DOES SOIL TESTING PAY IN PRACTICE?*

M P W FARIÑA, College of Agriculture and Research Station, Cedara

Introduction

Farmers today do not wish to know whether or not fertilizer is necessary, but what quantities are required to maximise profits; what the nett returns on additional increments of fertilizer are likely to be; and above which level of fertilization further capital is likely to be better spent on other farm enterprises. To obtain this information some measure of both present and desirable soil fertility status is needed. For annual crops, chemical soil testing is probably the most satisfactory means of obtaining such indices and extensive use is made of soil testing in most developed countries.

Soil test services have been available to South African farmers for many years, but use of soil tests is low in comparison with cropping areas in the United States and Western Europe. Cropping areas in South Africa are presently sampled at an intensity of approximately 140 hectares per sample, while in the North Central United States a cropping area of some 68 million hectares was sampled at an intensity of 31 hectares per sample in 1966 (Enfield, 1967; Delury, 1973) and almost two decades ago 22,6 million hectares in Western Europe were sampled at an intensity of 27 hectares per sample (Williams & Riehm, 1956). Thus, allowing for increases which have almost certainly occurred since in the United States and Europe, the intensity of sampling in South Africa is probably less than 20 per cent of that attained in these areas.

Comparisons of this nature are open to criticism, but there is evidence that these rather coarse statistics reflect a somewhat disturbing situation in South Africa. In the United States and Europe it is generally accepted that soil testing is essential if per hectare profitability is to increase, but relatively poor usage in South Africa suggests that farmers do not find soil testing a valuable aid in determining fertilizer requirements. Indeed, doubts frequently expressed by farmers, agricultural advisors, and research workers regarding the efficacy of soil testing seriously question the economic rationality of present soil testing services. Anomalies between chemically determined nutrition status and nutritional status assessed by crop performance are not uncommon, advice based on the same analytical data often varies widely from one advisor to the next, variation between laboratories is frequently considerable, and interpretation in economic terms — those terms in which farmers are interested — is almost totally lacking. Do the returns from soil testing justify the not inconsiderable investment by the State and the fertilizer industry?

In this paper some of the more important weaknesses in the South African soil testing process have been examined and an exercise designed to test the practical value of soil testing in Natal has been discussed.

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Soil test problem areas

No effort will be made to make a detailed examination of the problems associated with soil testing as literature on the subject is extensive (Bondorff, 1956; Ferrarie & Vermeulen, 1956; Reihm, 1956; Walsh, 1956; Hamilton, 1967; Colwell, 1967a, b) and such a discussion would be beyond the scope of this paper. However, some of the major problems will be discussed briefly in order to emphasise those aspects which, it is considered, presently mitigate against farmer acceptance of soil testing in South Africa.

Problems associated with soil testing necessarily fall into one of three distinct, but interdependent areas, which together constitute the soil testing process:

1 Field sampling
2 Laboratory analysis
3 Interpretation

Breakdown in any one area invalidates the soil testing process and hence ultimate on farm fertilizer recommendations and there is evidence that South African soil test services are presently plagued by weakness in all three.

1 Field sampling

The essential consideration in field sampling is to obtain a representative sample. In the laboratory 10 g or less of soil finally represents several thousand tonnes and the heterogeneity of most ploughed fields makes high intensity sub-sampling absolutely essential (Williams, 1956; Peck & Melsted, 1967). Opinion regarding the optimum method, time, pattern, and frequency of sampling differs, but there is general agreement that composite samples should be made up of 20—30 cores per field (Fitts, 1958; Peaslee, Miller, Weels & Murdock, 1973). In many areas recommended practices are more precise and samples are collected from land units of 2 hectares or less (Williams & Riehm, 1956; Dow, James & Russell, 1973; Halvorsen, 1973). Sampling at the latter intensities is impracticable in the South African context, as fertility advisors have to travel appreciable distances and do not have sufficient time available. However, few advisors collect as many as 20—30 cores per field and it is not uncommon for single site samples to be submitted for analysis. The probability that samples of this type are representative is minimal and the ultimate fertilizer recommendations may be economically most unsound.

Although little work has been done on the problem, there is also evidence that errors are incurred by sampling at times or stages in the cultural programme, which either fail to take residuals from band placed fertilizer into account or overestimate those from broadcast applications. In Natal for example, a high percentage of samples are collected after harvesting, but before ploughing or discing. In such cases cores are usually collected from between the rows to avoid zones of high fertility in the row or to make sampling easier. As a result the analyses are significantly biased downwards in situations where fertilizer has been band placed or are biased upwards where it has been broadcast, since the rooting density of crops such as maize is very low in the surface 15 cm between rows. In Natal it has in fact been found on fields which had received broadcast applications of fertilizer, that very misleading indices of fertility were obtained by sampling before ploughing, even where as many as 30 soil cores were composited per hectare.

2 Laboratory analysis

Generally the errors associated with laboratory analysis are considered to be far lower than those involved in sampling (Cline, 1944; Tisdale, 1967). However, analytical error is undoubtedly a significant source of error in many soil testing laboratories in South Africa and instances of faulty analysis are not uncommon. The majority of such errors naturally remain undetected unless the samples are re-submitted by alert advisors or originate from controlled experiments where approximate values can be anticipated. In the research laboratory at Cedara faulty analyses, those repeated and found to be incorrect, represent approximately 3 per cent of the annual output. In larger 'service' laboratories processing 1 000 or more samples a month in peak periods this error is probably appreciably higher. There is, in fact, evidence that analytical error has on occasions reached very serious levels in such laboratories.

In a recent effort to establish the relationship between two P extractants, 64 samples from a 4^3 N,P,K factorial experiment in Natal were analysed at Cedara using one extractant and subsequently submitted to a large comcorcial laboratory for analysis using another extractant. It is known that a good relationship exists between the two methods on any one soil, but in this possibly isolated instance the analyses performed by the larger laboratory proved to be completely valueless (figure 1).

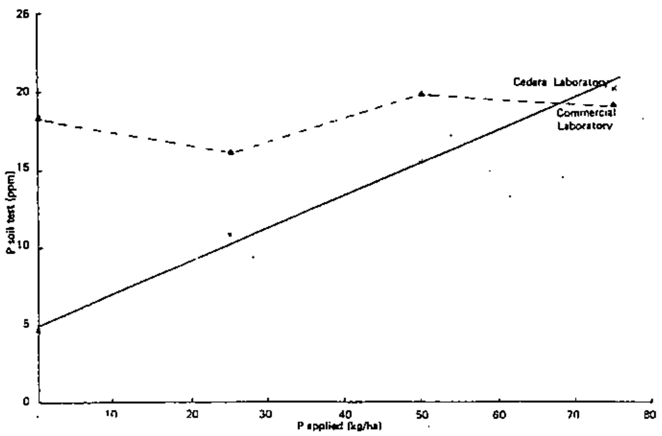


FIG 1 Relation between P soil test and P applications as determined by two laboratories

The diversity of analytical techniques used by various laboratories in South Africa also introduces difficulties. Advisors are frequently unaware that indices of nutrient availability vary appreciably between one extractant and another and farmers are often confused by apparent inexplicable discrepancies when samples have been analysed by laboratories using different techniques. Complete technique standardisation might appear to be the answer to this problem. However, it is unlikely that standardisation would result in any significant improvement in the prognosis of fertility requirements. Not only are other areas of error of far greater significance, but it is improbable that any single method will be the best for all crops on all soils (Williams, 1956; Colwell, 1967a; Thomas, 1967). Interpretational difficulties which may arise are a problem of education rather than a weakness in the soil testing process *per se* and it would be a relatively simple task to familiarise advisors of the relationships which exist between methods.

3 Interpretation

The most accurate sampling and laboratory procedure are of little value if the analytical data cannot be effectively interpreted. Such data will indicate gross deficiencies or excesses, but will not assist in answering those questions to which farmers require answers eg what quantities and combinations of fertilizers are required to maximise profits? These questions can only be answered once response equations have been established for experimentally developed yield response surfaces.

Unfortunately, there is still very little information available regarding the nature of response surfaces for the most important crop-soil-bioclimatic systems in South Africa and, since problems in sampling and analysis can be fairly easily rectified, interpretation must be considered the weakest link in the soil testing process. Progress has been made recently with regard to establishing soil test levels below which yield responses are probable (Möhr, 1971, 1973), but economic analysis has been largely ignored and nutrient responses have in most instances been treated separately rather than in combination. Consequently, recommendations capable of adjustment to accommodate individual resource situations and nutrient interaction cannot be made. Indeed, fertilizer recommendations frequently vary so markedly between advisors, who often rely largely on personal experience, that scepticism regarding the value of soil tests is inevitable.

A measure of prevailing advice variability can be obtained from Table 1. Several fertilizer advisors in Natal from

*TABLE 1 Fertilizer recommendations formulated from two sets of analytical data by several advisors**

Advisor	kg/ha N	P	K	Lime	Cost/ha
	AVALON soil sample from Dundee area				
1	120	65	50	–	R58,94
2	122	28	19	2 000	R46,91
3	98	21	18	–	R32,62
4	142	59	–	500	R56,33
5	140	65	50	–	R63,45
6	150	60	30	1 000	R64,07
7	80	50	75	1 000	R50,50
8	130	92	50	–	R71,66
9	133	75	193	–	R84,95
10	118	102	63	–	R74,59
11	120	65	50	1 000	R61,94
12	121	68	73	1 000	R45,81
CV	19%	23%	49%		14%
	MSINGA soil sample from Winterton area				
1	130	65	–	–	R54,45
2	136	64	22	2 000	R64,39
3	107	45	24	–	R44,76
4	130	59	–	–	R52,13
5	140	130	47	2 000	R94,14
6	150	80	–	2 000	R70,76
7	80	50	–	1 000	R40,38
8	140	92	32	–	R71,48
9	133	75	43	–	R64,80
10	103	85	13	–	R57,88
11	120	65	25	–	R55,56
12	124	28	19	1 500	R45,81
CV	20%	26%	17%		15%

*N costed at 22,50c/kg
P costed at 38,76c/kg
K costed at 13,49c/kg
Lime costed at R3,00/tonne

both the private and public sectors were asked to formulate fertilizer recommendations for two hypothetical maize farmers. Two soil samples, one an Avalon sandy loam and the other on Msinga sandy clay loam, were analysed using the methods of the Cedara soil testing service and the Fertilizer Society of South Africa to simplify interpretation, and a full description of the soils and environmental conditions were provided. In addition, agronomic practices were stipulated, the farmers were regarded as having no capital limitations, and the most profitable yield per hectare was considered to be 6 000 kg/ha.

Not only did the recommended expenditure per hectare vary tremendously, but there appeared to be little agreement regarding the ratios in which N, P and K should be provided.

Present value of soil testing

It could be presumed from the above discussion that soil testing in South Africa is, indeed, an agricultural tool of doubtful value. However, even the incomplete and limited interpretive data available can be profitably used if needless and easily rectified sources of error in sampling and analysis are avoided.

Between 1966 and 1971 efforts were made at the Dundee Research Station to determine the optimum rates of N, P, and K fertilization for maize on the sandy Avalon soils of Northern Natal. Experimental design limitations and N induced Al toxicity made it impossible to determine the optimum level of N accurately or to accommodate the N x P interaction, but a P response function relating P soil test to maize yields at specified levels of N and K was established (Fariña & Mapham, 1973).

Since in experimentation many of the most important practical limitations to yield are absent (eg fertilizer is spread by hand, seed is hand planted, weed control is good, and hand harvesting ensures total crop recovery), the gap between experimental plot and field practice may be considerable. The financial risk to farmers accepting advice based on the P response function was for this reason considered unacceptable without further supporting evidence and an 11 hectare validation trial was initiated in 1971. The land was virgin and ranges fertilized according to normal farm practice were compared with ranges fertilized to the point of maximum profit as determined from the P response function.

The experimental work indicated that:

1 The optimum level of P would be obtainable from the production function ($y = 4,51 - 2,96\ P + 33,78P^{\frac{1}{2}}$; where y = yield and P = ppm P in soil), information regarding the price of maize, the cost per ppm P, and all other costs (Fariña & Mapham, 1974).

2 On sandy Avalon soils 6,5 kg P are required per hectare to raise the soil test by 1 ppm if the fertilizer is disced in.

3 With the prevailing cost/price structures optimum fertilization would result in a long term grain yield average of approximately 6 000 kg/ha.

All fertilizer, except half the N which was side-dressed, was broadcast and disced in prior to planting. The fields were sampled at an intensity of 30 cores per hectare after ploughing to predict fertilizer requirement, and 14 days after fertilization to monitor the effects of fertilizer. In each season actual costs (eg fertilizer, machinery, chemicals, seed, labour, etc.) were recorded and nett profits were calculated.

This exercise has now run for three seasons and it is considered, in the light of the seasonal variability experienced, (Table 2) that the results are practically meaningful.

Details with regard to pre- and post- fertilization soil test data, the quantities of fertilizer applied each season, and the yields obtained are presented in Tables 3 and 4. It is noteworthy that the soil P level obtained each season was very close to that aimed at, that the yields have been close to the long term average predicted and that by basing P requirement on soil test it has been possible to maintain yields while drastically reducing P applications. Not only have ranges fertilized according to soil test proved twice as profitable as ranges fertilized at levels considered desirable by farmers (Table 5), but actual nett returns have consistently been very close to predicted nett returns (Figure 2).

TABLE 2 Dundee Research Station seasonal rainfall figures from 1966/67 to 1973/74 (mm per month)

Season	Oct	Nov	Dec	Jan	Feb	Mar	Total
1966/67	64,0	114,0	216,0	305,0	140,0	102,0	941,0
1967/68	49,0	78,0	170,5	83,5	37,7	64,5	483,2
1968/69	9,2	79,0	116,0	106,7	87,5	143,2	541,6
1969/70	110,5	55,0	121,9	181,0	138,5	39,0	645,9
1970/71	106,0	94,0	56,5	95,0	25,0	22,0	398,5
1971/72	103,0	40,0	147,5	147,5	94,5	121,0	653,5
1972/73	60,0	125,2	50,0	149,0	128,5	42,0	554,7
1973/74	10,0	132,1	46,8	187,0	104,8	27,2	507,7
Mean	64,0	89,7	115,6	156,8	94,6	70,1	590,7

TABLE 3 Soil analytical data (high fertility ranges)

	pH (KCl)	pH (H_2O)	P (ppm)	P target	Exch cations (me %) Ca	Mg	K	Al
Before fert 1971	4,2	5,5	4		0,46	0,42	0,18	0,30
After fert 1971	4,7	5,4	26	25	1,36	0,59	0,32	0,10
Before fert 1972	4,4	5,5	12		0,80	0,38	0,19	0,22
After fert 1972	4,3	5,0	20	21	0,84	0,46	0,28	0,18
Before fert 1973	4,5	5,4	13		0,75	0,35	0,20	0,21
After fert 1973	4,2	4,8	19	19	0,89	0,41	0,26	0,24

TABLE 4 Fertilizer applications and yields obtained per hectare (kg/ha)

Ranges	Year	N	P	K	Zn	B	Lime	Yield
High fertility	1971	120	131	42	–	1,8	1 000	6 525
	1972	121	64	43	7,5	1,3	–	6 369
	1973	129	41	28	5,0	1,0	–	6 399
'Farmer'	1971	60	23	15	–	–	1 000	3 549
	1972	61	32	22	3,8	–	–	3 938
	1973	65	38	26	4,5	1,0	–	3 509

TABLE 5 Dundee demonstration lands — data averaged over three seasons (1971/72–1973/74)

	High fertility ranges	'Farmer' range
Yield (kg/ha)	6 431	3 665
Yield (200 lb bags/morg)	61	35
Plant population/ha	33 100	33 000
Fixed costs/ha (Ploughing, spreading fertilizer, planting, cultivation, etc.)	R 19,82	R 18,32
Variable cost/ha (fertilizer, chemicals, hail insurance, harvesting, bags, transport, etc)	R135,00	R 78,36
Total cost/ha	R154,82	R 96,68
Gross income/ha	R278,59	R159,14
Nett income/ha	R123,77	R 62,46
Return on investment (land valued at R150 per hectare, repayments at 10% per annum)	70%	43%
Cost per 90 kg bag	R 2,17	R 2,37

Any validation exercise of this nature obviously lacks the rigorous statistical control required to eliminate elements of random chance. Nevertheless, it is considered that the very good agreement between predicted and actual soil test, yield, and profit data in this exercise can legitimately be cited as evidence in support of soil testing. Not only was there considerable seasonal variability, but P applications varied so markedly that the probability of such good agreement being due to chance intuitively appears to be very low.

Conclusions

That soil testing has proved so effective in the validation exercise at Dundee bodes well for the future. Both the State and the Fertilizer Society of South Africa are at present conducting fertility experiments in many parts of the country. Many of these experiments have been specifically designed to provide information which will make possible the formulation of 'most profitable' fertilizer recommendations under varying conditions of capital availability. It is probable that valuable information with regard to the economics of fertilizer use will be made available to farmers during the coming decade and such information will go a long way towards rectifying present rather serious deficiencies in the area of soil test interpreation. Farmer acceptance of this information, however, will be slow unless steps are taken to eliminate weakness in other areas of the soil testing process.

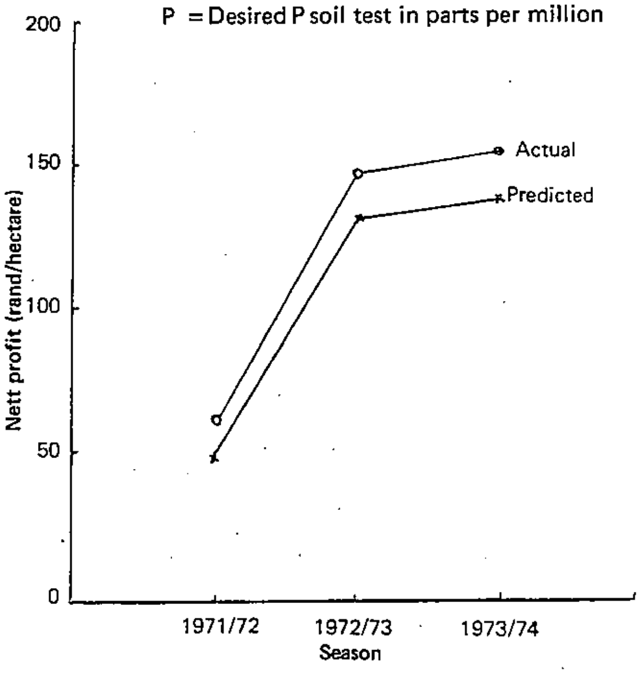
It is imperative that the quality of soil samples submitted for analysis be improved. To date there has been little

$$\text{Nett profit} = [\ (x)\ (4{,}51 - 2{,}96\ P + 33{,}78\ P^{\frac{1}{2}})\ ] - Y$$

$$X = \frac{\text{Maize price per tonne}}{16{,}08}$$

Y = Total cost of production

P = Desired P soil test in parts per million



% Return on investment land valued at R150 per hectare, repayments at 10% per annum)

	Actual	Predicted
1971/72	35%	26%
1972/73	95%	86%
1973/74	94%	84%

FIG 2 Three year comparison between predicted and actual nett returns from maize on sandy AVALON soils

effort made to encourage farmers to take their own samples, but since fertility advisors have insufficient time available to service the farming community adequately, there does not appear to be any reasonable alternative. Farmers have a vested interest in sample quality, the cost of suitable sampling tools is insignificant in relation to the money invested in fertilizers, and correct sampling procedures could rapidly be disseminated.

Similarly, it is essential that quality control in 'service' laboratories be maintained at the highest possible level. In areas where different analytical techniques are used, the relationships between techniques must be established and fertility advisors informed accordingly.

In summary, it appears that soil testing in South Africa can pay in practice, but that much of the money and effort presently devoted to soil testing services is providing a poor return.

References

BONDORFF, K.A., 1956. Soil testing results, their interpretation and application. pp 149–164. In The Organisation and Rationalisation of Soil Analysis. O.E.E.C. Paris.

CINE, M.G., 1944. Principles of soil sampling. Soil Sci. 58: 275–288.

COLWELL, J.D., 1967a. Soil tests for phosphorus fertilizer requirements. J. Aust. Inst. Agric. Sci. 33: 289–295.

COLWELL, J.D., 1967b. The calibration of soil tests. J. Aust. Inst. Agric. Sci. 33: 321–330.

DELURY, G.E., 1973. World Almanac and Book of Facts. Newspaper Enterprise Association, New York.

DOW, A.I., JAMES, D.W. & RUSSELL, T.S., 1973. Soil variability in Central Washington and sampling for soil fertility tests. Wash. Agr. Exp. Sta. Bull. 788.

ENFIELD, G.H., 1967. Soil testing doubles in 10 years. Plant Food Rev. 13: 17–18.

FARIÑA, M.P.W. & MAPHAM, W., 1973. The relationship between P soil test and maize yield on an Avalon medium sandy loam. Fert. Soc. S. Afr. J. 1: 21–26.

FERRARIE, T.J. & VERMEULEN, F.H.B., 1956. Soil heterogeneity and soil testing. pp 113–126. In the Organisation and Rationalisation of Soil Analysis. O.E.E.C. Paris.

FITTS, J.W., 1958. The uses and values of soil tests. pp 333–338. In A. Stefferud (ed.) Land: USDA Yearbook of Agric. Washington, D.C.

HALVORSEN, A.R., 1973. Taking routine soil samples for cultivated crops. Wash. State Univ. Coll. Agric. Ext. Circ. 387.

HAMILTON, H., 1967. Soil Testing and Plant Analysis Part 1. SSSA special publication no. 2. Madison, Wisconsin, U.S.A.

MÖHR, P.J., 1971. The response of maize to nitrogen, phosphorus and potassium on certain soil series of the Avalon and Hutton forms. Paper presented at Fourth National Congress of Soil Sci. Soc. of S.A., Stellenbosch, 28 Sept to 1 Oct.

MÖHR, P.J., 1973. Guidelines for fertilization of maize on soil series of the Avalon and Hutton forms: 1 Phosphorus. Fert. Soc. S. Afr. J. 2: 75–82.

PEASLEE, D.E., MILLER, H.F., WEELS, K.L. & MURDOCK, L., 1973. Soil sampling: How to and what for. Univ. of Kentucky College of Agric. AGR – 16.

PECK, T.R. & MELSTED, S.W., 1967. Field sampling for soil testing pp 25–36. In H. Hamilton (ed) Soil Testing and Plant Analysis. Part 1. SSSA special publication no. 2. Madison, Wisconsin, U.S.A.

RIEHM, H., 1956. Methods of soil sampling and preparation of samples. pp. 93–112. In The Organisation and Rationalization of Soil Analysis. O.E.E.C. Paris.

THOMAS, G.W., 1967. Problems encountered in soil testing methods. pp. 37–53. In H. Hamilton (ed) Soil Testing and Plant Analysis. Part 1. SSSA special publication no. 2. Madison, Wisconsin, U.S.A.

TISDALE, S.L., 1967. Problems and opportunities in soil testing. pp. 1–12. In H. Hamilton (ed) Soil Testing and Plant Analysis. Part 1. SSSA special publication no. 2. Madison, Wisconsin, U.S.A.

WALSH, T., 1956. The requirements of methods of soil testing for advisory purposes. pp 78–88. In. The Organisation and Rationalisation of Soil Analysis. O.E.E.C. Paris.

WILLIAMS, R., 1956. Some conclusions drawn from the study trip of Dr R. Williams and Dr H. Riehms through Western Europe. pp. 207–210. In The Organisation and Rationalisation of Soil Analysis. O.E.E.C. Paris.

WILLIAMS, R. & RIEHM, H., 1956. Intra-European study of the organisation and rationalisation of soil analysis. pp 21–66. In The Organisation and Rationalisation of Soil Analysis. O.E.E.C. Paris.