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Yield response of process beans to fertiliser application

A report prepared for the
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New Zealand Vegetable and Potato Grower's Federation Inc.

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CONTENTS

Page

1 EXECUTIVE SUMMARY

Results from a trial conducted for Vegfed in 1995/96 suggested that traditional high fertiliser application rates to process bean crops could be unnecessary and/or economic, at least in higher soil fertility situations. A multi-site experiment was conducted in 1996/97 to measure the yield response of beans to fertiliser application across a range of soil fertility conditions. The objective was to develop guidelines and, ultimately, a forecasting system that would enable growers to use fertilisers more efficiently. The main result was a large difference in crop response to the method of fertiliser application: a visual assessment of the growers' crops surrounding the trial plots in which fertiliser was applied down-the-spout at planting indicated that this method was far superior to fertiliser broadcast and mixed with the surface soil at planting, as used in the trial plots. This suggested that the fertiliser broadcast by some growers before planting in addition to that applied down-the-spout is probably unnecessary. It also meant that the objectives of the 1996/97 project could not be achieved, and it was abandoned before harvest.

In this report we describe how the project was repeated successfully in 1997/98, with fertiliser treatments both broadcast and applied down-the-spout. Trials were conducted at five sites in commercial process bean crops in the Irwell-Southbridge area of central Canterbury. The sites were selected to obtain a diverse range of soil fertility levels. At each site the crop was managed in the same manner as the rest of the paddock except that the usual fertiliser application was not applied to the experimental area. Instead, three replicates of four fertiliser treatments were applied: none, part, and full rates down-the-spout at planting (about 100-150 and 250-300 kg/ha respectively); and 300 kg/ha broadcast and mixed with the surface soil at planting time. The fertiliser used at all sites was Cropmaster 15 (N:P:K = 15:10:10).

Soil pH, N, P and K were measured in all plots at planting time, before the fertiliser treatments were applied. Yield and yield components, and N, P and K uptake were measured in all plots at harvest maturity, and a nutrient balance was calculated for each treatment. As well as the usual analysis of differences among treatments at each site, an across-site analysis was done to develop a model of yield response to plant population, pH, and availability of N, P and K. Finally, we demonstrated how the model can be used to predict responses of yield and hence crop profitability to each nutrient applied as fertiliser in different soil fertility conditions.

The main results and conclusions were:

- fertiliser broadcast and incorporated at planting did not increase yield at any of the sites. This confirmed the result from the previous season. Consequently, we recommend that all fertiliser applied to increase the yield of process beans should be applied down-the-spout with the seed at planting time,

- fertiliser applied down-the-spout was much more effective, but the yield response differed among sites because soil fertility differed. The part rate increased yield significantly at two of the five sites, and the full rate increased it at four sites. The challenge at any site is to use soil test results at planting to determine the quantity, if any, and type of fertiliser to apply, and to forecast whether the crop produced will generate a profit,

- yield differences among sites were strongly influenced by plant population and soil pH. Optimum yield and profitability occurred at a population of about 320 000 plants/ha. Yield was reduced substantially if pH was less than about 5.6,

- it is unlikely that the yield increases were caused by the K and P in the fertiliser. High levels of both nutrients were available in the soil at all sites, and crop uptake of both was much less than the amounts available. For K, the amount applied in the fertiliser was very small compared with the amount available in the soil. We conclude that applications of K and P fertiliser to beans are unnecessary unless soil nutrient results are very low. However, any K and P applied will remain in the soil and may benefit subsequent crops in the rotation,

- the entire increase in bean yield was due to the N in the fertiliser, even though quite a small amount was applied. The amount of N available in the soil was low at all sites. However, the differences among sites were large enough to cause large variations in the yield response. Whether or not fertiliser N was applied, the crops relied substantially on N fixation for their requirements. Even with the full fertiliser rate, crops at some sites may not have grown to their full potential because of inadequate N availability. More N fertiliser may have produced further yield increases,

- forecasts with a model suggested that profitable yield increases may occur with applications of up to 180 kg N/ha. This was much higher than the applications in the trials, and the forecast of responses to the higher levels would need confirmation by more trials. However, it is likely that large applications of N down-the-spout are unrealistic because they would probably cause crop damage. It may be worthwhile to investigate the possibility of post-planting side-dressings of N, and

- Cropmaster 15, the fertiliser used in the trials, has a relatively low N content. The K and P in it are unnecessary. It could be more efficient to use alternative fertilisers, such as Cropmaster 20 or Calcium Ammonium Nitrate, to deliver N to beans provided these fertilisers do not damage the crop.

2 INTRODUCTION

Process bean crops are grown in intensive cropping systems, and high fertiliser rates are usually applied. Typical applications to crops grown in central Canterbury are 250-300 kg/ha of fertilisers such as Cropmaster 15 (N:P:K = 15:10:10) or Nitrophoska (N:P:K = 12:10:10). The yield response to about this level of fertiliser input was measured in a foliar fertiliser trial conducted for Vegfed in 1995/96 by Crop & Food Research, and was much smaller than expected (Wilson et al. 1996). This suggests that traditionally high fertiliser applications could be unnecessary and/or uneconomic, at least in higher soil fertility situations. The total value of fertiliser applied to the 600 ha of process beans grown in central Canterbury is about $65 000 annually. Growing costs could be reduced significantly and fertilisers used more efficiently if fertiliser requirements could be forecast more effectively. Therefore, Crop & Food Research was asked by Vegfed to further investigate the fertiliser requirements of process beans. The project had the following objectives:

- to determine the yield response of process beans to the availability of three major nutrients (N, P and K), from both soil reserve and fertiliser sources, in a range of soil fertility conditions, and

- to make a start on the longer term goal of developing a system for forecasting the fertiliser requirements of bean crops using soil fertility information.

It started in 1996/97 with a field experiment in which several fertiliser treatments were applied at planting time to crops at five sites with diverse soil fertility conditions (Wilson et al. 1997). Fertiliser was broadcast on the experimental plots and mixed with the surface soil by raking. At all sites the results were dominated by a major contrast in crop response between the experimental area and the surrounding grower's crop where most fertiliser was applied down-the-spout. In all cases the beans responded vigorously to the fertilisers applied down-the-spout but not to the broadcast fertilisers. This large difference in response to the method of fertiliser application was unexpected. There were very few visual differences in plant growth among the plots within the experimental area at any of the sites. This suggested that the fertiliser broadcast before planting as well as that applied down-the-spout is probably unnecessary. In consultation with Vegfed the project was abandoned before harvest because it was very unlikely that the original objectives could be achieved.

In this report we describe how the project was repeated in 1997/98 with fertiliser treatments both broadcast and applied down-the-spout. The multi-site approach was used again to avoid the problem of site-dependent results which occurs because every paddock has a different soil fertility level depending on its cropping and fertiliser application histories. Soil test and crop response measurements in a range of soil fertility conditions will make it possible to develop a model of yield response to N, P and K. Once developed and tested, such a model could be used with soil test results to forecast fertiliser requirements.

3 METHODS

The project was conducted at five sites in commercial process bean crops (cv. Labrador) in the Irwell-Southbridge area of central Canterbury during the 1997/98 season (Table 1). The sites were selected in November 1997 in consultation with representatives of Vegfed and Heinz-Wattie, using growers' soil test results and paddock history information, with the aim of obtaining a diverse range of fertility levels, particularly for N, P and K.

Table 1: Details of the five trial sites.

Grower	Location	Soil type	Planting date	Harvest date
Geoff Heslop	Irwell	Wakanui	2 Dec	18 Feb
Murray Stephens	Irwell	Templeton	5 Dec	18 Feb
Geoff McFadden	Southbridge	Waimakariri	12 Dec	25 Feb
Bill Abbott	Southbridge	Waimakariri	19 Dec	4 Mar
Liffey Partnership	Southbridge	Tai Tapu	23 Dec	9 Mar

At each site, the crop in the experimental area was managed by the grower in the same manner as the rest of the paddock except that the usual fertiliser was not applied. Sowing was done with precision planters that were either 11 or 12 rows wide, with 0.4 m row spacing. Plot size was 8 m long and one planter-width wide.

The experiment at each site consisted of three replicates of four fertiliser treatments in a randomised complete block design. The treatments are shown in Table 2. They were a control with no fertiliser, part and full fertiliser rates down-the-spout at planting, and 300 kg/ha of fertiliser broadcast and mixed with the surface soil by raking at planting time. The fertiliser was Cropmaster 15 (N:P:K = 15:10:10). The fertiliser applicator on the planter was turned off when it passed over the control and broadcast plots, and was adjusted to apply the down-the-spout treatments. The part and full rates differed among sites, ranging from 85 to 144 kg/ha and 250 to 315 kg/ha respectively (Table 2).

Immediately before planting, a soil sample consisting of 10 random 0-15 cm deep soil cores was taken from each plot at each site. Standard analytical procedures were used to measure exchangeable K and Olsen P in the Crop & Food Research soil science laboratories at Lincoln, and available N was measured by Analytical Research Laboratories Ltd, Hastings. In addition, a single measurement was made of total N, organic C and pH on a composite sample from each site.

Table 2: Application rates of Cropmaster 15 in the four treatments.

Grower	Control	Part rate (Down spout) (kg/ha)	Full rate (Down spout) (kg/ha)	Full rate (Broadcast) (kg/ha)
Heslop	0	85	315	300
Stephens	0	135	300	300
McFadden	0	107	300	300
Abbott	0	144	250	300
Liffey	0	126	253	300

Immediately before each crop was harvested by Heinz-Wattie (see Table 1 for harvest dates), a sample from each plot was harvested by hand. All plants in an 8 m^2 area (5 m length of four rows) were cut at ground level. The number of plants was counted and their total fresh weight was recorded. Then a random sample of 50 plants was removed. Their total fresh weights were measured, and all harvestable (> 6 cm long) pods were counted and weighed. Results were then used to calculate the number of plants and pods/unit area, number of pods/plant, fresh pod yield, pod fresh harvest index (pod yield as a proportion of total yield), and mean pod weight. Sub-samples of pods and stover were dried at 60°C and analysed to determine their N, P and K contents. These and the yield and soil test results were used to calculate N, P and K uptake and a nutrient balance for each treatment, and to calculate yield responses to fertiliser application and total nutrient availability.

Analysis of variance was used to determine statistically significant differences between treatments at each site. In the across-site analyses, results from every plot were used in a composite analysis to develop a model of yield response to plant population and to each of the three nutrients (N, P and K). Finally, examples were calculated to demonstrate how the model could be used to predict responses of yield and hence crop profitability to each nutrient applied as fertiliser in different soil fertility conditions.

4 RESULTS

4.1 Soil fertility

The five sites had diverse soil fertility conditions (Table 3). Soil organic matter levels, indicated by the total N and organic C values, varied considerable among the sites with ranges from 0.19 to 0.29% and 2.1 to 3.5% respectively. This variation was also reflected in the available N test results which ranged from about 50 to 100 kg/ha, although overall these values were regarded as low (<150 kg N/ha is low). The K and P test values both varied over wide ranges, but all were judged to be sufficiently high not to restrict crop growth.

Table 3: Mean values of the soil test results from the five sites.

Grower	Available N (kg N/ha)	Total N (%)	Exchangeable K (µg K/g)	Olsen P Quick Test (µg P/g)	Organic carbon (%)	pH
Heslop	104	0.27	300	16	3.0	6.0
Stephens	63	0.19	260	38	2.1	6.1
McFadden	51	0.20	280	50	2.9	5.6
Abbott	60	0.20	160	28	2.3	5.1
Liffey	73	0.29	180	18	3.5	5.4

4.2 Bean yield

Bean yields ranged from 12 to 24 t/ha (Table 4), considerably higher than the processed yields that are used as the basis for payment to growers. The difference occurred because there were no field losses in the hand harvest (all harvestable beans were recovered), and there were no deductions to account for losses during processing. The processed yield for each paddock, which corresponded to the full-rate down-the-spout treatment in the trial, was obtained from Heinz-Wattie. On average, processed yield was 57% of hand-harvested yield. This conversion factor was used to estimate the processed yields shown in brackets in Table 4. These adjusted yields were used in the yield response and profitability analyses presented later.

Yield responses to the fertiliser treatments differed among the sites because of the different soil fertility levels (Table 4). There was no significant yield response to the broadcast treatment compared with the control at any of the sites, confirming the result from the previous season. At the Heslop site, where the soil N and K levels were the highest of all the sites but the P level was the lowest, yield was high and there was no significant response to any of the fertiliser treatments. At the Stephens site, which had low soil N but high K and P levels, yield was high in the full rate down-the-spout treatment. There was a large reduction in yield compared with the control when the full rate was not applied down-the-spout or if the fertiliser was broadcast. A similar result occurred at the McFadden site which also had low soil N but high K and P levels. The overall yield level was low at the Abbott site. The reasons for this were not identified, but possibilities included uneven plant establishment and low soil pH (Table 3). At this site, N and K levels were low and P was high, and the yield in the full rate down-the-spout treatment was significantly higher than in the control. Finally, at the Liffey site, which had relatively low levels of N, P and K, there was a significant yield response to both down-the-spout treatments compared with the control.

Table 4: Effect of the fertiliser treatments on hand-harvested fresh bean yield (t/ha) at the five sites. Estimates of corresponding processed yields are in brackets.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	15.6 (8.9)	22.3 (12.7)	16.9 (9.6)	11.9 (6.8)	17.4 (9.9)
Part rate down spout	17.5 (10.0)	21.9 (12.5)	21.4 (12.2)	15.2 (8.7)	19.0 (10.8)
Full rate down spout	22.2 (12.7)	24.0 (13.7)	22.0 (12.5)	18.7 (10.7)	20.1 (11.5)
Full rate broadcast	15.4 (8.8)	22.4 (12.8)	18.6 (10.6)	14.8 (8.4)	17.7 (10.1)
F-prob[1]	0.018	0.176	0.091	0.048	0.001
CV (%)[2]	11.1	4.7	11.3	14.4	2.0
LSD ($p<0.05$)[3]	3.9	2.1	4.4	4.3	0.7

[1] F-prob is the probability that the effect of the treatments was not different. Conventionally, treatments are significantly different if F-prob is less than 0.05.

[2] CV is the coefficient of variation, a measure of the variability of the trial site. A high CV makes it more difficult to identify significant treatment effects.

[3] LSD is the least significant difference. Treatment values that are greater than the LSD apart are significantly different from each other (df=6).

4.3 Crop growth and harvest index

The full-rate down-the-spout treatment significantly increased stover yield over the control at the Stephens, McFadden and Liffey sites (Table 5). Total yield was increased at all sites (Table 6). However, the treatments had very little effect on fresh harvest index (pod yield as a proportion of total yield) at any of the sites (Table 7).

4.4 Components of bean yield

The plant population was not affected by the fertiliser treatments at any of the sites (Table 8). However, it varied among sites, ranging from just over 30 plants/m^2 at the McFadden and Abbott sites to almost 40/m^2 at the Stephens site. These population differences were taken into account in the across-site yield response and profitability analyses which are presented later.

Number of pods was the main component associated with the yield responses to the fertiliser treatments. The number of pods/plant, and, therefore, the number of pods/m^2, were both affected significantly by the treatments at all except the Heslop site where yield was not changed by the fertiliser treatments (Tables 9 and 10).

In contrast, mean pod weight was generally stable, with differences among treatments of little practical significance in most cases (Table 11). The main exception was at Stephens where pod weight in the full rate down-the-spout treatment was significantly greater than in the control.

Table 5: Effect of the fertiliser treatments on fresh stover yield (t/ha) at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	8.3	15.8	12.5	11.0	12.6
Part rate down spout	11.7	14.9	14.3	12.2	13.6
Full rate down spout	14.1	18.0	19.0	16.9	15.2
Full rate broadcast	8.4	16.4	13.8	11.8	12.1
F-prob	0.002	0.122	0.088	0.144	0.013
CV (%)	10.9	8.2	17.7	21.9	5.9
LSD ($p<0.05$)	2.3	2.7	5.3	5.7	1.6

Table 6: Effect of the fertiliser treatments on total fresh yield (t/ha) at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	23.9	38.1	29.4	22.9	30.0
Part rate down spout	29.2	36.8	35.7	27.4	32.6
Full rate down spout	36.3	42.0	41.0	35.6	35.3
Full rate broadcast	23.8	38.8	32.4	26.6	29.8
F-prob	0.006	0.090	0.054	0.072	0.001
CV (%)	10.4	5.3	11.7	16.6	3.1
LSD ($p<0.05$)	5.9	4.1	8.1	9.3	2.0

Table 7: Effect of the fertiliser treatments on fresh harvest index at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	0.65	0.58	0.58	0.52	0.58
Part rate down spout	0.60	0.60	0.60	0.55	0.58
Full rate down spout	0.61	0.57	0.54	0.53	0.57
Full rate broadcast	0.65	0.58	0.57	0.56	0.59
F-prob	0.037	0.435	0.455	0.565	0.367
CV (%)	2.9	3.0	8.0	6.9	2.5
LSD ($p<0.05$)	0.04	0.03	0.09	0.07	0.03

Table 8: Effect of the fertiliser treatments on number of plants/m^2 at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	40.1	34.3	29.9	31.5	33.4
Part rate down spout	39.9	34.5	32.2	30.0	35.8
Full rate down spout	38.8	35.4	30.0	31.2	33.2
Full rate broadcast	40.2	34.8	30.1	32.6	34.7
F-prob	0.891	0.848	0.630	0.122	0.067
CV (%)	6.3	4.7	7.9	3.5	3.1
LSD ($p<0.05$)	5.0	3.3	4.8	2.2	2.1

Table 9: Effect of the fertiliser treatments on number of pods/plant at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	7.5	11.1	10.0	6.5	10.7
Part rate down spout	8.7	10.9	11.8	9.8	10.8
Full rate down spout	9.6	11.5	14.6	11.5	12.4
Full rate broadcast	7.7	10.8	10.6	8.0	10.8
F-prob	0.056	0.689	0.004	0.008	0.054
CV (%)	9.7	6.6	7.9	12.7	6.1
LSD (p<0.05)	1.6	1.5	1.8	2.3	1.4

Table 10: Effect of the fertiliser treatments on number of pods/m^2 at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	299	382	297	205	356
Part rate down spout	347	377	379	293	387
Full rate down spout	371	406	435	360	412
Full rate broadcast	308	376	321	260	372
F-prob	0.061	0.732	0.002	0.02	0.033
CV (%)	8.5	9.5	7.3	14.9	4.5
LSD (p<0.05)	56	73	52	83	34

Table 11: Effect of the fertiliser treatments on mean harvestable pod weight (g/pod) at the five sites.

Treatment	Stephens	Heslop	McFadden	Abbott	Liffey
Control	6.0	6.3	6.0	6.0	5.4
Part rate down spout	5.7	6.6	5.9	5.9	5.6
Full rate down spout	6.7	6.6	5.9	5.8	5.7
Full rate broadcast	5.9	6.3	6.5	6.3	5.3
F-prob	0.044	0.146	0.139	0.095	0.001
CV (%)	5.4	3.1	4.6	3.1	1.2
LSD (p<0.05)	0.6	0.4	0.6	0.4	0.1

4.5 K uptake and balance

A high level of K was available in the soil at all sites, and the amount of K applied in the fertiliser was small in comparison (Table 12). Substantial quantities of K were taken up by the crops, but these amounts were much less than the amounts available in the soil. Even at the Abbott and Liffey sites, which had the lowest soil K values, there were large excess amounts of K in the soil. Therefore, although the fertiliser treatment increased yields and consequently increased K uptake by the crops, it is unlikely that the increases were attributable to the K in the fertiliser.

Table 12: Potassium (K) balance for the control and full-rate down-the-spout treatments at the five sites. Each balance accounts for available K from fertiliser and soil sources, the total amount of K taken up by the crop, the excess of available K over the amount taken up, and the amount of K removed in the harvested beans All quantities are in kg K/ha.

	Heslop	Stephens	McFadden	Abbott	Liffey
Control					
Fertiliser K	0	0	0	0	0
Soil K	580	500	530	300	350
K in crop	176	103	140	106	127
Excess K	404	397	390	194	223
K removed	83	58	60	37	60
Full rate					
Fertiliser K	32	30	30	25	25
Soil K	580	500	532	300	350
K in crop	200	153	247	153	140
Excess K	412	377	315	172	234
K removed	91	74	88	56	72

4.6 P uptake and balance

The amount of P taken up by the crops was much less than K uptake, and the amount available in the soil was much greater than the crop requirement at all sites (Table 13). Unlike K, the amount of P applied in the fertiliser was quite large in comparison with the amounts available in the soil. Nevertheless, it is unlikely that the yield increases were caused by the P in the fertiliser. This was supported by the Heslop site result where yield was highest and there was no yield response to fertiliser, even though this site had the lowest soil P level. The P balances show that similar amounts of P were removed in both control and fertilised plots. The P applied in fertiliser accumulated in the soil and will lead to increased Olsen P values.

Table 13: Phosphorus (P) balance for the control and full-rate down-the-spout treatments at the five sites. Each balance accounts for available P from fertiliser and soil sources, the total amount of P taken up by the crop, the excess of available P over the amount taken up, and the amount of P removed in the harvested beans All quantities are in kg P/ha.

	Heslop	Stephens	McFadden	Abbott	Liffey
Control					
Fertiliser P	0	0	0	0	0
Soil P	32	73	98	54	35
P in crop	15	9	12	8	10
Excess P	17	64	86	46	25
P removed	9	6	7	4	6
Full rate					
Fertiliser P	32	30	30	25	25
Soil P	32	73	98	54	35
P in crop	16	10	15	10	13
Excess P	48	93	113	69	47
P removed	9	7	8	5	8

4.7 N uptake and balance

Available soil N varied from about 50 to 100 kg/ha, with the highest values at the Heslop and Liffey sites where the yield responses were the smallest (Table 14). All of the soil N levels were substantially smaller than the amounts of N taken up by the crops, which ranged from about 100 to 190 kg/ha. The amounts of N applied in the fertiliser were quite small, so crop uptake of N was greater than the amount of N available from soil plus fertiliser sources at all sites. In all cases there was a deficit of N (a 'negative excess'), with deficits ranging from about 30 to 70 kg/ha. In general, the deficit was greater at sites with lower soil N levels. The extra N taken up came from symbiotic N fixation by the beans and release from the organic matter in the soil. It is interesting to note that applying N helped to reduce the N deficit at two of the sites, but at other sites the N deficit remained similar or increased. This is because bean plants take up N from various sources (soil, fertiliser and N fixation). Applying fertiliser increased plant growth and stimulated recovery from some or all of these sources.

We conclude that the entire yield response was attributable to the N in the fertiliser, even though the amounts applied were small. The amount of N available in the soil was low at all sites and, whether or not fertiliser N was applied, the crops relied substantially on N fixation to meet their requirements. Even at the full fertiliser rate, crops at some sites may have not produced to their full potential because of inadequate N availability, and more N fertiliser may have produced further yield increases.

Table 14: Nitrogen (N) balance for the control and full-rate down-the-spout treatments at the five sites. Each balance accounts for available N from fertiliser and soil sources, the total amount of N taken up by the crop, the excess of available N over the amount taken up, and the amount of N removed in the harvested beans All quantities are in kg N/ha.

	Heslop	Stephens	McFadden	Abbott	Liffey
Control					
Fertiliser N	0	0	0	0	0
Soil N	104	63	51	60	73
N in crop	167	97	120	106	119
Excess N	-63	-34	-69	-46	-46
N removed	80	53	57	37	53
Full rate					
Fertiliser N	47	45	45	38	38
Soil N	104	63	51	60	73
N in crop	189	139	170	160	138
Excess N	-38	-31	-74	-62	-27
N removed	91	72	74	62	67

4.8 Model analysis of yield responses to plant population, pH, N, P and K across sites

Yield results and soil N, P and K values from the control and down-the-spout treatments from all sites were pooled to calibrate a model of yield response to fertiliser application that was developed in the UK by Greenwood and colleagues (Greenwood et al. 1971; Greenwood 1981). The model has already been used in New Zealand in a maize project (Reid et al. 1997).

The calibration procedure starts by calculating a potential yield for each site assuming that there were no limitations due to nutrient or other agronomic stresses. Then the fraction of the potential yield that is lost in each treatment due to inadequate uptake of N, P or K is calculated. Greenwood found that the formulation of the model accounted for the apparent interactions between the effects of these nutrients on yield.

It assumes that yield responds to increasing availability of P on a 'diminishing returns' curve, whereas the response to N and K initially increases, then plateaus, and subsequently decreases as more and more N or K are made available. We found that it was necessary to make the following changes to the original model:

- an independent measure of available soil N, using anaerobic incubation at 40 °C (Keeney & Bremner 1967), was included,

- different efficiencies were allowed for in the response by crops to native soil and fertiliser N, P and K,

- the yields were adjusted to correct for the negative effects of soil pH below a threshold value, and

- the effects of plant population differences among the sites were accounted for using an equation derived from the work of Swan et al. (1987).

The model constructed from the results was used to calculate a yield for each treatment, and these yields were then related to the measured yields (Fig. 1). Two statistical values indicated that there was good agreement between the calculated and measured yields. The r^2 value for the linear regression in Figure 1 indicated that 62% of the variations in yield between and within sites was accounted for by variations in plant population, pH, N, P and K. There was a tendency for the model to underestimate the highest yields and overestimate the lowest ones, but this did not significantly affect the interpretation of the fertiliser or population responses. The second statistical value, the root mean square error of the calculated values, was 2.1 t/ha which was about 8-18% of the measured yields. This value is larger than desirable and indicates that factors other than plant population, pH, N, P and K substantially influenced the variations in yield between plots and sites.

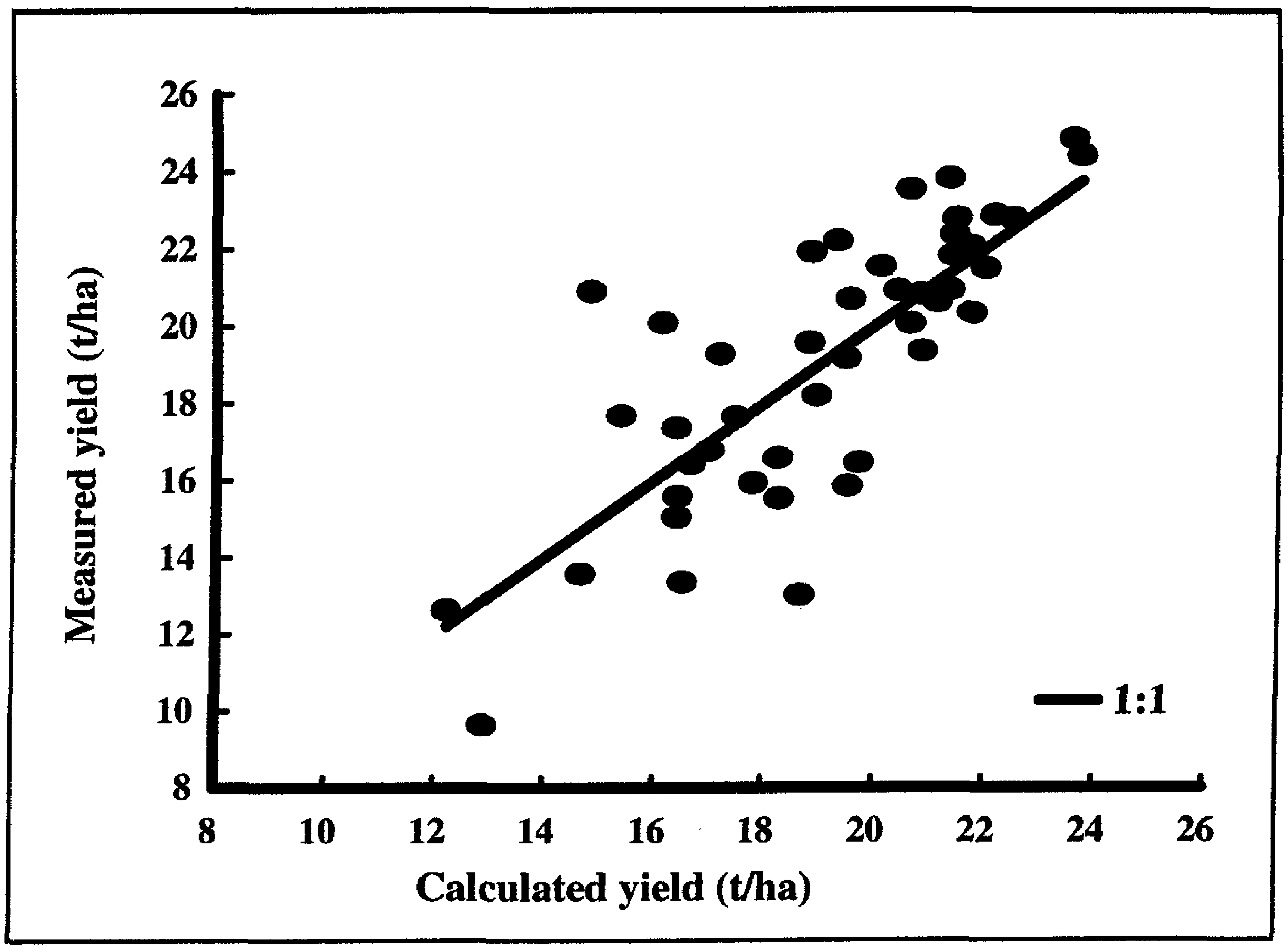

Figure 1: Relationship between yields measured in the trials (Y_m) and calculated with the model (Y_c). The regression equation is: $Y_m = -0.5 + (1.0*Y_c)$, (r^2=0.62).

Yield differences among the five sites were strongly influenced by plant population which varied from about 300 000 to 400 000/ha (at McFaddens and Stephens respectively, Table 8). Model calculations showed that the optimum yield occurred at about 320 000/ha (Fig. 2).

Yield was also influenced strongly by soil pH which ranged from 5.1 to 6.1 (Table 3). Yield was reduced substantially if pH was less than 5.6; about 36% of yield was lost for every 1.0 of pH below that critical value.

Model calculations confirmed the conclusions from the nutrient balance calculations (Sections 4.5 and 4.6 above) that the yield increases caused by the fertiliser applications were not responses to the K and P in the fertiliser. Yields calculated across a wide range of K and P applications showed virtually no response to either nutrient (Figs 3 and 4).

In contrast, the model calculations confirmed the conclusions from Section 4.7 that soil and fertiliser N were very important determinants of yield, and that the entire yield response was to the N in the fertiliser. There was a large yield response to N fertiliser application, especially when soil N levels were low (Fig. 5). Calculations were continued up to 200 kg N/ha, much higher than the applications in the trials, and yields continued to increase. Responses to the higher levels would need to be confirmed in more trials, but they are probably unrealistic because large quantities of N applied down-the-spout could damage the crop. However, post-planting side-dressings of N could be worthwhile.

The analyses with the model showed no evidence of any interactions between N, P and K, so the relationships in Figure 5 should accurately represent the responses to N-only fertilisers. In these trials, yield was determined largely by the N content of the fertiliser and, over the range of application rates used in the trials, there was no indication that yield was ever depressed by too much fertiliser.

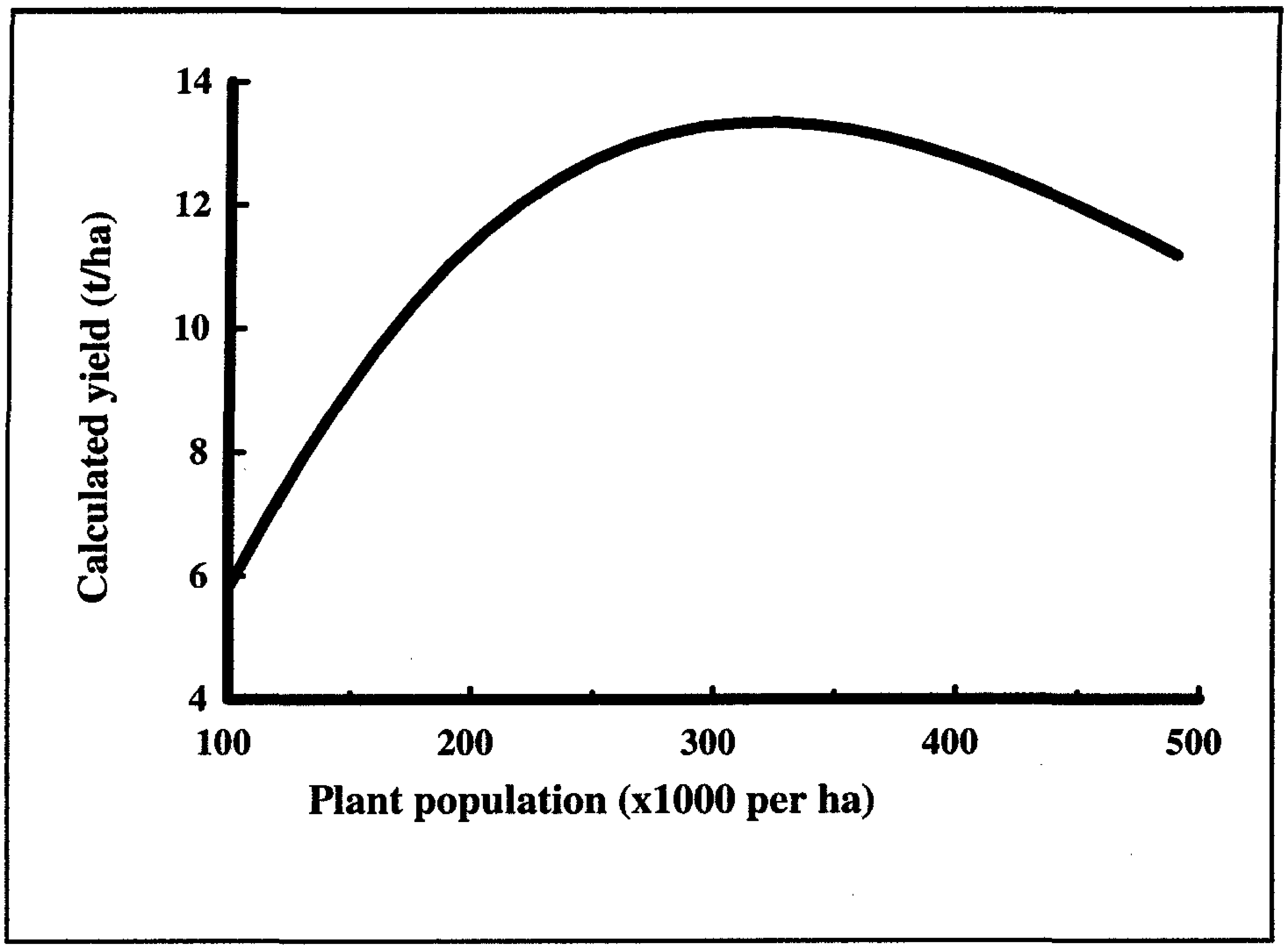

Figure 2: Model calculation of the relationship between yield and plant population with 50 kg N/ha applied. Soil N, P, K and pH were set at 70 kg N/ha, 30 µg P/g, 230 µg K/g and 5.7 respectively.

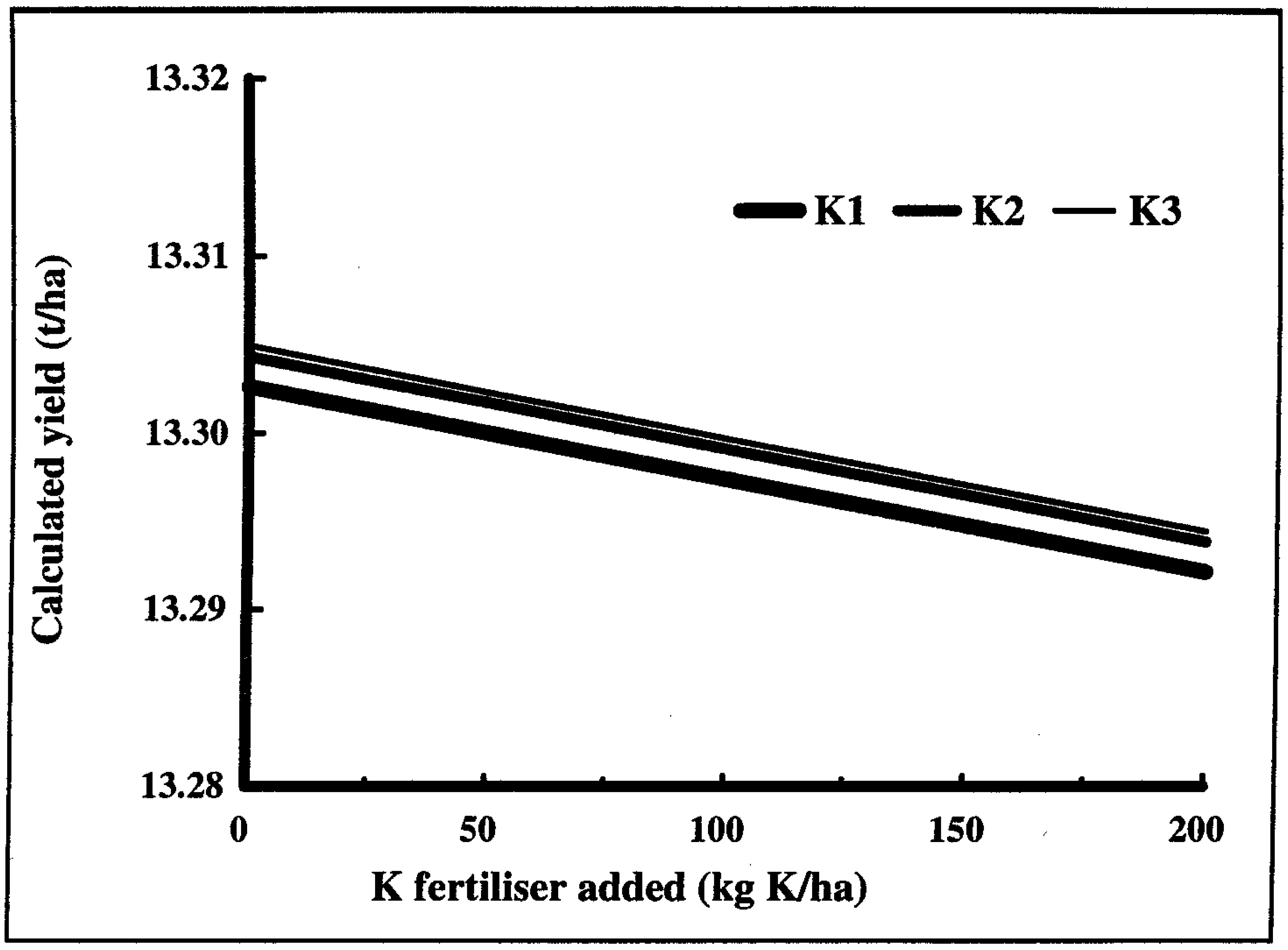

Figure 3: Model calculations of yield responses to K fertiliser application at three soil K levels (K1 = 114; K2 = 230; K3 = 360 µg K/g). Soil N, P and pH were set at 70 kg N/ha, 30 µg P/g and 5.7 respectively.

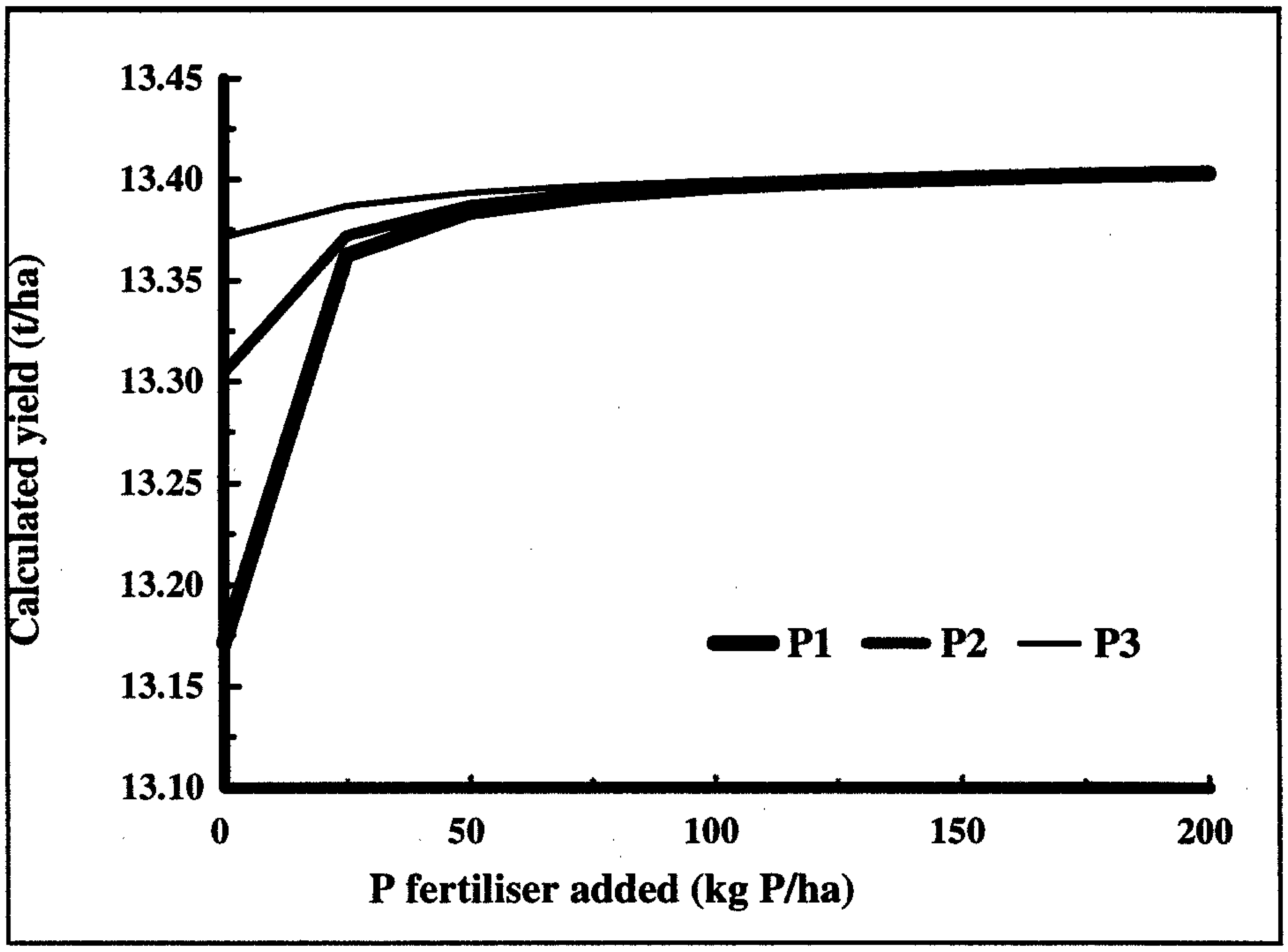

Figure 4: Model calculations of yield responses to P fertiliser application at three soil P levels (P1 = 13; P2 = 30; P3 = 84 µg P/g). Soil N, K and pH were set at 70 kg N/ha, 230 µg K/g and 5.7 respectively.

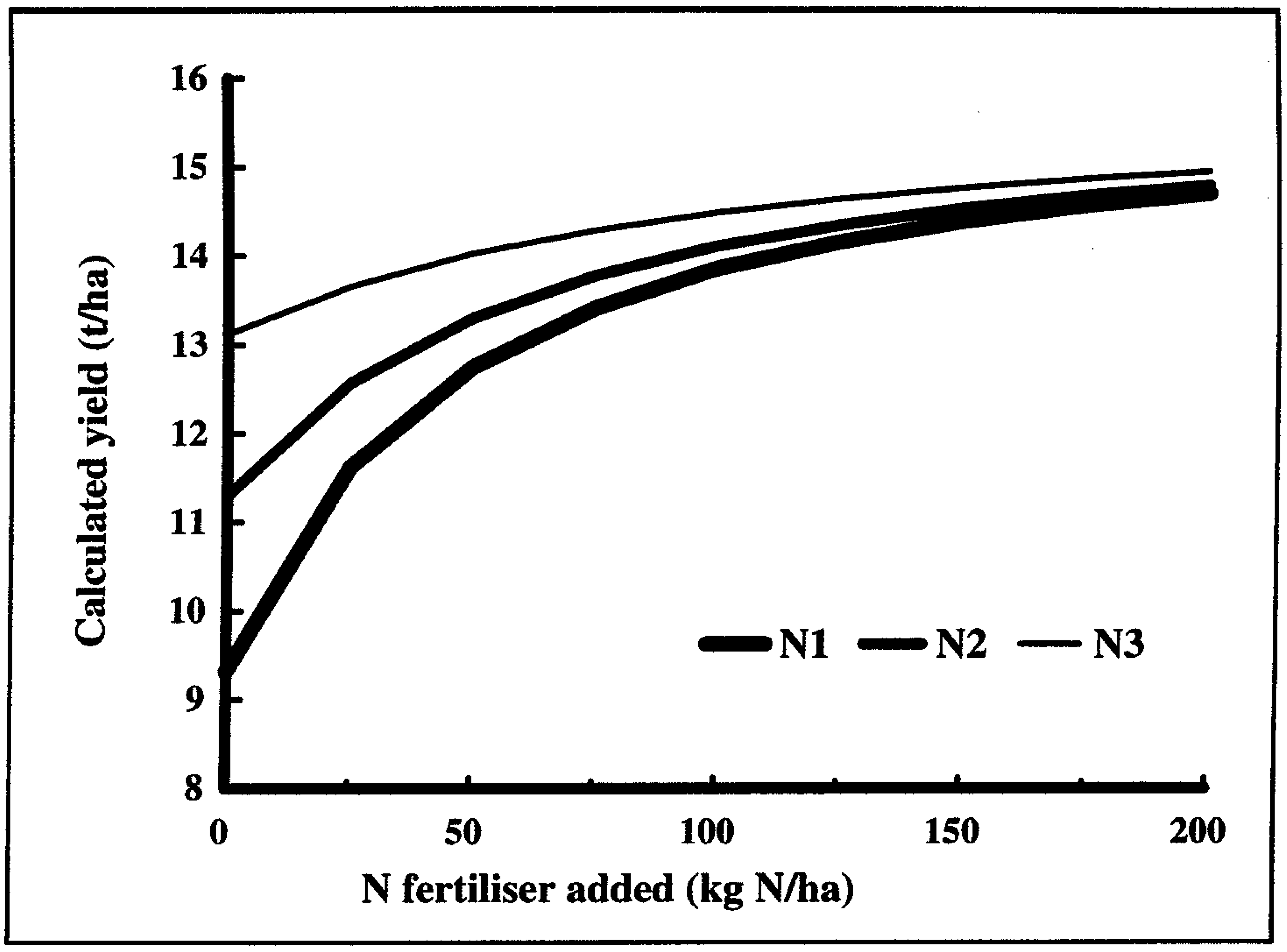

Figure 5: Model calculations of yield responses to N fertiliser application at three soil N levels (N1 = 40; N2 = 70; N3 = 134 kg N/ha). Soil K, P and pH were set at 30 µg P/g, 230 µg K/g and 5.7 respectively.

4.9 Model analysis of profitability of responses to plant population and N

The effect on profitability of varying plant population was calculated assuming that:

- yield responds to population as shown in Figure 2,
- bean seed costs $6-15/kg,
- there are about 3800 seeds/kg, and
- the average pay out to growers for processed beans is $298/tonne.

The result was similar to the yield response in Figure 2, with optimum profitability at about 320 000 plants/ha (Fig. 6). Additional seed costs with no further yield gain reduced profitability at higher populations while, at lower populations, profitability was limited by low yield.

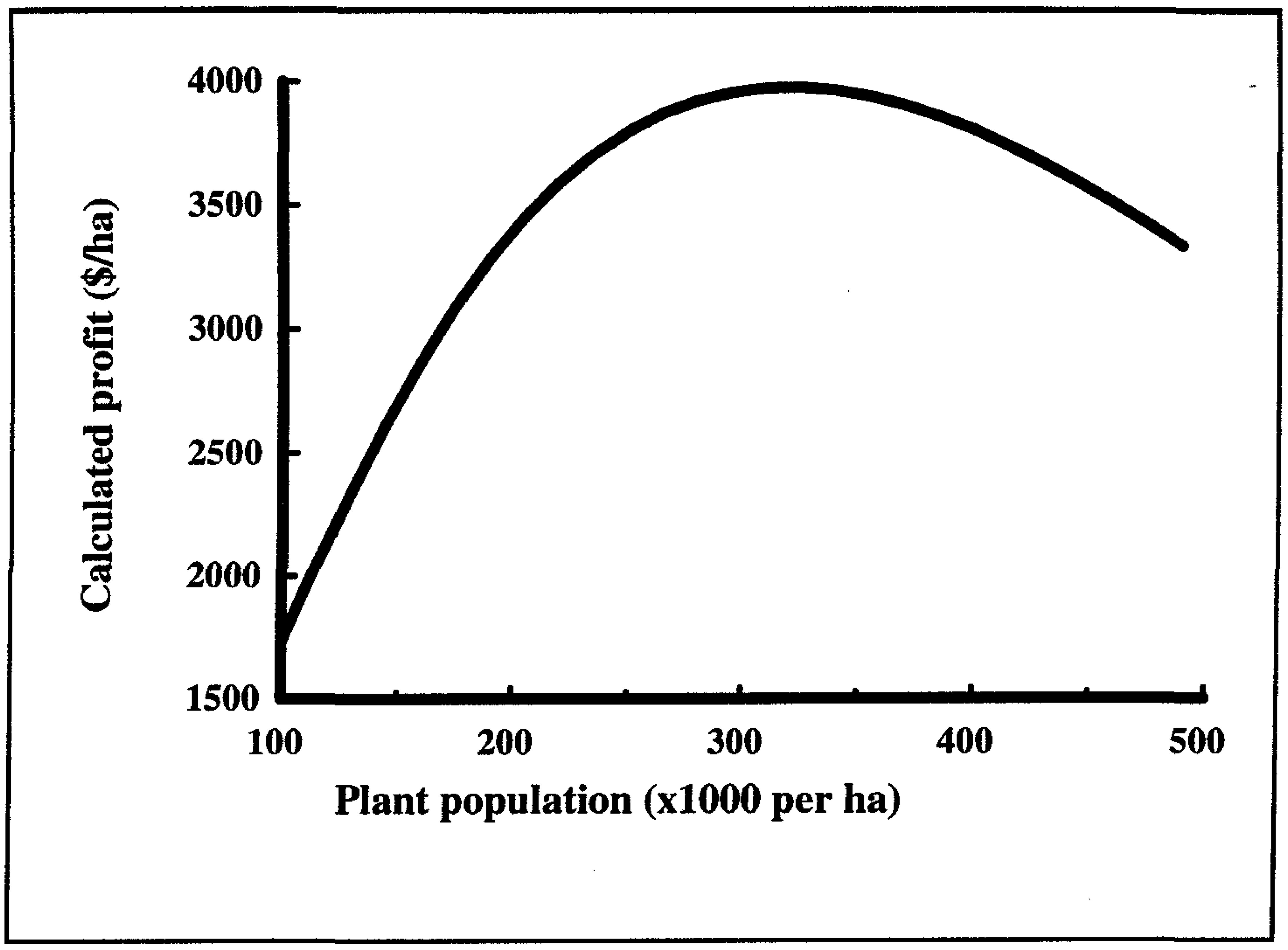

Figure 6: Model calculation of the effect of plant population on profitability with 50 kg N/ha applied. Soil N, P, K and pH were set at 70 kg N/ha, 30 µg P/g, 230 µg K/g and 5.7 respectively.

The effect on profitability of applying N in the form of Cropmaster 15 (N:P:K = 15:10:10) was calculated assuming that:

- yield responds to N fertiliser as shown in Figure 4,
- Cropmaster 15 costs $450/tonne, and
- the average pay out to growers for processed beans is $298/tonne.

At all levels of soil N, profitability continued to increase in response to applications of up to 1200 kg/ha, or 180 kg N/ha (Fig. 7). As discussed earlier, the effects of higher levels of application need to be tested in more trials. However, they are probably unrealistic because large quantities of fertiliser applied down-the-spout could damage the crop. Also, Cropmaster 15 has a relatively low N content and the K and P in it are unnecessary. It could be more efficient to use alternative fertilisers, such as Cropmaster 20 or Calcium Ammonium Nitrate, to deliver N to beans provided they do not damage the crop.

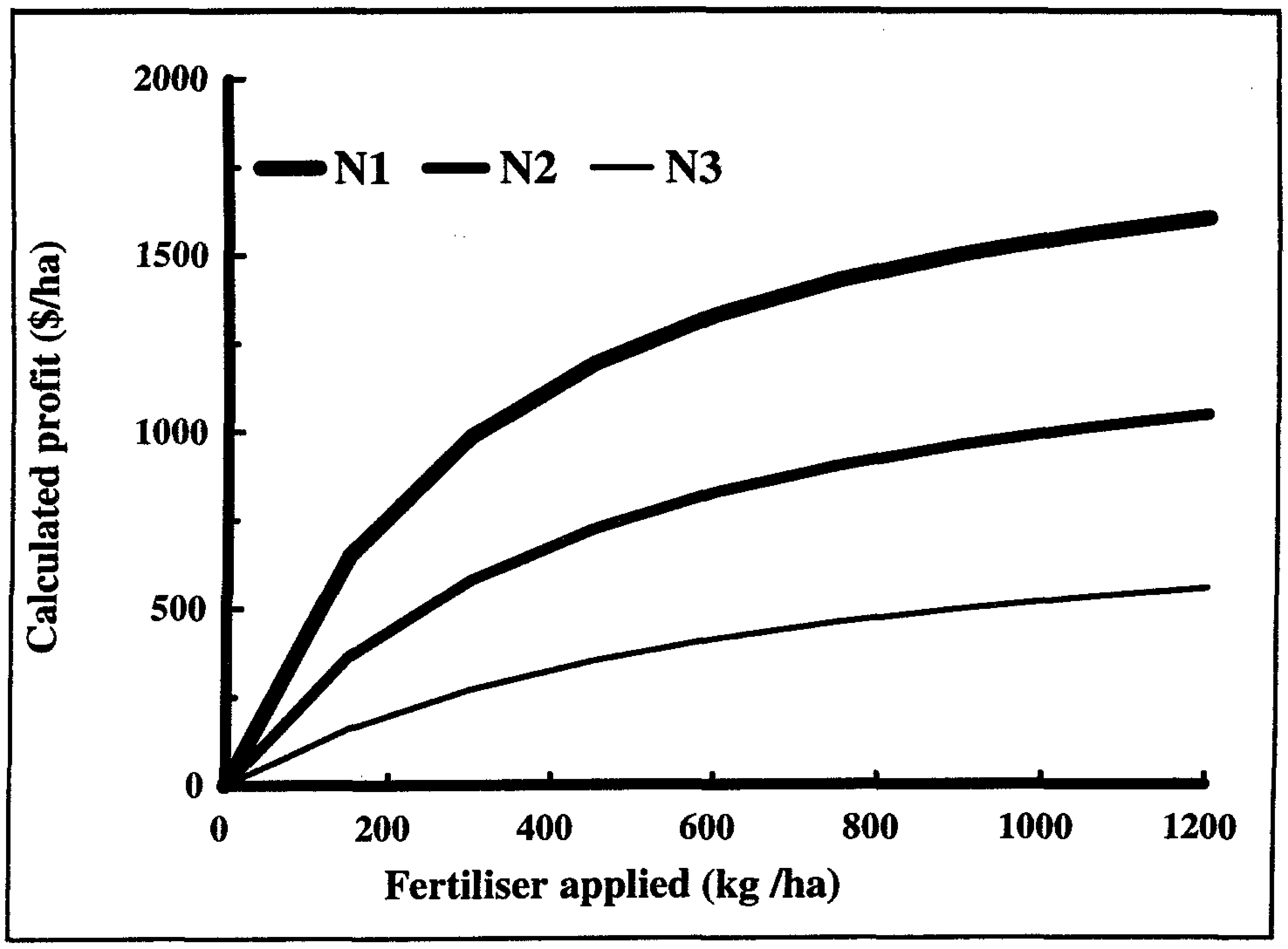

Figure 7: Model calculations of the effects on profitability of N applied as Cropmaster 15 (N:P:K = 15:10:10) fertiliser at three soil N levels (N1 = 40; N2 = 70; N3 = 134 kg N/ha). Soil K, P and pH were set at 30 µg P/g, 230 µg K/g and 5.7 respectively.

5 CONCLUSIONS

- Fertiliser broadcast and incorporated at planting did not increase yield at any of the sites. This confirmed the result from the previous season. Consequently, we recommend that all fertiliser applied to increase the yield of process beans should be applied down-the-spout with the seed at planting time.

- Fertiliser applied down-the-spout was much more effective, but the yield response differed among sites because the soil fertility status of sites varied. The part rate increased yield significantly at two of the five sites, and the full rate increased it at four sites. The challenge at any site is to use soil nutrient test results at planting time to determine the quality, if any, and type of fertiliser to apply, and to forecast whether the crop produced will generate a profit.

- Yield differences among sites were strongly influenced by plant population and soil pH. Optimum yield and profitability occurred at a population of about 320 000 plants/ha. Yield was reduced substantially if pH was less than about 5.6.

- It is unlikely that the yield increases were caused by the K and P in the fertiliser. High levels of both nutrients were available in the soil at all sites, and crop uptake of both was much less than the amounts available. For K, the amount applied in the fertiliser was very small compared with the amount available in the soil. We conclude that applications of K and P fertiliser to beans are unnecessary unless soil nutrient test results are very low. However, any K and P applied will remain in the soil and may benefit subsequent crops in the rotation.

- The entire bean yield response was to the N in the fertiliser, even though quite a small amount was applied. The amount of N available in the soil was low at all sites. However, the differences were large enough to cause large variations in the yield response. Whether or not fertiliser N was applied, the crops relied substantially on N fixation for their requirements. Even at the full fertiliser rate, crops at some sites may not have grown to their full potential because of inadequate N availability. More N fertiliser may have produced further yield increases.

- Model calculations suggested that profitable yield increases may occur with applications of up to 180 kg N/ha. This was much higher than the applications in the trials, and the forecast of responses to the higher levels would need to be confirmed in more trials. However, it is likely that large applications of N down-the-spout are unrealistic because they would probably damage the crop. It may be worthwhile investigating the possibility of post-planting side-dressings of N, and

- Cropmaster 15, the fertiliser used in the trials, has a relatively low N content and the K and P in it are unnecessary. It could be more efficient to use alternative fertilisers, such as Cropmaster 20 or Calcium Ammonium Nitrate, to deliver N to beans provided they do not damage the crop.

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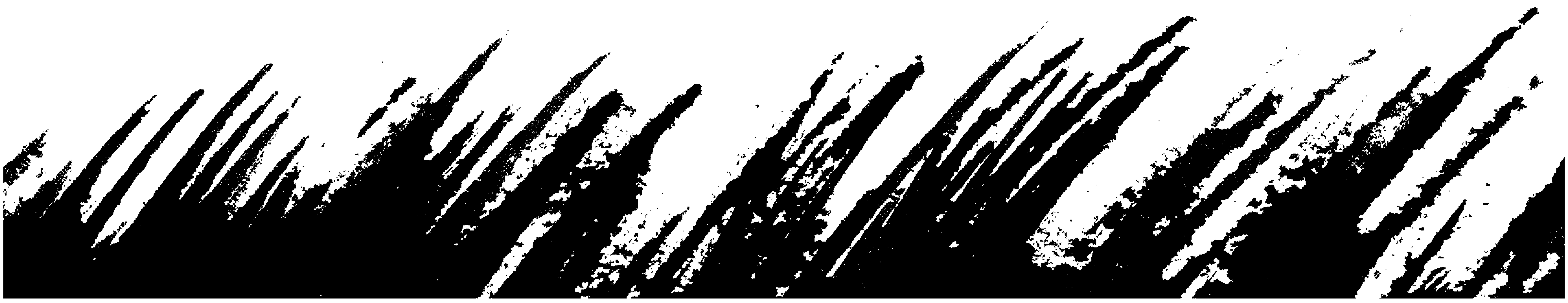

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