# MAF vegetable fertiliser trials

## —a reappraisal using a new model

A report prepared for the

**Fertiliser Manufacturers Research Association and the New Zealand Federation of Vegetable and Potato Growers**

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# CONTENTS

# 1 EXECUTIVE SUMMARY

The project aim is to work toward developing sustainable nutrient management practices by re-analysing and reinterpreting some of the past research findings on N, P and K fertiliser use on New Zealand-grown vegetables. These findings consisted of unpublished results and statistical analyses of dozens of vegetable crop fertiliser response trials carried out by MAF from about 1960 to 1984. Specifically we sought to:

1. identify the usable results from the large amount of unpublished reports,

2. analyse the most suitable data sets obtained in our prior screening efforts using a new N P K yield response model developed by Crop & Food Research. The analysis will include the marginal return on fertiliser costs at different rates,

3. summarise the findings of the modelling and economic analysis and interpret the value of these findings as an information base. This will include identification of those crop/fertiliser combinations where knowledge is definitive enough to support recommendations for responsible fertiliser use.

Our main requirements for re-analysis of the data using the fertiliser response model were that we had access to the original records of applied fertiliser treatments, pre-treatment soil test results, and yield measurements. The trials could not include other treatments which could obscure the main effects. The data from 12 trials met all these criteria: five for cabbage; two each for onions, squash, and spinach; and one for cauliflower.

Using the results from each of the five crops we compared the conclusions possible from the original trial analyses with those possible from the model analysis. Rather than testing for differences between particular rates of fertilisers, the model provides continuous response curves to nutrient supply (a weighted combination of fertiliser and native soil concentration for each nutrient). This greater detail in the information generated by the model creates an improved information base for future hypothesis testing and field validation.

The cabbage analysis demonstrated the benefit of analysing data combined from a number of trials which, even though they were in sites close to each other, differed in growing environment and some soil factors. Conclusions from the model graphs for winter cabbage are a robust guide to fertiliser use in the Pukekohe district and should now be validated in field trials in other areas.

Based on the cabbage model prediction curves for Pukekohe soils at a range of Olsen P values and exchangeable K values we can make the following recommendations. When Olsen P is less than 20 µg/ml it will pay to apply 75 to 100 kg P/ha. When exchangeable K is < 0.3 meq/100 g it will pay to use up to 300 kg K/ha, but when soil K is 0.6 meq/100 g or higher K fertiliser is uneconomic.

Since only one or two data sets were used for each of the other four crops there is a greater need to further test the models of N, P, and K responses using additional trial data and for growers to validate the model outputs. These trial data could be from overseas research results, which could be very efficiently interpreted and applied to New Zealand now that the Crop & Food Research model has been found to work well with pre-existing data sets. Salvaging and re-analysing this unpublished historical data has improved the information base for sustainable nutrient management practices as hoped, but it is clear that additional work needs to be done prior to making general fertiliser use recommendations for these vegetable crops.

# 2 INTRODUCTION

The development of sustainable soil management practices is a high priority for the vegetable industry. Sustainable soil management systems are economically viable, preserve the soil resource for future production, have minimal impact on the environment and meet the required product quality standards.

Recently, several grower groups (e.g. North Otago Volcanic Soils Environmental Group, and the Franklin Sustainability Group) have formed with the aim of developing sustainable management practices. One of the key issues facing the growers is efficient management of nutrients, particularly N, P and K. Current practices are based on industry journal articles, growers' experience, and the opinions of neighbours and consultants.

Often the method and rate of fertiliser application results in the accumulation of nutrients, increasing the possibility that these may leak into waterways and the atmosphere. In many areas of New Zealand where vegetables are intensively grown, the nitrate concentration in the groundwater exceeds the recommended levels, causing considerable environmental concern.

The inefficient use of applied nutrients is also undesirable from an economic viewpoint. Furthermore, excessive nutrients in the soil can accumulate in plant tissue and affect crop quality and storage. While growers are aware of the consequences of using excessive rates of fertiliser, they are often reluctant to lower the rates, lest crop yields are compromised. Moreover, there are few data available to show growers the optimal fertiliser rates and methods of application for vegetable production.

The aim of this project is to work toward developing sustainable nutrient management practices by making accessible to fertiliser users our interpretation of past research on N, P and K fertiliser use on many New Zealand-grown vegetables. Our approach was to review published New Zealand findings and a large number of unpublished trial results. The principal crops to be covered will be those for which the current review delivers the most complete information.

## 2.1 Objectives and strategy

1. Identify the usable results from the large amount of unpublished reports.

2. Analyse the most suitable data sets obtained in our prior screening efforts using PARJIB, a new N P K yield response model developed by Crop & Food Research. The analysis will include an economic analysis, i.e. the marginal return on fertiliser costs at different rates.

3. Prepare a report for the Fertiliser Manufacturers Research Association and New Zealand Federation of Vegetable and Potato Growers which summarises the findings of the modelling and economic analysis and interprets the value of these findings as an information base. This will include identification of those crop/fertiliser combinations where knowledge is definitive enough to support recommendations for responsible fertiliser use.

4. Prepare and submit an article to the NZ Commercial Grower reviewing the findings, as described in objective 3, by 31 March 1999.

# 3 REVIEW OF RELEVANT LITERATURE

A thorough search was made of the literature on responses to N, P, and K fertilisers by vegetable crops in New Zealand. It was confirmed that the information base is neither large nor accessible to growers and consultants. Hundreds of English language records in Current Contents and the CAB Abstracts from 1984 to 1996 on 16 vegetable types were examined. The totals of New Zealand records, by crop type, were: beans two, beet one, capsicum one, onions two, peas one, spinach two, and squash six. These publications are listed in Appendix I.

These papers were found in the New Zealand Journal of Experimental Agricultural and the New Zealand Journal of Agricultural Research or in overseas journals such as Fertilizer Research or Scientia Horticulturae. Some were popular articles in the Commercial Grower. Nearly all were from scientists in MAF or at Lincoln University. The subjects ranged from specific soil problems to fairly comprehensive series of papers on a single crop species.

Clearly, the considerable amount of New Zealand research known to be done between 1950 and 1980 is unpublished or at least not indexed. The most comprehensive bulletin is the MAF *Fertiliser Recommendations for Horticultural Crops, 1986.* It was compiled by MAF staff, with the help of a large Advisory Committee. Vegetable crops occupy 14 of the 70 pages. The references listed for further information included two New Zealand and two overseas books. This bulletin is a good source of information on nutritional deficiency symptoms for several crops and specifies the use of fertilisers on many New Zealand soils (fertility changes from the application of a given amount of P or K). Likely nutrient uptake by crops is also tabulated.

Another MAF publication which has information on squash, pumpkin and sweet corn is titled *Comparison of Effects of Three Different Organic Fertilisers on Vegetable Crops and Soil Properties*, F. Kell et al., 1992. This includes soil quality measures which are relevant to current work on sustainability.

A 1991 report to the New Zealand Federation of Vegetable and Potato Growers focused on a single crop, broccoli, combining a summary of six of the unpublished MAF trials at Levin with an overseas literature search. It is titled *Report on Nutrition of Autumn and Winter Broccoli.*

If there are gaps in this list of New Zealand publications, it is timely to be raising this issue among vegetable researchers, consultants, and processor field reps, since most of the scientists directly involved in the fertiliser work have, or soon will have, retired.

## 3.1 Conclusions from literature review

Our assessment of the value of this New Zealand information base, in the light of the current realities of vegetable production for New Zealand and world markets, leads to three conclusions:

1. it is inadequate as a guide to meeting expected standards for protection of water resources from fertiliser runoff and leaching,

2. it is focused on yield response, but gives no guidance on the economics of fertiliser use, such as indicating the marginal rates of return on fertiliser purchases, and

3. it is an inadequate foundation for efficiently applying the abundant overseas findings to New Zealand vegetable growing or research activities.

One of the difficulties of comparing overseas and New Zealand trials is that overseas fertiliser rates are linked to different soil test methods for N and K. A New Zealand research effort on each crop would eventually sort this out. However, it is much more efficient to improve the New Zealand information base with a systematic treatment, such as a re-analysis of historical MAF trial data using a new Crop & Food Research fertiliser model designed to integrate data from different test sites. The model, which has been successfully tested with recent vegetable trials, also addresses the economic issue in the second conclusion above. It should help determine which overseas literature is most relevant, both for direct use in vegetable production and as the basis for hypotheses for researchers to test in New Zealand. Analysis using the model will link the issue of wasted fertiliser expense with environmental issues, helping to alter such vegetable grower attitudes as 'if in doubt, apply extra fertiliser'.

# 4 APPROACH

## 4.1 Identifying suitable data

Dr John Minard and Mr Ross Marshall of MAF Levin carried out a series of fertiliser trials on vegetables from c.1960 to 1984. Additional trials were carried out by Graham Wilson and John Scheffer of MAF at Pukekohe Research Station in the 1970s. Unfortunately neither set of findings was published. Files containing the original data were located at the Levin Research Station, but now the entire collection has been transferred to Crop & Food Research at Lawn Road.

The trials that were run by MAF were grouped into series. Each series had the same treatments applied. Each series is identified by a number, proceeded by 'LN' to indicate they are Levin trials or 'LP' to indicate Pukekohe trials.

Each series of fertiliser trials at the Levin Research Station were run concurrently on separate areas, and concentrated on a different selection of nutrients. For example, the LN63 series had four rates of N by four rates of P by four rates of K. Permanent trial plots were set up for each series of trials, with the same treatments being applied to each plot throughout the series. A summary of the identified trial series is given in Appendix II.

A series of vegetable crops was grown sequentially at the permanent trial sites. For example, in the LN63 series, the first crop was cauliflower (file LN63/01), the second crop was broad beans (file LN63/02), the third crop was cucumber (LN63/03), etc. There were up to 16 crops or files in each series, spanning a period up to 10 years.

The data in the files are, in most cases, complete for the intended measures. Original data sheets for yield measurements, soil test results and plant analyses are available. Statistical analysis of trial results were done by the Biometrics Division of MAF in Wellington, and copies of these outputs are also included in each file. A short final report summarising the trial results completes each file.

Our requirements for the fertiliser response model include original records of applied fertiliser treatments, pre-treatment soil tests results, and yield measurements. While some of the files were missing data these were often found in the previous file due to the trials being run sequentially. For example, pre-treatment soil test results could often be obtained from the previous file as post harvest soil test results. Many of the trials had residual fertiliser (i.e. applications from a previous trial) as treatments; these treatments were discounted for the model analysis because the effect of the residual fertiliser is reflected in the soil test results.

Despite the completeness of files, some important factors are not included. The most important variable we do not have values for is soil N levels. Soil N was not a common soil test when the trials were conducted, but likely values can be estimated during calibration of the model. While we can obtain historical climatic data from the NIWA database, there are no records of trial irrigation, and soil moisture deficit can be a major factor in the model under dry conditions. Trials where water stress was noted in reports were, therefore, excluded.

## 4.2 Trials identified as most promising for re-analysis

This report will compare the results and interpretation of the original fertiliser trials with the output and interpretation made possible by fitting the PARJIB model to the same data. For this project we identified six series of fertiliser trials (with one to five trials per series) with data sets that appeared promising for use. The initial number of trials that appeared to be suitable was 13. However, once the original reports of data analyses were studied the 1970 cauliflower trial had to be dropped. The poor yield and fertiliser response was probably due to water stress, since soft rot was present and irrigation was withheld to avoid making it worse. The 12 remaining trials are identified by their original File Number and year of planting in Table 1.

**Table 1: Data sets processed by the fertiliser response model.**

| Crop | File number | Year of planting | Fertiliser treatment |
|---|---|---|---|
| Cabbage | LP 01/01 | 1970 | N x P |
| Cabbage | LP 01/02 | 1970 | N x P |
| Cabbage | LP 01/03 | 1970 | N x P |
| Cabbage | LP 01/04 | 1970 | N x P |
| Cabbage | LP 01/05 | 1970 | N x P |
| Cauliflower | LN 63/01 | 1969 | N x P x K |
| Onion | LN 105/02 | 1966 | N x P x K |
| Onion | LN 105/3 | 1967 | N x P x K |
| Spinach | LN 65/04 | 1969 | N x P x K |
| Spinach | LN 65/05 | 1970 | N x P x K |
| Squash | LN 63/07 | 1973 | N x P x K |
| Squash | LN 92/15 | 1976 | N x K |

## 4.3 Fertiliser response model

### 4.3.1 *Background*

PARJIB is a new model. It has been developed by Dr Jeff Reid of Crop & Food Research with funding from the Public Good Science Fund and vegetable industry clients. This model forecasts fertiliser yield response from a snapshot of soil factors at planting. The starting premise is that potential yield is driven primarily by the weather and plant population and reduced by inadequate water supply, soil nutrients (N, P, K, and Mg), and soil pH. Without going into the mathematical details, the model calculates a nutrient supply index, which shows the proportion of the optimum amount of each nutrient that is being supplied. It is important to note that the model equates soil and fertiliser nutrients and analyses the yield response to a weighted total supply. The soil test values are from the 0-15 cm profile, which is reflected in the weighting used between soil and fertiliser. If soil nutrients are measured in deeper profiles the fertiliser v. soil weighting would be changed.

The means by which the model calculates the yield response to nutrients allows it to handle a wide range of real-world situations. Where only one nutrient is limiting yield, yield response increases with nutrient supply but in a 'diminishing returns' curve. For nutrients like N the yield can also decrease at above optimum supply levels for various reasons. When two or more nutrients are deficient the model successfully predicts their interactions, which can strongly reduce yield.

### 4.3.2 *Calibration (fitting) of the model*

The model allows the user to predict the yield response for a crop species based on past results from several fields in the district, or even from results of a single trial with that crop, provided the conditions in the new situation where model predictions are to be applied are within the calibration range. The calibration procedure requires a number of inputs: soil P (Olsen P µg/ml); soil exchangeable K (meq/100 g); fertiliser N, P, and K (kg of element/ha); bulk density of the soil after preparation for testing (g/cm$^3$); bulk density of the soil in the field (g/cm$^3$); actual yield (t/ha); and the standard population used for the crop (per ha). It is important to note that the model equates soil and fertiliser nutrients (by including coefficients for fertiliser efficiency) and evaluates response to a weighted total supply. Curves for yield response to a nutrient can be extrapolated above and below the applied fertiliser rates when the range of soil nutrient levels in plots include nutrient amounts in the relevant range (with the proviso that the predicted response is tentative and will need verification). Another feature of the model is that it estimates a minimum supply level needed to achieve any yield and will not extrapolate yield response curves below this minimum value.

Optional data inputs which are useful are soil available N (kg/ha); soil exchangeable Mg (meq/100 g); fertiliser Mg (kg Mg/ha); treatment plant populations (per ha); soil pH; soil available water content (plus maximum deficit and evapotranspiration for experiments involving drought responses); and potential yield. The calibration program can estimate available N and potential yield if these are not known, but as averages for the planting they offer less reliable conclusions.

The calibration process finds the set of model parameters that give the closest agreement between the observed and the predicted yields. Combining results from several trials for one integrated analysis posed some problems. Soil N and potential yield can be expected to vary between trials. In these circumstances we analysed the trials in two stages. First each trial was analysed separately, estimating soil N and potential yield for each. Then we combined the data sets for an integrated analysis, keeping these previously estimated values as inputs for each trial.

### 4.3.3 *Assessing model performance*

The determinant of how well the model can be fitted to a particular data set (matching the actual yields to the simulated yields) is the size of the root mean square error (RMSE), in tonnes per hectare. This was calculated using data for individual plots. Another test of fit is to see how close to the 1:1 line the actual yield points are. The percentage of yield variation accounted for is the closeness of fit ($R^2$). And finally, it is important to look at a plot of residual error terms (actual minus simulated yields) versus yield, to see if there is a pattern indicating systematic error as actual yield increases.

# 5 RESULTS OF RE-ANALYSIS OF FERTILISER TRIALS

## 5.1 Experimental details of the 12 original trials

Table 2 shows the crop and year of planting for each trial. All of the cabbage trials were at Pukekohe and the other seven trials were at Levin. The size of the trial is indicated by the total number of plots.

Fertiliser treatments are listed under N, P, and K, showing the rates in kg per hectare. When only a single rate is shown, that nutrient is not a treatment for comparison, but is a basal application to all plots. In some trials there was also a basal application of the nutrients being compared, which have been added to each of the treatment rates. Potassium (K) rates were sometimes residuals from prior fertilisation of the same replicated plots (denoted by an 'R' after the rates). These were handled like fertiliser treatments in the original statistical analyses in the 1970s, and shown as the original fertiliser rate.

Except in the case of the first trial of the series, soil tests (which never included soil N) were done at the end, rather than the start of trials, so the values used in the model were taken from the records of the previous trial in the series. The last columns in Table 2 are the ranges of soil P and K values in each plot. Phosphorus values are reported as Olsen P (in µg/ml) and soil-exchangeable K as meq/100 g. MAF Quick Test values were used in the original reports.

**Table 2: Fertiliser trials at MAF research centres in Levin and Pukekohe between 1967 and 1976, with rates of fertiliser elements, N, P, and K, and ranges of soil test Olsen P (µg/ml) and exchangeable K (meq/100 g) values.**

| | | | | Fertiliser treatments ( kg/ha) | | | Soil test ranges | |
|---|---|---|---|---|---|---|---|---|
| Crop | Cultivar | Site[1] | Plots | N | P | K | P µg/ml | K meq/100 g |
| Cabbage 1 | Wintercross | P | 27 | 100, 200, 400 | 50, 100, 200 | 250 | 20-42 | 0.31-0.59 |
| Cabbage 2 | Wintercross | P | 27 | 100, 200, 400 | 50, 100, 200 | 250 | 21-45 | 0.31-0.66 |
| Cabbage 3 | Wintercross | P | 27 | 100, 200, 400 | 50, 100, 200 | 250 | 18-42 | 0.27-0.47 |
| Cabbage 4 | Wintercross | P | 27 | 100, 200, 400 | 50, 100, 200 | 250 | 18-33 | 0.27-0.47 |
| Cabbage 5 | Wintercross | P | 27 | 100, 200, 400 | 50, 100, 200 | 250 | 15-33 | 0.27-0.43 |
| Cauli 69 | PhenomenalY404 | L | 64 | 0, 115, 230, 345 | 60, 120, 180, 240 | 0, 158, 315, 473 | 2-4 | 0.20-0.35 |
| Onion 66 | Australian Brown | L | 64 | 0, 158 | 40, 120 | 0, 315 | 4-11 | 0.20-0.59 |
| Onion 67 | E H Winstones | L | 32 | 0, 158 | 40, 120 | 0, 315 | 5-13 | 0.16-0.82 |
| Spinach 69 | Prickly Supreme | L | 64 | 53, 158 | 45, 135 | 315, 1050, res[2] | 11-46 | 0.12-0.82 |
| Spinach 70 | Hybrid 7 | L | 64 | 53, 158 | 45, 135 | 315,1050, res[2] | 13-47 | 0.08-0.55 |
| Squash 73 | Buttercup (late) | L | 64 | 115, 230, 345 | 120, 240, 360, 480 | 210, 420, 630 | 5-11 | 0.20-0.35 |
| Squash 76 | Buttercup | L | 64 | 100, 200, 300 | 300 | 0, 210, 420, 630, res[2] | 27-55 | 0.08-0.66 |

[1]L = Levin, P=Pukekohe

[2]res = residual from these rates of prior fertiliser, analysed as Treatments in these trials (the model uses levels calculated from soil tests).

## 5.2 Presentation of results

The results of our re-analysis of these unpublished trial data are grouped by vegetable crop. We list the ranges of yields and significant yield responses to each fertiliser, based on the original statistical analyses, and then present the model output graphs and associated conclusions. This comparison will illustrate any gains in understanding and improved recommendations from using the model.

Overall, the model performed well. The best example is for cabbage. Figure 1 shows how close the actual yield points fell to the 1:1 line for actual v. simulated yield. The proportion of yield variation accounted for ($R^2$) along with the RMSE of prediction in each crop are given in Table 3.

**Table 3: Summary of statistics indicating closeness of fit for the yield estimate model.**

| Crop | RMSE (t/ha) | $R^2$ [(1)] |
|---|---|---|
| Cabbage 1 | 2.98 | 0.63 |
| Cabbage 2 | 2.59 | 0.6 |
| Cabbage 3 | 4.55 | 0.62 |
| Cabbage 4 | 6.53 | 0.7 |
| Cabbage 5 | 4.5 | 0.72 |
| Cabbage Combined | 4.88 | 0.91 |
| Cauliflower 69 | 5.87 | 0.63 |
| Onion 66 | 5.66 | 0.39 |
| Onion 67 | 18.9 | 0.72 |
| Onion Combined | 13.1 | 0.85 |
| Spinach 69 | 4.26 | 0.21 |
| Spinach 70 | 4.31 | 0.57 |
| Squash 73 | 4.52 | 0.72 |
| Squash 76 | 3.6 | 0.56 |
| Squash Combined | 4.04 | 0.75 |

[(1)]The $R^2$ is the closeness of fit between estimated and actual yield (an $R^2$ of 1.0 is a perfect fit).

## 5.3 Comparing original trial conclusions and the model

### 5.3.1 *Cabbage results*

The sites of the five 1970 trials by MAF at the Pukekohe Research Station were fairly near to each other, but different enough in soil properties, especially phosphate retention, to be representative of the range of soils in the Pukekohe vegetable-growing district. They also differed in growth environment, due to their wide range of planting dates, from 5 February to 4 May. Table 4 shows the ranges in yield among the plots of each trial and the maximum rate of each fertiliser nutrient which resulted in a significant yield increase compared to the next lower rate.

To contrast what can be deduced from the original data analyses and the model output, first consider what the Table 4 data allow you to conclude. There was no analysis done in 1971 to compare the five plantings since it would not be considered valid to do so by analysis of variance, given that planting date and site changed together. The trend, however, was for higher yield with the later (April and May) plantings. The model, in contrast, is designed to do a combined analysis of different sites and planting dates.

1. **Original trial analysis**

   Starting with fertiliser response, the most obvious conclusion is that K response cannot be assessed since there was only a single basal rate of K applied (250 kg K/ha). The model, as will be discussed, does assess K response based on soil K levels in each plot. While this is not as reliable as if a range of fertiliser rates was applied, it is still very useful whenever a fairly wide range of soil levels is represented (see below). Since the trials had three N and three P fertiliser treatments (applied half at planting and half side-dressed after one month) the most specific conclusions in each trial relate to these two nutrients. There was no 0 rate for either N or P, however, so response to the lowest rate of each was not tested directly. The first two plantings responded to 200, but not 400 kg N/ha; however, nothing can be said about rates between 200 and 400 kg/ha. In the last three plantings yield did respond to 400 kg N/ha, which leaves open the possibility that maximum yield may have come at an even higher rate. These results did not, of course, indicate whether there would be a return to the grower from purchasing and applying such a high rate of N (not to mention environmental issues related to a winter crop).

   The first cabbage planting in Table 4 responded to 100, but not 150 kg P/ha. This is more definitive than in the following four plantings, where there was no yield difference at the three rates of P. All that can be concluded is that with 50 kg P/ha cabbage might have yielded better than with a lower rate.

**Table 4:** **Results of original cabbage analysis; significant yield responses (5% level) to fertilisers.**

| | | Maximum rate which gave a signif. yield increase (kg/ha) | | |
|---|---|---|---|---|
| Crop | Yield (t/ha) | Nitrogen | Phosphorus | Potassium |
| Cabbage 1 | 69-89 | 200 | 100 | - |
| Cabbage 2 | 45-59 | 200 | <50 | - |
| Cabbage 3 | 57-85 | 400 | <50 | - |
| Cabbage 4 | 67-115 | 400 | <50 | - |
| Cabbage 5 | 68-107 | 400 | <50 | - |

This result might be expected to vary depending on the soil level of P and also, therefore, the trial site. That is a serious limitation of a conventional fertiliser trial, considering the cost and effort involved.

**2. Analysis by model**

The model was successfully fitted to the data using all five trials as a single large data set, so it will not be necessary to examine the graphs from each trial separately. Rather, we will report on the combined set of all five.

Figure 1 shows how well the model performed at matching the actual (observed) yields of plots to the simulated yields that it had created from the data set. The graphs plotting yield for the five individual cabbage crops are not shown, but have been summarised in Table 3. The proportion of variation in actual yield which each analysis accounted for (known as $R^2$) varied from 0.60 to 0.72 in the five individual trials and was 0.91 in the analysis where data from the five trials are combined (Fig. 1). Note that different symbols are used for each planting, which gives some indication of the effect of planting/harvest time on yield (the last two plantings had the highest yield).

The Root Mean Square Error (RMSE) ranged from 2.59 to 6.53 t/ha, and was 4.88 t/ha for the combined set. This is small relative to the actual yields of 45 to 115 t/ha, but should be taken into account when determining recommendations from the graphs. The line relating yield response to fertiliser rate is actually the midline of a band whose width is proportional to the RMSE, so the relationship is not as precise as it appears. When two curves for different soil nutrient levels are close to each other they should not be considered to differ. There was no problem with the pattern of residual errors and the slopes were all close to the 1:1 line (ranging from 0.9 to 1.07). If later verification of the cabbage model is done in other growing districts we recommend that the accuracy of the model estimate of soil N is checked.

| | |
|---|---|
| RMSE | 4.88 |
| $R^2$ | 0.91 |

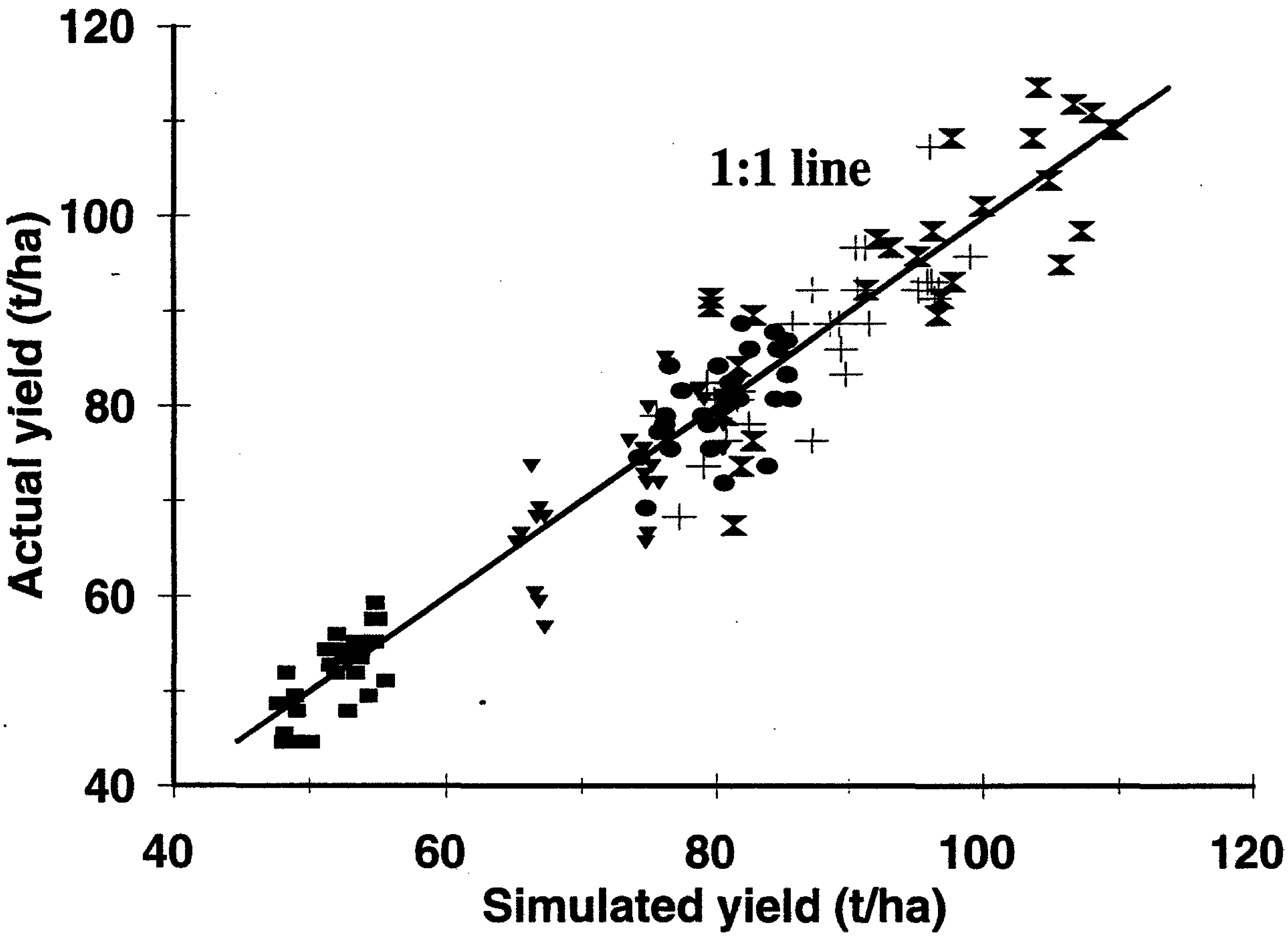


**Figure 1:** **Fit of actual yield to predicted yield for five combined cabbage trials.**

Figures 2, 4, and 6 show the predicted yield response to N or P or K. There are four curves on each of the P and K graphs because it is useful to visualize the response at different soil levels for that nutrient. This is an advantage of the model analysis over a conventional fertiliser trial, which would require a large number of treatments in order to make such comparisons. While soil N was not measured there are also four curves for cabbage yield response to N because the five trials had different estimated soil N values which spanned the range of curves presented.

Look first at Figure 2 on fertiliser N. Unlike the individual trial analyses for the other four crop species, there were five cabbage trials with differing estimated soil N levels. So four curves were calculated, using the soil N levels shown

# Cabbage 1970 Pukekohe

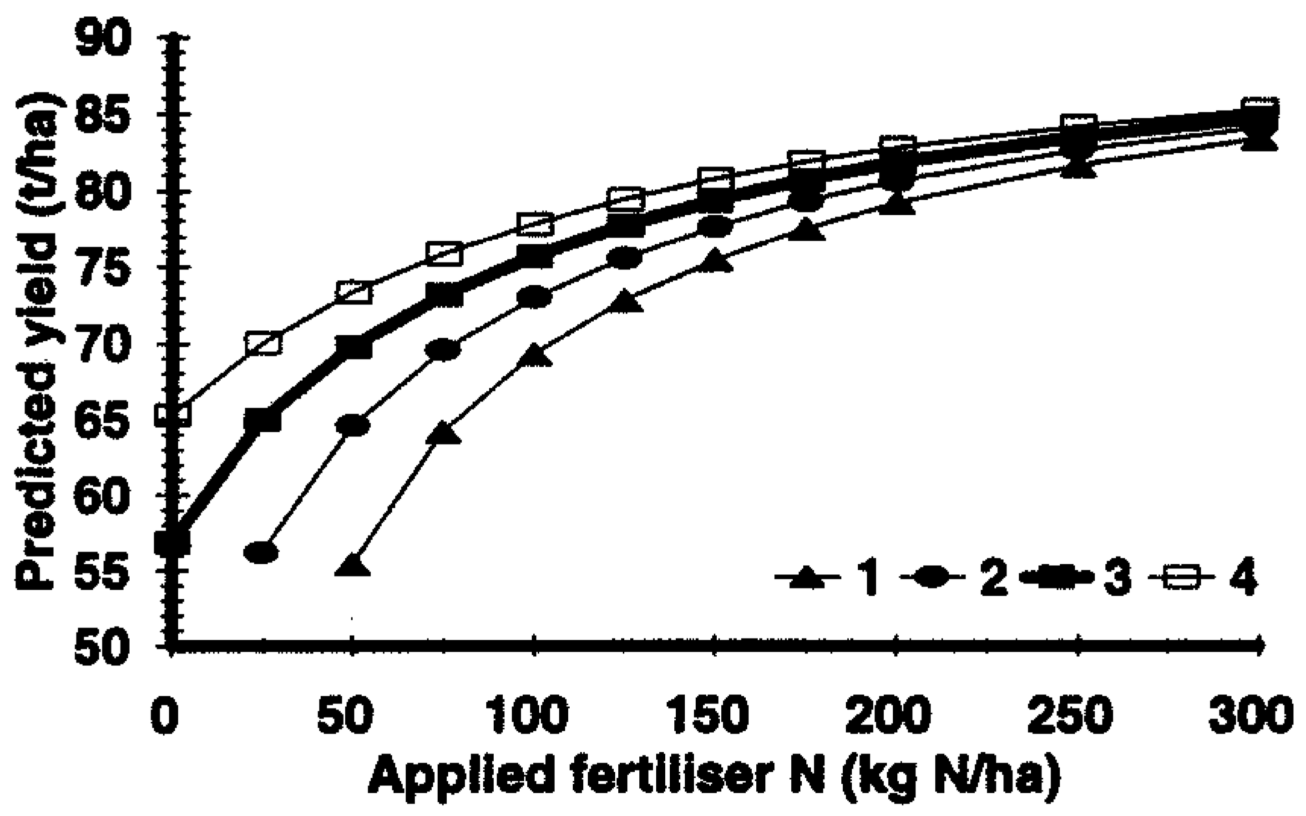


**Figure 2: Predicted yield response of cabbage to N fertiliser**
Soil P, K, Mg and pH non limiting, no drought
1. $N_s$ = 65 kg/ha
2. $N_s$ = 90 kg/ha
3. $N_s$ = 115 kg/ha
4. $N_s$ = 140 kg/ha

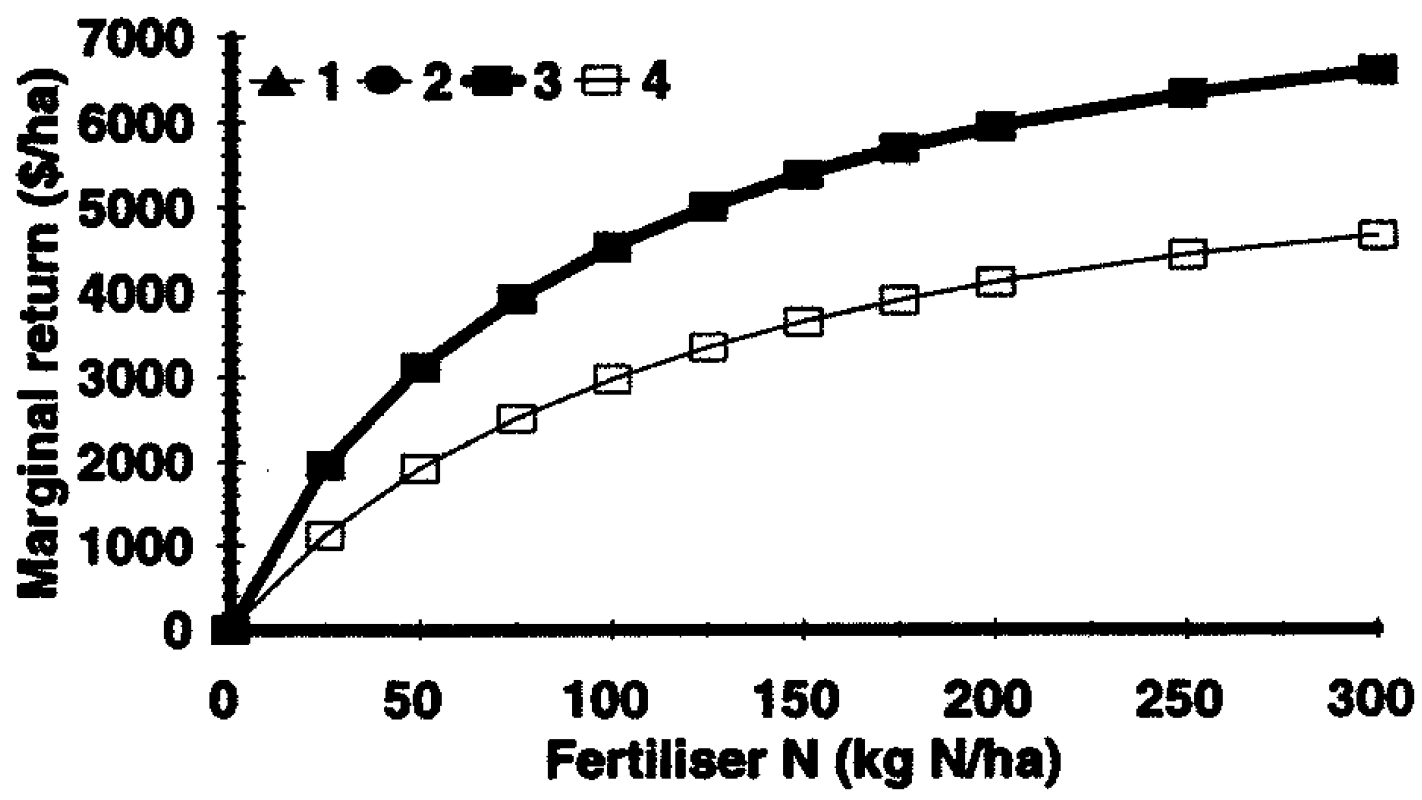


**Figure 3: Marginal return to N fertiliser**
1. $N_s$ = 65 kg/ha
2. $N_s$ = 90 kg/ha
3. $N_s$ = 115 kg/ha
4. $N_s$ = 140 kg/ha

| Fertiliser Costs | |
|---|---|
| $ kg N | 0.74 |
| $ kg P | 1.8 |
| $ kg K | 0.78 |

| Crop Value | $ | |
|---|---|---|
| $ per saleable tonnne | 350 | |
| Salable % | 0.7 | Includes trimming |
| $ per total tonne | 245 | |

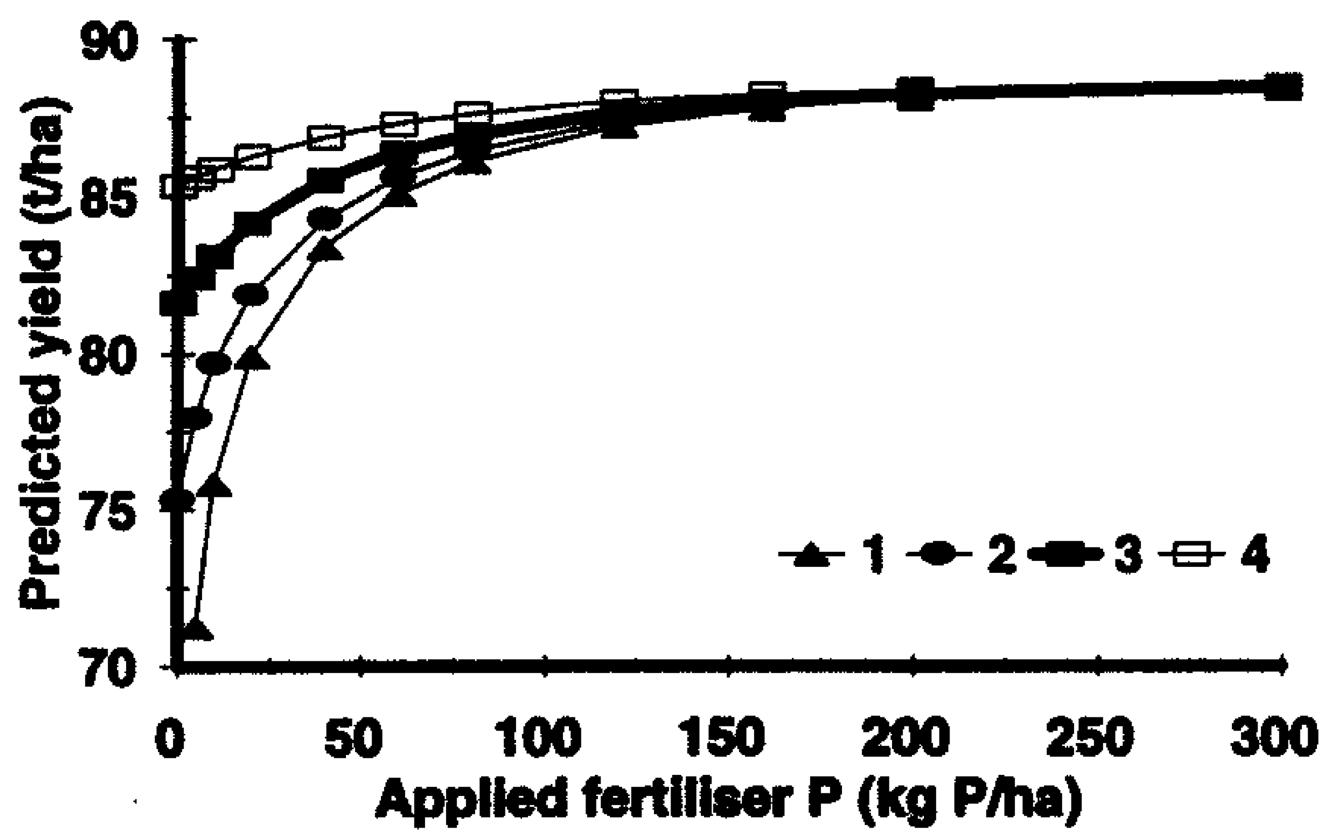


**Figure 4: Predicted yield response of cabbage to P fertiliser**
Soil N, K, Mg and pH non limiting, no drought.
1. Olsen P = 5 µg/ml (outside calibration range)
2. Olsen P = 10 µg/ml (outside calibration range)
3. Olsen P = 20 µg/ml
4. Olsen P = 40 µg/ml

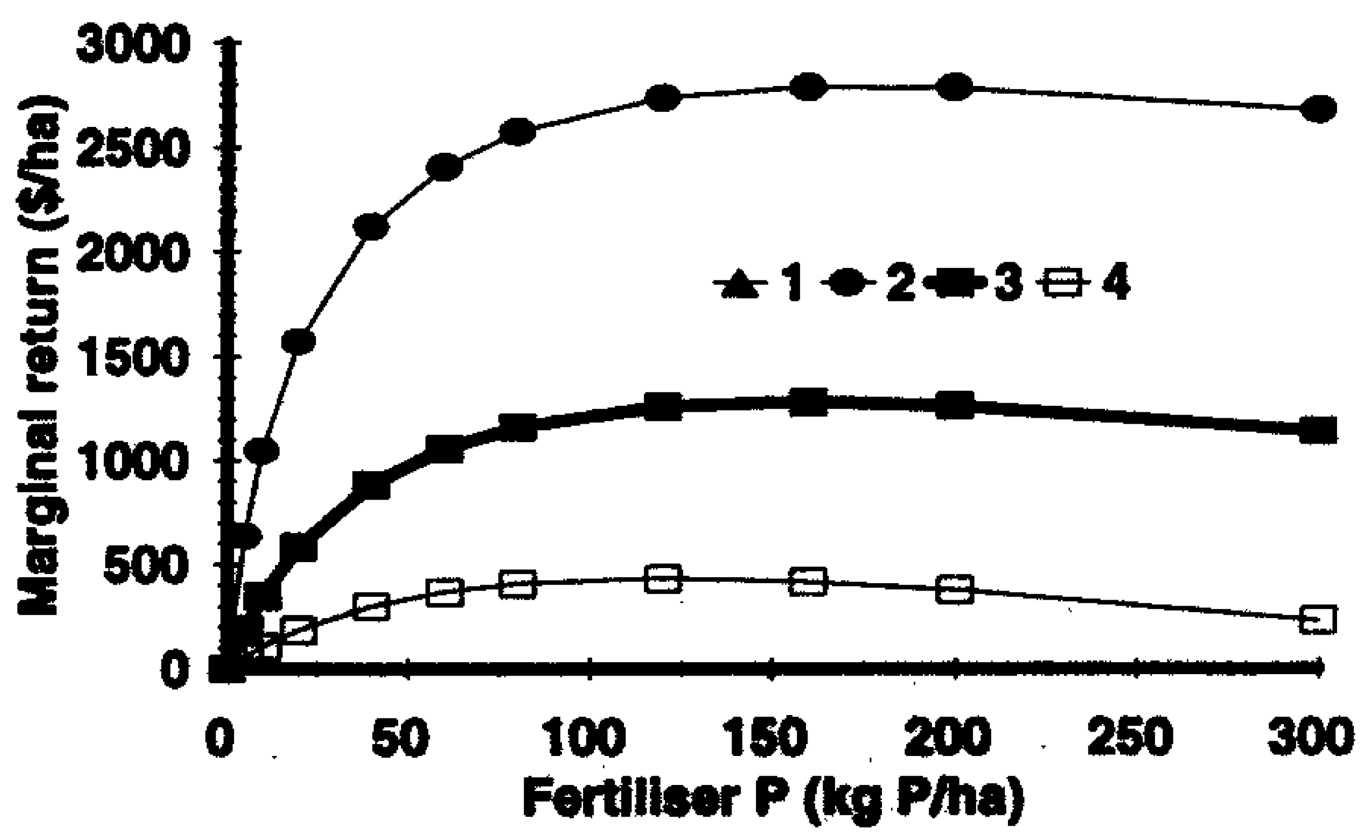


**Figure 5: Marginal return to P fertiliser**
1. Olsen P = 5 µg/ml (outside calibration range)
2. Olsen P = 10 µg/ml (outside calibration range)
3. Olsen P = 20 µg/ml
4. Olsen P = 40 µg/ml

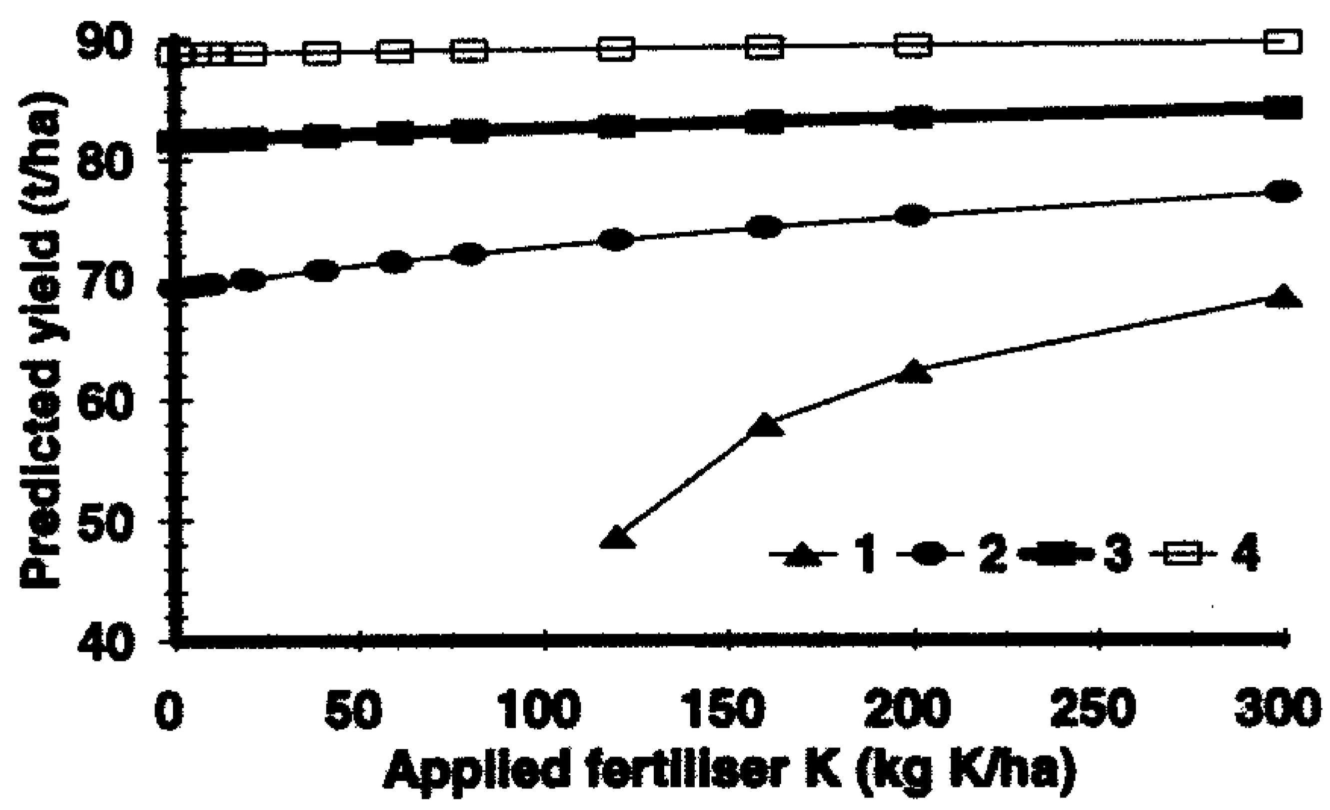


**Figure 6: Predicted yield response of cabbage to K fertiliser**
Soil N, P, Mg and pH non limiting, no drought.
1. Exchangeable K = 0.15 meq/100g (outside calibration range)
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

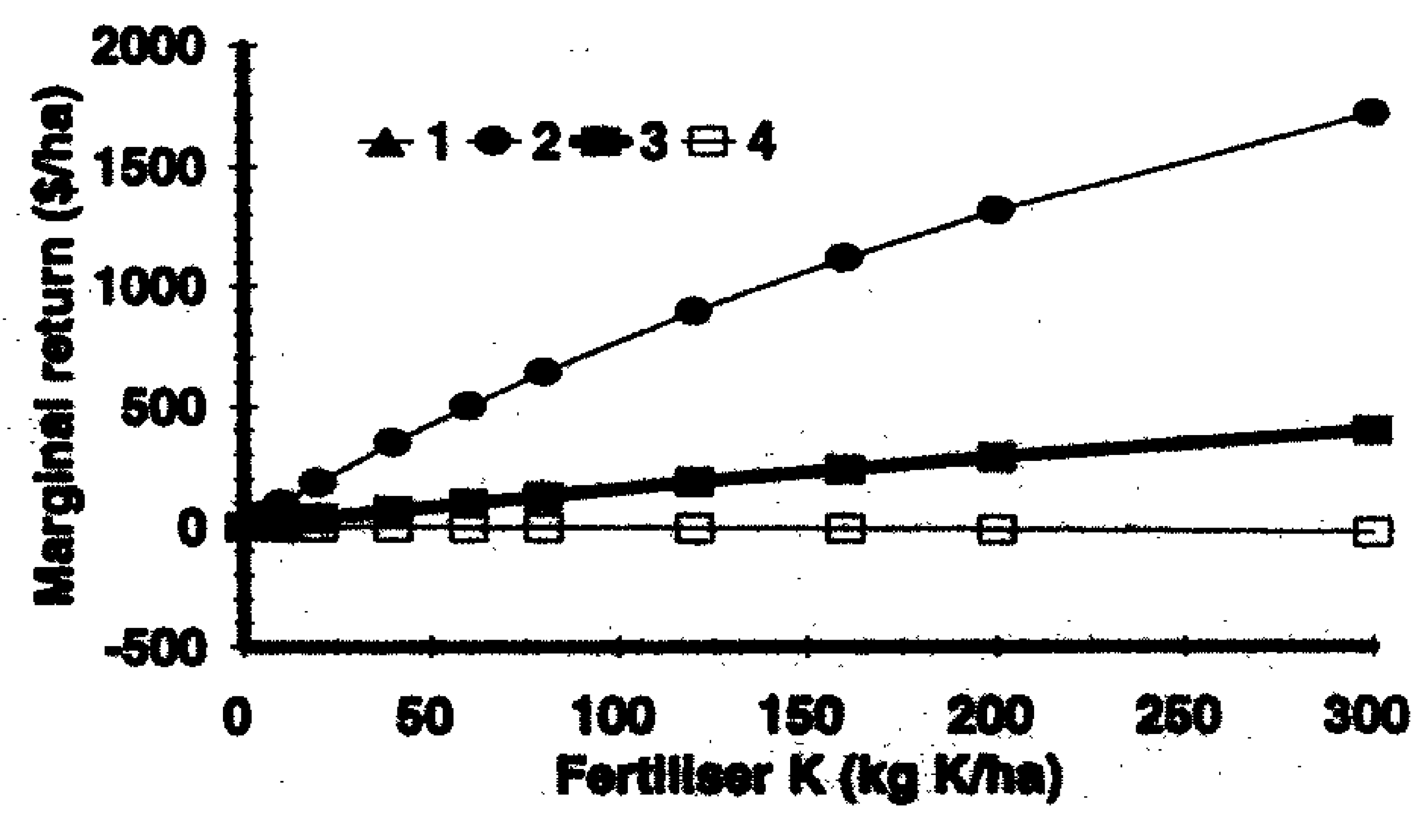


**Figure 7: Marginal return to K fertiliser**
1. Exchangeable K = 0.15 meq/100g (outside calibration range)
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

below the graph, which spanned (in increments of 25 kg N/ha) the range of the five sites. The N fertiliser response pattern is a yield increase up to and beyond 300 kg N/ha at all four soil N levels, but with diminishing returns which begin first at the higher soil N levels. The curves indicate that cabbage response to N fertiliser is greater at the lower levels of soil N. For cabbage it would have been useful to calculate values above the highest fertiliser level that the model was set to display (300 kg N/ha). The low ends of two curves stop before reaching the vertical axis because the model will not predict yield when total N supply is less than the minimum needed to achieve any yield. Overall, this is more refined and useful information about N response than the conclusion from the original trials, i.e. that there was a statistically significant yield gain up to either 200 or 400 kg N/ha.

Now look at Figure 3, where the response to fertiliser N is in dollars/ha rather than tonnes. The marginal return, where added yield is converted to $/ha, is calculated by multiplying the yield increase (in tonnes) by the price per gross tonne (which is adjusted from the selling price by the proportion of the harvested crop which is saleable). The fertiliser cost is then subtracted. One generic difference between the marginal return graph and the yield graph is that the four curves will reverse in top to bottom position on the graph because there is nearly always a better return when the soil levels are lower. In this case there are only two curves, because the marginal return cannot be calculated for soil nutrient levels 1 and 2 where the yield curves stop before reaching the zero fertiliser rate, for the reason explained in the previous paragraph. It can be inferred that the marginal return on fertiliser N at these levels would probably have been very high, considering that there is a calculated $6000 return on 300 kg/ha N for soil N level 3. The calculated return of course depends on accurate crop value inputs as well as accuracy in the model estimates of soil N. The crop value estimates are shown below Figure 3. For a leafy crop like cabbage (especially grown in winter) there appears to be a big return on N fertiliser, assuming that commercial yields can go as high as in these trials without quality or disease problems occurring. This very high marginal return at very high fertiliser N rates for cabbage (and spinach, to be shown below) is not the norm, as will be seen in the model output for other crops.

The graph for yield response to fertiliser P (Fig. 4) differs from those for fertiliser N due to the narrow range of P rates where yield response occurs. There is no response to P at the soil P levels 3 and 4 above rates of about 125 kg/ha. For the two lower soil P levels the maximum rate for yield increase is about 150 kg/ha. At these lower soil P levels there is a rapid yield increase from the first 75 kg of fertiliser P applied. The lowest P level curve stops short at the bottom, as with N. Since both levels 1 and 2 of soil Olsen P level are below the calibration minimum P value in this data set the curves need to be regarded as unproven, but still a useful basis for future testing. In contrast, the original 1971 analysis only applied to a comparison of 50, 100, and 200 kg P/ha and found no significant difference. The conclusion from the model analysis, while tentative, points to a specific question to answer in future research, namely what is the effect of low P rates in low P soils?

Figure 5, showing marginal returns on fertiliser P, predicts that soil P levels have a very big impact on returns from fertiliser P (assuming the yield responses are verified). Even the level 3 soil P curve shows a fair marginal return, and the level 2 soil pays a return of $2700/ha on 125 kg P/ha. The level 1 soil would presumably pay much higher yet (keeping in mind that the yield responses these are based on must be verified). One caution when comparing the N, P, and K graphs for marginal return is to note that the scales are not the same between graphs (go by the dollar values on the left axis rather than the slope of curves).

Fertiliser K responses (Figs 6 and 7) are based on soil K, since no K treatments were used in this trial. The actual plot soil K values were all within the range of the middle two soil level curves. The model predicted a positive response to fertiliser K at the two lower soil K levels. However, the lowest level was below the calibration range. At level 2 the yield response was small, but the marginal return (Fig. 7) was still over $1000/ha. This is a useful guide for further testing, which the original trial analysis could not provide.

### *5.3.2 Onion results*

1. **Original trial analysis**
   Table 2 shows the two rates of N, P, and K used in the 1966 and 1967 trials. The 1966 plot yield range was 19-56 t/ha. The original analysis found that 158 kg/ha of fertiliser N (the only rate tested) gave a 19% yield increase. For fertiliser P the maximum rate was <40 kg P/ha, since a rate of 120 kg/ha did not give an increase over 40 kg/ha. There was no response to fertiliser K.

   The 1967 trial ranged in plot yield from 17 to 144 t/ha. The conclusions from the original analysis were that fertiliser N significantly increased yield (by 9%) at a rate of 158 kg/ha compared to a zero rate, and that fertiliser P did so at a rate of 120 compared to 40 kg P/ha. There was again no response to K.

2. **Analysis by model**
   The model fit from the 1966 onion trial only had an $R^2$ of 0.39, while that from the 1967 trial was 0.72. When the two were combined $R^2$ improved to 0.85. Each of the N graphs for onions has two curves, with fertiliser response at two levels of

soil N which cover the range of model-estimated levels of soil N for the two trials.

Predicted yield response to N fertiliser (Fig. 8) when soil N was 30 kg/ha was positive up to 250 kg N/ha (although it did not increase by much after 180 kg/ha). When initial soil N is 80 kg/ha yield is predicted to be 100 t/ha with zero fertiliser and to increase in response to N fertiliser up to about 125 kg/ha. Both original trials found a significant effect on yield from the one fertiliser rate used (158 kg N/ha). The model used its estimate of initial soil N to show how much greater the predicted response to fertiliser is at lower soil N.

Turning to marginal returns from fertilising onions with N, Figure 9 predicts an extremely large return on N fertiliser cost up to a fertiliser rate of 200 kg N/ha at soil N level 1, while the return stopped rising after 100 kg N/ha at soil N level 2. These rates of N are somewhat higher than usually recommended and a note of caution is required in that the cultivar used in the 1967 trial, Winstones Early Hybrid, was very high yielding and could respond to higher N rates than today's cultivars. Note that the fertiliser rate which ceases to pay a return would be lower when the onion price is lower, so accurate price forecasts are a useful input for this model.

Predicted onion yield response to fertiliser P (Fig. 10) is for little or no yield gain at the two higher soil P levels, and a big response with lower soil levels. These two predicted responses are within the actual range of soil P values. The results agree with the original analyses from 1967, which found a yield gain over the middle range of these curves (40-120 kg P/ha), while the 1966 original result was no response to 120 kg P/ha. The model predictions have clearly added helpful detail to guidelines for rates with different soil K levels. Marginal returns on fertiliser P (Fig. 11) are predicted to be very dependent on initial soil P, ranging from near zero at soil N level 4 up to over $6000/ha with 300 kg P/ha in soil with the lowest Olsen P (level 1). This is a more comprehensive guide to fertiliser use than possible with the original trial, which had a top rate of 120 kg/ha. It should be confirmed with onion trial data where high P rates were used.

There were also large responses to fertiliser K predicted (Fig. 12), but again only at the two lower initial soil levels of K. Since soil K level 1 is below the calibration range, this predicted response needs to be confirmed with additional trial results. The fact that neither original trial analysis detected a K response suggests that the many plots with high soil K and no yield response to fertiliser obscured the effect in low K plots. The pattern of marginal returns on fertiliser K (Fig. 13) is similar to that for P in that initial soil K has a strong effect on response to fertiliser. The two highest K soils (levels 3 and 4) show a negative return and in soil level 2 response was weak, but it was predicted to continue

# Onion 1966 - 1967 Levin

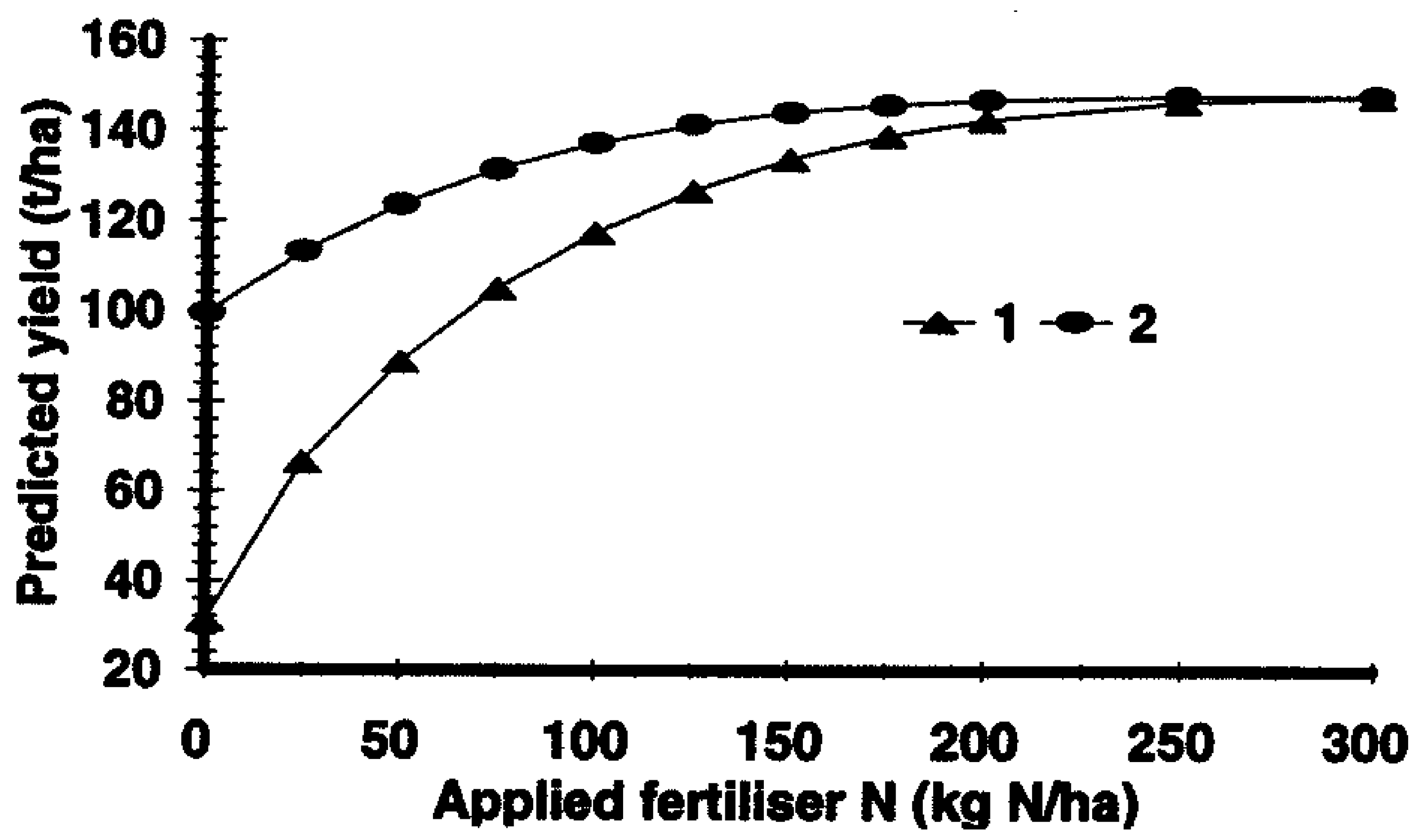


Figure 8: Predicted yield response to N fertiliser
Soil P, K, Mg and pH non limiting, no drought
1. $N_s$ = 30 kg/ha
2. $N_s$ = 80 kg/ha

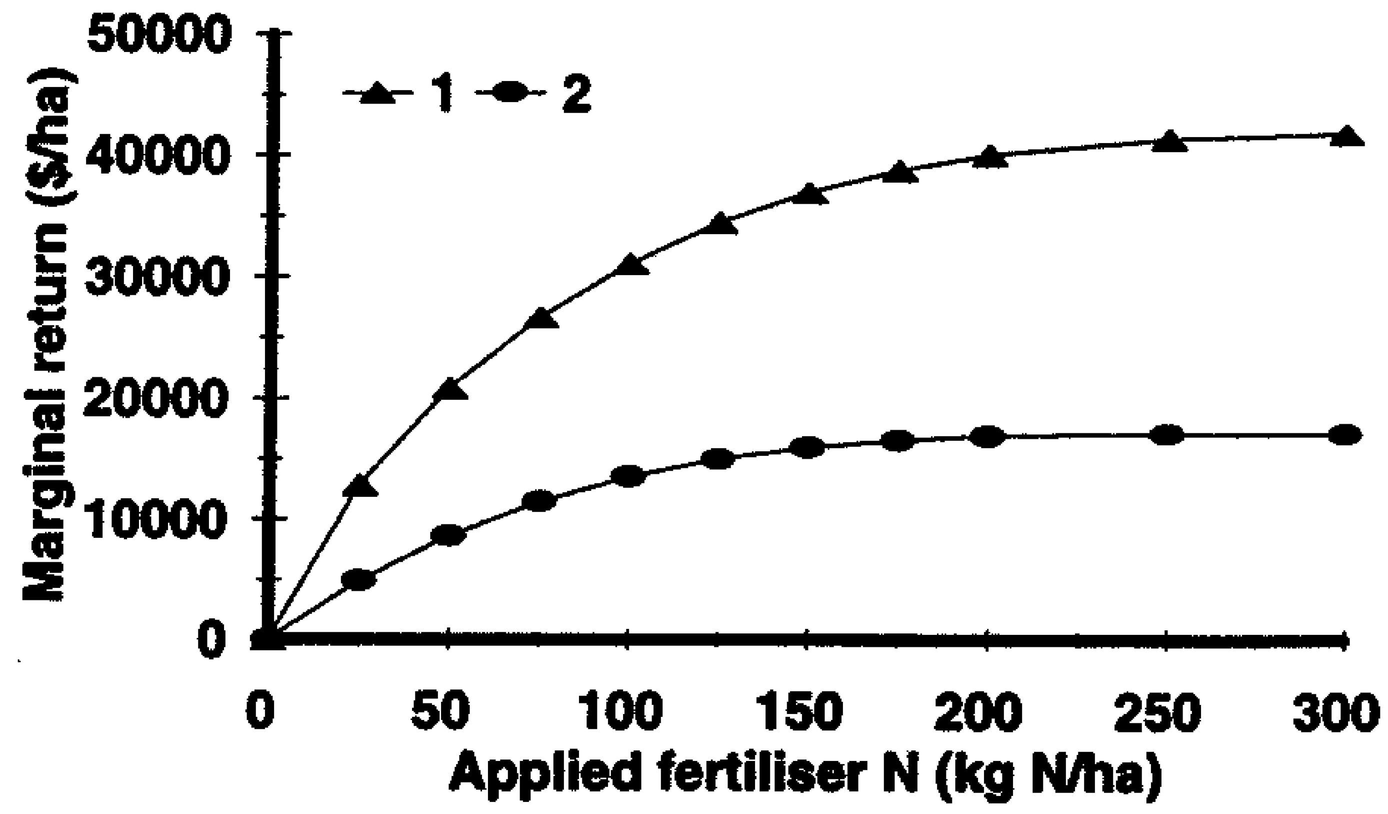


Figure 9 : Marginal return to Nitrogen fertiliser
1. $N_s$ = 30 kg/ha
2. $N_s$ = 80 kg/ha

| Fertiliser Costs | | Crop Value | $ |
|---|---|---|---|
| $ kg N | 0.74 | $ per saleable tonne | 450 |
| $ kg P | 1.8 | Saleable % | 0.8 |
| $ kg K | 0.78 | $ per total tonne | 360 |

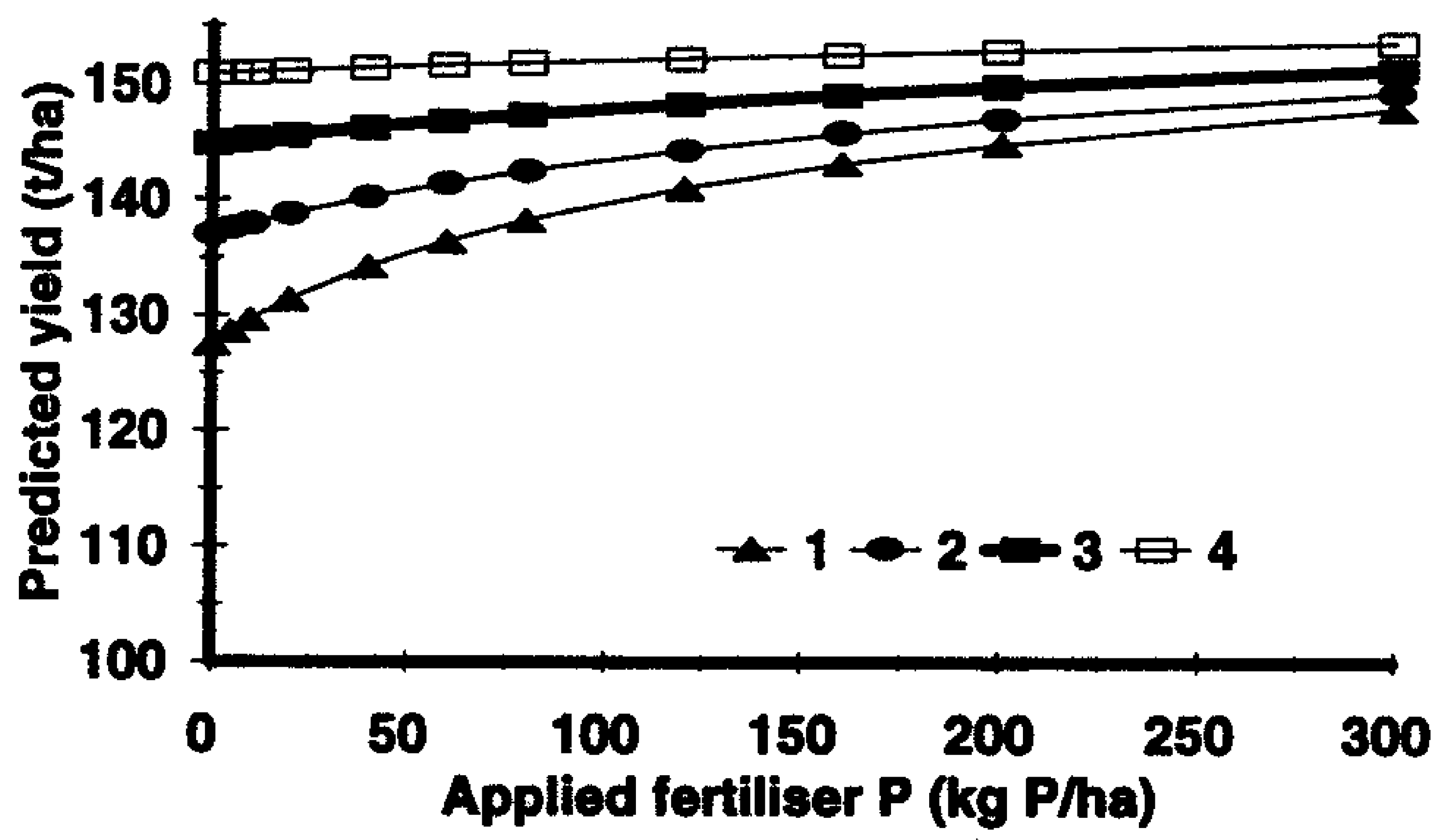


Figure 10: Predicted yield response to P fertiliser
Soil N, K, Mg and pH non limiting, no drought.
1. Olsen P = 5 µg/ml
2. Olsen P = 10 µg/ml
3. Olsen P = 20 µg/ml (outside calibration range)
4. Olsen P = 40 µg/ml (outside calibration range)

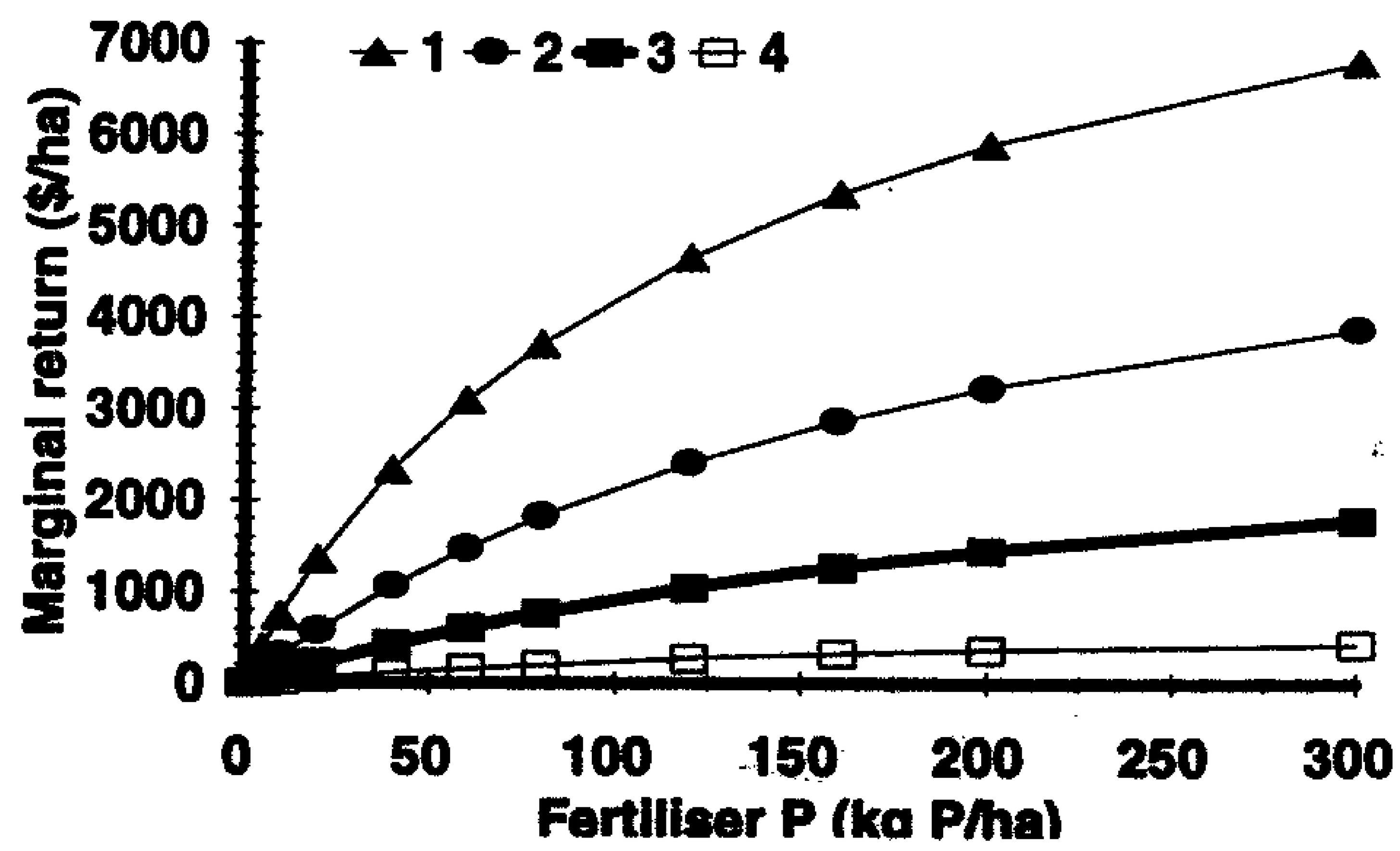


Figure 11: Marginal return to Phosphorus fertiliser
1. Olsen P = 5 µg/ml
2. Olsen P = 10 µg/ml
3. Olsen P = 20 µg/ml (outside calibration range)
4. Olsen P = 40 µg/ml (outside calibration range)

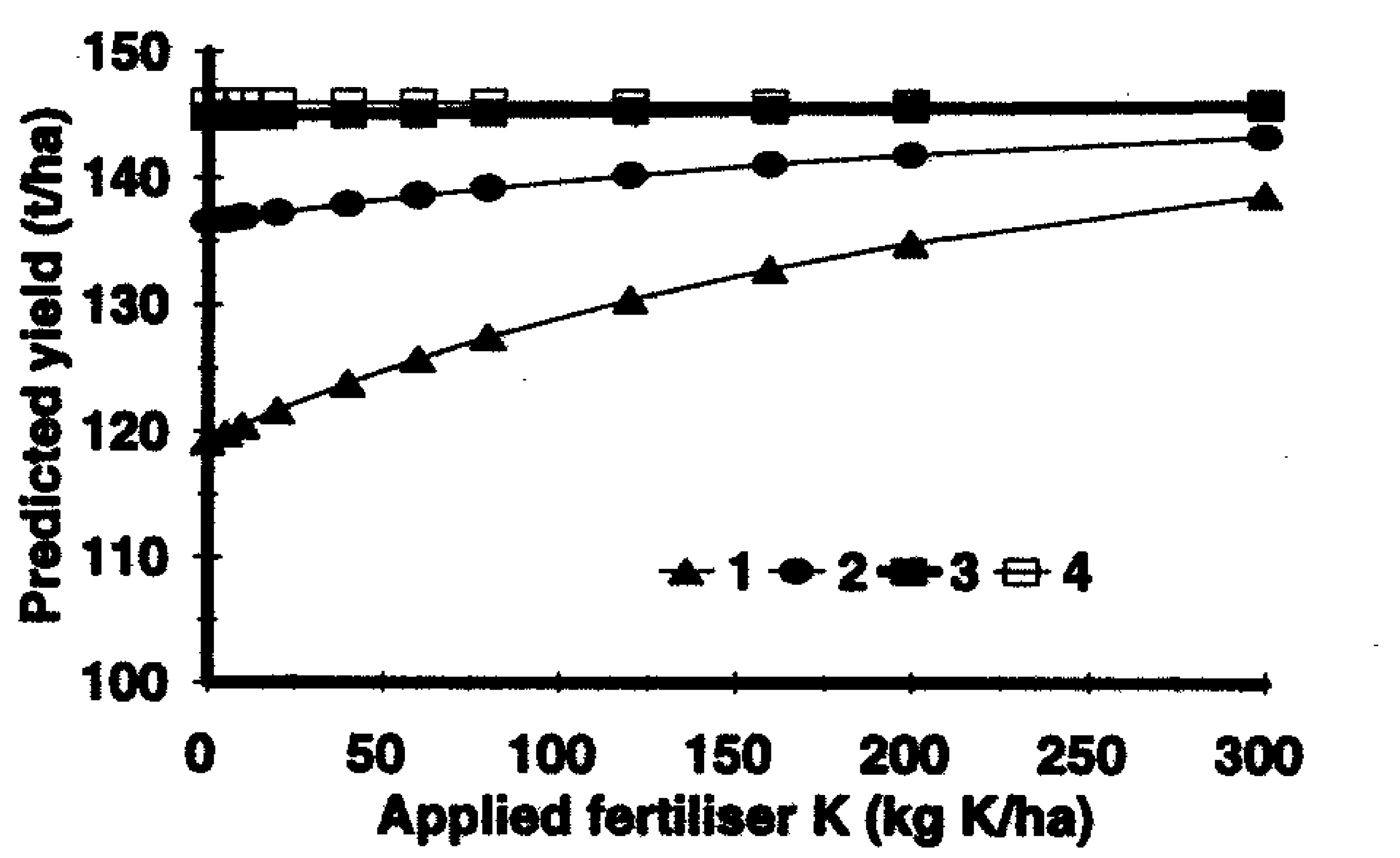


Figure 12: Predicted yield response of cabbage to K fertiliser
Soil N, P, Mg and pH non limiting, no drought.
1. Exchangeable K = 0.15 meq/100g (outside calibration range)
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g

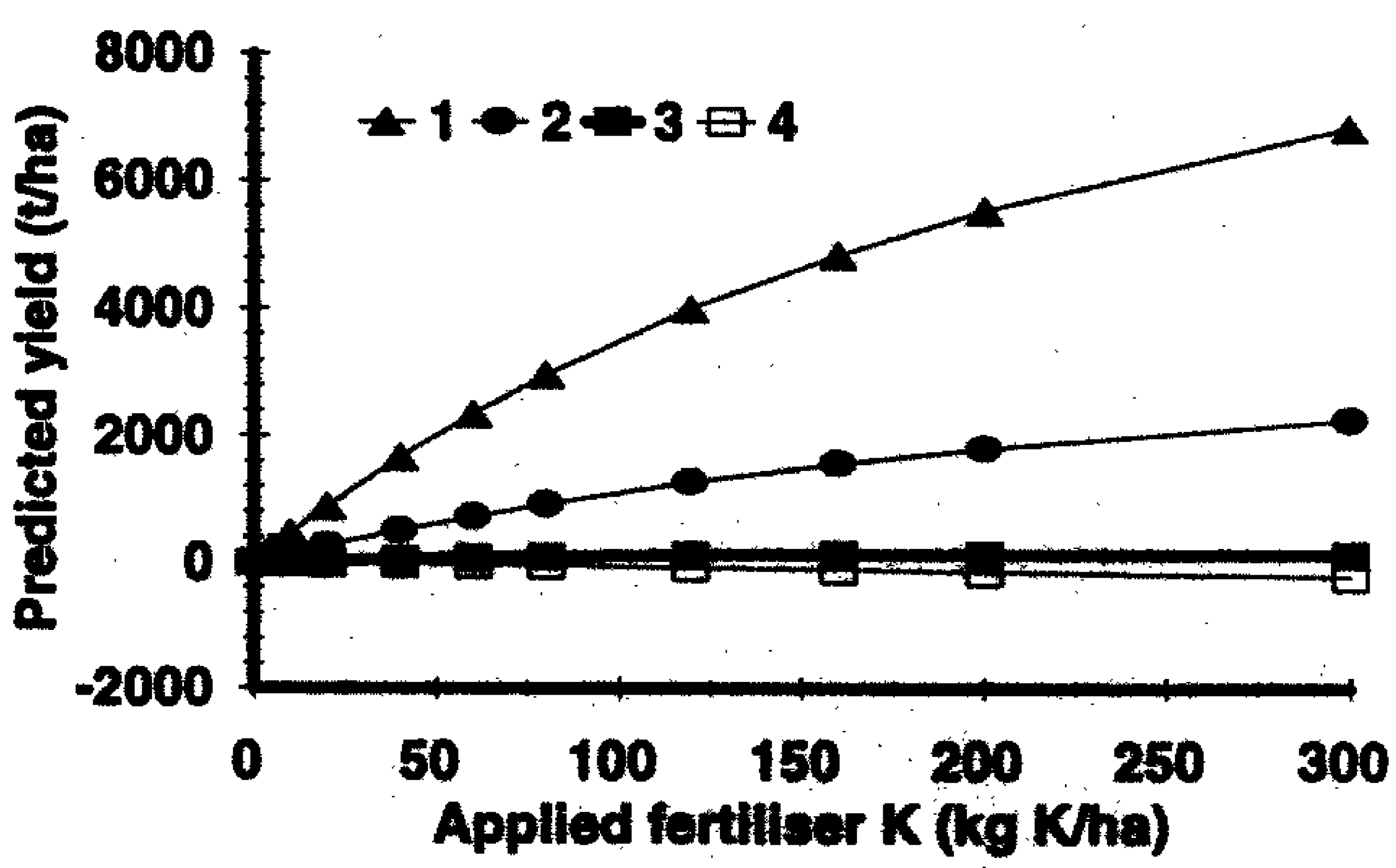


Figure 13: Marginal return to K fertiliser
1. Exchangeable K = 0.15 meq/100g (outside calibration range)
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g

over a wide range of fertiliser rate. A $6000/ha return on 300 kg K/ha was predicted at the lowest soil K level (but note that this soil K level is outside the calibration range so this needs to be proven). Once again, the model outputs offer more detailed and useful information than was possible with a traditional interpretation of the fertiliser trial results.

### 5.3.3 *Squash results*

1. **Original trial analysis**

   Two promising trials were examined (see Table 2). The 1973 trial involved a wide range of rates of N, P, and K fertilisers, but did not have zero rates. Plot yields ranged from 14 to 49 t/ha and the maximum rates for yield increase were 360 kg P/ha and 630 kg K/ha. Surprisingly, there was no yield response to the N treatment. This was probably due to the fact that the plots had just come out of pasture and had high soil N. The 1976 trial had no fertiliser P treatments and only residual K treatments; plot yields ranged from 12 to 27 t/ha. The maximum rates of fertiliser for yield increase were 100 kg N/ha (the lowest rate used) and the residual from 420 kg K/ha applied in a previous season.

2. **Analysis by model**

   The model calibration with these squash trial data worked quite well giving an $R^2$ of 0.72 in 1973 and 0.56 in 1976 (Table 3). The only reason to combine the trials would be with regards to N fertiliser response, but both trials were problematic in terms of N. One had uniformly high soil N and the other (which only tested N fertiliser) was part of a trial series with a history of different N rates. Since no soil N was measured it was uncertain what the total N supply was in the different 1976 treatments. The average value, estimated by the model, was very high.

   The 1973 model output for N response (Fig. 14) reflected the original finding of no response to N. Figure 15, showing marginal return, predicts that any money spent on N fertiliser would be wasted. One explanation for the lack of N response in this trial is the model estimate of soil N, which was 163 kg/ha, a high level which reflects the site history as pasture.

   The 1973 yield response to P graph (Fig. 16) confirms the large response to P indicated by the original trial analysis. The 1986 trials by Buwalda found the same high P response. The curves at the two lower soil P levels (which were within the calibration range) are based on extrapolation below 120 kg P/ha, since that was the lowest trial rate. The curves stop before going below the minimum P value required for any yield (the predicted negative yield values are erroneous). Due to this, the marginal returns at these two soil levels could not be calculated in Figure 17, but the returns would most probably be very large.

# Squash 1973 Levin

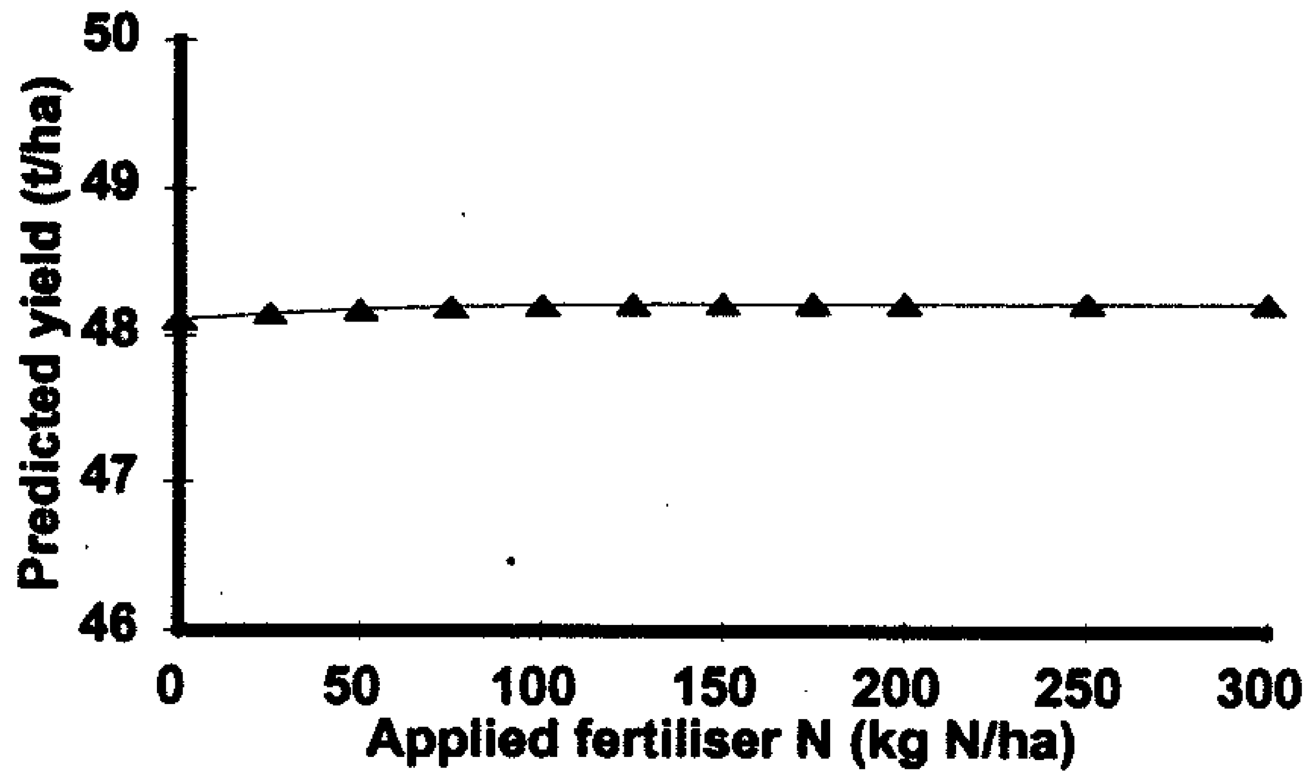


**Figure 14: Predicted yield response to N fertiliser**
Soil P, K, Mg and pH non limiting, no drought
1. $N_s$ = 163 kg/ha

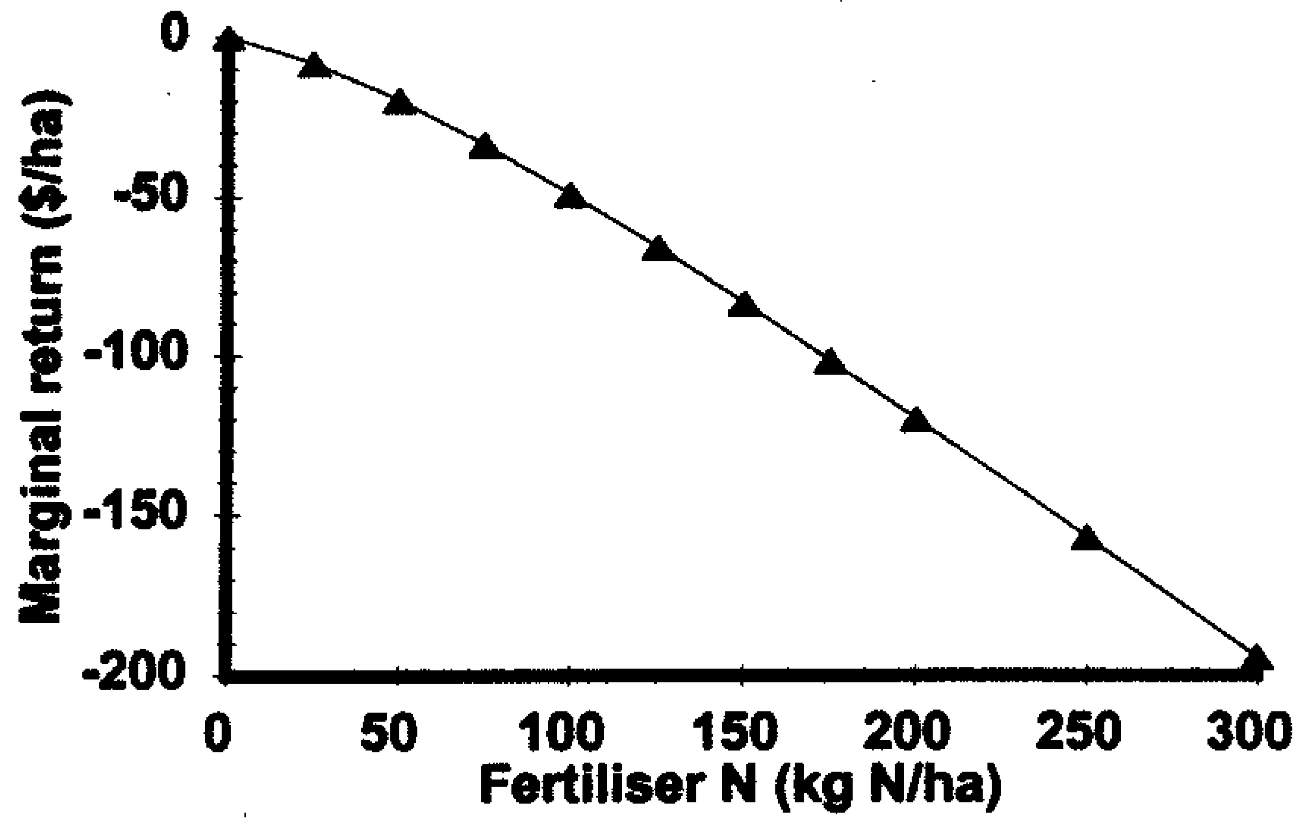


**Figure 15: Marginal return to Nitrogen fertiliser**
1. $N_s$ = 163 kg/ha

| Fertiliser Costs | |
|---|---|
| $ kg N | 0.74 |
| $ kg P | 1.8 |
| $ kg K | 0.78 |

| Crop Value | $ |
|---|---|
| $ per saleable tonne | 300 |
| Saleable % | 0.8 |
| $ per total tonne | 240 |

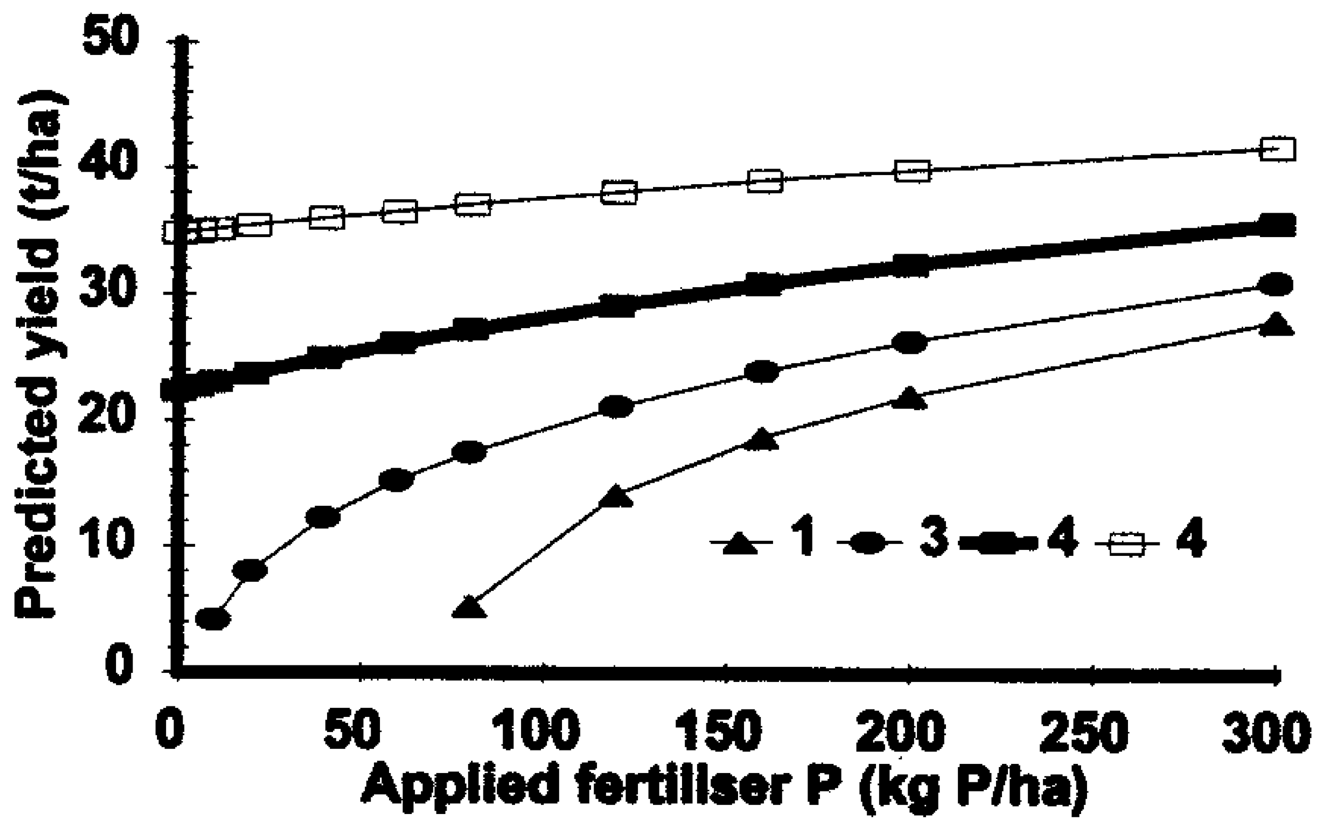


**Figure 16: Predicted yield response to P fertiliser**
Soil N, K, Mg and pH non limiting, no drought.
1. Olsen P = 5 µg/ml
2. Olsen P = 10 µg/ml
3. Olsen P = 20 µg/ml (outside calibration range)
4. Olsen P = 40 µg/ml (outside calibration range)

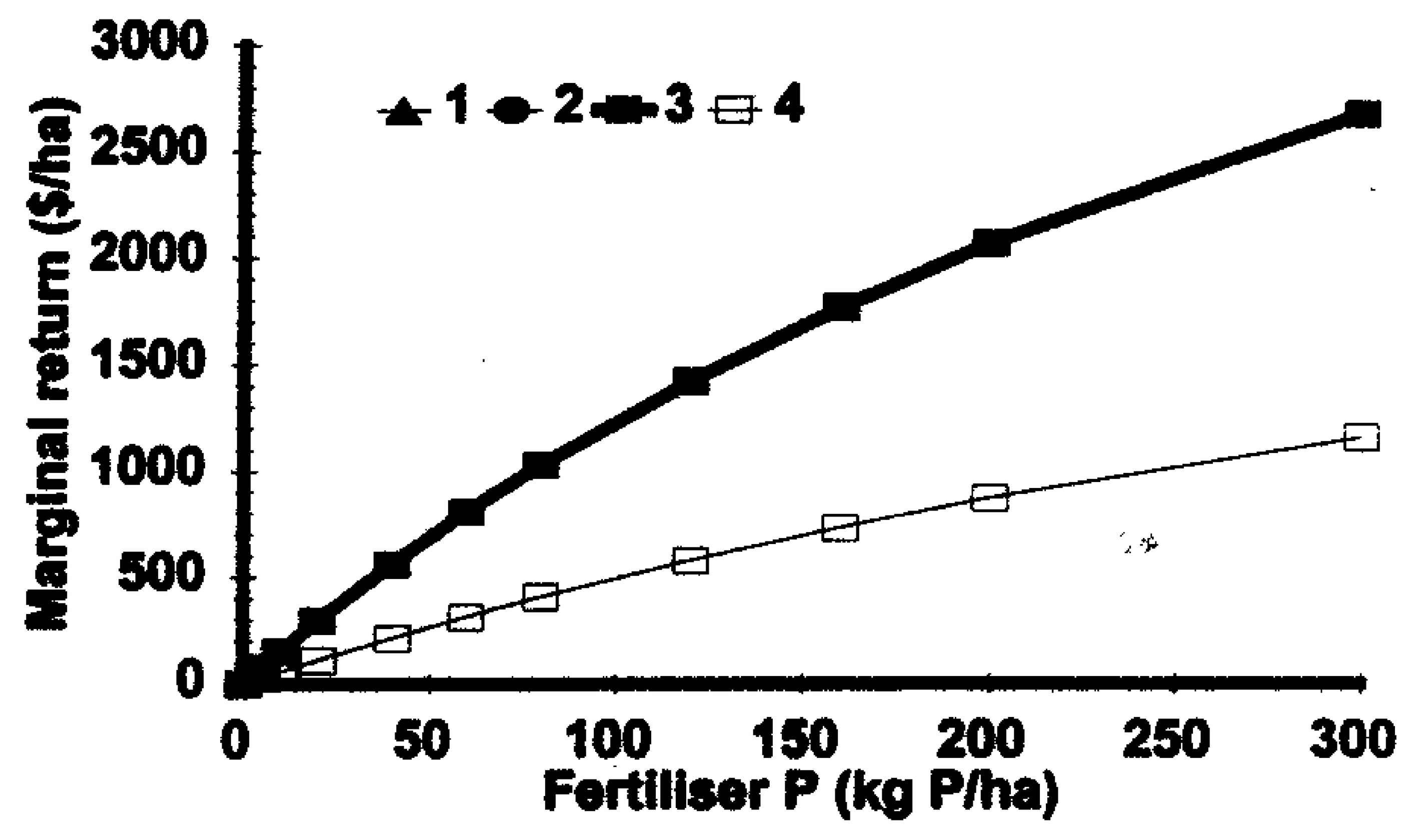


**Figure 17: Marginal return to Phosphorus fertiliser**
1. Olsen P = 5 µg/ml
2. Olsen P = 10 µg/ml
3. Olsen P = 20 µg/ml (outside calibration range)
4. Olsen P = 40 µg/ml (outside calibration range)

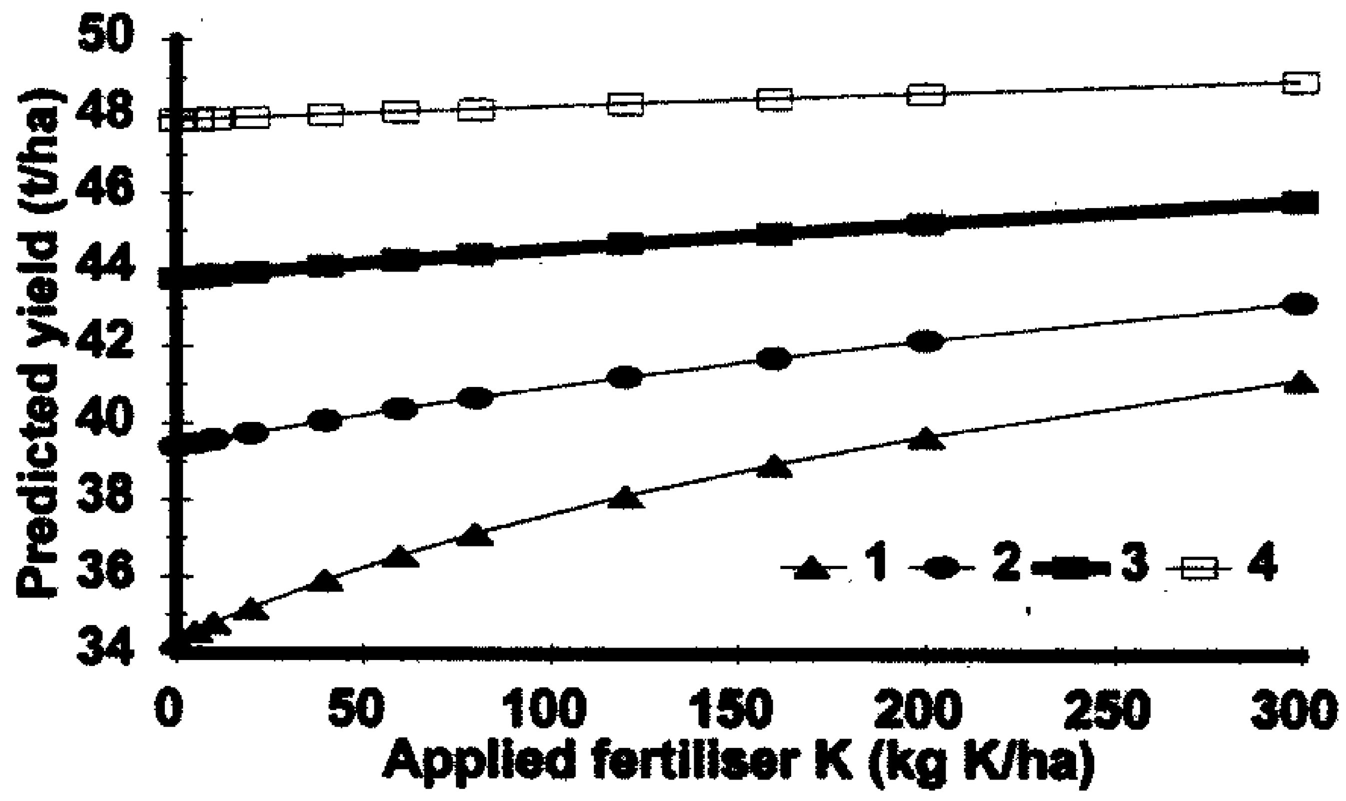


**Figure 18: Predicted yield response to K fertiliser**
Soil N, P, Mg and pH non limiting, no drought.
1. Exchangeable K = 0.15 meq/100g (outside calibration range)
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g (outside calibration range)
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

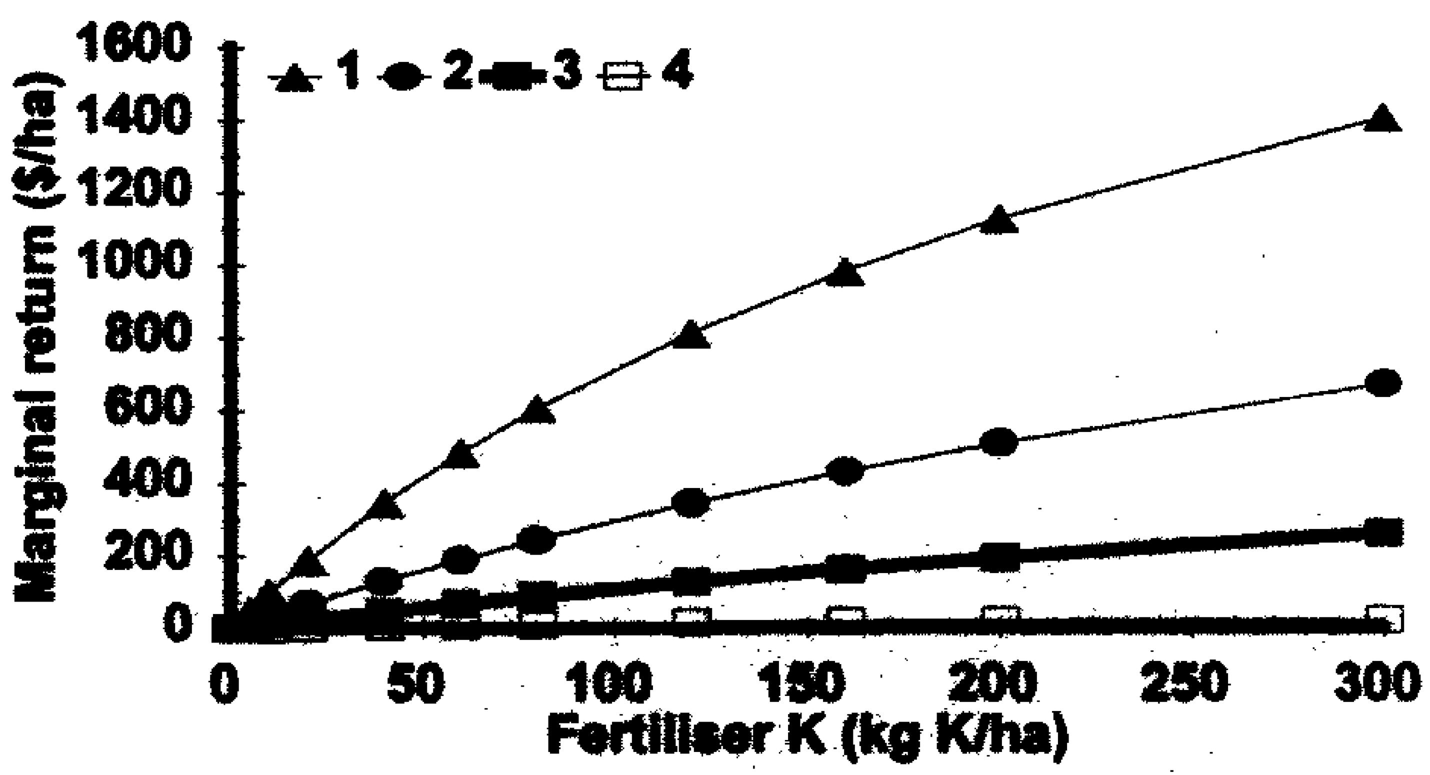


**Figure 19: Marginal return to Potassium fertiliser**
1. Exchangeable K = 0.15 meq/100g (outside calibration range
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g (outside calibration range
4. Exchangeable K = 1.2 meq/100g (outside calibration range

The 1973 yield graph (Fig. 18) shows a small positive response to K when soil K is 0.6 meq/100 g, the only level within the calibration range. The marginal return (Fig. 19) at this soil K level was also small. The predicted yield and return for fertiliser K at the lowest soil K was more substantial, which is in agreement with the 1986 results of Buwalda on low K soil.

The 1976 yield response to N fertiliser was greater than in 1973, but still not large (figures not shown). Response was positive all the way up to 300 kg N/ha, which is higher than the rate noted in the original trial results. The fertiliser rate where marginal return is predicted to stop increasing was only about 200 kg/ha, however. It should be noted that the maximum plot yields were only half of those in the 1973 trial, suggesting some unknown limitation existed. The model does not have much data to use where both fertiliser N and initial soil N are low since neither trial had a zero rate of fertiliser. In this trial the soil N estimated by the model was 174 kg/ha, even higher than the 1973 trial which went in right after pasture. This figure is, by necessity, just an average N value, since the trial was the fourth in a series where the N fertiliser rates had been applied cumulatively (so some plots had moderate N and other very high N). Regarding squash response to N fertiliser, these two Levin trials did not contribute results that could be used to make fertiliser recommendations, even after re-analysis by the model. The best available guidelines are the Buttercup Squash Cultural Guidelines (1990), which are presumably based on the 1986 MAF trial results from Pukekohe (see Section 6).

The 1976 trial did not compare P or K treatments and the model re-analysis produced predictions which should not be utilised without being fortified by additional trial data

The overall conclusions on squash for the two trials are that there is a strong yield response to fertiliser P on soils with an Olsen P below 10 µg/ml, but both N and K response patterns cannot be confirmed without more data from squash in soils low in those nutrients.

### *5.3.4 Spinach results*

1. **Original trial analysis**

The two Levin trials in 1969 and 1970 both had 2 x N and 2 x P treatments and 2 x K (residual). The plot yields ranged from 2 to 27 t/ha in 1969 and 6 to 40 t/ha in 1970. Conclusions from the original 1969 analysis were that maximum rates of fertiliser for yield increases were: 158 kg N/ha, <45 kg P/ha, and the residual from 1050 kg K/ha in a prior year. In 1970 the maximum values were: <53 kg N/ha, <45 kg P/ha, and the residual from 1050 kg K/ha. So the P and K results were the same, but N response results were very contradictory.

## 2. Analysis by model

The model fit of actual yield to simulated yield for the 1969 trial was poor ($R^2$ = 0.21), and possibly related to the unknown cause of the somewhat low yields that year. Yet the fertiliser response graphs appear to offer a useful starting point.

In 1969 yield response to N fertiliser at the soil level estimated by the model of 38 kg/ha (Fig. 20) is predicted to be positive across the whole range of N fertiliser to 300 kg/ha. The marginal return on N fertiliser (Fig. 21) is predicted to be spectacular, due to the high value per tonne of spinach.

Spinach responses to P fertiliser in 1969 (Fig. 22) are predicted to be nearly zero at the two higher soil P levels, but at an Olsen P value of 10 µg/ml there should be a response to P at rates up to 75 kg/ha. This would also be expected to occur at soil P level 1, but 5 µg/ml was below the calibration range in this data. The corresponding effects of increasing P fertiliser on marginal return (Fig. 23) would be: no benefit at the soil P level 4, a significant return on a very small application at soil level 3, a dramatic return up to 75 kg P/ha with soil level 2 and presumably an even greater effect at the lowest soil P. These predicted large returns reflect the high crop value. While such predictions remain speculative until field verification of the effects of low fertiliser rates on soils with lower P levels, the large possible returns do underline the importance of further investigation. By comparison, the conclusions made at the time of the original trial are less informative and do not include the interesting economic aspect.

Yield response to fertiliser K (Fig. 24) is based on soil test measurement of the residual fertiliser, since no new K was applied. Fortunately, there was a wide range of soil K (0.12 to 0.84 meq/100 g). The predicted effect is once again very dependent on initial soil K, since in the two higher levels of soil K (3 and 4) there was little or no response. It looks likely that spinach in soils with lower levels of K would have a positive response up to 300 kg K/ha (and apparently higher), but the gain would be small in soils with K at level 2. The marginal return on these fertiliser applications (Fig. 25) was zero for soil K level 4, while in the other soil K levels it increased right up to 300 kg/ha; the lower the initial soil K level, the greater the dollar return at the upper fertiliser rates. The high returns were due to the high crop value, since the yields only increased by small tonnages.

The model outputs for the 1970 spinach trial for both P and K were very similar to that just presented for 1969. The degree of model fit ($R^2$=0.57) was better than the 1969 trial, lending strength to the P and K results just cited. Let's look at these two fertilisers first.

# Spinach 1969 Levin

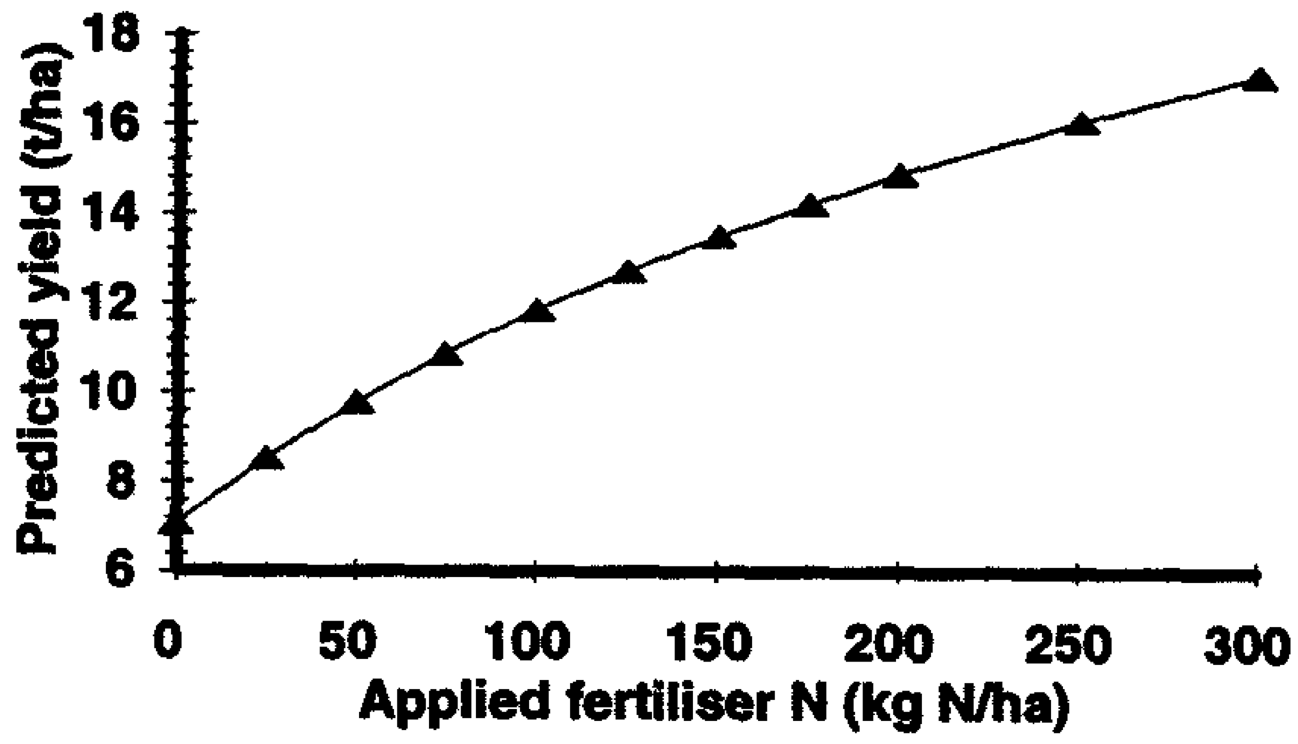


**Figure 20: Predicted yield response to N fertiliser**
Soil P, K, Mg and pH non limiting, no drought
1. $N_s$ = 38 kg/ha

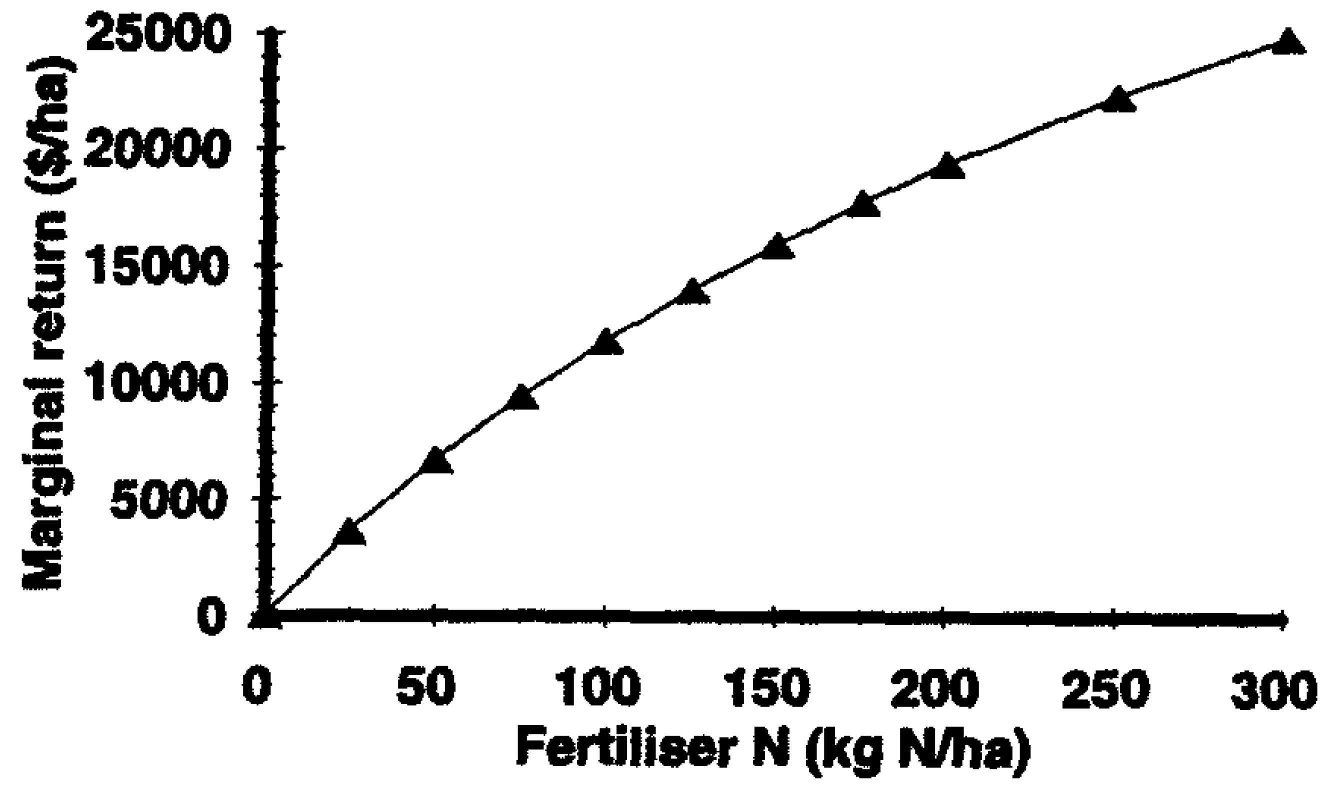


**Figure 21: Marginal return to N fertiliser**
1. $N_s$ = 38 kg/ha

| **Fertiliser Costs** | |
|---|---|
| $ kg N | 0.74 |
| $ kg P | 1.8 |
| $ kg K | 0.78 |

| **Crop Value** | |
|---|---|
| $ per saleable tonne | 5000 |
| Saleable % | 0.5 |
| $ per total tonne | 2500 |

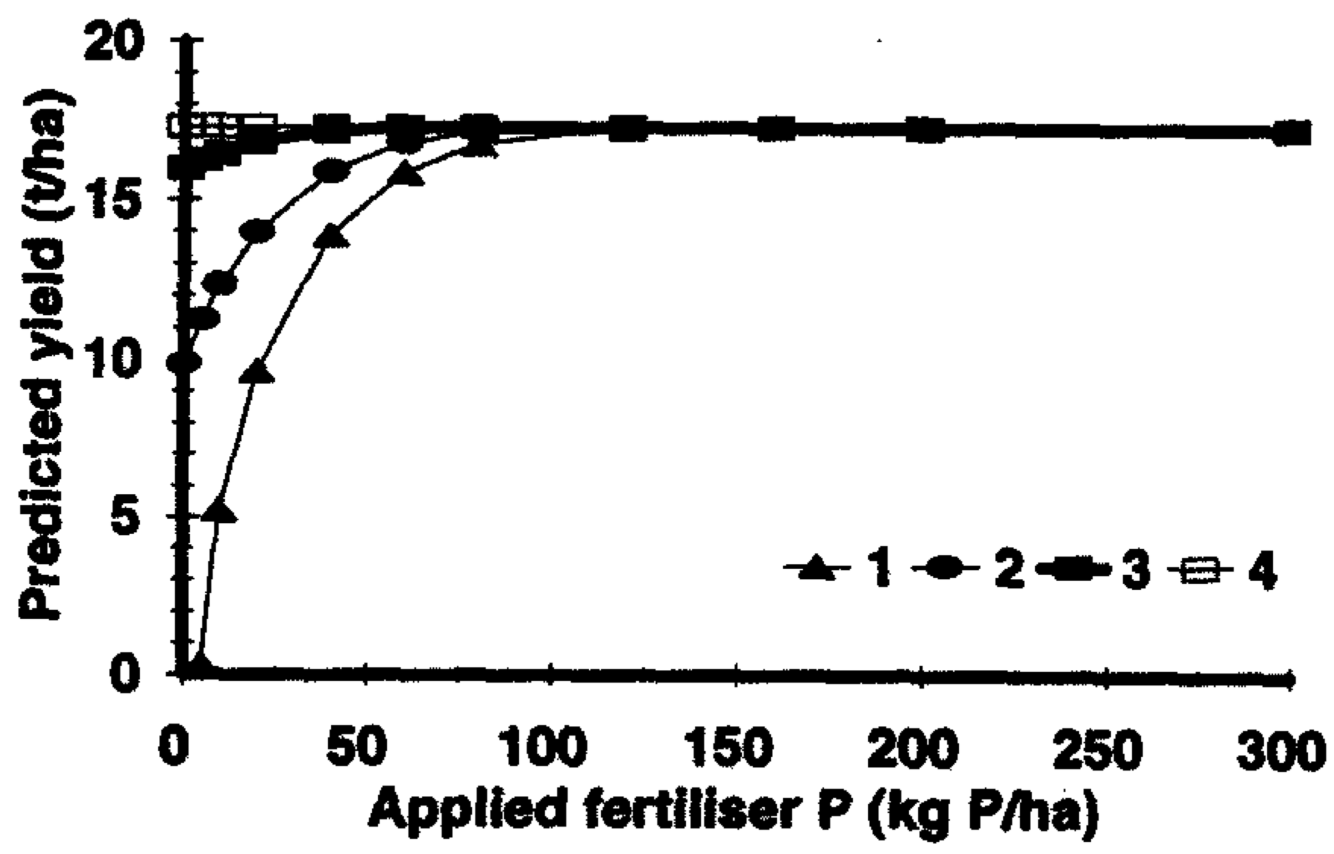


**Figure 22: Predicted yield response to P fertiliser**
Soil N, K, Mg and pH non limiting, no drought.
1. Olsen P = 5 µg/ml (outside calibration range)
2. Olsen P = 10 µg/ml
3. Olsen P = 20 µg/ml
4. Olsen P = 40 µg/ml

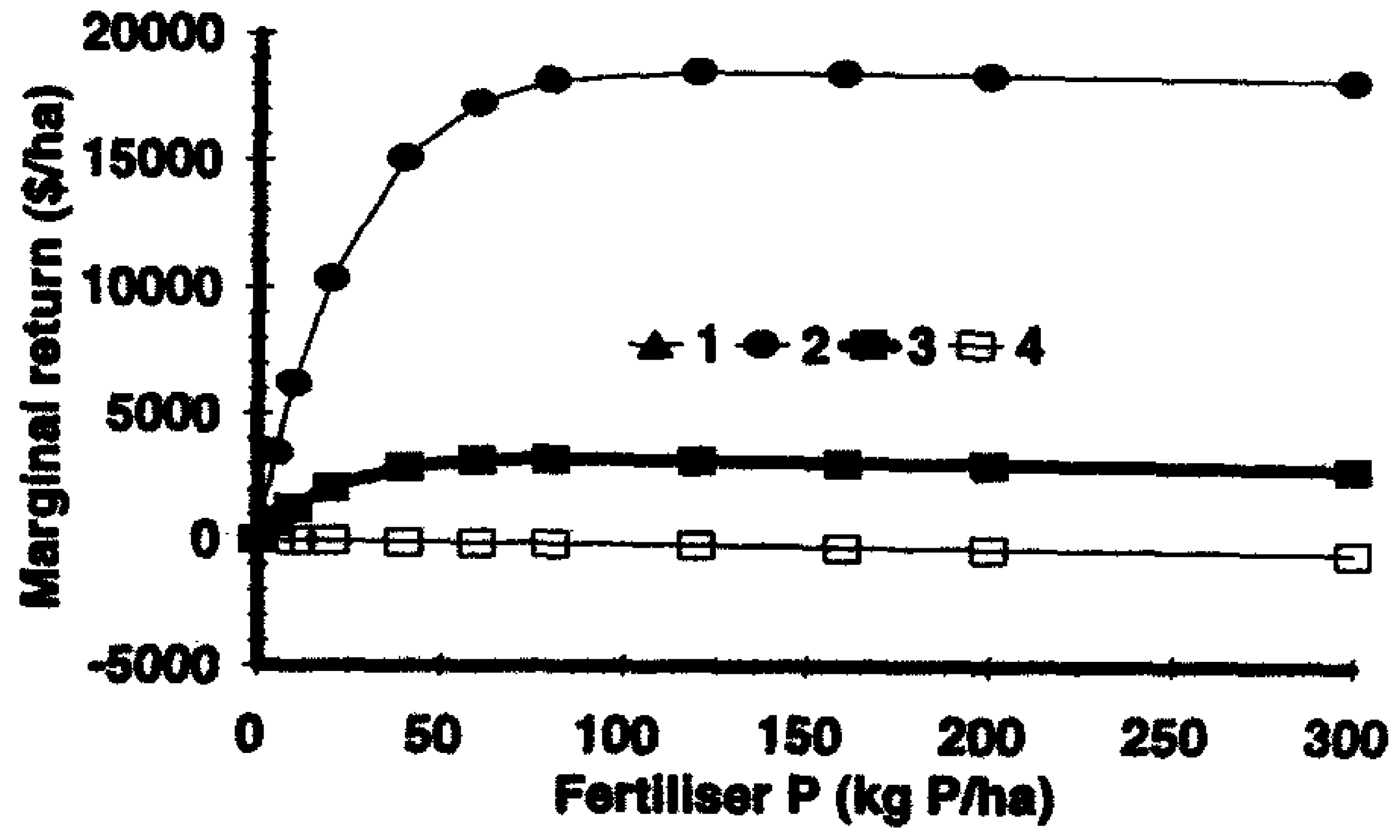


**Figure 23: Marginal return to P fertiliser**
1. Olsen P = 5 µg/ml (outside calibration range)
2. Olsen P = 10 µg/ml
3. Olsen P = 20 µg/ml
4. Olsen P = 40 µg/ml

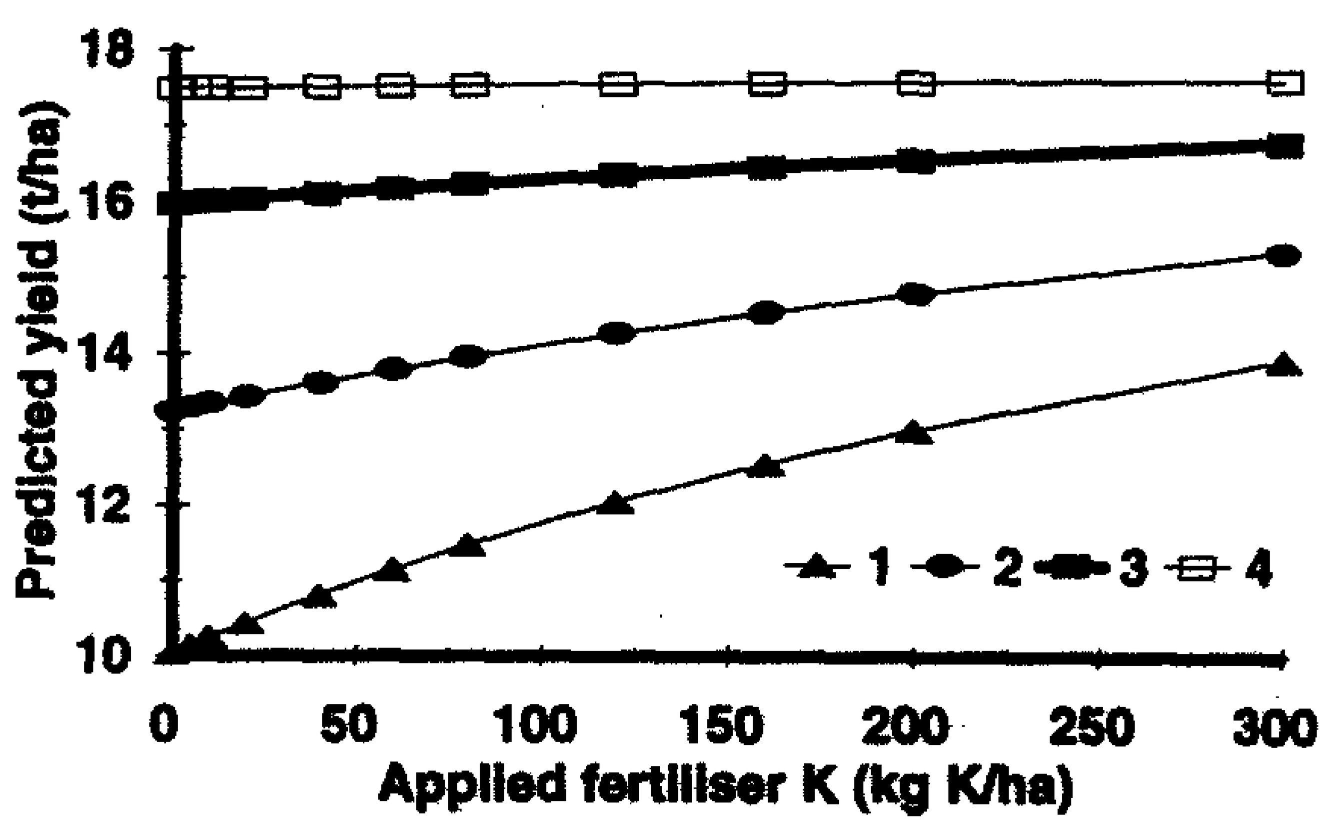


**Figure 24: Predicted yield response to K fertiliser**
Soil N, P, Mg and pH non limiting, no drought.
1. Exchangeable K = 0.15 meq/100g
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

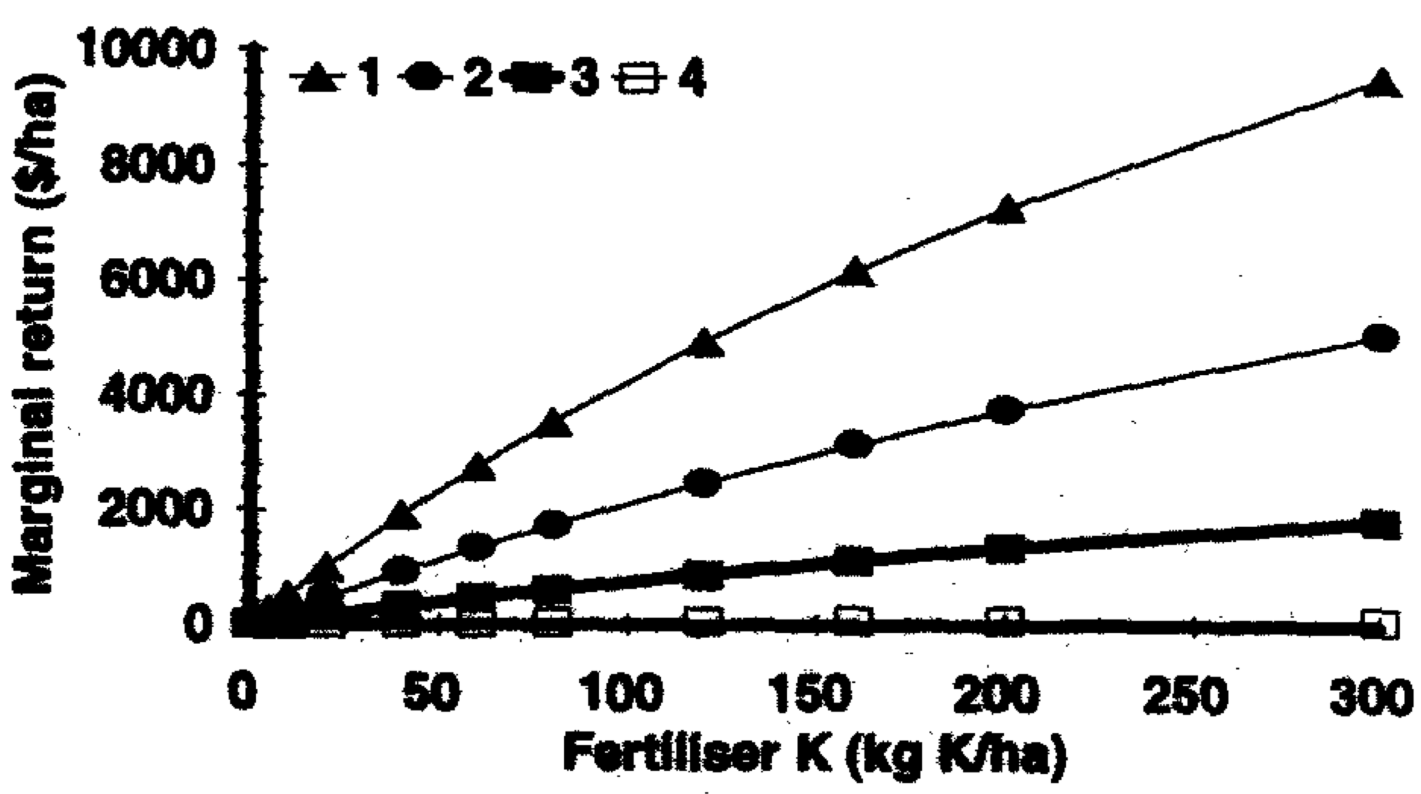


**Figure 25: Marginal return to K fertiliser**
1. Exchangeable K = 0.15 meq/100g
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

# Spinach 1970 Levin

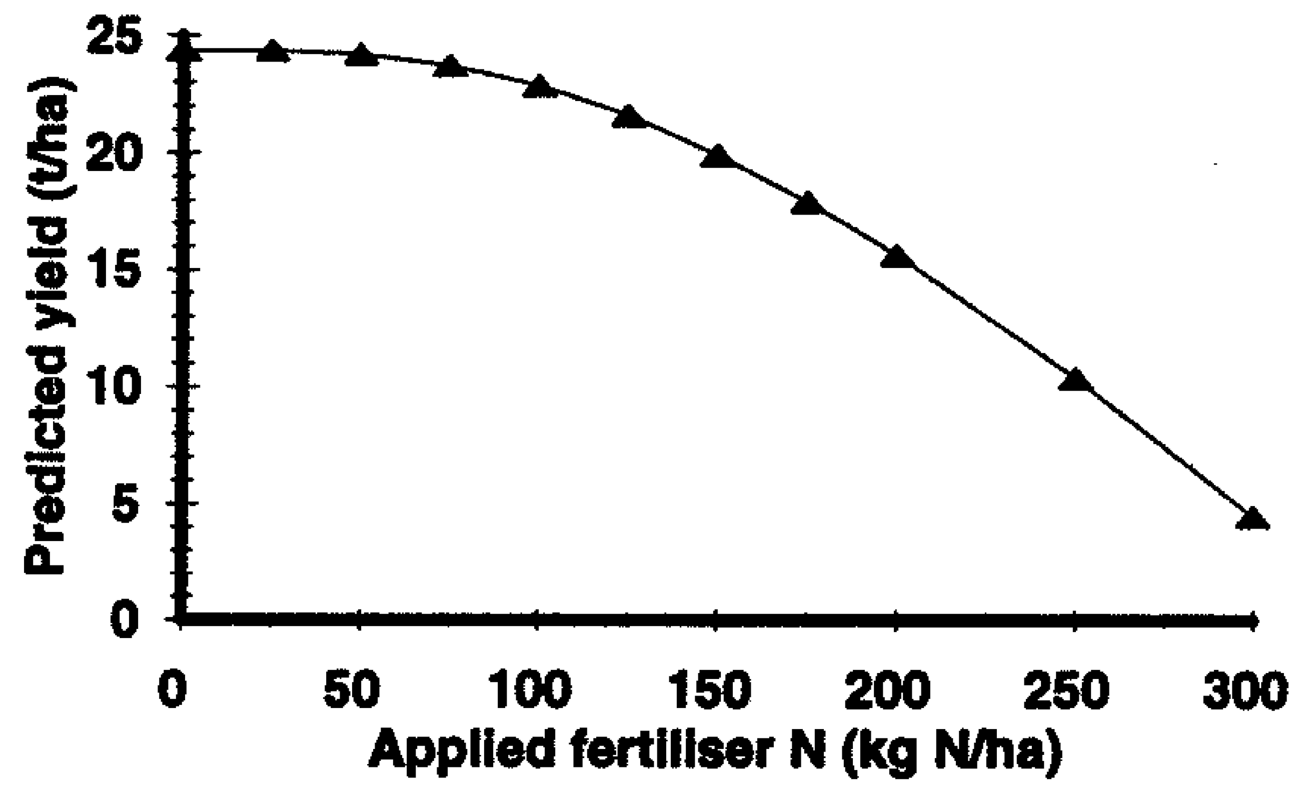


**Figure 26: Predicted yield response to N fertiliser**
Soil P, K, Mg and pH non limiting, no drought
1. $N_s$ = 90 kg/ha;

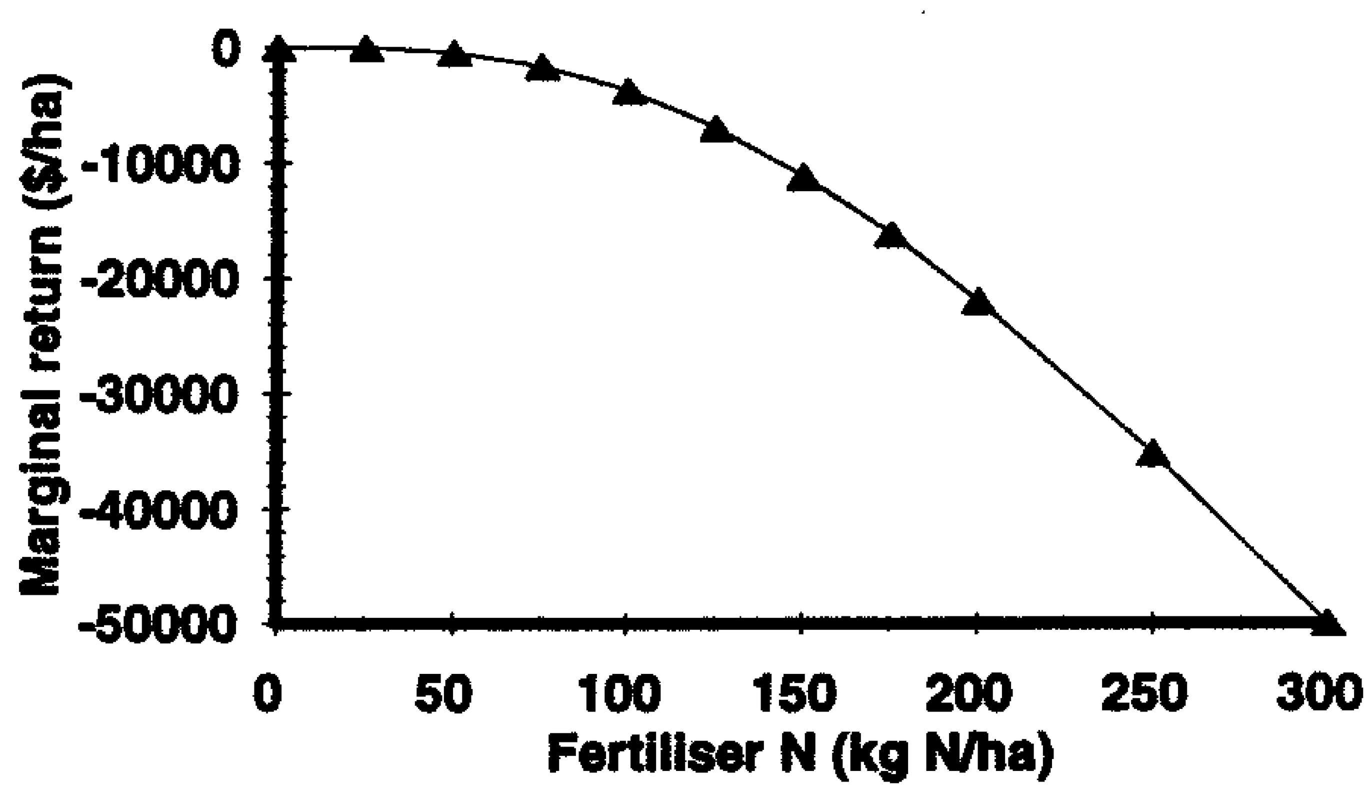


**Figure 27: Marginal return to Nitrogen fertiliser**
1. $N_s$ = 90 kg/ha;

| Fertiliser Costs | |
|---|---|
| $ kg N | 0.74 |
| $ kg P | 1.8 |
| $ kg K | 0.78 |

| Crop Value | $ |
|---|---|
| $ per saleable tonne | 5000 |
| Saleable % | 0.5 |
| $ per total tonne | 2500 |

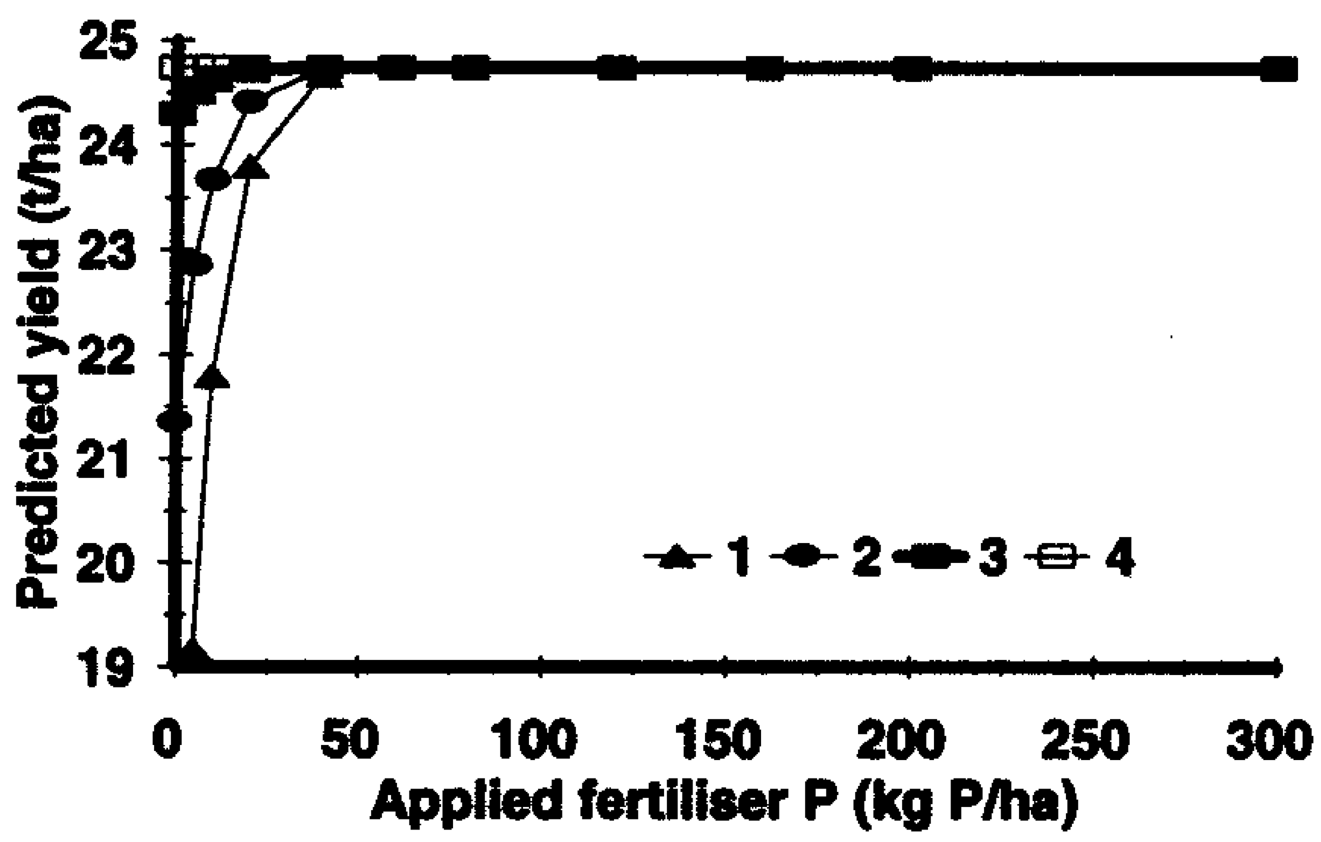


**Figure 28: Predicted yield response to P fertiliser**
Soil N, K, Mg and pH non limiting, no drought.
1. Olsen P = 5 μg/ml (outside calibration range)
2. Olsen P = 10 μg/ml
3. Olsen P = 20 μg/ml
4. Olsen P = 40 μg/ml

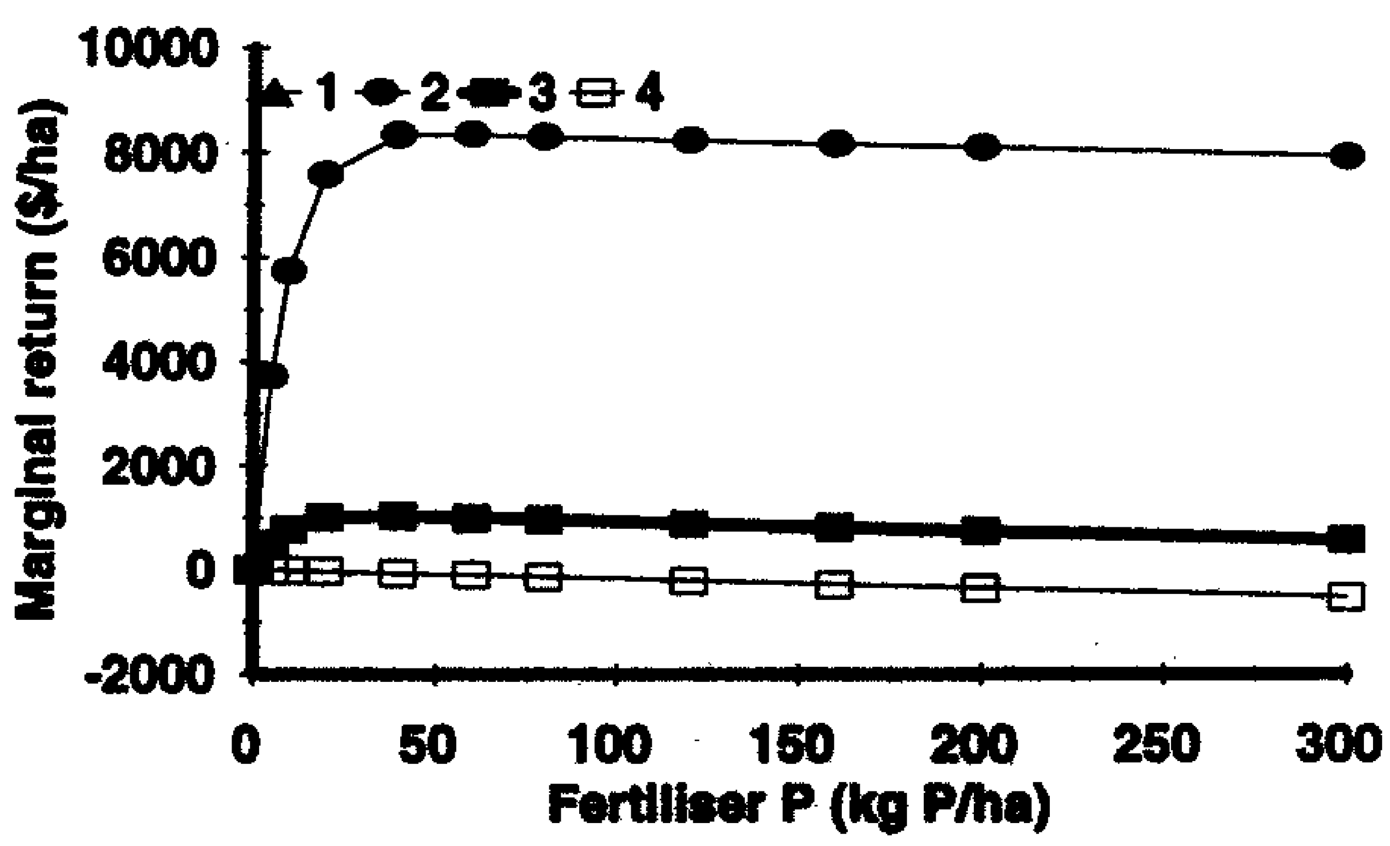


**Figure 29: Marginal return to Phosphorus fertiliser**
1. Olsen P = 5 μg/ml (outside calibration range)
2. Olsen P = 10 μg/ml
3. Olsen P = 20 μg/ml
4. Olsen P = 40 μg/ml

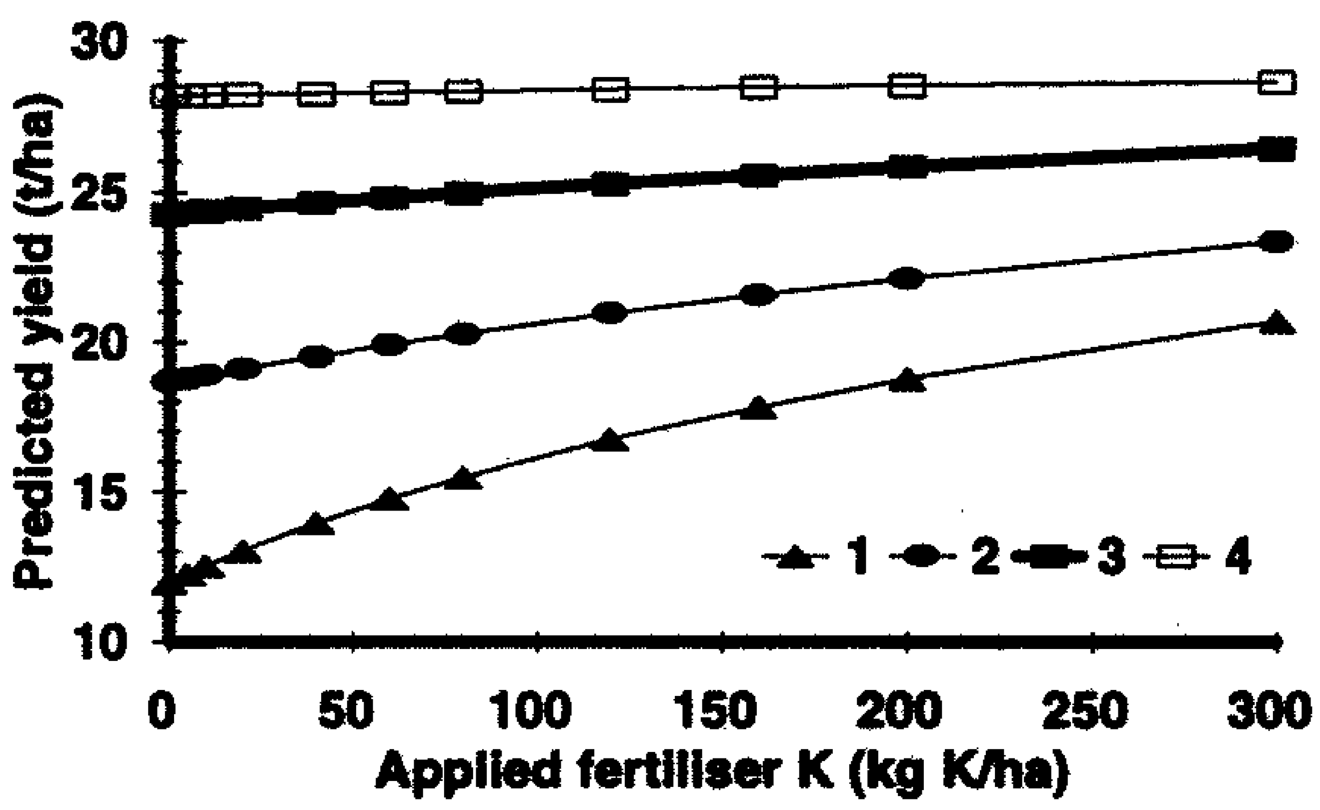


**Figure 30: Predicted yield response to K fertiliser**
Soil N, P, Mg and pH non limiting, no drought.
1. Exchangeable K = 0.15 meq/100g
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

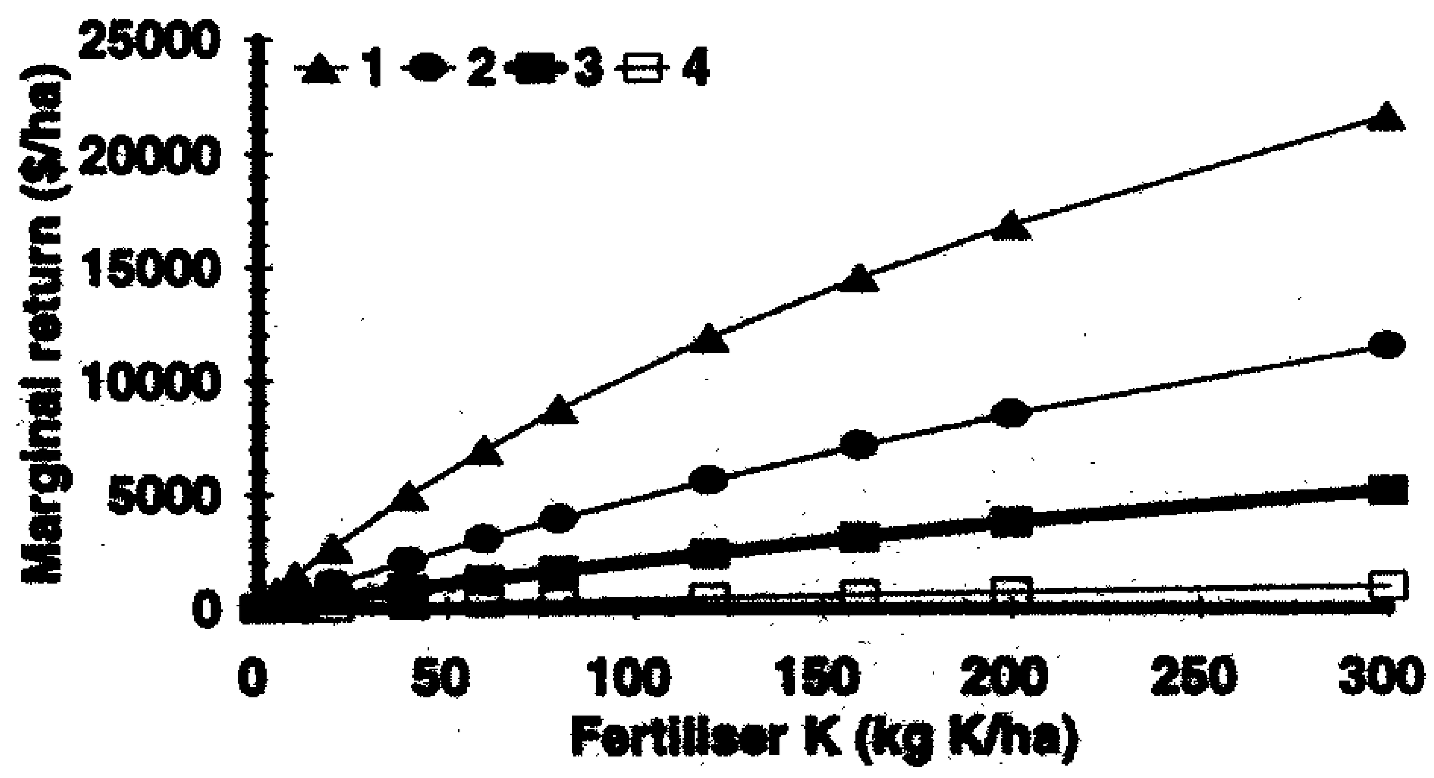


**Figure 31: Marginal return to Potassium fertiliser**
1. Exchangeable K = 0.15 meq/100g
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

The predicted yield response to P (Fig. 28) was zero, except at rates of P fertiliser below 40 kg P/ha on soils with P levels of 10 µg/ml or less. No plots in the trial were in this range so the prediction is tentative until data are available from a trial in low P soil. This would have given a marginal return on fertiliser of over $8000/ha (Fig. 29), so it is worth checking.

The 1970 yield response to K fertiliser (Fig. 30), predicted based on soil levels with residual fertiliser, was positive for the lower two soil K levels. Since these are within calibration range and the original trial analysis found a response to the high residual treatment, this result is a useful guideline for K fertilisation. The marginal return on K at the two lower soil K levels is predicted to be very high (Fig. 31).

The yield response to N (Fig. 26) was negative, which runs against most experience with spinach and contradicts the results of the 1969 trial in the same Levin test plots. The model result does agree with the original 1970 trial analysis, indicating no yield gain even at the low N rate. It is worth noting that the starting level of soil N estimated by the model was fairly high and the predicted yield with zero N was 25 t/ha, higher than the best treatment yield in the 1969 trial. Given the value of a tonne of spinach, the negative marginal return (loss) on N (Fig. 27) was predicted to be devastating. If this model prediction that high N can depress yield is confirmed, it is a very valuable piece of information which the original fertiliser trial analysis was not able to detect.

### 5.3.5 Cauliflower results

1. **Original trial analysis**
   The trial compared N, P, and K treatments and plot yields ranged from 23 to 66 t/ha. The conclusions drawn from the original data analyses were that the maximum rates for yield response were 115 kg N/ha, 180 kg P/ha, and no response to K fertiliser.

2. **Analysis by model**
   The calibration of the 1969 trial data for the model was reasonably good for a single trial (Table 3). Predictions for P and K response are based largely on fertiliser treatments in this trial since all plots had very similar soil test values for P (all low) and K (all medium low).

   Nitrogen fertiliser at the average soil N level estimated by the model (Fig. 32) gave a positive response up to 300 kg/ha. Marginal returns (Fig. 33) ceased at a somewhat lower fertiliser rate near 200 kg/ha, with a $2000/ha return.

Yield response to fertiliser P (Fig. 34) is predicted to be positive at all four soil P levels, although the higher three levels were above the calibration range. The maximum rate for yield increase at Olsen P of 5 µg/ml was 175 kg/ha. The model predicts maximum P rates for added marginal return as 150 kg/ha (Fig. 35), and the dollar value is $20 000/ha, assuming our crop value figures are right.

Fertiliser K is predicted to give positive, but small, yield responses at the two lower soil K levels (Fig. 36). The maximum rates for a yield increase was over 200 kg K/ha for both of these soil K levels, but the marginal returns (Fig. 37) showed a loss on the three higher soil K levels, but a reasonable marginal return up to 200 kg K/ha with exchangeable soil K of 0.15 meq/ha.

In summary, the model predictions for cauliflower improves on the original conclusion for K by detecting a response at low soil K, raises the N requirement (but this should be tested), and refines the P requirement (a lower P rate and none for soil with Olsen P >40 µg/ml).

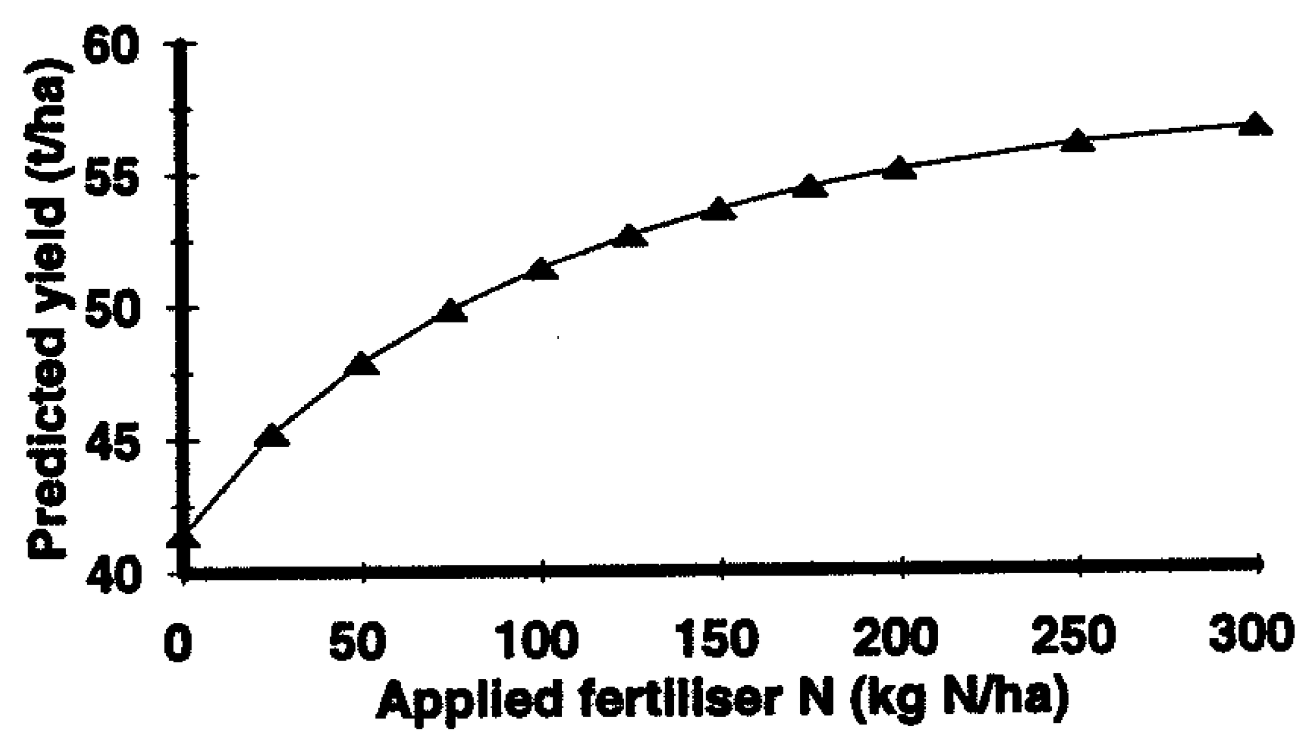


**Figure 32: Predicted yield response to N fertiliser**
Soil P, K, Mg and pH non limiting, no drought
1. $N_s$ = 62 kg/ha

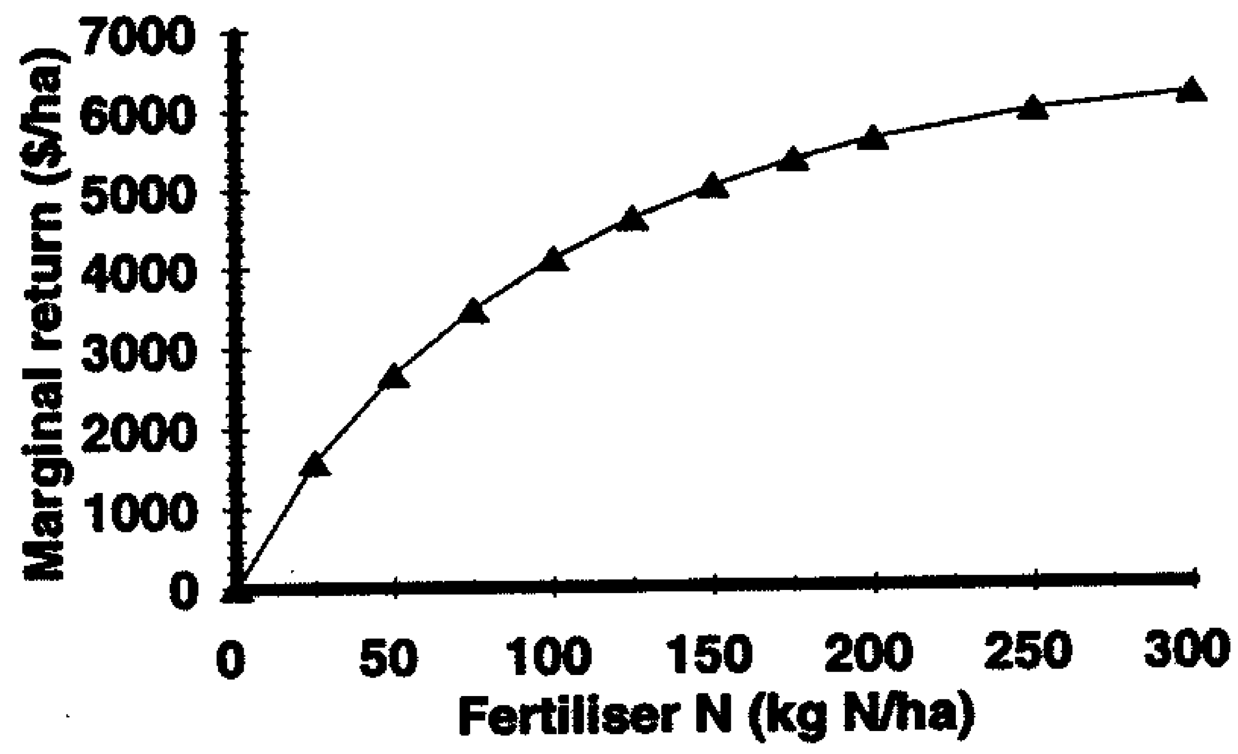


**Figure 33: Marginal return to N fertiliser**
1. $N_s$ = 62 kg/ha

| Fertiliser Costs | |
|---|---|
| $ kg N | 0.74 |
| $ kg P | 1.8 |
| $ kg K | 0.78 |

| Crop Value | $ | |
|---|---|---|
| $ per saleable tonne | 600 | |
| Saleable % | 0.7 | Includes trimming |
| $ per total tonne | 420 | |

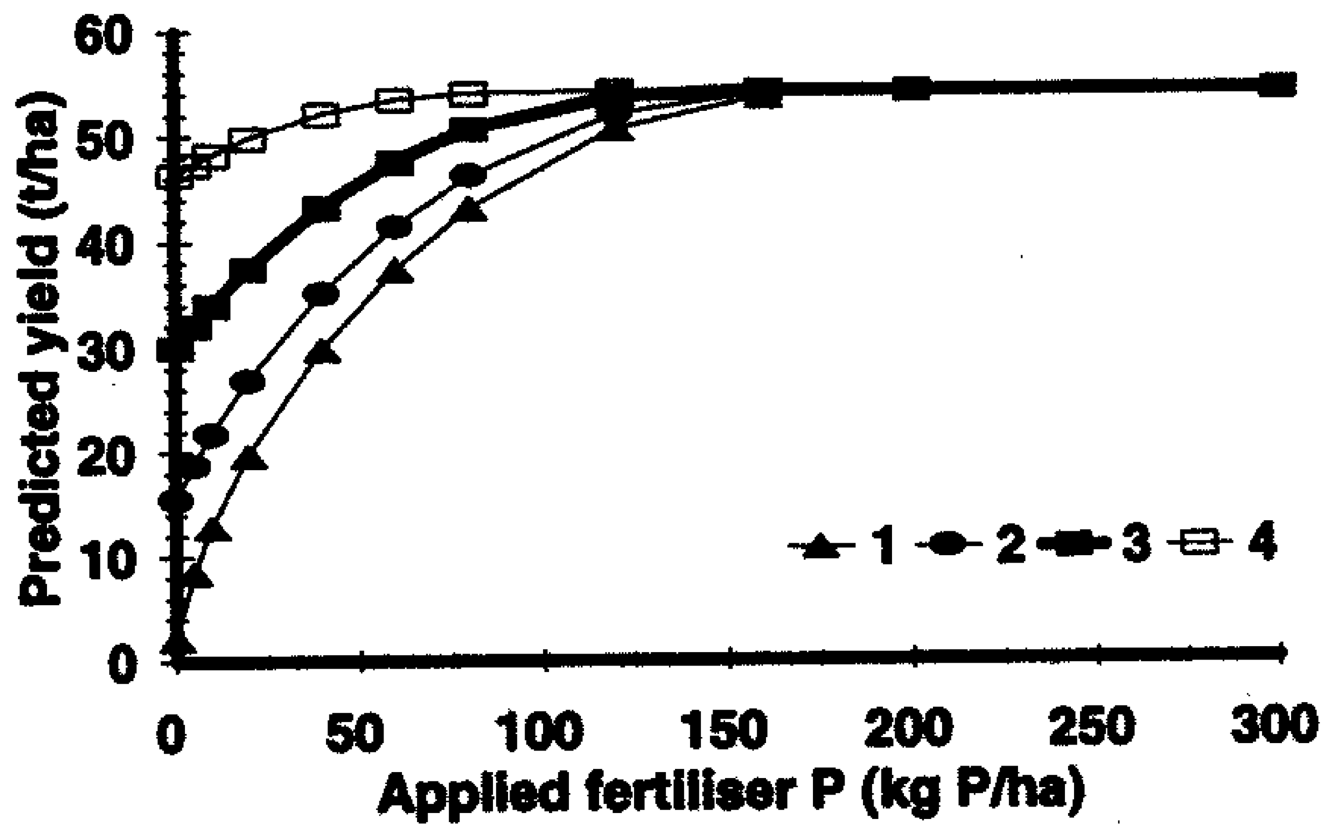


**Figure 34: Predicted yield response to P fertiliser**
Soil N, K, Mg and pH non limiting, no drought.
1. Olsen P = 5 μg/ml
2. Olsen P = 10 μg/ml (outside calibration range)
3. Olsen P = 20 μg/ml (outside calibration range)
4. Olsen P = 40 μg/ml (outside calibration range)

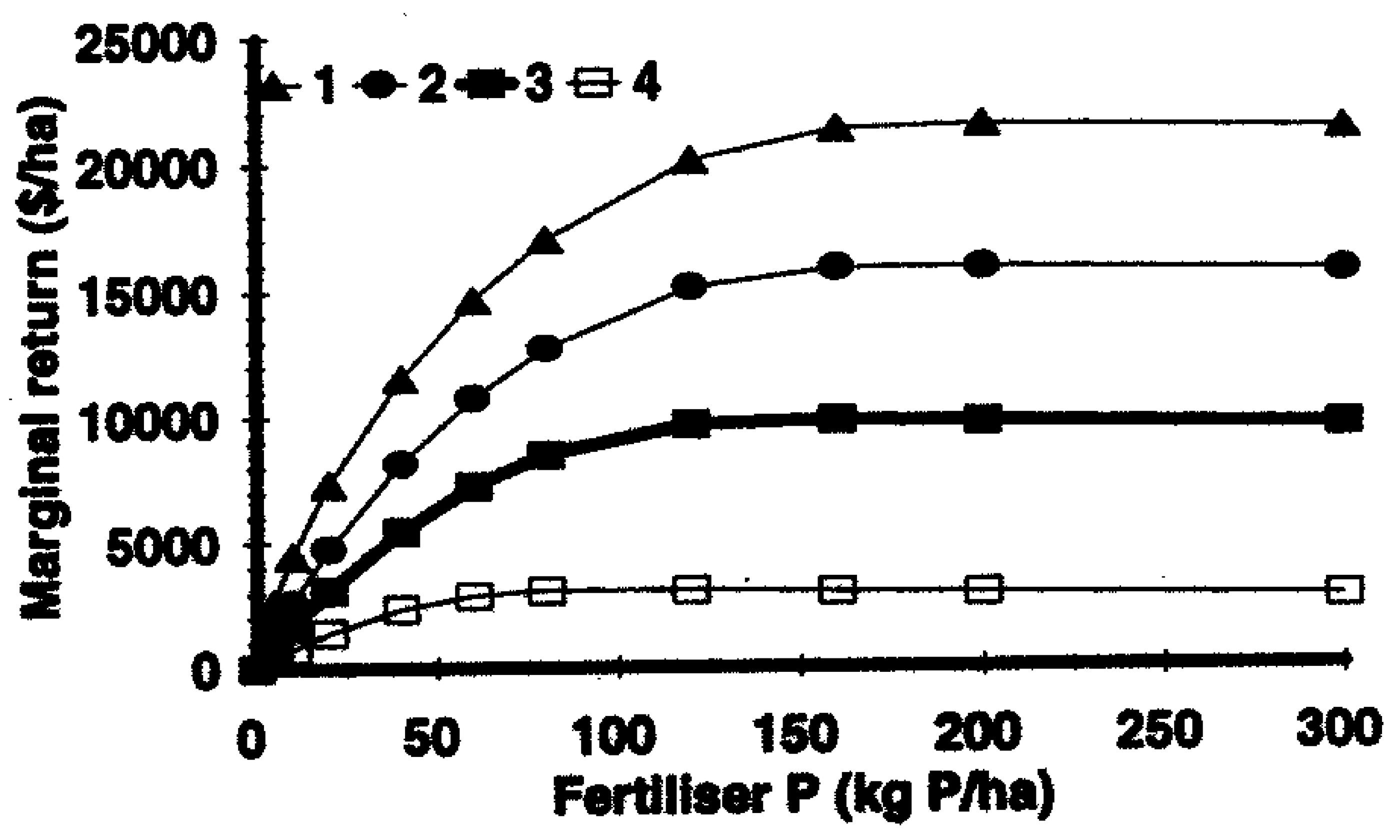


**Figure 35: Marginal return to P fertiliser**
1. Olsen P = 5 μg/ml
2. Olsen P = 10 μg/ml (outside calibration range)
3. Olsen P = 20 μg/ml (outside calibration range)
4. Olsen P = 40 μg/ml (outside calibration range)

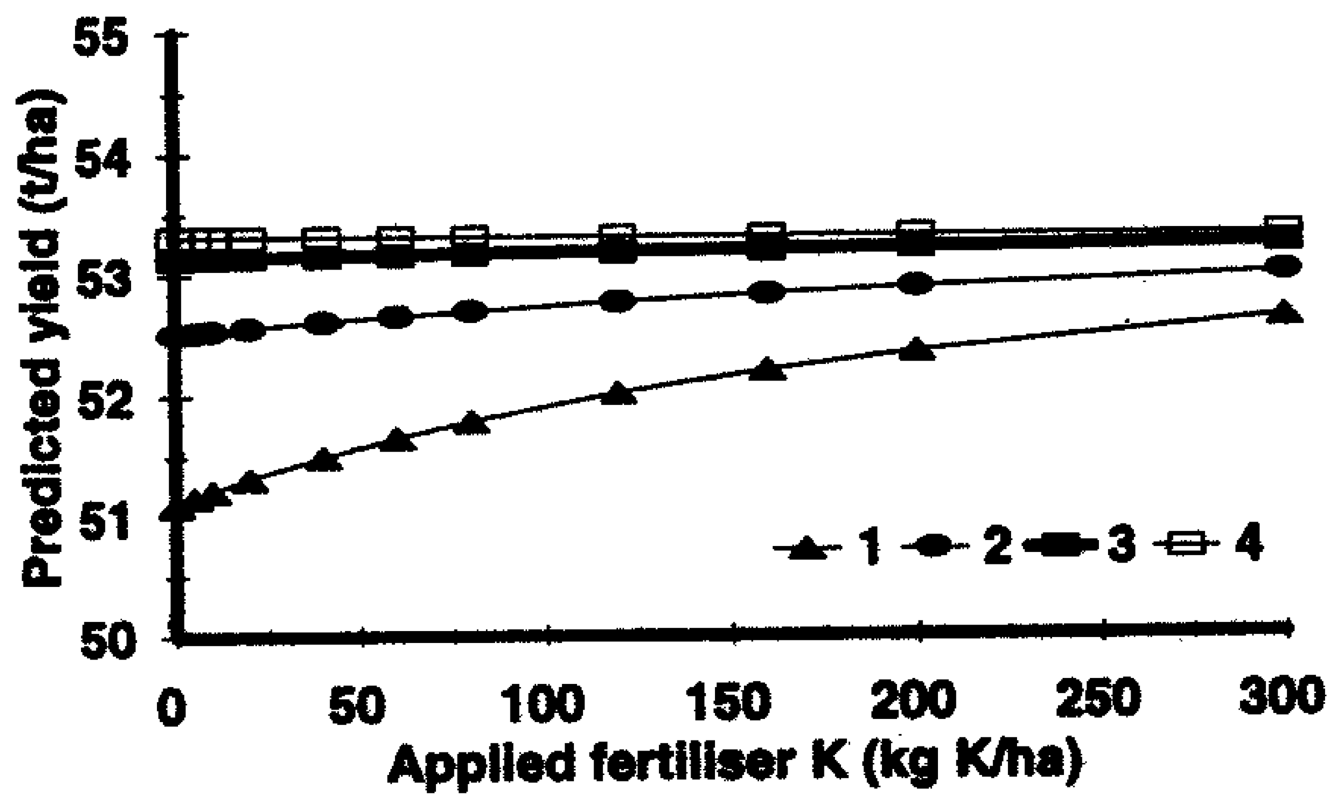


**Figure 36: Predicted yield response to K fertiliser**
Soil N, P, Mg and pH non limiting, no drought.
1. Exchangeable K = 0.15 meq/100g
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g (outside calibration range)
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

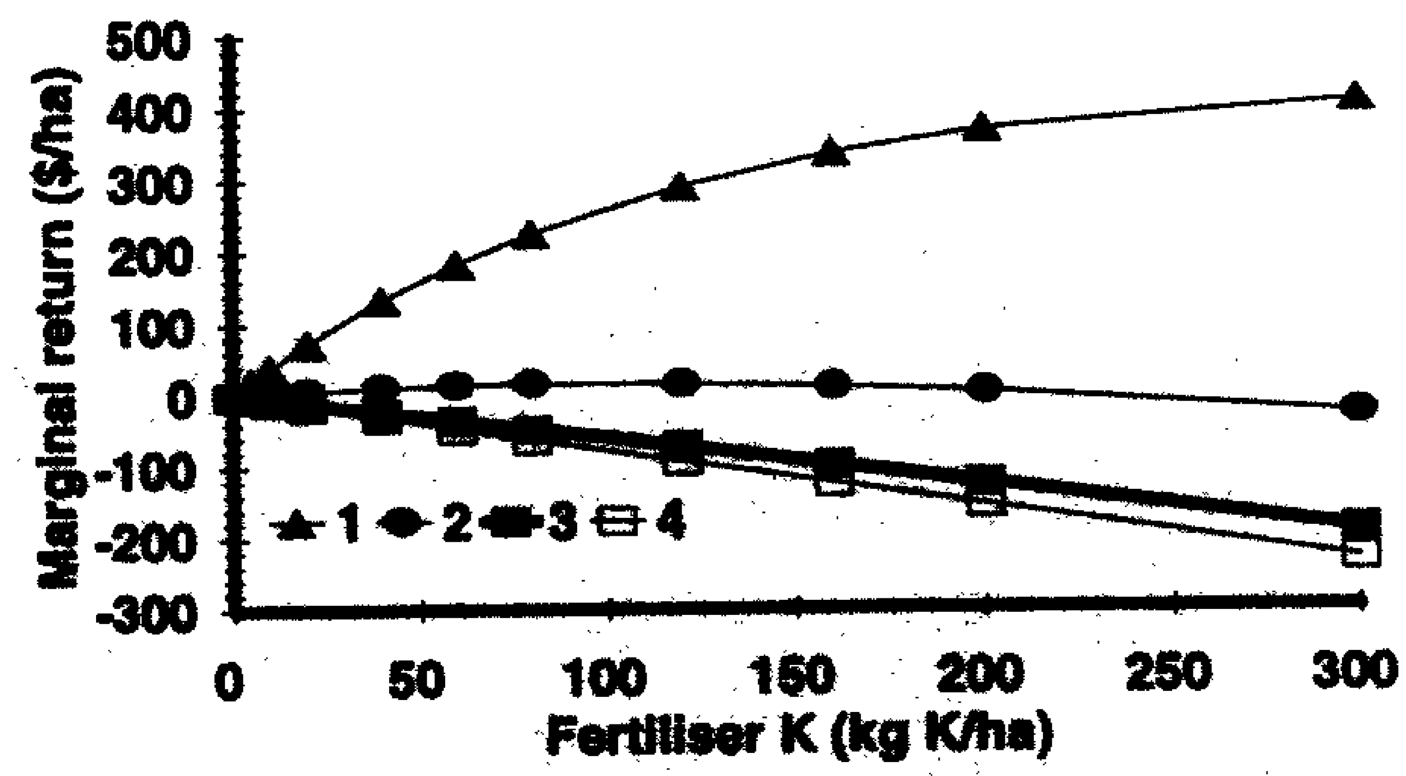


**Figure 37: Marginal return to K fertiliser**
1. Exchangeable K = 0.15 meq/100g
2. Exchangeable K = 0.3 meq/100g
3. Exchangeable K = 0.6 meq/100g (outside calibration range)
4. Exchangeable K = 1.2 meq/100g (outside calibration range)

# 6 RESULTS SUMMARY

We identified 13 trials with data sets which appeared to meet all criteria for re-analysis by the PARJIB model, and were able to use 12 sets: five for cabbage, two each for spinach, onions, and squash, and one for cauliflower.

Using the results from each of the five vegetable crops we drew specific conclusions as to how the use of the fertiliser response model compared to the conclusions possible from the original trial analyses. Rather than testing for differences between a few particular rates of fertilisers, the model provides continuous yield response curves to fertiliser rate, and does so for P and K fertilisers at each of four initial soil levels of the nutrient in the fertiliser. When any of these were outside the range of soil levels in the plots it was noted with the footnotes to the output graph, and precautions in making conclusions are needed (see Section 6). Other parts of the graphs were based only on information for soil nutrient levels or only fertiliser rates. That is not as reliable as when both sources of information were available since the model is designed to use the weighted total supply of nutrient from soil and fertiliser. However, the results still indicate likely response curves and highlight the most promising areas for further research. Since soil N was never measured prior to the trials, the graph output for yield response for crops with only one set of trial data is a single curve for response at the soil N level estimated by the model (using the same method involved in optimising model parameters).

In most cases there will be substantial benefits to users in having the level of detailed information generated by the model. This proved true whether the analysis was based on just one or two trials (as with cauliflower, onions, spinach and squash) or a large data set, as with the five combined cabbage trials.

The main difference with the cabbage analysis was the greater success of the model in generating predicted yield values which matched the actual plot yields (an $R^2$ of 0.91). This fit is as good as that of recent models we have developed with new data from custom-designed trials of sweet corn, beans, peas, carrots, tomatoes, and maize. Conclusions from the model graphs for winter cabbage can, therefore, be regarded as robust for Pukekohe, although it will still be useful to field validate the model using data from additional districts and cultivars. Graphed responses for the other crops should be considered as guidelines only, until confirmed with additional trial data and grower validation. These trial data could be obtained from overseas research results, which could be very efficiently interpreted and applied to New Zealand now that the Crop & Food Research model has been found to work well.

It has been a productive exercise to salvage this historical, previously unpublished data from MAF trials at Levin and Pukekohe.

# 7 RECOMMENDATIONS

## 7.1 Winter cabbage

The soil test values prior to growing winter cabbage provide specific guidelines for rates of fertilisers, assuming the cultivars in use today do not differ greatly in response from Wintercross. Recommendations are also based on the particular combination of crop value and fertiliser price shown in Figure 3 (these can, of course, be changed as required). The yields in the graph are the total tonnage harvested, since that is what fertilisers will influence most directly. Therefore, a saleable % is estimated to allow for trimming and cullage and crop value per tonne is adjusted to use with the total tonnage.

Figs. 4 and 5 indicate that when Olsen P is less than 20 µg/ml, apply 75-100 kg P/ha. Figure 7 makes it clear that with exchangeable K values below about 0.3 meq/100 g use up to 300 kg K/ha. When soil exchangeable K is 0.6 meq/100 g or higher, K fertiliser is unneccesary. The graph for marginal return on N fertiliser (Fig. 3) shows that a rate of up to 250 kg N/ha would pay a return on soil with initial soil N content of 140 kg N/ha and for soils with lower N levels rates up to 300 kg N/ha pay a very good return. It will still be useful to do commercial scale validation of these recommendations for newer cultivars and districts other than Pukekohe. When this is done we recommend that the accuracy of the model estimate of soil N is checked.

## 7.2 Onions, squash, spinach, and cauliflower

The Crop & Food Research PARJIB model output graphs for marginal return on fertiliser provide (except for squash) an improved guide to fertiliser rate decisions using results of the MAF fertiliser trials of the 1960s and 1970s. Conclusions from the model should be considered a supplement to the 1986 MAF Fertiliser Recommendations for Horticultural Crops due to the added detail in predictions for different initial soil nutrient levels. For example, on page 63 of the MAF handbook the N requirement for onions is given as 120 kg N/ha. Using your own test results for available N and Figures 8 and 9 in this report you will have an improved basis for deciding to apply either less than 120 kg/ha or higher rates (up to 175 kg N/ha). For P and K the actual rates suggested by Figures 10 to 13 are a convenient addition to the MAF handbook approach. For squash, which had additional MAF Pukekohe trials in the 1980s (published by Buwalda), the benefits of re-analysis of the Levin trials were minimal. The Pukekohe trials had already led to well defined recommendations, used by the Buttercup Squash Council in its book on cultural guidelines (King & Wishart

1990). There may also have been private trials on onions, spinach or cauliflower since 1986, but we have not had access to them for comparison to the model predictions.

Since the graphs are based on only one or two trials with each crop it will be useful to strengthen the fit of the model (which will refine the shapes of the response curves) using additional trial data. This could include past overseas trials if we could obtain full sets of raw data from researchers. This should be followed by commercial scale validation in New Zealand.

## 7.3 Limitations

When interpreting the effect of fitting these trial data sets into the new model, some inherent limitations need to be kept in mind. Firstly, several trials had no zero rate of fertiliser for some nutrients so the low ends of the yield response curves are outside the range of values used in the model analysis. Secondly, in field trials there are often different levels of crop stresses from environment or pests, which can cause some difficulty in combining different trials on the same crop. Thirdly, combining different cultivars can have similar problems, but not as great as might be imagined. For example, with processing tomatoes the model was first calibrated for one cultivar, but was found to apply to several other cultivars during later trials.

When using the model output graph to identify the maximum rate of fertiliser which increases yield, it is necessary to keep in mind the degree of precision associated with a prediction curve. The line relating yield response to fertiliser rate is actually the midline of a band whose width is proportional to the RMSE (Table 3), so when two curves for different soil nutrient levels are close to each other they should not be considered as proven different.

The graphs calculating profit response should use the saleable yield, rather than gross yield per plot. This was often not measured in these MAF trials so it has had to be estimated. Crop values will vary widely based on market prices and crop grade. For consultant or grower use of model output there needs to be a means of customising these inputs (or else produce tables with output from various combinations of crop value and fertiliser price).

# 8 APPENDICES

## Appendix I New Zealand publications on fertilisation of vegetables

Buwalda, J G, and Freeman, R E 1986. Hybrid squash: responses to nitrogen, potassium, and phosphorus fertilizers on a soil of moderate fertility. *New Zealand Journal of Experimental Agriculture 14*: 339-345.

Buwalda, J G 1986. Hybrid squash: yield responses to potassium and phosphorus fertilizers at four sites of varying initial fertility. *New Zealand Journal of Experimental Agriculture 14*: 347-354.

Buwalda, J G, and Freeman, R E 1987. Effects of nitrogen fertilisers on growth and yield of potato, onion, garlic, and hybrid squash. *Scientia Horticulturae 32*: 161-173.

Buwalda, J G, Rajan, S S S, and Scheffer, J J C 1987. Reducing fertiliser requirements for hybrid squash with localised applications of phosphorus and potassium and use of partially acidulated phosphate rock. *Fertilizer Research 13*: 169-180.

Buwalda, J G, and Freeman, R E 1988. Effects of phosphorus levels on phosphorus accumulation, growth and yield of hybrid squash in the field. *Scientia Horticulturae 34*: 201-210.

Carter, K E, and Stoker, R 1988. Responses of non-irrigated and irrigated garden peas to phosphorus and potassium on Lismore stony silt loam. *New Zealand Journal of Experimental Agriculture 16*: 11-15.

Clarke, C J, Smith, G S, Prasad, M, and Cornforth, I S eds. 1986. Fertiliser Recommendations for Horticultural Crops. MAF Agricultural Research and Advisory Services Divisions bulletin.

Goh, K M, and Vityakon, P 1983. Effects of fertilisers on vegetable production. 1. Yield of spinach and beetroot as affected by rates and forms of nitrogenous fertilisers. *New Zealand Journal of Agricultural Research 26*: 349-356.

Haynes, R J 1988. Comparison of fertigation with broadcast applications of urea-N on levels of available soil nutrients and on growth and yield of trickle-irrigated peppers. *Scientia Horticulturae 35*: 189-198.

King, D, and Wishart, G. 1990. Buttercup squash: cultural guidelines for export production. New Zealand Buttercup Squash Council, Wellington.

Mclenaghen, R D, Cameron, K C, Lampkin, N H, Daly, M L, and Deo, B. 1996. Nitrate leaching from ploughed pasture and the effectiveness of winter catch crops in reducing leaching losses. *New Zealand Journal of Experimental Agriculture 39*: 413-420.

Newton, S D, and Hill, G D 1987. Response of field beans (*Vicia faba*) to time of sowing, plant population, nitrogen, and irrigation. *New Zealand Journal of Experimental Agriculture 15*: 411-418.

Ofsofski, Nevan. 1991. Report of nutrition of autumn and winter broccoli (prepared for the New Zealand Federation of Vegetable and Potato Growers). MAF Technology, Levin.

Rajan, S S S, and Marwaha, B C 1993. Use of partially acidulated phosphate rocks as fertilizers. *Fertilizer Research 35*: 47-59.

Wilson, G J, and Scheffer, J J C 1983. Potassium responses in onions and spinach. *New Zealand Commercial Grower 38*: 11, 16.

Wood, R J 1997. Fertiliser use for vegetable production. In *Proceedings of the Workshop on Nutritional Requirements of Horticultural Crops*, L D Currie and P Loganethan, eds. Pp. 21-27, Massey University.

**Appendix II Fertiliser trial series conducted at Levin and Pukekohe Research Stations**

| Trial Series | Fertiliser Treatments | Number of Plots |
|---|---|---|
| LN 61 | 4 N x 4 P | 80 |
| LN 62 | 5 N x 5 P x 5 B x 5 Lime | 30 |
| LN 63 | 4 N x 4 P x 4 K | 64 |
| LN 65 | 2 N x 2 P x 2 K x 2 Lime x 2 Mg x 2 Na | 64 |
| LN 69 | 4 P x 4 residual P | 64 |
| LN 92 | 4 K x 4 Mg | 64 |
| LN 101 | 2 P x 2 Lime x 2 Gypsum x 2 Mo | 64 |
| LN 102 | 2 P x 2 Lime x 2 Gypsum x 2 Mo | 64 |
| LN 103 | 2 P x 2 Lime x 2 Gypsum x 2 Mo | 64 |
| LN 104 | 2 P x 2 Lime x 2 Gypsum x 2 Mo | 64 |
| LN 105 | 2 N x 2 P x 2 K x 2 Lime | 64 |
| LN 106 | 5 N x 5 P x 5 K x 5 Lime | 30 |
| LN 107 | 5 N x 5 P x 5 K x 5 Lime | 60 |
| LN 108 | 5 N x 5 P x 5 K x 5 Lime | 60 |
| LN 109 | 2 P x 2 Lime x 2 Gypsum x 2 Mo | 64 |
| LN 110 | 4 P x 4 Lime | 32 |
| LN 116 | 4 N x 4 P x 4 K | 64 |
| LN 117 | 4 N x 3 Lime | various |
| LN 121 | 4 P | 48 |
| LN 122 | 4 N x 4 cultivars | 64 |
| LN 218 | 4 N x 4 P x 4 Lime | 64 |
| LP 1 | 3 N x 3 P | 135 |