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FACTORS AFFECTING PHOSPHORUS NUTRITION AND FERTILIZER USE BY SUGARCANE IN SOUTH AFRICA

By J. H. MEYER and R. A. WOOD

South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300, South Africa

Abstract

In the South African sugar industry during the past sixty years considerable research has taken place in the field, laboratory and glasshouse with regard to the phosphorus requirement of sugarcane. Reference is made to the amounts of P used by sugarcane and to the economics of fertilization. The value of phosphatic fertilizer for cane production is reviewed using available field experimental data. Correlations established between soil and leaf analysis and crop response to P are discussed, as are the effect of P on cane quality and ways of reducing P fertilizer costs. Results of recent glasshouse trials have indicated that on some soils it may be necessary to revise certain features of the current system for making P recommendations.

Introduction

Consumption of phosphorus (P) fertilizer by the South African sugar industry is presently about 8 500 tons P per annum, costing about R30 million, which is double the amount spent in 1984. This sharp rise in cost makes it essential to ensure that P fertilizer is being used as efficiently as possible. This paper is a review of the field, laboratory and glasshouse work that has been carried out on P by the South African Sugar Association Experiment Station over the past 60 years, and also the value of phosphatic fertilizer for cane production. Factors influencing the availability of P to sugarcane, which may therefore affect the reliability with which P recommendations can be made on certain soils, are also discussed.

Amounts of P used by sugarcane

P is required by sugarcane in amounts which are substantially lower than those of either nitrogen (N) or potassium (K). Bishop[3], reported that under South African conditions the aerial parts of an adequately fertilized 12-month old rainfed plant cane crop contained 18 kg P per hectare compared to 168 kg N and 214 kg K per hectare. The lower requirement of P relative to N and K is reflected in Figure 1, which shows the average amounts of these nutrients used per hectare under cane in South Africa between 1951 and 1987. In a recent review of fertilizer use in the sugar industry Thompson[19], noted that during the 1950's the importance of N and K were recognised and rational proportions of N, P and K in fertilizer were established. Since then the amounts of N and K have generally increased to similar extents, though more recently the increased use of N has been somewhat greater than that of K. The relative amount of P used, however, has tended to fluctuate according to industrial development, increasing when larger planting programmes have been carried out. For example in 1970, when strongly P fixing soils were first encountered in the newly developed cane areas of the Natal Midlands, glasshouse and field trials confirmed that economic returns were possible from broadcasting substantial applications of P fertilizer (Meyer[13]). Between 1961 and 1981 the average amount of P used for cane increased markedly from 7 to more than 20 kg P/ha per annum. It is evident that these higher amounts were justified when assesed in terms of crop removal data obtained by Bishop[3] and Thompson[20].

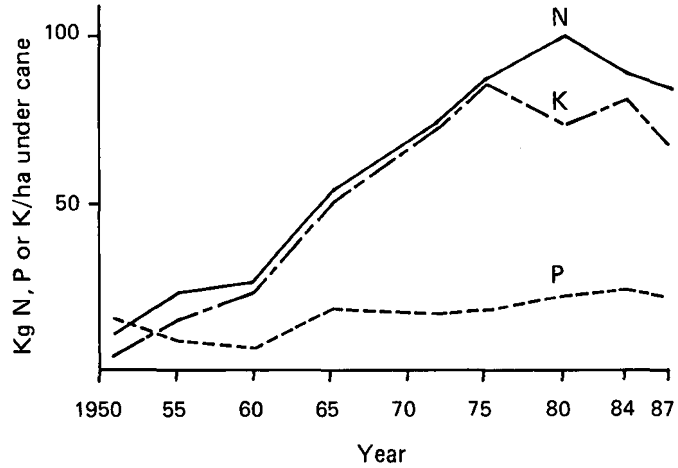

Figure 1 Amounts of N, P and K used per hectare under cane in South Africa, 1951 to 1987.

Economics of increased fertilizer use

Whilst the area under cane increased by a factor of 2,4 from 1951 to 1985, the amounts of nutrients used as fertilizer increased approximately as follows: N by a factor of 20, P by a factor of 3,5 and K by a factor of 49.

Over approximately the same period the value of a ton of sugarcane increased from R3,20 (1950) to R26 (1985) which is about an eight-fold increase. During this time the costs of ammonium sulphate, single superphosphate, and potassium chloride increased on average by about a factor of seven. Table 1 shows that a response of 12 tons of cane was required in 1950 to pay for a third of a ton of each of the three nutrient carriers, whereas between 1970 and 1985, between 6 and 10 tons of cane would have been sufficient to cover the cost of the same materials.

Table 1
The value of sugarcane in relation to fertilizer costs 1950 to 1985

Year	Value ton cane (R)	Cost of fertilizer/ton (R)			Tons cane required to break even on 1/3 t A + 1/3 t B + 1/3 t C
		Ammonium sulphate (A)	Single supers (B)	Potassium chloride (C)	
1950	3,20	48,35	15,20	50,20	12
1970	5,40	36,00	25,53	43,30	6
1980	15,00	129,50	82,17*	155,20	8
1985	26,00	232,00	218,00	380,00	10

*adjusted from 11,3 to 8,3% P

When cane yields between 1951 and 1985 are compared with the average amounts of N, P and K used, the increase in mean yield over this period from 25 to 55 tons cane/ha/a (see Figure 2) has more than justified the additional fertilizer cost. However, new varieties and improved cultural practices also contributed significantly to the doubling of the average yield over the 34 year period.

The Response of Sugarcane to Applied P

Early trials

Thompson[19] pointed out that when replicated field trials were started in the 1920's, the results of Dodds and Fowlie[5] confirmed the longstanding observation that P was the most commonly deficient major element in the soils of the South African sugarbelt. Of the 52 experiments conducted between 1925 and 1948, significant responses to applied P were measured in 29 of them. Results reported by Lintner[11] clearly showed the strong residual effect of P applied in the furrow at time of planting on yield of the first ratoon crop.

The establishment by the Experiment Station of thirty-one 3 × 3 × 3 exploratory NPK fertilizer tirals in 1950, followed by fifty-three 4N × 2P × 3K regional fertilizer trials (RFT) led to a major improvement in the understanding of sugarcane nutrition under local conditions. The 3 × 3 × 3 trials provided data to construct the P response curves for plant and ratoon cane shown in Figure 3, and the results of these trials were summarised by du Toit[6].

Trials on high P-fixing soils

In the mid sixties, the sugar industry expanded into the more highly leached soils of the Natal Midlands and poor yields were frequently obtained on well weathered soils, which varied from deep porous red loams of the Hutton form to humic clay loams of the Inanda form. Investigations to determine reasons for the stimulating effects of wattle brushwood ash on cane growth (Meyer[12]) identified aluminium toxicity and P fixation as likely growth limiting factors. Since the early 1970's research involving P adsorption isotherm measurements, glasshouse studies and field trials has shown that heavy P fertilizer applications are economically justified on certain high P-fixing soils in the Natal Midlands (Meyer[15]). In 1974 and 1975 six P fertilizer trials were established on soils providing a satisfactory range of combinations of extractable P and P-fixing capacity. Yield results of the plant and first ratoon crops showed that combined broadcast and in-furrow placement of P fertilizer applied at planting was generally more effective than the conventional in-furrow P application alone, since the advantages of high P availability during the early stages of crop growth were coupled with a large soil P root contact area during later growth (Meyer and Dicks[16]). Responses averaged 21 tons cane or 2,4 tons sucrose/ha to a broadcast application of 250 kg P/ha in addition to the standard in-furrow treatment of 100 kg P/ha. The relationship obtained between total applied P and the average combined yield of the plant and first ratoon crops for five of the trials is shown graphically in Figure 4.

Soil and Leaf Analysis and Crop Response to P

Soil tests for measuring extractable soil P and P fixation

Recommendations given by the Fertilizer Advisory Service at the Experiment Station are based on soil analysis. Of the many methods for determining P requirements that were tested by du Toit *et al*[8], the modified Truog procedure based on extracting the soil with 0,02N sulphuric acid for 30 minutes, using a 1:50 ratio of soil to extracting solution was found to give the best correlation between soil P levels and response to applied P. Threshold values of 31 ppm and 11 ppm were selected for advisory purposes for plant and ratoon cane respectively. In testing the reliability of these threshold values, Bishop[4] concluded that responses to applied P would have been correctly predicted in 72% of the instances, incorrectly in 16%, while predictions for the remaining 12% would have been of doubtful value. For strongly P-fixing oxisol soils that occcur in the Natal Midlands, the accuracy of predicting a response to a broadcast application

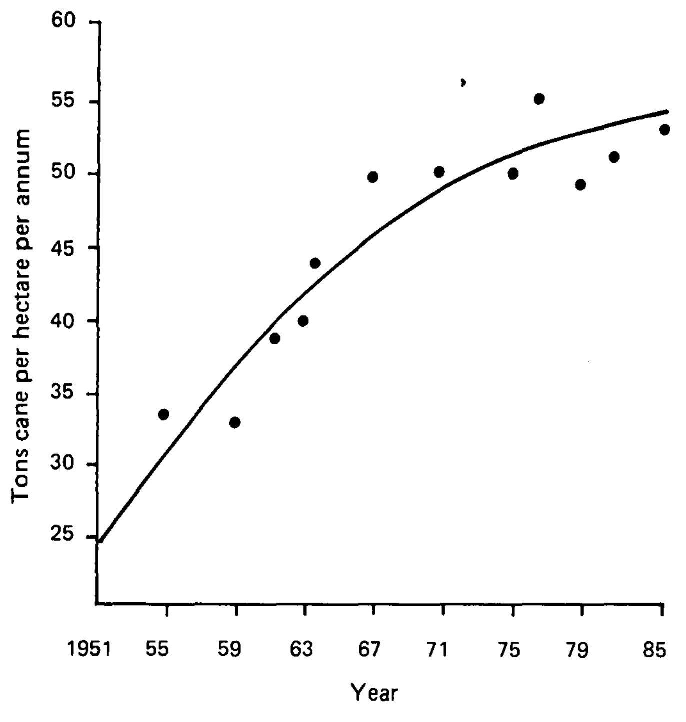

Figure 2 Average yield of sugarcane (tc/ha/a) between 1951 and 1985.

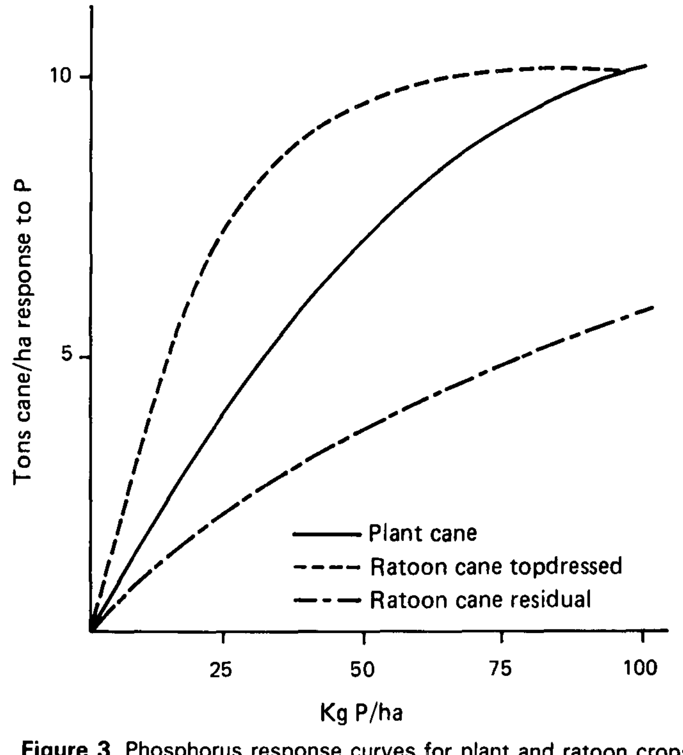

Figure 3 Phosphorus response curves for plant and ratoon crops (3 × 3 × 3 trials).

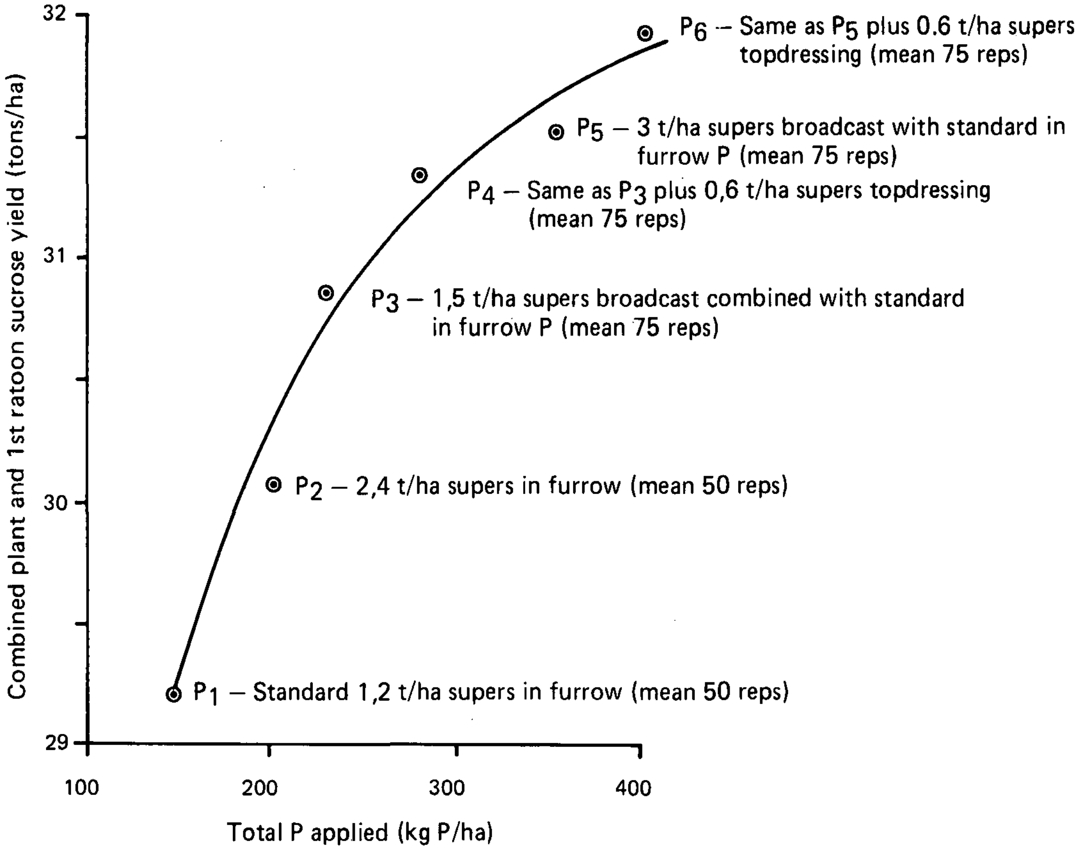

Figure 4 The average combined plant and first ratoon yields of five trials in relation to applied P.

of superphosphate was further improved by supplementing the Truog method with a rapid phosphorus desorption index (PDI) method developed by Reeve and Sumner[18] to measure the P fixation capacity (Meyer[13], Meyer and Dicks[16]). The technique has been used routinely on an advisory basis for the past decade and soils are classified into strongly, moderately and weakly P fixing categories and the P fertilizer recommendations adjusted accordingly.

Foliar diagnosis

Leaf analysis (conducted on the central portion of the top visible dewlap or third leaf without the midrib) has been used to great advantage in assessing the P status of sugarcane and compares favourably with soil analysis in correlating with responses. Du Toit[7] reported that responses to applied P were found to be common up to a leaf content of 0,19%, but above this level P responses were not likely to occur. In practice soil and leaf analyses are considered to be complementary and this approach was emphasized when whole cycle fertilizer advice was introduced into the industry by the Experiment Station some years ago (Wood[23]). In this system soil analysis is limited to a comprehensive pre-plant sample taken after ploughout from which fertilizer recommendations are given for the plant crop and for four succeeding ratoons. Leaf analysis during each ratoon should then be used as a check on the adequacy of the recommendations given.

P and cane quality

Wood[21] reported that an application of phosphatic fertilizer to a soil highly deficient in P may significantly increase cane yield and improve cane quality, as shown in the plant crop results of two experiments on Inanda form soils (see Table 2). Generally, however, application of P fertilizer does not affect sucrose % cane significantly, as indicated by the results from P fertilizer trials in the Natal Midlands reported by Meyer and Dicks[16]. Wyatt[24] concluded that there was little or no difference in the efficiency of different P fertilizers used for cane in so far as their effects on yield or quality were concerned. A notable exception, however, is filtercake which is a by-product from the sugar mills and is used primarily as a substitute for inorganic P fertilizers. Excellent yield responses to P, when filtercake was applied in large quantities, were reported by Moberly and Meyer[17], especially on the strongly P-fixing Midlands soils, but frequently cane quality was significantly depressed due to the gradual release of excessive amounts of N, which is also contained in filtercake.

Table 2

Response to superphosphate - plant cane

Treatments	Inanda			Melmoth		
	t/ha cane	Suc % cane	t/ha suc	t/ha cane	Suc % cane	t/ha suc
Control - No P	66,7	13,4	8,9	19,9	15,7	3,1
Supers - 1 100 kg/ha	166,4	14,9	24,8	95,6	17,5	16,8

Reducing P fertilizer costs

There was a time when P was as cheap as either N or K fertilizer, but currently on a unit mass basis this nutrient is three times as expensive as nitrogen, and almost four times as expensive as potassium. Phosphatic fertilizers have been used for many years in the sugar industry with the result that, apart from some of the strongly P-fixing soils in the Natal Midlands which require regular broadcast P applications to every ratoon, there has been an appreciable build up of available P levels in the soil. In particular, P content may now be very high where heavy applications of filtercake have been made in the past.

While there is still a need to supply P where required at time of planting, the need to apply additional P fertilizer to subsequent ratoons based on whole cycle fertilizer advice is sometimes questionable, as shown in a survey by Hulbert[9]. Soil test P values from 1 000 miller-cum-planter and 1 000 grower fields in an extension area were examined (see Table 3). Based on the current Fertilizer Advisory Service recommendations for P in ratoon crops, only 10 to 13% of the fields would have required additional P fertilizer, while between 42 and 46% of fields would have required no additional P even at time of planting, thus confirming that substantial reductions in P fertilizer costs could be achieved. Should there be any doubt, however, regular leaf sampling can be used to identify any P deficiency.

An assessment of P uptake by the three crops in relation to the various P treatments and soil chemical properties is shown graphically in Figure 5. The total amount of P removed by the three crops increased curvilinearly with additional P applied, with the highest and lowest rates of P uptake being associated with the weakly and strongly P-fixing Mayo and Inanda soils respectively. In general the best initial responses to the application of P were obtained on those soils for which both the available (Truog) P and PDI values were low. Conversely the best residual P treatment effects were obtained in soils for which both the available P and PDI values were high. There is now sufficient evidence to indicate that strongly P-fixing soils outside the Midlands area occur more widely than previously thought and field trials are in progress to confirm whether additional P fertilizer is required at planting, and in subsequent ratoons.

Table 3

Distribution of soil P (survey of 2 000 fields)

Soil test P kg/ha	*M.C.P. % (1 000 fields)	Growers % (1 000 fields)
< 20	4	3
20–29	9	7
30–39	10	12
40–49	11	13
50–59	12	13
60–69	8	10
> 70	46	42

* MCP = miller-cum-planter

Table 4

Effect of incorporating 160 kg P/ha on the average yield of three cane crops

Soil Series	Pre-plant soil analysis		Dry weight of tops (g)		
	Truog P (ppm)	PDI	P0*	P1**	% incr.
Non-Midlands					
Milkwood	6	0,13	14	42	200
Shortlands	33	0,19	17	32	88
Dansland	10	0,19	32	46	43
Mayo	33	0,32	38	38	0
Midlands					
Balmoral	23	0,23	43	51	19
Fountainhill	4	0,24	17	39	129
Inanda	4	0,07	11	32	191

P0* = no P applied: P1** = 160 kg P/ha

Factors affecting the availability of P

Results of recent laboratory and glasshouse investigations have indicated that in some instances problems still exist in predicting correctly the P fertilizer requirement of sugarcane. These will be discussed under three main headings.

P fixation in non-Midlands soils

The PDI method for predicting the capacity of soils to fix P was developed mainly for the highly leached soils found within the Nottingham soil system in the Natal Midlands. It has therefore not been used when formulating P fertilizer advice for soils from other parts of the sugar industry. However, results of a comprehensive laboratory and glasshouse study conducted on coastal soils of the Milkwood, Shortlands, Dansland and Mayo series indicated that they were able to fix varying amounts of P fertilizer, and that current recommendations may not always be adequate to meet the P requirements of cane at the time of planting (Anon[1]). In the glasshouse trial single-eyed cane setts were planted in pots containing the four coastal soils mentioned above and, for the purpose of comparison, three Midlands P-fixing soils of the Balmoral, Fountainhill and Inanda series. There was a control treatment to which no P fertilizer was applied (PO), and three treatments in which P was incorporated as single superphosphate at rates equivalent to 160 kg P/ha (P1), 400 kg P/ha(P2), and 800 kg P/ha(P3). A plant crop and two ratoon crops were harvested. Table 4 shows that marked yield responses were obtained on some of the non-Midlands as well as the Midlands P-fixing soils when cane received the equivalent of 160 kg P/ha compared to the control treatment to which no P was applied.

Residual value of fertilizer P applied to P-fixing soils

Studies using P adsorption isotherms provide information on the extent to which P is held on colloidal surfaces in the soils. However, little is known about the chemical nature of surface phosphates resulting from reactions between water soluble P and reactive components in the soil. Such information would be useful in determining the value to ratoon cane of residual P from high rates of broadcast fertilizer applied to plant cane on P-fixing soils. The availability of so-called fixed phosphate has been classified by Heck[10] on the basis of relative solubility in 0,02 N H_2SO_4 as follows: (i) readily available, $Ca_3(PO_4)_2$, (ii) moderately available $AlPO_4$ (iii) slightly available Fe PO_4, $Al_2(OH)_3PO_4$ and Fe $(OH)_3PO_4$.

Du Toit *et al*[8] confirmed that the availability to sugarcane of P from $AlPO_4$ is surprisingly high, whereas P from $Ca_3(PO_4)_2$ and Fe PO_4 is only slightly available. In P fractionation studies on strongly P-fixing soils from several P trials, Meyer[14] indicated that increases in extractable P following treatment with superphosphate were generally accompanied by marked increases in the moderately available Al-bound fraction.

More recently a glasshouse trial was conducted to determine the amount and rate of release of P available to the plant from the various P fractions under continuous cropping on different soils. Figure 6 shows that for a moderately P-fixing Fountainhill series soil treated with 160 kg P/ha, more P was removed by five successive cane crops than

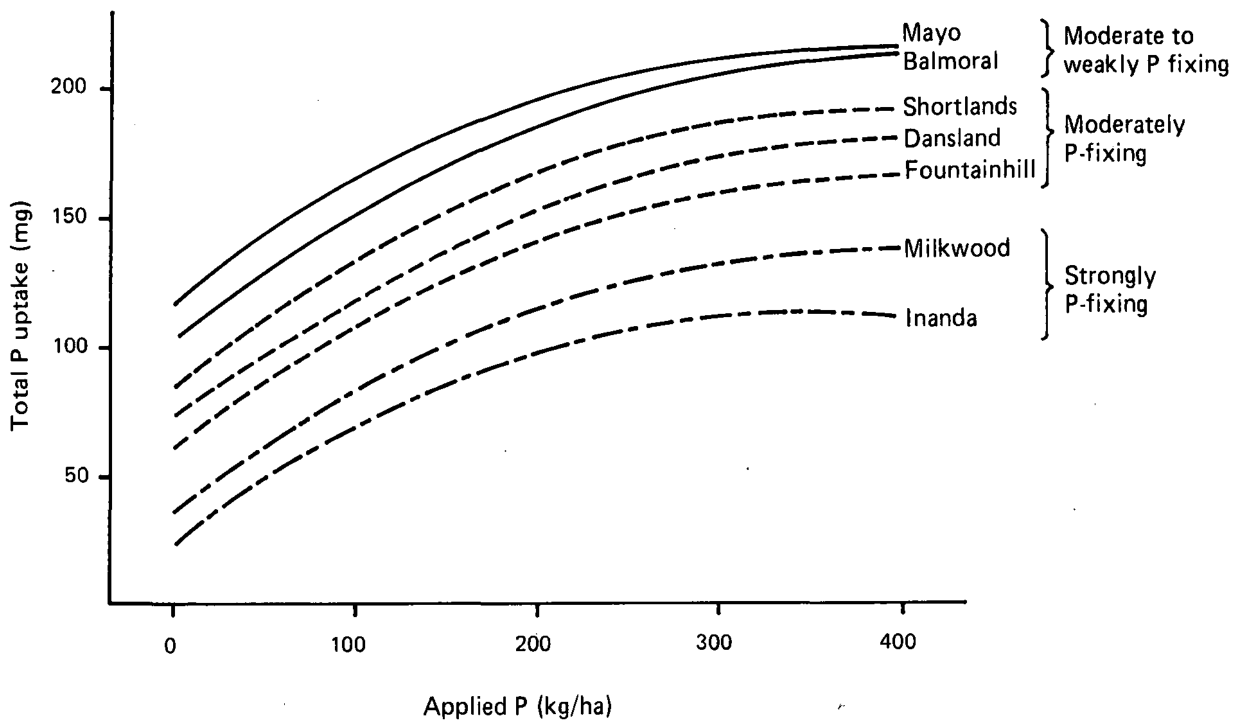

Figure 5 Total amount of phosphorus taken up by three crops in relation to amount applied.

could be accounted for by the decline in Truog extractable P. Changes in the amounts of Al, Fe and Ca phosphate with time indicated that most of the additional P was derived from $AlPO_4$. Over the cropping period the amount of P present in the soil in this form declined from 65 to 25 mg/kg. The difference of 40 mg was only slightly less than the total amount of P removed by cropping (45 mg). From the decline in the Ca phosphate fraction it may be inferred that a smaller amount of P was derived from this source. The lack of any change in the Fe phosphate form indicated that this source did not contribute to the P nutrition of the crop. The main conclusion from this work was that fertilizer P applied to strongly P-fixing soils is not irrevocably lost due to P retention by the soil. At least 20% of the applied P was used efficiently by the crop mainly in the Al-bound form. In moderately P-fixing soils an efficiency between 30 and 35% of the applied P was observed. In view of these significant residual effects, it is possible that in the range of Truog P values from 18 to 25 ppm, the amount of P that is recommended as a top-dressing for ratoons in the Midlands could be reduced.

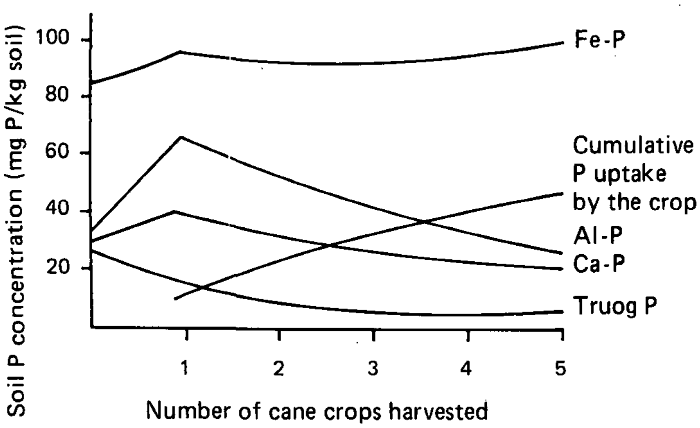

Figure 6 Soil and crop removal by cane of applied P (160 kg P/ha) (Fountainhill series soil).

P availability in alluvial soils

Analysis of slightly alkaline alluvial soils taken from Umfolozi and other areas in Natal subjected to past and recent flooding has indicated that they are adequately supplied with available P as measured by the standard Truog procedure. In some cases, however, leaf analysis from cane growing on these soils has indicated marginal to deficient levels of P, suggesting that the P requirement of the crop has not been met.

For a glasshouse trial bulk topsoil samples with apparently adequate amounts of Truog available P were taken from five estate fields. However, marked differences were observed in the amounts of P extracted by various methods (see Table 5). Four replicates of each soil were treated as follows: no P added (PO), superphosphate added at rates equivalent to 230 and 460 kg P/ha (treatments P1 and P2). Pots were planted either with forage sorghum or pre-germinated cane setts. Three cuts were taken from the sorghum and the plant cane crop was harvested. The comparative yield data for sorghum and sugarcane are shown in Table 6. Both crops showed a marked response to the lower rate of superphosphate (P1) when applied to soils from all fields, while the higher rate of superphosphate showed no additional benefit (Anon[2]). With regard to available soil P determined by the Truog method, relative yields increased linearly from 30 to 80% for soil P values ranging from 50 to 110 ppm (see Figure 7).

These preliminary results imply that the Truog procedure provides an overestimate of plant available P and that the current threshold value of 31 ppm is too low to diagnose a P deficiency under these conditions. Further investigation is now required before the introduction of a correction factor to compensate for the Truog P value or alternatively it may be necessary to replace the Truog method with one more suited to soils with high pH values.

Table 5
Comparison of soil P availability in pre-plant soil samples

Field No.	Pre-plant P values (ppm)					Texture			Soil pH
	Truog	Ambic	Bray P2	Bray P1	Olsen	Clay	Silt	Sand	
A	66	27	17	3,6	5	12	11	17	7,4
B	45	24	19	2,0	3	10	3	87	7,0
C	49	25	15	1,0	1	9	8	83	7,1
D	56	24	16	2,0	2	12	2	76	8,0
E	59	24	18	2,0	1	14	19	67	7,3

Table 6
Effect of P treatment on sorghum and cane yields (average g dry weight yields)

Field No.	Treatment	*Sorghum				**Sugarcane (plant cane)
		1st cut	2nd cut	3rd cut	Average	
A	P_0	1,0	1,5	3,3	1,9	25,8
	P_1	2,2	3,5	6,3	4,0	38,6
	P_2	2,8	4,0	6,4	4,4	36,4
B	P_0	0,8	1,2	4,8	2,3	26,7
	P_1	2,7	4,2	7,0	4,6	41,5
	P_2	3,1	5,3	7,1	5,2	40,2
C	P_0	0,5	1,2	3,4	1,7	18,6
	P_1	2,4	4,0	5,2	3,9	42,5
	P_2	3,3	3,9	6,8	4,7	45,4
D	P_0	1,0	2,0	5,3	2,2	13,4
	P_1	2,9	3,8	10,8	5,8	24,8
	P_2	3,5	4,1	11,0	6,3	25,4
E	P_0	0,5	1,6	4,6	2,3	8,7
	P_1	4,5	3,7	11,5	6,6	26,2
	P_2	5,3	4,9	12,1	7,4	25,5

* Mean of four replicates
** Mean of three replicates

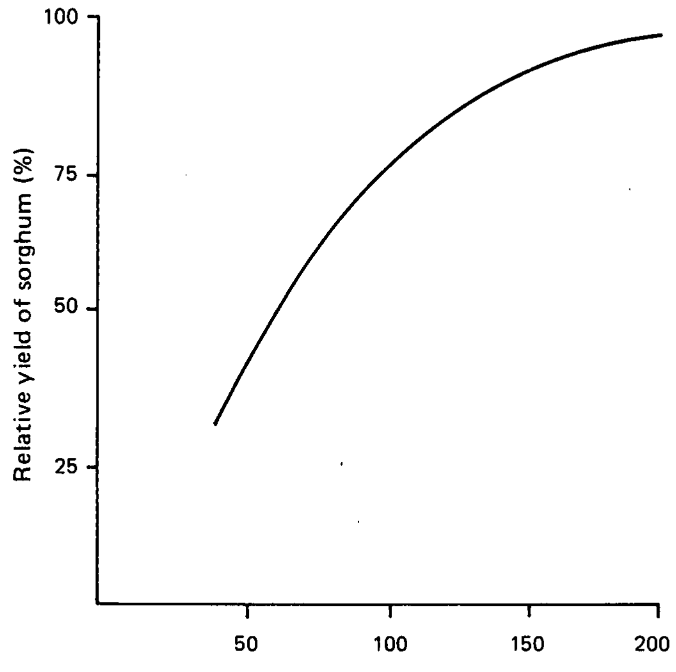

Figure 7 Relative yield of sorghum in relation to soil Truog phosphorus values (mean of five soils).

Conclusions

Over the past 60 years considerable progress has been made in determining the P requirement of sugarcane grown under the wide range of climatic and soil conditions found in the South African sugar belt. In general the amounts of P used in the sugar industry have been similar to those which experimental results indicate to be necessary, and the Fertilizer Advisory Service of the Experiment Station has played an important role in this regard. The sharp rise in recent years in the price of P fertilizer makes it necessary to consider ways of reducing P fertilizer costs. Further increases in the price of P fertilizer relative to the value of a ton of cane will mean smaller net returns from the rates recommended at present. It is believed that in many areas of the sugar industry substantial reductions in P fertilizer costs can be achieved without detriment to yields.

Field trials are in progress to confirm whether extra P fertilizer is required when cane is grown on moderately to strongly P-fixing soils in areas other than the Natal Midlands. Investigations based on glasshouse trials and P fractionation measurements are also being conducted to assess the suitability of the Truog extraction procedure for measuring available soil P in comparison with other methods, both on P-fixing and alkaline alluvial soils.

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