SOIL DEGRADATION - II: EFFECT OF TRASH AND INORGANIC FERTILISER APPLICATION ON SOIL STRENGTH

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Abstract

A long term trial to study the sustainability of a vertisol under continuous sugarcane monocropping was commenced in 1939 at the Experiment Station of the South African Sugar Association. The design of the trial consists of four replications of two main plots, each split into four sub-plots. The treatments comprise various combinations of trashed, burnt, fertilised and non-fertilised cane. The burnt treatment was further subdivided, with tops either spread or raked and burnt after harvest. Composite soil samples at depth intervals of 0-50, 50-100 and 100-200 mm were collected in 1997 from each plot and chemically analysed for pH, exchangeable P, Al, Na, K, Ca and Mg, soil organic matter and CEC. Soil physical analyses included cone penetrometer resistance, soil water content, soil bulk density, dispersion index, linear shrinkage index, modulus of rupture and aggregate stability. Soil chemical analysis indicated that the trashed treatments had a slightly acidifying effect when compared with the burnt treatments, while the fertilised treatments had a highly significant acidifying effect on the soil compared with the unfertilised treatments. The fertilised treatments had a significantly larger soil aggregate stability and *in situ* measured soil strength compared with the unfertilised treatments. However, the strength of samples remoulded in the laboratory was larger for the unfertilised compared with that of the fertilised treatments.

Introduction

One of the easiest and quickest methods for quantifying soil strength is to measure 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 alternate 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 Rodrìguez, 1996). Greacen (1960) found that the resistance of soils to deformation 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.

Critical soil resistance values (cone penetrometer) for cane cultivation are scarce, but 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 for variety NCo376 of 30 and 50% for plant and first ratoon crops respectively, growing on a duplex soil where the penetrometer resistances were 2,8 to 3,2 MPa at a depth of 100 mm compared with the same values from a depth of 400 mm for the unaffected site.

An approximate linear, positive correlation between the modulus of rupture of dried soil and the amount of readily dispersed clay (not the total clay) in the soil was shown by Shanmuganathan and Oades (1982). 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 packed particles and, therefore, increased soil strength. Dexter and Chan (1991) proposed that the exchangeable cations which give rise to greater repulsion between, and dispersion of, clay particles in soil water enabled particle rearrangements to take place more readily during drying and resulted in denser packing arrangements and increased soil strength. They have also shown a positive correlation between tensile strength and all cations except calcium.

Rose (1966) and Levy and van der Watt (1990) determined that exchangeable potassium had a less drastic effect on soil dispersion when compared with sodium, and Keren (1989) found that magnesium when compared with calcium had a slightly dispersive effect on two montmorillonitic soils from Israel. Dexter and Chan (1991) found that dispersion by Mg was 0,8 times as great as that of Na when expressed in terms of electronic charge, or 0,4 times as great when expressed on a molar basis. Emerson and Chi (1977) found that, compared with Na, Mg had to occupy ten times more of the exchange sites to have an equivalent effect on dispersion. Black (1968) reported that preferential adsorption of Ca is on the soil organic matter (SOM) as opposed to the clay mineral fraction in soils. Turpault *et al.* (1996) determined that the CEC distribution between clay and SOM, for a soil with a similar clay content and CEC value as the vertisol at the BT1 trial site, was nearly equal at 52 and 48% respectively.

Dexter and Chan (1991) found that magnesium increased the tensile strength of air dried 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 while Ma *et al.* (1991) showed the potential for ammonium fertiliser to cause dispersion and eventually crusting. Thus, the potential order of cations to cause dispersion and to increase soil strength is: $Na > NH_4 \geq K > Mg > Ca$. Dowdy and Larson (1971) found that the decrease in tensile strength of oriented montmorillonite clay films caused by cations were in the order: $Fe > K \geq Na > Al > Ca$.

Recent work on soil quality within the South African sugar industry was covered by a literature survey on soil degradation (Meyer *et al.*, 1996), soil degradation in northern KwaZulu-Natal (van Antwerpen and Meyer, 1996), soil acidification (Schroeder *et al.*, 1994) and soil compaction (Swinford and Boevey, 1984). Production of sugarcane in South Africa is by continuous monocropping, with a mean cycle of about six crops under rain grown conditions before fields are re-established to sugarcane. Little is known about the long term effects of sugarcane monocropping on soil physical properties, and this paper will quantify these effects using a 58-year old trial established on a vertisol. This is a burning and trashing (leaves stripped from the stalk at harvest and left on the surface as a mulch) trial (BT1) that was established at the South African Sugar Association Experiment Station in 1939, and is thought to be the oldest sugarcane trial in the world.

Methods and materials

The BT1 trial is situated at Mount Edgecombe (longitude: 31° 04' 29" and latitude: 29° 43' 20") in KwaZulu-Natal on a vertisol (Arcadia form, Lonehill family; Soil Classification Working Group, 1991) with an A-horizon depth of about 500 mm and mean annual rainfall of about 950 mm. 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 and non-fertilised plots with the tops after harvest either spread or raked and burnt for the burnt plots only (see Table 1). Composite soil samples at depth intervals of 0-50, 50-100 and 100-200 mm were collected in January 1997 from each plot and chemically analysed for pH (water), plant available P (0,02N H_2SO_4), Al, K, Na, Ca and Mg (1N NH_4OAc), CEC (1N NH_4Cl, 1N KCl) and SOM (Walkley and Black, 1934).

Soil physical analysis included cone penetrometer resistance, soil water content, soil bulk density, texture, dispersion index, shrinkage index, modulus of rupture and aggregate stability. 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 surface 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 soil water content and dry soil bulk density in triplicate for each plot at depths of 0-50, 0-150 and 0-300 mm. Soil water content, bulk density and penetration resistance were determined simultaneously on a plot by plot basis.

Soil texture was determined by the hydrometer method. Dispersion index was calculated after samples were shaken for one minute in de-ionised water and left standing for four minutes, and readings from a hydrometer expressed as a percentage of those from samples dispersed with Calgon, mechanically stirred for five minutes, shaken for one minute, and left standing for four minutes before taking the hydrometer reading. For linear shrinkage determination a smooth paste was prepared with a mechanical stirrer, using de-ionised water, and poured into a mould with a loose base and dimensions of 9,4 x 31,6 x 69,6 mm. A thin layer of grease was applied to the inside of the mould and base plate to allow free shrinkage. Samples were dried at 28°C for 48 hours, after which sample shrinkage was expressed relative to the length of the mould. Modulus of rupture (MOR) was determined on the soil blocks prepared for linear shrinkage with an apparatus using the same principles, but different in design, to that used by Richards (1953). MOR (kPa) was calculated from the equation $MOR = (3FL)/(2WD^2)$ in which F is the breaking force (N/cm^2) applied half way between the sample supports with L the distance between supports (cm). W is the width of the beam (cm) and D is the depth of the beam (cm). Soil aggregate stability was determined with the technique described by Sumner (1958).

The mean value of each of these parameters was calculated for each plot and used in the statistical analysis of the trial with the aid of the Genstat 5 (release 3.2) computer program.

Results and discussion

Chemical analyses

The selected soil constituents presented in Table 1 reflect the chemical condition of the soil for each treatment after 58 years of continuous sugarcane monocropping. The results showed that the significant differences obtained were mainly between the fertiliser (F) versus no fertiliser (Fo) treatments. Applying fertiliser over such a long period has directly and indirectly decreased the pH, Na, Ca, Mg and CEC and increased the P (not shown), exchangeable Al, K and SOM levels of the soil. A recent survey of paired sites in the northern cane areas of KwaZulu-Natal showed a similar loss of Ca and increasing soil acidity and Al with monocropping (van Antwerpen and Meyer, 1996). The reduced Ca level is probably due to the combined effect of acidification and the use of high grade fertilisers containing relatively small amounts of Ca in the carrier compared with those used about 40 years ago. Comparison of the trashed (T) with the burnt (B) treatment showed that the treatments did not appear to have affected the soil constituents listed above, except for SOM, which significantly increased where tops were left scattered (Bt) on the surface after harvest.

Soil strength

There was a non-significant but consistent trend, in that dispersion index (DI), linear shrinkage index (LSI), modulus of rupture (MOR) and sample density (SD), all determined on

Table 1. Mean chemical values for each treatment from soil samples collected after 58 years of sugarcane monocropping.

Parameter	Depth (mm)	Treatments						F-value of comparisons								
		TFo n=8	TF n=8	BFo n=4	BtF n=4	BtoFo n=4	BtoF n=4	F/Fo	TFo/BFo	TF/BF	T/B	TF/TFo	BF/BFo	BF/TFo	BtoF/ BtF	BFo/TF
pH (water)	0-50	5,46	4,70	5,58	4,99	5,45	4,80	78,68**	0,26	3,34	2,74	48,00**	31,54**	26,03**	1,54	55,38**
	50-100	5,51	4,86	5,57	4,79	5,58	5,04	72,61**	0,38	0,24	0,62	35,55**	37,07**	29,92**	2,57	43,30**
	100-200	5,57	4,84	5,77	5,07	5,56	5,12	74,39**	0,69	5,54*	5,07*	47,05**	28,49**	20,31**	0,13	59,15**
Na (cmol/kg)	0-50	0,67	0,44	0,59	0,53	0,54	0,72	2,20	1,68	5,45*	0,54	8,20*	0,59	0,28	3,03	2,46
	50-100	0,54	0,50	0,58	0,67	0,68	0,66	0,01	0,70	2,50	2,93	0,20	0,09	1,30	0,01	1,65
	100-200	0,52	0,48	0,68	0,46	0,58	0,36	7,30*	2,51	1,42	0,08	0,27	10,89**	2,94	1,11	4,44*
K (cmol/kg)	0-50	0,29	0,59	0,39	0,88	0,20	0,57	39,77**	0,00	2,56	1,28	13,39**	27,66**	27,66**	7,27*	13,39**
	50-100	0,16	0,28	0,18	0,30	0,12	0,22	18,99**	0,07	0,38	0,38	10,62**	8,43**	7,00*	1,75	12,37**
	100-200	0,14	0,24	0,16	0,34	0,12	0,25	40,28**	0,01	3,42	1,87	13,02**	28,82**	29,77**	4,74*	12,39**
Mg (cmol/kg)	0-50	5,57	4,00	5,81	3,82	6,11	3,31	53,04**	1,03	1,27	0,01	16,63**	38,71**	27,09**	0,89	25,96**
	50-100	5,51	3,89	5,51	3,37	5,94	3,82	65,49**	0,43	0,78	0,03	24,54**	42,13**	34,47**	0,94	31,47**
	100-200	5,37	4,03	5,82	3,91	5,82	3,78	50,44**	1,81	0,32	0,03	16,52**	35,74**	21,46**	0,07	29,28**
Ca (cmol/kg)	0-50	11,27	8,07	10,05	8,26	10,04	6,87	14,89**	1,39	0,23	1,38	9,47**	5,66*	12,66**	0,89	3,61
	50-100	11,49	8,36	10,53	7,73	10,53	9,36	13,75**	0,97	0,04	0,32	10,31**	4,13	9,11**	1,41	4,95*
	100-200	11,76	8,84	11,36	9,52	10,37	9,54	8,41**	0,73	0,45	0,02	7,91*	1,66	4,60*	0,00	3,83
Al x 0,01 (cmol/kg)	0-50	0,28	19,90	0,00	23,63	0,28	14,73	18,67**	0,00	0,01	0,01	9,60**	9,07**	8,94**	0,99	9,74**
	50-100	0,14	9,45	0,00	41,42	0,00	1,11	8,25**	0,00	2,45	1,20	1,53	7,98**	7,87**	14,33**	1,58
	100-200	0,00	8,48	0,00	16,96	0,00	2,50	7,87**	0,00	0,07	0,04	3,41	4,49*	4,49*	4,96*	3,41
Soil organic matter (%)	0-50	5,77	6,22	4,83	6,24	5,24	5,11	7,61*	6,82*	3,69	10,28**	2,58	5.27*	0,10	8,12**	17,79**
	50-100	5,34	5,47	5,16	5,81	5,37	4,85	0,43	0,13	0,47	0,55	0,39	0,09	0,00	10,59**	0,98
	100-200	5,08	5,44	4,80	5,50	4,80	4,83	5,73*	1,75	1,74	3,49	2,86	2,87	0,14	4,90*	9,80**
CEC (cmol/kg)	0-50	19,78	16,20	17,80	16,95	19,00	14,83	11,84**	1,21	0,06	0,91	8,17**	4,03	9,66**	1,44	3,09
	50-100	19,34	17,40	17,67	15,68	19,00	18,33	4,56*	0,86	0,16	0,88	3,16	1,54	4,72*	3,03	0,72
	100-200	20,10	16,80	19,25	17,07	19,25	17,25	10,23**	0,31	0,07	0,04	7,17*	3,40	5,78*	0,01	4,49*
Clay (%)	0-50	39,13	44,38	45,25	44,50	47,50	46,00	4,00	24,68**	0,36	15,50**	12,94**	0,59	17,62**	0,53	1,88
	50-100	43,75	44,88	45,00	44,75	42,50	46,00	1,23	0,00	0,08	0,04	0,41	0,86	0,86	0,26	0,41
	100-200	43,75	46,88	43,75	48,75	46,50	47,75	5,20*	0,50	0,50	1,01	2,60	2,60	5,39*	0,13	0,81
Silt (%)	0-50	15,88	16,37	18,50	17,75	13,75	15,25	0,25	0,04	0,01	0,05	0,16	0,09	0,26	2,04	0,04
	50-100	15,50	16,37	16,50	16,50	13,25	14,75	0,88	0,26	0,37	0,63	0,51	0,37	0,01	1,02	1,50
	100-200	14,25	13,88	20,00	15,00	14,00	15,50	0,53	1,79	0,45	2,02	0,03	0,73	0,24	0,03	2,31

Analyses of variance are expressed as probability levels of the F value for various comparisons between treatments.

T=Trashed B=Burned F=Fertilised Fo=No fertiliser t=tops scattered to=no tops

* P=0,05 ** P=0,01

disturbed samples in the laboratory, had larger values for the Fo treatments compared with the F treatments (Table 2). A possible reason for this is dispersion caused by Mg in the Fo treatment, which has resulted in closer packing and increased soil strength on drying. The aggregation potential of Ca in the Fo treatment was probably reduced due to the preferential adsorption of Ca by the organic matter (Black, 1968), causing the inorganic clay fraction to become relatively enriched in Mg, which resulted in dispersion rather than aggregation, of the wet soil.

Soil aggregate stability

Of all the soil physical parameters measured, soil aggregate stability (SAS) was the most sensitive indicator of differences between treatments. The 5,0-0,5 mm and 5,0-2,0 mm SAS fractions, of the Fo and T treatments respectively, were highly significantly more resistant to structural collapse in single de-ionised water compared with the SAS fractions of the F and B treatments. A possible reason for this is the significantly higher K concentration in the F treatment compared with the Fo treatment which, together with the Na content, has the potential to cause the breakup of aggregates in de-ionised water into smaller units. This was confirmed by the greater SAS in the 2,0-1,0 mm and 1,0-0,5 mm fractions found for the F treatment compared with the Fo treatment. It is not clear what caused the difference in SAS between the T and B treatments, but it is possible that the difference in SOM between these treatments could have been a factor.

Soil penetrometer resistance

Figure 1 compares the effects of F versus Fo on soil penetration resistance (SPR) on plots where cane was trashed (Figure 1A), tops were scattered (Figure 1B) or where all surface organic matter was burned after harvest (Figure 1C). The most prominent feature from Figure 1 was that SPR was consistently higher under the F plots compared with the Fo plots to a depth of at least 500 mm. When Figures 1A and 1B are compared with Figure 1C, it is apparent that in the absence of applied organic matter, the SPR was higher than where either trash or scattered tops were present, and that the differences increased with increasing depth for both the F and Fo treatments. A further comparison of Figures 1A and 1B with 1C revealed that trash or tops left scattered on the soil surface were effective in reducing SPR in the F plots only to a depth of about 100 mm. This is confirmed by the values of the F treatments in Table 1, which showed a 12,1, 6,9 and 5,1% decline in SOM for the trashed, burnt with tops scattered and total burn treatments respectively, from the 0-50 mm to the 50-100 mm depth interval. The change in SOM for these treatments from the 50-100 mm to 100-200 mm depth interval was negligible.

The reason for the higher SPR under the F treatments is not clear and cannot be explained by the available data. Dispersion leading to increased soil strength when the soil is dry can be ruled out because of the low pH. Churchman *et al.* (1993) found that a kaolinitic soil becomes more flocculated as pH declines due to increased exchangeable Al, which tends to increase resistance to dispersion. This could also explain the reduced dry bulk density under the F treatments compared with treatments receiving Fo (Table 3). The effect of soil water content on SPR can also be ruled out. Although highly significant soil water content differences between plots receiving T and those B were measured to a depth of at least 300 mm, no significant differences between these treatments were recorded for SPR to a depth of less than 300 mm (Table 3). Small insignificant soil water content differences between the F and Fo treatments were measured to a depth of 300 mm while significant SPR differences were recorded from a depth of only 50 mm.

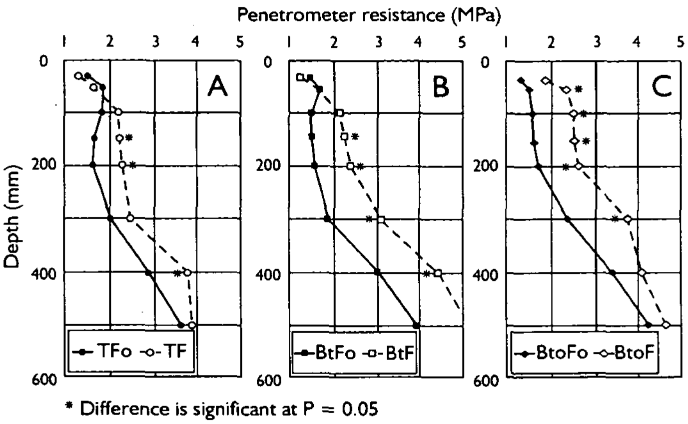

Figure 1. Comparison of the penetration resistance of a vertisol between plots trashed (T), burnt with tops spread (Bt) and burnt with no tops spread (Bto) in relation to fertiliser (F) and no fertiliser (Fo) applied.

Conclusions

The results from this study have shown that fertiliser versus no fertiliser were the dominant treatments to affect both soil chemical and physical properties at the trial site. The trash versus burnt treatments affected soil water content only directly after rain, and soil aggregate stability and soil strength as measured through modulus of rupture.

Evidence is presented to suggest that the higher soil Mg under the unfertilised treatment was the cause of the higher dispersion and greater strength of disturbed samples on drying compared with that from the fertilised treatment. Despite reduced Ca and Mg, the increased K in the fertilised treatments was not sufficient to cause dispersion due to the low pH (<5) which resulted in exchangeable Al levels as high as 0,20 cmol/kg. Aluminium was the principal soil constituent binding soil particles together and resulting in the higher penetration resistance observed for this treatment, despite the reduced soil bulk density. The potential of trash and scattered tops to reduce soil penetrometer resistance was also shown. Although the trashed treatment contained highly significantly more soil water when compared with the burnt treatment, the difference was insufficient to affect *in situ* measured penetrometer resistances between these treatments.

Results from this work have also shown that, by using disturbed samples, results opposite to measurements made *in situ* on undisturbed soils, are obtainable. Great care should be

Table 2. Mean values for the physical parameters determined in the laboratory. Soil samples were collected on 25/01/97 after 58 years of sugarcane monocropping.

Parameters	Depth (mm)	Treatments						F-value of comparisons								
		TFo n=8	TF n=8	BtFo n=4	BtF n=4	BtoFo n=4	BtoF n=4	F/ Fo	TFo/ BFo	TF/BF	T/B	TF/ TFo	BF/ BFo	BF/ TFo	BtoF/ BtF	BFo/ TF
Dispersion index (%)	0-50	16,25	14,00	12,25	11,75	12,00	13,00	0,43	3,62	0,56	3,52	1,08	0,01	3,19	0,17	0,75
	50-100	16,00	12,75	15,50	14,25	17,00	12,50	4,40*	0,01	0,09	0,09	2,48	1,94	1,62	0,36	2,87
	100-200	13,25	13,38	13,00	9,75	12,75	10,50	1,22	0,05	3,73	2,32	0,01	2,67	3,45	0,10	0,09
Linear shrinkage (%)	0-50	16,36	16,37	16,45	14,87	16,55	15,40	2,10	0,04	3,53	1,40	0,00	4,28*	3,46	0,32	0,04
	50-100	17,48	17,26	16,60	17,07	17,37	17,22	0,00	0,78	0,04	0,59	0,15	0,09	0,35	0,04	0,25
	100-200	16,15	15,68	15,80	15,13	16,38	15,02	2,64	0,01	0,87	0,53	0,54	2,46	2,77	0,01	0,40
Modulus of rupture (kPa)	0-50	3 228	2 855	2 633	2 456	3 192	2 411	5,93*	1,62	2,90	4,43*	2,27	3,75	10,31**	0,02	0,05
	50-100	3 417	3 154	3 115	3 249	3 870	2 292	6,67*	0,08	2,02	0,65	0,95	7,17*	5,74*	6,29*	1,58
	100-200	2 878	2 620	2 072	2 326	2 369	2 039	0,43	4,24*	1,87	5,87*	0,64	0,01	4,74*	0,40	1,56
Density of sample at breakage (kg/m^3)	0-50	1 710	1 684	1 728	1 692	1 793	1 734	4,90*	4,57*	1,48	5,62*	1,22	4,10	0,01	1,59	10,51**
	50-100	1 738	1 762	1 778	1 733	1 773	1 761	0,02	2,20	0,37	0,38	0,89	1,31	0,11	0,58	0,29
	100-200	1 696	1 693	1 689	1 707	1 792	1 784	0,00	2,74	3,72	6,42*	0,01	0,03	3,30	4,12	3,12
Water content at breakage (g/g, %)	0-50	4,45	4,59	4,06	3,97	3,94	4,34	0,33	1,51	1,39	2,89	0,14	0.18	0,64	0,51	2,58
	50-100	4,43	4,17	4,02	3,85	3,97	3,97	0,53	1,70	0,61	2,18	0,61	0,07	2,43	0,07	0,28
	100-200	5,08	5,11	3,83	5,41	6,56	5,39	0,55	0,28	0,18	0,00	0,00	1,01	0,23	0,00	0,33
Aggregate stability 5,0-0,5mm fraction (%)	0-50	91,80	88,80	79,90	79,90	89,30	64,80	9,01**	4,02	21,02**	21,72**	0,69	11,64**	29,35**	8,88**	1,38
	50-100	92,97	88,82	87,77	84,81	94,34	75,65	18,16**	0,59	11,95**	8,93**	2,79	18,99**	26,28**	6,79*	0,81
	100-200	92,26	87,61	84,71	83,07	91,38	79,15	8,73**	2,30	5,50*	7,46*	2,81	6,26*	16,17**	1,00	0,02
Aggregate stability 5,0-2,0 mm fraction (%)	0-50	73,10	59,40	47,70	41,90	59,80	25,40	9,44**	6,21*	10,99**	16,86**	3,10	6,68*	25,76**	2,25	0,53
	50-100	70,90	56,00	63,60	47,90	75,60	35,10	24,22**	0,04	5,51*	3,27	5,82*	20,68**	22,65**	2,13	4,84*
	100-200	66,20	48,50	59,30	38,40	69,40	37,00	38,04**	0,14	4,50*	3,12	12,17**	27,39**	31,47**	0,04	9,69**
Aggregate stability 2,0-1,0 mm fraction (%)	0-50	12,90	19,60	20,50	21,40	20,50	22,30	3,53	6,26*	0,57	5,29*	4,86*	0,21	8,74**	0,04	0,09
	50-100	16,40	22,80	16,30	26,20	13,90	24,90	14,70**	0,17	0,77	0,11	4,26	11,28**	8,65**	0,09	6,16*
	100-200	18,65	26,49	15,88	29,30	15,53	26,53	45,98**	1,98	0,47	0,26	14,05**	34,12**	19,67**	0,86	26,56**
Aggregate stability 1,0-0,5 mm fraction (%)	0-50	5,88	9,86	11,81	16,62	9,06	17,18	13,64**	5,18*	12,37**	16,79**	3,96	10,45**	30,34**	0,04	0,08
	50-100	5,64	10,01	7,82	10,77	4,84	15,68	24,84**	0,19	4,05	2,99	7,48*	18,61**	22,52**	4,72*	5,30*
	100-200	7,36	12,63	9,52	15,35	6,50	15,63	39,80**	0,21	4,00	3,01	13,61**	27,38**	32,35**	0,02	10,46**

Analyses of variance are expressed as probability levels of the F value for various comparisons between treatments.

T=Trashed B=Burned F=Fertilised Fo=No fertiliser t=tops scattered to=no tops

* P=0.05 ** P=0.01

Table 3. Mean penetrometer resistance values, soil water content and soil bulk density for each treatment in relation to depth. Data were collected on 25/01/97 after 58 years of sugarcane monocropping.

Depth (mm)	Treatments						F-value of comparisons						
	TFo n=8	TF n=8	BtFo n=4	BtF n=4	BtoFo n=4	BtoF n=4	F/ Fo	TFo/ BFo	TF/ BF	T/ B	TF/ TFo	BtF/ BtFo	BtoF/ BtoFo
Penetrometer resistance (MPa)													
30	1,404	1,226	1,473	1,298	1,333	1,905	0,00	0,00	2,36	1,17	0,53	0,26	2,76
50	1,785	1,589	1,763	1,688	1,530	2,378	0,28	0,29	3,01	0,71	0,59	0,04	5,49*
100	1,790	2,170	1,530	2,270	1,610	2,250	8,65*	0,60	0,69	0,00	1,64	3,18	5,24*
150	1,626	2,214	1,590	2,390	1,680	2,563	22,52**	0,00	1,52	0,81	7,61*	7,06*	8,59*
200	1,593	2,286	1,680	2,545	1,780	2,665	20,49**	0,31	1,69	1,73	8,01*	6,23*	6,52*
300	2,020	2,480	2,000	3,270	2,610	3,850	12,34*	0,68	9,92**	7,91*	1,75	6,82*	6,47*
400	2,920	3,890	3,250	4,700	3,740	4,170	11,98*	2,17	1,96	4,13	6,17*	6,90*	0,61
500	3,660	4,010	4,110	5,130	4,340	4,800	4,86*	2,57	7,37*	9,33*	1,01	4,25	0,86
Soil water content (v/v, %)													
0-50	42,3	42,6	32,4	39,2	35,6	28,9	0,01	5,63*	5,93*	11,56**	0,01	1,90	1,80
0-150	38,6	37,4	33,6	33,9	31,3	30,3	0,16	5,80*	4,31*	10,06**	0,20	0,01	0,07
0-300	38,7	37,8	30,8	33,5	30,5	30,9	0,03	9,62**	4,70*	13,88**	0,12	0,54	0,01
Dry bulk density (kg/m^3)													
0-50	1 077	968	1 268	973	1 088	1 255	1,79	1,23	2,56	3,67	1,42	5,19*	1,66
0-150	1 184	1 088	1 153	1 108	1 201	1 260	2,44	0,03	5,63*	2,42	5,66*	0,62	1,05
0-300	1 173	1 077	1 281	1 129	1 224	1 248	5,09*	2,56	4,95*	7,31*	3,64	4,60*	0,11

Analyses of variance are expressed as probability levels of the F value for various comparisons between treatments.

T=Trashed B=Burned F=Fertilised Fo=No fertiliser t=tops scattered to=no tops

* P=0,05 ** P=0,01

taken to ensure that the analysis techniques selected are well understood in order to draw meaningful conclusions from soil condition differences between treatments.

This paper has shown measurable degradation of a vertisol and the work of van Antwerpen and Meyer (1996) showed that oxisols (red soils) and alfisols (grey soils) are far more sensitive to soil degradation when compared with vertisols. It can thus be speculated that, had this trial been on either an alfisol or an oxisol, the differences between treatments would have been far more pronounced.

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