The effect of tillage and nitrogen application on soil water retention, hydraulic conductivity and bulk density at Loskop, KwaZulu-Natal, South Africa

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Abstract
The effects of agricultural management practices on soil physical parameters provide fundamental information for assessing sustainability. Tillage and fertilizer rates were evaluated for their effects on soil bulk density (P_b), water retention characteristics and saturated hydraulic conductivity (K_s) on a clay loam (Typic Haplustox). The field experiment was initiated in 2003 and planted to dry-land maize. Tillage regime and limestone ammonium nitrate (LAN) application rate significantly affected soil physical properties in the topsoil (0 - 5 cm). Under no-till (NT) the P_b, saturated water content and K_s were considerably lower than under conventional tillage (CT) and greater plant available water was retained under NT. At 200 kg N/ha P_b, water retention and K_s was significantly lower than at the lower rates of LAN application, especially under NT. These results suggest there is a need to re-evaluate the sustainability of using high rates of LAN to increase crop yields, especially under NT systems.

Key Words
Soil quality, soil physical properties, conservation tillage, nitrogen fertilizer

Introduction
Soil quality is linked to human health and environmental sustainability. As such, there is a need to evaluate the effect of agroecosystems on soil quality (Janke and Papendick, 1994). Tillage alters the physical, chemical and biological properties of soil ecosystems (Doran, 1980) and thus it is an agricultural practice of particular interest in its effect on soil quality. A large body of literature has accumulated on the sustainability of various agricultural practices and their long-term effects on soil and environmental quality (e.g. Jackson *et al*., 2003; Spedding *et al*., 2004; Riley *et al*., 2008; Fuentes *et al*., 2009). Much of the published literature focuses on the role of different tillage systems with an emphasis on conservation tillage in commercial farming systems in developed countries. However, there is a deficit of similar research on the African continent, where agro-ecological and socio-economic conditions differ markedly from those experienced in developed countries (Fowler and Rockstrom, 2001). In view of this, an investigation was undertaken of the effects of nitrogen application and tillage practice on soil physical properties, as part of a wider study, at a field experiment in KwaZulu-Natal, South Africa.

Field experiment
The field experiment was established in 2003 at Gourton Farm, near Loskop (KwaZulu-Natal Province, South Africa) to investigate the combined effects of cultivation methods (no-till and conventional tillage) and nitrogen application (urea and limestone ammonium nitrate (LAN)) on maize yield and soil fertility. The field trial includes three tillage treatments, namely no-till (NT; direct seeding into undisturbed soil), annual conventional tillage (CT1; annual ploughing with a moldboard plough to a depth of 30 cm, followed by disking) and conventional tillage (CT5; conventional tillage after every four seasons of no-till). Nitrogen is applied at five rates to each tillage treatment as either urea or LAN. In the 2008/2009 season nitrogen was applied at application rates of 0, 50, 100, 150 and 200 kg/ha (previously 0, 40, 80, 120 and 160 kg/ha) due to a linear response in maize production to the fertilizer application rate used in the 2007/2008 season. Lime is applied at a rate of 2 Mg/ha every second season to the entire trial. The trial is arranged as a split plot design; with randomized tillage strips forming whole plots and N source and rate of application forming sub-plots which are randomized within the whole plots. Each treatment is replicated three times (three blocks). Each sub-plot has 12 rows each of 9.5 m of maize at a density of 70 000 plants/ha. The area is cropped to dry-land maize in the summer and stands fallow in the winter. Wheels from mechanized equipment are restricted to inter-rows 1, 3, 5, 7, 9 and 11.

Materials and methods

The soil is classified as Hutton form (Soil Classification Working Group, 1991); Typic Haplustox (Soil Survey Staff 2003) with a clay-loam texture. Only the plots under NT and CT1 were investigated with N (applied as LAN) application rates of 0, 100 and 200 kg/ha (6 treatments). Three undisturbed soil cores (50 mm height x 75 mm diameter) were collected from the topsoil (0 - 5 cm) in each plot and a single core was collected from each of inter-rows 4, 8 and 10 (unaffected by wheeled traffic). Cores were collected 20 weeks after planting. The cores were prepared and analysed for water retentivity characteristics, saturated hydraulic conductivity (K_s) and bulk density (P_b) using the method of Moodley *et al.* (2004). Water retention characteristics were determined at 0, -1, -2, -4, -6, -8 -33 and -100 kPa matric potential using a tension table and pressure plate apparatus (Avery and Bascomb 1974), after which K_s was determined prior to oven drying for determination of P_b. A value of -33 kPa was used to represent field capacity (Givi *et al.,* 2004). Wilting point (-1500 kPa) moisture content was determined in a high pressure chamber apparatus using <2 mm soil samples.

To determine K_s an empty core was taped to the soil core to increase the length and the soil sample was re-saturated by capillary wetting. The core was then placed on a steel mesh held inside a funnel and K_s measured by the constant head method (Klute and Dirksen, 1986).

Treatment effects on P_b , K_s, total porosity, moisture content at field capacity and wilting point were analysed by ANOVA (GENSTAT, 12th edition). Where significant overall effects were found, means were compared by LSD at the 5% level of significance.

Results and discussion

Tillage has a considerable impact on the soil physical properties in the upper 5 cm of the soil profile. Bulk density is significantly ($p = 0.015$) greater under NT than under CT (Table 1).

Table 1. The effect of no-till (NT) and annual conventional tillage (CT) on bulk density and saturated hydraulic conductivity in the topsoil (0 - 5 cm) at different application rates of nitrogen fertilizer.

Fertilizer application rate (kg N/ha)	Bulk density (g/cm^3)		Saturated hydraulic conductivity (mm/hr)	
	NT	CT	NT	CT
0	1.40	1.35	220	426
100	1.38	1.32	212	395
200	1.53	1.38	121	157

Under CT the bulk density in the plough layer is lowered by the mechanical inversion of the soil during tillage which creates macropores and increases soil porosity. Many authors (e.g. Osunbitan *et al*., 2005; Bescansa *et al*., 2006) have found that bulk density in the top 5 to 20 cm of soil is greater under conservation tillage compared to CT up to 10 years after conversion to conservation tillage. Higher bulk density under NT corresponds to the significantly ($p = 0.008$) lower saturated water content (Figure 1) and lower K_s (Table 1) under NT compared to CT. Tillage-induced macropores allow more water to be held at saturation. However, plant available water is greater under NT than under CT, which had a significantly ($p = 0.024$) higher volumetric water content under NT at field capacity (-33 kPa; Figure 1). This is due to a higher proportion of mesopores which is a consequence of increased aggregate stability that allows for the maintenance of soil structure.

The application rate of LAN fertilizer also has a marked effect on the soil physical properties in the soil surface. An application rate of 200 kg N/ha significantly increased bulk density (Table 1) and lowered the water retention (Figure 2) at all matric potentials, especially under NT .Comparisons by LSD(5 %) indicate that the volumetric water content at 0 kPa and -33 kPa in the 200N treatment is significantly ($p < 0.001$) lower than the 100N and 0N fertilizer treatments. In addition, there is a decrease in K_s at 200 kg N/ha under both NT and CT compared to the lower rates of nitrogen fertilizer application (Table 1). It is proposed that the high application rate of fertilizer on the soil surface is an irritant to soil fauna and thus pore formation and aggregate stability are reduced leading to higher bulk density and lower moisture retention. Under CT the negative effect of 200 kg N/ha is less marked as the effect of ploughing dominates leading to greater soil macroporosity.

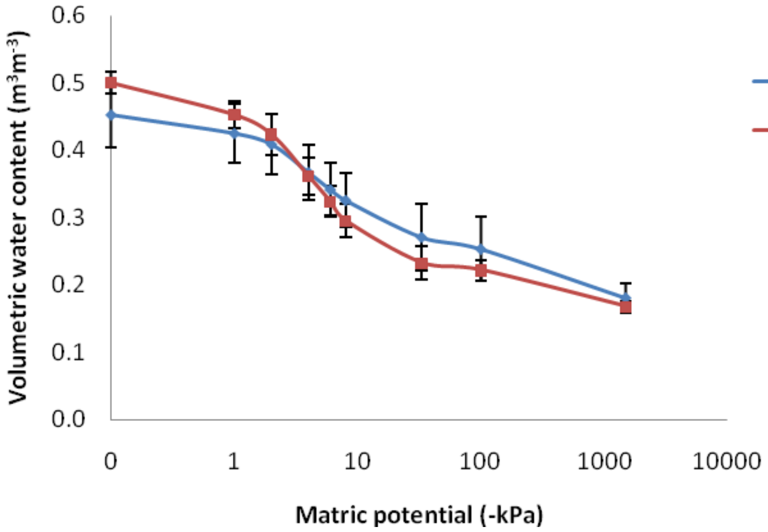

Figure 1. The overall effect of no-till (NT) and annual conventional tillage (CT) averaged across fertilizer treatment (n = 9) on the water retention characteristics for the topsoil (0 - 5 cm).

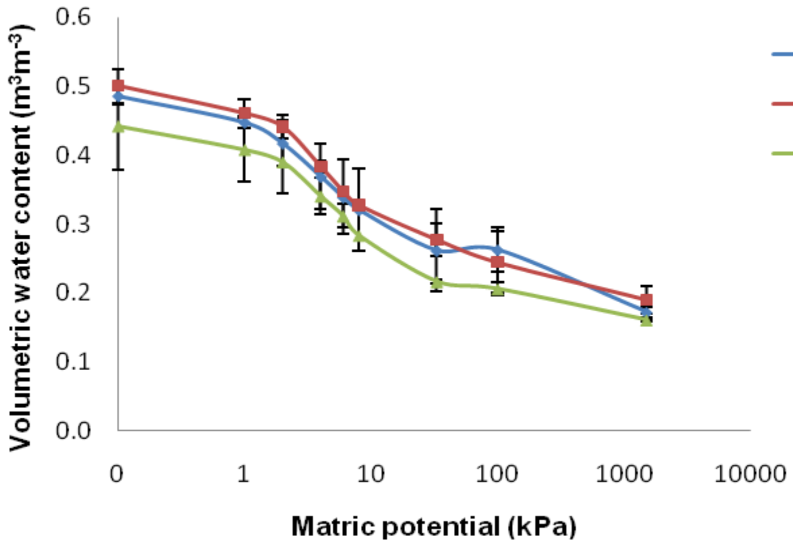

Figure 2. The overall effect of limestone ammonium nitrate (LAN) fertilizer application rate (0 kg N/ha (0N), 100 kg N/ha (100N) and 200 kg N/ha (200N) averaged across tillage treatment (n = 6) on the water retention characteristics for the topsoil (0 – 5 cm).

Conclusion

Although soils under CT have greater saturated water content and lower bulk density the water retained within the plant available range (-33 to -1500 kPa) is greater under NT. Furthermore, plant growth under NT is not adversely affected by reduced porosity and therefore NT is the preferred tillage practice to provide long-term sustainability and soil quality without causing negative soil structural properties for crop productivity in the short-term. In addition although the increased levels of nitrogen fertilizer results in higher yielding maize plants, the effect of high application rates of LAN result in a negative effect on the soil physical properties. This suggests that the mechanisms for these negative impacts need to be investigated.

References

Avery BW, Bascomb CL (1974) Soil Survey Laboratory Methods. Rothamsted Experimental Station, Harpenden.

Bescansa P, Imaz MJ, Enrique A, Hoogmoed WB (2006) Soil water retention as affected by tillage and residue management in semiarid Spain. *Soil and Tillage Research* **87**, 19-27.

Doran JW (1980) Soil microbial and biochemical changes associated with reduced tillage. *Soil Science Society of America Journal* **44**, 765-771.

Fowler R, Rockstrom J (2001) Conservation tillage for sustainable agriculture: An Agrarian revolution gathers momentum in Africa. *Soil and Tillage Research* **61**, 993-1007.

Fuentes M, Govaerts B, De Leon F, Hidalgo C, Dendooven L, Sayre KD, Etchevers J (2009) Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. *European Journal of Agronomy* **30**, 228-237.

Givi J, Prasher SO, Patel RM (2004) Evaluation of pedotransfer functions in predicting the soil water contents at field capacity and wilting point. *Agricultural Water Management* **70**, 83-96.

Jackson LE, Calderon FJ, Steenwerth KL, Scow KM, Rolston DE (2003) Responses of soil microbial processes and community structure to tillage events and implications for soil quality. *Geoderma* **114**, 305-317.

Janke RR, Papendick RI (1994) Preface. In `Defining soil quality for a sustainable environment`. (Eds JW Doran, DC Coleman, DF Bezdicek, BA Stewart), pp. ix-xi. (SSSA, Madison).

Klute A, Dirksen C (1986) Hydraulic Conductivity and Diffusivity: Laboratory Methods. In `Methods of Soil Analysis, Part 1`. (Ed A Klute) (ASA, SSSA, Madison).

Moodley M, Johnston MA, Hughes JC, Titshall LW (2004) Effects of water treatment residues, lime, gypsum, and polyacrylamide on the water retention and hydraulic conductivity of two contrasting soils under field conditions in KwaZulu-Natal, South Africa. *Australian Journal of Soil Research* **42**, 273-282.

Osunbitan JA, Oyedele DJ, Adekalu KO (2005) Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. *Soil and Tillage Research* **83**, 57-64.

Riley H, Pommeresche R, Eltun R, Hansen S, Korsaeth A (2008) Soil structure, organic matter and earthworm activity in a comparison of cropping systems with contrasting tillage, rotations, fertilizer levels and manure use. *Agriculture, Ecosystems and Environment* **124**, 275-284.

Soil Classification Working Group (1991) Soil classification: a taxonomic system for South Africa. Department of agricultural development. Pretoria. p. 241.

Soil Survey Staff (2003) Keys to Soil Taxonomy. 9th edition, USDA, Natural Resources Conservation Service, U.S. Government Printing Office, Washington, DC.

Spedding TA, Hamel C, Mehuys GR, Madramootoo CA (2004) Soil microbial dynamics in maize-growing soil under different tillage and residue management systems. *Soil Biology and Biochemistry* **36**, 499-512.