SOIL QUALITY IN A COTTON FIELD IN SOUTHERN NEW MEXICO

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ABSTRACT

The goal of sustainable agriculture is to maintain a non-negative and preferably an increasing trend in per capita productivity while maintaining the soil quality. The objective of this research was to understand interactions among key soil physical and chemical properties for long-term sustainability of the existing cropping system. We collected core and bulk soil samples in a continuous cotton farm at 0-10, 10-20 and 20-30 cm depths. The soil was classified as Glendale (fine-silty, mixed, calcareous, thermic typic Torrifluvents)-Harkey (coarse-silty, mixed, calcareous, thermic typic Torrifluvents). Experimental field was minimum tilled in 2004 and conventional tilled in 2003 and 2005. Soil properties measured were bulk density (BD), drainable porosity (θ_a), effective porosity (θ_e), available water capacity (AWC), volume of transport pores (VTP), volume of storage pores (VSP), saturated hydraulic conductivity (K_s); organic carbon (SOC), nitrate-N, ammonium-N concentration; pH, electrical conductivity; and texture. We found a negative relationship among BD and K_s (R = -0.88), VTP (-0.81), nitrate-N content (r= -0.73), and θ_e (r = -0.61), respectively. A positive relationship was obtained among K_s and θ_e (r = 0.80) and VTP (r = 0.79), respectively. In general, soil properties did not vary with depth, except for AWC and VSP, which were lowest at the 10-20 cm depth. Using critical levels and relative weighting factors (RWF) for soil physical and chemical properties available in literature, ten measured soil properties were assigned a rating factor f and were added to provide a cumulative rating (CR) for each depth, separately. The CR for the farm ranged from 25 to 27 for various depths indicating that the existing cropping system is sustainable with high input. Use of cover crops, crop rotations, and less intense tillage may likely improve soil structural properties and sustainability of the cropping system.

INTRODUCTION

It is a common knowledge that productive soil is an important resource for agricultural sustainability. Over the last several decades, the major focus of research was centered on the twin objectives of increasing productivity and protecting the environment quality under different farming systems. Such efforts have shown that conventional farming systems and management practices involving use of fertilizers and pesticides increase crop yields enhance food security and sustain agriculture production system around the globe. More recently, in spite of the high yields associated with the conventional farming, the sustainable soil fertility and environmental quality associated with conventional system has become questionable. Conventional farming systems are reported to be associated with problems such as decline in soil structure, increase in soil bulk density, decline in soil aggregation, increase in soil salinity, decrease in water infiltration and increase in nitrogen leaching and ground water contamination. The answers to problems associated with conventional cropping practices can be found in alternate cropping systems, such as conservation or minimum tillage, that use best management practices and can improve soil structure, increase water storage and transmission, enhance soil C and N concentration in soil profile (Gantzer and Blake, 1978; Jordahl and Karlen, 1993; Shukla et al. 2003).

To determine sustainability of a cropping system, criteria based upon the critical limits of key soil properties in relation to threshold values beyond which productivity decline is severe or impact on the environment is very drastic can be used (Lal, 1994; Shukla et al. 2004). Several minimum data sets have been proposed to quantitatively assess sustainability of a soil management practice (Doran and Parkin, 1994; Larson and Pierce, 1994). It is important to establish critical levels of SQIs, assign a weighting factor, and relate them to productivity. The area under conservation tillage system is consistently increasing in the USA and around the globe. According to Baker and Rouppet (1996), New Mexico farmers have also practiced conservation tillage system for many years. The "swampbuster" and "sodbuster" portions of 1985 Food Security act required growers to initiate an approved conservation plan by 1990 on highly erodible cropland. However, the potential of conservation tillage in the arid- New Mexico is not fully utilized (Baker and Rouppet, 1996). This study was undertaken on a farm, which is currently on the first year of minimum and conventional tillage rotation. The objectives of this study were to: (1) examine soil physical and chemical properties, (2) understand interactions among soil physical and chemical properties, and (3) assess sustainability of the land use and management system based on critical levels.

METHODS AND MATERIALS

We selected a field that was minimum tilled in year 2004 and conventional tilled in years 2003 and 2005 (Fig. 1). Experimental field is located about 3780 ft above sea level at N32° 03'13'', W106° 38'29'' in Anthony, Dona Ana County, New Mexico. Soils of the area are classified as Glendale (fine-silty, mixed, calcareous, thermic typic Torrifluvents)-Harkey (coarse-silty, mixed, calcareous, thermic typic Torrifluvents). These soils are deep, nearly level, well drained, and formed in alluvium on flood plains and stream terraces along the Rio Grande Valley. The alluvium is modified by wind and Aeolian material. The typical surface layer for a Glendale soil is clay and the layers below are clay loam and very fine sandy loam. The upper surface for a Harkey is loam and layers below are very fine sandy loam and silt loam. The climate of the experimental area was classified as arid with mean annual temperature range from 18 to 20^{o}C and mean annual precipitation from 180 to 230 mm mostly between May and August (Bulloch and Neher, 1980). The experimental farm was under continuous cotton (Pima DP340) and Urea Ammonium Nitrate (URAN) liquid fertilizer was applied at the rate of 100 gallons per acre.

Core and bulk soil samples were collected in triplicate for 0-10, 10-20, and 20-30 cm depths from the experimental farm during September 2005. Core samples were obtained using 7 cm diameter and 7 cm long stainless steel cylinders and soil bulk density (BD) calculated on oven dry basis (Blake and Hartge, 1986) and saturated hydraulic conductivity (K_s) by the constant head method (Klute and Dirksen, 1986). Soil moisture characteristics [h(θ)] were determined on the same cores for 3 kpa and 6 kpa using the tension table (Leamer and Shaw, 1941) and for 30 kpa, 300 kpa, and 1500 kpa suctions using the pressure plate apparatus (Klute, 1986). The soil moisture content at 1500 kpa was determined on the ground soil sample <2-mm size. The difference between volumetric moisture content at saturation and 30 kPa was computed to assess effective porosity (θ_e) and between θ at 30 kpa and 1500 kpa to assess plant available water capacity (AWC).

Pore size distribution was obtained from the SWC curves and was divided into three classes on the basis of their equivalent cylindrical diameter (e.c.d): (i) transmission pore (VTP) (>50 µm), (ii) storage pores (VSP) (0.2 and 50 µm), and residual pores (<0.2-µm) (Greenland, 1977).

Bulk soil samples were air-dried and passed through a 2 mm sieve. About 50 g of the sieved soil was used for particle size analysis by the hydrometer method (Gee and Bauder, 1986). The pH and electrical conductivity (EC) were measured on 1:1 soil: water paste by a portable handheld pH and EC meter (OAKTON Instruments, Vernon Hills, IL), respectively. Nitrate and nitrite N were determined in 2.0 M KCl extracts on a Technicon Autoanalyzer II (Technicon, Tarrytown, NY) using Cadmium Reduction Method (Maynard and Kalra, 1993). Ammonium N was also determined in 2.0 M KCl extracts by the Technicon Autoanalyzer II using Indophenol Blue Method (Maynard and Kalra, 1993). Soil organic C was measured by dry combustion methods (Elementar, GmbH, Hanau, Germany).

The analysis of means was carried out for depth x sample interaction using the proc mean option of SAS Institute (1989). The least significant differences were calculated for alpha = 10%. The correlation analysis was carried out using the data analysis tool pack of Microsoft Excel.

Fig. 1. The experimental site

RESULTS AND DISCUSSION

Soil texture for all three depths was silt loam according to the USDA classification and showed low variability (CV<0.16). Coarse fractions were always < 3% at all depths. Sand content was higher at the 10-20 cm depth than at other depths, however, standard deviations for sand content were also larger at this depth. Therefore, analysis of means for depth x sample interactions also showed no significant differences among sand, silt or clay contents (Table 1). These results were expected as soil texture is strongly related to the pedogenetic than a management processes.

Soil bulk density did not change with depth, a direct consequence of deep conventional tillage up to 10 to 14 inch depth (Table 2). Although, soil moisture content decreased with depth at the time of core sampling, saturated hydraulic conductivity did not follow the same trend. Saturated hydraulic conductivity was greatest at the 0-10 cm and lowest at 10-20 cm depth. Such a variation in hydraulic conductivity cannot be explained by the small variations in sand, silt or clay contents.

The available water content did not vary with depth but volume of transport pores and effective porosity did (Table 3). Volume of transport pores and effective porosity values were highest at the 0-10 cm depth. The higher saturated hydraulic conductivity values for 0-10 cm depth were likely due to the higher volume of transport pores and effective porosities.

Table 1. Mean ± Standard deviations of sand, silt and clay content

Depth (cm)	Sand (%)	Silt (%)	Clay (%)
0-10	13.6 ± 3.2	63.1 ± 1.9	23.2 ± 1.4
10-20	16.0 ± 6.4	59.2 ± 4.9	24.8 ± 1.6
20-30	11.7 ± 3.1	64.1 ± 1.2	24.2 ± 2.7

Table 2. Mean ± Standard deviations of bulk density (BD), volumetric moisture content (θ) and saturated hydraulic conductivity (K_s) of soil

Depth (cm)	BD (g cm^{-3})	θ (cm^3 cm^{-3})	K_s (cm h^{-1})
0-10	1.51 ± 0.01	0.38 ± 0.07	1.90 ± 2.42
10-20	1.50 ± 0.05	0.37 ± 0.05	0.73 ± 0.60
20-30	1.48 ± 0.01	0.32 ± 0.01	1.20 ± 1.10

Table 3. Mean ± Standard deviations of available water content (AWC), volume of transport pores (VTP), volume of storage pores (VSP), and effective porosity (θ_e) of soil

Depth (cm)	AWC (cm)	VTP (cm^3 cm^{-3})	VSP (cm cm^{-3})	θ_e (cm cm^{-3})
0-10	2.5 ± 0.5ab	0.10 ± 0.05	0.26 ± 0.04ab	0.11 ± 0.06
10-20	2.2 ± 0.1b	0.05 ± 0.02	0.22 ± 0.02b	0.06 ± 0.03
20-30	2.7 ± 0.2a	0.06 ± 0.01	0.30 ± 0.03a	0.07 ± 0.01

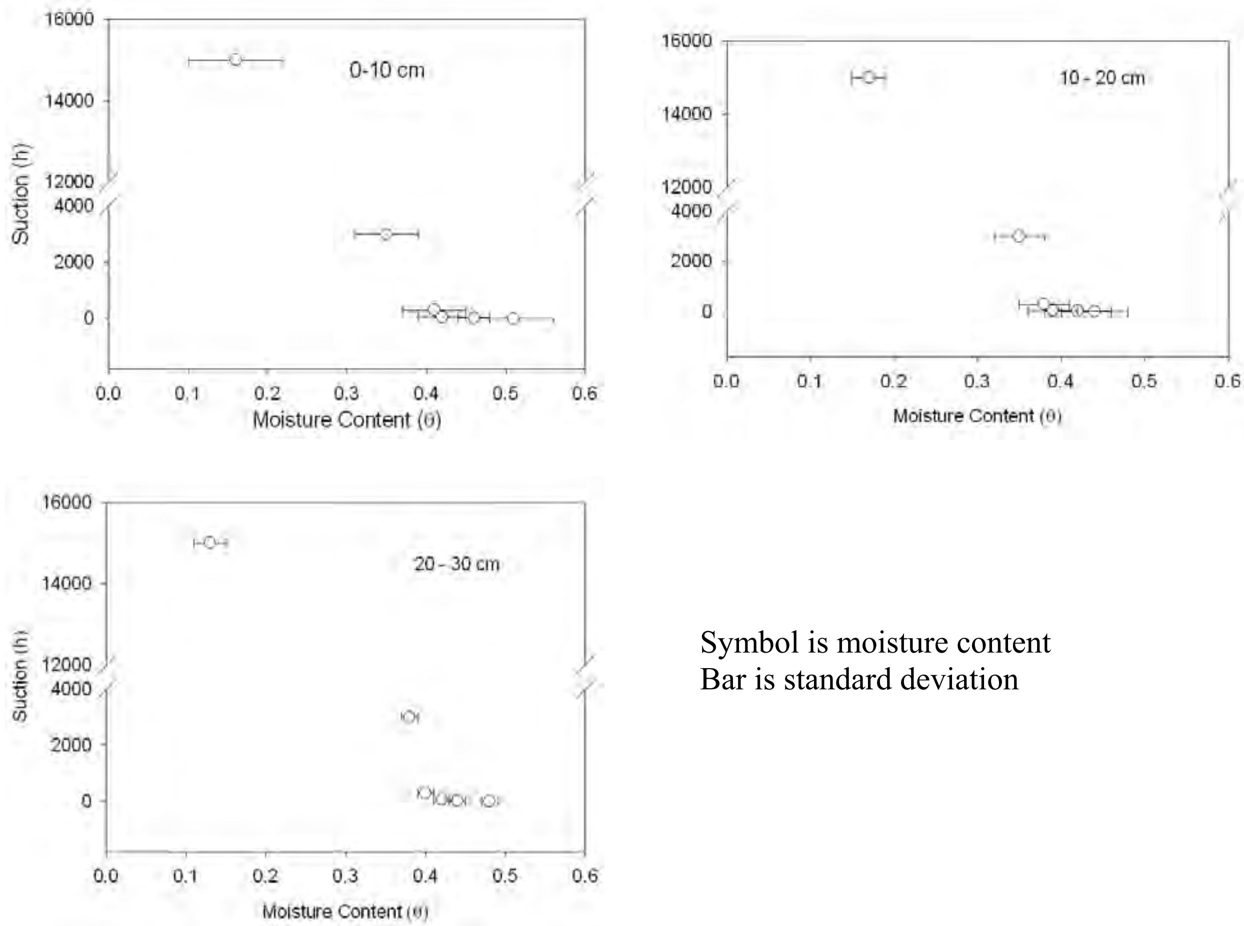

Fig. 2. Soil moisture release curve for the experimental farm

The soil moisture characteristics curves are presented in Fig 2. The standard deviation of soil moisture contents for all five suction heads were smallest at 10-20 cm depth, indicating that with respect to soil moisture release curve the soil at the this depth was relatively homogeneous. Available water content and the volume of storage pores were also higher at 20-30 cm than other two upper layers. On accord with the volume of transport pores and available water content, soil moisture contents were higher at 0-10 cm depth for all suctions than 10-20 cm depths. Water transmission properties were always smallest at 10-20 cm depth.

The soil pH was lower than 8.4 for all depths and showed that inorganic or pedogenic C contents of soil were significant (Table 4). High values of pH were expected because of the high $CaCO_3$ contents in the soil. Soil electric conductivity values were much lower and indicated that no soil salinity problem exists in the study area. Total inorganic N contents were highest at the 0-10 cm depth. The ammonium N contents increased with depth, however, no definite trends were observed for nitrate-N. This may be due to the application of liquid URAN in the field, which likely resulted in the volatilization of ammonium at the soil surface. The other possibilities of increases in ammonium N contents with increasing depth were likely due to the initial leaching of positively charged ammonium followed by the adsorbed on the negatively charged clay.

The interdependence among soil properties was obtained by correlation analysis. We found a strong negative relationship among bulk density and saturated hydraulic conductivity (R= -0.88), volume of transport pores (-0.81), nitrate-N content (r= -0.73) and effective moisture content of soil (r = -0.61), respectively. The effective porosity, saturated water content and volume of transport pores also produced a positive relationship with saturated hydraulic conductivity with r = 0.80, 0.72 and 0.79, respectively. Moderate negative correlation was also obtained among clay content and effective porosity (r = -0.60) and saturated hydraulic conductivity (r = -0.63). A negative relationship between nitrate-N and clay content (r = -0.61) was expected as both are negatively charged, however, we did not see increasing nitrate-N with depth and therefore, no evidence of leaching due to anion exclusion of nitrate-N. A moderate and inverse relationship between EC and clay was rather unexpected because of the adsorption of micronutrients and chemicals on clay particles. This was likely due to the poor aggregation in the soil. A significant inverse relationship between clay content and volume of transport pores (r = -0.53) further indicated poor soil aggregation due to tillage. Sand content showed a positive relationship with volume of transport pores (r = 0.42) and silt content with available water content (r = 0.45) which are in accord with the sizes of these primary particles and their influence on total porosity.

Table 4. Mean ± Standard deviations of pH, electrical conductivity (EC), ammonium-N (NH_4-N), and nitrate-N (NO_3-N) of soil

Depth (cm)	pH	EC (dS m^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})
0-10	8.4 ± 0.1	0.34 ± 0.05	1.97 ± 0.65	6.57 ± 3.71
10-20	8.5 ± 0.1	0.39 ± 0.05	2.20 ± 1.05	1.50 ± 0.72
20-30	8.5 ± 0.1	0.43 ± 0.14	2.87 ± 0.85	4.27 ± 2.87

Table 5. Interdependence of soil physical and chemical properties

Property	**BD**	θ_s	θ_r	**AWC**	**VTP**	**VSP**	θ_{ef}	K_s	**Sand**	**Clay**
θ_s	-0.61									
AWC	0.40		-0.76							
VTP	-0.81	0.79								
VSP			-0.78	0.98						
θ_{ef}	-0.78	0.81			0.98					
K_s	-0.88	0.72			0.79		0.80			
Sand					0.42			0.46		
Silt				0.45		0.43			-0.91	
Clay	0.39	-0.56			-0.53		-0.60	-0.63	-0.60	
EC										-0.42
pH		-0.63	-0.52					-0.48		
NO_3-N	-0.73	0.57			0.66		0.68	0.61		-0.64

Table 6. Critical levels and relative weighting factors (RWF) for soil physical and chemical properties

Limitation	RWF	BD Mg m^{-3}	θ_e cm^3cm^{-3}	θ_r cm^3cm^{-3}	AWC cm	K_s cm h^{-1}
None	1	<1.3	>0.20	>0.15	> 30	>2
Slight	2	1.3-1.4	0.18-0.20	0.15-0.18	20-30	0.2-2
Moderate	3	1.4-1.5	0.15-0.18	0.18-0.20	38949	0.02-0.2
Severe	4	1.5-1.6	0.10-0.15	0.20-0.25	38756	0.002-0.02
Extreme	5	>1.6	<0.10	<0.25	< 2	>0.002

Limitation	RWF	SOC Mg ha^{-1}	Texture	CF %	EC ds m^{-1}	pH
None	1	70-130	loam	< 10	< 3	6-7
Slight	2	45-70	SiL, SiCL	10-20	3-5	5.8-6 and 7-7.4
Moderate	3	14-45	CL, SL	20-40	5-7	5.4-5.8 and 7.4-7.8
Severe	4	7.5-14	SiC, LS	40-60	7-10	5.0-5.4 and 7.8-8.2
Extreme	5	<7.5	C, S	>60	>10	<5.0 and >8.2

Each measured soil property was assigned a rating factor using table 6 for each sampling depth. The table 6 shows that the rating and the soil condition are inversely related. The lowest rating of 5 (extreme limitation) was obtained for effective moisture content of soil for 10-20 cm and 20-30 cm depths. Effective soil moisture content for 0-10 cm depth, and pH and bulk density of soil for all three depths showed moderate limitation and received a rating of 3. The available water content, saturated hydraulic conductivity, soil organic C and soil texture received a rating of 2 indicating slight limitation. However, residual moisture content, coarse fraction and electrical conductivity did not show any limitation (rating=1).

The cumulative rating of 25, 27 and 27 were obtained for 0-10, 10-20 and 20-30 cm depths, indicating that the current land use and management system is sustainable with high input (Table 7). Use of cover crops, crop rotation, manures, and less intense tillage can likely improve the soil structural and water transmission and storage properties.

Table 7. Sustainability of a land use in relation to the cumulative rating (CR)

Sustainability	RWF	CR
Highly sustainable	1	<20
Sustainable	2	20-25
Sustainable with high input	3	25-30
Sustainable with another land use	4	30-40
Unsustainable	5	>40

CONCLUSIONS

The correlation analysis of soil physical and chemical properties showed a strong negative relationship (r > -0.71) between BD and K_s, BD and VTP, BD and nitrate-N content, and BD and θ_e. A strong positive relationship (r > 0.7) was obtained between K_s and θ_e and K_s and VTP. The critical levels were obtained for the key soil properties using the measured data to understand the sustainability of a land use system for the southern New Mexico. This study showed that soil bulk density and macroporosity were limiting factors primarily due to the soil texture and the conventional tillage system practiced in the study area. The water transmission and retention properties were also moderately limiting. The cumulative rating for the land use and management system suggested that the present land use is sustainable with high input.

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REFERENCES

Blake, G.R. and K.H. Hartge. 1986. Bulk density. *In* Methods of Soil Analysis, Part I. A. Klute (ed.). ASA Monograph No. 9. ASA, Madison, WI, p.363-376.

Bulloch, H.E. and R.E.Neher. 1980. Soil survey of Dona Ana county area New Mexico. United States Department of Agriculture, Soil Conservation service.

Doran, J.W. and T.B. Parkin. 1994. Defining and assessing soil quality in defining soil quality for a sustainable environment. In: Doran et al. (Eds.) Soil Sci. Soc. Am. Spec. Publ. No. 35, Madison, WI, p3-21.

Gantzer, C.J. and G.R. Blake. 1978. Physical characteristics of a Le Seur clay loam following no till and conventional tillage. Agron. J., 70:853-857.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. *In* Methods of Soil Analysis, Part 1. 2nd Ed. A. Klute (ed.) Agron. Monogr. No.9. ASA, Madison WI, p.337-382.

Greenland, D.J. 1977. Soil damage by intensive arable cultivation: temporary or permanent? Phil. Trans. Roy Soc. London, B, 281: 193-208.

Jordahl, J.I. and D.L. Karlen. 1993. Comparison of alternative farming systems. Soil aggregate stability. Am. J. Altern. Agric. 8:27-33.

Klute, A. 1986. Water retention: Laboratory methods. *In* Methods of Soil Analysis, Part 1. 2nd Ed. A. Klute (ed.) Agron. Monogr. No.9. ASA, Madison WI, p.653-661.

Klute, A. and C. Dirkson. 1986. Hydraulic conductivity and diffusivity: Laboratory methods. p.687-734. In A. Klute (ed.), Methods of Soil Analysis, Part I. ASA Monograph No. 9, Madison, WI.

Lal, R. 1994. Methods and guidelines for assessing sustainable use of soil and water resources in the tropics. Soil Management Support Services, USDA-NRCS, Washington, D.C

Larson, W.E. and F.J. Pierce. 1991. Conservation and enhancement of soil quality, in evaluation for sustainable land management in the developing world. Vol. 2, IBSRAM Proc. 12(2). Bangkok, Thailand. Int. Board for Soil Res. and Management.

Leamer, R.W. and B. Shaw. 1941. Simple Apparatus for Measuring Non-Capillary Porosity on an Extensive Scale. J. Am. Soc. Agron. 33:1003-1008.

Maynard, D.G., and Y.P. Kalra. 1993. Nitrate and exchangeable ammonium nitrogen. p. 25-38. *In* M. R. Carter (ed.) Soil sampling and methods of analysis, Can. Soc. Soil Sci., Lewis Publishers, Ann Arbor, MI.

SAS Institute. 1989. SAS/STAT user's guide. Version 6. 4^{th} ed. Vol. 1 and 2. SAS Inst. Cary, NC.

Shukla, M. K., R. Lal, and M. Ebinger. 2003. Tillage effects on physical and hydrological properties of a typic Argiaquolls in central Ohio. Soil Sci. 168: 802-811.

Shukla M.K., R. Lal, and M. Ebinger. 2004. Soil quality indicators for the Northern Appalachian experimental watersheds in Coshocton Ohio. Soil Sci. 169: 195 - 205.