SOIL SAMPLING IN SOUTH AFRICA: PRACTICES AND PROBLEMS*

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Introduction

A detailed description of soil sampling principles, procedures and problems in South Africa was given by Claassen (1980) and Buys & Claassen (1985).

The purpose of this paper is to review current procedures and practices and to define and illustrate some of the major problems of soil sampling in South Africa. Hopefully this paper will indicate and stimulate the need for local research, for standardization of equipment and procedures, for the determination of policy and responsibility, for the training of technicians and for control over sampling practice.

The success or failure of soil analysis as an aid to fertilizer guidance or any other use, depends firstly on securing a representative soil sample. Several workers abroad have shown the standard error arising from sampling and sample treatment to be 3 to 6 times greater than those arising from subsampling and analytical procedures (Vermeulen, 1960; Peck and Melsted, 1973; Cline, 1944). This fact gave rise to the dictum which states that the soil test can be no better than the soil sample taken. This popular belief represents only a half-truth. Evidence by Buys & Claassen (1985) indicates standard error in analytical results, for a particular sample, between various laboratories of repute in the RSA, could be of an order approaching the abovementioned standard error for sampling. Although the precision of individual laboratories in the RSA is good to excellent, the accuracy of analytical results often remains in question (Buys, 1984). This fact points to systematic errors in the analytical procedures and emphasizes the necessity for further standardization in soil test laboratories in terms of procedures, equipment used, etc as well as improved internal quality control (see Figure 3b).

Nevertheless, considering the time and expense required for soil testing operations subsequent to sampling, frequently too little time and thought are put into soil sampling plans.

How to improve soil sampling techniques and plans will depend on the purpose of the sampling. In any event the soil sampler will have to understand and contend with the nature and extent of spatial and temporal soil variation.

Closely related to sampling is the need to tailor field experimental designs and soil mapping techniques to soil variations in order to facilitate more meaningful interpretation and application of the results from field calibration trials. In this regard geostatistics can play a part (McBratney, 1985; Shumway, 1985).

Soil variability will probably become more marked as a result of the modifying effects of soil management and crop production practices such as cultivation, placement of fertilizers and ameliorants, irrigation etc. Spatial variation is complicated by row and band application of fertilizers, which is common practice in South Africa. Furthermore, these in-line applications are not uniform in density. (Unpublished work by Division of Agricultural Engineering, Department of Agriculture and Water Supply, 1984). Even with broadcoast applications of fertilizer a salt and pepper distribution pattern is found after incorporation by discing and ploughing (Buys, 1978 & 1980).

Sources of variability are summarized by Beckett & Webster (1971). They also reviewed latteral variability of soil characteristics with a view mainly to application in soil mapping. The survey showed that up to half of the variance within a field may already be present within any m^2 in it and that this variance often does not change much with the size of the field. Nevertheless, going to larger scale mapping units, the variability increased with the size of the area sampled. The form of this spatial relation had, however, not been extensively studied.

Friesen & Blair (1984) compared soil sampling procedures used to monitor soil fertility in permanent pastures and stated that soil spatial variability is a major problem affecting the reliability of soil testing for fertilizer advisory purposes. They found that cluster sampling, ie small 'monitoring plots', to be the most appropriate procedure with the least variance, for estimating the nutrient status of grazed pastures, i.a. because it should allow more reasonable estimates to be made of temporal variations in soil test. (A 'cluster' is a small representative plot in a field).

The method of kriging, using semi-variograms, to estimate values of soil characteristics within small rectangular blocks of land, was expounded by Webster & Burgess (1984). They showed that true variances as well as sampling efforts can be much less than those apparent when using classical theory. The classical formula for sample size, n, needed to estimate the mean, μ, within the limits μ-x and μ+x, at the level of probability, a, is: $n = \frac{t^2 s^2}{(x-\mu)^2}$ where 't' is Student's t. They claim the reason for pessimistic conclusions in many soil sampling studies is that any spatial dependence of soil characteristics is not taken into account and hence the sampling effort is over-estimated. To contend with spatial variability the weights allocated to each of the n increments should not be equal. The

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kriging procedure may be used to determine the weights. In classical statistics the variance determines precision or sampling effort, but in geostatistics they are controlled by the semi-variogram in which semi-variance is plotted against distance. They define semi-variance as half the expected squared difference between values of the characteristic at places x and x + h.

Determining the defining spatial variation of soil characteristics using geostatistics is useful in soil surveys and mapping of soil characteristics on a macro scale in virgin soils. (Trangmar, Yost *et al*, 1984; Uehara, Trangmar *et al*, 1985; Wilding, 1985).

The realities of practical field sampling must in the end determine the nature of sampling schemes. It is a matter of striking a balance between a complexly variable medium and the need for it to be sampled in a comparatively simple way. Cameron, Nyborg *et al* (1971) believe that sampling to evaluate the level and extent of nutrient deficiency trends within a delineated field should be achieved with only a few composite samples. Sonneveld (1979) stressed the importance of precise instructions for soil sampling, tailored for different crops and growing systems, in order to decrease deviations.

The sampling rate of the 10,5 million ha of cultivated South African arable land is about 70 ha per compound representative sample. The actual size of fields sampled is probably an average of 20-30 ha, because fields are sampled about once in three years. Very little work has been done in South Africa to study spatial variation of soil characteristics or to improve soil sampling practice.

Present practice

Sampling schemes used in South Africa are summarized in Table 1.

These programmes are, as far as we are aware, based on very limited investigations and probably mainly on examples and research findings from abroad. The programmes are recommended procedures and only in exceptional cases are they enforced. Since there is no control over sampling practice, the programmes, whether adequate or not, cannot guarantee that these minimum and somewhat arbitrary requirements are met.

A few examples of the sampling programmes from abroad are shown in Table 2. In many cases the farmer is responsible for taking the sample according to the prescriptions supplied by the laboratories or advisory services. In the Netherlands sampling is done only by trained samplers in the employ of the laboratory and advisory organisation. In all these cases the integrity of the sampler is not really questioned, although concern is sometimes expressed as to the quality of samples.

It is clear that neither in South Africa nor abroad have sampling programmes taken soil spatial variation into account. The only exception is where row and inter-row specifications are given.

Research into the number of cores per representative composite sample to achieve a certain degree of reliability have been reported by several research

TABLE 1. Soil sampling programmes in South Africa

Crop	Field size per sample	Increments per representative sample		Sampling configuration
		Topsoil	Subsoil	
Deciduous fruit	one orchard	20	20 (strat.)	within tree drip
Citrus and subtropical fruit	≤3 ha (orchard)	10	yes	within tree drip
Vineyards	≤10 ha	5 profiles (x 2 cores each)	5 profiles (strat.)	
Cereals and vegetables	2 to ≤50 ha	5 to 10 to ≥30	0 to 10	inter-rows
Cerials (FSSA; presently)	≤50 ha	≥20	5	inter-rows
Cereals (FSSA; previously)	≤50 ha	≥20	4 to 5	3 in row 17 in row
Sugarcane	field	27 to ≥30		ratoon: 3 x (1+8) in row + inter-row

TABLE 2. Some soil sampling programmes abroad

Country		Field size per sample	Increments	Reference
Netherlands		ha 1	40	Sonneveld, 1979
Iowa, USA		field	5 to 25	Walsh & Beaton, 1973
Alberta, Canada		field	10 to 15	Cameron *et al*, 1971
North Carolina, USA		1 to 6 field	15 to 20	NC State University NC Dept Agriculture
Georgia, USA		6 field	12 to 15	University of Georgia and USDA
W Germany	pastures	field	30 to 40	LUFA
	crops	field	10 to 15	

TABLE 3. Research findings: Number of increments required to achieve a certain precision, (ie % within which the analysis can be expected to be of the true value)

Determination	Crop	Field size per sample	Increments per representative sample	Precision	Reference
				%	
P, Ca, K		2	30	10	Reed and Rigney (1947)
P K pH	Apple orchard		24 24 24	25 15 4	Holland *et al* (1967)
P & K			15	25	Nelson and McCracken (1962)
Mg N P K			2 to 89 11 to 569 6 to 321 28 to 193	10	Leo (1963)

workers from abroad. Some of these results are summarized in Table 3.

The differences are interesting and the number of increments required in some cases are alarming and impractical.

It would seem that to achieve a precision of, say, 10-20% some 30 increments would in most cases be sufficient. This could serve as a minimum norm in general until research in any specific case warrants otherwise. This does not resolve the problem of imposed variabilities due to cultural practices show as row, band or zonal application of fertilizers.

Examples of variability

Spatial variability

Experiment plot, Bronkhorstspruit (Buys, 1978)

One experiment plot, 6 m x 20 m, to which phosphate had been applied evenly and incorporated by discing and ploughing, was sampled in 20 positions, 5 of which were three-increment clusters, as shown in Figure 1.

Variation of P over very small distances, 250 mm, was tested at the five clusters. The analyses are given in Table 4a, showing CVs of between 16 and 30%. The analysis of the 20 separate positions sampled varied between 24 and 59 mg P kg^{-1} and the results are summarized in Table 4b. A further analysis of the P values showed that to come satisfactorily near the mean of the 20 positions, at least more than 5 cores should be taken on this 0,012 ha plot. Some combinations of grouped increments are given in Table 5.

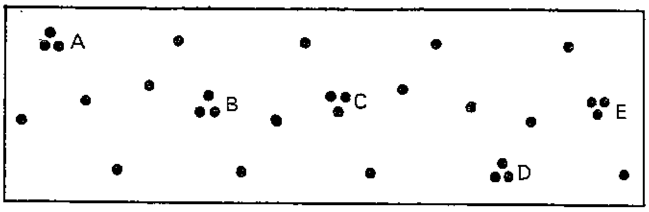

FIG 1. Increment positions in an experiment plot of 6m x 20m at Bronkhorstspruit (Buys, 1978) (See Table 2)

TABLE 4. Variation of soil P (Bray 2) in an experiment plot of 6m x 20m, treated with P at Bronkhorstspruit (Buys, 1978; Buys & Claassen, 1985)

(a)

Clusters positions:	A – (5,5m) –	B – (4m) –	C – (5m) –	D – (3,5m) –	E
	mg kg⁻¹				
250mm	35	26**	24**	32*	40
250mm	38	28**	27**	41	41
250mm	59**	35**	35	49**	65**
X_3	44,0*	29,7**	28,7**	40,7	48,7**
s	13,1	4,7	5,7	8,5	14,2
CV %	30	16	20	21	29

Increments within clusters 250 mm apart
Clusters 3,5 — 5,5m apart
See Figure 1

(b)

	All positions: (mg P kg^{-1}) using averages per cluster
$\bar{X}_{20}$	38,7
s	9,2
CV %	24
s_{agr}	2,7
$\frac{Max}{Min}$	$\frac{59}{24} = 2,5$
Range ratio	$\frac{59-24}{38,7} = 0,91$

Interpretation scale, mg kg^{-1}:

**	*	●	*	**
< 31,9	31,9 – 34,6	34,6 – 42,8	42,8 – 45,5	> 45,5

(s_{agr} = arbitrary std dev based on agricultural considerations) (Buys, 1980)
** incorrect (according to agric standards)
* doubtful, but acceptable
● good ('correct')

Experiment plots, Heidelberg (Buys & Claassen, 1985)

Four two-increment clusters (i.e. 8 increments) were drawn along the diagonal of two experiment plots and a farm field, and analysed separately. The results are given in Table 6, showing much greater variation of P in plots that had received P treatment (broadcast).

Experiment, Ottosdal (Dijkhuis, 1986)

The 18 treatments in a row-width x N x plant population experiment that had been equally treated with phosphate were sampled and analysed for P (Bray 1). These are schematically shown in Figure 2, indicating 'high', 'low' and 'medium' P levels found ('Low' was arbitrarily

TABLE 5. Combinations of more or less evenly spread increments to estimate mean P of the plot (Buys & Claassen, 1985)

Number of increments (N)	$\bar{X}_N$	$\bar{X}_N - \bar{X}_{20}$
5	40,2	1,5
5	33,0*	5,7
6	35,7	3,0
7	37,1	1,6
9	35,4	3,3
10	38,2	0,5
20	38,7	–

* Too low (FSSA norms)

taken as 25-30 mg kg^{-1}; 'medium' as 31-42; 'high' as 43-50 mg kg^{-1}). Analytical data are shown in a sequential pattern in Figure 3a.

The spatial variation in this experiment site is compared with the analytical variation when one sample was analysed by 22 laboratories (Figure 3b). This showed that between-laboratory variations may be even larger than within-field variations.

Temporal variability

Nitrogen, Viljoenskroon (Dijkhuis, 1984)

The fluctuation of mineral nitrogen over short periods and longer term seasonal fluctuations, makes time of sampling an important issue unless N is to be monitored over a period of time to determine the changes. Dramatic changes, that coincided with N uptake by the crop, was found at Viljoenskroon, as shown in Figure 4.

TABLE 6. Variation of soil P (Bray 1) over short distances at Heidelberg (Experiment M9/S, and farm field). Eight increments per plot. (Buys & Claassen, 1985)

	Range	$\bar{X}$	Std dev	CV	Max/Min	Range ratio
				%		Range ÷ $\bar{X}$
Topsoil:						
Control (virgin soil)	7-9	8,3	0,7	9	1,3	0,24
P1 appl (broadcast)	20-40	27,6	6,2	22	2,0	0,72
Farmer's field (fertilized)	47-69	58,5	10,5	18	1,5	0,36

I		II		III	
H	LM	LM	LM	LM	?
M	LM	LM	?	LM	LM
M	M	M	LM	H	M
L	LM	LM	LM	LM	M
LM	M	H	M	L	H
LM	LM	LM	LM	LM	LM
H	LM	LM	LM	LM	LM
H	LM	H	LM	M	LM
?	LM	M	H	H	?

FIG 2. Spatial variability of P (Bray 1) in an N x row width x plant population at Ottosdal experiment (Dijkhuis, 1986)

Potassium, Ermelo (Venter, 1983; unpublished)

Freshly applied potassium also undergoes seasonal changes, which could be different for different soils. This obviously has an influence on sampling time, and Venter recommends sampling five weeks after application of fertilizer K in order to best correlate yield response with soil test and K application. The changes of exchangeable K over time are shown in Figures 5a and b.

Phosphorus, Ficksburg (Dijkhuis, 1984)

While phosphorus also changes over relatively short periods due to fixation, changes over the longer term have also been found. This is demonstrated by P history in an experiment at Ficksburg, as shown in Figure 6.

Problems in sampling programmes

According to Rigney (1956) the major problems faced in any sampling programme are:

- delineation of the area into homogeneous units;
- number of increments required for the specified degree of accuracy;

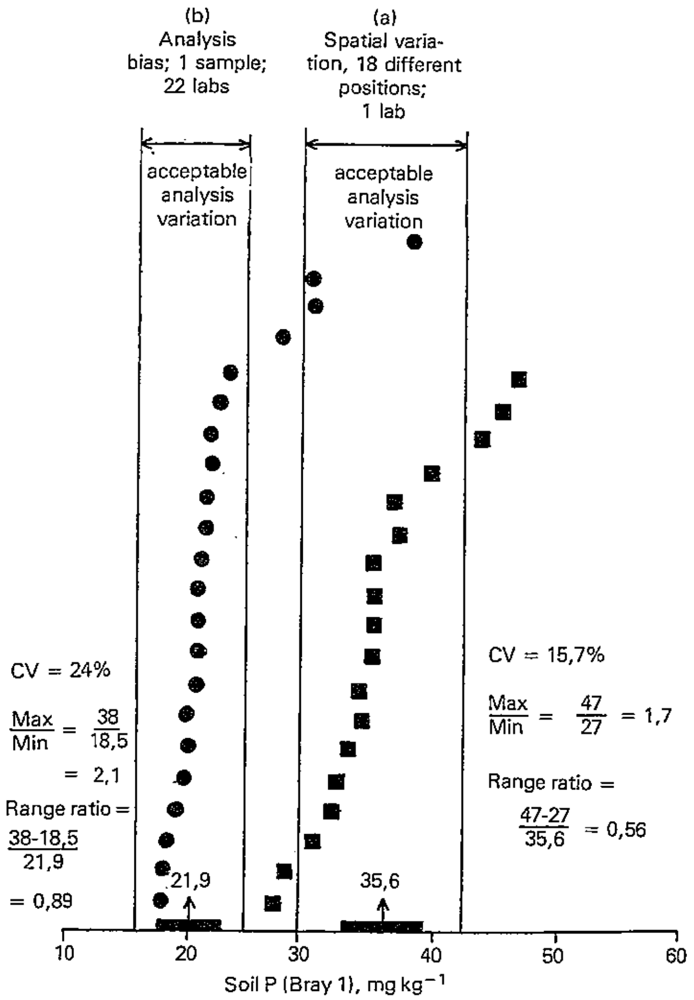

FIG 3. Examples of soil P variation, sequentially arranged:
(a) Spatial variation in 18 experimental plots (Dijkhuis, 1986)
(b) Analysis variation between 22 laboratories on one sample (Buys & Claassen, 1985)

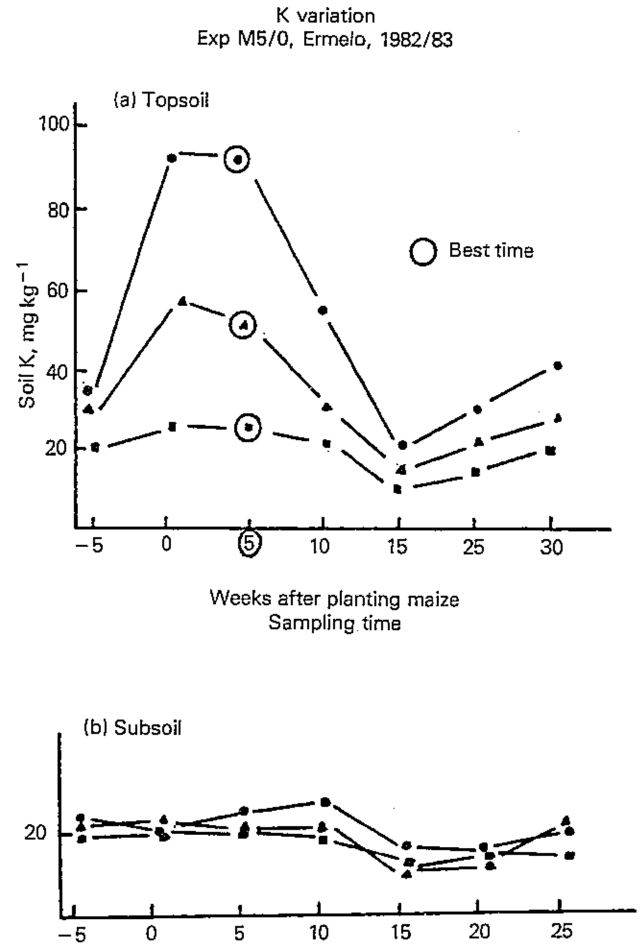

FIG. 5 Changes in soil K over time in an experiment plot at Ermelo (Venter, 1983 unpublished)

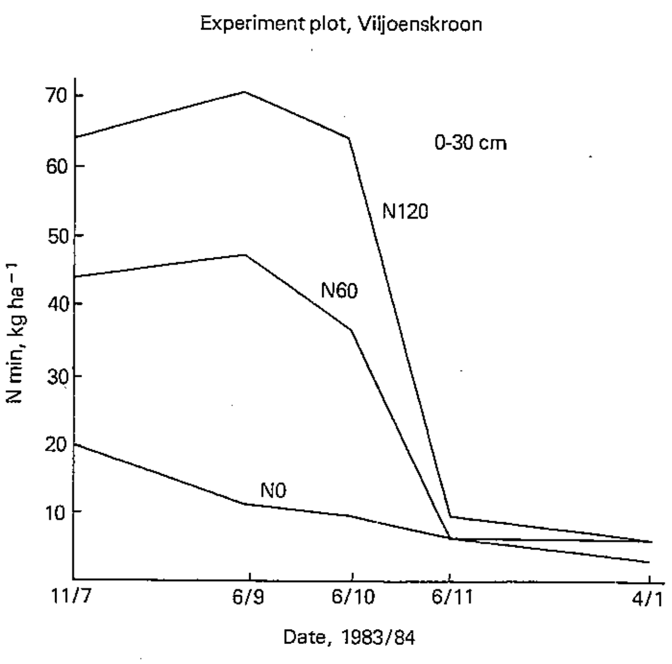

FIG 4. Changes in soil mineral N over time in an experiment plot at Viljoenskroon (Dijkhuis, 1984)

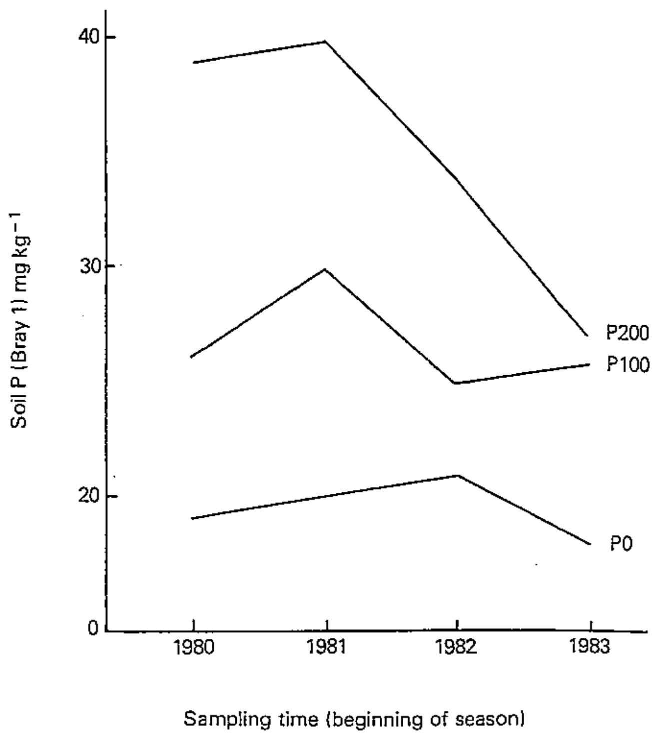

FIG 6. Long-term changes in soil P (Bray 1) in an experiment plot at Ficksburg, W21/OV/79. (Dijkhuis, 1984 unpublished)

- determining the most useful sampling plan or pattern (configuration of increments);
- distribution of effort for minimum cost and maximum returns.

The sampling problems were grouped by Buys & Claassen (1985) into categories such as the human factor, the nature of the soil, the nature of plants, sampling equipment and sampling techniques and programmes. The importance of activities subsequent to sampling was also identified.

In order to try and resolve the problems it is perhaps opportune to arrange them in terms of the steps in a soil sampling operation and then consider appropriate investigations and research.

Field delineation

The objective is to delineate homogenous practical workable field units intended for crop production. The spatial variability of soil characteristics should be considered. Such fields will provisionally be delineated according to obvious macro features such as size, topography, aspect, soil colour, soil texture, soil depth, soil form, soil series associations, soil drainage properties, as well as crop to be grown, the proximity of environment features that may differently affect plant growth, soil management possibilities and uniformity in growth of previous crops.

This suggest an intensive soil survey and poses the problem of time, cost and skilled technicians to perform such elaborate operations. the main responsibility here lies with the farmer, since delineation of fields forms the basis of sampling and since it is in his interest to secure meaningful samples. The farmer himself, if sufficiently skilled, or solicited specialists should perform this task. One of the considerations will be to decide which kinds and to what extent deviating features to allow as part of the 'homogeneous' unit.

Field description

(i) The field description should include all *relevant data* pertaining to soil properties, climate and crop in order to enable a more meaningful recommendation based on the soil test.

(ii) The description should be accompanied by an annotated *sketch*, preferably to scale, of the field and its locality. The increment positions should be indicated. If the fertility status is to be monitored regularly *monitoring points* should be indicated in order to facilitate more accurate repeat increments.

Training of soil samplers is required in this regard.

Sampling time

Sampling time should take cognizance of temporal soil variability. Sampling is often done during a convenient quiet period towards the end of the previous growing season and prior to any applications of amendments. This may be a good time in most cases, but not necessarily in the case where nitrogen is to be determined. The physical condition of the soil at sampling time may have an influence on the quality of the sample and the practicability of the sampling procedure. This needs to be investigated. Sampling time should feature prominently in fertilization field calibration work. The through-put time of the lab and the timeousness of soil test results must also be taken into account.

Increments

The number of increments required for a composited representative sample will depend on the soil's spatial variability, the degree of accuracy desired, the characteristics to be tested (elements to be analysed), the purpose of the sampling and other specialised factors such as the time elapsed after application of certain amendments (eg fertilizer) and how they were applied etc. In Tables 1, 2 and 3, reported number of increments per sample are summarized. These facts are both enlightening and confusing. It would seem that in most cases the number can simply be stated as 'the more the better', but in practice one has to contend with the tendency to say 'the quicker it can be done the better'. Some work needs to be done in this regard in order to replace the rules of thumb used now.

Sampling depth

Sampling depths reported for topsoil varies from 25, 50, 75 and 100 mm for pastures (Friesen & Blair, 1984), to the plough layer depth (200 mm). Birch (1980) stressed the importance of standardizing sampling depth in the topsoil in order to limit variation between increments. On the other hand, sampling to the depth of largest root concentration is perhaps more sound. In some cases sampling depth based on morphological features is necessary.

Sampling patterns

Sampling patterns or the configuration of increment positions in the field to be sampled should take into account the spatial variability of soil characteristics, even in the 'homogeneous' unit. According to Webster & Burgess (1984) the most serious obstacle to using optimal sampling strategies is that semi-variograms are not known in advance.

There are many schemes, such as purely arbitrary sampling schemes (alas!), grid sampling, zig-zag patterns, cluster sampling, random increment positions, stratified sampling etc. (Wilding, 1985).

Black (1965) considers systematic sampling techniques better than simple random sampling. Such plans require special precautions to avoid bias from superimposing the grid parallel to some systematic variation in the soil.

The patterns will also depend on the purpose of the sampling. In soil surveys a knowledge of spatial variability within and between field units for mapping may be required. In crop production, again, only a single representative value for each of the tested characteristics is required.

The possible use of geostatistics and kriging in this regard should be investigated in order to avoid the possible over-estimation of the sampling effort referred to by Webster & Burgess (1984).

It is not always practicable to adopt the safe pattern of grid sampling and extracting, say, 50 increments or more per field as suggested by some workers. Such a high increment rate will lead to an even larger average size per land sampled than the present 70 ha per representative sample in South Africa.

Control over the execution of sampling according to a 'safe' elaborate scheme is also not practicable, and it may be assumed that such a scheme will not faithfully be adhered to.

Sample treatment

The contamination-free combining, mixing, subsampling, packaging, labelling, storage and preservation after extraction of the increments are still the responsibility of the sampler. It is possible that the effort put into the planning and extraction of soil material can be wasted if sufficient care is not taken during the field treatment of the sample. Procedures should be clearly defined and scrupulously followed. Motivation and training of samplers are indicated.

Sampling equipment

Sampling equipment has been standardized to a reasonable extent, although there is a need for general acceptance of standard equipment. The suitability of equipment for large-scale sampling and for specialised sampling need to be evaluated and improvements investigated.

Sampling responsibility and control

In the last instance the success of a sampling programme can only be assured if some control is exercised over the operations. This aspect is grossly neglected, partly because sampling is not taken seriously. It is not used as a means to aid quality control as in manufacturing, and it is sometimes done for purely sales promotional reasons. The farmer, for whose enefit the sample is taken, is often satisfied with the mere fact that a sample has been taken, either not caring much, or trusting too much in the sampler's expertise and integrity.

There is an urgent need for an improvement in this aspect of sampling. The crux of the matter is the responsibility for sampling. This needs to be seriously considered, but it would seem that in the case of sampling for advisory purposes, responsibility ought to be vested in the farmer himself. The farmer would have to be knowledgeable about the required operations and techniques, or would have to delegate the control function to a suitable person or body. In the Netherlands sampling is the responsibility of the laboratory, but this laboratory is owned by the farmers. More direct involvement of farmers in the sampling operations is found elsewhere, for example in many states of the USA. The contention is that the average American farmer is sufficiently trained and knowledgeable to take the full responsibility of sampling. They also seem to take soil testing, including the sampling aspect, seriously as a needed tool in their crop production programmes.

Suggestions

Needs and priorities with a view to improve the soil sampling scene in South Africa have been indicated by Buys & Claassen (1985).

Needs:

It is suggested that the listed needs be regarded as a starting point in furthering the cause of meaningful soil sampling. The following needs were identified:

- *study* of spatial, profile and temporal *variability* of soil characteristics for certain crop production situations, for field experiments and for survey purposes, in order to evaluate the present sampling procedures and where necessary to improve these procedures;
- further *standardization* of sampling *procedures* and *equipment;*
- determining soil sampling *responsibility;*
- institution of sampling *control* measures;
- *training* of sampling *technicians;*
- improvement of sampling *equipment;*
- standardization of pre-analysis sample *handling and treatment;*
- planning *co-ordinated sampling programmes* with a view to the improvement of crop production advisory services.

Sampling committee:

It is further suggested that the identified problems i.a. be brought before the proposed *Sampling Committee,* intended to be formed under the joint auspices of the South African Chemical Institute (The Northern Transvaal branch) and the School of Chemical Sciences of the Pretoria Technikon. The need for such a coordinating committee was identified during and after two symposia on sampling arranged by the above bodies in 1980 and 1985 respectively.

Meeting:

It is suggested that a *meeting* be arranged to discuss possible research and development work in soil sampling, as well as the management and control of soil sampling. Priorities may then be determined and participation in the investigations volunteered and/or allocated.

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