EVALUATION OF LOW ORDER YIELD RESPONSES IN FERTILITY STUDIES ON MAIZE*

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Abstract

A comparison of seasonal and cumulative yield responses to applied phosphorus was determined over a period of four years in the same locality. Phosphorus was applied before commencement of the trial. Results were evaluated in terms of (a) the significance of treatment mean squares (MS) and the linear component of treatment sums of squares of seasonal yields, and (b) the additive property of X^2 and analysis of variance of total yields over four years. The cumulative response was highly significant. With one exception seasonal yield responses were low and non-significant when judged on the F-test for treatment MS. This indicates that cumulative residual effects can be underestimated when yield responses are evaluated on a seasonal basis.

In single season NPK trials the t-test was used successfully to establish the significance of consistent low order yield responses to applied phosphorus on soils with medium to high phosphorus reserves.

Introduction

Most statistical designs in fertility research are basically the randomised blocks design in which a classified set of treatments is replicated a number of times. The treatments might for example be five equally spaced levels of phosphorus or they might form a factorial set of NPK combinations.

The statistical analysis of the randomised blocks design consists of a two-way analysis of variance in which sums of squares (SS) for replications, treatments and error are calculated. Most classified sets of treatments of the type used for fertility research define predetermined comparisons which should be reflected in the analysis of variance by subdividing the treatment SS into component sums of squares. Thus in the first example above the treatment SS should be subdivided into linear, quadratic and higher order effects of phosphorus.

These subdivisions are often not carried out and the significance of treatments is judged by the F-test of the treatment mean squares (MS). It often happens that a component sum of squares can be statistically significant on its own, but its effect is diluted in the overall test of treatments MS, which then turns out to be non-significant. It follows, therefore, that the non-significance of the overall treatments F-test is no guarantee that certain of the predetermined treatment comparisons in the classified set of treatments may not be statistically significant.

In fertility studies on maize where the F-test for overall treatments is non-significant, but where consistent positive yield trends are evident either in multi-annual trials or single season trials repeated under more or less similar conditions, such responses are normally of a relatively low order. Depending upon the size of the standard error, these 'non-significant' responses are usually less than 500 to 600 kg/ha, but can be as high as 1 000 kg/ha. They are often referred to in research reports as 'non-significant responses' or 'yield trends' and are mostly ignored when, for example, fertilizer requirements are evaluated in terms of crop response. This unwarranted rejection of potentially important responses is possibly the result of strict conformance to the results of incomplete statistical evaluation and/or a lack of understanding of the meaning of statistical significance. It is not always appreciated that low order 'non-significant' yields may add up to significant cumulative yield trends over a period of time.

The purpose of this study is to show that statistical significance can indeed be attached to persistent low order 'non-significant' yield responses when available data is subjected to further statistical treatment. The linear component of treatment SS, additive property of X^2 and analysis of variance on total yield were evaluated in a selected multi-annual trial. The t-statistic was also evaluated on observed yields of treatment pairs and on estimated yield at different phosphorus levels in single season trials. Yield response data of maize to applied and residual phosphorus on soils with medium to high phosphorus reserves was used for the above statistical evaluations.

Materials and methods

Since 1971 the FSSA has conducted a large number of fertility trials throughout the maize-producing areas of the Transvaal and Orange Free State. Most of these trials were conducted in those parts of the Western Transvaal and North Western Orange Free State which have a mean annual rainfall of 525 to 600 mm. The fertility research consisted mainly of multi-annual phosphorus depletion trials and single season trials with different levels of N, P and K.

The phosphorus depletion trials were designed as randomised blocks with five levels of phosphorus at constant levels of nitrogen and potassium. The P levels were selected to create differential soil P levels in order to facilitate soil P/yield calibration work. Phosphorus, in the form of double

Paper presented at the Eighth Congress of the SA Society of Crop Production, 23—25 January 1979 superphosphate (19,6 per cent P), was broadcast and incorporated into the soil before commencement of the trials. In most of the trials conducted on soils with low P soil tests, very marked responses to applied and residual phosphorus were obtained (FSSA Research Reports, 1973 to 1979). However, on soils with higher P levels these responses were usually less pronounced and of a lower order. One of these trials, M51/WT/74–77, which was conducted in the Lichtenburg district on a Hutton form soil, was selected for the first part of this study. During the duration of the trial a significant F value for P treatments (P 0,01) was obtained in one season whereas non-significant F values were obtained in the remaining three seasons. The initial P status of this soil was 21 ppm P (Bray No 2 extract).

The single season NPK trials (San Cristobal design; Rojas, 1962) were conducted on different sites each season. A large number of these trials were conducted on soils with medium to high soil P levels. From these, 22 were selected on the following basis:

(a) Trials conducted in the North Western Orange Free State and Western Transvaal on soils with phosphorus status greater than 25 parts per million;

(b) trials with coefficients of variation less than 20 per cent;

(c) trials with the same levels of applied phosphorus (0 to 30 kg P/ha), bandplaced at planting.

Selection of data on this basis makes possible the comparison of phosphorus treatment effects on yield with respect to (i) a production area of similar mean annual rainfall, day lengths and summer temperatures, (ii) constant row widths (2,28 m) and (iii) fairly constant plant densities. These trials were also reported in FSSA Research Reports (1972 to 1979). Statistical treatment of the San Cristobal design consists of analysis of variance (Rojas, 1962), the estimation of N, P and K main effects from the yield equation and the testing of their significance (FSSA Research Reports, 1977 and 1979).

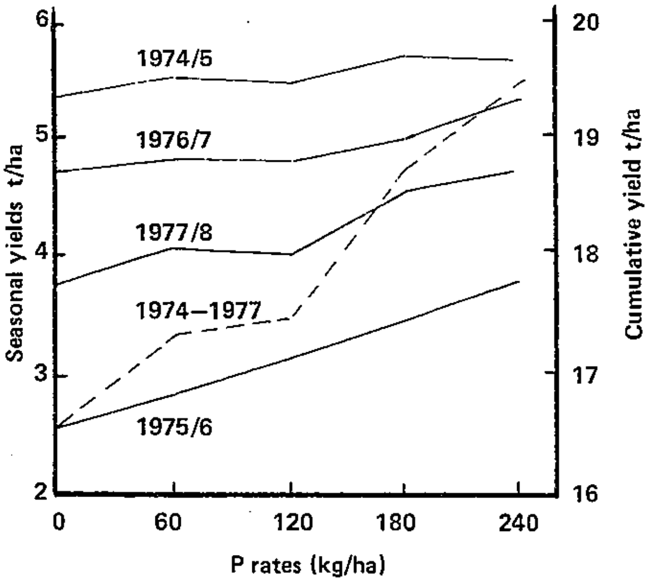

FIG 1 Seasonal and cumulative yield responses to phosphorus rates applied in 1974

Results and discussion

Multi-annual phosphorus depletion trial

Yield trends for each season are illustrated in Figure 1.

The linearity of yield response to applied and residual phosphorus in each season is clearly evident. The order of response (P4–P0) differs considerably between seasons and is inversely proportional to the yield levels attained. A possible explanation is that phosphorus uptake is inhibited to a greater degree under conditions of growth stress, resulting in better responses to applied and residual P.

The first step in the statistical evaluation of yield response is the F-test for treatments MS for each season (Table 1).

TABLE 1 Yield and statistical data of the multi-annual phosphorus depletion trial

Observation	1974/5	1975/6	Season 1976/7	1977/8	1974–1977
Mean yield, kg/ha	5 586	3 150	4 956	4 250	17 942
Maximum yield increase	358	1 265	622	848	3 007
F treatments MS	3,15	6,46 **	2,58	2,67	6,12 **
LSD (P 0,05)	248	594	428	851	1 491
P (F) treatments MS	0,945	>0,99	0,909	0,916	>0,99
F linear effect of P	9,15 *	25,75 **	7,91 *	9,48 **	23,38 **
χ^2	–	–	–	–	19,97 **
P (χ^2)	–	–	–	–	0,99

* *Significant at 95 per cent confidence level*
***Significant at 99 per cent confidence level*

A significant F-value was only obtained for the 1975/76 season. In the remaining seasons the yield responses were non-significant, but showed a consistent positive yield trend (Figure 1).

If the statistical analysis is not carried further it could be concluded that the value of phosphorus fertilization on this soil with a medium phosphorus content is of minor importance.

However, subdivision of the treatment SS resulted in significant F-values for the linear effect of phosphorus in each season (Table 1). Summation of the yields over the four year period resulted in a much steeper slope when compared with individual seasons, clearly illustrating the cumulative effect (Figure 1). The yield differences between PO and any of the P levels now acquire a new meaning in quantitative terms.

The significant contribution of each season's yield response to the total response is further verified by the estimation of cumulative significance using the additive property of X^2 (Fischer, as described by Rayner, 1969). The computed value of X^2 is highly significant (Table 1). An analysis of variance on four year total yields was also carried out. The F-test for both treatments MS and linear effect of P is highly significant (Table 1).

Total incremental yield of 3 tons per hectare for the four year period is of obvious economic and agronomic importance. Working on a similar model with respect to mean maximum yield and yield increases, Jurgens (1978) has shown that very substantial returns of approximately 40 per cent are accrued on capital invested in soil P reserves when soil P is increased from 20 to 25 ppm.

All evidence points to the fact that multi-annual fertilizer trials warrant greater sophistication in statistical treatment. Evaluation of yield responses in seasonal 'compartments' is likely to lead to an underestimation of cumulative residual effects of applied plant nutrients on yield.

Single season NPK trials (San Cristobal design)

Yield data with respect to the selected single season trials are presented in Figure 2 and Table 2.

Figure 2 illustrates the higher frequency of positive yield differences between treatment combinations with P (222, 220, 131) and corresponding treatments without or with

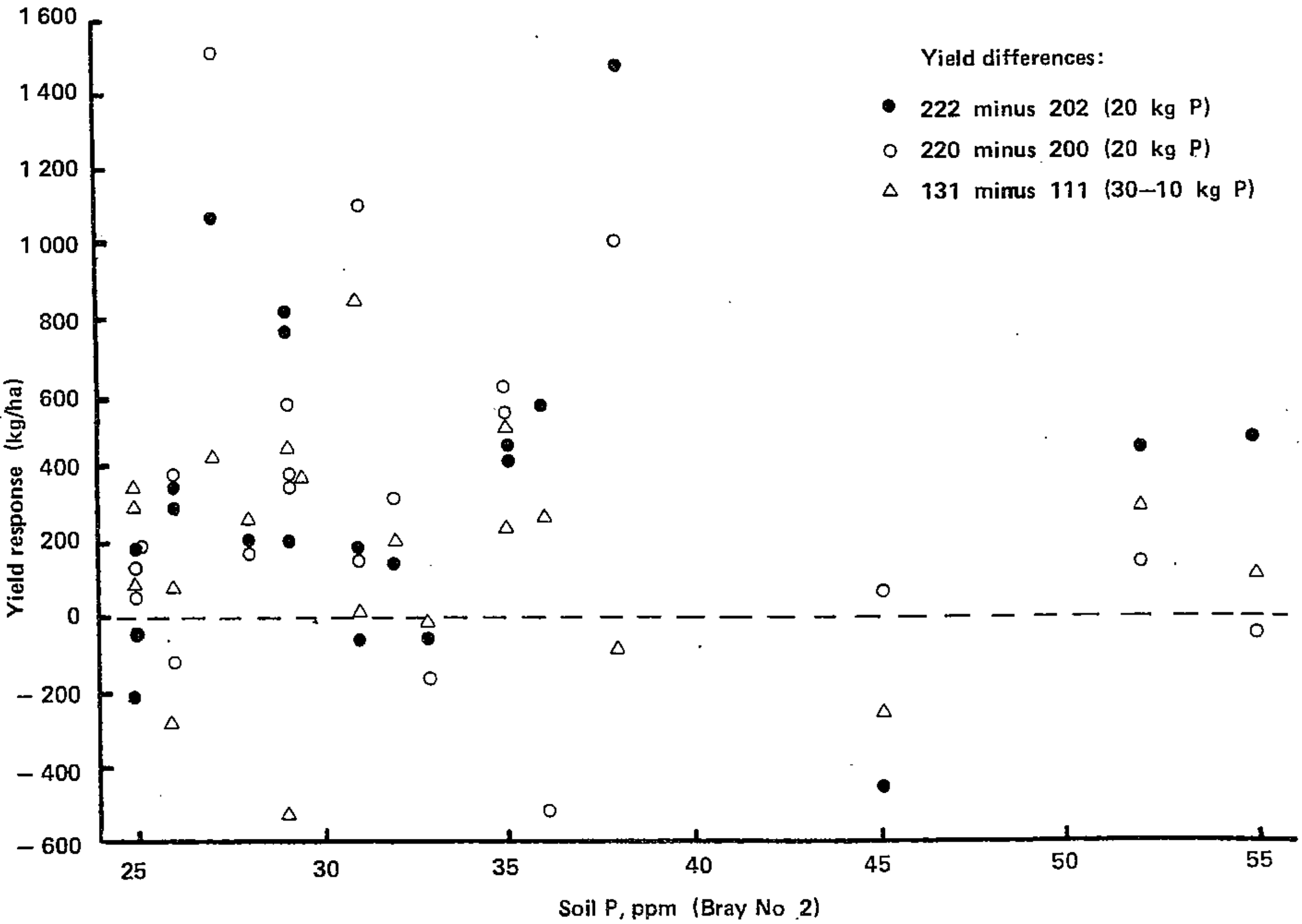

FIG 2 Scatter diagram showing the order and variation of observed maize yield responses to applied phosphorus in single season trials on soils with medium to high P levels

TABLE 2 Yield differences between estimated P mean yields in single season NPK trials (San Cristobal design)

Trial No / season	Soil P, ppm (Bray No 2)	Yield differences, kg/ha			Estimated significance of P main effect
		P1–PO	P2–PO	P3–PO	
M22/71	38	1 012	1 426	1 740	*
M24/71	31	– 81	– 48	– 32	NS/NB
M27/71	31	151	269	382	NS/NB
M33/71	33	– 51	– 38	– 16	NS/NB
M35/71	29	716	704	572	*
M42/71	45	– 355	– 499	–595	NS/NB
M40/72	26	254	268	243	*
M40/73	55	235	230	198	NS/NB
M46/73	29	74	9	193	NS/NB
M22/74	26	25	68	114	NS/NB
M25/74	32	129	119	85	NS/NB
M26/74	25	– 97	– 88	– 61	NS/NB
M27/74	27	764	974	1 092	*
M37/74	25	55	246	461	*
M40/74	52	265	373	454	*
M21/75	35	239	417	586	*
M37/75	35	283	450	598	*
M38/75	28	130	277	427	NS/NB
M10/76	29	273	392	357	NS/NB
M11/76	25	– 10	68	234	NS/NB
M18/76	36	91	68	– 70	NS/NB

**Significant at $P < 0,05$*

less P (202, 200, 111). The yield increases are very variable and, with relatively few exceptions, of a low order viz less than 600 kg/ha. Similar trends are observed for estimated mean yields at increasing phosphorus levels (Table 2). The estimated P main effects read significance in roughly one third of the trials.

As a relatively large pool of yield data was available (Figure 2 and Table 2), the null hypothesis that treatment pairs result in the same yield was tested by means of the t-test. A similar hypothesis was also tested with respect to estimated mean yields for P0 vs P1, P2 and P3 respectively. Results of the t-statistic evaluation are presented in Table 3. The philosophy of this approach is that different single season trials on medium to high P soils constitute replications of the same treatments (0, 10, 20 and 30 kg P/ha) in different seasons and on different sites.

The null hypothesis is rejected with respect to observed yields for all treatment pairs and estimated mean yields for P0 vs P1, P2 and P3 (Table 3 A and B). The mean yield differences between treatment pairs 222, 220 and 202, 200 become less as soil P increases, and the null hypothesis is not rejected in the soil P class of 41 to 55 ppm (Table 3 C). The null hypothesis is also rejected in both yield level classes (Table 3 D), with a slightly higher difference in the low yield level class. This seems to verify the observation in the multi-annual trail that yield responses to applied P are greater under stress conditions which is to a certain degree manifested in lower yield levels. The t-statistic apparently succeeds in establishing the statistical significance of consistent yield trends which may go undetected in the application of analysis of variance.

The variability of yield responses (Figure 2, Table 2) points to the fact that the predictive value of a yield response in the short term under a given set of conditions is poor. Consequently, mean differences between treatments (Table 3) should be seen in the right perspective, ie the level of phosphorus recommended to achieve a certain yield response has to be seen in the context of what a reasonable expected response might be over a number of seasons, rather than for a single season.

TABLE 3 *Evaluation of the t-statistic on yields of treatment pairs and estimated P mean yields*

A Comparison of treatment pairs

Treatment	222	202	220	200	131	111
Mean yield	4 170	3 830	4 050	3 732	3 779	3 615
Mean difference	340		317		164	
Degrees of freedom	20		20		20	
t	3,5**		3,1*		2,4*	

B Comparison of estimated P mean yields

Treatment	P1	P0	P2	P0	P3	P0
Mean yield	4 006	3 816	4 087	3 816	4 144	3 816
Mean difference	190		271		328	
Degrees of freedom	20		20		20	
t	2,8*		3,1**		3,2**	

C Comparison of 222/202 and 220/200 treatment pairs in three soil P classes

Soil P class	25–29 ppm		30–40 ppm		41–55 ppm	
Treatment	P2	P0	P2	P0	P2	P0
Mean yield	3 914	3 478	3 992	3 732	5 103	5 008
Mean difference	435		260		95	
Degrees of freedom	21		13		5	
t	4,2**		2,4*		0,7 NS	

D Comparison of 222/202 and 220/200 in two yield ranges

Yield ranges	<4 499 kg/ha		>4 500 kg/ha	
Treatment	P2	P0	P2	P0
Mean yield	3 323	2 966	4 975	4 678
Mean difference	357		297	
Degrees of freedom	19		21	
t	3,9**		2,8**	

* *Null hypothesis rejected at 95 per cent confidence level*
***Null hypothesis rejected at 99 per cent confidence level*

Opsomming

EVALUERING VAN LAE-ORDE OPBRENGSREAKSIES IN BEMESTINGSTUDIES OP MIELIES

Die seisoenale en kumulatiewe opbrengsreaksies van mielies op toegediende en residuele fosfor in 'n meerjarige fosforbemestingsproef op 'n grond met medium fosforgehalte is ge-evalueer. Met die uitsondering van een seisoen was die opbrengsreaksies van 'n betreklik lae orde en het nie betekenisvolheid bereik met die toepassing van die F-toets vir behandelings GK nie (Figuur 1, Tabel 1). Die data is vervolgens onderwerp aan verdere statistiese behandeling: onderverdeling van behandelings SK in 'n lineêre komponent, berekening van die gesomeerde waarde van X^2 *as 'n aanduiding van kumulatiewe betekenisvolheid en variansie-analise op totale opbrengste vir die vierjaar periode. Nie-betekenisvolle seisoenale opbrengsverhogings gebaseer op die F-toets vir behandelings GK, verkry 'n hoogs betekenisvolle waarde wanneer genoemde statistiese behandelings toegepas word (Tabel 1). Hoë orde kumulatiewe opbrengsverhogings van meer as 3 ton per hektaar (Figuur 1) word opgemaak uit lae orde seisoenale komponente. Dit is 'n aanduiding dat evaluering van meerjarige bemestingsproewe in streng seisoenale kompartemente aanleiding mag gee tot 'n onderskatting van kumulatiewe residuele effekte van toegediende plantvoedingstowwe op opbrengste.*

Opbrengsreaksies op toegediende fosfor (10 tot 30 kg P/ha) op gronde met medium- tot hoë fosforreserwes in eenjarige NPK-bemestingsproewe is meesal van 'n lae orde (<600 kg/ha). Hierdie opbrengsverhogings is baie variërend (Figuur 2) en inkonsekwent in terme van statistiese betekenisvolheid (Tabel 2). Oesopbrengste van geselekteerde behandelingskombinasies en van gemiddelde opbrengste vir die onderskeie fosforpeile is aan die t-toets onderwerp om die nulhipotese te toets. Verwerping van die nul-hipotese (Tabel 3) verleen statistiese betekenis aan die voorkoms van herhaalde lae-orde opbrengsverhogings.

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