Kale dry matter yield responses to nitrogen and phosphorus application

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Abstract

Forage brassica crop establishment and subsequent growth are affected by nutrient availability, particularly of nitrogen (N) and phosphorus (P). The effects of P and N applications on kale dry matter (DM) accumulation were examined in three field experiments in Canterbury and one in the Central North Island region of New Zealand. Nitrogen, as urea (46%), was applied at sowing and mid-season and P as triple superphosphate (P = 21 %) was hand broadcast, hand broadcast and soil incorporated or banded at 0 or 50 kg P ha^{-1} at sowing. Nitrogen fertiliser doubled kale yields at Te Pirita, from 5 to 10 t DM ha^{-1} but there was no difference between the 100 and 200 kg N ha^{-1} rates. Total DM increased with P supply from 5 t DM ha^{-1} in the control to a mean of 8 t DM ha^{-1} with 50 kg P ha^{-1}. At Fairlie, total DM yield increased with P supply and with N application when P was applied. Total DM at Methven increased more than 2 t ha^{-1} when 170 kg N ha^{-1} was applied compared with the 70 kg N ha^{-1} for kale crops. There was also an effect of background soil P at Methven, mostly affecting the stem DM accumulation. Because of the nature of the treatments (nested) at Te Pirita and Fairlie, it was not possible to determine whether the effect of N was due to the total N applied or the time of application. The lack of response, to all the treatments, at Lochinvar was probably due to moisture stress meaning the initial soil N (mean 220 kg N ha^{-1}) and P (Olsen P = 22) levels were adequate for the 4-6 t DM ha^{-1} crops grown. For most situations a P application of up to 50 kg ha^{-1} is recommended at establishment with N managed more dynamically throughout the growing season based on soil N and crop yield potential.

Additional keywords: Banded, broadcast, *Brassica oleracea* var. *acephala*, establishment, Gruner kale, independent, interaction, leaching, metabolisable energy

Introduction

The New Zealand dairy industry has set two goals to achieve by 2015; to increase metabolisable energy (ME) by 50 % and to reduce N leaching losses by 50 % (FoRST, 2007). This will require a higher proportion of farms growing high producing specialist forage crops (de Ruiter *et al.*, 2009a) such as kale (*Brassica oleracea* var. *acephala* L.). Kale establishment and subsequent growth are affected by availability of key nutrients such as nitrogen (N) and phosphorus (P). Phosphorus affects crop establishment (Grant *et al.*, 2000), as it is associated with improved root development (Claridge, 1972) while N affects kale growth throughout the season (Fletcher *et al.,* 2007). Kale crops respond strongly to N and P application, especially if they are sown after depletive crops like cereals. Previous research with kale has shown a higher response to banded than broadcast P fertiliser (Wilson *et al.,* 2006). These authors also reported that kale was more efficient at utilising fertiliser P than soil P, irrespective of the method of P application.

Kale is an important forage crop in the southern parts of New Zealand, occupying over 25,000 ha (Gowers and Armstrong, 1994) and can produce dry matter (DM) yields over 20 t ha^{-1} (Zyskowski *et al.,* 2004; Fletcher *et al.,* 2007). Despite this potential, kale yields are often variable as it is grown in a range of climates and soil fertility situations (Wilson *et al.,* 2006) with varying levels of management expertise. Kale crops have high nutrient requirements. For example, Wilson *et al*. (2006) estimated that an 18 t ha^{-1} kale crop removes about 360 kg N ha^{-1} and 50 kg P ha^{-1}.

The high kale N requirement (Wilson and Maley, 2006; Fletcher *et al.,* 2007) may lead to adverse animal health effects and create a potential environmental risk from N leaching into ground water. The environmental effects may be exacerbated by urine returns after grazing, especially under wet conditions. Kale, like most forage brassica species, is inefficient at N uptake compared with other crops (Wilson *et al.,* 2006), which accentuates the need for appropriate rates and times of application.

There are also likely to be strong interactions between P and N supply that influence kale yields. For example, lower responses to P fertiliser are expected on soils with a low N supply and when little fertiliser N is applied at establishment. To make the most efficient and economic use of applied P and N fertilisers it is necessary to quantify the extent of these interactions.

This paper reports four experiments that aimed to refine N and P fertiliser recommendations for kale crops. They investigated the effects of method of P application, rate of P and N application and time of N application on kale DM accumulation. The specific objectives were to:

(1) measure the yield response to different rates of N and P,
(2) confirm the yield response to P application method and
(3) quantify any interactions between N and P application.

Materials and methods

The four experiments are grouped based on sowing year: Experiment A (2004) and Experiment B (2007). All trials were located in farmers' fields and none of the crops were irrigated. One of the Experiment A sites was at Te Pirita (43 ° 43 'S, 171 ° 45 'E) on a stony Lismore soil (Haynes, 2000). Another was at Fairlie (44 ° 10 'S, 170 ° 83 'E) on a yellow grey earth with gravelly subsoil (McLaren and Cameron, 1996), in Canterbury. The third site was at Lochinvar (38 ° 58 'S, 176 ° 21 'E) on a yellow brown pumice soil (Toxopeus and Gordon, 1985), in the Central North Island. Experiment B was at Methven (43.38 ^{o} S, 171.4 ^{o}E) on a Lyndhurst silt loam soil (Martin, 1986), in Canterbury. Gruner kale seed was drilled into cultivated soils at Te Pirita and direct drilled at the three other sites. Kale crops followed a rape crop at Fairlie and long term pasture at Methven, Lochinvar and Te Pirita.

Treatments and experimental design

The design for the three Experiment A sites was a randomised complete block with three replicates of 12 treatments. Triple superphosphate (TSP; 21% P) was either hand broadcast, hand broadcast and incorporated or banded (Table 1) below the seed at sowing at 0 or 50 kg P ha^{-1}. Nitrogen, as urea (46%), was broadcast and incorporated into the soil at 0, 50 and 100 kg ha^{-1} at sowing (Table 1). Mid-season N was applied after the first sampling and was broadcast onto the soil surface.

A soil test to 150 mm depth was taken from each of the 36 plots at each site before sowing. Average 'Quick test' result for each site and available N results are shown in Table 2.

Table 1: Fertiliser treatments for experiments at Te Pirira, Fairlie and Lochinvar, 2004-05.

Treatment	Phosphate at sowing			Nitrogen	
	[1]Band	[2]Broadcast	[3]Incorporated	[4]At sowing	[5]Mid-season
F_1	0	0	0	0	0
F_2	0	0	0	50	50
F_3	0	0	0	100	100
F_4	50	0	0	0	0
F_5	0	50	0	0	0
F_6	0	0	50	0	0
F_7	50	0	0	50	50
F_8	0	50	0	50	50
F_9	0	0	50	50	50
F_{10}	50	0	0	100	100
F_{11}	0	50	0	100	100
F_{12}	0	0	50	100	100

[1]Triple superphosphate (TSP; P = 21%) placed below seed, at sowing. [2]TSP on the surface just after sowing. [3]TSP on the surface and incorporated by a surface cultivation just before sowing. [4]Urea (N = 46%) on the surface and incorporated by surface cultivation just before sowing. [5]Urea broadcast on the surface mid-season.

Table 2: Average soil test results and optimum quick test for Te Pirita, Lochinvar and Fairlie (2004-05) and Methven sites (2007-08) and optimum nutrient requirements (McLaren and Cameron, 1996).

Site	pH	Olsen P (μg kg^{-1})	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Available N (kg ha^{-1})
Te Pirita[1]	5.7 (6.2-6.6)[2]	11 (6-18)	6 (3-6)	5.0 (7-9)	15 (7-12)	65 (51-86)
Fairlie[1]	5.6 (5.5-5.9)	31 (26-36)	7 (4-11)	6.0 (4-7)	6 (4-8)	126 (85-176)
Lochinvar[1,3]	6.1 (5.9-6.2)	22.0 (10-46)	4 (3-5)	2.0 (1-4)	4 (2-6)	220 (108-310)
Methven[1]	5.9 (5.8-6.1)	7.0 (5-11)	3 (11-21)	6 (5-8)	7 (5-9)	187 (143-225)
Optimum	5.8-6.0	20-25	5-7	4-10	8-10	200-300

[1]Average values from all plots. [2]Numbers in parentheses are the ranges of each nutrient on a per plot basis. [3]P retention of 62%.

Base fertiliser was applied at 1.5 kg ha^{-1} boron, 50 kg K ha^{-1} as potassium chloride. Seed was direct drilled with an 11 row cone seeder in 150 mm rows at a depth of approximately 20 mm (Lamp, 1962) at all sites. Sowing rate was 3.5 kg ha^{-1} of viable seed, pelleted with 'Superstrike®' which contains systemic insecticides to control springtails (*Bourletiella* species) and fungicides to control *Pythium* and *Fusarium* diseases (Salmon and Dumbleton, 2006). Karate (a.i. 250 g l^{-1} lambda-cyhalothrin) at 0.04 l ha^{-1} and Contact at 0.1 l ha^{-1} were applied on 10 January and 17 February 2005 at Te Pirita and at the same rates for Karate and Contact on 10 January and 3 March 2005 at Fairlie to control insect pests. Details of key activities at each site are summarised in Table 3

Table 3: Key dates and activities for Gruner kale crops grown at four experimental sites.

Site	Year	Sowing date	Sampling Date		Area harvested (m^2)
			1	2	
Te Pirita	2004-05	1 December	4 April	2 June	2
Fairlie	2004-05	30 November	4 April	2 June	2
Lochinvar	2004-05	13 December	6 April	21 June	2
Methven[1]	2007-08	26 November	-	26 May	2

[1]Harvested once at the end of the season.

Experiment B

The design at Methven was a randomised complete block with three replicates of 16 treatments. The TSP was either broadcast by hand before sowing and soil incorporated or banded below the seed at sowing at 0, 25, 50 or 75 kg P ha^{-1}. N, as urea, was broadcast at 70 and 170 kg ha^{-1} with the higher rate split and applied at 100 kg and 70 kg N ha^{-1} at 8 and 14 weeks after sowing, respectively. The low rate of N was applied 14 weeks after sowing. Gruner kale seed treated with 'Superstrike®' was direct drilled with a 13 row cone seeder at 4 kg ha^{-1} of viable seed.

A soil test to 150 mm depth was taken from all 24 plots before sowing. Average Quick test results are shown in Table 2. Base fertiliser was applied at 1.5 kg ha^{-1} boron, 25 kg K ha^{-1} applied as potassium chloride 30 kg Mg ha^{-1} was applied from a commercial calcium/magnesium fertiliser. The crop was managed using best practices (de Ruiter *et al.,* 2009b) to minimise the risk of weeds, pests and diseases. Pre emergent Treflan® (a.i. 480 g l^{-1} trifluralin EC) was the only herbicide used for weed control.

Measurements

Herbage yield and partitioning.

At each harvest plant counts and crop fresh weights were determined. A representative 10 plant sub-sample was kept for DM determination and leaf and stem partitioning. Samples were dried in a forced air oven at 60 ^{o}C to constant weight.

Meteorological conditions

No site-specific weather data were available for Experiment A. Results from the nearest weather station are shown in Table 4. The closest recorded weather data for the Lochinvar site was Taupo; about 40 km west. Weather data for Experiment B were obtained on site. Total rainfall was lower than the long term mean (403 mm), a third (115 mm) of which fell in February. Temperatures were similar to the long term mean (12.2 ^{o}C) except for a low of 4.2 ^{o}C in May.

Table 4: Mean weather data for the three Experiment A sites (NIWA, 2010) and Methven site.

Site	Weather Station	Location	Rainfall (mm)	Temp (^{o}C)
Te Pirita	4722	43 ° 69 'S, 171 ° 90 'E	423	13.6
Fairlie	7726	44 ° 12 'S, 170 ° 88 'E	373	13.6
Lochinvar (Taupo)	25040	38 ° 68 'S, 176 ° 10 'E	442	13.9
Methven		43 ^{o} 38 'S, 171 ^{o} 40 'E	338	11.8

Data analysis

Leaf, stem and total DM yields at each site were analysed using analysis of variance (ANOVA) fitted with least squares in GenStat version 12. This was followed by a meta-analysis of the data from all three Experiment A sites; using a mixed model fitted with the restricted maximum likelihood (REML) programme in GenStat version 12. An estimate of the variation associated with treatment means was given by least significant difference ($LSD_{5\%}$) with associated degrees of freedom (df). Sum of squares were partitioned to allow for treatment structure and enable direct comparison of the control with treatment means. For the Methven site, background soil P and N levels were used as covariates in the analysis because they had a significant effect.

Results

Experiment A

There was no interaction of N, P and method of P application for any of the variables measured at Te Pirita (Figure 1). The total DM yield increased (P<0.001) with application of N from a mean of 5 t ha^{-1} for the unfertilised crops to 10 t ha^{-1} with applied N. There was no difference in yield between 100 and 200 kg N ha^{-1}. There was some evidence that adding P increased (P=0.025) total DM yield (Figure 1) but application method had no effect (P=0.723).

Both leaf and stem DM increased (P<0.001) with N application. The leaf (P=0.014) and stem (P=0.034) DM yields were also increased with P application but application method had no effect on either component.

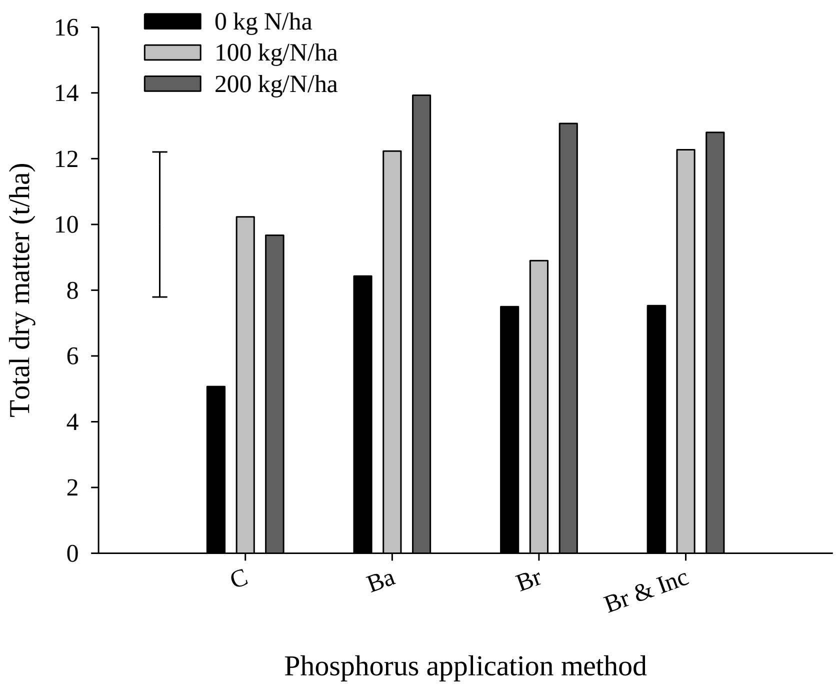

Figure 1: Total dry matter yield (t ha^{-1}) for kale crops grown with three rates of nitrogen (N = 0, 100 & 200 kg ha^{-1}), three methods of phosphorus (P) application (Ba = Banding, Br = Broadcast, Br & Inc = Broadcast & Incorporated) and two rates of P (Control or 50 kg ha^{-1} for Ba, Br or Br & Inc) at Te Pirita, Canterbury in 2005. Bar represents 5% LSD with 22 df.

There was a significant interaction (P=0.034) between N and P rate for total DM yield at Fairlie (Figure 2). Specifically, application of 50 kg P ha^{-1} had little impact when no N was applied. Equally when no P was applied (control) there was no response to 100 or 200 kg ha^{-1} of N. However, when 50 kg P ha^{-1} was banded or broadcast both N levels improved the yield with a maximum of 15 t ha^{-1}. This yield was only achieved for broadcast and incorporated P when 200 kg N ha^{-1} was applied.

There were also interactions of N and P rate for stem (P=0.038) and leaf (P=0.048) DM yield at Fairlie. However, P application method had no effect on either leaf or stem DM yield.

At Lochinvar, leaf, stem and total DM yield were unaffected by rate of N or P application or the method of P application (Figure 3). Overall yield was lowest at 4-6 t ha^{-1} with a high degree of variability.

Meta-analysis of the three Experiment A sites showed an interaction (P=0.017) between P rate and N rate. This indicated that overall the total DM yield only increased with application of 200 kg N ha^{-1} when P had been applied at establishment (Figure 4).

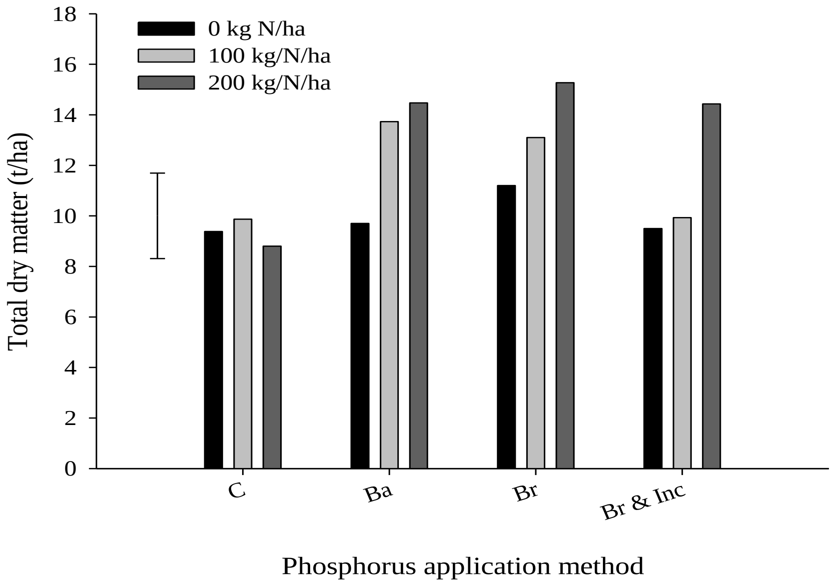

Figure 2: Total dry matter yield (t ha^{-1}) for kale crops grown with three rates of nitrogen (N = 0, 100 & 200 kg ha^{-1}), three methods of phosphorus (P) application (Ba = Banding, Br = Broadcast, Br & Inc = Broadcast & Incorporated) and two rates of P (Control or 50 kg ha^{-1} for Ba, Br or Br & Inc) at Fairlie, Canterbury in 2005. Bar represents 5% LSD with 22 df.

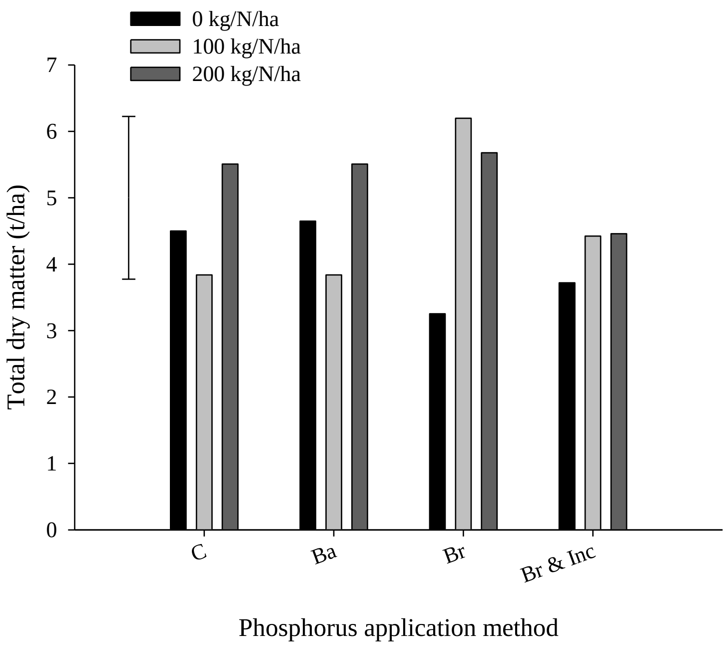

Figure 3: Total dry matter yield (t ha^{-1}) for kale crops grown with three rates of nitrogen (N = 0, 100 & 200 kg ha^{-1}), three methods of phosphorus (P) application (Ba = Banding, Br = Broadcast, Br & Inc = Broadcast & Incorporated) and two rates of P (Control or 50 kg ha^{-1} for Ba, Br or Br & Inc) at Lochnivar, Central North Island in 2005. Bar represents 5% LSD with 22 df.

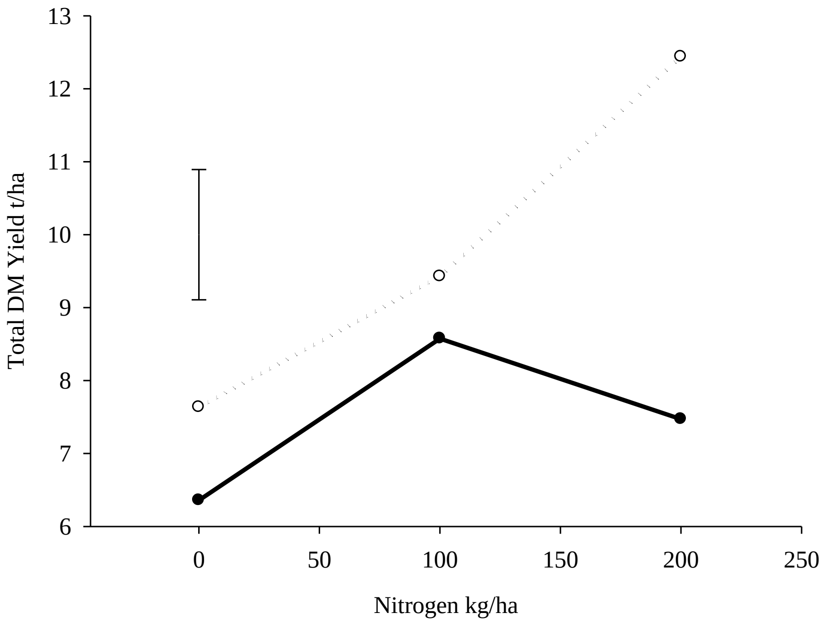

Figure 4: Total dry matter yield of kale crops grown with two rates of phosphorus, 0 (-●-) and 50 (--○--) kg P ha^{-1} at three nitrogen levels (0, 100, 200 kg ha^{-1}), at three sites in New Zealand (Experiment A). Bar represents 5% LSD with t = 2.

Experiment B (Methven)

Mean total DM yield across treatments increased (P<0.001) by 2.5 t ha^{-1} to 14.7 t ha^{-1} when 170 kg N ha^{-1} was applied compared with 70 kg N ha^{-1} (Figure 5, Table 5).There was some evidence of an interaction (P=0.064) among the rate of P and methods of P application at 170 kg N ha^{-1} (Figure 5b). Specifically, banded P crops yielded more than the broadcast P crops when 25 or 50 kg P ha^{-1} was applied at 170 kg N ha^{-1} but this was reversed at 75 kg P ha^{-1}. Background N had no effect on total DM yield.

Mean leaf DM increased (P<0.001) by 0.4 t ha^{-1} to 3.6 t ha^{-1} when 170 kg N ha^{-1} was applied compared with 70 kg N ha^{-1}. However, there was no evidence that adding any P had an effect on leaf yield at any rate (25, 50 and 75 kg ha^{-1}) or method of application (Banded or Broadcast).

Mean total stem DM increased (P=0.002) by 2 t ha^{-1} to approximately 11 t ha^{-1} when 170 kg N ha^{-1} was applied compared with 70 kg N ha^{-1}. However, there was no evidence that the unfertilised crops were different from the average of P treated crops (P=0.391). However, once the initial soil P status was used as a covariate, there was some evidence (P=0.086) that the 75 kg P ha^{-1} treatment was different from the others. However there was evidence (P=0.036) that the effects of P rate, P application method and N rate were not consistent for stem DM production; signified by the 3-way interaction. Stem DM also responded (P=0.01) to the interaction of background soil P and N.

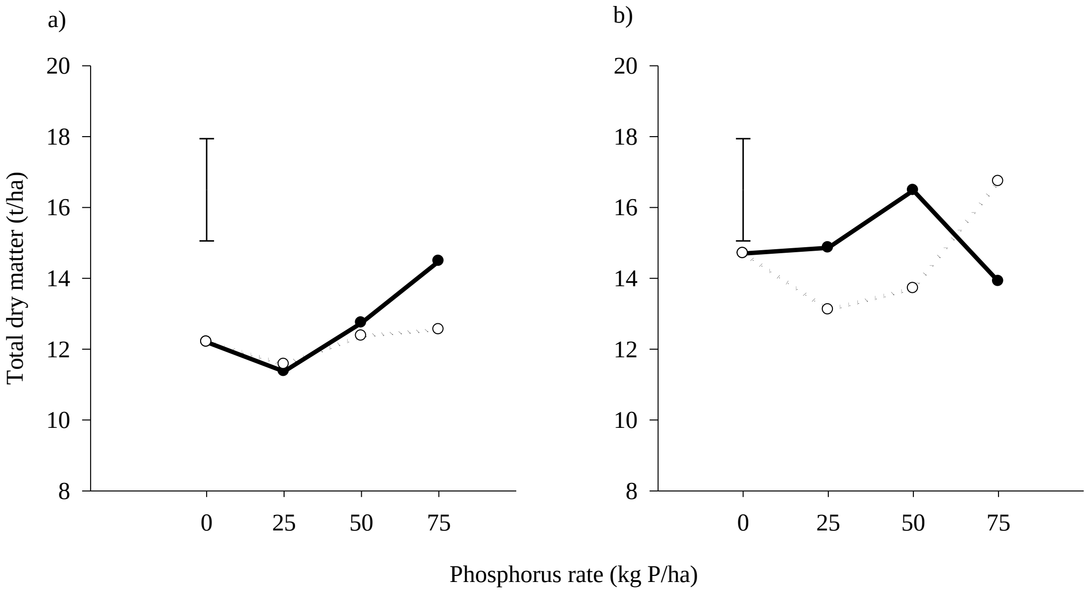

Figure 5: Total dry matter yield (t ha^{-1}) for kale crops grown with two methods of phosphorus (P) application; Banding (-●-) and Broadcast (--○--) and four rates of P, at (a) 70 kg N ha^{-1} and (b)170 kg N ha^{-1} at Methven, in 2008. Bar represents average 5% LSD with 32 df.

Table 5: Summary of kale dry matter yield responses to nitrogen and phosphorus application at four sites across New Zealand.

Site	Yield (t DM ha^{-1})			[1]Response to:			
	No fertiliser	Highest	Range	N rate	P rate	P method	Interaction
Te Pirita	5.0	14.0	5-14	√	√	x	x
Fairlie	9.4	15.3	8-15.3	√	√	x	√
Lochinvar	4.5	6.2	3.2-6.2	x	x	x	x
Methven							
(a) 70 kg N ha^{-1}	12.2	14.5	11-14.5	-	x	x	x
(b) 170kg Nha^{-1}	14.7	16.7	13-16.7	√	x	x	√

[1]√ = responded, x = no response

Discussion

The DM yield at Lochinvar, in the Central North Island, did not respond to any of the treatments (Figure 3, Table 5). The highest yield of 6 t ha^{-1} (Table 5) was lower than at the other three sites and lower than the optimum yields of 18-20 t ha^{-1} reported in literature (Wilson *et al.,* 2006; Fletcher *et al.,* 2007). This may indicate that nutrients were not the limiting factor at this site. The low yield potential meant that background N and P gave adequate nutrition (Table 2). The overall mean yields when both N and P were applied ranged from 9 to 12 t DM ha^{-1} in Experiment A (Figure 4) and 13.6 t DM ha^{-1} in Experiment B (Figure 5). These are medium yields for kale as well grown irrigated kale crops can produce more than 18 t DM ha^{-1} (Wilson *et al.,* 2006; Fletcher *et al.,* 2007). The lack of irrigation at all sites probably limited yields. The mean leaf yield of 3.3 t DM ha^{-1} at Fairlie, Lochinvar and Methven was consistent with reports in the literature (Stephen 1976; Adams *et al.,* 2005; Fletcher *et al.,* 2007). However, the mean leaf yield of 2.6 t DM ha^{-1} at Te Pirita was lower.

Experiment A

The response to N application at Te Pirita (Figure 1) and Fairlie (Figure 2) was expected as the background soil N was low to medium (Table 2). De Ruiter *et al*. (2009b) state that a response to N is unlikely when soil N is greater than or equal to 150 kg ha^{-1}. The treatments at Te Pirita and Fairlie were nested and therefore it was not possible to determine whether the responses were due to total N applied or time of application. However, most of the yield increase at Te Pirita was from stems this could potentially reduce feed quality (Chakwizira, 2008). Total DM yield also increased with P application at Te Pirita and Fairlie (Table 5) but was unaffected at Lochinvar. A response to P at Fairlie was unlikely, due to a high soil P (Olsen P = 31), but was expected at Te Pirita (Olsen P = 11) (de Ruiter *et al.,* 2009b) This was an inconsistent result as Lochinvar had a moderate soil P level (Olsen P = 22) compared with Fairlie. This anomaly could possibly be attributed to a high soil N and moderate P retention (Table 2) at Lochinvar. Fertiliser application at Lochinvar (Figure 3) was not economic. At all four sites method of P application had no effect on total DM yield.

Experiment B

Total kale DM yield did not respond to either application method or rate of P (Figure 5). This, together with the no response to method of P application at Te Pirita (Experiment A), was a surprising result because the soil P background levels were low (Olsen P < 11). The results are inconsistent with the literature, for both method and rate of P application (Wilson *et al.,* 2006) and rate of P (Chakwizira, 2008). However, the failure to respond to method of application was similar to findings for both kale (Chakwizira, 2008) and Pasja (Chakwizira *et al.,* 2009). This was attributed to low soil P retention capacity and hence most of the P was available to the crop irrespective of application method. Kale crops have a more extensive root system than other brassicas and therefore access P from a larger soil volume and possibly satisfy growth requirements despite soil P tests indicating available soil P was low.

These experiments (Wilson *et al.,* 2006; Chakwizira, 2008; Chakwizira *et al.,* 2009) were carried out in Canterbury at mean Olsen P levels of 13, and therefore the differences in yield responses to P with the current experiments are unlikely to be attributed to either background soil P or P retention because the soils are similar. The background soil P was a significant covariate affecting yield. It is proposed that the total amount of P supply (both background P and applied P fertiliser) is an important determinant of yield.

There was a strong response to fertiliser N application at this site despite the high concentration of available soil N (186 kg ha^{-1}, Table 2) which was higher the 150 kg N ha^{-1} proposed by de Ruiter *et al*. (2009b). Yield increased by 2.5 t DM ha^{-1} (Figure 5) when 170 kg N ha^{-1} was applied compared with 70 kg N ha^{-1}.

This result highlights the depth limitation of the readily available N test, as it indicates available N only in the top 150 mm. Deep and extensively rooted crops, like kale, can access additional N from a greater soil volume. However, if subsoil N is low, N applied and incorporated near the soil surface may still give yield responses even if N tests show an adequate soil N concentration.

Conclusion

Nitrogen increased DM yield by more than 2 t DM ha^{-1} at Methven and doubled DM yield to 10 t DM ha^{-1} at Te Pirita but had no effect on kale yield at Fairlie or Lochinvar. The response to N was more pronounced in the presence of P. The non-responses to method and rate of P application may have been due to adequate available soil N at Methven and Fairlie and soil P at Lochinvar. The effects of P may be manifested only under low available N as it is proposed that P influences the rate of N uptake.

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References

Adams, C.M., Scott, W.R., Wilson, D.R. and Purves, L. 2005. Dry Matter accumulation and phonological development of four brassica cultivars sown in Canterbury. *Agronomy New Zealand* 35: 1-18.

Chakwizira, E. 2008. Growth and development of 'Pasja' and kale crops grown with two methods and four rates of phosphorus (P) application. Lincoln University. 127 p. researcharchive.lincoln.ac.nz/dspace/.. ./3/Chakwizira_M.Ag.Sc.pdf.

Chakwizira, E., Moot, D.J., Scott, W.R. and Fletcher, A.L. 2009. Effect of rate and method of phosphorus application on the growth and development of 'Pasja' crops. *Proceedings of the New Zealand Grassland Association*. 71: 101-106.

Claridge, J.H. 1972. Arable farm crops. A.H. & A.W. Reed Ltd, Wellington. 345 pp.

de Ruiter, J.M., Fletcher, A.L., Maley, S., Sim, R.E., George, M., Tabley, F.J. and Gillespie, R. 2009a. Aiming for 45 t/ha per annum: Yield of supplementary feed crops grown in sequences designed for maximum productivity. *Proceedings of the New Zealand Grassland Association* 71: 107-116.

de Ruiter, J.M., Wilson, D.R., Maley, S., Fletcher, A.L., Fraser, T.J., Scott, W.R., Dumbleton, A.J., Berryman, S. and Nichol, W. 2009b. Management practices for forage brassicas. Forage Brassica Development Group, Christchurch, New Zealand. 62 pp.

Fletcher, A.L., Brown, H.E., Wilson, D.R. and Maley, S. 2007. Forage production and nitrogen uptake of kale. pp. 335-342. *In*: Proceedings of 3rd Australasian Dairy Science Symposium, 18-20 September 2007, Melbourne.

FoRST 2007. New research investment in Pastoral Industries: a model for the future. http://www.frst.govt.nz/news/New-research-investment-in-Pastoral-Industries.

Gowers, S. and Armstrong, S.D. 1994. A comparison of the yield and utilisation of six kale cultivars. *New Zealand Journal of Agricultural Research* 37: 481-485.

Grant, C.A., Flaten, D.N., Tomasiewicz, D.J. and Sheppard, S.C. 2000. The importance of early season phosphorus nutrition *Canadian Journal of Plant Science* 81: 211-224.

Haynes, R.J. 2000. Labile organic matter as an indicator of organic matter quality in arable and pastoral soils in New Zealand. *Soil Biology and Biochemistry* 32: 211-219.

Lamp, C.A. 1962. Improved turnip establishment. *Tasmanian Journal of Agriculture* 33: 42-48.

Martin, R.J. 1986. Growth of sugar beet crops in Canterbury. *New Zealand Journal of Agricultural Research* 29: 391-400.

McLaren, R.G. and Cameron, K.C. 1996. Soil science: sustainable production and environmental protection. 2nd Edition. Oxford University Press, Auckland. 218 pp.

NIWA 2010. National Climatic Data. http://cliflo.niwa.co.nz/pls/niwp/wgenf.genform1.

Salmon, R.W. and Dumbleton, A.J. 2006. The effect of seed treatment and depth of sowing on forage brassica crop establishment in no-tillage situation. *Proceeding of the New Zealand Grassland Association* 68: 211-214.

Stephen, R.C. 1976. The effect of sowing date and harvest dates on the leaf and stem yield of marrow stem kale in relation to feed quality. *Proceedings of the Agronomy Society of New Zealand* 6: 43-47.

Toxopeus, M.R.J. and Gordon, R.B. 1985. Pasture responses to magnesium fertiliser on a yellow-brown pumice soil. *New Zealand Journal of Crop and Horticultural Science* 13: 39-45.

Wilson, D.R. and Maley, S. 2006. Nitrogen balance for kale. *In*: Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006, Perth.

Wilson, D.R., Reid, J.B., Zyskowski, R.F., Maley, S., Pearson, A.J., Armstrong, S.D., Catto, W.D. and Stafford, A.D. 2006. Forecasting fertiliser requirements of forage brassica crops. *Proceedings of the New Zealand Grassland Association* 68: 205-210.

Zyskowski, R.F., Wilson, D.R. and Maley, S. 2004. A cohort model for simulating forage brassica crops with variable plant size. *In*: Proceedings of the 4th International Crop Science Congress, 26 September-1 October 2004, Brisbane. http://www.cropscience.org.au/icsc2004/.