Forecasting fertiliser requirements of forage brassica crops

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Abstract
Fertiliser management is an important aspect of growing good forage brassica crops. Every crop has a different requirement, depending on soil fertility and the expected yield response. Systems were developed for forecasting how much fertiliser, and what types, to apply to individual kale and Pasja crops. First, yield responses to fertiliser application were measured in trials in diverse climates and soil fertility conditions. Yield responded strongly to N and P availability, there were few responses to K fertiliser application, and there were no responses to S application. Second, overall responses to the nutrient supply from soil and fertiliser sources were determined in a comprehensive across-trials analysis using the PARJIB model. R-squared values for correlations between actual yields and yields simulated with the PARJIB calibrations were 0.65 and 0.64 for Pasja and kale respectively. Finally, the results were programmed into new software systems (*The Kale Calculator* and *The Pasja Calculator*) that deliver a forecast for each crop of the types and amounts of fertiliser that will give the best economic return on the investment in fertiliser.
Keywords: *The Kale Calculator, The Pasja Calculator*, fertiliser application, yield response, PARJIB analysis

Introduction
Summer and winter forage brassica crops are grown widely to supplement pastures in NZ's animal production systems. They are important for their potential to produce high yields of high quality forage and for their role as break crops during pasture renewal. Despite their potential, the performance of brassicas is very variable because they are grown in a range of climates and soils, and with varying levels of management expertise.

Fertiliser management is an important aspect of growing high-yielding brassica crops because they are grown in diverse soil fertility situations and have large nutrient requirements. For example, an 18 t/ha kale crop takes up about 450 kg K/ha, 360 kg N/ha, 100 kg S/ha and 50 kg P/ha. Yield response to fertiliser application is very variable because crops respond to total nutrient availability from both soil and fertiliser, and soil fertility differs from paddock to paddock. This means that every crop has a different fertiliser requirement for optimum yield and economic return and, therefore, it is inefficient to use a recipe approach for fertiliser recommendations.

The challenge is to interpret soil test results and other relevant information to decide how much fertiliser, and what types, to apply to each crop. In this paper we describe a project in which (a) yield responses of two forage brassicas to nutrient availability were measured in several trials in diverse conditions, (b) the results were analysed to determine the underlying response to each nutrient, and (c) the resulting calibrations were incorporated into a system for forecasting the fertiliser requirement to ensure responsible use of fertiliser and get the best economic return on the investment in fertiliser for each crop.

Methods
Forecasting systems were developed for two contrasting brassicas: kale which provides single-graze winter feed and Pasja, a multi-graze leafy type used to supplement pasture production during summer and autumn. A three step procedure was followed for each crop:

1. Yield was measured in 22 field trials, 11 for each crop, that were conducted during three seasons at sites with diverse climates (from Waikato to Southland) and soil fertility conditions. There were two groups of trials with each crop:
   (a) Three trials to determine the regulation of potential yield, without any nutrient or water limitations. The crops were managed intensively and different yields were generated with six treatments in each trial: a factorial of two planting dates and three sowing rates. Crop growth and development were measured to obtain information about phenology, leaf canopy development and crop growth, and the results were used to build a potential yield model for inclusion in the forecasting system.
   (b) Trials to measure yield responses to availability of N, P, K and S from soil and fertiliser sources. The trials were done at sites with a range of soil fertility levels. The treatments in each trial depended on the fertility at the site, which differed among trials, and by the requirements of the PARJIB analysis

system (see 2 below). Some trials consisted of 16 treatments with various combinations of rates of N, P, K and S applied at planting and, in some treatments, additional N was applied during crop growth. Other trials were focussed on determining responses to N and P, and had fewer treatments. Soil fertility was measured in every plot at planting immediately before the fertiliser treatments were applied. Soil was analysed using standard techniques (Cornforth, 1980) supplemented by measurements of readily mineralisable N using anaerobic incubation at 40°C (Keeney & Bremner 1966). Yield was also measured in every plot, once in kale, at the end of the season, and twice in Pasja, after two successive 60 day growth cycles.

2. Yield responses to the availability of each nutrient from both soil and fertiliser sources, and the effects of interactions among them, were determined using a comprehensive across-trials analysis called PARJIB (Reid 1999, 2002; Reid *et al*. 1999, 2002). The PARJIB system resolved the diverse results from the fertiliser trials by deducing the underlying response to availability of each nutrient (from soil and fertiliser), and the interactions among them, in a combined analysis of data from all sites for each crop. The analysis assesses the yield of every individual plot in each trial in relation to (a) the potential yield at each trial site, and (b) the availability of nutrients based on the soil test result and the amount of fertiliser applied to each plot. For the analysis, the potential yield is taken as the maximum produced by the fully fertilised treatment plots at each site. The output from the PARJIB analysis defines the following for each crop:
   (a) The yield response to each nutrient from both soil and fertiliser sources.
   (b) The threshold soil fertility level below which a yield response to fertiliser occurs.
   (c) The yield responses to fertiliser applied below the thresholds and the efficiency with which the fertiliser is used.
3. The nutrient response calibrations from the PARJIB analyses were incorporated into two software systems (*The Kale Calculator* and *The Pasja Calculator*) that were developed to deliver forecasts of the optimum type and amount of fertiliser to apply to each crop.

Results

Potential yield

The potential yield trials and development of the potential yield models were described in a previous paper (Wilson *et al*. 2004). Briefly, production was high with an average growth rate of about 150 kg/ha/day during the growth cycle of both crops. During peak mid-season growth the average was over 250 kg/ha/day for kale, and slightly lower for Pasja. Final yield depended on sowing date, with lower yields from later sowings, because it determined the growth duration and availability of solar radiation which is the principal driver of growth rate. Yield was not affected by plant population across a wide range in either crop. Maximum yields for kale were well over 20 t DM/ha and Pasja produced over 8 t DM/ha per 60 day growth cycle. Results from the trials were used to develop and test models that simulate the phenology, leaf canopy development, growth and, ultimately, predict the potential yield of a kale or Pasja crop, driven by radiation and temperature, as a function of sowing date and growth duration.

Fertiliser response trials

There was a wide range of soil N, P and K fertility, both among and within the sites used for the trials. There was also a wide range of soil S levels but the results are not presented because there were no cases where yield responded to S fertiliser application, even when soil S levels were low. Among the Pasja sites (Table 1), mean readily mineralisable soil N at planting ranged from 60 kg N/ha following a cropping sequence at Fairlie to 175 kg N/ha following long-term pasture at Gore. Olsen P values ranged from very low (3.1) to moderate (21.2), the latter at the Fairlie site. Quicktest K values ranged from 2.2 to 12.7. Comparable ranges at the kale sites (Table 2) were 61 to 231 kg N/ha, Olsen P values of 9.3 to 30.9, and Quicktest K values from 2.5 to 9.9. There was considerable variation of N, P and K values among plots within each trial, and this was taken into account in the PARJIB analysis which assessed the yield response to nutrient availability in every individual plot.

Yield responded differently to fertiliser application in every trial, reflecting the diverse yield potentials and soil fertilities among the sites. Responses were generally smaller in high fertility situations than in low fertility ones, and they were generally larger in high yielding crops with higher nutrient requirements. Apart from nutrient effects, most crops produced below their full potential to varying extents and, for a variety of reasons, there was a wide range of yield levels among the sites. Less than ideal crop establishment and water deficits were common causes of lower yields. The main yield response was to N and P availability, and there was an interaction between the effects of N and P on yield. There was seldom a response to K application because the soils at most sites had a high capacity to supply K. Exceptions occurred for crops with high potential yield when they were grown in soils with low TBK values (low capacity to supply K).

The example in Figure 1 shows a typical response from a lower fertility site. The results are from the first harvest of the Pasja trial at Lake Ferry in Wairarapa where

Table 1 Mean, minimum and maximum readily mineralisable N ("Available N"), Olsen P and Quicktest K values from all plots at each Pasja trial site.

Location	Available N (kg/ha)			Olsen P (mg/l)			Quicktest K		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Lincoln	76	60	98	6.0	1	10	12.7	7	19
Gore	175	100	248	9.2	8	13	2.2	1	4
Waikato	158	35	246	7.4	3	15	2.3	1	4
Masterton	109	82	134	3.1	2	6	2.6	2	4
Lake Ferry	100	79	116	5.4	4	8	4.4	3	6
Fairlie	60	52	82	21.2	17	29	5.0	3	10

Table 2 Mean, minimum and maximum readily mineralisable N ("Available N"), Olsen P and Quicktest K values from all plots at each kale trial site.

Location	Available N (kg/ha)			Olsen P (mg/l)			Quicktest K		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Lincoln	61	43	109	11.5	8	15	9.9	7	15
Balfour	166	110	210	9.3	7	15	3.3	3	5
Waikato	168	31	236	9.6	6	16	2.5	1	4
Te Pirita	62	8	79	10.4	6	15	4.1	3	6
Drummond	231	154	294	11.0	5	23	9.7	6	14
Lochinvar	118	58	168	24.0	10	46	4.0	3	6
Te Pirita	65	51	86	10.7	6	18	5.7	3	9
Fairlie	126	85	176	30.9	26	36	6.8	4	11

Figure 1 Dry matter yield responses to applications of N and P fertilisers from the first harvest of Pasja at the Lake Ferry site with low P and moderate N fertility.

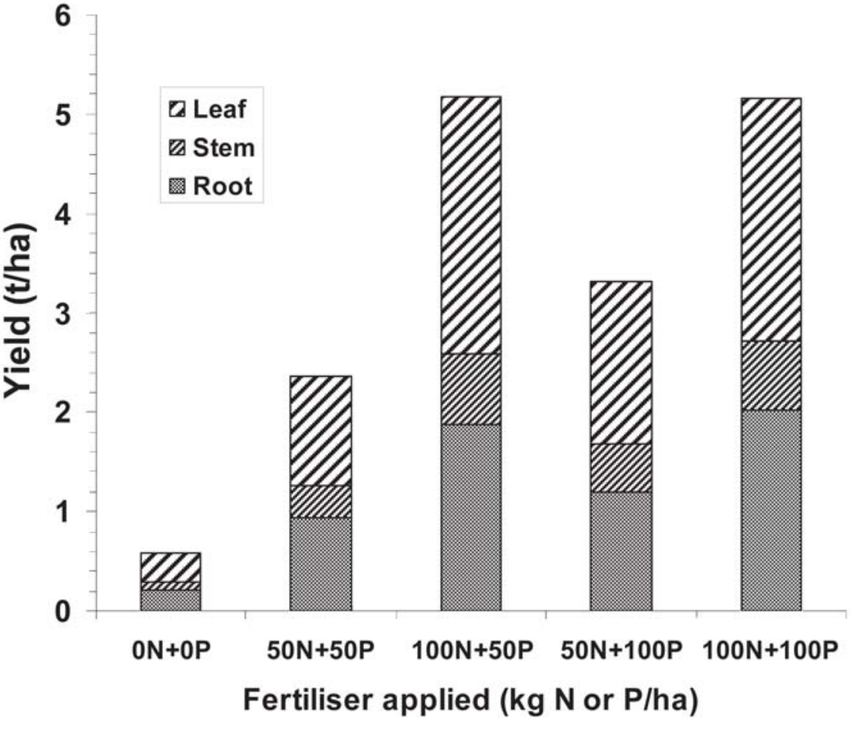


Table 3 Yields in the treatments with no fertiliser applied and with the highest yield, and the yield range, in each of the Pasja and kale fertiliser trials. Each Pasja yield is the total of two harvests. Comments indicate local features that influenced results.

Location	Yield (t DM/ha)			Comment
	No Fertiliser	Highest	Range	
Pasja				
Lincoln	6.9	13.3	6.4	Irrigated
Gore	7.1	15.0	7.9	Ex-pasture
Waikato	4.8	5.9	1.1	Ex-pasture, dry
Masterton	3.6	5.8	2.2	Dry, low P
Lake Ferry	1.5	9.2	7.7	Dry, direct drilled, low P
Fairlie	8.2	12.6	4.4	Irrigated
Kale				
Lincoln	14.2	19.1	4.9	Irrigated, deep soil N
Balfour	8.2	12.6	4.4	Dry
Waikato	10.7	14.1	3.4	Ex-pasture, dry
Te Pirita	2.8	8.1	5.3	Very dry
Drummond	12.7	14.2	1.5	Ex-pasture
Lochinvar	4.1	6.1	2.0	Very dry
Te Pirita	5.1	13.3	8.2	Irrigated
Fairlie	6.5	14.7	8.2	Irrigated

soil P fertility was low and N was moderate (Table 1). Overall yield was low because of dry conditions, but there was a strong response to N and P applications. The yield was very low with no fertiliser applied, it responded strongly to application of 50 kg P/ha, but not to more, and there was a strong yield response to increasing N application.

There was a wide range of yield levels and responses among the sites (Table 3). Local features that influenced the results are indicated briefly in Table 3. With no fertiliser applied, Pasja yields varied from 1.5 to 8.2 t DM/ha and the range for kale was from 2.8 to 14.2 t DM/ha. Values for the highest yielding fertiliser treatment at each site ranged from 5.8 to 15.0 t DM/ha for Pasja and 6.1 to 19.1 t DM/ha for kale.

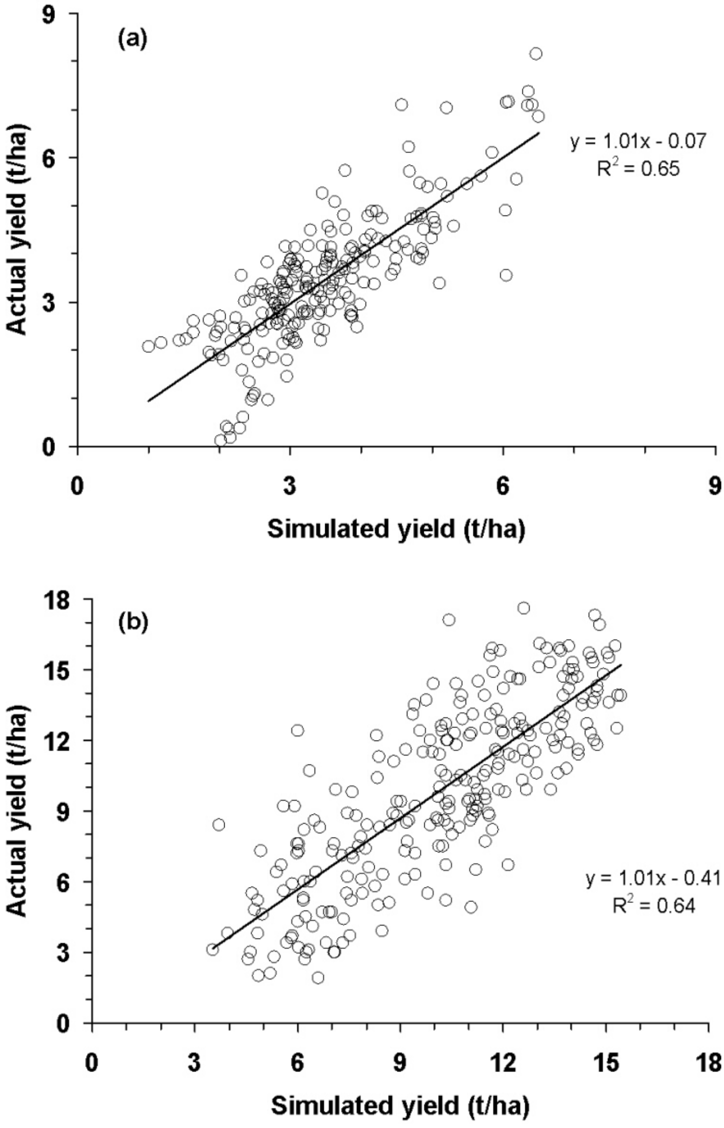
It is not feasible to present the full yield results from all the trials here. Nor would it be very instructive because the results from each trial have little value on their own. The responses to fertiliser application are specific to the circumstances of each trial, and it is not possible to deduce the underlying responses to availability of each nutrient and extrapolate the results to forecast fertiliser requirements. However, the combined results from all trials are very valuable when analysed with PARJIB.

Analysis of responses to nutrient availability

The analysis with the PARJIB system optimised values of parameters that quantified the yield responses to N, P and K analysis across all the trials. It did this with a combined assessment of the yield of every individual plot in each trial. Key results from the analyses were as follows:

1. Kale and Pasja both had high values of a parameter that defines the amount of N, from soil and fertiliser, that they require access to per tonne of yield. This indicated that they have a high demand for N but are relatively inefficient at taking it up from the soil compared with many other crops. The other main parameter from the analysis indicated that both crops utilise fertiliser N applied down the spout more efficiently than they utilise broadcast N. Also, they use soil and fertiliser N with similar efficiencies.
2. The two crops had similar, intermediate values of the parameter that defines the amount of P that they need access to. However, they were very different in their ability to utilise fertiliser P. Kale utilised fertiliser P very efficiently regardless of whether it was applied down the spout or broadcast, and it utilised fertiliser P almost three times as efficiently as soil P. In contrast, Pasja was only half as efficient as kale at utilising fertiliser P applied down the spout, and about 40% less efficient again at utilising soil P. When fertiliser P was broadcast, Pasja used it about seven times less efficiently than when it was applied down the spout. These results indicate that Pasja's root system has poor ability to access P from both soil and fertiliser sources whereas kale apparently has a vigorous root system with good ability to scavenge for soil and fertiliser P.
3. Kale and Pasja had intermediate and very high values respectively of the parameter that defines their need

Figure 2 Correlations between dry matter yields simulated using the parameters derived from the PARJIB analysis with the actual yields in the trials for (a) Pasja and (b) kale.



for access to K. The result for kale is consistent with its high requirement for K and that high yielding crops responded to fertiliser K application on soils with low TBK values. Pasja utilised K fertiliser applied down the spout about twice as efficiently as broadcast K fertiliser, and about three times as efficiently as soil K. In contrast, kale utilised broadcast K fertiliser about three times as efficiently as soil K, and K applied down the spout was used with low efficiency.

The PARJIB calibrations were assessed by correlating yields simulated using the parameters derived from the PARJIB analysis with the yields measured in the trials. The results in Figure 2 show that the R-squared values for the correlations were 0.65 and 0.64 for Pasja and kale respectively. These values represent a very acceptable internal calibration check in view of the diverse set of yield response data and the high variability among plots in factors such as plant population.

Forecasting systems

The potential yield models and the N, P and K yield response parameters were programmed into two new software systems (*The Pasja Calculator* and *The Kale Calculator*) which can be used to provide farmers with a forecast for each individual crop of the optimum types and amount of fertiliser to apply. Inputs required for each forecast are:

1. Results of a standard soil fertility test, and also a readily mineralisable N test, from the paddock.
2. An estimate of the crop's expected yield. The estimate is based on an upper-limit yield, calculated with the system's potential yield model, which is reduced to a realistic target by the user, taking account of the circumstances of the individual crop.
3. An estimate of the expected economic value of the crop, in $ per kg of dry matter.

The systems then calculate the following outputs:

1. The amount of N, P, K and S required by the crop from both soil and fertiliser sources to produce the expected yield.
2. A forecast of the types and rates of fertiliser that will give the maximum economic return on the investment in fertiliser. It produces this forecast by:
   (a) Selecting from a database the fertiliser type best suited to the circumstances of the crop based on technical and economic criteria: the ratio of nutrients delivered by the various fertiliser options, the forecast yield response and its economic value, and the cost of each option.
   (b) Displaying a graph of the calculated yield response to increasing application rates of the selected fertiliser.
   (c) Identifying the point on the yield response where the economic return is optimum. Beyond that point yield continues to increase, but the value of the extra yield is less than the cost of the additional fertiliser.
   (d) Repeating steps (a) to (c) to determine whether it is economic to add other fertiliser types to the mix, and what their rates of application should be.

Conclusions

Yields of both Pasja and kale respond strongly to total availability of N, P and K but not to S. The supply of nutrients from the soil is different for every crop. In general, yield often responds to N and P fertiliser application. However, there is seldom a response to K application because there is an adequate supply of K from most soils unless the TBK value is very low. Also, every crop has a different potential yield and, therefore, a different requirement for nutrients. These factors mean that the fertiliser requirement for optimum yield and economic return is also different for every crop, and it is not appropriate to use a recipe approach for fertiliser recommendations. The results from this project provide a new approach for producing a fertiliser recommendation that is tailored for each crop.

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