THE EFFECT OF RESIDUE MANAGEMENT AND VEHICLE CHARACTERISTICS ON SOIL COMPACTION

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Abstract

Two soil compaction trials were conducted at Riverside and Kaalrug near Malelane in the northern irrigated area of the South African sugar industry. Treatments for the trial at Riverside were fresh citrus peel incorporated at 318 tons/ha (95 ton/ha dry material), dry cane trash at 30 tons/ha left on the soil surface and a combination of these two. Compaction was applied by driving a 30 ton rigid truck/trailer combination either on the interrow or the row. Treatments at the Kaalrug trial were compaction at various soil water contents using a 30 ton payload truck fitted with radial tyres, a similar vehicle fitted with high flotation tyres and a 52 kW tractor with a 5 ton payload trailer both fitted with radial tyres.

The Riverside trial showed that incorporated citrus peel combined with trash left on the surface at 30 tons/ha was effective in reducing damage due to compaction. Soil water content at the time of compaction at Kaalrug was a major factor affecting the final soil bulk density rather than the type of vehicle causing compaction. Maximum soil strength was obtained at a depth of only 50 mm with all vehicles and its magnitude was strongly affected by the amount of soil water present at the time of compaction. Significant increases in soil bulk density were measured to a depth of at least 300 mm.

Keywords: sugarcane, compaction, organic matter, soil water content, tyres

Introduction

Cane growers and contractors generally do not wait for the soil water content (SWC) to decline below the critical value at which soil compaction due to infield traffic has no significant effect on yield. They tend to stay out of wet fields only if there is a danger of vehicles becoming bogged down. Such action destroys soil structure and leads to severe compaction and loss of cane yield. Therefore, revised recommendations are needed to reduce yield loss and the area affected by compaction.

In laboratory studies reported by Ekwue and Stone (1995), Ohu *et al.* (1985), van Antwerpen (2001) and Zhang (1994) increased levels of soil organic matter were found to be effective in reducing the density to which soils can be compacted. More important, however, is the longevity of this effect. In sugar industries worldwide cane is harvested predominantly on an annual basis, which means that the applied and/or incorporated organic matter has to be present for at least 12 months before its effects on reducing soil compaction can be measured. This means that long term field trials are required, which evaluate the effectiveness of incorporated organic matter. Paul (1974) reported on the effect of incorporated filtercake on soil physical properties, but samples were taken only four months after the field trial was established.

This paper reports on two trials which studied the effect of incorporated organic matter on soil compactibility and the depth to which two soils can be compacted as affected by different soil water contents, types of tyres fitted to a range of infield equipment and axle loadings.

Experimental procedure

Trial 1: Riverside

The first trial was established at Riverside near Malelane on a shallow (300 to 700 mm) Hutton (Oxisol) form soil containing 24 to 30% clay, 9 to 13% silt and 1.2 to 1.9% organic matter in the topsoil. All cane was burnt before harvest and treatments were with (C) and without (Co) organic matter incorporated as fresh citrus peel at 318 tons/ha (95 ton/ha dry material), with (T) and without (To) dry cane trash applied to the soil surface at 30 tons/ha. In each of these treatments a 30 ton payload truck (loaded to capacity) was driven once only either on the interrow (IR) or directly on the cane row (OR). The citrus peel had been incorporated to a depth of 150 mm prior to planting in June 1999 and the trash spread and compaction applied after harvesting the plant crop in July 2000. The vehicle used to apply compaction was a seven axle 6x4 rigid truck with a four-axle drawbar trailer (gross combination mass of 55 tons) fitted with dual standard radial ply tyres (315/80/22.5). Pressure in the front tyres was 820 kPa and 620 kPa in the remainder. Maximum load per axle was 9 tons on the back axle of the truck. Soil measurements taken before and after compaction were bulk density using a Troxler nuclear density gauge (model 3411-B) and soil penetration resistance using a computer controlled penetrometer. The penetrometer took readings at 5 mm intervals and penetrated the soil at a rate of 1000 mm per minute using a cone with a diameter of 20.27 mm and a surface area of 320 mm^2.

Trial 2: Kaalrug

The second trial was established at Kaalrug near Malelane on a deep (>1200 mm) Hutton form soil containing 61 to 66% clay, 9 to 11% silt and 2.9 to 3.4% organic matter in the topsoil. Treatments included compaction of the soil at various moisture contents using three types of vehicles. Vehicles used were two 30 ton payload 6x4 rigid trucks coupled to a four-axle drawbar trailer, fitted with either dual standard radial ply tyres (V1) or single Trelleborg high flotation tyres (V2). The third vehicle was a 52 kW standard two-wheel drive agricultural tractor with a 5-ton walking beam axle basket trailer fitted with radial ply tyres (V3). Tyre specifications for V1 were similar to those described for the Riverside trial and specifications for V2 were steering axle 400/65 26.5 and all other axles 620/50 22.5. Pressure in the front tyres was 250 kPa and in all other tyres it was 300 kPa. Tyres for V3 were tractor front 7.50/16 6 ply and back 16.9/30 6 ply. Trailer tyre specifications were 10.50/16 14 ply. Tyre pressures were 200 kPa on the tractor and 500 kPa on the trailer. Measurements made were similar to those described for the Riverside trial and were recorded before and after compaction. Irrigation was applied in the period between measurements to ensure soil bulk density readings were at different soil water contents. Bulk density for the 50 mm soil depth after compaction was applied, was not determined due to equipment failure. It is also for this reason that insufficient data were collected to analyse information statistically obtained after compaction was applied by vehicle type V2 (Table 3). Each treatment was replicated six times and statistical comparisons were made by comparing standard errors of treatment means.

Results and Discussion

Riverside trial

The large amount of fresh organic matter applied at the Riverside trial before planting (318 tons/ha) is normal for this estate. Soil water content in the field was very variable as in the interrow it was near field capacity (27% by volume), while in the row it was much drier (Table 1). The water content in the interrow was sufficiently high for the truck to become bogged down in places and data from the trial plots so affected were therefore not considered for analysis. The mean differences in soil water contents for measurements made before and after compaction were 4% and for the wet interrow and 3% for the drier row.

A single pass of the 55 ton capacity loaded truck (no more than 9 tons per axle) on the interrow of the treatment where no citrus peel or trash was applied, resulted in a significant increase in bulk density (348, 330 and 253 kg/m^3 at depths of 50, 150 and 300 mm respectively). Over this soil depth the smallest increase in bulk density (128 kg/m^3) was in the surface layer (50 mm) for treatments where citrus peel was incorporated (CTIR & CToIR) before planting (Figure 1). The beneficial effect of incorporated organic matter decreased with increasing soil depth, as the small increases in bulk density values found in the surface soil were not maintained. Comparison of interrow compaction treatments with (C) and without (Co) incorporated citrus peel showed that the largest difference (186 kg/m^3) in soil bulk density was associated with the surface soil layer. The differences in bulk density after compaction, between treatments with trash (T) and with no trash (To) were not significant (34 kg/m^3) and showed no clear trend. It was apparent that 30 tons/ha of surface applied cane trash was not sufficient to reduce the compactive effect of a vehicle transferring not more than 9 tons per axle. On the other hand 318 tons/ha citrus peel incorporated a year prior to compaction was effective in keeping soil bulk density values in the surface soil layer below those obtained further down the profile.

The effect that driving on the interrow had on soil bulk density on the row, is also shown in Figure 1. Where no citrus peel or trash were applied (CoToOR) the increase in bulk density on the row was significant for both depths shown (i.e. 50 and 150 mm). Where cane trash was applied (CoTOR) mean bulk densities were increased by compaction, but not significantly. Where citrus peel was incorporated before planting soil bulk density increased on the row due to lateral movement after interrow compaction, and surface applied trash had a small effect on the bulk densities obtained.

The greatest increase in soil bulk density due to compaction on the row (340, 296 and 162 kg/m^3 at depths 50, 150 and 300 mm respectively) was in the treatment where neither citrus peel nor trash (CoToOR) were applied (Figure 2). The reduction in bulk density relative to CoToOR where only cane trash was applied (CoTOR) was slight in the surface layer (43 kg/m^3) and not significant when compared with that where citrus peel had been incorporated (101 kg/m^3 for CToOR and 152 kg/m^3 for CTOR). The incorporated organic matter reduced soil bulk density only in the surface layer (compare before and after compaction results at 150 mm depth for treatments CToOR and CTOR, Figure 2). The depth to which the soil was compacted on the row was at least 300 mm. Although soil bulk density before compaction was similar in the interrow and row, after compaction the drier soil in the row plus the presence of the stool was not sufficient to keep soil bulk density at values below those in the interrow (Figure 2). The effect that compaction on the row (Figure 2) had on soil bulk density in the interrow (CoTIR, CoToIR, CTIR and CToIR) showed an increase for all treatments, but was not significant (Figure 2).

Table 1. Soil water content (volume by volume %) at three depths (cm) measured before and after compaction was applied at the Riverside trial site.

	Before			After		
Treatments	**50 mm**	**150 mm**	**300 mm**	**50 mm**	**150 mm**	**300 mm**
CoTIR	21	20	20	19	17	17
CoToIR	24	22	21	18	18	18
CoToOR	12	13	13	10	10	10
CoTOR	11	10	10	9	9	9
CTIR	24	22	22	19	17	17
CToIR	24	21	19	22	19	19
CToOR	12	10	10	9	8	8
CTOR	17	17	14	12	11	12

Co- No citrus peel incorporated C- Citrus peel incorporated @ 318 tons/ha To- No cane trash on surface
T- Cane trash applied @ 30 tons/ha OR- Measurements made on the row IR- Measurements made on the interrow

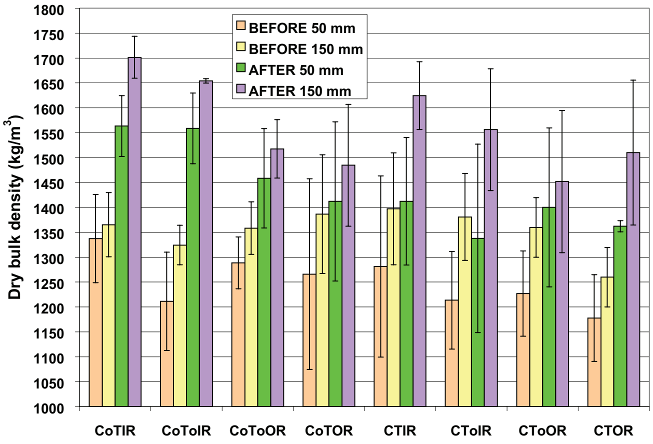

Figure 1. Mean dry bulk density (DD, kg/m³) for various treatments (Co = no citrus peel, C = citrus peel incorporated, To = no trash and T = with surface trash), two measurement positions (IR = interrow, OR = on the row) and two soil depths measured before and after the truck had passed through the field driving on the interrow at the Riverside trial site. The bars represent standard error of the mean.

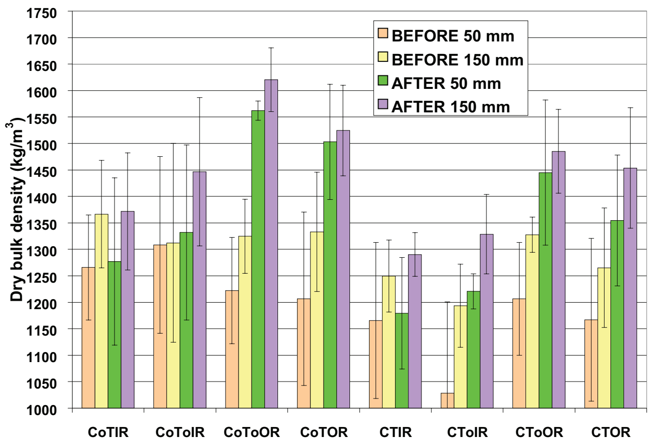

Figure 2. Mean dry bulk density (DD, kg/m³) for various treatments (Co = no citrus peel, C = citrus peel incorporated, To = no trash and T = with surface trash), two measurement positions (IR = interrow, OR = on the row) and two soil depths measured before and after the truck has passed through the field driving on the row at the Riverside trial site. The bars represent standard error of the mean.

Kaalrug trial

Surprisingly, the increase in soil bulk density was greatest for vehicle type 2 (V2), which was fitted with high flotation tyres, and was significant for the dry treatment only. Differences in soil water content can be ruled out when trying to explain this anomaly due to the fairly uniform values between all treatments (Table 2). A significant increase in bulk density was also obtained for vehicle type 3 (V3) in the dry treatment, but only at the 150 mm soil depth. However, the results in 2000 (Table 3) showed that the greatest differences between before and after applied compaction occurred at the 50 mm depth, and that these differences decreased with increasing depth and increased with increasing soil water content. In contrast with the 1999 results, those for 2000 showed the least bulk density increase in treatment V2 (high flotation tyres) and the greatest increase in treatment V1 (conventional radial tyres).

Due to equipment failure the effect of compaction on soil bulk density at the 50 mm depth could not be determined. However, soil strength measured with a penetrometer at 5 mm intervals (Figure 3) revealed that the highest resistances were recorded at a depth of only 50 mm below the surface for all vehicle types and moisture contents.

The applied compaction resulted in a net bulk density increase but did not appear to be linked to the vehicle type but rather to the amount of water present at the time of compaction (Figure 4). A similar relationship between dry bulk density and gravimetric moisture content was reported by Chancellor (1971). A possible reason for the lack of response was the net mass load per axle, which was relatively similar for vehicle types V1 and V2 (9.5 tons and 8.7 tons respectively) and only 4 tons for vehicle type V3. However, V3 was driven over the trial area three times to simulate the commercial cane extraction routines with similar equipment. Soil compaction from vehicles is independent of tyre pressure and is related to axle weight only where the load is above 5 tons (Soane, 1983).

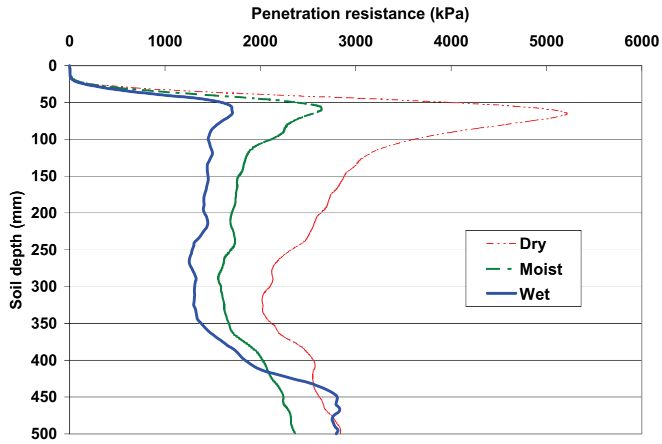

Figure 3. Mean soil penetrometer resistances for various moisture treatments at the Kaalrug trial site taken in the interrow.

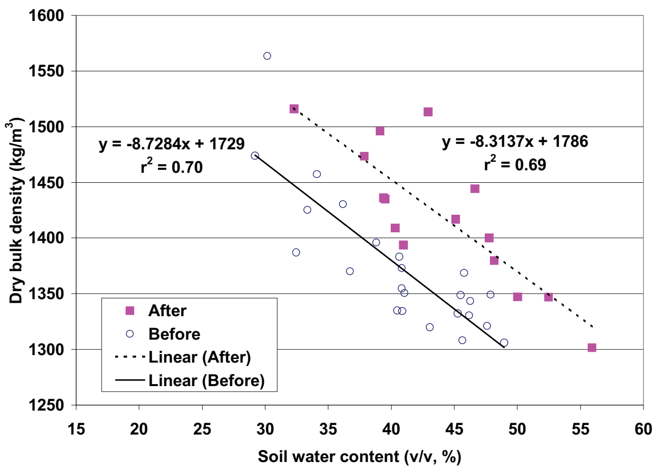

Figure 4. The effect of soil water content at time of compaction on dry bulk density determined with the Troxler nuclear density meter at the Kaalrug trial site. Field capacity was at 40% and permanent wilting point at 25% soil water content.

Table 2. Mean dry bulk density (DD) and soil water content (SWC, volume by volume %) for two depths and three moisture levels before and after compaction was applied in 1999 at the Kaalrug trial site. The trial site was irrigated after the 'before' measurements were made and before compaction was applied.

BEFORE 1999		**150 mm**			**300 mm**		
Treatment		**DRY**	**MOIST**	**WET**	**DRY**	**MOIST**	**WET**
C	Mean DD	1396	1349	1320	1387	1333	1324
	Std Error	81	67	58	79	72	91
	Mean SWC %	28	34	33	28	36	33
V1	Mean DD	1383	1330	1332	1352	1309	1316
	Std Error	26	59	89	27	80	84
	Mean SWC %	29	35	34	31	37	35
V2	Mean DD	1334	1321	1308	1313	1318	1298
	Std Error	37	58	40	18	66	32
	Mean SWC %	31	36	35	31	35	36
V3	Mean DD	1355	1369	1343	1359	1335	1354
	Std Error	72	34	66	52	76	66
	Mean SWC %	30	33	34	29	34	34
AFTER 1999							
V1	Mean DD	1394	1347	1301	1354	1280	1226
	Std Error	60	75	61	37	31	53
	Mean SWC %	29	39	43	30	41	46
V2	Mean DD	1435	1380	1347	1381	1296	1275
	Std Error	48	82	14	41	42	25
	Mean SWC %	28	35	37	28	37	39
V3	Mean DD	1436	1417	1400	1395	1376	1382
	Std Error	70	56	91	75	67	87
	Mean SWC %	27	32	34	29	33	33
DIFFERENCE (AFTER – BEFORE)							
V1	Mean DD	10	17	-31	1	-29	-91
V2	Mean DD	101	59	39	68	-22	-23
V3	Mean DD	81	48	57	36	40	29

Figure 5 shows that compaction applied in 1999 had no significant effect on cane yield in any of the treatment combinations. The reason was the inherently high resistance to deformation and compaction of soils with very high clay content such as that at the Kaalrug site (Chancellor, 1971; Smith *et al*., 1997). This strengthens the contention that stool damage is the major factor causing yield loss (Torres *et al.,* 1990) when compared with interrow compaction for soils with a high clay content.

Conclusions

Incorporation of organic matter can be effective in reducing the density to which soils may be compacted especially on highly compactible soils such as those with low organic matter. However, very few growers would have access to large quantities of organic matter, as is the practice at Riverside Farm. It is thus necessary to determine what could be regarded as an adequate amount of trash to incorporate to meaningfully reduce infield compaction effects, as this is a source of organic matter to which all growers have access. In a laboratory study van Antwerpen (2001) showed that where the organic matter content of a soil similar to that at Riverside was increased from 1.3 to 4%, the maximum density to which the soil could be compacted was reduced by between 5 and 19%, depending on the type of organic matter used. Sixty tons of air-dried organic matter would be needed to increase the soil organic matter content from 1.3 to 4%. However, the effect on N immobilisation of incorporating large amounts of cane trash (C:N ratio 150:1; Wood, 1966) would need to be carefully considered. Provision would have to be made to apply additional N fertilizer to lower the C:N ratio to ensure that nitrogen deficiency did not restrict cane growth. Incorporation of 22 tons/ha trash into a wide range of soils in the South African sugar industry would require about 200 kg N/ha to stimulate decomposition and to ensure sufficient N for crop growth (Wood, 1966). If the normal rate of N fertilisation is 160 kg/ha then an additional 64 kg N/ha would need to be applied for every 22 tons trash/ha used.

Cane trash left on the surface at 30 ton/ha was not sufficient to significantly reduce the compactive pressure exerted by a 30 ton payload transport vehicle. The only treatment that had consistently reduced dry bulk densities significantly was the combination of incorporated citrus peel and cane trash on the surface.

The results from Kaalrug showed that there is still much to be learnt regarding the dynamic interactions of soil under stress. It is difficult to explain why the increase in bulk density caused by a vehicle fitted with high flotation tyres was greater than

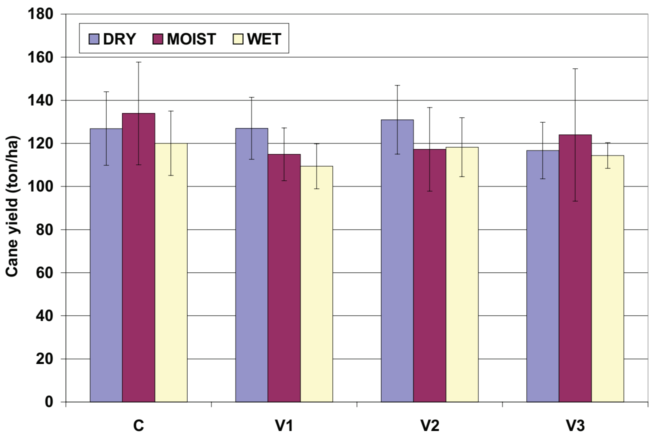

Figure 5. The effect that soil compaction caused by three different vehicles at three soil water contents had on cane yield at the Kaalrug trial site. The bars represent the standard error of the mean. C=control, V1=57ton truck fitted with radial tyres, V2=48ton truck fitted with high flotation tyres, V3=12ton tractor and trailer fitted with radial tyres.

that of a similar vehicle fitted with conventional radial tyres in the first year of the trial, while the situation was reversed in the following year. It may have been due to the amount of soil water present when measurements were taken, as it was noticeable that the driest treatments had the highest bulk densities and vice versa.

The increase in bulk density due to compaction was larger at the Riverside site (348 kg/m^3 at a depth of 50 mm), which had a lighter soil with lower organic matter than the heavier soil at the Kaalrug site (274 kg/m^3 for the 'wet' treatment at a depth of 50 mm). The highest mean soil bulk density measured in the interrow at the Riverside trial site was 1654 kg/m^3 at a depth of between 50 to 150 mm compared with 1536 kg/m^3 at a depth of between 150 to 300 mm at the Kaalrug trial site.

In order to alleviate interrow compaction, subsoiling to a depth of at least 100 mm or possibly to a depth of 300 mm could be considered. However, yields obtained indicated that interrow compaction had no significant effect on crop yield so that subsoiling would be of limited value and would serve only to improve water infiltration rates on the interrow.

Table 3. Mean dry bulk density (DD) and soil water content (SWC, volume by volume %) for three depths and three moisture levels before and after compaction was applied in 2000 at the Kaalrug trial site. The trial site was irrigated after the "before" measurements were made and before compaction was applied.

BEFORE 2000		**50 mm**			**150 mm**			**300 mm**		
Treatment		**DRY**	**MOIST**	**WET**	**DRY**	**MOIST**	**WET**	**DRY**	**MOIST**	**WET**
C	Mean DD	1236	1266	1415	1387	1474	1564	1378	1464	1490
	Std Error	127	69	98	103	28	86	56	28	39
	Mean SWC %	33	27	30	32	29	30	32	30	31
V1	Mean DD	1308	1200	1204	1430	1373	1306	1369	1390	1290
	Std Error	54	58	181	36	50	135	36	101	128
	Mean SWC %	34	41	49	36	41	48	36	32	48
V2	Mean DD	1324	1223	1271	1457	1335	1349	1384	1399	1328
	Std Error	52	117	69	36	39	51	24	140	146
	Mean SWC %	35	41	44	34	40	30	35	39	47
V3	Mean DD	1293	1243	1239	1425	1370	1350	1387	1412	1405
	Std Error	92	72	57	68	58	43	59	58	18
	Mean SWC %	33	36	41	33	37	41	33	37	41
AFTER 2000										
V1	Mean DD		1421	1478		1496	1514		1509	1486
	Std Error		56	23		23	9		13	58
	Mean SWC %		39	44		39	43		38	45
V2	Mean DD		1296	1438		1409	1444		1412	1428
	Std Error		NSD	NSD		NSD	NSD		NSD	NSD
	Mean SWC %		40	45		40	47		40	45
V3	Mean DD		1405	1428		1516	1474		1536	1488
	Std Error		73	89		31	78		58	66
	Mean SWC %		33	37		32	38		33	37
DIFFERENCE (AFTER – BEFORE)										
V1	Mean DD		220	274		123	207		119	196
V2	Mean DD		73	168		74	95		13	100
V3	Mean DD		161	190		146	123		124	83

NSD = Not sufficient data

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1 ton = 1000 kg