ND 58105.

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Abstract. *Subsurface drainage (or tile drainage) is expected to expand significantly in the Red River Valley of the North, yet its effects on soil quality have not been studied. The objectives of this project are to evaluate the changes of soil hardness and physical properties overlying tile drained and undrained areas. In 2002, tile was installed in the south half of a 47 ha field located in southeastern North Dakota. During the fall of 2007, after soybeans were harvested, soil borings were taken to a depth of 2.1 m and soil samples collected at intervals of 15 cm. Two soil borings were in the undrained portion of the field and four soil borings were in the tile drained portion of the field. Soil properties were measured to determine if there were differences due to tile drainage. Soil hardness, an indicator of compaction, was measured at the site of each boring. The soil samples, taken from 15 cm increments of the soil borings, were analyzed to determine soil moisture content, texture, bulk density and saturated hydraulic conductivity. There was no significant difference of the soil bulk density, moisture content, and soil texture. However, as expected, there was large variability for each of these parameters. There was no significant difference in the saturated hydraulic conductivity, but there was great variability between increment samples. This may be due to the variability of the soil texture at different depths. Soil hardness was statistically significant only in the 0-15 cm interval (the tillage zone).*

Keywords. Tile drainage, soil physical properties, soil water content, and soil hardness.

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Introduction

Tile drainage is a process for removing excess subsurface water. Tile drainage has been installed in the United States for over 150 years, mainly in the upper Midwest. Only within the last decade has tile drainage been actively installed in the Red River Valley of the North (RRV). The RRV drains most of eastern North Dakota and northwestern Minnesota and locally the drainage area is referred to as the Red River Valley. The recent adoption of this technology in the region is mainly due to increased rainfall since 1993, higher land values, and better crop prices. Many farmers were unable to plant in the spring due to the wet conditions. Over an 8 year period, prevented planting due to wet soil conditions in the spring varied from 81,000 ha (0.2 million acres) in 2002 to over 647,000 ha (1.6 million acres) in 2004. The increased rainfall also caused salinity to become a problem due to rising water tables. Saline affected soils in the RRV occupy over 607,000 ha (1.5 million acres) which accounts for about $50 to $90 million USD of lost revenue to the regions' farmers. Tile drainage is a promising way to control and reduce salinity in wet soils.

The concept of tile drainage is appealing to many landowners in the RRV. Drainage controls salinity buildup in the soil, allows early access to the field (compared to non-tiled field) in the spring, and consequently results in increased yields. Tile drainage enables the root zone to be drained of excess water and decreases the length of time for the soil surface to warm up, seeds to germinate, and allows access to the field with heavy equipment for seeding and cultivation. By lowering the water level, tile drainage is also effective at reducing the potential for soluble salts to accumulate at the soil surface. The USDA (2005) recommends that to prevent the upward movement of salts into the root zone via capillary rise, the water table must be moved to depths greater than 1.2 m.

Maintaining or improving soil quality is a critical management concern when changing water table management regimes. Soil characteristics that can be influenced by drainage and subirrigation are bulk density, crusting, porosity, and aggregate stability. Soil bulk density has been shown to decrease when drainage and subirrigation have been used compared to undrained soils (Chieng and Hughes-Games, 1995) and soil bulk density has also been shown to be lower in subirrigated soils compared to drained soils (Baker et al., 2004). This decrease in bulk density in some studies may have been the result of an increase in soil macropores compared to micropores (Baker et al., 2004; Hundal et al., 1976). However, Van Hoorn (1958) found that micropores were more evident than macropores in a subirrigated soil. Research results also differ on whether drained soils can decrease the amount of surface crusting (Hundal et al., 1976; Lal and Fausey, 1993). When a soil crust develops, the soil hardness increases and the power required for tillage is also increased. This situation becomes more serious if the soil has high sodium content. Clearly, there are discrepancies on the impacts of drainage on soil hardness and soil parameters. These results are most likely influenced by localized soil characteristics and frequency of wetting and drying cycles.

The objectives of this project are to evaluate the changes of the soil hardness and physical properties overlying tile drained and undrained areas.

Methods and Materials

The demonstration field is located in the RRV about 3 km south of the town of Fairmount, Richland County, North Dakota. The site is near the corner of South Dakota, North Dakota and Minnesota. The total area of the experimental field is 47 ha, with 20 ha of tile and 27 ha with no tile. Four soil series are present in the field (Figure 1). The eastern half is Antler silty clay loam

(1396A) and Antler-Mustinka silty clay loam (1397A), which are both fine loamy soils and typic calciaquolls. The west half is Doran clay loam (typic argiborolls, 1243A) and Clearwater-Reis silty clays (vertic haplaquolls, 1236A) (Web Soil Survey, 2008).

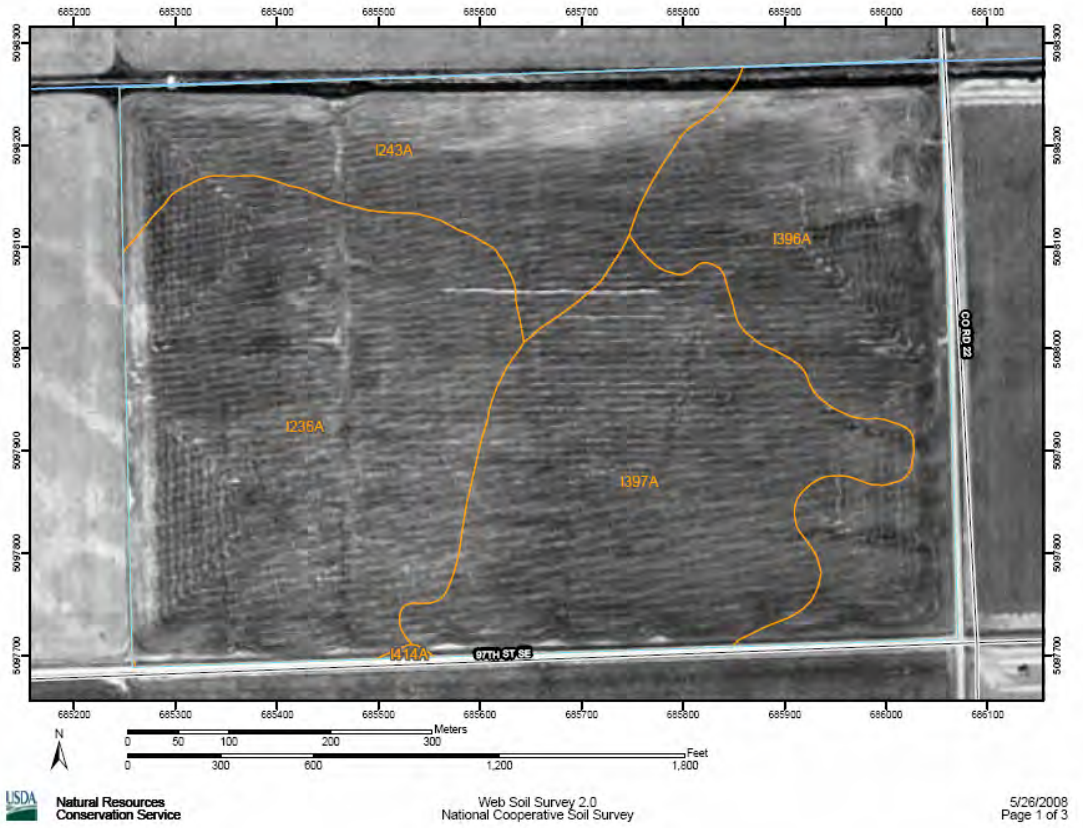

Figure 1. Soil map unit for the study field (Web Soil Survey, 2008)

The tile drainage on the south half of the field was installed in the fall of 2002 (Fig. 2). Of the 20 ha of tile drainage, 10 ha will be used for subirrigation during the 2008-growing season. The tile spacing is 18.3 m, and the tile depth varies from 1.0 m to 1.5 m from the west to the east of the field. Two 3.0 m wide alleys were installed permanently at either end of the field for the experiment . These alleys are used for instrumentation setup, soil and water sampling and monitoring, and data retrieval.

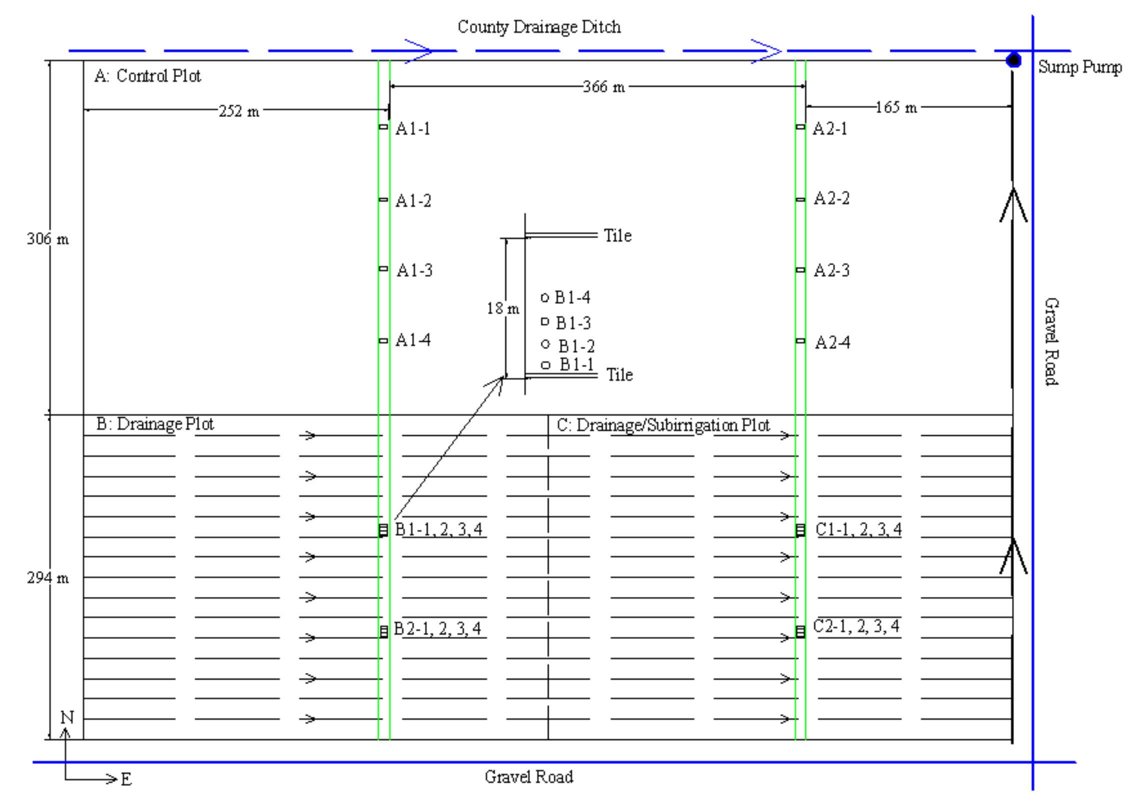

Figure 2. Schematic diagram of the field with indications of sample points. Four sample points at B2, C1 and C2 are similar to that at B1, where B1-1, B1-2, B1-3, and B1-4 are 0.9, 4.0, 7.0, and 10.1 m to the tile at the south side.

The field is located over the Fairmount aquifer. The landowner has drilled two wells to supply the water to subirrigate a portion of the tile drainage system. The well water, determined before April 2006 prior to applying for a subirrigation permit, has an electrical conductivity and sodium absorption ratio of about 1.5 dS m^{-1} and 6, respectively. The combination of drainage and subirrigation may increase crop yields, or yields may be decreased due to increased salinity levels and waterlogging caused by the subirrigation.

Changes in soil physical properties will be determined by deep core sampling down to 210 cm with soil samples taken in 15-cm increments in the fall, after harvest and before any tillage. However, in the fall of 2007, the first deep core sampling was conducted after tillage. For bulk density measurement, soil cores with a length of 15 cm were dried at 105 ^{o}C for 24 hours in a drying oven. After the soil bulk density test, a soil core of 5 cm diameter was cut from the middle of the 15 cm diameter soil sample. The cut sample was then wetted for 24 hours and then slid into a 30 cm acrylic column. The falling head method was used to determine the saturated hydraulic conductivity (K_S) (Klute and Dirksen, 1986).

Soil hardness was measured with a soil compaction tester (Dickey-john, Auburn, IL) at depths of 15, 30, 45, and 60 cm in the field.

Results and Discussions

Soil Hardness

The field was planted to soybeans in 2007 and the soil was tilled immediately after harvest. The soil hardness measurement should be performed before tillage since tillage may minimize the hardness difference of the surface layer between the drained and undrained parts of the field. However, it rained intermittently for about a week before the soil hardness test. The wetting front due to the rainfall events was 40-50 cm below the soil surface and made the hardness test easy to perform. The results are shown in Table 1. The samples labeled Undrained were taken at A1-2 and A2-3 (see locations on Fig. 2), and Drained at B1-3 (7.0 m to drain pipe), B2-1 (0.9 m to drain pipe), C1-4 (10.1 m to drain pipe), and C2-2 (4.0 m to drain pipe). Three replicates were taken at each site. The average values at each site were listed in Table 1. The average and standard deviation of all measured values in the drained and undrained fields are also shown in Table 1.

Table 1. Soil Hardness for Drained and Undrained Fields in Pressure (kPa).

Depth (cm)	Undrained				Drained					
	A1-2	A2-3	**Avg**	**Std**	B1-3	B2-1	C1-4	C2-2	**Avg**	**Std**
15	1048	689	**869**	**248**	483	393	531	365	**441**	**165**
30	1606	1358	**1482**	**228**	1434	1496	1551	862	**1338**	**400**
45	2985	2117	**2551**	**779**	1882	2082	2296	1606	**1965**	**365**
60	3565	3330	**3447**	**717**	2530	3054	3689	4137	**3296**	**627**

Soil hardness is a measure of soil strength to resist mechanical disturbance. The higher the pressure required to penetrate through the soil, the harder the soil. Soil hardness is influenced by soil moisture and soil density. The undrained soil has been in extended wet conditions. Soil particles tend to be more dispersed and fewer soil pores are occupied by air. When the soil becomes dry, it is more compacted. In the other hand, the soil in the drained field has no gravimetric water in the large pores, and soil tends to be loose when it is dry. Van Hoorn (1958) showed that there was a distinct deterioration of soil structure after five years for a high water table (undrained condition). Our measured results showed that the undrained field was harder or more compacted, or denser than the drained field, with the highest hardness difference, 428 kPa, between the drained and undrained fields at the 15 cm depth or near the soil surface. At deeper depths, the hardness in the undrained fields was slightly higher (3 – 23%) than the undrained fields.

Soil Bulk Density

The change of pore size distribution in the drained and undrained areas was evidenced by the difference in soil hardness, as well as other soil properties. Soil bulk density is the total soil mass in a known volume. The measured bulk density for undrained and drained fields are shown in Table 2.

Table 2. Bulk Density for Drained and Undrained Fields (g cm^{-3}).

Depth (cm)	Undrained				Drained					
	A1-2	A2-3	**Avg**	**Std**	B1-3	B2-1	C1-4	C2-3	**Avg**	**Std**
0-15	1.11	1.14	**1.12**	**0.02**	1.26	1.36	1.35	1.36	**1.33**	**0.05**
15-30	1.63	1.38	**1.50**	**0.17**	1.51	1.15	1.38	1.42	**1.46**	**0.16**
30-45	1.52	1.42	**1.47**	**0.07**	1.35	1.32	1.34	1.31	**1.33**	**0.02**
45-60	1.42	1.36	**1.39**	**0.04**	1.34	1.46	1.10	1.33	**1.31**	**0.15**
60-75	1.34	1.29	**1.32**	**0.04**	1.28	1.42	1.25	1.29	**1.31**	**0.08**
75-90	1.49	1.33	**1.41**	**0.11**	1.33	1.28	1.39	1.45	**1.36**	**0.07**
90-105	1.47	1.33	**1.40**	**0.10**	1.37	1.31	1.36	1.53	**1.39**	**0.10**
105-120	1.41	1.51	**1.46**	**0.07**	1.57	1.43	1.44	1.55	**1.50**	**0.07**
120-135	1.43	1.67	**1.55**	**0.17**	1.48	1.49	1.48	1.53	**1.49**	**0.02**
135-150	1.54	1.68	**1.61**	**0.10**	1.45	1.58	1.53	1.70	**1.56**	**0.10**
150-165	1.55	1.55	**1.55**	**0.00**	1.47	1.44	1.49	1.49	**1.47**	**0.02**
165-180	1.42	1.43	**1.43**	**0.01**	1.66	1.34	1.60	1.65	**1.56**	**0.15**
180-195	1.34	1.50	**1.42**	**0.12**	1.55	1.52	1.52	1.68	**1.57**	**0.08**
195-210	1.56	1.48	**1.52**	**0.05**	1.46	1.51	1.76	1.53	**1.56**	**0.13**

Comparing the average bulk density of the two fields, there is no significant difference (P = 0.86) for this set of samples. Above the tile that is 1.5 m deep, the bulk density is higher in the undrained field with an exception of the 0-15 cm samples. This is probably due to the tillage operation before the soil sampling. The bulk density below the tile is slightly higher in the drained field.

Soil Saturated Conductivity

Saturated hydraulic conductivity (K_S) is often used to describe the velocity of water in a soil and is a required parameter in drainage modeling. The measured K_s results are shown in Table 3.

Table 3. Soil Saturated Conductivity for the Drained and Undrained Fields (cm h^{-1}).

Depth (cm)	Undrained				Drained					
	A1-2	A2-3	**Avg**	**Std**	B1-3	B2-1	C1-4	C2-2	**Avg**	**Std**
0-15	0.06	3.20	**1.63**	**2.22**	0.65	1.00	0.35	0.12	**0.53**	**0.38**
15-30	0.77	0.85	**0.81**	**0.05**	0.58	0.64	2.07	0.56	**0.96**	**0.74**
30-45	0.49	3.25	**1.87**	**1.95**	0.52	1.07	3.21	1.25	**1.51**	**1.17**
45-60	0.32	3.51	**1.91**	**2.25**	5.05	1.17	5.53	1.20	**3.24**	**2.38**
60-75	3.12	8.49	**5.80**	**3.80**	8.80	0.74	3.55	1.56	**3.66**	**3.62**
75-90	0.01	3.11	**1.56**	**2.20**	4.67	1.04	0.22	1.43	**1.84**	**1.95**
90-105	0.02	0.69	**0.36**	**0.47**	1.63	1.73	1.81	0.10	**1.32**	**0.82**
105-120	0.01	1.57	**0.79**	**1.10**	0.73	2.86	0.63	0.48	**1.18**	**1.13**
120-135	0.19	1.56	**0.87**	**0.97**	0.82	1.04	0.01	0.07	**0.48**	**0.52**
135-150	0.55	1.16	**0.86**	**0.43**	16.19	0.06	0.05	0.11	**0.07**	**0.03**
150-165	0.25	1.53	**0.89**	**0.91**	0.03	1.45	0.01	0.06	**0.39**	**0.71**
165-180	0.06	0.33	**0.20**	**0.19**	0.01	0.01	0.01	0.15	**0.04**	**0.07**
180-195	0.02	**	**0.02**	**	0.02	0.05	**	0.01	**0.02**	**0.02**
195-210	0.07	1.03	**0.55**	**0.68**	0.18	0.10	0.31	0.01	**0.15**	**0.13**

Statistically, there is no significant difference in the measured K_s values. However, there is high statistical variability among all the treatments. Additional saturated hydraulic conductivity tests are required to verify the statistical significance.

Soil Moisture Content

Soil moisture content was measured gravimetrically on a dry weight basis and converted to volumetric soil moisture content using the measured bulk density values (Table 4).

Table 4. Soil Moisture Content (cm^3 cm^{-3}).

Depth (cm)	Undrained		Drained				Avg Dif
	A1-2	A2-3	B1-3	B2-1	C1-4	C2-2	
0-15	0.29	0.28	0.35	0.34	0.35	0.34	-0.05
15-30	0.40	0.35	0.39	**	0.31	0.32	0.03
30-45	0.31	0.29	0.32	0.23	0.20	0.24	0.05
45-60	0.28	0.24	0.28	0.24	0.18	0.19	0.04
60-75	0.28	0.28	0.25	0.22	0.23	0.20	0.06
75-90	0.33	0.29	0.29	0.22	0.27	0.27	0.05
90-105	0.32	0.28	0.30	0.25	0.29	0.30	0.01
105-120	0.32	0.33	0.35	0.27	0.30	0.31	0.01
120-135	0.37	0.35	0.28	0.31	0.36	0.33	0.04
135-150	0.39	0.35	0.35	0.34	0.39	0.35	0.02
150-165	0.39	0.34	0.35	0.31	0.35	0.33	0.03
165-180	0.37	0.32	0.39	0.29	0.37	0.38	-0.01
180-195	0.34	0.35	0.38	0.33	0.38	0.40	-0.03
195-210	0.40	0.35	0.35	0.35	0.44	0.37	0.00

The water content in the undrained area is generally greater than the undrained area. The last column in Table 4, Avg Dif, indicates the soil moisture difference between the average for the undrained and drained fields. Except the surface layer, the soil moisture in the undrained field is higher than the drained field, ranging from 0.01 to 0.05 for depths from 15 cm to 165 cm. For layers below 165 cm, the moisture difference was probably due to the soil properties and not associated with the tile drainage. However, there is no statistical difference between samples. The highest difference, 0.06, occurred at the 60 to 75 cm layer. Due to the prior rainfall events the wetting front was at about 50 cm from the soil surface. The soil moisture difference above the wetting front was less than 10%. The soil moisture difference below the wetting front was probably due to the previous moisture conditions prior to the rainfall events. However, the difference may also due to the soil texture difference.

Soil Texture

As indicated above, soil hardness, bulk density and soil moisture content are different due to soil texture. At the same matric potential, a sandy soil has a lower soil hardness, a higher bulk density, and a lower soil moisture content compared with a fine-textured soil. A high difference in the soil texture may override any difference observed above. The soil textures for the six sampling sites are shown in Table 5.

Table 5. Soil Texture (Sicl: silty clay loam; sil: silty loam; scl: sandy clay loam; cl: clay loam; l: loam; and c: clay).

. Depth (cm)	Undrained		Drained			
	A1-3	A2-2	B1-3	B2-1	C1-4	C2-2
0-15	Sil	Sicl	Sil	Sil	Sicl	Sicl
15-30	Sicl	Sil	Sicl	Sicl	Sil	Sil
30-45	Cl	Sicl	Cl	Sicl	Cl	Cl
45-60	C	Cl	C	Cl	Cl	Cl
60-75	Cl	Cl	Cl	Cl	L	Cl
75-90	Cl	Cl	Sicl	Cl	Cl	Cl
90-105	Cl	Cl	Cl	Cl	Cl	L
105-120	Cl	L	Cl	Cl	Cl	L
120-135	Sil	Cl	Cl	Cl	Sil	Scl
135-150	Sil	L	Sil	L	Sil	L
150-165	Sil	Cl	L	Cl	Cl	L
165-180	L	Cl	Cl	L	L	L
180-195	L	L	Cl	Cl	Cl	L
195-210	L	L	L	L	L	L

The clay content for the drained fields were always higher than that for the undrained fields, with 25.4% for undrained, and 28.7% for drained. The high clay content in the drained field indicates a high potential for a higher water holding capacity, but the drainage system overrides this effect. The higher clay content in the drained field may imply that the difference in soil hardness and bulk density were due to the higher clay content instead of drainage.

Conclusion

In 2002, tile was installed in the south half of a 47 ha field located in southeastern North Dakota. During the fall of 2007, after soybeans were harvested, soil borings were taken to a depth of 2.1 m and soil samples collected at intervals of 15 cm. Two soil borings were in the undrained portion of the field and four soil borings were in the tile drained portion of the field. Soil properties were measured to determine if there were differences due to tile drainage. Soil hardness, an indicator of compaction, was measured at the site of each boring. The soil samples, taken from 15 cm increments of the soil borings, were analyzed to determine moisture content, texture, bulk density and saturated hydraulic conductivity. There was no significant difference of the soil bulk density, moisture content and soil texture. However, as expected there was large variability for each of these parameters. There was no significant difference in the saturated hydraulic conductivity but there was great variability between increment samples. This may be due to the variability of the soil texture at different depths. Soil hardness was statistically significant only in the 0-15 cm interval (the tillage zone).

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