OPTIMUM SOIL P LEVELS FOR SERIES OF THE AVALON AND HUTTON FORMS*

(Met opsomming in Afrikaans)

P J MÖHR, Fertilizer Society of South Africa

Abstract

The results of 41 P depletion experiments on maize, carried out during 1971/72 – 1973/74 over a wide range of series of the Avalon and Hutton forms, were used to establish optimum soil P levels for these soils. It was found that optimum soil P, in terms of maize yield response, is mainly determined by soil form and degree of leaching. For poorly leached Avalons, the optimum level is of the order of 25 ppm (Bray No 2) and for highly leached Avalons, 30 ppm. Corresponding figures for Hutton soils are 30 and 40 ppm respectively. In addition to the above investigation, the quantity of P fertilizer required to increase soil P levels by 1 ppm was also determined. In this regard P required was shown to be dependent on soil P level, soil form and degree of leaching. With increasing soil P level the P required decreased, but only until the optimum P level was reached. Beyond this level, however, the P required remained more or less constant. Regarding soil form and degree of leaching, it was found that more P is required for Hutton than for Avalon soils, but that the difference decreases with increasing soil P level. Furthermore, more P is required for highly leached than for poorly leached series within each form. The relationship between soil P and P required is not linear but logarithmic in nature and the curves are in fact very similar to P fertilizer guideline curves as compiled by Möhr (1973).

Introduction

Guidelines for phosphorus fertilization of maize on soil series of the Avalon and Hutton forms have been established (Möhr, 1973). In addition, optimum soil P levels for these soils in terms of maize yield response were indirectly determined. In order to test these indirectly determined levels and further refine them if possible, specific field experiments were laid down using a P depletion technique as suggested by Skeen (1971). This paper reports on the results of this investigation in the establishment of optimum soil P levels. The practical implication of optimum soil P levels when using the P guidelines referred to, is that the planning of P fertilization programmes, once the soil P reaches the optimum level, becomes a relatively simple matter – the reason being that P fertilization is then mainly based on maintenance applications.

The principles involved, advantages of soil P build-up and the actual planning of the P fertilization programme, have been discussed in detail elsewhere (Möhr 1974 a).

*Paper presented at the Sixth National Congress of the Soil Science Society of Southern Africa at Blyde River, 30th June – 4th July, 1975.

Apart from the establishment of optimum soil P levels, the P depletion experiments also provide data for determining the quantity of P fertilizer required to increase soil P content by 1 ppm. This is an important aspect when considering P fertilization programmes in terms of the advantages of attaining optimum soil P levels.

When using 'optimum soil P' as a criterion, it is important to define the term precisely. The optimum soil P level in the present study is used in the biological sense – i e the specific level beyond which no further statistically significant maize yield increases are obtained by additional P applications. Theoretically, this optimum should be a constant figure for a specific soil series or set of soil conditions. Because relative responses of maize to increasing soil P levels served as an indicator for the optimum soil P, it remains a moot point whether the level might not vary if other crops are used. Experiments are at present being conducted by the Fertilizer Society on sunflower and *Cenchrus ciliaris* in order to determine whether optimum soil P levels are in any way dependent on the particular crop grown.

Farina & Mapham (1973), working along similar lines, define optimum soil P as that level where either maximum profit is obtained, or where maximum return on capital invested is achieved. Their figures may therefore vary with a change in P fertilizer costs and maize prices.

Soil forms and series as used in the context of this paper, refer to the nomenclature and classification system of Van der Eyk, MacVicar & de Villiers (1969) as modified and extended by Loxton, Hunting & Associates (1970, 1971, 1973).

Material and methods

In 1971/72, four P depletion experiments were laid down. This was followed up by a further 10 experiments in 1972/73 and nine in 1973/74 giving a total of 23 experiments. As the first four experiments have been running for three seasons and the second 10 experiments for two seasons, 41 sets of experimental results were in effect therefore available for this study.

The technique of the P depletion experiments is simply the application of five levels of P in a randomized block design (with four replications) starting with a zero level. Phosphorus is applied only in the first season. This was done in these experiments by broadcasting double superphosphate (19,6%) prior to planting, and ploughing it down. All experiments received standard dressings of N, K, Zn and B (where applicable). The levels of P were so selected that at least the second highest and highest level increased soil P level well above that level indirectly determined as optimum by Möhr (1972 a). The P guidelines (Möhr, 1973) were used as a basis for this selection. Maize was planted in these experiments to deplete soil P over time. The experiments will continue for a number of seasons until significant yield increases are obtained from the highest soil P level in each experiment. The hypothesis, therefore, is that no significant yield differences should occur where soil P levels are higher than a certain critical level — i e the optimum soil P level.

Soil analyses* from composite samples per replication for pH, P, K, Ca, Mg, Na, S value and CEC were carried out for all experimental sites prior to fertilizer application in each particular first season. In addition, composite samples per single plot (20 cores per plot) were analysed for soil P content.

The pH was determined in a 1 : 2,5 (soil: 1 N KCl) suspension. Phosphorus was extracted with Bray No. 2, and the cations with 1 N ammonium acetate at pH7.

Apart from the above soil analyses, profile descriptions and mechanical and chemical analyses for the various profiles were carried out. From these data, soils were identified according to Loxton *et al* (1970, 1971, 1973). A summary of the analyses and descriptive data for the various soil series, and full particulars on the 23 experiments have been reported (Möhr, 1972a & b; 1973; 1974b).

For the P calibration work and determination of P required to increase soil P, composite samples per plot (20 cores) were taken one month after planting and again after harvesting. In the latter case, the experimental sites were ploughed before sampling was done. Farina (1974) uses P analysis figures of samples taken one month after planting for his calibration work. In the present study however, it was found that samples one month after planting gave extremely variable figures as compared to samples taken after harvesting (Möhr, 1973). Results from the latter sampling date were therefore used.

Optimum soil P levels were established by relating yield index (Skeen, 1971) to soil P content. Yield indices are merely the yields from the different P levels for each experiment expressed as a percentage of the highest yield (= 100) in the particular experiment. By using the yield index, results from the various experiments are placed on a comparative basis.

In 'calculating' P required to increase soil P, a constant P removal figure of 0,25 kg P/100 kg grain (Orchard 1971) has been used. Furthermore, P required was calculated in unit terms — a unit being 1 ppm soil P increase. The reason for this is also to place results on a comparative basis. The actual method has been described (Möhr, 1972b). Criticism may well be brought to bear on the above approach especially with regard to the constant P removal figure used. Dijkhuis (1973), in a study on P removal figures, found variations due to cultivars, climate, and fertilization of the order of 0,23—0,34 kg P/ha. By varying the removal figure in the above calculation the deviations are, however, so small that the end results are not influenced to any marked extent as illustrated by the following example of how the calculations were done:

P levels applied	Soil P determined after harvesting	Mean yields	P removal by crop kg/ha	'Balance' of P applied	Increase in soil P due to P fertilization	P required to increase soil P by 1 ppm
kg/ha	ppm	kg/ha	kg/ha	kg/ha	ppm	kg/ha
P0	X0	Y0	Y0 x 0,25	P0—Y0x0,25=A0*	—	—
P1	X1	Y1	Y1 x 0,25	P1—Y1x0,25=A1	X1 — X0	(A1+A0)÷(X1—X0)
P2	X2	Y2	Y2 x 0,25	P2—Y2x0,25=A2	X2 — X0	(A2+A0)÷(X2—X0)
P3	X3	Y3	Y3 x 0,25	P3—Y3x0,25=A3	X3 — X0	(A3+A0)÷(X3—X0)
P4	X4	Y4	Y4 x 0,25	P4—Y4x0,25=A4	X4 — X0	(A4+A0)÷(X4—X0)

*The actual figures used are A0 = 0, and A1 + A0; A2 + A0, A3 + A0 and A4 + A0 because P required is calculated on the basis of soil P increase above the control (X0)

*The analytical methods used are fully described in Fertilizer Society of S A Publication No. 37: 'Soil Analysis Methods').

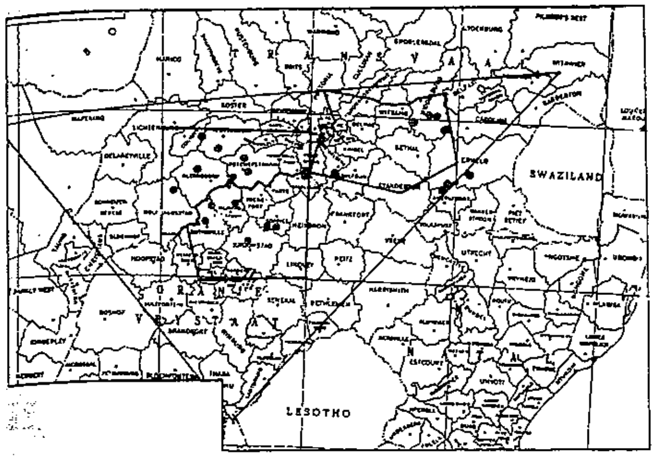

FIG 1 Distribution of P depletion experiments

Distribution of the 23 experiments are shown on the map in Figure 1, and the number of experiments per series and season when commenced, in Table 1.

TABLE 1 Number of P depletion experiments per soil series and season commenced.

Soil form	Soil series	Number of experiments		
		1971/72	1972/73	1973/74
Hutton	Hutton	—	1	—
	Msinga	1	2	—
	Mangano	—	1	1
	Shorrocks	1	2	—
	Balmoral	—	—	1
	Kyalami	—	—	1
	Doveton	—	—	1
	Bontberg	—	—	1
Avalon	Avalon	—	1	—
	Soetmelk	1	2	—
	Bleeksand	1	1	—
	Kanhym	—	—	1
	Ruston	—	—	1
	Leksand	—	—	1
	Bergville	—	—	1
Total	15	4	10	9
	—		41	

Results and discussion

Optimum Soil P

The actual yield results from the various experiments and corresponding soil P analyses have been previously reported (Möhr 1972a & b; 1973, 1974). Therefore, only the relationship between yield index and soil P levels is graphically presented in Figure 2 for Hutton soils and in Figure 3 for Avalon soils.

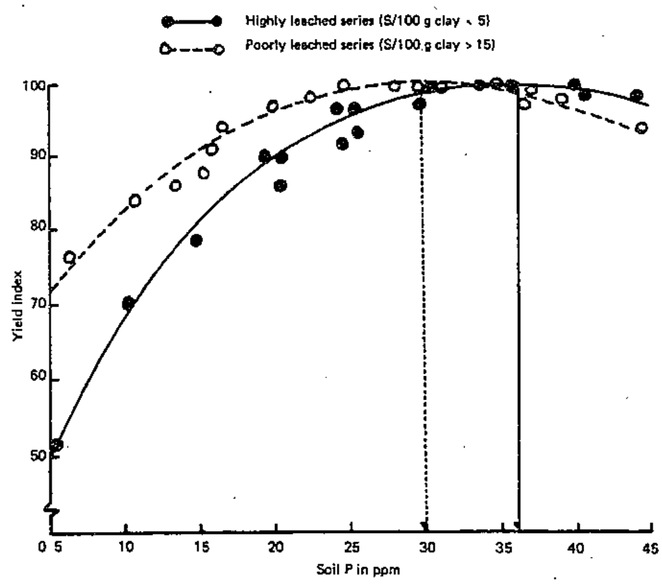

FIG 2 Relationship between soil P and yield index for soil series of the Hutton form

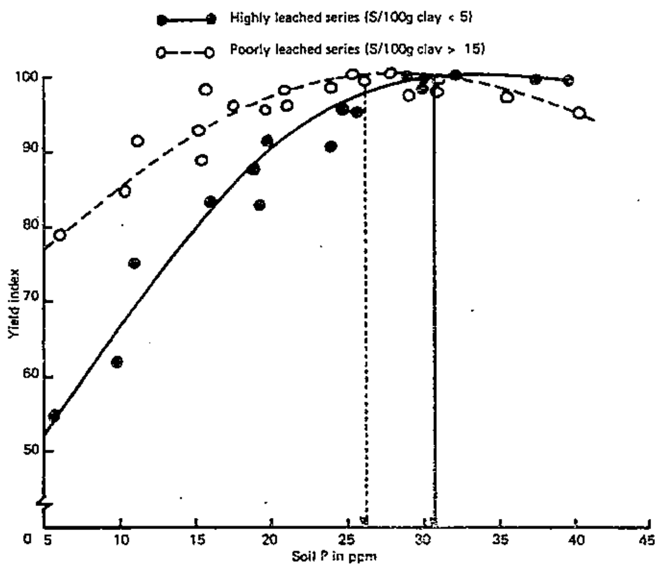

FIG 3 Relationship between soil P and yield index for soil series of the Avalon form

Although some deviations from the fitted curves are evident, the points (soil P levels) beyond which no further relative yield increases occur are clearly shown. From these curves it is concluded that the optimum soil P level for poorly leached series of the Avalon form is of the order of 25 ppm and for highly leached series, 30 ppm. The corresponding figures for series of the Hutton form are 30 ppm and 40 ppm respectively. It is further quite obvious that the optimum levels on the whole are higher for Hutton than for Avalon soils but within soil forms, are again higher for highly leached than for poorly leached series. The optimum levels for moderately leached series are more or less the mean of that of poorly and highly leached series. Degree of leaching as used in this context is derived from the S/100g clay ratio.

The conclusion with regard to the Hutton form is in agreement with the optimum range (30–40 ppm) as found by Skeen, Dudding & Clayton (1972) who worked on a Hutton series. Although Farina & Mapham (1973) define optimum soil P in economical terms and use a different P extraction method (0,05N H_2SO_4), preliminary results by Farina (1974) on a Msinga series indicate an optimum soil P of 30 ppm when assuming a conversion factor of 1,5 in terms of Bray No 2. For the sandy Avalons when defining optimum soil P in terms of maximum profit his optimum soil P is about 40 per cent higher than that indicated by the present study. On the other hand, in terms of maximum return on capital invested the results are more or less similar.

Since it is logical that an economical optimum soil P level (other things being equal) cannot be higher than a biological optimum level, the discrepancy between Farina's preliminary results for sandy Avalons and those of the present study may be explained in terms of different extraction methods used to determine soil P level, or to some other unknown variable.

Apart from differences in P extraction methods and definition of optimum soil P by various research workers concerned, depth of sampling may well be an important factor in calibration studies of this nature (Farina, 1974). In future work it will perhaps be beneficial to indicate clearly sampling depth or even calibrate for different depths. Additional factors which will also have to be considered are depth of incorporating P fertilizer and standardization of analytical techniques, or at least determination of relationships between P extraction methods.

The present study is being followed up by extending the experiments to other series within the Avalon and Hutton forms as well as to other soil forms. The current experiments will also be continued until such time that significant yield responses are obtained from the highest P levels.

P required to increase soil P by 1 ppm

Actual quantities calculated of P required to raise the soil P level by 1 ppm for the various experiments have been presented (Möhr, 1973, 1974). A graphic presentation of the relationship between P required and soil P for Hutton soils is given in Fig 4 and for Avalon soils in Fig. 5.

From these curves, the following can be concluded:

(i) It is obvious that the relationship is not linear but logarithmic in nature as expressed by the form of regression equation, $Y = a + b \log x$. Furthermore, the curves are very similar to those of the P guidelines (Möhr, 1973). Farina's (1974) results, expressed in terms of added P and increase in soil P, indicate a linear relationship. The reason may be due to the different P extraction method he used, or to some as yet undetermined difference in experi mentation.

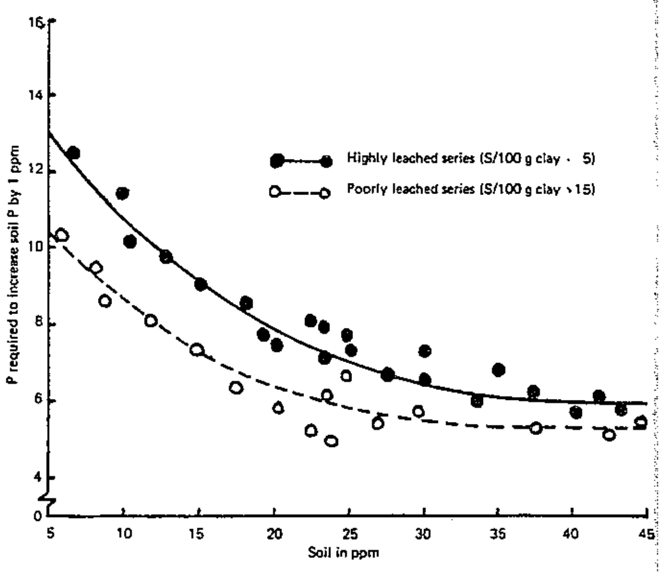

FIG 4 Relationships between P required to increase soil P by 1 ppm and soil P level for soil series of the Hutton form

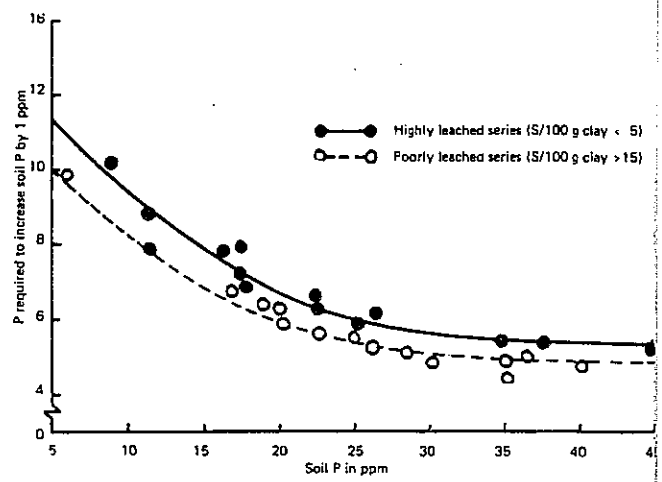

FIG 5 Relationship between P required to increase soil P by 1 ppm and soil P level for soil series of the Avalon form

(ii) P required decreases rapidly with increasing soil P level, but the curve flattens out at the higher soil P levels. Above the optimum level, the P required remains more or less constant.

(iii) On the whole, Hutton soils require more P to increase soil P by 1 ppm than the Avalon soils. Within soil form, highly leached series again require more P than poorly leached series. It is, however, quite clear that differences between soil form and degree of leaching decrease with increasing soil P. In fact, as soon as the various optimum soil P levels are reached, there is hardly any difference – the average being about 5,1 kg P/ha. Dijkhuis (1973), in a similar study using the same P extraction and method for calculating P required, shows a figure of 5,6 kgP/ha on a Msinga series with soil P levels of the order of 60 ppm. When considering that one hectare of soil to plough depth weighs between 4 and 5 x 10^6 kg it would appear that almost all the P added to soils where optimum soil P levels or higher have been attained, is readily available for increasing soil P. At lower soil P levels, however, only part of the added P can be measured in terms of increased soil P levels – the effect of the remaining part being 'buffered' and therefore not showing up in the analyses.

Although the curves in Figure 4 and 5 show reasonable patterns, there are quite a number of unexplained deviations. This may be due to insufficient data per subgroup, sampling errors, limitations in the particular method of calculating P required or even P extraction method, or to other factors which were not considered at this stage. The fact remains that these results still need further confirmation and considerable refinement. The present investigation will therefore be continued and extended in future. Preliminary guidelines for use in the meantime have, however, been compiled as presented in Figure 6.

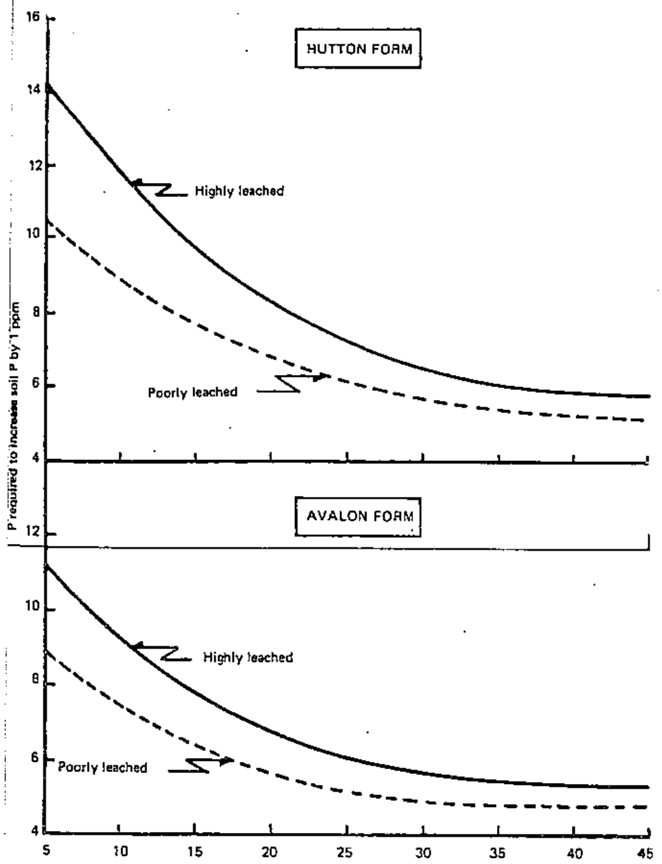

FIG 6 Guideline for determining the quantity of P required to increase soil by 1 ppm

From these curves, P required to build up soil P at different soil P levels to the optimum, have been calculated as given in Table 2.

TABLE 2 P in kg/ha required to build up soil P to the optimum level in poorly, medium and highly leached series of the Avalon and Hutton forms.

Soil P level	P required to build up soil P to the optimum level					
	AVALON FORM			HUTTON FORM		
	Poor* (25ppm)**	Medium (28 ppm)	High (30 ppm)	Poor (30 ppm)	Medium (35 ppm)	High (40 ppm)
5	95	128	159	159	227	295
10	65	90	113	115	170	226
15	41	60	77	79	124	170
20	20	35	48	49	86	125
25	–	13	23	23	54	87
30	–	–	–	–	26	55
35	–	–	–	–	–	27
40	–	–	–	–	–	–

* Degree of leaching
**'Optimum soil P' for particular series

The figures in Table 2 may in future be proved to be higher than is actually needed. In practice this is, however, not a serious disadvantage because 'over-fertilization' with P in any one year is not a long-term loss as correction/exploitation can easily be done in ensuing years. In fact, a high soil P reserve, even higher than the optimum level can never be a loss but is a valuable asset to any farmer.

Opsomming

OPTIMUM GROND-P-PEILE VIR SERIES VAN DIE AVALON- EN HUTTONVORMS

Die resultate van 41 P-uitputtingsproewe met mielies wat gedurende 1971/72 tot 1973/74 op 'n wye reeks van grondseries van die Avalon- en Huttonvorms uitgevoer is, is gebruik om optimum grond-P-peile vir hierdie gronde vas te stel. Dit is gevind dat optimum grond-P, soos weerspieël deur mielie-opbrengsreaksies, hoofsaaklik deur grondvorm en graad van loging bepaal word. Vir laaggeloogde Avalons is die optimum peil in die orde van 25 dpm (Bray Nr 2) en vir hooggeloogde Avalons, 30 dpm. Ooreenstemmende waardes vir Huttongronde is ongeveer 30 en 40 dpm onderskeidelik. Behalwe bogenoemde ondersoek, is die hoeveelheid P-bemesting benodig om 'n 1 dpm grond-P verhoging te gee, ook bepaal. In dié verband is daar sterk aanduidings dat die hoeveelheid P benodig afhang van die betrokke grond-P-status, grondvorm en graad van loging. Met toenemende grond-P-gehalte neem die P benodig af totdat die optimum grond-P bereik is. Met hoër grond-P-gehaltes as die optimum, bly die P benodig min of meer konstant. Wat grondvorm en graad van loging betref, word *meer P benodig vir die Hutton- as vir die Avalongronde, en weer meer P vir hooggeloogde as vir laaggeloogde series binne elke grondvorm. Die verskille weens grondvorm en graad van loging verklein egter met verhoogde grond-P-gehalte. Die verband tussen grond-P en P benodig is nie liniêr nie, maar logaritmies van aard, en die betrokke krommes trouens baie soortgelyk aan die van die P-bemestingsriglynkrommes soos saamgestel deur Möhr (1973).*

References

FARINA, M.P.W., 1974. Personal communication. Natal Region, (Cedara) Dept of Agric. Tech. Serv.

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

LOXTON, R.F., HUNTING & ASSOCIATES, 1970; 1971; 1973. Soil classification projects: Eastern Transvaal Highveld/North Western Orange Free State/ Western Transvaal/Eastern Orange Free State. Sponsored by the Fertilizer Society of South Africa in consultation with the Dept of Agric. Tech. Services. Loxton R F, Hunting & Associates, Johannesburg.

MÖHR, P.J., 1972a. Navorsingsverslag Nr III – Samevatting en verwerking van NPK-proefgegewens op mielies (1961/62 tot 1970/71). MVSA-publikasie, Feb. Pretoria.

MÖHR, P.J., 1972b. Navorsingsverslag Nr IV – Samevatting en verwerking van NPK-proefgegewens op mielies (1961/62 tot 1971/72). MVSA-publikasie, Okt, Pretoria.

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

MÖHR, P.J., 1974a. Handleiding vir mielieproduksie en gebruik van die mielierekenaar. MVSA-publikasie Nr 36, Sept, Pretoria.

MÖHR, P.J., 1974b. Navorsingsverslag Nr VI-Samevatting en verwerking van resultate van bemestingproewe met mielies en ander gewasse. MVSA-publikasie Nr 41, Des, Pretoria.

SKEEN, J.B., 1971. Personal communication. Agricultural Division, Triomf Fertilizers (Pty) Ltd.

SKEEN, J.B., DUDDING, F.S. & CLAYTON, J.H., 1972. The maintenance of soil fertility with specific reference to nitrogen, phosphorus, potassium and lime. Fert Soc SA J, 1; 29–33.

ORCHARD, E.R., 1971. Step-by-step to higher maize yields. Frms Wkly, Aug 18, 7.

VAN DER EYK, J.J., MACVICAR, C.N. & DE VILLIERS, J.M. 1969. Soils of the Tugela Basin. A report and research project conducted under the auspices of the Natal Town and Regional Planning Commission, the Dept Agric. Tech. Serv. and the Univ of Natal. Durban, Interpak Ltd.