CHANGES IN SOIL PHYSICAL PARAMETERS OF A VIRGIN SOIL DUE TO COMPACTION BY COMMERCIAL SUGARCANE HAULAGE VEHICLES

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KEYWORDS: Soil Bulk Density, Soil Penetration Resistance, Axle Load Pressure, Radial Tyres, High Flotation Tyres.

Abstract

SOIL COMPACTION is often studied by comparing virgin field sites with commercial fields that have experienced long-term cultivation histories. Implementation of a new experiment farm in a virgin area of Mpumalanga Province, South Africa, provided the opportunity to repeatedly induce compaction over a period of three years to quantify the buffer capacity of a virgin soil against degradation. The soil of the trial site was a shallow (0.4 m) Cambisol with 38 to 44% clay, and 3.6 to 4.0% organic matter in the A-horizon, overlying weathered basalt. Following clearing of native bush from the virgin site, sugarcane was planted (2002) at 1.8-m row spacing which perfectly aligned with wheel spacing of the haulage vehicles, which were the only vehicles allowed in the field throughout this 4-year study. Three compaction treatments were imposed, including no vehicular traffic (control) and two compaction treatments consisting of pressure applied once per annum with commercial 30-tonne capacity loaded haulage vehicles fitted with either radial tyres or high flotation tyres. Compaction effects on soil properties and sugarcane yield were assessed on both dry soils and wet soils during the latter half of the 4-year study. Results show reduced water infiltration rates, increased soil bulk density, increased penetration resistance, and reduced root distribution in all the compaction treatments. Soils with higher water contents were more susceptible to degradation. It is concluded that even a virgin soil in very good condition will be degraded over a period of a few years to the physical threshold limits.

Introduction

Factors such as soil water content, texture, structure and organic matter affect the final density of soils. Taylor and Pohlen (1962) proposed a guide to benchmark the bulk density classes of uncompacted virgin soils.

From a survey of 28 soil profiles covering most of the South African sugar industry, Meyer (1985) concluded that typical wet bulk densities of uncompacted grey hydromorphic soils were >1.7 tonnes/m^3, for red soils (well drained and aerated) between 1.3 and 1.6 tonnes/m^3 and for black soils (high clay content) between 1.2 and 1.5 tonnes/m^3.

The objective of this paper is to quantify degradation of a virgin soil caused by two infield haulage traffic management systems under two different soil water content levels relative to a system with no wheel traffic.

Materials and methods

The field trial was established on a newly acquired South African Sugarcane Research Institute (SASRI) experimental farm near Komatipoort (Latitude –25.553, Longitude 31.955, Elevation 166 m) in the northeastern corner of South Africa. In preparation for trial work, the natural vegetation was removed with a bulldozer. The soil was a Cambisol (World Reference Base published by FAO, ISRIC & IUSS, 1999; Hutton/Glenrosa, Soil Classification Working Group, 1991) with between 3.6 and 4.0% organic matter and between 38 and 48% clay in the surface 100-mm soil profile. Depth of the A-horizon ranged from 300 mm to 700 mm after which it abruptly changed into weathered basalt.

The site was planted to sugarcane (variety N32) in July 2002 in a tramline arrangement (1.2 m inter-row space and 0.6 m cane row space), and the first compaction treatments were applied after the plant crop was harvested in July 2003. This was repeated in 2004 and 2005.

All vehicle-applied treatments could not be randomised due to the size of the vehicle and the space required to turn. Each treatment was replicated four times. The three compaction treatments included no soil compaction (control), and compaction applied with a fully loaded 30-tonne Mercedes Powerliner rigid truck fitted either with conventional radial tyres or high flotation tyres. The pressure in the high flotation tyres was approximately 20% and 50% lower for the front and back tyres respectively compared with the pressure in the radial tyres (Table 1).

Table 1—Axle load (tonne/axle) and vertical pressure per wheel (kPa) of a laden truck.

Axle	Radials				High flotation			
	2003		2004		2003		2004	
	t/axle	kPa	t/axle	kPa	t/axle	kPa	t/axle	kPa
1st	7.26	527	7.62	553	7.38	535	7.7	559
2nd	9.04	164	10.38	188	8.6	122	10.3	145
3rd	7.62	138	9.14	166	7.52	106	9.1	128

In 2003, compaction was applied when the soil water content was near permanent wilting point only. In 2004 and 2005, soil compaction was applied at two levels of soil water content, near permanent wilting point and near field water capacity by irrigating (30 mm) 3 days before compaction. Changes in soil properties due to compaction by a fully loaded cane truck were quantified by bulk density, resistance to penetration and water infiltration rates.

Clay content was determined with the hydrometer method (Day, 1965). The soil's resistance to penetration by a steel rod fitted with a 12.5 mm wide cone tip (129 mm^2 surface area) was determined with a computer-controlled penetrometer using a depth penetration rate of 1080 mm/minute. Resistance was recorded at 5-mm intervals to a maximum soil depth of 500 mm on the inter-row areas in triplicate. Because soil water content was different between years of measurement, the original data were weighted for soil water content using equation 1. Water infiltration rates were determined using the double ring infiltrometer as described by Bouwer (1986).

Adjusted resistance (kPa) = resistance (kPa) × (current soil water content / field water capacity) (1)

The penetrometer data for depths 100 mm and 150 mm were averaged (the depths with the highest resistance values) and log transformed before analysis with restricted maximum likelihood analysis (REML; Genstat, 2006). Significant differences between each level of the main effects (i.e. year, water, tyre) and their interactions were established by the Wald's test for fixed effects in REML. The Sidak allpairwise multiple comparison test and the t-test were used to quantify significant differences. The dry soil bulk density data were not transformed and significant differences between each level of the main effects (i.e. year, tyre) and their interactions were established by the Wald's test for fixed effects in REML. Least significant difference (LSD) allpairwise multiple comparison test was used to quantify these significant differences (at 5% level).

Results and discussion

Soil dry bulk density was significantly higher in 2005 and 2006 compared to 2004 over all depths (Table 2). However, the difference between 2005 and 2006 was not significant at the 5% level, suggesting that the maximum density has already been reached in 2005. Results analysed for the effect of tyre type on soil bulk density over three compaction events showed significant increases in bulk density irrespective of tyre type. The exception, however, was at a depth of 50 mm, where the use of high flotation tyres did not result in a significant increase in bulk density compared to the control where no vehicles were allowed despite the fact that the pressure in the front wheels was 20% lower compared to that in the radial tyres.

Table 2—Soil bulk density (t/m^3) as affected by number of compaction events (once per annum) and tyre type. Data were analysed separately for years, tyre type and depth.

Depth mm	2004		2005		2006		Control		HF		Rad	
50	1.124	a	1.268	b	1.195	ab	1.155	x	1.200	xy	1.231	y
150	1.240	c	1.387	d	1.366	d	1.269	v	1.380	w	1.344	w
300	1.327	e	1.430	f	1.482	f	1.365	r	1.482	s	1.391	r

Data followed by the same letter within each group (years or tyre type or depth) were not significantly different (5% level) from each other. HF = High Flotation tyre, Rad = Radial tyre

Based on t-test analysis for significance within years, penetration resistance between the dry and wet areas was only significantly different in 2004 and 2005 (data not shown). This corresponds perfectly with water management as additional water was only applied to the 'wet area' in the latter two years. The effect of compaction treatment (control= no tyres; high flotation tyres; radial tyres) on soil penetration resistance showed that the values from the dry areas were not significantly different between treatments (Figure 1). Regarding the wet areas, soil penetration resistance values were not significantly different between the control and high flotation treatments and both latter treatments were significantly smaller compared to values from the radial tyre treatment.

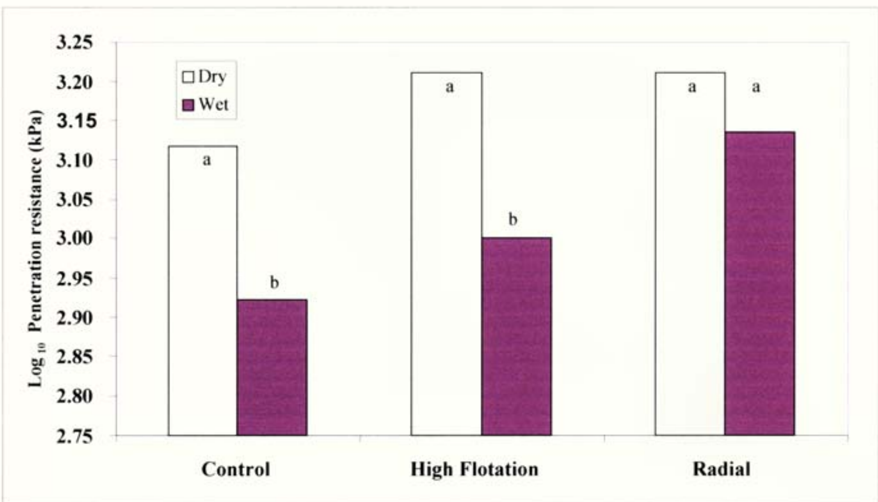

Fig. 1—Soil penetration resistance comparisons between compaction treatments (values averaged over four years) taking water management into account. Significant treatment differences were determined with the Sidak test. Bars with the same letter were not significantly different (at the 5% level of significance). Penetration resistance values on the Y-axis were $\log_{10}$ transformed before the analysis.

Water infiltration rates were determined in 2006 and revealed the damaging effects of tyres relative to non-traffic areas (control) (Figure 2). In general, wheel traffic reduced water infiltration rates by a factor of four. Neither soil water content (data not shown) nor the type of tyre used seemed to have made a difference in the severity of this reduction in water infiltration.

Cane yields showed no significant differences across all treatments and water regimes from the plant crop to the third ratoon.

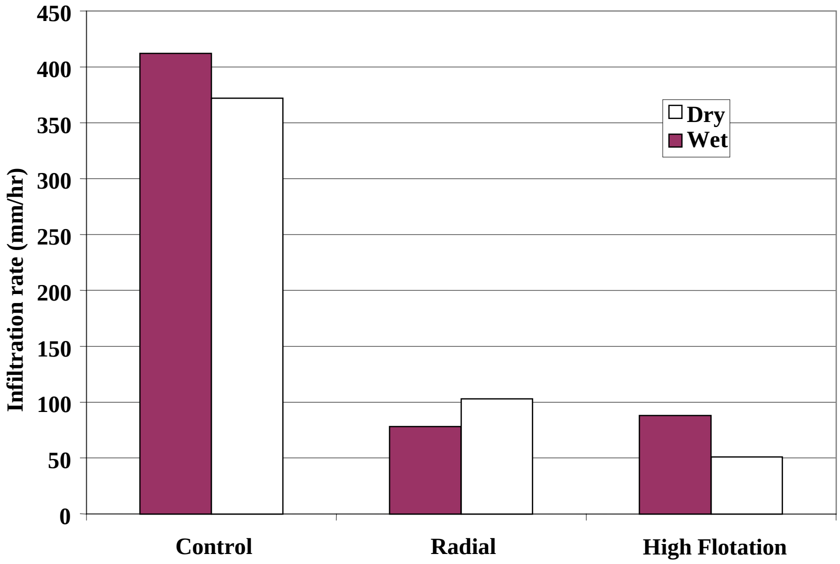

Fig. 2—Water infiltration rates measured in the inter-row area for three treatments and two soil water regimes. Values are the means from only two measurements.

Conclusions

The pristine condition of a virgin soil was not enough to protect it against degradation, which started to shown signs of being compacted after only the second compaction effort. Soil bulk density data also showed that high flotation tyres had a slightly reduced compactive effect compared to radial tyres. However, it is expected that this difference will be much greater should the pressure of the front steering wheels in high flotation tyres be significantly lower compared to the radial tyres. However, soil penetration measurements were nevertheless able to show that the use of high flotation tyres in wet conditions was less destructive on the soil compared to radial tyres.

Although this virgin soil offered some resistance to compaction, it was not sufficient and was degraded to the point where it was classified as compacted after only three once-per-annum compaction efforts by laden commercial haulage vehicles. However, due to appropriate row spacing, cane stools were kept away from vehicle wheels which resulted in no yield loss, i.e. inter-row soil compaction was not damaging to cane yields.

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CHANGEMENTS DES CARACTERISTIQUES PHYSIQUES D'UN SOL VIERGE INDUITS PAR LA COMPACTION DU MATÉRIEL DE TRANSPORT DE LA CANNE À SUCRE

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MOTS-CLES: Densité Apparente, Résistance à la Pénétration, Charge à l'Essieu, Pneus Radiaux, Pneus de Basse Pression.

Résumé

LA COMPACTION des sols est souvent étudiée par la comparaison de parcelles non cultivées à des parcelles exploitées depuis longtemps en culture intensifiée. La création d'une nouvelle station d'essai dans un secteur vierge de toute culture dans la province d'Mpumalanga, Afrique du Sud, a été l'occasion d'induire de la compaction sur une période de trois ans afin de quantifier la capacité tampon de sols vierges contre leur dégradation. Le sol du site d'expérimentation était un Cambisol peu profond (0.3m, localement jusqu'à 0.7m), reposant sur du basalte peu altéré, à 38 – 44% d'argile et 3.6 à 4.0% de matière organique dans l'horizon A. Après défrichement des broussailles du site vierge, la canne à sucre a été plantée en 2002 avec un espacement entre les lignes 1.8m de sorte que cela corresponde parfaitement à l'écartement des pneus des véhicules de transport de la canne récoltée, les seuls véhicules qui étaient autorisées à entrer dans le champ lors de cette étude de 4 ans. Trois traitements de compaction ont été appliqués, comprenant aucune circulation des véhicules (le témoin) et deux traitements dans lesquels la compaction était provoquée par le passage, une fois l'an, à la récolte, de véhicules de transport de capacité de 30 tonnes, équipés soit de pneus radiaux soit des pneus à basse pression. Les effets sur les propriétés de sol et sur la production de la canne à sucre ont été évalués pendant la dernière moitié de cette étude de 4 ans, aussi bien sur des sols secs qu'humides lors du passage des véhicules. Les résultats obtenus montrent une vitesse d'infiltration d'eau réduite, une augmentation de la densité apparente et une réduction de l'enracinement et de la résistance à la pénétration du sol dans tous les traitements induisant une compaction. Ils montrent aussi que l'effet sur les sols humides était plus important. On en conclut que même un sol vierge en très bon état sera physiquement dégradé en quelques années par les véhicules ramassant dans les parcelles la canne récoltée.

CAMBIOS EN LOS PARÁMETROS FÍSICOS DEL SUELO DE UN SUELO VIRGEN DEBIDO A LA COMPACTACIÓN DE VEHÍCULOS DE TRANSPORTE COMERCIAL DE CAÑA DE AZÚCAR

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PALABRAS CLAVE: Densidad de Bloque de Suelo, Resistencia a la Penetración al Suelo, Presión de Carga de Eje, Neumáticos Radiales, Neumáticos de alta Flotación.

Resumen

LA COMPACTACIÓN de los suelos generalmente es estudiada comparando sitios de suelos vírgenes con campos comerciales que han experimentado un historial de siembras de largo plazo. La implementación de una nueva finca experimental en el área virgen de la Provincia de Mpumalanga, Suráfrica, proporcionó la oportunidad de inducir repetidamente una compactación en un período de tres años para cuantificar la capacidad de amortiguamiento de un suelo virgen contra la degradación. El suelo del sitio del ensayo era un Cambisol superficial (0.4 m) con 38 a 44% de arcilla, y 3.6 a 4.0% de materia orgánica en el horizonte A, sobrepuesto a un basalto temperizado. Luego de la limpieza de los arbustos nativos del sitio virgen, la caña de azúcar fue plantada (2002) con un espaciamiento de surcos a 1.8-m con un alineamiento perfecto con el espaciamiento de las ruedas de los vehículos de transporte, que eran los únicos vehículos autorizados en los campos durante el estudio de 4 años. Tres tratamientos de compactación fueron impuestos, incluyendo sin tráfico vehicular (testigo) y dos tratamientos de compactación consistentes en presión aplicada una vez por año con vehículos comerciales de transporte cargados con su capacidad de 30 ton y equipados con neumáticos radiales o neumáticos de alta flotación. Los efectos de la compactación en las propiedades del suelo y el rendimiento de la caña de azúcar fueron determinados tanto en suelos secos como húmedos durante la última mitad del estudio de cuatro años. Los resultados muestran tasas reducidas de infiltración de agua, aumentos en la densidad de bloque del suelo, aumentos en la resistencia a la penetración, y una menor distribución de raíces en todos los tratamientos de compactación. Suelos con más altos contenidos de agua eran más susceptibles a la degradación. Se concluyó que aún un suelo virgen en muy buenas condiciones se degradará en unos pocos años a los límites de los umbrales físicos.