PFR SPTS No. 8620

Potato Yield Gap investigation 2012–13. Part B: Effect of nutrient supply on yield

Michel A, Brown H, Sinton S, Meenken E, Dellow S, Pethybridge S, Searle B, Reid J

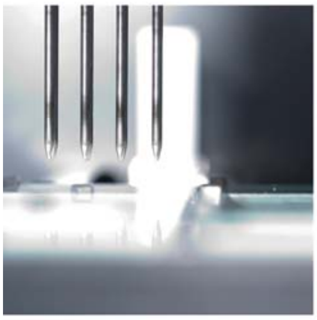
June 2013





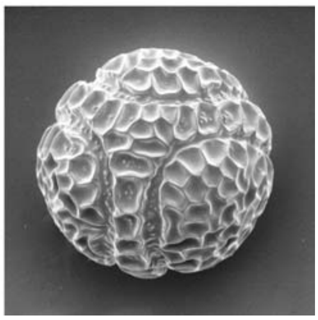










Confidential Report for:
Potatoes New Zealand, McCain Growers Group and Ravensdown Fertiliser Co-operative Limited

PUBLICATION DATA

Michel AI, et al. June 2013. Potato Yield Gap investigation 2012–13. Part B: Effect of nutrient supply on yield. A report prepared for: Potatoes New Zealand, McCain Growers Group and Ravensdown Fertiliser Co-operative Limited. Plant & Food Research Client Report No.8620. Contract No. 29598. Milestone No. 53336. Job code: P/421028/01. SPTS No. 8620.

Report approved by:

Alexandre Michel
Research Associate, Sustainable Production
Date: June 2013

Derek Wilson
Science General Manager, Sustainable Production
Date: June 2013

This report has been prepared by The New Zealand Institute for Plant & Food Research Limited (Plant & Food Research).
Head Office: 120 Mt Albert Road, Sandringham, Auckland 1025, New Zealand, Tel: +64 9 925 7000, Fax: +64 9 925 7001.
www.plantandfood.co.nz

Contents

Executive summary

Potato Yield Gap investigation 2012–13. Part B: Effect of nutrient supply on yield

Michel A, Brown H, Sinton S, Meenken E, Dellow S, Pethybridge S, Searle B, Reid J

June 2013

Potato yields in Canterbury have remained static at 50–60 t/ha (paid yield), and crop production at this level is becoming uneconomic. Computer-based modelling shows that, yields of 90 t/ha are theoretically possible in most years.

Potatoes New Zealand, McCain Growers Group and Ravensdown Fertiliser Co-operative Limited supported a grower-initiated field research project, to determine factors responsible for this “yield gap”. The project was carried out during the 2012–13 growing season by the New Zealand Institute for Plant & Food Research.

Fertiliser trials were conducted in four commercial crops as part of this project and are the focus of this report. Other factors found to be limiting yield are reported on in Potato yield gap investigation 2012–13. Part A: Factors limiting yield, SPTS No 8706. Two cultivars (Russet Burbank and Innovator) and two cropping histories (old and new ground) were used in these trials, each site being a different combination of those two factors. Old ground has been defined as a site previously cultivated with potatoes within the last 10 years, while new ground corresponded to a site that had not been cultivated in potato during the last 10 years. The trials looked at the effect of nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) supply on yield. Two rates of nutrient were tested for N, P and K: the grower’s rate and twice that rate. For Ca, the two rates were: the grower’s rate and 500 kg/ha. Depending on the treatment, these rates were applied for each nutrient in different combinations. The treatments were replicated three times at each site. The grower’s rate was applied at planting and throughout the season by the grower. The second rate (twice the grower’s rate) was applied by hand on relevant plots at planting and throughout the season (side dressing). For all other management purposes, the trial area was treated the same as the rest of the crop by the grower (e.g. irrigation, pesticide applications).

Before planting, soil background fertility was quantified. This allowed the initial concentrations of each nutrient (including magnesium (Mg)) to be accounted for before any fertiliser was applied.

An area of two rows of potatoes by 8 m long was harvested at the end of the season (close to the harvest date for the rest of the crop). This was used to assess:

- Yield, dry matter content and tuber size distribution
- Quality of the tubers, which included among other parameters tuber visual defects and colour testing
- Other measurements that may help to explain any yield reduction not caused by nutrient supply.

These measurements were carried out by both Plant & Food Research and McCain Growers Group.

Overall, no nutrient was shown to limit yield strongly at the four sites where the fertiliser trials were conducted. This means that the current fertiliser practices used by growers for nitrogen, phosphorus, potassium and calcium are near optimum or at least not a major factor of the “yield gap”.

Recommendations to growers following these findings are that they should keep with current fertiliser management practices because they are not responsible for the "yield gap".

Future research projects around this theme could look at:

- Improving the fertiliser use efficiency by the crop by investigating the possibility of splitting some fertiliser applications and/or improving the timing of these throughout the season.

For further information please contact:

Alexandre Michel
The New Zealand Institute for Plant & Food Research Ltd
Plant & Food Research Lincoln
Gerald Street, Lincoln 7608
Private bag 4704
Christchurch 8140
NEW ZEALAND
Tel: +64-3-325 9634
Fax: +64-3-325 2074
Email: alexandre.michel@plantandfood.co.nz

1 Introduction

Quantifying yield loss is paramount for the development of cost-effective crop management tactics that minimise the differential effects of various physical and biological factors on yield. Potential yield is that possible if all factors contributing to yield are optimised. Actual yield is that obtained at the field level. Cost-effective implementation of management strategies that attempt to minimise a range of stresses (yield-limiting factors) a crop may encounter throughout its productive life will enhance actual yield. The difference between potential and actual yield from a crop is referred to as the “yield gap”.

Potato growers in Canterbury have reported that yields have remained static for the last 10 years at 50 to 60 t/ha, and crop production at this level is becoming uneconomic. Computer-based modelling predicts that, yields of 90 t/ha are theoretically possible in most years, thus highlighting a yield gap of up to 40 t/ha in current production of processing potatoes.

A project to investigate the yield gap in Canterbury processed potato crops was carried out during the 2012–13 growing season. There were two objectives for the project: one was to conduct a detailed field survey of a representative range of processing potato crops in Canterbury, to identify factors which may be limiting yield (Sinton et al, 2013). The other one was looking at nutrient supply effect on the yield and is the focus of this report.

Nutrient supply is one of the main drivers of yield for a crop. This study aimed at testing the hypothesis that potato yields around Canterbury were restricted by the current fertiliser management practices. The objective was to identify any changes in fertiliser management needed to reach the potential yield of 80–90 t/ha predicted by models. To address that issue, four fertiliser trials were conducted in four different crops across Canterbury. These four crops were also intensively surveyed as part of the Potato Yield Gap Investigation project conducted this season (Sinton et al, 2013).

This report describes the methods used in these trials and the results obtained to address the issue. Implications of these results for the industry and growers are discussed.

2 Materials and Methods

2.1 Trial design, set-up and management

Field experiments of the same design were conducted in four separate commercial crops in South and Mid Canterbury. Two of the sites have been planted with ‘Russet Burbank’ (RB). One of these sites had a cropping history including potatoes within the last 10 years (old ground) and the other did not (new ground). The remaining sites were planted with ‘Innovator’, with sites selected based on the inclusion or otherwise of potatoes in their cropping history within the last ten years (Table 1). These sites also contributed to the yield gap analysis (Sinton et al, 2013).

Table 1. General and agronomic information on the sites included in this study in 2012–13.

Site ID	Location	Cultivar	Cropping history	Timing of soil sampling	Planting date
4	Rakaia	‘Russet Burbank’	New	Paddock was still in pasture	26-Oct
9	Temuka	‘Russet Burbank’	Old	Paddock was still in pasture	10-Nov
10	Temuka	‘Innovator’	Old	Just before bed forming	25-Oct
11	Temuka	‘Innovator’	New	Post-cereals but no cultivation yet, bulls present on the trial area	02-Nov

For each site, the same protocol was followed throughout the season.

Each trial consisted of three replicates of 12 treatments (n = 36 plots) with varying rates of N, P, K and Ca. Two rates of nutrients were used in this study: the grower’s rate and twice that rate for N, P and K; the grower’s rate and 500 kg/ha for Ca. Please note that the grower’s rate was different for each site. N, P and K were chosen because they represent the main nutrients for plant growth and development. Ca was selected due to anecdotal evidence for a significant effect on yield (unpublished data from pot trials conducted by McCain Foods Ltd). Furthermore, in commercial practice, most growers were providing only a small amount of Ca to the crop (less than 50 kg/ha), other than what was applied as lime to control pH. Half grower’s rates were not tested in these trials because, as a preliminary study, the main aim was to check for any deficiencies in nutrient supply. Finally, toxicity in nutrient supply can still be investigated with this experimental design, as shown by the relationship between plant yield and nutrient concentration (Figure 1) (McLaren & Cameron 1996).

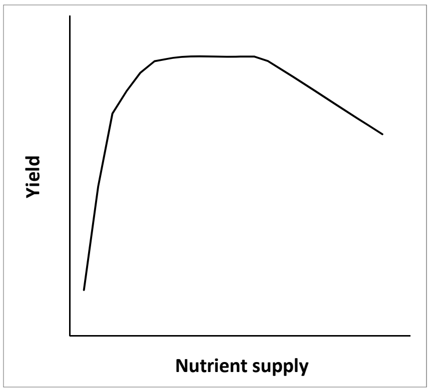


Figure 1. Potato crop yield according to nutrient supply to the crop.

Considering nutrient supply for a given nutrient, there is usually a linear relationship between supply and yield increases in ranges where the supply is limited (deficiency), until it reaches a limit (equilibrium) and then starts to decline when too much of that nutrient is supplied (toxicity). In the current experiment, if the yield reached with the grower's rate was less than the yield reached by the plots with twice the grower's rate, then the grower had not applied enough of that nutrient to the crop (deficiency). If the yield for both treatments was similar, then the grower had applied enough of that nutrient to the crop. Finally, if the yield reached for the plots with twice the grower's rate was less than the yield reached with the grower's rate, then the grower had applied too much of the nutrient to the crop (toxicity). The same logic may be applied to all the nutrients and nutrient combinations tested in this experiment.

Plots were set up to be eight rows of potatoes by 10 m long. This set up included at least a buffer row each side and offered a reasonable area available for the harvest. The area of the crop where the trial was established for each site has been chosen according to the soils map for that site, so that the trial was sited in the most homogenous area of the crop.

Before planting, each individual plot was soil sampled to establish the base fertility. This happened at different times for each site (Table 1). Please note that, because of the presence of bulls at site 11, the test results for this site will need to be interpreted cautiously in terms of nitrogen concentrations (even though the sampling was done avoiding obvious areas of faeces).

The sampling consisted of nine cores per plot taken at 0 to 15 cm depth, and three cores per plot taken at each of 0 to 30 cm and 30 to 60 cm depths.

The samples from the core at 0–15 cm depth were separated into two halves. One half was used to run basic soil tests, which included: pH, Olsen-soluble P (µg/mL), Calcium (Quick Test Units), Magnesium (QTU), Potassium (QTU), Sodium (QTU), Anaerobic mineral N (kg/ha), Dry Weight/Volume (g/mL), CEC (me/100 g), Calcium (me/100 g), Magnesium (me/100 g), Potassium (me/100 g), Sodium (me/100 g), Ca Base Saturation (%), Mg Base Saturation (%), K Base Saturation (%), Na Base Saturation (%), Total Base Saturation (%), P Retention (%) and Reserve Potassium (me/100 g). These tests were conducted by Analytical Research Laboratories Ltd (Napier, New Zealand). The other half of each sample was dried in a fan-forced oven at 40°C for 48 h before being sent to the laboratory of the South Australian Research and Development Institute (SARDI) (Adelaide, Australia) to determine inoculum densities (pg DNA/g of soil) for each of the major potato pathogens: including: *Rhizoctonia solani* AG2.1, *R. solani* AG3 (causal agents of Rhizoctonia stem canker), *Meloidogyne fallax* and *M. hapla* (Root knot nematodes), *Spongospora subterranea* (Powdery scab), *Streptomyces* sp. (Common scab), *Colletotrichum coccodes* (Black dot) and *Verticillium dahliae* (Verticillium wilt).

The samples from the cores at 0-30 cm and 30-60 cm depths were used to determine the initial mineral N concentration (kg/ha) by a 1-hour extraction of 5 g soil with 25 ml of 2 M KCl and subsequent analysis of the filtered extract for NH4-N and NO3-N on a FOSS FIAstar 5000 analyser (Keeney & Nelson 1982).

All four sites were planted in beds of two rows per bed by the grower, including the area for the trial which was treated like the rest of the crop (Table 1).

For practicality, it was decided that the grower would apply fertiliser to the trial area, treating it like the rest of the crop, and so would cover the grower's rate treatment. PFR staff would then double the nutrient applications on some plots according to the treatments, to cover the rate corresponding to twice the grower's rate (Table 2).

Table 2. Nutrient treatments (Rates: 1 = grower's rate, 2 = twice grower's rate) used in the potato yield trials.

Treatment	Rate of N	Rate of P	Rate of K	Rate of Ca
1	1	1	2	1
2	1	2	2	1
3	1	1	2	2
4	1	2	2	2
5	2	1	2	1
6	2	2	2	1
7	2	1	2	2
8	2	2	2	2
9	1	1	1	1
10	2	1	1	1
11	1	1	1	2
12	1	2	1	1

At planting, the treatments were applied by hand to the plots (Table 3). Urea was used to double the rate of N, Triple Super was used to double the rate of P, potassium chloride was used to double the rate of K, and gypsum was used to apply the rate of Ca.

During the growing season, the treatments were applied by hand and consisted mainly of doubling the rate of N on the concerned plots. Urea or CAN was used, depending on the fertiliser used by the grower at each application (Table 3). Applications were made as close as possible to the date of application by the grower.

Table 3. Summary of fertiliser applications at the grower's rate for each site across the whole season (including planting). To get the amount of fertiliser applied to the plots receiving twice the grower's rate for a given nutrient, double the fertiliser quantity for the corresponding nutrient. Please note that the amount of nutrients applied by the grower was equivalent but using different products.

Site	Date	Urea applied (kg/ha)	CAN applied (kg/ha)	Triple S applied (kg/ha)	KCl applied (kg/ha)	Gypsum applied (kg/ha)
4	26-Oct-12	135	0	338	376	500
4	7-Dec-12	0	200	0	0	0
4	21-Dec-12	125	0	0	0	0
4	9-Jan-13	205	0	0	0	0
4	22-Feb-13	80	0	0	0	0
10	27-Oct-12	274	0	615	651	500
10	14-Dec-12	0	225	0	0	0
10	9-Jan-13	125		0	0	0
10	28-Jan-13	205	0	0	70	0
11	2-Nov-12	215	0	567	561	500
11	14-Dec-12	0	225	0	0	0
11	28-Dec-12	0	75	0	0	0
11	14-Jan-13	0	400	0	0	0
11	26-Jan-13	0	75	0	0	0
9	9-Dec-12	254	0	660	546	500
9	28-Dec-12	0	180	0	0	0
9	14-Jan-13	100	0	0	0	0
9	28-Jan-13	100	0	0	0	0
9	22-Feb-13	90	0	0	0	0
9	8-Mar-13	80	0	0	0	0

Throughout the season, the trial area was managed in the same way as the rest of the paddock by the grower (e.g. irrigation, fungicides, herbicides, insecticides, fertiliser), the only difference being the application of the treatments as close as possible to fertiliser applications conducted by the grower.

2.2 Harvest protocol

The harvest at each site was made around the same time as for the rest of the crop. First, the grower harvested the rest of the crop and then the trial was harvested a few days or 3 weeks later at most (depending on the weather).

Before harvest, each site was prepared for mechanical harvest by removing two plants from each harvested row at both the top and the bottom of the plot, to make room for the harvester. Plant, stem and missing plant numbers were recorded at the same time.

The area harvested on each plot was two rows of potatoes by 8 m long. Sites 10 and 11 were harvested first (see Table 4 for harvest dates and crop duration) by hand digging. Then, sites 4 and 9 were harvested later, using a two-row harvester (seed harvester).

Table 4. Trial harvest calendar for all four potato yield trial sites.

Site ID	Planting date	Harvest date	Crop duration (days)
4	26-Oct	9-May-13	195
9	10-Nov	15-May-13	186
10	25-Oct	1-May-13	188
11	02-Nov	2&3-May-13	181

For each plot, all the tubers were collected in bags and transported to McCain Foods Ltd in Timaru for later subsampling and measurements.

Total yield from each plot was measured. Then, a 12-kg subsample was taken to assess yield with dirt and clean yield after washing the tubers and measuring dirt content. Then the subsample was reduced to 10 kg in order to measure size distribution and carry out a defect testing (external and internal). The size distribution was measured by weighing tubers over 67 mm and tubers over 90 mm (total weight) out of the 10-kg subsample. Defect testing consisted of: measuring solid contents (specific gravity), running a colour test by deep frying 25 core samples out of random selected tubers from the 10-kg subsample, and assessing visual defects on the whole 10-kg subsample, which included: green tubers, rotten tubers, insect damage, scab, hollow heart, brown centre, damage and ‘other’ defects. All these measurements were conducted by McCain Foods Ltd.

A 12-kg subsample was also given to Plant & Food Research to conduct additional measurements. These included a disease severity assessment. This was looking mainly at visual external defects, especially powdery scab. Also, dry matter percentages were measured for each plot by drying a subsample of at least 700 g in a fan-forced oven at 90°C for 48 h. Finally, for the two extreme treatments (grower’s rate and twice grower’s rate for all nutrients), the length and the weight of each individual tuber in the 12-kg subsample were measured.

2.3 Statistical analyses

All statistical analyses presented in this report were carried out using analysis of variance (ANOVA). An estimate of the variation associated with predicted means is given by the 5% least significant difference (LSD) and associated degrees of freedom. All statistical analyses were carried out in GenStat v. 14. Figures were prepared using SigmaPlot v. 10.

2.3.1 Disease assessment

Prior to assessment of nutrient effect, the impact of disease as described by the inoculum levels of the main pathogens in the soil pre-planting were tested and included as a linear covariate. This helped to ensure that any 'noise' in the data due to variation in disease inoculum was removed, in addition to assessing the relative impact of these diseases on yield.

2.3.2 Nutrient assessment

The design of the experiment allowed subsets of the data to be used to assess the full impact of each nutrient given the effect of the other nutrients, with the exception of K, which was assessed up to two-way interactions. The analysis therefore involved three steps. First, the overall treatment effect investigated whether at least one of the 12 treatments stood out as being particularly different given the amount of disease present. This analysis focused on the yield indicators (yield, dry matter % and tuber size distribution: over 67 mm, over 90 mm, and rest of the tubers).

The next step was planned to differentiate between the effects, if any, of N, Ca and P, independently of any effect of K. To do this, K was restricted to K = 2 and the data analysed as a full 2 × 2 × 2 factorial, allowing the assessment of main effects, two-way and three-way interactions.

Finally the data set was restricted to allow balanced assessment of K (up to two-way interactions). A fractional factorial design was designed to be present within the full treatment layout, allowing partial assessment of K. Because of design constraints, the treatments were confounded so that it was not possible to assess the three- or four-way interactions of the other nutrients with K. Treatments 4, 6, 7 and 8 were excluded from this part of the analysis to ensure balance.

Please note that this part of the analysis did not take account of the background nutrient levels in the soil (obtained with the soil sampling pre-planting). This was the purpose of the next part of the analysis (see 2.4).

2.4 Analyses using the PARJIB model

The next step of the analysis consisted of combining baseline concentrations of available nutrients with fertiliser nutrients to explore response curves to nutrients using the PARJIB model. PARJIB is a nutrient forecasting model that provides fertiliser recommendations based on initial soil nutrient supply and target yield potential in a given field (Reid et al. 2011). See appendix 8.1 for the detailed protocol of the analysis with the PARJIB model.

3 Results

3.1 Disease assessment

Results suggested that verticillium wilt may have influenced yield at sites 9 and 10. Following the yield gap analysis monitoring throughout the season (Sinton et al, 2013), verticillium wilt symptoms were observed at site 9 but not at site 10. Results also showed that common scab may have had an effect on yield at site 11, although no symptoms were observed on either the plants or the tubers throughout the season (Sinton et al, 2013).

As mention in the Materials and Methods section, those pathogens which might have had an effect on the yield were used as covariates in analyses (excluding the PARJIB analysis). However, because in two cases, no symptoms were observed in the field during the season or at harvest, the results for those sites need to be interpreted cautiously. In fact, inoculum was used as a measure of disease risk rather than a measure of disease impact.

In addition, symptoms caused by Rhizoctonia were observed in all these four crops from early in the season and these might have affected the yields (Sinton et al, 2013).

3.2 Nutrient assessment with disease as covariate

There was no evidence of an overall treatment effect, except for a marginal effect on DM% at site 9 (Table 5). These effects were too small to allow for any strong conclusion of an effect of doubling rates of nutrients on yield.

Table 5. Mean and p-value for each treatment and yield variable at each site. 5% LSD and degrees of freedom (df) are given.

Treatment	N	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*1*	*2*	*1*	*1*			
	P	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*1*	*1*	*2*			
	K	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*1*	*1*	*1*	*1*			
	Ca	*1*	*1*	*2*	*2*	*1*	*1*	*2*	*2*	*1*	*1*	*2*	*1*			
Site	**Variable**	**Mean**												**p-value (treatment effect)**	**5% LSD**	**df**
4	Tuber yield	68627	69326	61469	72065	69809	73479	70689	71119	67262	67604	71109	67428	0.254	7778	22
4	Total weight tubers >90 mm	46703	41234	41694	48588	39904	49984	45133	49870	45328	37358	49597	43084	0.566	13229	22
4	Total weight tubers >67 mm	63050	67122	60331	69565	66347	71548	66566	66965	64683	63225	69703	64758	0.358	8610	22
4	Total weight tubers rest	5665	2223	1154	2529	3501	1951	4171	4188	2609	4413	1424	2704	0.689	4610	22
4	Dry matter content	21.2	21.6	21.5	21.8	21.2	22.1	22.0	21.9	22.0	21.1	22.2	21.8	0.52	1.1	22
9	Tuber yield	84228	78625	89981	85727	86933	81374	101767	87682	80236	78854	80117	77510	0.181	14930	22
9	Total weight tubers >90 mm	61592	52517	65150	64580	58400	57966	74926	62328	57097	59098	51957	50205	0.465	18374	22
9	Total weight tubers >67 mm	80936	73914	84884	81396	81083	77147	98075	76211	76559	76768	75462	73319	0.325	16513	22
9	Total weight tubers rest	3320	4776	5153	4370	5922	4271	3728	11550	3711	2101	4700	4249	0.616	7799	22
9	Dry matter content	18.4	20.6	19.1	19.2	19.6	19.9	19.5	18.9	19.3	20.3	21.3	20.1	0.017	1.3	22
10	Tuber yield	57717	69547	75323	84140	78081	67923	73155	65925	72343	72065	52582	73788	0.385	21789	22
10	Total weight tubers >90 mm	41296	50586	57290	60177	50691	47323	52743	45086	47343	48505	37749	45059	0.618	19020	22
10	Total weight tubers >67 mm	53768	65613	71097	78935	73800	63952	70465	60330	67379	68045	51275	67622	0.404	20683	22
10	Total weight tubers rest	4107	4004	4289	5334	4331	4080	2778	5719	5111	4142	1375	6265	0.759	4204	22
10	Dry matter content	21.3	21.5	21.3	20.7	21.5	20.2	22.0	21.3	21.2	21.6	21.9	21.9	0.466	1.5	22
11	Tuber yield	76444	75869	77483	74317	73578	74320	72975	69151	73736	72899	74165	72163	0.926	11536	22
11	Total weight tubers >90 mm	57304	62099	66711	62553	59433	55298	59719	62222	57053	58100	62407	59309	0.691	15454	22
11	Total weight tubers >67 mm	67958	74752	74371	71940	71765	70207	70021	67062	67223	69300	72126	69681	0.609	11915	22
11	Total weight tubers rest	8776	1144	3182	2438	1856	4220	3039	2140	6748	3722	2098	2534	0.346	5728	22
11	Dry matter content	18.9	19.0	18.9	18.4	19.8	18.7	19.8	18.9	19.4	19.2	20.0	19.5	0.037	1.1	22

3.3 Effect of N, P and Ca, independently of K

No effects of N and Ca on yield were highlighted by the results. P had a significant effect on at least one of the response variates at each site, but the responses were not consistent in terms of interactions with other nutrients, or between sites (Tables 5, 6 and 7).

Table 6. *p-value* (N, Ca and P interaction) for each yield variable at each site.

Site	Variable	p-value (3 way interaction)
4	Dry matter content (%)	0.321
4	Tuber yield (kg/ha)	0.085
4	Total weight tubers >90 mm (kg/ha)	0.089
4	Total weight tubers >67 mm (kg/ha)	0.219
4	Total weight tubers rest (kg/ha)	0.533
9	Dry matter content (%)	0.335
9	Tuber yield (kg/ha)	0.733
9	Total weight tubers >90 mm (kg/ha)	0.36
9	Total weight tubers >67 mm (kg/ha)	0.332
9	Total weight tubers rest (kg/ha)	0.17
10	Dry matter content (%)	0.848
10	Tuber yield (kg/ha)	0.905
10	Total weight tubers >90 mm (kg/ha)	0.852
10	Total weight tubers >67 mm (kg/ha)	0.886
10	Total weight tubers rest (kg/ha)	0.194
11	Dry matter content (%)	0.934
11	Tuber yield (kg/ha)	0.319
11	Total weight tubers >90 mm (kg/ha)	0.037
11	Total weight tubers >67 mm (kg/ha)	0.043
11	Total weight tubers rest (kg/ha)	0.036

Table 7. Mean and p-value (P main effect) for each relevant treatment and yield variable at each site. 5% LSD and degrees of freedom (df) are given.

Site	Variable	P rate		5% LSD	df	p-value (P main effect)
		1	2			
4	Dry matter content (%)	21.5	21.8	0.5	14	0.141
4	Tuber yield (kg/ha)	67649	71497	3795	14	0.047
4	Total weight tubers >90 mm (kg/ha)	43359	47419	5200	14	0.116
4	Total weight tubers >67 mm (kg/ha)	64073	68800	4151	14	0.028
4	Total weight tubers rest (kg/ha)	3623	2723	2726	14	0.49
9	Dry matter content (%)	19.2	19.6	0.6	14	0.189
9	Tuber yield (kg/ha)	90181	83898	9099	14	0.15
9	Total weight tubers >90 mm (kg/ha)	65036	59329	11882	14	0.337
9	Total weight tubers >67 mm (kg/ha)	85924	77487	10288	14	0.096
9	Total weight tubers rest (kg/ha)	4303	6469	4994	14	0.374
10	Dry matter content (%)	21.7	20.8	0.7	14	0.011
10	Tuber yield (kg/ha)	71461	71492	12502	14	0.876
10	Total weight tubers >90 mm (kg/ha)	50194	51104	13067	14	0.881
10	Total weight tubers >67 mm (kg/ha)	68139	66352	11565	14	0.900
10	Total weight tubers rest (kg/ha)	3404	5256	2294	14	0.146
11	Dry matter content (%)	19.4	18.7	0.6	14	0.031
11	Tuber yield (kg/ha)	75134	73400	4349	14	0.405
11	Total weight tubers >90 mm (kg/ha)	60808	60526	6128	14	0.925
11	Total weight tubers >67 mm (kg/ha)	71045	70974	4509	14	0.976
11	Total weight tubers rest (kg/ha)	4211	2488	2483	14	0.157

The effect of P (alone or combined with other nutrients) on some yield parameters are the following:

- At site 4 there was some indication of a three-way interaction (N x P x Ca) for Yield and Total weight of tubers >90 mm (Figures 2 and 3).
- At site 9 there was some evidence of a two-way interaction (N x P) for DM % (Figure 4).
- At site 10 there is some evidence of a two-way interaction (N x P) for Total weight of tubers >67 mm (Figure 5).
- At site 11 there is some indication of a three-way interaction (N x P x Ca) for Total Weight of tubers response variates (Figure 6).

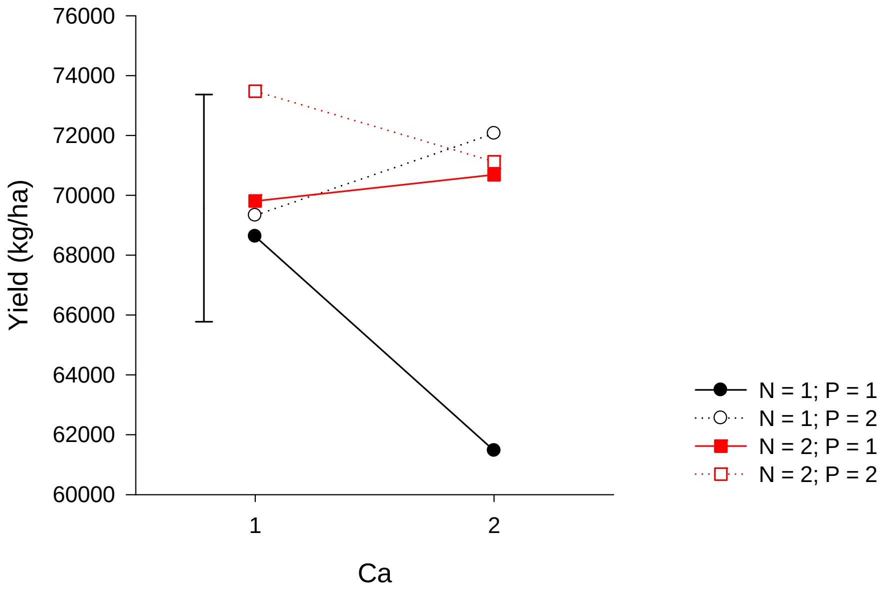


Figure 2. Effects of N, P and Ca rates on potato yield (kg/ha) at site 4 (on the horizontal axis, “1” means the grower’s fertiliser rate and “2” means twice the grower’s fertiliser rate. For Ca, “2” means 500 kg/ha of gypsum was applied). Bar represents 5% LSD with 14 df.

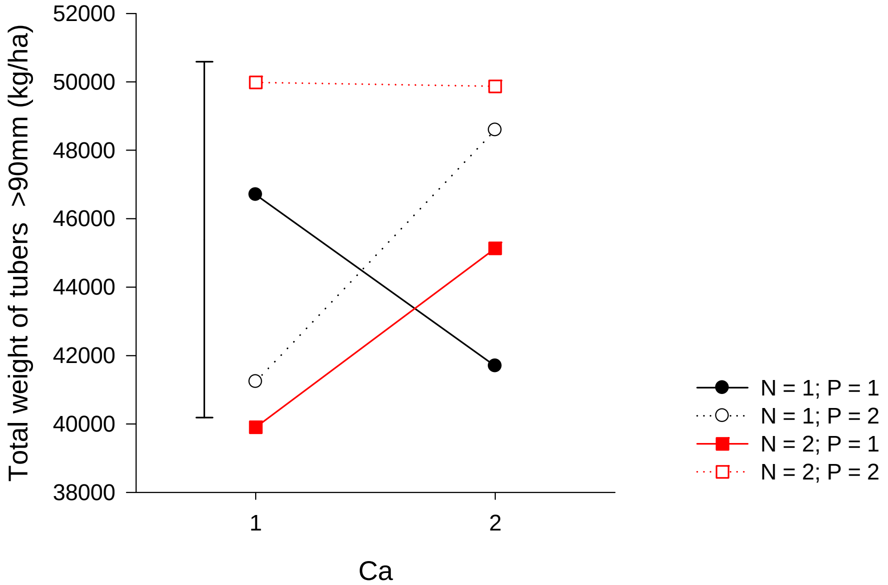


Figure 3. Effects of N, P and Ca rate on total weight of potato tubers >90 mm (kg/ha) at site 4 (on the horizontal axis, "1" means the grower's fertiliser rate and "2" means twice the grower's fertiliser rate. For Ca, "2" means 500 kg/ha of gypsum was applied). Bar represents 5% LSD with 14 df.

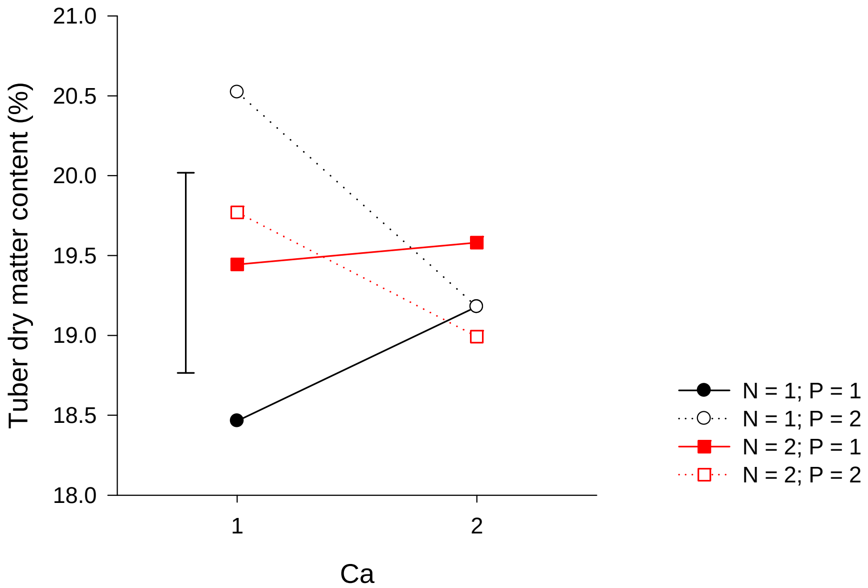


Figure 4. Effects of N, P and Ca rate on potato tuber dry matter (%) at site 9 (on the horizontal axis, "1" means the grower's fertiliser rate and "2" means twice the grower's fertiliser rate. For Ca, "2" means 500 kg/ha of gypsum was applied). Bar represents 5% LSD with 14 df.

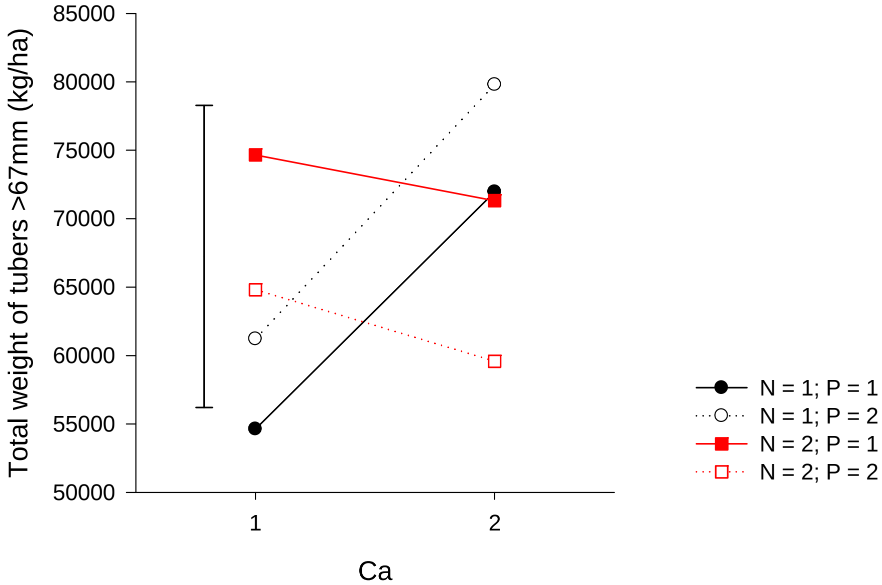


Figure 5. Effects of N, P and Ca rate on total weight of potato tubers >67 mm (kg/ha) at site 10 (on the horizontal axis, “1” means the grower’s fertiliser rate and “2” means twice the grower’s fertiliser rate. For Ca, “2” means 500 kg/ha of gypsum was applied). Bar represents 5% LSD with 14 df.

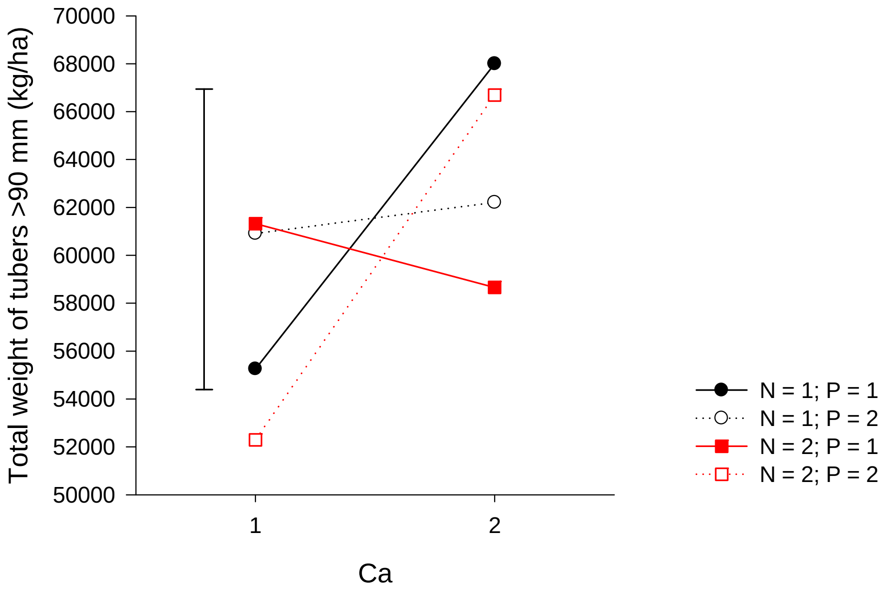


Figure 6. Effects of N, P and Ca rate on total weight of potato tubers >90 mm (kg/ha) at site 11 (on the horizontal axis, “1” means the grower’s fertiliser rate and “2” means twice the grower’s fertiliser rate. For Ca, “2” means 500 kg/ha of gypsum was applied). Bar represents 5% LSD with 14 df.

3.4 Effect of K independent of N, P and Ca

There was a marginal evidence of an effect of K on yield and dry matter content at site 9 and dry matter content at site 11 (Table 8). Also, there was marginal evidence of an effect of K interacting with N on yield at site 4 and dry matter content at site 9 (Table 8). But, because this analysis does not allow for higher order interactions, it cannot be considered complete: the effects of K with relation to the other nutrients are not clear. Furthermore, there was no consistency in the results between the four sites.

Table 8. *p-value* for each yield variable at each site (nutrient main effect, 2-way interaction of K with the other nutrients and covariate effect).

			Nutrient main effect				*2-way interactions*			
Site	**Variable**	**Covariate**	**N**	**Ca**	**P**	**K**	**N.K**	**Ca.K**	**P.K**	**Covariate**
4	Dry matter content (%)	None	0.082	0.526	0.798	0.163	0.338	0.817	0.544	N/A
4	Tuber yield (kg/ha)	None	0.612	0.447	0.878	0.602	0.353	0.043	0.610	N/A
4	Total weight tubers >90 mm (kg/ha)	None	0.174	0.730	0.463	0.693	0.533	0.428	0.890	N/A
4	Total weight tubers >67 mm (kg/ha)	None	0.953	0.968	0.527	0.551	0.269	0.119	0.376	N/A
4	Total weight tubers rest (kg/ha)	None	0.357	0.196	0.344	0.778	0.557	0.627	0.391	N/A
9	Dry matter content (%)	Verticillium wilt	0.914	0.128	0.019	0.032	0.830	0.040	0.203	0.627
9	Tuber yield (kg/ha)	Verticillium wilt	0.571	0.128	0.360	0.024	0.317	0.243	0.848	0.281
9	Total weight tubers >90 mm (kg/ha)	Verticillium wilt	0.535	0.483	0.133	0.190	0.311	0.258	0.732	0.533
9	Total weight tubers >67 mm (kg/ha)	Verticillium wilt	0.538	0.241	0.247	0.076	0.856	0.287	0.676	0.640
9	Total weight tubers rest (kg/ha)	Verticillium wilt	0.719	0.258	0.200	0.084	0.007	0.884	0.335	0.036
10	Dry matter content (%)	Verticillium wilt	0.924	0.769	0.434	0.559	0.875	0.450	0.835	0.545
10	Tuber yield (kg/ha)	Verticillium wilt	0.299	0.695	0.130	0.986	0.715	0.097	0.147	0.025
10	Total weight tubers >90 mm (kg/ha)	Verticillium wilt	0.788	0.551	0.299	0.385	0.619	0.284	0.128	0.048
10	Total weight tubers >67 mm (kg/ha)	Verticillium wilt	0.257	0.936	0.143	0.942	0.720	0.143	0.114	0.023
10	Total weight tubers rest (kg/ha)	Verticillium wilt	0.852	0.145	0.541	0.791	0.920	0.158	0.787	0.594
11	Dry matter content (%)	Common Scab	0.615	0.430	0.860	0.025	0.086	0.048	1.000	0.003
11	Tuber yield (kg/ha)	Common Scab	0.633	0.601	0.900	0.153	0.932	0.582	0.953	0.092
11	Total weight tubers >90 mm (kg/ha)	Common Scab	0.661	0.216	0.460	0.460	0.979	0.588	0.839	0.415
11	Total weight tubers >67 mm (kg/ha)	Common Scab	0.960	0.244	0.144	0.158	0.727	0.661	0.591	0.090
11	Total weight tubers rest (kg/ha)	Common Scab	0.541	0.318	0.027	0.979	0.523	0.888	0.484	0.936

3.5 Analysis with PARJIB

3.5.1 Initial fitting results

Figure 7 is showing the performance of the model with the data collected in the 4 trials. A tolerance range of 1 Root Mean Square Deviation (RMSD) is assumed as shown by the upper and lower limit lines.

With the exception of one data point that is above the tolerance range, most data points are within the tolerance range or below it (Figure 7). Points that are below the tolerance range are illustrating what is called a yield gap.

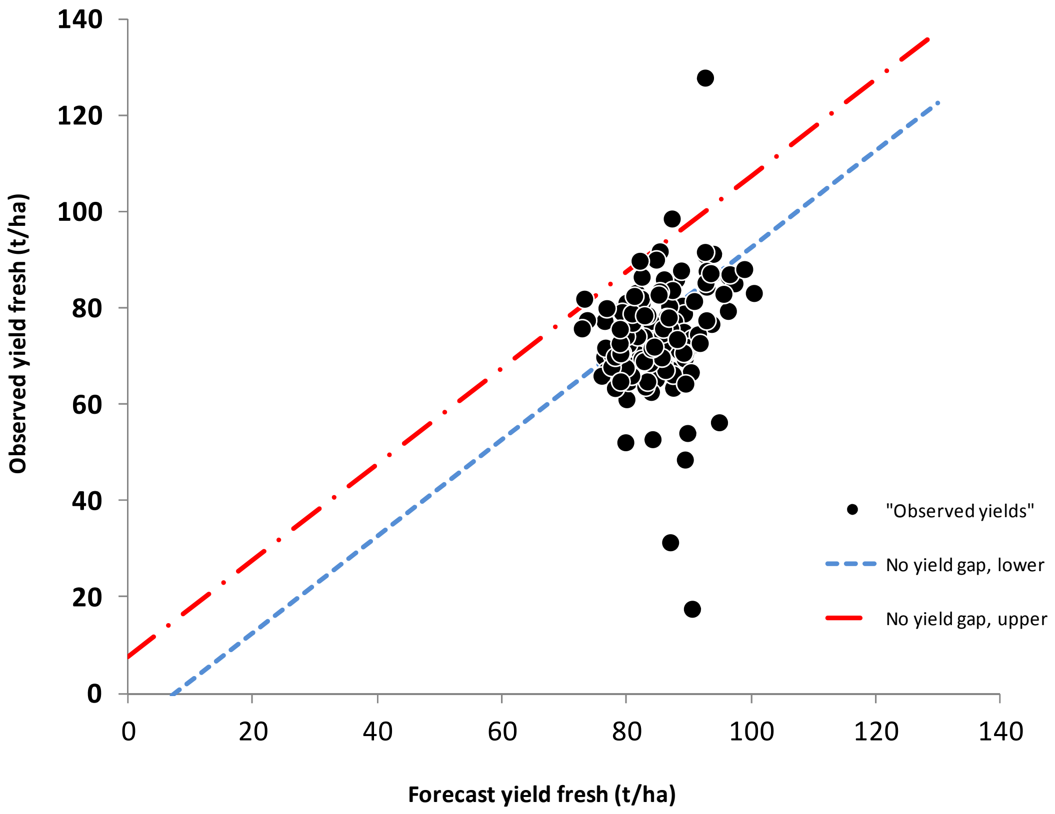


Figure 7. Observed fresh yield (t/ha) for individual potato plots at the four sites compared with the predicted yield (t/ha) for the same plots. A tolerance range of 1 Root Mean Square Deviation (RMSD) is assumed and shown by the lower limit (blue dashes) and the upper limit (red dashes and points).

3.5.2 Assessing nutrient response and fertiliser management

There are two types of yield gap. The first is the difference between the maximum (potential) yield and the attainable yield. The maximum yield is dictated by the climatic conditions and the cultivar planted. The attainable yield is the maximum yield reduced by taking account of non-optimal factors that are included in the PARJIB model (here they are mainly N, P and K supply). Mg supply and pH effects are built into the model.

The second type of yield gap is the difference between the attainable yield (which accounts for mineral nutrition influence) and the observed yield.

The following results are presented per nutrient for more clarity.

3.5.3 Nitrogen

Figure 8 shows the fresh yield loss (t/ha), between the potential yield and the attainable yield, associated with N supply. These results suggest that N supply was limiting yield for some plots at all sites. But in most cases, the fresh yield loss was around 7 t/ha or less.

Figure 9 shows the fresh yield gap (t/ha), between the attainable yield and the actual observed yield, according to N supply. For most plots, the yield gap was between 0 and 20 t/ha. R^2 was low (0.01) which suggests that the yield gap measured on the plots was caused by another factor than N supply.

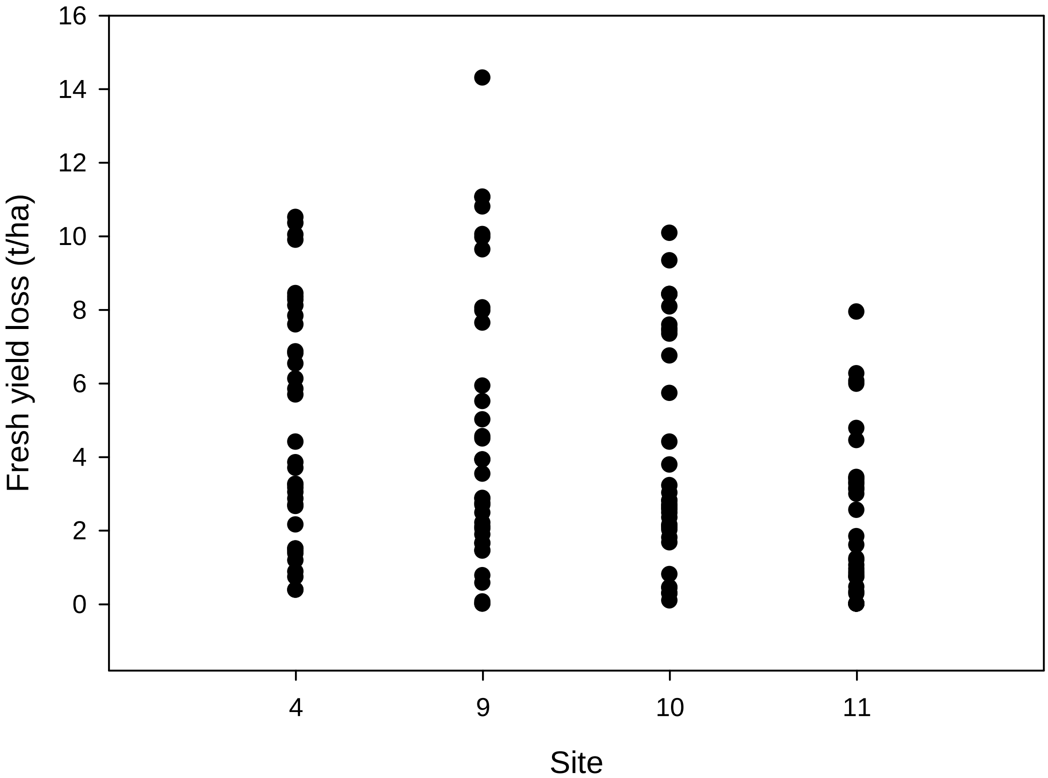


Figure 8. Fresh yield loss (t/ha), between potential and attainable yields, associated with N supply for individual potato plots at the four sites.

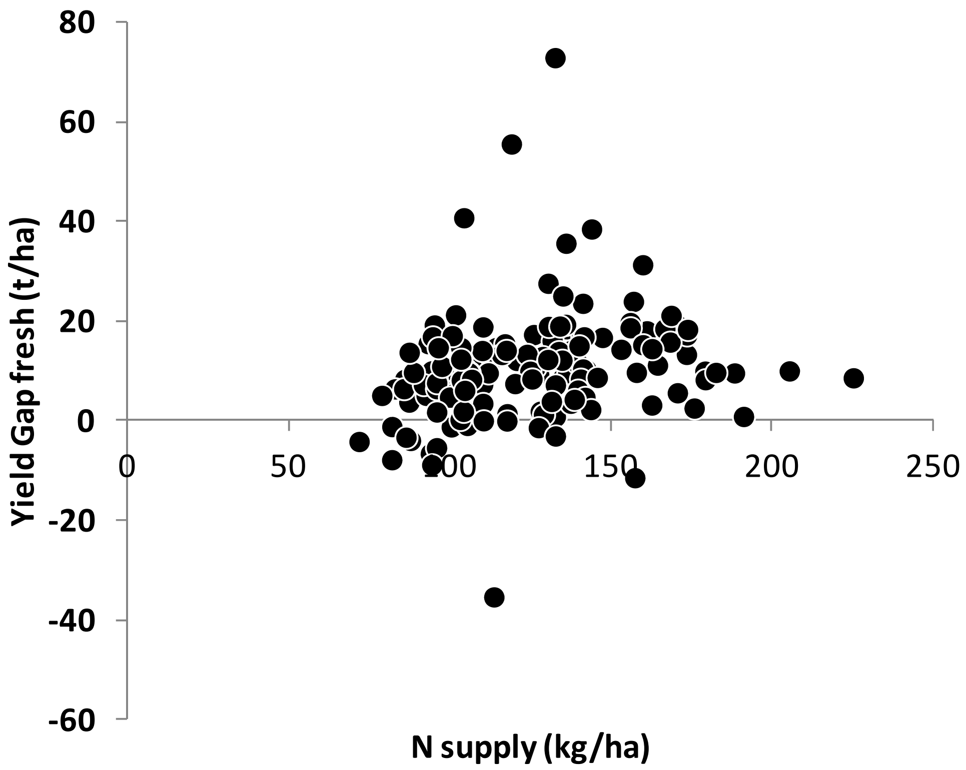


Figure 9. Fresh yield gap (t/ha), between attainable and observed yields, for individual potato plots at all sites according to N supply (kg/ha). R^2 = 0.01.

3.5.4 Phosphorus

Figure 10 shows the fresh yield loss (t/ha), between the potential yield and the attainable yield, associated with P supply. These results suggest that P supply was limiting yield for some plots at all sites. But in most cases, the fresh yield loss was around 4 t/ha or less at sites 4, 10 and 11. The fresh yield loss was around 8-10 t/ha or less at site 9.

Figure 11 shows the fresh yield gap (t/ha), between the attainable yield and the actual observed yield, according to P supply. For most plots, the yield gap was between 0 and 17 t/ha. R^2 was really low (0.0005) which suggests that the yield gap measured on the plots was caused by another factor than P supply.

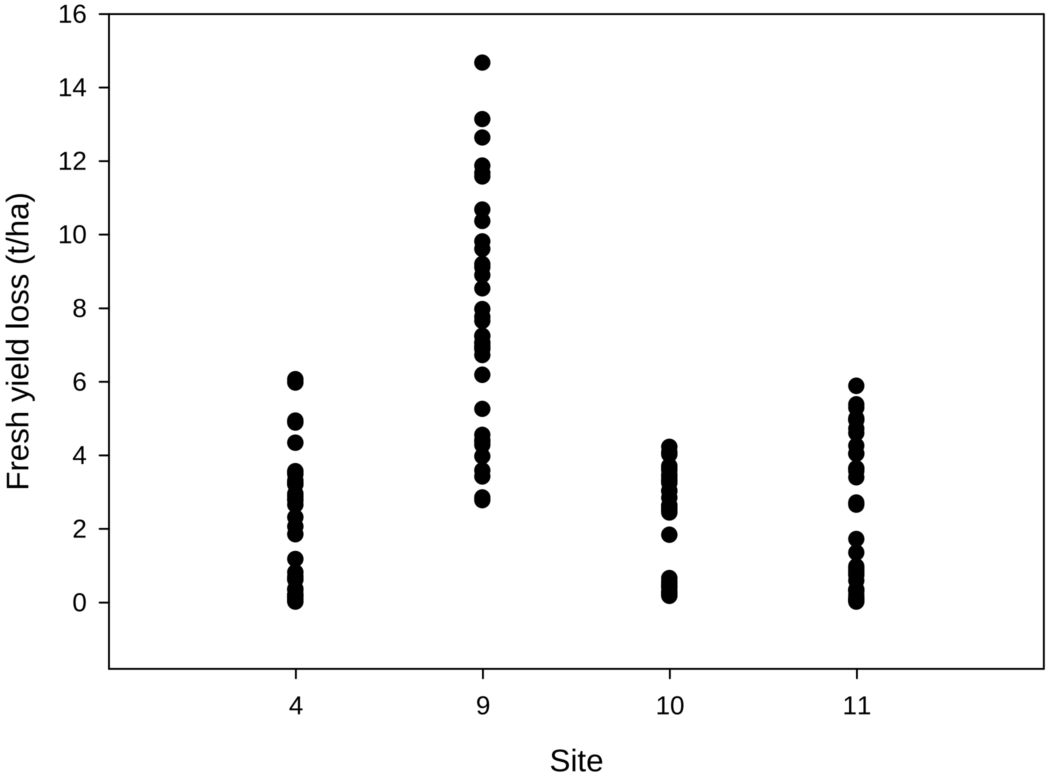


Figure 10. Fresh yield loss (t/ha), between potential and attainable yields, associated with P supply for individual potato plots at the four sites.

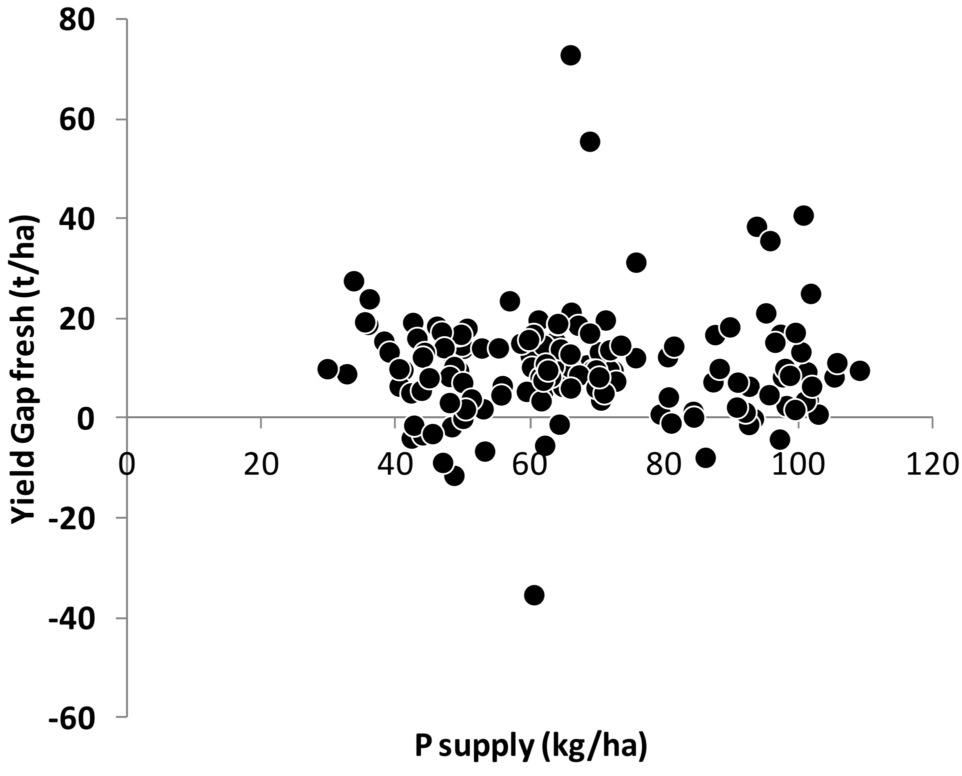


Figure 11 . Fresh yield gap (t/ha), between attainable and observed yields, for individual potato plots at all sites according to P supply (kg/ha). R^2 = 0.0005.

3.5.5 Potassium

Figure 12 shows the fresh yield loss (t/ha), between the potential yield and the attainable yield, associated with K supply. These results suggest that K supply was not limiting yield at any site.

Figure 13 shows the fresh yield gap (t/ha), between the attainable yield and the actual observed yield, according to K supply. For most plots, the yield gap was between 0 and 19 t/ha. R^2 was really low (0.0001) which suggests that the yield gap measured on the plots was caused by another factor than K supply.

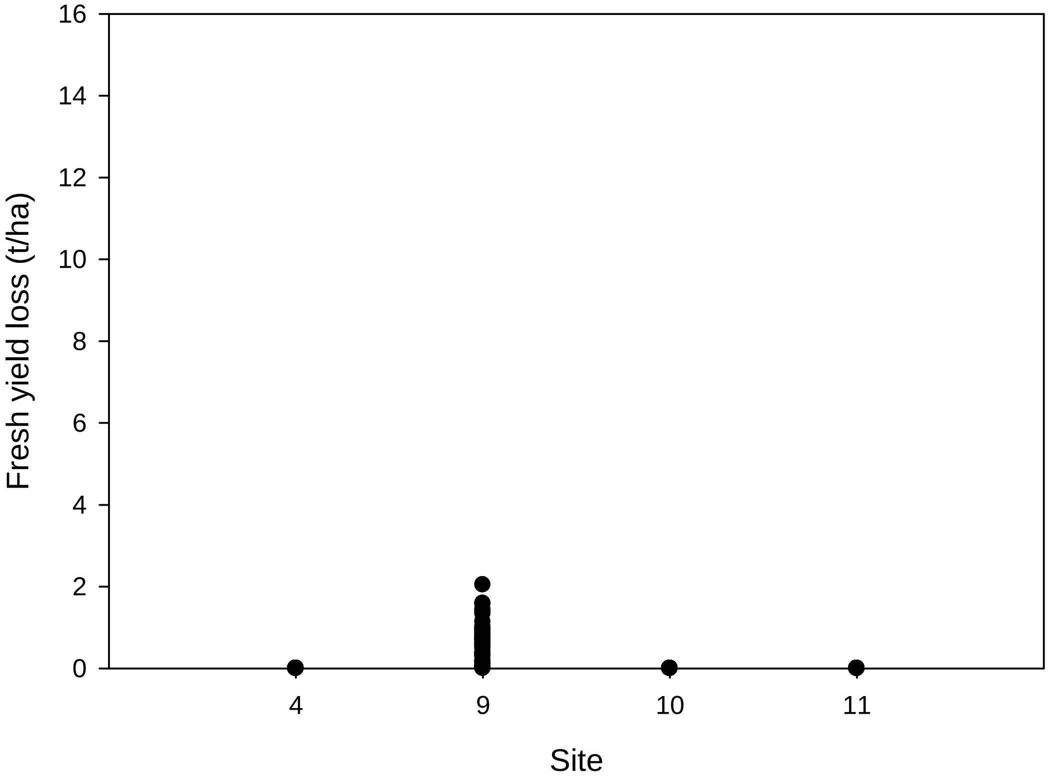


Figure 12. Fresh yield loss (t/ha), between potential and attainable yields, associated with K supply for individual potato plots at the four sites.

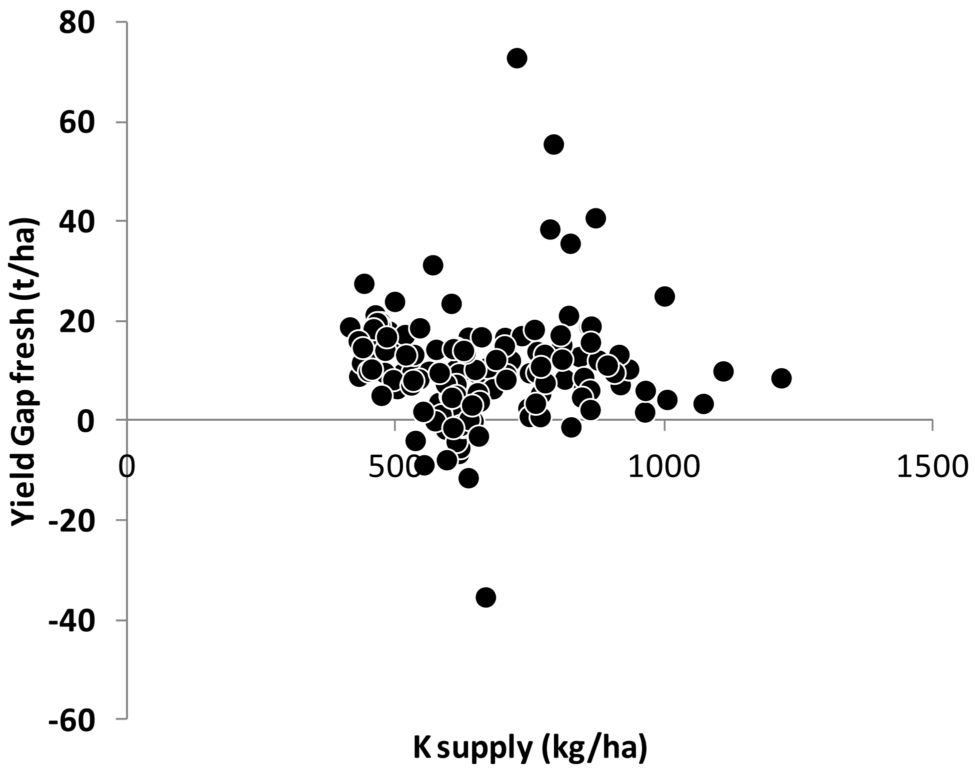


Figure 13. Fresh yield gap (t/ha), between attainable and observed yields, for individual potato plots at all sites according to K supply (kg/ha). R^2 = 0.0001.

3.5.6 Calcium

Figure 14 is showing the fresh yield gap (t/ha) measured on individual plots for both rates of Ca tested (0 and 116.5 kg/ha of Ca) at all four sites. Most of these yield gaps ranged between -10 t/ha (no yield gap) and 25 t/ha for both rates. The R^2 was low (0.01), which suggests that the yield gap measured on the plots was caused by another factor than Ca fertiliser supply.

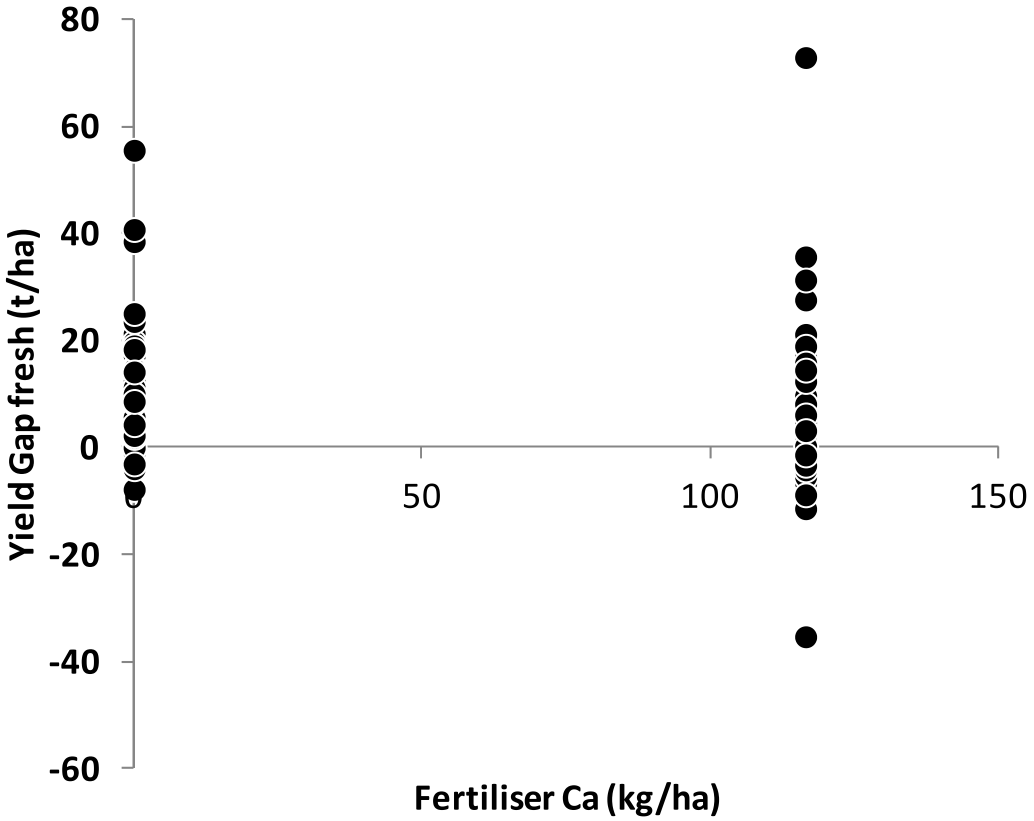


Figure 14. Fresh Yield "gap" (t/ha) for individual potato plots at the four sites according to Ca fertiliser supply (kg/ha). 2 treatments were tested (0 kg/ha and 116.5 kg/ha of Ca). This is excluding pre-planting lime application to regulate pH. R^2 = 0.01.

3.5.7 Magnesium

Figure 15 shows the fresh yield gap (t/ha), between the attainable yield and the actual observed yield, according to Mg supply. For most plots, the yield gap was between 0 and 20 t/ha. R^2 was almost equal to 0 (1.10^{-5}) which suggests that the yield gap measured on the plots was caused by another factor than Mg supply. Please note that only the grower's rate of Mg was tested here.

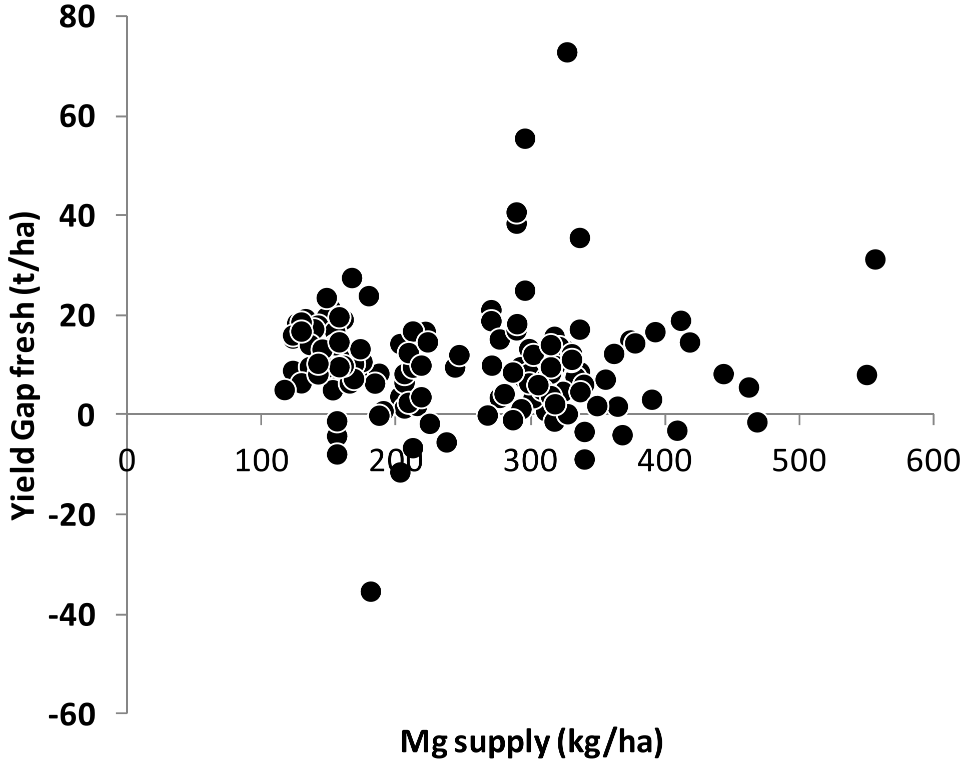


Figure 15 . Fresh yield gap (t/ha), between attainable and observed yields, for individual potato plots at all sites according to Mg supply (kg/ha). $R^2 = 1.10^{-5}$.

4 Discussion

4.1 Yield indicators

Yield, dry matter content and tuber size distribution were used to measure the effects of nutrient supply on yield. Pre-planting pathogen inoculum concentrations of key diseases were also measured and used as covariates when relevant to the analysis. Disease incidence and a range of quality assessment of tubers at harvest were also conducted on a 10-kg subsample.

Overall, no effect of the different nutrient treatments on yield was found.

Quantifying the interactions between nutrient responses identified a few marginal effects for some interactions on yield parameters at some of the sites. P was the nutrient involve in most of those marginal effects on yield, including DM content and tuber size distribution. K was also responsible for some marginal effects on yield at one of the sites (site 9).However, even though there were small indications of an effect of some treatments on the yield measured, these effects were not consistent across the sites or even in the way the impact of the nutrients was influenced by the presence of the other nutrients.

This first part of the analysis considered only the quantity of nutrients added by the fertiliser to the crop. The second part of the analysis, using the PARJIB model, also took account of the soil base fertility: how much of each nutrient was already in the soil and how much of each was added by the fertiliser.

4.2 PARJIB analysis

This part of the analyses used the data from the soil sampling taken at pre-planting and explored response curves to baseline nutrient concentrations and added fertiliser for each of the nutrients (only baseline nutrient concentration for Mg).

The initial fitting of the model underlined a yield gap for most plots at all sites. This is supported by the findings of the crop survey (Sinton et al, 2013).

The assessment of nutrient response and fertiliser management through the PARJIB model, showed that there was a yield gap between the potential yield (dictated by the climate and the cultivar used) and the attainable yield (accounts for influence of mineral nutrition) at most site related to N and P supply. However, that yield gap was under 10 t/ha for most of the plots at each site. K supply was not responsible for any yield gap at any site.

When looking at the yield gap between the attainable yield and the observed yield measured in the field at harvest, there was a yield gap of around 20 t/ha for most plots at all of the four sites. This is supported by the initial fitting of the model and the data from the crop survey (Sinton et al. 2013, unpublished). However, because the R^2 value for all nutrients (N, P, K, Ca and Mg) was low, the factor causing those yield gaps was not nutrient supply to the crop. Please note that for Mg, only the soil base concentration has been taken in account in the model.

5 Conclusion and recommendations

Overall, no nutrient was shown to limit yield strongly at the four sites where the fertiliser trials were conducted. This means that the current fertiliser practices used by growers for nitrogen, phosphorus, potassium and calcium are near optimum or at least not a major factor of the “yield gap”.

Future projects could look at:

- Improving fertiliser use efficiency by the crop for some nutrients (N in particular): this can be done by managing the timing of fertiliser application and/or splitting fertiliser application

6 Acknowledgements

This project was funded by Potatoes New Zealand, McCain Foods (New Zealand) Ltd, Ravensdown Fertiliser Co-operative Limited and the McCain growers group.

Duncan McLeod (Seed and Field), the growers and their agronomists are thanked for allowing access to and use of the crops for the purpose of this project.

The many Plant & Food Research staff members and other people who helped with advice and field work: Craig Tregurtha, Richard Falloon, Farhat Shah, Mike George, Peg Gosden Joanna Sharp, Mika Brown, Thibault Herreman, Loreto Hernandez, Sarah Newton and Andy McKay.

7 References

Keeney DR, Nelson DW 1982. Nitrogen – inorganic forms, In: Page A.L., Miller R.H., Keeney D.R. (Eds.), Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2 ed. American Society of Agronomy and Soil Science Society of America, Madison, USA, pp. 643–709.

McLaren RG, Cameron KC 1996. Soil Science: sustainable production and environmental protection. 2nd ed. Melbourne: Australia, Oxford University Press. Pp. 188–191.

Reid JB 2002. Yield response to nutrient supply across a wide range of conditions -1. Model derivation. Field Crops Research 77: 161–171.

Reid JB, Searle BP, Sinton S 2011. Does my potato crop need fertiliser? A modelling approach. Agronomy New Zealand 41: 79–95.

Sinton S, Falloon R, Brown H, Tregurtha C, Michel A, Dellow S, Reid J, Shah F, Pethybridge S, Searle B 2013. Potato yield gap investigation 2012–13. Part A: Factors limiting yield. Plant & Food Research confidential report no. 8706.

Appendix – PARJIB analysis detailed protocol

PARJIB (as described by Reid 2002) was fitted to predict individual plot yields across all four sites using individual plot soil test data for nitrogen (AMN in top 15 cm and mineral N in the top 60cm), phosphate (Olsen P), potassium, calcium, magnesium (available K, Ca and Mg) and pH and site-specific potential yield predictions. Root-mean square deviation (RMSD) was calculated, which compares the predictions of yield for all plots with their respective yield observations. One thousand iterations of the model were set up and each given a random combination of model parameters. The patterns of RMSD for each parameter were then compared across the range of values for that parameter, to identify parameter values that resulted in poor fits, and parameter ranges were gradually constrained until optimal values were obtained. The treatments used in the model fitting included all combinations of grower's rate and double grower's rate nutrient application (except for Mg, which included only grower's rate application). This analysis allowed for a finer approach given that it took account of the whole supply for each nutrient, including what was already present in the soil at planting. This helped to confirm the results from the previous parts of the analysis and also highlighted other differences between treatments that might have not been highlighted in the previous parts of the analyses.

DISCOVER. INNOVATE. GROW.