SOIL DEGRADATION - I: EFFECT OF FERTILISER USE ON PENETROMETER RESISTANCE

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Abstract

A 58-year old burning and trashing trial receiving fertiliser and no fertiliser was used to quantify treatment effects on soil penetrometer resistance. The results showed that penetrometer resistance was significantly lower in those treatments where no fertiliser was applied. Increased soil water content in treatments with a trash cover did not reduce penetrometer resistance values in the soil where fertilisers were applied.

Introduction

Although somewhat limited, the work reported to date on soil quality within the South African sugar industry has covered a literature survey on soil degradation (Meyer *et al.*, 1996), soil acidification (Schroeder *et al.*, 1994), soil compaction (Swinford and Boevey, 1984) and soil degradation in northern KwaZulu-Natal (van Antwerpen and Meyer, 1996). Production of sugarcane in South Africa is largely a monocropping practice with a mean cycle of eight crops before fields are re-established to sugarcane. Little is known about the long term effects of sugarcane monocropping on the physical properties of soils, and this paper is the first in a series to quantify these effects using a 58-year old trial as the source. The trial referred to is a burning and trashing trial (BT1) which was established at the South African Sugar Association Experiment Station in 1939, and is now thought to be the oldest sugarcane trial in the world.

One of the easiest and quickest methods of quantifying soil strength is to use soil resistance to penetration by a stainless steel cone penetrometer. Soil factors affecting cone penetrometer resistance are porosity (or bulk density), water content (or matric potential), texture, organic matter content, exchangeable cation composition, cementation, orientation of soil particles as a result of alternative wetting and drying and the effect of overburden pressure or degree of confinement against the upward displacement of soil particles (Bennie and Burger, 1988). The major factors affecting cone penetration are soil water content and texture (Chancellor, 1976 as reported by Torres and Rodriguez, 1996). It is therefore important when penetrometer resistance is to be determined, that soil water content and texture are also known. Critical soil resistance values (cone penetrometer) for sugarcane cultivation are scarce, although Vepraskas and Miner (1986) reported resistance values of 2,8 to 3,2 MPa for tillage pans in coarse textured soils of North Carolina. Swinford and Boevey (1984) reported a significant decline in cane rooting density below soil depths where cone penetrometer resistances of 2,8 to 3,2 MPa were measured. They also found sucrose yield declines in variety NCo376 of 30 and 50% for plant and first ratoon crops respectively, growing on a duplex soil where penetrometer resistances were 2,8 to 3,2 MPa at a depth of 100 mm compared with 400 mm for the unaffected site.

Gerard (1965) determined that the strength of soil briquets increased with slow drying and with an increase in exchangeable sodium content. He concluded that the cohesive action of water molecules during slow drying was similar to the dispersive action of sodium, causing close packing of particles and, therefore, increased soil strength. Levy and van der Watt (1990) found that exchangeable potassium had a less drastic effect on soil dispersion than sodium, and Keren (1989) reported from Israel that magnesium when compared with calcium had a slightly dispersive effect on two montmorillonitic soils. Gusli *et al.* (1994) showed that soils wetted with a calcium solution, when compared with water, did not affect the degree of structural collapse and produced beds with larger soil pores and a lower tensile strength. Mathers *et al.* (1966) found that sodium saturated soils had a greater dry strength than calcium or aluminium saturated soils, and Ma *et al.* (1991) showed the potential for ammonium fertiliser to cause dispersion and eventual crusting. According to Rose (1966) the tendency to disperse is shown most strongly in clays where exchangeable ions are predominantly sodium and less strongly by potassium. Thus, the potential order of cations to cause dispersion and to increase soil strength is: sodium > ammonium = potassium > magnesium > calcium.

Methods and materials

The BT1 trial is situated on a vertisol (Arcadia form, Rydalvale series) with an A-horizon depth of about 500 mm and a clay content of about 58% (±2%) in the first 200 mm soil depth. The design of the trial consists of four replications of two main plots, each split into four sub-plots. The treatments are various combinations of trashed, burnt, fertilised, non-fertilised, tops spread and tops raked and burnt (see Table 1). Composite soil samples to a depth of 200 mm were collected on 18 September 1995 from each plot and chemically analysed for pH (water), plant available P (0,02 N H_2SO_4), K, Ca and Mg (1 N NH_4OAc) and soil organic matter (Walkley and Black, 1934). Soil physical analysis included cone penetrometer resistance, soil water content and soil bulk density measurements. Cone penetrometer data were collected in quadruplicate at depths of 30, 50, 100, 150, 200, 250, 300, 400 and 500 mm in all plots. The cone had a maximum diameter of 12,7 mm, a 30° angle and a cross sectional area of 130 mm^2. The diameter of the shaft was 10 mm and the length 700 mm. A Troxler nuclear surface moisture-density gauge (Swinford and Meyer, 1985) was used to determine water content and dry soil bulk density in triplicate on each plot, at depths of 0-50, 0-150 and 0-300 mm. The soil water content, bulk density and penetration resistance were determined simultaneously on a plot-by-plot basis. The mean value of each of these parameters was calculated for each plot and used in the statistical analysis of the trial using the Genstat 5 (release 3.2) computer program.

Results and Discussion

The selected soil constituents presented in Table 1 reflect the chemical condition of the soil in relation to treatment after 58 years of continuous sugarcane monocropping. Results showed that the significant differences obtained were mainly between the fertiliser versus no fertiliser treatments. Applying fertiliser over such a long period has reduced the pH and Ca and increased the P and K levels of the soil. The reduced Ca level is likely to be due to the combined effect of acidification and the use of high grade fertilisers containing relatively small amounts Ca in the carrier compared with those of 40 years ago. No significant differences in soil organic matter were detected between treatments because the sampling depth was too great.

Table 2 shows that the soil strength of all treatments increased with depth. The cone penetrometer resistances of the trashed plots were similar to those of the burnt plots to a depth of 200 mm, and the soil strength of the trashed plots was significantly lower than that of the burnt plots at depths 300, 400 and 500 mm (Table 2, column 8). Soil water contents determined at the same time as penetrometer resistance (Table 3) and soil organic matter (Table 1) were significantly higher for the trashed plots than the burnt plots over at least the first 200 mm soil depth. In accordance with these results, Greacen (1960) found that the resistance of soils to deform decreased with an increase in water content and Ekwue and Stone (1995) reported that penetration resistance and shear strength decreased with increasing organic matter content at lower levels of water content. It is possible therefore that the reduced calcium and increased potassium content of the soil from the prolonged use of fertilisers had a dispersive effect on the soil which resulted in an increase in soil strength that was greater than the ability of the soil water content to reduce penetration resistance.

The largest and most significant differences in cone penetrometer resistances with depth was found between fertilised and non-fertilised plots. These differences, however, were not apparent over the first two depths (30 and 50 mm) possibly because they had the highest organic matter percentages (Table 2, column 10). Comparison of penetrometer resistance between the trashed plots receiving fertiliser and not fertilised (Table 2, column 11) showed significant differences beyond a depth of 150 mm compared with a depth of only 50 mm for the burnt plots receiving fertiliser and not fertilised (column 12). No significant differences were obtained when comparing trashed and burnt plots where no fertiliser was used (column 9). This suggests that the addition of trash was a factor which kept soil strength low over the first 100 mm soil depth, and that the fertilisers used had a tendency to increase soil strength, this being more pronounced for treatments with no trash cover.

Table 4 shows that the mean bulk density values of trashed plots were generally lower than those that were burnt at harvest. Statistical analysis of these results showed some significant dry bulk density differences between treatments, the most significant comparison being obtained between the trashed and burnt

Table 1

Mean chemical values for each treatment from soil samples collected to a depth of 200 mm on 18.09.1995. The samples for soil organic matter (SOM) determination were collected on 03.10.1996. Analyses of variances are expressed as probability levels of the F value for various comparisons between treatments.

Variate	Treatment						F value of comparison				
	Trashed, no fertiliser n = 8	Trashed, fertilised n = 8	Burnt, tops scattered, no fertiliser n = 4	Burnt, tops scattered, fertilised n = 4	Burnt, no tops, no fertiliser n = 4	Burnt, no tops, fertilised n = 4	Trashed vs burnt	Trashed, no fertiliser vs burnt, no fertiliser	Fertilised vs no fertiliser	Trashed, no fertiliser vs trashed, fertilised	Burnt, no tops, no fertiliser vs burnt, no tops, fertilised
pH water	5,38	4,68	5,63	5,03	5,55	4,91	5,29*	1,81	38,03**	21,53**	8,70**
P mg/kg	1,2	8,8	2,2	15,5	1,00	10,9	1,58	0,02	24,99**	7,85**	6,70*
K mg/kg	98	228	137	211	131	186	0,02	1,47	20,90**	18,81**	1,62
Ca mg/kg	1 627	1 318	1 591	1 425	1 650	1 417	0,38	0,00	10,66**	7,87**	2,24
SOM %	5,40	5,44	4,98	5,72	5,37	5,03	0,57	0,69	0,40	0,02	0,75

* p=0,05 ** p=0,01

Table 2

Mean penetrometer resistance values (MPa) for each treatment in relation to depth. Soil penetration resistance measurements were made on 25.01.1997. Analyses of variance are expressed as probability levels of the F value for various comparisons between treatments.

Depth (mm)	Treatment						F value of comparison				
	Trashed, no fertiliser n = 8	Trashed, fertilised n = 8	Burnt, tops scattered, no fertiliser n = 4	Burnt, tops scattered, fertilised n = 4	Burnt, no tops, no fertiliser n = 4	Burnt, no tops, fertilised n = 4	Trashed vs burnt	Trashed, no fertiliser vs burnt, no fertiliser	Fertilised vs no fertiliser	Trashed, no fertiliser vs trashed, fertilised	Burnt, no tops, no fertiliser vs burnt, no tops, fertilised
30	1,404	1,226	1,473	1,298	1,333	1,905	1,17	0,00	0,00	0,53	2,76
50	1,785	1,589	1,763	1,688	1,530	2,378	0,71	0,29	0,28	0,59	5,49*
100	1,790	2,170	1,530	2,270	1,610	2,250	0,00	0,60	8,65*	1,64	5,24*
150	1,626	2,214	1,590	2,390	1,680	2,563	0,81	0,00	22,52**	7,61*	8,59*
200	1,593	2,286	1,680	2,545	1,780	2,665	1,73	0,31	20,49**	8,01*	6,52*
300	2,020	2,480	2,000	3,270	2,610	3,850	7,91*	0,68	12,34*	1,75	6,47*
400	2,920	3,890	3,250	4,700	3,740	4,170	4,13*	2,17	11,98*	6,17*	0,61
500	3,660	4,010	4,110	5,130	4,340	4,800	9,33*	2,57	4,86*	1,01	0,86

* p=0,05 ** p=0,01

Table 3

Mean volumetric soil water content values (%) for each treatment and depth. Analyses of variance are expressed as probability levels of the F value for various comparisons between treatments.

Depth (mm)	Treatment						F value of comparison				
	Trashed, no fertiliser n = 8	Trashed, fertilised n = 8	Burnt, tops scattered, no fertiliser n = 4	Burnt, tops scattered, fertilised n = 4	Burnt, no tops, no fertiliser n = 4	Burnt, no tops, fertilised n = 4	Trashed vs burnt	Trashed, no fertiliser vs burnt, no fertiliser	Fertilised vs no fertiliser	Trashed, no fertiliser vs trashed, fertilised	Burnt, no tops, no fertiliser vs burnt, no tops, fertilised
0-50	42,3	42,6	32,4	39,2	35,6	28,9	11,56*	5,63*	0,01	0,01	1,80
0-150	38,6	37,4	33,6	33,9	31,3	30,3	10,06*	5,80*	0,16	0,20	0,07
0-300	38,7	37,8	30,8	33,5	30,5	30,9	13,88**	9,62**	0,03	0,12	0,01

* p=0,05 ** p=0,01

Table 4

Mean dry bulk density values (g/cm3) for each treatment and depth. Analyses of variance are expressed as probability levels of the F value for various comparisons between treatments.

Depth (mm)	Treatment						F value of comparison					
	Trashed, no fertiliser n = 8	Trashed, fertilised n = 8	Burnt, tops scattered, no fertiliser n = 4	Burnt, tops scattered, fertilised n = 4	Burnt, no tops, no fertiliser n = 4	Burnt, no tops, fertilised n = 4	Trashed vs burnt	Trashed, no fertiliser vs burnt, no fertiliser	Trashed, fertilised vs burnt, fertilised	Fertilised vs no fertiliser	Trashed, no fertiliser vs trashed, fertilised	Burnt, no tops, no fertiliser vs burnt, no tops, fertilised
0-50	1 077	968	1 268	973	1 088	1 255	3,67	1,23	2,56	1,79	1,42	1,66
0-150	1 184	1 088	1 153	1 108	1 201	1 260	2,42	0,03	5,63*	2,44	5,66*	1,05
0-300	1 173	1 077	1 281	1 129	1 224	1 248	7,31*	2,56	4,95*	5,09*	3,64	0,11

* p=0,05

treatments where fertilisers were used (column 10). However, unlike the trend towards higher penetration resistance values from fertiliser application, bulk density values were generally lower in treatments containing fertiliser. Similar soil bulk density values for this trial were reported by Thompson (1965). Although the use of fertiliser could have increased the close packing arrangement of soil particles through dispersion as previously discussed, this was probably offset by the increased soil organic matter levels in the fertiliser treatment plots, which will give lower bulk density values. Previous researchers have indicated that no clear-cut relationship exists between soil penetrometer resistance and bulk density (Bennie and Burger, 1988; Torres and Rodrìguez, 1996) which corroborates the finding that bulk density is not necessarily correlated to penetrometer resistance.

Conclusions

The many effects of chemicals used on soils are not known, and the results of these effects may become apparent only after many years of continuous chemical application. This is certainly the case where inorganic fertilisers are used. With inorganic fertilisers it is important to consider more than the N, P and K requirements of the plant; the long term effects on the soil should also be taken into account. The results of this study suggest that the loss of Ca from the profile under continual fertilisation led to an unfavourable cation balance and resulted in the observed increased resistance to soil penetration. A recent survey of paired sites in the northern cane area of KwaZulu-Natal showed a similar trend in loss of Ca and increasing soil acidity with monocropping (van Antwerpen and Meyer 1996). The potential of trash to reduce soil penetrometer resistance and bulk density, and to increase rainfall efficiency through improved soil water content, was also demonstrated. However, the effect that fertiliser usage had on increasing soil strength was greater than the ability of soil water content and trash to reduce penetration resistance. Despite the potential negative effect of fertilisation on the penetration resistance of the soil there is no evidence from the yield data which would suggest that the average response to fertiliser could have been larger than the average responses of 36,4 and 40,0 tc/ha obtained under trash and burning management respectively. It is possible that on soils with less structure development the negative effects could eventually impact on cane yield, but this would require verification.

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