

NUTRITION OF THE SOUTH AFRICAN SUGAR CROP: CURRENT STATUS AND LONG-TERM TRENDS

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Abstract

The sugarcane crop has a high demand for nutrients due to its rapid growth rates, high biomass production and the appreciable nutrient removals in harvested material. Information contained in leaf and soil analytical databases of SASRI's Fertiliser Advisory Service (FAS) was used to assess fertility trends in the South African sugar industry. Leaf data suggest that nitrogen (N) deficiency is a widespread growth limitation, with ~36% of samples submitted from the various extension regions being deficient in N. Soil test data indicate that phosphorus (P) supply is adequate in the majority of soils; indeed, many of the soils are classified as containing high P levels, which raises concerns in terms of the potential for ground and surface water pollution. Exchangeable potassium (K) reserves in many of the topsoils in the dryland areas are low in terms of crop requirements, possibly making it necessary for the crop to scavenge below the plough layer to meet K requirements. As noted in earlier nutrient surveys of the industry, low pH and associated calcium (Ca) and magnesium (Mg) deficiencies are pervasive problems in the dryland areas. Large differences in leaf silicon (Si) levels were noted between irrigated and dryland production areas, and a need for an effective strategy to address the widespread Si deficiency in dryland areas is emphasised.

Keywords: FAS database, soil acidity, nitrogen, phosphorus, potassium, silicon

Introduction

Due to the high biomass production of sugarcane relative to other crops, proportionately high inputs of nutrients are required to optimise crop growth. Satisfying the nutritional requirements of the sugarcane crop contributes significantly to production costs, and sound management of crop nutrition is thus a key driver of profitability. In addition to economic considerations, however, is the need for sound environmental stewardship of production systems. Crop production has the potential to detrimentally affect the environment through, for example, changes in soil chemistry or accelerated nutrient loss to water bodies.

Leaf and soil analytical data captured by the Fertiliser Advisory Service (FAS) have proved to be an extremely useful resource for monitoring fertility trends in the South African sugar industry. In 1970, a comprehensive soil survey was undertaken to investigate whether widespread nutrient and trace element deficiencies existed within the industry (Meyer *et al.*, 1971). Major findings included that (a) the only extensive nutrient deficiency was potassium (K) (~40% of soils), (b) there were no major trace element deficiencies, although zinc (Zn) was identified as being problematic in certain areas of the Midlands and Coast Lowlands, and

(c) the Midlands Mistbelt region and sandy soils of the Coast Lowlands were prone to toxic aluminium (Al) levels.

Beginning in 1980, soil and leaf sample analytical data were captured electronically, and in 1989 and 1998, this data was used to further analyse fertility trends in the industry (Meyer *et al.*, 1989, 1998). From the soil data considered during the 1989 survey, 51% of soils with <30% clay were marginal to deficient in K, while 56% of rainfed and 59% of irrigated soils were observed to be marginal to deficient in K. For the survey conducted in 1998, soil data indicated a build-up of K in many areas, suggesting an over-application of this nutrient, and this was also reflected in the leaf analysis data. A decline in the percentage of soils deficient in P from 17% in 1970 and 12% in 1989, to 'fairly low incidences' in 1998 was reported. Leaf analyses revealed that higher proportions of deficiencies were observed for nitrogen (N) (13%), phosphorus (P) (12%), K (28%) and sulphur (S) (18%) than for calcium (Ca) (4%), magnesium (Mg) (1%) and Zn (8%). An industry-wide increase in soil acidification was also clear, with average soil pH (H₂O) values decreasing from 6.2 in the 1980-82 period to 5.6 in the 1996-97 period.

The objective of this paper is to use FAS soil and leaf sample data that has been collected since the previous survey (1998) to monitor trends in crop nutritional status and soil chemistry for the various extension regions. Particular attention is afforded the most recent period (2006-09), as these data provide an indication of the current fertility status of the industry, and should be of value in informing the direction of nutrition-related research and extension initiatives.

Materials and Methods

Soil and leaf sample data from the FAS database for the period 1998-2009 were analysed. In soils, exchangeable cations were analysed using the ammonium acetate method, pH was analysed in water, and the Truog method was used to analyse for P. Standard procedures were used to determine leaf nutrient levels. Summarised soil data for the most recent three year period (2007-09) are reported for each extension region and discussed. Mean leaf nutrient deficiency data for the past four years (2006-09) are also presented and discussed. As silicon (Si) has not been considered in previous surveys, this nutrient is addressed in some detail in this paper. Extension regions considered are Mpumalanga, Swaziland, Pongola, Umfolosi, Zululand North, Zululand Central, Zululand South, North Coast, Durban North Coast, Midlands North, Midlands South, South Coast and Lower South Coast.

Results and Discussion

Number of samples analysed and sampling intensity

Since 1992 the number of leaf samples submitted annually has fluctuated more than has been observed for soil samples. The long-term average number of leaf samples analysed annually is 4070, and over recent years has declined slightly (Figure 1). For soil samples, the long-term average annual number of samples submitted is 11 660. Although the number of soil samples analysed annually generally decreased between 2001 and 2007, an increase in submitted samples has once again been observed over the past two years.

The area under sugarcane in South Africa is currently estimated to be approximately 450 000 hectares. Using this figure, along with the long-term averages for soil and leaf submissions, an industry sampling intensity of 39 ha per sample for soil and 111 ha per sample for leaf is indicated. Given the variability of soil resources in the Sugar Industry, this intensity of sampling is clearly far from satisfactory. The reduction in the number of leaf samples submitted for analysis is of particular concern.

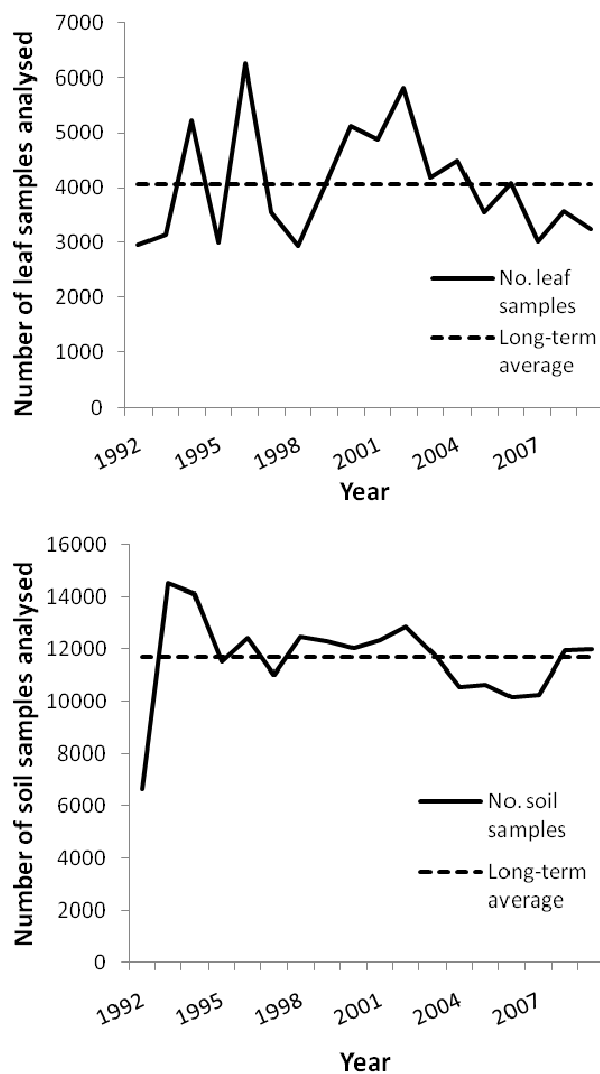


Figure 1. Number of leaf (above) and soil (below) samples analysed by the Fertiliser Advisory Service laboratory between 1992 and 2009.

Overview of analytical results

A summary of soil pH levels, selected nutrient levels and percentage of soil samples deficient for each extension region for the 2007-09 period is presented in Table 1. Percentages of leaf samples deficient in N, P, K and S for the different extension regions are presented in Table 2. Criteria used to define deficiency levels are also shown at the bottom of each table.

Table 1. Mean soil pH (H₂O), selected nutrient concentrations and percentage deficient samples for the different extension regions.

Region	pH (H ₂ O)		P* (mg/kg)		P*** (mg/kg)		K (mg/kg)						S (mg/kg)		Ca (mg/kg)		Mg (mg/kg)		Zn (mg/kg)	
	Mean	Low (%)	Mean	Deficient (%)	Mean	Deficient (%)	<30% clay		30-40% clay		>40% clay		Mean	Deficient (%)	Mean	Deficient (%)	Mean	Deficient (%)	Mean	Deficient (%)
							Mean	Deficient (%)	Mean	Deficient (%)	Mean	Deficient (%)								
Mpumalanga (i)***	7.2	0	58	13	40	5	215	17	285	4	314	17	21	10	3028	1	779	2	2.1	31
Swaziland (i)	7.3	0	40	11	40	1	186	2	203	0	221	5	13	34	2599	0	859	0	2.1	4
Pongola (i)	6.4	0	38	11	39	5	184	4	277	2	323	0	24	29	1264	0	445	0	2.6	0
Umfolosi (i)	6.7	0	44	11	38	4	147	15	179	10	183	22	14	33	1399	1	489	1	1.5	9
Komatipoort (i)	6.9	0	40	18	36	5	123	27	168	15	200	29	24	8	2426	0	833	0	2.6	2
Zululand North	5.7	9	27	40	27	5	150	16	218	4	212	6	40	8	856	2	310	2	2.3	14
Zululand Central	5.3	17	38	19	33	3	147	10	221	2	235	6	26	18	406	14	113	18	2.2	16
Zululand South	5.5	6	32	20	35	1	125	35	217	6	232	15	22	19	788	4	263	5	3.4	0
North Coast	5.5	9	33	27	34	5	112	34	164	7	192	28	20	32	553	10	168	12	2.3	12
Durban North Coast	5.5	7	37	18	36	1	122	22	186	5	202	13	92	26	543	11	164	13	2.5	12
Midlands North	5.3	8	41	15	41	4	138	18	207	2	223	4	30	9	565	2	160	4	3.2	4
Midlands South	5.2	9	33	23	32	4	118	24	164	11	166	36	20	22	432	8	127	15	2.7	8
South Coast	5.3	7	33	22	37	2	162	15	326	0	351	0	16	26	545	6	173	9	2.7	10
Lower South Coast	5.2	11	30	25	33	3	228	5	344	1	355	6	12	36	344	11	113	18	2.2	8
Deficiency criteria	< 5.0		< 31		< 13		< 112		< 150		< 225		< 15		< 200		< 75		< 1	

* At planting

** Ratoon

*** Production predominantly under irrigation

Table 2. Percentage of leaf samples deficient in selected nutrients.

Region	No. samples	N	P	K	S
		%			
Mpumalanga	192	44	2	19	1
Swaziland	244	51	15	15	28
Pongola	38	71	11	37	0
Umfolozi	261	54	15	13	1
Komatipoort	1053	30	5	10	1
Zululand North	419	35	28	15	5
Zululand Central	215	37	19	17	0
Zululand South	26	4	12	4	4
Midlands North	423	35	15	5	3
Midlands South	232	40	8	3	9
North Coast	554	28	18	9	5
Durban North Coast	190	32	14	15	8
South Coast	388	41	9	5	5
Lower South Coast	37	49	24	8	46
Deficiency criteria		< 1.8%	< 0.19%	< 1.05%	< 0.12%

Soil acidity

As previously mentioned, Meyer *et al.* (1998) observed a definite increase in soil acidification, with average industry pH (H₂O) values declining from 6.2 in 1980-82 to 5.6 in 1996-97. Data from the past 10 years show that, although this trend in soil acidification was maintained in most regions initially, during 2007-09 there has been an increase in soil pH consistently across all regions except Pongola. This rise in pH may be the direct result of the introduction of higher lime recommendations aimed at addressing the issue of soil health (Nixon, 2005). Nonetheless, pH means are currently still below those measured 10 years ago for many of the regions. If liming is effectively raising soil pH, in all but very sandy soils this effect will be restricted largely to topsoils. Evidence of widespread severe subsoil acidification (data not shown) is cause for concern in terms of the sustainability of sugarcane cropping practices in the dryland areas.

An additional cause for concern in terms of these pH data is that increases in pH would be expected to coincide with increases in Ca and Mg availability, and this is not apparent across many extension regions. Caution in the interpretation of these data, along with careful monitoring of soil pH trends in the future, is therefore recommended.

Nitrogen

Leaf N thresholds used by FAS range from 1.6 to 1.9%, depending on crop age and month of sampling. With it not being possible to reliably establish sampling details from the database, a threshold of 1.8% was applied in the derivation of the N deficiency statistics presented in Table 2. It is worth noting that 1.8% N is generally below or at the lower limit of threshold ranges used in several overseas countries (Reuter and Robinson, 1997; Kingston, 2000; McCray *et al.*, 2006).

An alarmingly high percentage of leaf samples received by the FAS laboratory over the past four years were deficient in N. This is consistent with trends noted in earlier interrogations of the FAS databases. Between the 1980-82 and 1996-97 periods, leaf samples deficient in N for the whole Industry increased from 10 to 26% (Meyer *et al.*, 1998). The percentage of N-deficient samples for the whole Industry has now risen to 36%. Meyer *et al.* (1998) attributed

this increase to grower response to the *Eldana saccharina* threat and increased use of sugarcane varieties with different N uptake patterns. Additionally, recent high fertiliser prices, coupled with ongoing deterioration in soil health due to organic matter depletion are plausibly contributing further to this occurrence.

Phosphorus

The regions with the highest percentage of soil samples deficient in P at planting are Zululand North, North Coast and Lower South Coast, while the northern irrigated regions have the lowest P deficiencies at planting. It must be cautioned, however, that use of the Truog P soil test in the irrigated north may result in an over-estimation of the solubility of calcium phosphates. In future analyses, pH-neutral and alkaline soils will be evaluated using a non-acidic extractant. Deficient levels of P are infrequent in ratoon crops.

Of increasing concern, however, are the high levels of P occurring in many regions in the industry. Phosphorus soil test values well in excess of crop requirements imply an increased potential for P pollution through export to fresh waterways via runoff and leaching losses. Table 3 shows the percentage of soil samples per extension region with P levels above 41 mg/kg, a value empirically selected to indicate high levels. Excessive P levels are of particular concern on sandy soils, and extremely high P test values (>500 mg/kg) have occasionally been observed on sands (data not shown). Indications are that prolonged use of chicken litter is often associated with soils with excessive P levels, a consideration emphasising the need for a more responsible approach in the use of this amendment. A similar trend was observed at the global scale, where it was estimated that between 1950 and 1995, $\sim 600 \times 10^6$ Mg of fertiliser P was applied to agricultural land, but only $\sim 50 \times 10^6$ Mg removed through harvest, and some of the harvested P was reapplied as animal manure (Carpenter *et al.*, 1998).

Table 3. Percentage of soil samples with high P levels (>41 mg/kg) for the different extension regions during the 2007-2009 period.

Region	% samples
Mpumalanga	68
Swaziland	40
Pongola	42
Umfolosi	58
Komatipoort	41
Zululand North	22
Zululand Central	41
Zululand South	23
North Coast	28
Durban North Coast	34
Midlands North	43
Midlands South	28
South Coast	26
Lower South Coast	23

Considering the high P levels noted in certain regions, and that P is most often the limiting factor for eutrophication (Walmsley, 2000), management practices should be adapted to mitigate potential environmental impacts. Phosphorus pollution from agriculture has required statutory control measures in certain countries, for example, the Netherlands, where a Soil Protection Act regulates the management of P-saturated soils (De Haan and Van der Zee, 2003). Hooda *et al.* (2001) observed that the degree of soil saturation with P (DSSP) can potentially be used to assess the P export potential of a soil, and this is calculated using P, iron (Fe) and aluminium (Al) contents (ammonium oxalate-oxalic acid extract). A similar approach, as well as further research to relate soil P tests to soil solution P levels is recommended for the sugar industry.

Potassium

Potassium deficiencies generally occur most frequently in low clay soils (<30%), followed by high clay soils (>40%), with soils having intermediate clay levels (30-40%) showing the lowest incidences of deficiencies. Potassium deficiencies were particularly marked in Komatipoort, Zululand South, North Coast and Midlands South. This, however, is not clearly reflected in the leaf data (Table 2), with higher leaf K deficiencies occurring in the irrigated regions, most notably Pongola.

Sulphur

Widespread S deficiencies are apparent in soils of the industry, with S levels having dropped sharply from pre-1998 levels for many regions. Particularly high deficiencies exist in Swaziland, Pongola, Umfolosi, North Coast, Durban North Coast, South Coast and Lower South Coast. For leaf data, however, high levels of S deficiency were only observed for Swaziland and Lower South Coast. This raises the possibility that the current soil S threshold value is excessive.

Calcium and magnesium

In a number of regions, between 8 and 14% of the soil samples were deficient in Ca (Table 1). This is generally lower than the percentages of deficient samples that were observed during the survey conducted in 1998. For example, Ca deficient soil samples have decreased by 15% in Durban North Coast, North Coast and Lower South Coast, and by 8% in Zululand Central. This may be a reflection of increased lime use by growers. Nonetheless, for many regions, soil Ca levels have still dropped significantly from pre-1998 levels.

A much sharper decline can be observed for Mg levels throughout the regions. This is a clear continuation of the trend observed by Meyer *et al.* (1998), who attributed a depletion of Mg reserves to continued crop removal as well as soil acidification. For this reason the dryland production regions, in particular, will need to address Mg management to avoid deficiencies.

Despite the declining levels of these two nutrients in soils, leaf samples were rarely deficient in Ca and Mg (<5%) (data not shown). Reasons for this are not readily apparent, and a review of the deficiency criteria currently used may be required.

Zinc

In many areas, Zn soil levels increased slightly from pre-1998 levels. Soil Zn deficiencies are nevertheless still fairly common in a number of regions (Table 1).

Leaf silicon

The importance of Si in crop nutrition has been increasingly recognised in recent years, with research indicating that Si has a favourable impact on yield through improved resistance to

biotic and abiotic stresses (Savant *et al.*, 1999). FAS analysis of leaf samples for Si commenced in 2001, and regional leaf Si levels are reported on for the first time in this paper. Mean leaf Si percentage and percentage of samples considered deficient in Si (<0.5%) are presented in Figure 2. Data from Zululand was not included in this analysis due to low sample numbers. From these data it is apparent that frequent Si deficiencies occur in the dryland production regions (North and South Midlands, North Coast, Durban North Coast, South Coast and Lower South Coast). In sharp contrast, Si supplies are generally adequate in the irrigated regions. This is due to impoverishment of Si reserves in the dryland regions through weathering and leaching processes, with confirmation of this being furnished by the close relationship between soil pH and leaf Si concentrations.

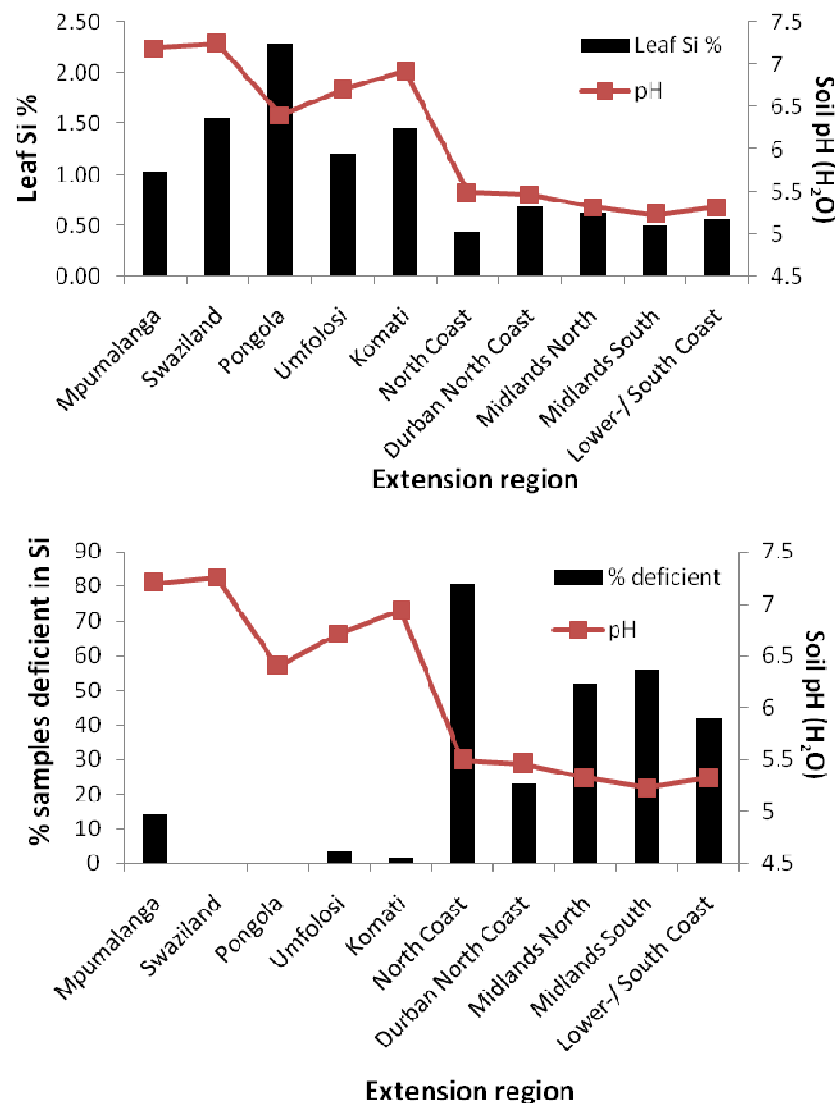


Figure 2. Mean leaf sample silicon (Si) percentage and soil pH (above) and percentage of samples deficient in Si (<0.5%) and soil pH (below) for the different extension regions (Zululand data excluded due to low sample numbers).

Conclusions

Data presented in this paper will hopefully assist Extension Officers and growers in achieving increased profitability and sustainability.

Analyses play a crucial and irreplaceable role in guiding nutrient management practices. It is envisaged that following the current revision of crop recommendations based on analytical results, along with continued improvements being made to FAS protocols, sample numbers will increase and leaf and soil testing will once again play their necessary pivotal role in guiding fertilisation practices in the industry.

Frequent macro-nutrient deficiencies are apparent in the soil and leaf data presented. These problems, along with excessive acidity in soils of the dryland cropping areas, undoubtedly limit cane production. Of particular concern is the evidence of pervasive N deficiency throughout the industry. Given that responses to N are invariably linear to levels of application approaching sufficiency, and therefore highly profitable, it is suggested that improved N management should receive particular attention in research and extension programmes.

Mounting evidence of P excesses in many soils of the industry is disturbing. In terms of sound environmental stewardship, a strategy for the more rigorous monitoring of soil P levels, particularly where there is regular use of chicken litter, needs to be developed.

Silicon leaf data for the sugar industry were reported on for the first time in this paper. Clear differences in Si supply can be observed between the irrigated and dryland production areas, and the need for an effective strategy to address widespread Si deficiencies in the dryland areas is indicated.

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