INDICATORS OF SOIL HEALTH FOR USE IN THE SOUTH AFRICAN SUGAR INDUSTRY: A WORK IN PROGRESS

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Abstract

Sugarcane growers acknowledge the importance of the soil's contribution to optimal yields. However, a question frequently asked is: which of the parameters have to be taken into account to assess the condition of a soil? The objective of this paper is to compile a list of parameters that can be easily measured in the laboratory, and from which the condition of a soil can be gauged to suggest a system of interpretation. Soil samples were collected from 28 cane fields comprising three different land uses, i.e. cane fields burnt at harvest, cane fields that were trashed at harvest and undisturbed virgin areas. All soil samples were analysed for their chemical (pH, total N, P, K, Ca and Mg), physical (texture, dispersion and aggregate stability) and biological (soil carbon, microbial biomass, basal respiration and nematodes) properties. These are all routinely assayed in the SASRI laboratories. The clay contents for the burnt and trashed cane fields were similar, and they significantly differed to that found in the virgin sites. However, this variation in clay content was overshadowed by organic carbon, which had a greater effect on all soil properties. All indicators were then linked to threshold values so that laboratory results could be meaningfully interpreted. Although most threshold values were taken from the literature, those for biological soil properties were developed from work done in the South African sugar industry. A format was subsequently developed to present the soil health ratings with comments to clients. Most of the parameters considered were able to reflect differences between land uses, which could be explained by soil carbon content differences.

Keywords: biological, chemical, nematodes, paired sites, physical, sugarcane, soil health index

Introduction

'Soil health' and 'soil quality' are terms frequently used in the literature. For the purpose of this paper, the term 'soil quality' will be regarded as the condition of a soil reflecting climatic conditions and applied management options over an extended period of time. 'Soil health' will be regarded as the condition of the soil at the time of sampling (van Antwerpen, 2005). The latter term will be used in this paper and was also used by Gugino *et al.* (2007) and Pattison *et al.* (2008) in the same context.

About 90% of all cane fields are burned at harvest, and the remainder are trashed at harvest (South African Cane Growers Association, 2005). A strong link exists between land use management and the properties of a soil (van Antwerpen and Meyer, 1996). Improper management of soils can lead to damaging changes in soil function, which in turn can lead to yield losses. Although growers often optimise yields using appropriate management strategies and targeted application of inputs, there is a need to quantify the condition of soils. To achieve this, an evaluation framework was needed to identify problematic or potentially problematic fields (Doran *et al.*, 1998) and to formalise sound corrective recommendations. Indicators of soil health (soil stress or productivity) are soil properties that are sensitive to changes in land use (Staben *et al.,* 1997) and where possible cover soil chemical, physical and biological properties (Haynes and Graham, 2004). This approach should be flexible, and should permit comparisons amongst soils with widely different properties (Haberern, 1992).

A comprehensive assessment of soil health includes a wide range of chemical, physical and biological parameters determined in the laboratory and in the field. However, the processes, particularly those that are field-based, and sampling requirements, are labour-intensive and possibly not achievable within a routine soil sample submission programme (van Antwerpen, 2005). This suggests that the methods used for assessing soil health are critical in the compilation of the parameter list. The South African sugar industry is fortunate in that it has a competent fertiliser advisory service (FAS) laboratory for routine soil, leaf and water assessments, receiving samples daily without any prior knowledge of the prevailing soil conditions and the production strategies that may affect the condition of the soil. The laboratory analyses the sample and makes recommendations pertaining to the nutritional requirements of an expected cane crop. It is within the boundaries of this system that this paper was written, i.e. only those parameters that can be measured in the laboratory were considered. In a review paper by van Antwerpen (2005), different soil parameters were assessed and discussed for possible inclusion in a user-friendly soil health index package. These are listed in Table 1.

Table 1. Suggested list of soil health indicators for use in the South African sugar industry (after van Antwerpen, 2005).

Chemical	Physical	Biological
FAS routine (soil)	Texture	Microbial biomass C
Mineralisable C	Dispersion index	Microbial biomass N
Mineralisable N	Aggregate stability	Basal respiration
Labile C	Plant available water capacity	Dehydrogenase activity
Total C	Soil colour	Bacteria to fungi ratio
		Nematodes

van Antwerpen (2005) concluded that soil organic carbon (labile fraction) was undoubtedly the parameter with the most significant impact on soil chemical, physical and biological properties, although this parameter is unfortunately not yet a routine measurement at the South African Sugarcane Research Institute (SASRI). Microbial biomass was regarded by Dalal (1998) as a sensitive indicator of changes in soil organic carbon content. The most sensitive soil physical parameter to reflect soil health was aggregate stability (Seybold *et al.*, 2002; Shukla *et al.*, 2004). The most useful soil chemical property was pH, because it is easy to measure, and it affects both microbial communities and nutrient availability (van Antwerpen, 2005).

The objectives of this paper were to establish a list of measurable parameters and to suggest guidelines for the interpretation of these values, and thus provide advice to improve the general health of soils used in sugarcane production.

Material and Methods

Topsoil samples (0-100 mm depth) from 28 paired sites (with each site composed of: one cane field and one nearby virgin site) were collected over a period of two years (May 2005 to May 2007) from cane fields adjacent to virgin areas. The cane fields were either burned at harvest (conventional practice) or trashed (green cane harvesting). The age of cane crops at the time of sampling ranged from just cut to fully grown. Samples were collected from only the rainfed areas of the sugar industry and all regions were covered (i.e. Midlands north and south, Coastal north and south, and Zululand). All land management options had to have been followed for at least five years in order to be considered for sampling.

Three soil samples, not closer than 10 metres from each other, were taken in a triangular pattern from each field and kept separate for analysis. All samples were analysed for a range of soil chemical, physical and biological properties. The soil chemical properties were: pH (determined in a 1:2.5 soil-to-water ratio using a glass electrode), plant-available P (determined by extraction with the modified Truog reagent (0.02 N H2SO4) (du Toit, 1962)), exchangeable K, Ca, Mg and Na (extracted with 1 N ammonium acetate (du Toit, 1959)) and cations in the extracts (analysed by atomic absorption spectrophotometry). Aluminium content was determined colorimetrically according to the method described by Skeen and Sumner (1965) and soil organic C was determined by a dichromate wet oxidation procedure (Sahrawat, 1982). Total soil N was determined by semi-micro Kjeldahl digestion with colorimetric determination of the liberated ammonium (Forster, 1995).

Soil physical properties included soil aggregate stability measured with the wet sieving method as described by Haynes (1993) and texture measured with the hydrometer method (Day, 1965). Soil biological properties were microbial biomass and basal respiration, both estimated with the fumigation-extraction method based on the difference between C extracted with 0.5 M K_2SO_4 from chloroform-fumigated and unfumigated soil samples using a Kc factor of 0.38 (Vance *et al.,* 1987). Nematodes were extracted from a 200 cm^3 soil sample with Seinhorst's elutriation technique (Seinhorst, 1962). All extracted nematodes were enumerated under the microscope. Nematodes were grouped into their different genera and those individuals belonging to Criconematinae were grouped and recorded as 'Criconematids'. The non-plant feeding genera were grouped together as 'free-living nematodes'.

Average values of the soil biotic and abiotic components were compared with ANOVA (GenStat v.11). Relationships between variables within the different land management options were investigated using principal component analysis (ADE-4, Thiolouse *et al*., 1997) and multiple correlations. Significant relationships were modelled using regression analysis (GenStat v.11). Soil samples were evaluated for different characteristics using a percentile rating system of Idowu *et al*. (2007). The 25th and 75th percentiles represent the lower and upper values for each characteristic, respectively.

Results

List of soil health indicators and trends

For this section, all the data from the project were grouped into one folder and analysed for the impact of land management on each soil health indicator. An important condition for the selection of a list of soil health indicators in the SA sugar industry was that all the information to rate the soil should come from laboratory results. Based on this criterion, and guided by the routine analyses offered by SASRI laboratories, a list of possible soil health indicators was compiled (Table 2). The land management options (i.e. burned at harvest, trashed at harvest and undisturbed veld (virgin, consisting mainly of low-growing grasses and sedges)) can be grouped in two ways: (i) 'carbon management' (receives carbon on a regular basis versus low carbon additions, i.e. cane burned at harvest but the tops retained) and (ii) 'cover crop type' (cane versus veld) (Table 2).

Chemical indicators

The virgin sites had higher pH values than both burned and trashed sites (Table 2). The same trend was found for K, Ca and Mg. Conversely, P and Al were significantly lower in virgin sites compared to both burned and trashed sites. All chemical indicators showed a significant split in regard to land management, i.e. samples collected from cane fields (burnt and trashed) were significantly different to those collected from virgin areas (Table 2). The only exception was Mg, which was significantly different between all three land uses.

Physical indicators

The virgin sites had a significantly lower clay content than the burned and trashed fields (Table 2). This was of great concern, as many other soil parameters are directly and indirectly linked to clay content. The same trend was evident for the overall soil aggregate stability SAS% (0.5-1.0 mm) and SAS% (1-2 mm) parameters, while the SAS% (2-5 mm) had a significantly higher value for virgin veld than for burned and trashed fields. On the other hand, the SAS% (0.5-5.0 mm) parameter had significantly higher values for virgin veld and trashed fields opposed to burned fields. The SAS fraction (0.5-5.0 mm) was significantly split in relation to carbon management between land uses (i.e. overall SAS was more stable where organic matter returns to the soils were regular and in large quantities). The other textural parameters (silt and sand) and dispersion index did not differ significantly between the three land uses.

Biological indicators

The virgin sites contained 0.26% more carbon than the burned sites but almost the same carbon content as the trashed sites. This is meaningful as trashed fields receive between 11 and 13 tons of organic residues after every harvest, mostly in the form of sugarcane leaves (Donaldson *et al*., 2008). Paired site 20 (data not shown, all three land uses were sampled at this site) with 14.9% less clay in the trashed site compared to the burned site, contained 1% more carbon in the top 100 mm soil layer. Values of biological indicators obtained from fields that were burned at harvest were significantly lower than those from the virgin sites, with most values from the trashed fields intermediate between the two (Table 2). Total soil N followed the same trend as carbon in terms of being non-significant between the virgin and trashed fields, but having significantly less total N in soils from the burned fields compared to virgin fields. Microbial biomass and basal respiration had similar trends regarding mean differences between sugarcane and virgin sites with virgin site values significantly larger than burned, and virgin just larger than trashed sites. Microbial quotient was the only biological ratio reflecting the impact of land management, with significantly larger values for land uses where organic matter was regularly added (trashed and virgin sites). The other two ratios (C/N and metabolic quotient) showed no significant differences between land uses.

Table 2. List of soil parameters from the SASRI laboratories that were considered as soil health indicators and their sensitivity to land uses.

Land use	**Burned**	**Trashed**	**Virgin**	**P-value**
Cover crop	**Cane**	**Cane**	**Veld**	
***Carbon management**	**No C add**	**C add**	**C add**	
CHEMICAL INDICATORS				
pH_{water}	5.32^{a}	5.32^{a}	5.72^{b}	$P < 0.001$
P (mg/kg)	42^{a}	48^{a}	35^{b}	$P < 0.001$
K (mg/kg)	202^{a}	208^{a}	249^{b}	$P = 0.015$
Ca (mg/kg)	786^{a}	714^{a}	989^{b}	$P < 0.001$
Mg (mg/kg)	369^{a}	278^{b}	475^{c}	$P < 0.001$
Al (mg/kg)	28^{a}	23^{a}	7^{b}	$P < 0.001$
PHYSICAL INDICATORS				
SAS % (0.5-1mm)	8^{a}	7^{a}	4^{b}	$P < 0.001$
SAS % (1-2mm)	9^{a}	11^{a}	8^{b}	$P < 0.001$
SAS % (2-5mm)	33^{a}	39^{a}	46^{b}	$P < 0.001$
SAS % (0.5-5mm)	50^{a}	57^{b}	58^{b}	$P < 0.001$
Clay %	24^{a}	22^{a}	20^{b}	$P < 0.001$
Silt %	10	11	12	
Sand %	66	67	68	
Dispersion index %	19	17	18	
BIOLOGICAL INDICATORS				
Carbon%	1.90^{a}	2.12^{ab}	2.16^{b}	$P = 0.027$
Total N (mg/kg)	1324^{a}	1431^{ab}	1524^{b}	$P = 0.010$
C/N	14.7	14.9	14.3	
Microbial biomass (ugC/g soil)	101^{a}	117^{ab}	131^{b}	$P = 0.009$
Basal respiration (ugCO$_2$-C/g/day)	10.5^{a}	13.3^{ab}	15.6^{b}	$P < 0.001$
Microbial quotient (MB/C)	0.68^{a}	0.88^{b}	0.81^{b}	$P = 0.014$
Metabolic quotient (BR/MB)	0.28	0.26	0.24	

*'No C add' means that much smaller amounts (0-5 tons/ha) of organic matter are returned compared to trashed fields 'C add' (11-13 tons/ha).

Nematodes as indicators

Numbers of three of the eight nematode genera (viz. *Pratylenchus, Helicotylenchus* and *Paratrichodorus*) were significantly different between the land uses (Table 3). In all three cases, there were significantly fewer individuals in trashed and virgin lands compared to burned fields. The trend for nematodes was similar to that of other indicators, i.e. numbers decreased from burned to trashed to virgin fields. Surprisingly, there were no significant differences in numbers of free-living nematodes between land uses.

Table 3. Effect of different land use on the abundance of plant parasitic nematode genera and on the abundance of free-living nematodes (number per 200 cm^3).

Land use	Burned	Trashed	Virgin	P-value
Cover crop	Cane	Cane	Veld	
*Carbon management	No C add	C add	C add	
Pratylenchus	325^a	204^b	77^c	P<0.001
Helicotylenchus	693^a	435^{ab}	348^b	P=0.031
Meloidogyne	135^a	35^a	96^a	P=0.577
Xiphinema	72^a	48^a	100^a	P=0.933
Paratrichodorus	93^a	43^b	30^c	P<0.001
Criconematids	21^a	5^a	28^a	P=0.452
Scutellonema	109^a	118^a	178^a	P=0.915
Rotylenchulus	33^a	20^a	23^a	P=0.516
Free-living nematodes	884^a	1071^a	1018^a	P=0.715

*'No C add' means that much smaller amounts (0–5 tons/ha) of organic matter are returned compared to trashed fields 'C add' (11-13 tons/ha).

Discussion

In a soil health assessment programme, it is important to understand the criteria by which indicators are interpreted. Most indicators studied had a meaningful relationship with at least one, or more, other soil indicator. These relationships can be used to shorten the initial indicator list to be assessed and thereby reduce the cost, which is an important factor in adoption of soil health assessments (Moebius *et al*., 2007).

The factorial maps generated from principal component analysis (PCA) (Figures 1 and 2) illustrate the relationships between indicators. Figure 1A shows that the three land management uses, in terms of soil health indicators, are scattered along the horizontal and vertical axes, i.e. the Burned and Trashed (sugarcane) plots are on the positive (top) part of the F2 (vertical) axis, converse to the Virgin plots which are on the negative (bottom) part of the F2 axis. Figure 1B shows the relationship between the various soil health indicators. It is evident that pH and Al are on opposite sides on the F2 (vertical) axis, indicating an inverse relationship. A similar relationship is shown between sand and clay (and silt) on the F1 (horizontal) axis. When read with Figure 1A, it is evident that there are no clear relationships between the land use options and soil texture. The burned land use option (Figure 1A) is not associated with any of the carbon-related parameters (Figure 1B, indicated in red) but is related to greater numbers of some nematode genera, particularly *Pratylenchus, Helicotylenchus* and *Paratrichodorus* (Figures 2A, B and Table 3).

In Figure 1, the larger fractions of stable aggregates (2-5 mm and 0.5-5.0 mm) (Figure 1B) are associated with the virgin land use (Figure 1A) which is also the land use which is constantly receiving fresh organic material. This land use is also associated with a higher Ca content, which, together with organic material and clay, is essential for structure formation and aggregate stability.

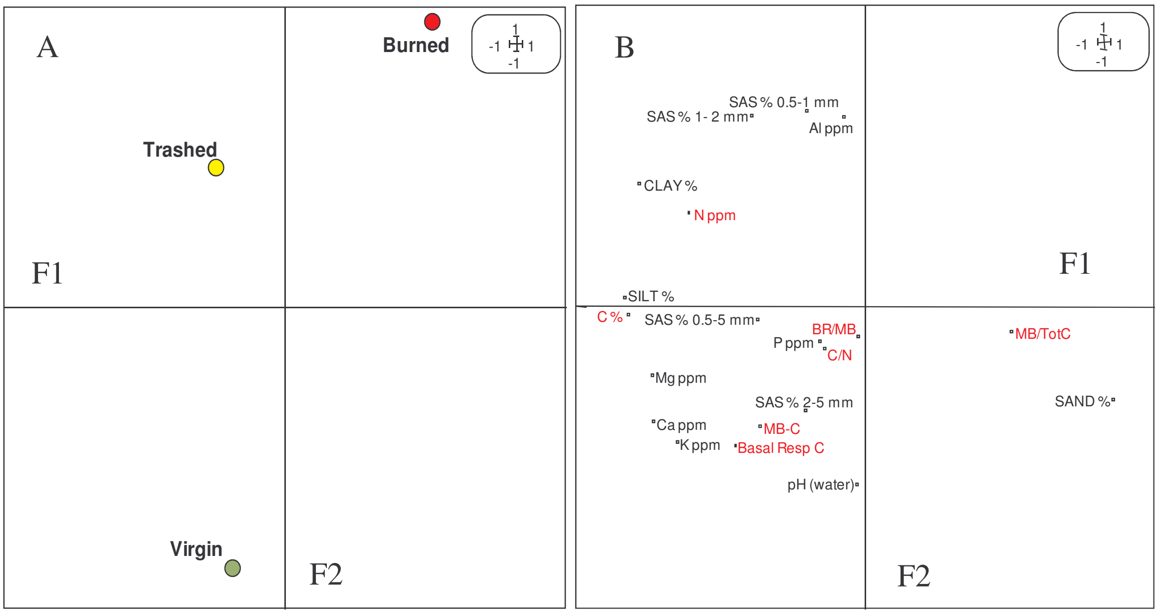


Figure 1. Factorial maps showing relationships between land management options (A) and soil health indicators (B).

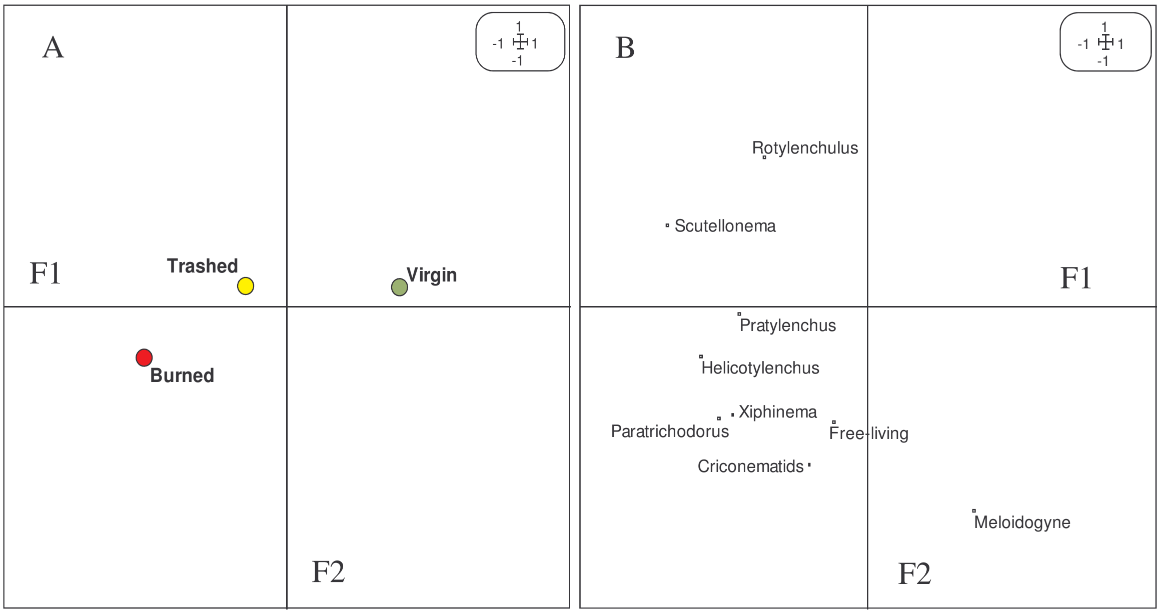


Figure 2. Factorial maps showing relationships between land management options (A) and nematode genera (B).

From the above discussion, the only predictable relationship is that between pH and Al. Considering the chosen list of soil health indicators (Table 2), eliminating Al from the final list will not significantly lower the cost per assessment, and thus Al was therefore retained in the final list (Table 4).

Table 4 summarises the list of soil health indicators in regard to threshold values, how it should be interpreted and how it is associated with other soil properties. Most of the threshold values were taken from literature (see bottom of Table 4), but for some (mostly biological) none existed and the minimum and maximum values from the current data set were therefore used to set some limits (in terms of low, moderate and high) for interpretation. In the case of carbon it was acknowledged that, although both sandy and clayey soils could have the same carbon contents, they should be interpreted differently. To accommodate this, confidence intervals were set to the relationship between carbon and clay (Miles *et al.,* 2008) in order to obtain lower and upper boundary levels which were used to aid interpretation.

To improve the readability of soil aggregate stability, the four values suggested in Table 2 were converted (using the calculation described by Le Bissonnais, 1996) into one value and termed 'mean weight diameter' (MWD) in Table 4. The threshold values to interpret the MWD values were also taken from Le Bissonnais (1996). Dispersion index was not used in Table 4 as a soil health indicator due to its insensitivity to land management. Texture determination and clay content in particular were retained because of their influence on many other soil parameters.

Threshold values for the biological indicators (microbial biomass, basal respiration, microbial quotient, metabolic quotient and nematode genera) are non-existent for sugarcane, but are required in order to interpret analyses. The database for this project combined with information taken from Graham (2003) was used to compile a set of interim criteria to be used for interpretation purposes (Table 4). Arbitrary low, moderate and high/ideal values were assigned to the clay and C/N parameters. These thresholds are required for interpreting the values presented in the laboratory report (Table 5). This is not the end, but rather the beginning of working towards interpretation criteria for these parameters.

Interpretation of most of the indicators in Table 4 is self-explanatory, although the biological indicators warrant further clarification. Microbial biomass typically accounts for 1-5% of total organic carbon content (Sparling, 1997). Due to its dynamic nature, microbial biomass responds rapidly to changes in soil management (i.e. addition of organic matter) with a rapid increase in mass long before any other changes in soil organic matter content are detected (Haynes and Beare, 1996). Microbial biomass and basal respiration are affected by seasonal changes (Díaz-Raviña *et al.,* 1995) and are therefore difficult to interpret. Alvarez *et al.* (1995 found a highly correlated (r^2=0.90) inverse power relationship between microbial C and soil temperature. In an effort to overcome this problem, quotients are calculated from these data (microbial quotient = microbial biomass/total carbon; metabolic quotient = basal respiration/microbial biomass). However, Alvarez *et al.* (1995) found that metabolic quotient (*in situ* respiration/microbial biomass) increased exponentially (r^2=0.89) with an increase in soil temperature, due to higher maintenance energy requirement at higher temperatures.

A good example of how soil health information could be presented was found in the Cornell soil health test report (Gugino *et al*., 2007). Due to differences in the objectives in developing soil health systems, the Cornell system could not be adopted 'as is', as the indicators used in the SASRI system are different. The Cornell system was therefore modified to suit the SASRI purposes (Table 5).

The laboratory report sheet is divided into the conventional laboratory contact details, client, advisor and crop details followed by the indicator list and their values. Additional information given relates to the expected constraints, and visualisation blocks are used to aid in reading.

The constraints block contains information that is associated with indicators that are problematic (low percentile ratings). The visualisation block contains a series of bar charts which, on a relative scale of 0 to 10, reflect the values reported relative to their threshold values. Finally, a soil health index value score is calculated by summation of all relative values used to generate the bar charts and weighted to 100%. The soil health index, laboratory reported values and constraints are then used to generate comments and recommendations.

Conclusion

The virgin sites had a significantly lower clay content than the sugarcane (burned and trashed) sites. This was of great concern as many other soil parameters are directly, and indirectly, linked to clay content. However, in this work, it was shown that organic carbon had an even greater effect on all soil properties, which totally masked the variation in clay content. A good illustration of this is shown in Table 2, where the large fraction of water-stable aggregates was the highest in the virgin sites, containing the lowest clay content but the highest organic carbon content. Most of the parameters considered were able to reflect differences between land uses, which could be explained by soil carbon content differences. Nearly all parameters included in Table 4 as representatives of soil health indicators were shown to be sensitive to land management. In most cases, significant differences were obtained between burned at harvest and virgin land uses, with trashed fields as intermediate. This was an important screening exercise since it is expected that the indicators must individually, and collectively, be able to reflect the condition of a particular soil. The importance of biological parameters as soil health indicators was acknowledged, despite reduced significance between land uses. This is still a relatively young science and potentially far more complex compared to traditional soil chemistry, biology and physics, where each discipline is usually treated individually and interactions between disciplines are rarely considered. The lack of threshold values for these biological parameters is proof of this. The challenge was to then establish tentative threshold values (Table 4) to enable analysis of the data. Based on personal experience (and unpublished data) in the South African sugarcane industry, threshold values were assigned to the various components of the biological dataset. It is acknowledged that, although these threshold values are weakly derived, they are considered an essential starting point, and will assist researchers in progressing in this area of research.

Acknowledgements

The authors are grateful for the comments made by Dr Neil Miles (SASRI) to improve the contents of Table 4 and Dr OJ Idowu (Cornell University) for information supplied for use in Table 5.

Table 4. List of potential soil health indicators, their respective threshold values, interpretations and associations in measuring soil health.

Indicator	Threshold	Interpretation	Associations
CHEMICAL INDICATORS			
$^{\#\#}$ pH$_{water}$	< 5.0	Strongly acid	Al toxicity, possibly Mn toxicity; P and Mo deficiency likely
	5.01-5.5	Moderately acid	Al and Mn may be toxic for acid sensitive crops
	5.51-6.5	Slightly acid – optimum range	
	6.51-7.5	Neutral	Zn, Cu and Mn deficiencies possible
	7.51-8.5	Slightly alkaline	P, Zn and other metal deficiencies
	> 8.5	Moderate to strongly alkaline	B and other oxyanion toxicities
$^{+}$P (mg/kg)	< 31	Deficient for plant cane	
	< 11	Deficient for ratoon cane	
$^{+}$K (mg/kg)	< 112	Deficient	<31% clay
	< 150	Deficient	30 – 40% clay
	< 225	Deficient	>40% clay (Northern irrigated area)
	< 325	Deficient	>40% clay (NIA), >4000mg/kg Ca+Mg, Winter cut cane
$^{+}$Ca (mg/kg)	< 200	Deficient	
$^{+}$ Mg (mg/kg)	< 25	Deficient	
	< 75	Deficient	If Ca is also deficient
$^{\#\#}$Al (mg/kg)	10-100	Moderate quantities	pH < 5.3
	> 100	High – adverse effects likely	pH < 4.0
*ASI %	> 40	Severe Al threat to cane growth (all varieties including N12)	pH < 5.0
	20 - 40	Al threat to varieties other than N12	pH < 5.0
PHYSICAL INDICATORS			
**MWD (mm)	< 0.4	Very unstable	Systematic crust formation
	0.4-0.8	Unstable	Crusting frequent
	0.8-1.3	Medium	Crusting moderate
	1.3-2.0	Stable	Crusting rare
	> 2.0	Very stable	No crusting
Clay %	< 15	Low	Nematodes, low C, N & water
	15-35	Moderate	
	> 35	High	Low infiltration, runoff, erosion
BIOLOGICAL INDICATORS			
$^{++}$ Carbon% =(0.048Clay+0.236)±0.637	< 1	Low	Low N, S mineralisation
	< -ve value	Low	=(0.048Clay+0.236)-0.637
	>-ve & <+ve	Moderate	=(0.048Clay+0.236)±0.637
$^{\#}$Total N (%)	< 0.1	Low	High C:N ratio
	0.1-0.5	Moderate	
	> 0.5	High	
C/N	< 12	Low (Desired)	
	12-16	Moderate	
	> 16	High	N too low, decomposition slow
Microbial Biomass (ugC/g soil)	< 20	Low	Low soil C or high temperature
	20-1000	Moderate	
	> 1000	High	
Basal Respiration (ugCO$_2$-C/g/day)	< 4	Low	Low microbial biomass, temp low
	4-40	Moderate	
	> 40	High	Large microbial population, high temp
Microbial quotient (%)	< 0.2	Low	High C/N
	0.2-1.0	Moderate	
	> 1.0	High (Desired)	Low C/N

Metabolic quotient ($ugCO_2$-C/g/day)	< 2	Low (Desired)	Low C/N
	2-10	Moderate (Less Desired)	
	> 10	High (System under stress)	High C/N, high temperature
NEMATODE INDICATORS (Number per 200 cm^3)			
Pratylenchus	< 10	Low (Desired)	
	> 10	High (likely to be a problem)	
Helicotylenchus	< 50	Low	Higher numbers of this nematode genus is beneficial for cane production
	> 50	High (Desired)	
Meloidogyne	< 10	Low (Desired)	
	> 10	High	
Xiphinema	< 10	Low (Desired)	
	> 10	High	
Paratrichodorus	< 100	Low (Desired)	
	> 100	High	

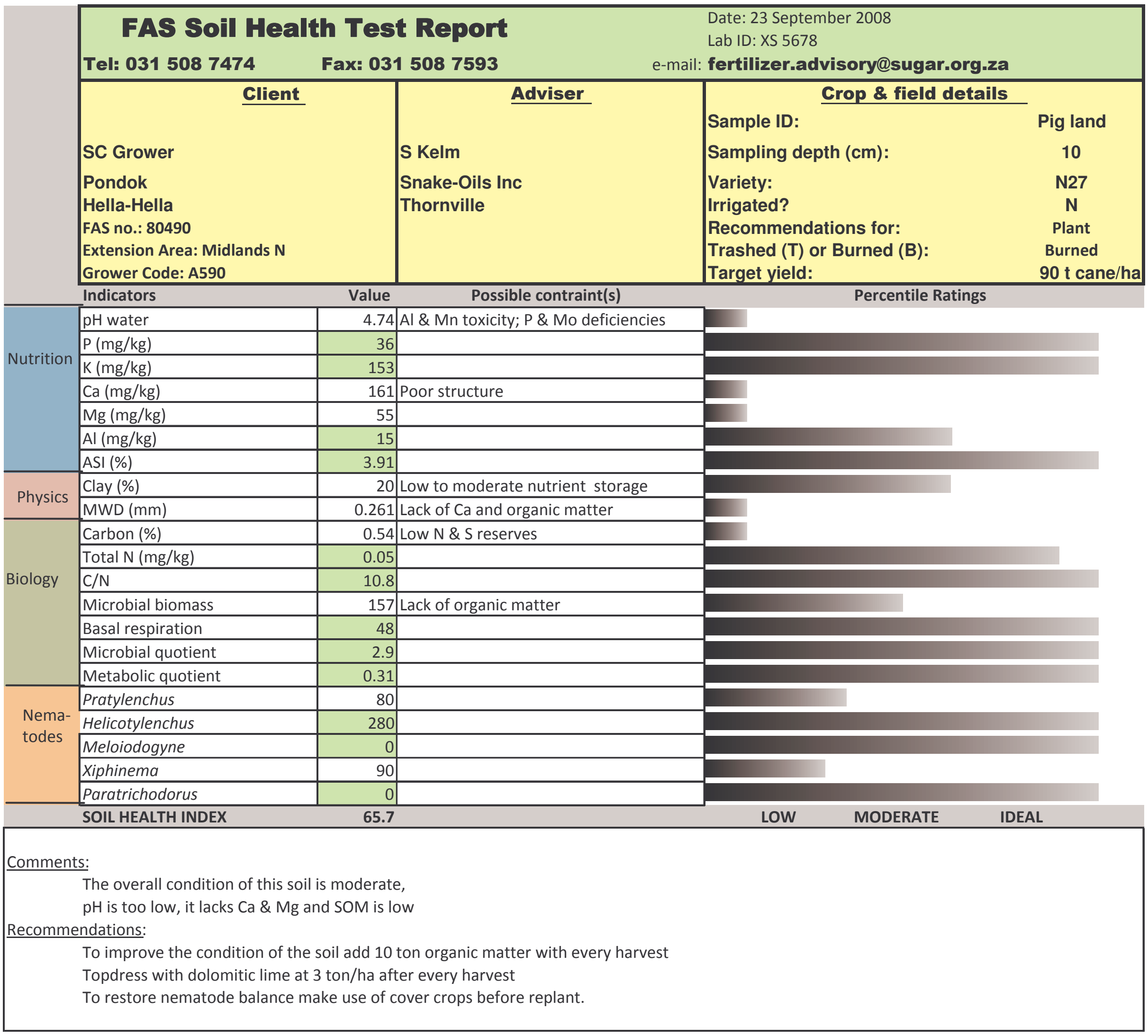
$^+$ Anonymous, 2004 $^{++}$ Modified after Miles *et al*., 2008

$^\#$ After Amacher *et al*., 2007 $^{\#\#}$ Modified after Amacher *et al*., 2007

* ASI = Aluminium Saturation Index (Nixon *et al*., 2003)

**MWD = Mean Weight Diameter of aggregates (mm) (after Le Bissonnais, 1996)

Table 5. An example of the SASRI soil health test report.



FAS Soil Health Test Report

Date: 23 September 2008
Lab ID: XS 5678

Tel: 031 508 7474 **Fax: 031 508 7593** e-mail: **fertilizer.advisory@sugar.org.za**

Client	**Adviser**	**Crop & field details**	
		Sample ID:	Pig land
SC Grower	S Kelm	Sampling depth (cm):	10
Pondok	Snake-Oils Inc	Variety:	N27
Hella-Hella	Thornville	Irrigated?	N
FAS no.: 80490		Recommendations for:	Plant
Extension Area: Midlands N		Trashed (T) or Burned (B):	Burned
Grower Code: A590		Target yield:	90 t cane/ha

	Indicators	Value	Possible contraint(s)	Percentile Ratings
Nutrition	pH water	4.74	Al & Mn toxicity; P & Mo deficiencies	
	P (mg/kg)	36		
	K (mg/kg)	153		
	Ca (mg/kg)	161	Poor structure	
	Mg (mg/kg)	55		
	Al (mg/kg)	15		
	ASI (%)	3.91		
Physics	Clay (%)	20	Low to moderate nutrient storage	
	MWD (mm)	0.261	Lack of Ca and organic matter	
Biology	Carbon (%)	0.54	Low N & S reserves	
	Total N (mg/kg)	0.05		
	C/N	10.8		
	Microbial biomass	157	Lack of organic matter	
	Basal respiration	48		
	Microbial quotient	2.9		
	Metabolic quotient	0.31		
Nema-todes	*Pratylenchus*	80		
	Helicotylenchus	280		
	Meloidogyne	0		
	Xiphinema	90		
	Paratrichodorus	0		
	SOIL HEALTH INDEX	65.7		LOW MODERATE IDEAL

Comments:

The overall condition of this soil is moderate,
pH is too low, it lacks Ca & Mg and SOM is low

Recommendations:

To improve the condition of the soil add 10 ton organic matter with every harvest
Topdress with dolomitic lime at 3 ton/ha after every harvest
To restore nematode balance make use of cover crops before replant.

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