

# SOIL DEGRADATION UNDER SUGARCANE CULTIVATION IN NORTHERN KWAZULU-NATAL

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## Abstract

In many crop producing areas of the world there are reports of yield decline and loss of productive potential in soils. Little is known about the long term effects of sugarcane monocropping on changes in physical, chemical and biological properties of soils. The aim of this study was to quantify the physical and chemical condition of soils under sugarcane production in northern Kwazulu-Natal, as industrial sugarcane yields have failed to break through the 'productivity plateau' during the past 15 years. Soil samples from 29 virgin and adjoining cultivated fields were examined with 15 originating from dryland and 14 from irrigated areas. The most prominent soil chemical properties contributing to soil degradation under sugarcane cultivation were increased acidity in dryland areas and increased salinity and sodicity levels in irrigated areas. The common thread linking results from the dryland and irrigated areas was the reduced organic matter of the cultivated relative to the virgin sites.

*Keywords:*

## Introduction

The effect of cultivation on soil degradation, and specifically soil organic matter or carbon, have been reported by

workers in Australia (Dalal and Mayer, 1986), Brazil (Lepsch *et al.*, 1994), Denmark (Schjønning *et al.*, 1994), Germany (Capriel *et al.*, 1992; Zhang, 1994), Italy (Saviozzi *et al.*, 1994), Nigeria (Hulugalle, 1994), South Africa (du Toit and du Preez, 1995), UK (Jenkinson and Coleman, 1994) and the USA (Karlen *et al.*, 1994; Haynes *et al.*, 1991). All concluded that soil quality decreases with reduced soil organic matter content. Studies conducted to determine the effect of sugarcane cultivation on soil organic matter content and soil degradation have been reported for the Herbert valley, Queensland, in Australia (Wood, 1985), Brazil (Vitorello *et al.*, 1989), India (Jadhav, 1995) and Swaziland in southern Africa (Henry and Ellis, 1995). However, no work concerning the soil degradation trend in the South African sugar industry has been reported to date. Despite the release of numerous new varieties, all with a yield potential higher than that of our current major variety (NCo376), industrial sugarcane yields have failed to break through the 'productivity plateau' during the past 15 years. For these reasons a survey was initiated to examine the differences in soil properties between virgin and adjoining cultivated soils in dryland and irrigated areas of northern Kwazulu-Natal.

Table 1

Selected characteristics of the cultivated sites used in this investigation

Site no.	Area	Parent material	Soil form		Cane burnt?	Spread tops?	
			SA	FAO			
41	Gingindlovu	Middle Ecça	Westleigh	Plintic acrisol	Yes	Yes	20+
42a	Gingindlovu	Natal Group Sandstone	Fernwood	Dustric regsol	Yes	Yes	20+
42b	Gingindlovu	Natal Group Sandstone	Fernwood	Dustric regsol	Yes	Yes	2
43	Eshowe	Natal Group Sandstone	Inanda	Humic ferralsol	Yes	Yes	10
44	Mandini	Middle Ecça	Westleigh	Plintic acrisol	No	Yes	20+
45	Mandini	Middle Ecça	Willowbrook	Humic gleysol	No	Yes	20+
46	Mandini	Lower Ecça	Westleigh	Plintic acrisol	No	Yes	20+
47	Mandini	Lower Ecça	Misphah	Lithosol	No	Yes	20+
48	Mandini	Dolerite	Milkwood	Rendzina	No	Yes	20+
49	Melmoth	Natal Group Sandstone	Glenrosa	Chromic cambisol	Yes	No	14
50	Melmoth	Natal Group Sandstone	Nomanci	Ranker	Yes	Yes	15
51	Nkwalini	Natal Group Sandstone	Katspruit	Dystric gleysol	Yes	No	30+
52a	Nkwalini	Natal Group Sandstone	Kroonstad	Mollic planosol	Yes	Yes	20+
52b	Nkwalini	Natal Group Sandstone	Kroonstad	Mollic planosol	Yes	Yes	10+
53	Nkwalini	Middle Ecça	Swartland	Chromic luvisol	Yes	No	25
54	Nkwalini	Middle Ecça	Glenrosa	Chromic cambisol	Yes	No	12
55	Hlabisa	Cretaceous sediments	Bonheim	Luvic phaeozem	Yes	Yes	10+
56	Hlabisa	Dolerite	Hutton	Ferralsol arenosol	Yes	Yes	10+
57	Hlabisa	Cretaceous sediments	Swartland	Chromic luvisol	Yes	Yes	20+
58	Hlabisa	Cretaceous sediments	Swartland	Chromic luvisol	Yes	Yes	20+
59	Mkuzi	Lower Ecça	Bonheim	Luvic phaeozem	Yes	Yes	12
60	Mkuzi	Dolerite	Shortlands	Dystric nitosol	Yes	No	12
61	Mkuzi	Dolerite	Hutton	Ferralsol arenosol	Yes	No	12
62	Mkuzi	Cretaceous sediments	Swartland	Chromic luvisol	Yes	No	30+
63	Empangeni	Recent sand	Hutton	Ferralsol arenosol	Yes	Yes	40+
64	Empangeni	Alluvium	Katspruit	Dystric gleysol	Yes	Yes	20+
65	Empangeni	Granite	Glenrosa	Chromic cambisol	No	Yes	20+
66	Empangeni	Dolerite	Mayo	Haplic chernozem	Yes	Yes	50+
67	Empangeni	Alluvium	Oakleaf	Orthic solochak	No	Yes	20+

Anon (1991)

## Methods

Soil samples were collected from 29 paired sites in the northern areas of KwaZulu-Natal of which 15 and 14 sites were from dryland and irrigated areas respectively. The sites were representative of alfisol, oxisol and vertisol soils and were located between latitude 28°23' and 30°45' south and longitude 31°20' and 32°03' east. Paired sites consisted of uncultivated (virgin) and adjoining cultivated areas no more than 30 m apart. Virgin areas included natural bush, and road reserves with natural grassland. Selected characteristics of the cultivated sites are presented in Table 1.

At each site soil samples were taken in triplicate at depths of 0-150, 150-300 and 300-450 mm for chemical examination. Duplicate undisturbed soil core samples were taken at depths of 0-20 and 200-220 mm for physical analysis. On cultivated sites, soil samples for chemical and physical examination were collected in the interrow, with crop ages ranging from one to 12 months. The fertilisers used were from an inorganic source with a nitrogen to phosphorus to potassium (N:P:K) ratio of either 5:1:5 or 1:0:1. Di-ammonium phosphate, mono-ammonium phosphate and urea were occasionally used. The amounts of N, P and K applied per hectare ranged from 120-160 kg, 20-40 kg and 100-160 kg respectively. On 15 paired sites cane was grown under dryland conditions and 14 sites were irrigated. On 55% of the dryland sites cane was burned before harvest and on 91% of these sites tops were spread after harvest. The remaining 9% tops were raked and burned after harvest. On all irrigated sites cane was burned before harvest and on 54% of these sites tops were spread after harvest.

Physical properties that were measured included bulk density (core method), soil water retention (pressurised close system), soil texture (hydrometer method) and electrical conductivity of the extract of a saturated paste. Total pore space (TPS)

was calculated from bulk density assuming a constant particle density of 2,65 g/cm<sup>3</sup> and plant available soil water capacity (PAWC) was calculated from the retention data. Chemical analysis included pH (water), P (Truog), Zn, K, Ca, Mg, Na, S, Al and total N (Meyer *et al.*, 1989), titratable acidity (Thomas, 1982), cation exchange capacity (sum of titratable acidity and NH<sub>4</sub>OAc extractable K, Ca, Mg and Na), acid saturation (titratable acidity/cation exchange capacity x 100) and organic matter (Walkley and Black, 1934). The extract from water saturated soil samples was used to determine electrical conductivity (EC<sub>e</sub>) and soluble Na, Ca and Mg concentrations. The significance of differences in analyses between cultivated and virgin sites was determined by means of the students' t-test.

Table 3

Soil chemical differences associated with pH changes between paired sites in a dryland and irrigated area

Soil property	Depth (mm)	Dryland			Irrigated		
		Mean virgin	Mean cultivated	Mean difference	Mean virgin	Mean cultivated	Mean difference
pH (water)	150	5,56	5,37	0,19	6,68	6,80	-0,13
	300	5,64	5,35	0,29	6,55	6,81	-0,27
	450	5,71	5,43	0,28	6,75	6,80	-0,05
Al (mg/kg)	150	6,93	9,13	-2,20*	2,55	2,36	0,18
	300	9,00	12,31	-3,31	2,09	2,45	-0,36
	450	9,38	11,77	-2,38	2,50	2,70	-0,20
<sup>1</sup> K (cmol/kg)	150	0,53	0,46	0,08	0,89	0,58	0,31*
	300	0,37	0,30	0,07	0,58	0,38	0,21
	450	0,27	0,21	0,06*	0,41	0,31	0,10
<sup>1</sup> Ca (cmol/kg)	150	6,89	6,14	0,75	8,32	6,97	1,35*
	300	7,21	6,23	0,98	9,17	7,27	1,90
	450	6,88	6,39	0,50	10,08	7,51	2,57**
<sup>1</sup> Mg (cmol/kg)	150	4,13	3,27	0,86*	4,07	3,86	0,20
	300	4,22	3,12	1,09**	4,34	4,24	0,10
	450	4,18	3,40	0,78	5,12	4,19	0,93
<sup>1</sup> Na (cmol/kg)	150	0,54	0,58	-0,03	0,64	1,03	-0,39*
	300	0,64	0,42	0,22**	0,83	1,54	-0,71*
	450	0,65	0,46	0,19*	1,44	2,08	-0,64
Titratable acidity (cmol/kg)	150	0,32	0,50	-0,18*	0,14	0,11	0,03*
	300	0,33	0,53	-0,20*	0,14	0,16	-0,01
	450	0,36	0,48	-0,12	0,18	0,15	0,02
CEC (cmol/kg)	150	12,41	10,94	1,47	14,06	12,57	1,49*
	300	12,76	10,61	2,16*	15,06	13,58	1,48
	450	12,34	10,94	1,40	17,22	14,25	2,97
Acid saturation (%)	150	5,82	10,42	-4,60*	1,67	2,48	-0,81
	300	7,52	13,43	-5,91	1,86	4,17	-2,32
	450	8,35	14,27	-5,93	2,02	4,30	-2,28
<sup>2</sup> Ca (mmol/dm <sup>3</sup> )	150	0,50	0,60	-0,10	0,74	0,74	0,00
	300	0,52	0,70	-0,18	0,62	0,58	0,04
	450	0,46	0,56	-0,10	0,73	0,60	0,14
<sup>2</sup> Mg (mmol/dm <sup>3</sup> )	150	0,57	0,59	-0,02	0,57	0,78	-0,21
	300	0,51	0,63	-0,12	0,49	0,57	-0,08
	450	0,44	0,50	-0,06	0,73	0,55	0,18
<sup>2</sup> Na (mmol/dm <sup>3</sup> )	150	2,70	2,23	0,47	3,00	5,51	-2,51
	300	2,67	2,11	0,56	3,08	5,80	-2,72**
	450	2,46	2,00	0,46	5,34	7,84	-2,50
Sodium absorption ratio	150	1,97	1,57	0,41	2,51	4,28	-1,77*
	300	1,86	1,43	0,43	2,85	5,29	-2,44**
	450	1,92	1,47	0,45	3,72	6,11	-2,39*
EC <sub>e</sub> (mS/m)	150	59,91	60,64	-0,73	63,77	96,92	-33,15
	300	56,56	63,22	-6,67	57,54	88,69	-31,15**
	450	49,67	52,56	-2,89	86,42	107,42	-21,00

\* Significant at P=0,05

\*\* Significant at P=0,01

<sup>1</sup> = extract with ammonium acetate

<sup>2</sup> = extract with water

CEC = cation exchange capacity

EC<sub>e</sub> = electrical conductivity of the saturated paste extract

Table 2

Soil physical properties of paired sites from a dryland and an irrigated area

Soil property	Depth (mm)	Dryland			Irrigated		
		Mean virgin	Mean cultivated	Mean difference	Mean virgin	Mean cultivated	Mean difference
Clay %	150	19,2	22,3	-3,1	20,6	19,7	0,9
	300	20,7	21,1	-0,4	23,1	23	0,1
	450	21,8	21,0	0,8	25,5	25,3	0,2
Silt %	150	14,8	13,6	1,2	9,2	8,9	0,3
	300	14,8	13,9	0,9	8,3	8,8	-0,5
	450	12,7	12,5	0,2	6,9	8,5	-1,6
Bulk density g/m <sup>3</sup>	20	1,208	1,340	-0,132*	1,396	1,444	-0,048
	220	1,416	1,455	-0,039	1,503	1,602	-0,099
SWC at saturation (v/v %)	20	44,6	40,8	3,8	50,1	47,2	2,9
	220	41,4	41,8	-0,4	47,3	42,2	5,1
SWC at 10 kPa (v/v %)	20	24,9	24,7	0,2	29,1	25,8	3,3
	220	25,1	25,4	-0,3	29,5	25,7	3,8
SWC at 1 500 kPa (v/v %)	20	17,8	15,1	2,7	16,6	13,9	2,7
	220	17,2	17,5	-0,3	18	15,9	2,1
Total pore space (V/V %)	20	54,5	49,4	5,18	47,3	45,5	1,8
	220	46,6	45,1	1,5	43,3	39,6	3,7
PAWC 0 to 10 kPa (mm/m)	20	197	161	3,6	211	212	-1
	220	163	164	-1,0	178	164	14
PAWC 0 to 1 500 kPa (mm/m)	20	71	96	-25*	125	119	6
	220	79	79	0	115	98	17

SWC = Soil water content

PAWC = Profile available water capacity

\* Significant at P=0,05

## Results

To facilitate easier interpretation of the data the word 'site' is used in conjunction with paired sites and 'area' is used when referring to the dryland and irrigated areas. The results are summarised in Tables 2, 3 and 4 as the mean per constituent per site per area. A summary of the soil physical parameters is presented in Table 2. Mean differences in texture between paired sites were less than 3% and not significant. Clay content between the dryland and irrigated areas was similar although the dryland area contained about 5% more silt than the irrigated area. Mean soil water contents at saturation and at matric potentials of -10 kPa and -1 500 kPa were all slightly higher and bulk density slightly lower in the virgin sites than in the cultivated sites of both the dryland and irrigated areas.

Mean soil chemical values associated pH changes are listed in Table 3. The mean pH value of the virgin sites was 5,64 for the dryland area compared with 6,67 for the irrigated area. In the dryland area cultivation reduced pH by about 0,26 pH units, and in the irrigated area cultivation increased pH on average by 0,14 pH units. Although these trends were not statistically significant they did explain the shift in the values of the chemical constituents between paired sites. Further assessment of the results showed significant increases in titratable acidity, extractable Al and acid saturation, and significant declines in exchangeable Mg, Na and CEC of the intermediate subsoil layer (150 to 300 mm). Overall these results suggest that cultivated dryland sites are acidifying relative to virgin sites.

**Table 4**  
Soil chemical differences associated with changes in organic matter content between paired sites in a dryland and an irrigated area

Soil property	Depth (mm) virgin	Dryland			Irrigated		
		Mean cultivated	Mean difference	Mean virgin	Mean cultivated	Mean difference	Mean
P (mg/kg)	150	21,83	32,69	-10,87	33,92	23,50	10,42
	300	24,52	29,04	-4,52	16,26	12,49	3,77
	450	18,57	20,84	-3,25	10,20	12,72	-2,52
S (mg/kg)	150	24,87	17,27	7,60	22,86	19,57	3,29
	300	18,92	17,00	1,92	22,07	24,29	-2,21
	450	18,54	19,85	-1,31	33,38	53,31	-19,92
Zn (mg/kg)	150	2,10	2,15	-0,04	1,46	1,30	0,15
	300	1,70	1,65	0,06	1,09	0,87	0,22
	450	1,36	1,05	0,31	0,67	0,77	-0,10
(Ca+Mg)/K ratio	150	21,21	20,36	0,85	15,93	20,98	-5,05
	300	33,21	28,85	4,36	27,98	33,54	-5,56
	450	30,35	42,46	-2,11	40,71	38,56	2,15
Organic matter %	150	3,87	3,31	0,56*	2,40	1,88	0,52*
	300	3,33	3,19	0,14	2,08	1,69	0,38*
	450	3,16	3,04	0,12	1,46	1,39	0,08
Total N (cmol/kg)	150	13,85	9,42	4,43**	7,57	5,39	2,18*
	300	7,07	9,28	-2,21	5,44	4,93	0,52
	450	9,35	8,25	1,11	4,78	4,14	0,64
C:N ratio	150	15,32	17,11	-1,79	13,69	13,54	0,15
	300	16,34	16,97	-0,63	16,28	14,92	1,36
	450	17,00	17,10	-0,10	12,50	12,69	-0,19

\* Significant at P=0,05

\*\* Significant at P=0,01

When paired sites from the irrigated area were compared, increased values relative to the virgin sites were evident for AS, SAR, EC<sub>e</sub>, NH<sub>4</sub>OAc extractable Na and water extractable Na and reduced values were noticed for TA, CEC, NH<sub>4</sub>OAc extractable K, Ca and Mg and water extractable Ca (Table 3). Statistically significant differences between paired sites in the irrigated area were obtained for TA, CEC, SAR, EC<sub>e</sub>, NH<sub>4</sub>OAc extractable K, Ca and Na and water extractable Na. Although the Na values in the topsoil were below the threshold value of

2 cmol/kg, the subsoil (450 mm depth) values of the irrigated area approached this threshold value. Similarly, salinity levels of both areas, as measured by EC<sub>e</sub>, are still well below the threshold of 200 mS/m after which yield decline would begin. It is evident from these results that the cultivated sites in the irrigated area are sodicified.

Table 4 contains mean values of chemical constituents susceptible to soil organic matter changes. The cultivated sites in both areas showed significantly reduced levels of organic matter in the top soil layer, but the decrease diminished with increasing depth. The P level was marginal for the cultivated sites in the dryland area and deficient in the irrigated area. Similar results were reported by Meyer and Wood (1989). The P differences between paired sites were greatest in the first soil layer (0 to 150 mm) of both dryland and irrigated areas and decreased with increasing depth. The remaining nutrients (S, Zn and total N) all showed reduced levels for the cultivated sites relative to the virgin sites in both the dryland and irrigated areas. The C:N ratio was slightly higher in the cultivated sites than the virgin sites in the dryland area, but the opposite effect was found in the irrigated area. The (Ca+Mg)/K ratio showed little change between paired sites of both the dryland and irrigated areas. Statistically significant differences between paired sites were obtained only for OM and total N.

## Discussion

The overall impression from this work is that the soil chemical properties were more affected by sugarcane cultivation than the physical properties. The small (not significant) textural difference between the virgin and cultivated areas indicates that the sampling system used was representative with no excessive soil variability between any of the paired sites. The higher bulk density of the cultivated sites might be due to structural breakdown (not measured) as a result of the reduced organic matter content (Schjønning *et al.*, 1994), chemical dispersion of clays through enhanced Na levels (Johnston, 1981) and compaction by infield haulage systems (Swinford and Boevey, 1984). The difference between paired sites of both the dryland and irrigated areas is relatively small compared with results from a similar study conducted in the Herbert Valley of Australia (Wood, 1985). This may be due to the South African system of mainly manual cutting and stacking followed by mechanised haulage at harvest. The values reported in Table 2 are well below a suggested critical density value of 1,72 g/m<sup>3</sup> (calculated from Maud, 1960) for the South African sugarcane industry.

Continuous monocropping, the intensive use of nitrogenous fertilisers, burning of crop residues and a relatively high rainfall of 900 to 1 200 mm (compared with the rest of southern Africa) are some of the major factors that have caused a reduction in soil organic matter, CEC and acidification and increased Al toxicity in the cultivated areas (Wood, 1985; Schroeder *et al.*, 1994; Henry and Ellis, 1995). Little can be done to break the continuous monocropping cycle in sugarcane production, as the average number of ratoons for the South African industry is eight and fallowing is not normally practised.

The most pronounced results from this survey are the relatively large differences between paired sites in terms of increased salinity and sodicity. It is evident from Figure 1 that the grey soils (alfisols) with a duplex character are prone to sodicity and the red soils (oxisols) to salinity. The accumulation of Na on grey soils under irrigation was excessive and caused the pH to increase on cultivated fields relative to virgin sites, which resulted in a decline in Al and titratable acid-

ity (TA) degradation indices (Figure 2). It may be inferred from the results that the irrigated grey soils are prone to sodicity, while those under dryland conditions are acidifying.

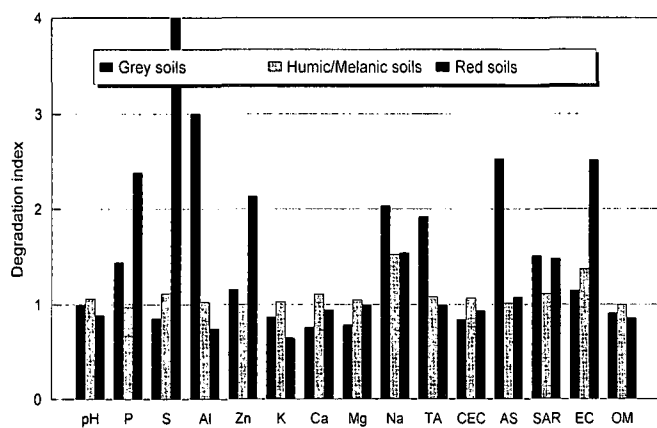


FIGURE 1: Comparison of the degradation index of selected soil chemical properties of grey, humic/melanic and red soils. TA = titratable acidity, AS = acid saturation. All abbreviations are described in the text.

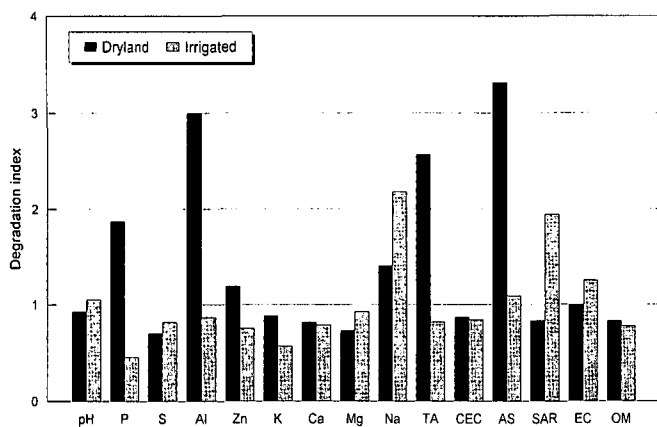


FIGURE 2: Comparison of the degradation indexes of grey soils (alfisols) from a dryland and an irrigated area. TA = titratable acidity, AS = acid saturation. All abbreviations are described in the text.

Red soils are normally the better drained soils and are well suited to irrigation. The quality of irrigation water used will thus determine the rate of degradation on these soils. Most red soils under irrigation occur in the northern parts where rivers with the poorest water quality in the South African sugar industry are located (Meyer and van Antwerpen, 1995). Salinity rather than sodicity appears to be the main effect from irrigating with poor quality water on the better drained soils.

It was shown that soil organic matter loss following the introduction of cultivation reached equilibrium in 5-10 years in the warmer, drier ecotypes and 40-60 years in the cooler, wetter ecotypes of southern Africa (du Toit *et al.*, 1994). The survey reported in this paper was not designed to look at the effect of cultivation over time on soil degradation. However, a trend was revealed from the samples collected in the dryland area at site 42 on a coastal loamy sand (results not shown). Two cultivated fields, two and >20 years in production respectively, were sampled within 20 metres of the virgin site. The soil degradation pattern for the old cultivation site followed the mean trend reported in Tables 1, 2 and 3 for the dryland area. Soil degradation for the two year old field had

already started to show small differences relative to the virgin site in terms of titratable acidity, acid saturation, CEC, P, S, Al and  $\text{NH}_4\text{OAc}$  extractable K, Ca and Mg. These, however, were not significant.

Organic matter is a rich source of mineral P, S and N in soil (Naidu and Rengasamy, 1993) and it can be expected that soil management practices leading to a decline of OM in soil will reduce the availability of these nutrients to plants. Reasons for the reduced P content of cultivated soils in the irrigated area may be due to lower OM, higher crop removal by cane growers and possible precipitation of P as phosphates by Ca and Mg in irrigation water on soils with a high P fixing capacity. P recommendations will probably need to be reassessed for irrigated cane.

The availability of Zn is mainly soil pH controlled (Naidu and Rengasamy, 1993) with optimum availability between pH values of 5,0 and 5,7 (Schroeder *et al.*, 1994). The mean pH of the dryland area was within this range but that of the irrigated area ranged between 6,5 and 6,8 for the virgin and cultivated sites respectively. The pH effect probably accounts for the unchanged Zn status between paired sites in the dryland area and the reduced Zn levels for the cultivated sites in the irrigated area.

The low OM content and C:N ratio found in the irrigated area is in many respects similar to that reported for sodic soils in Australia (Naidu and Rengasamy, 1993). The reduced C:N ratio from the cultivated sites in the irrigated area suggests that the loss of OM is larger than that of total N, which may be due to the practice of burning nearly all plant residues of cane produced under irrigation. The fact that more plant residues are retained in dryland compared with irrigated fields could be the reason why the C:N ratio was higher for the cultivated sites in the dryland area, and means that losses of total N were greater than losses of OM. The increased (Ca+Mg)/K ratio in the topsoil of the cultivated sites in the irrigated area indicates leaching of K relative to Ca and Mg, and suggests that the current K fertiliser recommendation for the irrigated area is not adequate. Similar results were reported by Henry and Ellis (1995) from an irrigated estate in Swaziland.

## Conclusion

As in many other parts of the world soil degradation, mainly in the form of increased acidification in dryland areas and salinity/sodicity build-up in irrigated areas, are factors that have been positively identified in the South African sugar industry. As these factors have been linked to yield decline, steps must be taken to prevent or reduce the rate of soil degradation. The common thread linking the results in all three tables is the decline in organic matter levels. Production of sugarcane in South Africa is a monoculture, with a mean of eight crops before fields are re-established with sugarcane. The cycle of monocropping can only be broken through crop rotation (Capriel *et al.*, 1992) and soil organic matter stabilised or even increased through green manuring, minimum tillage, green cane harvesting and spreading of crop residues. Growers in irrigated areas should also reduce sodium build up through drainage and the use of  $\text{Ca}(\text{SO}_4)_2$ . There may also be merit in the use of ammonium sulphate as the main N carrier to acidify soils to a pH value of between 5,5 and 6,0. Growers in the dryland areas will also need to conserve the OM content of their soils and make more use of  $\text{CaCO}_3$  to reduce soil acidification. P and K recommendations for the South African sugar industry will have to be checked and possibly verified to meet the requirements of the irrigated areas.

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