Validation of a forage brassica calculator for fertiliser forecasting system of kale and swede crops in New Zealand

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Abstract

Validation of the kale and swede models was performed using nine independent field datasets covering a latitude range from 43°S to 47°S in New Zealand, over a period of four years. The treatments comprised different cultivation techniques, fertiliser applications and methods of sowing. In these models, the cost of each nutrient and the predicted productivity are used to recommend both economic and environmentally appropriate application rates. Predicted yields were modelled by PARJIB from the soil available nutrients, potential yield and fertiliser rates. Actual (observed) yields are those measured in the field. Overall simulations for swede crops (R^2=0.54; RMSD≤4% (0.78 t/ha)) were more accurate than for kale crops (R^2=0.42; RMSD≤6% (0.65 t/ha)). Simulation of swedes was more accurate (R^2=0.56-0.99; RMSD<0.59 t/ha (<3.6%)) for ridged than conventionally sown crops (R^2=0.27-0.56; RMSD<0.64 t/ha (<3.6%)). The kale model accurately predicted yield ((R^2>0.82; RMSD≤5.3% (<0.65 t/ha)), except for two sites, Wilson's Crossing (R^2>0.53; RMSD=23.4% (2.90 t/ha)) and Lincoln in 2010 (RMSD=36.9% (3.50 t/ha)). This was attributed to severe moisture deficit at Wilson's Crossing during January and February. At Lincoln in 2010, the objective was to investigate the effects of time of application of adequate to excessive amounts of nitrogen (N) and therefore the models simulated similar yield across the treatments hence the high RMSD. Both models are able to predict site-specific N and phosphorus (P) fertiliser requirements. Further work is required to extend their capability to include other agronomic factors such as the methods of cultivation and sowing, methods of P application, tactical decisions around N application and the response to moisture sensitivity.

Additional keywords: *Brassica oleracea* ssp *acephala, Brassica napus* ssp. *napobrassica* or *rapifera*, agro-ecological zones, agronomic factors, nutrient requirement, PARJIB model, predicted yield

Introduction

Two main crops widely grown for supplementary winter feeding in New Zealand are kale (*Brassica oleracea* L. ssp. *acephala* DC.) and swedes (*Brassica napus* L. ssp. *napobrassica* (L.) Rchb. or *rapifera* Metzg.). Historic data suggests, combined, they cover about 42% of the forage brassicas sown in New Zealand annually (White *et al*., 1999). The same authors also reported that about 70% of kale and 88% of the swede crops are grown in the South Island of New Zealand.

Recent research has shown that forage

brassica crops, particularly kale, have large nutrient requirements (Wilson and Maley 2006; Wilson *et al*., 2006; Fletcher *et al*., 2007). For example, Wilson *et al*. (2006) estimated that an 18 t/ha kale crop removes about 360 kg N, 450 kg potassium (K) and 50 kg P/ha. However, research on the influence of K on forage brassica dry matter (DM) production has shown little or no response (Davies 1970; Wilson *et al*., 2006), primarily because most soils in New Zealand are high in potassium. However, peaty soil which have no K in their parent material or volcanic soils may show significant K responses, hence, there is a need to further investigate K responses particularly in the central North Island.

Chakwizira *et al.* (2011b) have shown that a 10-15 t DM/ha kale or swede crop (2.5% N and 0.3% P, Cornforth *et al*., 1978) would contain between 250 and 375 kg N/ha and 30 to 45 kg P/ha. Most soils are unable to supply these amounts of N and P naturally during the growing season and therefore fertilisers must be added. However, rapid and high nutrient uptake by plants may lead to adverse effects on grazing animals (Nichol *et al*., 2003), such as nitrate poisonings. In addition, high fertiliser requirements create the potential for environmental risk from N leaching into ground water and/or P runoff into surface water. These environmental effects may be exacerbated by urine returns after grazing, especially during wet winter conditions when most of the kale and swede crops are grazed.

The main objective for the development of the forage brassica calculators was to calculate the nutrient requirements (Chakwizira *et al*., 2011b) of high producing forage brassica crops. Actual amounts of fertilisers applied are based on predetermined information such as site history and crop details, current fertiliser costs and concentrations of soil macro-nutrients based on pre-planting soil tests. Forage brassica calculators have been fully described in earlier papers by Chakwizira *et al*. (2011b) and Wilson *et al*. (2006). In this paper the kale and swede models are validated with nine independent field experiments that covered a wide range of the agro-ecological zones found in New Zealand.

Materials and Methods

Nine field experiments were used, retrospectively, in the validation of the kale and swede models of the forage brassica calculator. These included two data sets for 'Regal' and 'Kestrel' kale from Lincoln, as described in recently published work (Chakwizira *et al*., 2010; Fletcher and Chakwizira 2012a; 2012 b). These will be referred to as Experiments A (Chakwizira *et al*., 2010) and B (Fletcher and Chakwizira 2012a; 2012b) for 'Regal' and 'Kestrel' kale, respectively. Experiments A and B were on a deep well-drained Templeton silt loam soil (Martin *et al*., 1992; Jamieson *et al*., 1995) with an available water-holding capacity of approximately 190 mm/m of depth. A third group of experiments conducted between 2006 and 2009 (de Ruiter *et al*., 2009) included 'Aparima Gold' swede and 'Gruner' kale crops at seven sites in the South Island (Table 1) of New Zealand. These data sets will be referred to as Experiment C. The soil details are in Table 1. The actual N and P rates and sowing and harvest dates are in Table 2. The amounts of soil nutrients were determined as 'MAF quick-test units' (Mountier *et al*., 1966) and converted into mg/kg dry soil using the following conversion factors: Ca, ×125; K, ×20; Mg, Na, ×5; P, ×1.1 (Chapman and Banister, 1994).

Experiment A (Chakwizira *et al*., 2010) was a randomised complete block design, replicated three times. Triple superphosphate (0:21:0:0) at 0, 20, 40 and 60 kg P/ha was applied either broadcast by hand and soil incorporated before sowing or banded below the seed at sowing with an Ɵyjord drill. 'Regal' kale seed treated with 'Superstrike®' was sown at 4 kg/ha on 17 December 2007. A soil test to 150 mm depth was taken from each of the 24 plots individually. The average soil test results were: pH 6.2 (5.8-6.5); Olsen P 13.3 (9-17), K 140 (80-220), Ca 1000 (875-1500), Mg 60 (40-90) mg/kg dry soil and available N of 76 (63-107) kg/ha. Numbers in parentheses are the nutrient ranges across the individual plots.

Experiment B (Fletcher and Chakwizira 2012a; 2012b) was a split plot randomised complete block design, replicated four times. It consisted of four forage brassica species ('Kestrel' kale, 'Titan' rape, 'Keystone' swede and 'Barkant' turnips) as the main plots and three factorial combinations of different fertiliser N rates and times of application. For the kale crops, Treatment 1 was 400 kg N/ha applied on 4 December 2009; Treatment 2 was 400 kg N/ha applied on 4 December 2009 and a further 400 kg N/ha applied on 29 January 2010 (800 kg N/ha total) and Treatment 3 was 400 kg N/ha applied on 29 January 2010. All N was applied in the form of urea (46:0:0:0) and was followed by an irrigation event to avoid volatilisation losses. Average soil test results to 150 mm depth of soil were: pH 6.1; Olsen P 13, K 160, Ca 1125, Mg 45, S 4 mg/kg soil and available N of 74 kg/ha. The experiment was sown on 18 November 2009 and the final harvest for kale crops was on 8 June 2010.

Experiment C (de Ruiter *et al.* 2009, Table 2) consisted of five treatments at four of the five kale sites and six treatments at each of the two swede sites (Table 1, 2). There were three treatments for kale crops at the Cromwell site. All experiments at each of the seven sites were replicated four times. 'Gruner' kale seed was sown at 4 kg/ha at five sites and 'Aparima Gold' swede at 0.8 kg/ha for the ridged crops and 1.5 kg/ha for the conventionally sown crops at the two Gore sites. The five sites for kale experiments (Table 2) were located at Bankside, on a stony Brown soil and Fairlie, on Pallic soil (McLaren and Cameron, 1996), in Canterbury. Two sites were in Southland: Wilson's Crossing near Winton, on a Wakanui silt loam (Radcliffe, 1974) and Riverton, on Brown soils (Metsons and Gibson, 1977). The fifth site was in Cromwell, on Brown soils often described as Semi-arid sand (Radcliffe and Cossens, 1974). All seven sites had been under long-term pastures (>10 years) and were not irrigated.

The treatments for the kale experiments (Table 2), except for the Cromwell site were: a control, and two rates each of N and P either broadcast after sowing or banded during sowing. At Cromwell, the three treatments were: control, N and P broadcast after sowing or banded during sowing. The rates of N and P applied differed with site, based on background soil fertility. For example, at Bankside 36 and 54 kg N/ha and 40 and 60 kg P /ha were each banded or broadcast, while 49 and 58 kg N/ha and 54 and 64 kg P/ha were each banded or broadcast at Fairlie.

Basal fertiliser was applied as muriate of potash (KCL; 50% K) at 240 kg/ha and 1.5 kg/ha boron at all the seven sites.

Table 1: Soil test results[1] for Experiment C (mg/kg soil unless stated otherwise) for South Island sites in 2006-09 (see year and crop type in Table 2) and the optimum nutrient requirements (McLaren and Cameron, 1996; Chakwizira *et al*., 2011a).

Site	pH	Olsen P	K	Mg	S	B	N (kg/ha)
Bankside[2]	6.2	20	120	50	12	1.5	136
Fairlie	6.1	13	80	125	4	0.6	108
Cromwell[3]	5.7	14	60	60	-	-	80
Wilson's Crossing	5.7	13	60	55	8	1.1	205
Riverton	5.8	10	60	70	8	0.8	296
Gore 2008	6.0	10	60	30	5	-	160
Gore 2009	5.9	16	100	50	-		262
Optimum	5.8-6.2	20-25	100-140	20-50	10-12	0.7-1.3	200-300

[1]Converted into mg/kg dry soil by the following conversion factors: Calcium (Ca), ×125; Potassium (K), ×20; Magnesium (Mg), Na, ×5; Phosphorus (P), ×1.1; Sulphur (S), ×1.0 (Chapman and Bannister, 1994). N was determined as available mineralisable nitrogen (Waring and Bremmer, 1964).
[2]Average values from all plots at all the sites.
[3]No test results for S and B, but included Ca (875) and Na (15).

Table 2: Fertiliser rates[1], time of application and the key sowing and harvest dates for Experiment C.

Site	Crop	Fertiliser rates (kg/ha)[1]				Mid-season N (at weeks)				Key dates	
		N		P		6		12			
		N1	N2	P1	P2	N3	N4	N3	N4	Sowing	Harvest
Bankside	Kale	36	54	40	60	55	86	55	86	28 Nov 2006	30 May 2007
Fairlie	Kale	49	58	54	64	57	92	58	92	30 Nov 2006	06 June 2007
Wilson's Crossing	Kale	54	63	60	70	14	42	14	42	13 Dec 2006	13 June 2007
Riverton	Kale	18	63	60	70	0		0		14 Dec 2006	13 June 2007
Cromwell[2]	Kale	54		60		62		62		15 Dec 2006	12 June 2007
Gore 2008	Swede	63		70		100		0		11 Dec 2007	21 May 2008
Gore 2009	Swede	70		50		0		0		01 Dec 2008	20 May 2009

[1]For kale crops, the treatments were: control (no N or P), N1 and P1 either broadcast at sowing (Treatment 2) or banded during sowing (Treatments 3) and N2 and P2 either broadcast at sowing (Treatment 4) or banded during sowing (Treatments 5). Additional N was applied during the season as N3 for treatments 2 and 3 or N4 for treatments 4 and 5.
[2]The three treatments were: control (no N or P), N and P broadcast at sowing and N and P banded during sowing.

The two 'Aparima Gold' swede experiments at Gore (Table 1, 2), were on a Waimumu silt loam soil (Carran *et al*., 1982). The experimental design was a split plot consisting of six treatments replicated four times. Treatments were two methods of sowing (ridging and conventional) as main plots and three factorial combinations of two rates of DAP (0 or 350 kg/ha) and two methods of DAP application (banding or broadcast) as the subplots.

Measurements

The DM yields for Experiments A and B were determined every 14-21 days by harvesting a 0.5 m^2 quadrat per plot. Dry matter yield for Experiment C was determined once at mid-season and once at the end of the season by harvesting 3 m^2 quadrats. For each plot harvested, the number of plants was counted and fresh weight was determined. A representative 5-plant sub-sample was then retained for leaf and stem partitioning. Partitioned sub-samples were dried in a forced air oven at 70°C to constant weight.

Meteorological conditions

Meteorological data for Experiment A and B were described in Chakwizira *et al*. (2010) and Fletcher and Chakwizira (2012a; 2012b), respectively. Experiment A and B crops were irrigated. Weather details for Experiment C sites are shown in Table 3.

Table 3: Mean weather data for the all Experiment C sites (NIWA, 2012); long term averages (LTA) and the actual recorded rainfall (mm) and temperature (Temperature °C) for the growing period.

Site[1]	LTA		Actual recorded		Differences	
	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.
Bankside (Rakaia, 8 km)	311	14.7	381	13.8	70	-0.9
Fairlie	285	13.7	271	12.7	-14	-1.0
Cromwell	324	13.8	298	14.4	-26	0.7
Wilson's Crossing (Winton, 13.3 km)	600	10.0	487	12.0	-113	2.0
Riverton (Otautau, 30 km)	600	10.0	540	10.0	-60	0.0
Gore 2008	460	12.4	366	12.8	-94	-0.4
Gore 2009	460	12.4	426	12.1	-34	0.3

[1]Actual station shown in parentheses, where there was no data from the site

The closest recorded weather data from the Riverton site was from Otautau, about 30 km north. Table 3 also shows moisture deficits for Riverton, Gore in 2008 and Wilson's Crossing which occurred between January and February, coinciding with a period of high radiation. Temperature was similar or higher than the long-term averages (LTA) except for the Bankside and Fairlie site which were 1°C lower.

Data analysis

Dry matter (DM) values were analysed using analysis of variance (ANOVA). An indication of the variation associated with means was given by the least significant difference (LSD) (P=0.05). Full descriptions for the data analyses were given by Chakwizira *et al*. (2011b). Briefly, a 1:1 line was used to determine the fit of the measured to simulated yield for the overall data for each crop. The root mean square of the deviation (RMSD) and adjusted coefficient of determination (R^2) (Kobayashi and Salam, 2000) were used as measures of accuracy of the simulation. An RMSD of ≤10% (Kobayashi and Salam, 2000) was considered as an accurate simulation. The most appropriate format for the RMSD was in t/ha (Reid *et al*., 2002), although we also calculated the errors as percentages. In this study, simulated yield was that modelled by PARJIB (Reid *et al*., 2002) - a model that analyses and forecasts yield responses to nutrients, from the soil available nutrient levels, the potential yield and the fertiliser rates as described by Chakwizira *et al.* (2011b).

Results

Kale crops

Dry matter yield increased with N and/or P supply in Experiments A and C, except for the Cromwell site. The method of P application and timing of N application had no effect on the final measured yields of kale crops in these experiments. The kale model simulated the same DM yield for all the fertiliser treatments because it does not account for method of P application and split application of N. It also consistently simulated a low yield for the control crop compared with fertilised crops (Figure 1).

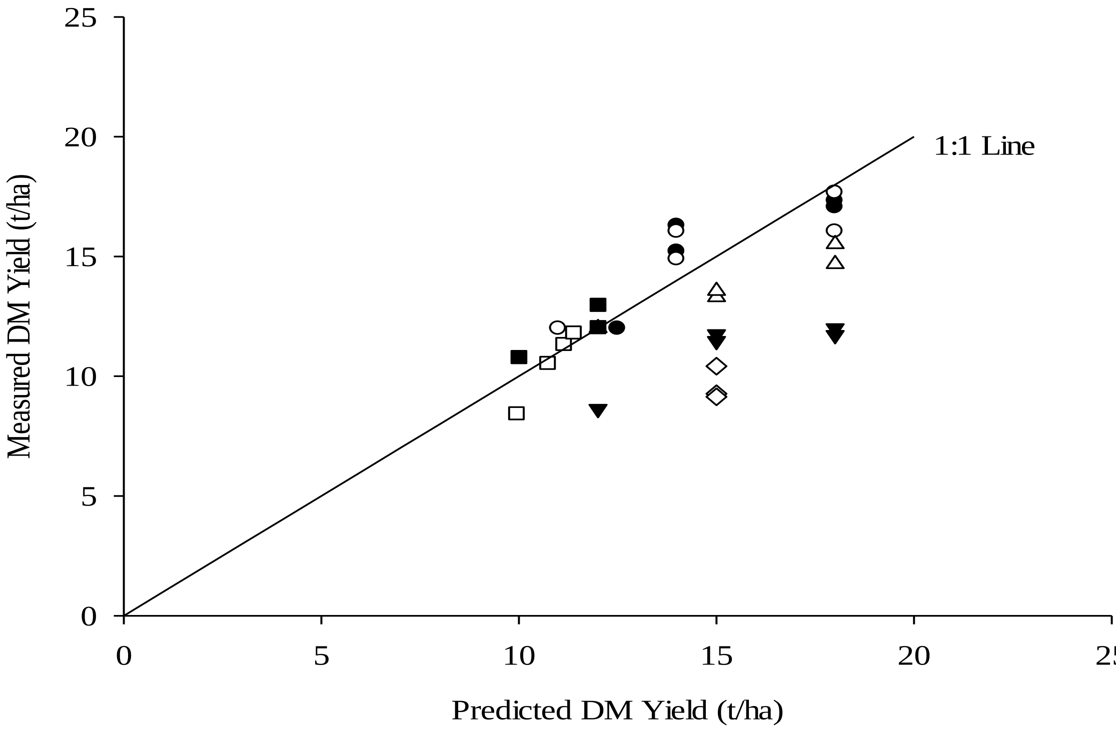

Figure 1: Measured versus predicted dry matter (DM) yields for kale crops grown between 2006 and 2010 at seven sites in South Island; ● Bankside, ○ Fairlie, ▼ Wilson's Crossing, Δ Riverton, ■ Cromwell (Experiment C), □ Lincoln (Experiment A) and ◇ Lincoln (Experiment B). 1:1 line perfect agreement.

Figure 1 shows the overall DM yield prediction was fair (R^2=0.42; RMSD≤6% (<0.65 t/ha)) for all the sites (Table 4). Overall, 73% of the points (22 out of 30) on the graph were within the 10% RMSD margin. The model accurately predicted the yield at individual sites (R^2>0.82; RMSD≤5.3% (< 0.65 t/ha)), except two sites; Wilson's Crossing (R^2>0.53; RMSD=23.4% (2.90 t/ha)) and Lincoln in 2010 (RMSD=36.9% (3.50 t/ha)). At both sites DM yield was over-predicted across treatments by up to 6 t/ha. The predicted yield was 15-18 t/ha compared with measured yields of approximately 12 t/ha at Wilson's Crossing and 9-10 t/ha at Lincoln in 2010, when fertiliser was applied. Figure 1 also shows DM yield was slightly over-predicted at Riverton by about 2 t/ha.

Table 4: The root mean square of the deviation (RMSD, t/ha and percentage (%) and adjusted coefficient of determination (R^2) for kale crops grown at different sites (Experiment A, B and C, Figure 1).

Site	RMSD		R^2
	t/ha	%	
Bankside	0.44	2.9	0.90
Fairlie	0.49	3.2	0.85
Wilson's Crossing	2.90	23.4	0.53
Riverton	0.60	4.5	0.95
Cromwell	0.64	5.3	0.82
Lincoln 2008	0.22	2.1	0.99
Lincoln 2010	3.50	36	-[1]

[1]Straight line (model predicted the same yield across treatments).

Swede crops

The measured DM yield for swede crops ranged from 11.4 to 15.2 t/ha. Dry matter yield in 2008 was 2 t/ha higher ($P<0.05$) when crops were conventionally sown (Figure 2) compared with ridging. Measured yield was also higher when DAP was drilled rather than broadcast. However, in 2009 swedes only responded to banded DAP under ridging, which produced 15.1 t/ha compared with 13.5 for broadcast DAP crops. The measured DM yield did not differ between the control and broadcast P crops. When conventionally sown, DM yield was about 2 t/ha more ($P<0.05$) than the control at 14 t/ha when DAP was applied, irrespective of method of fertiliser application.

The swede model simulated the overall DM yield reasonably well (R^2=0.54; RMSD=0.78 t/ha) across sites and years (Figure 3), with all the points on the graph within the 10% RSMD margin (Table 5). Prediction of DM yield for the conventionally sown crops was inconsistent between the years; under predicted by approximately 2 t/ha in 2008 and over predicted by the same margin in 2009. As expected, the predicted DM yield was similar across the fertiliser treatments, irrespective of method of P application. It was also consistently lower under the control treatments.

Simulation was better (R^2=0.56-0.99; RMSD<0.59 t/ha (<3.6%)) for ridged crops (Table 5) than for conventionally sown crops (R^2=0.27-0.56; RMSD<0.64 t/ha (<3.6%)) at both sites.

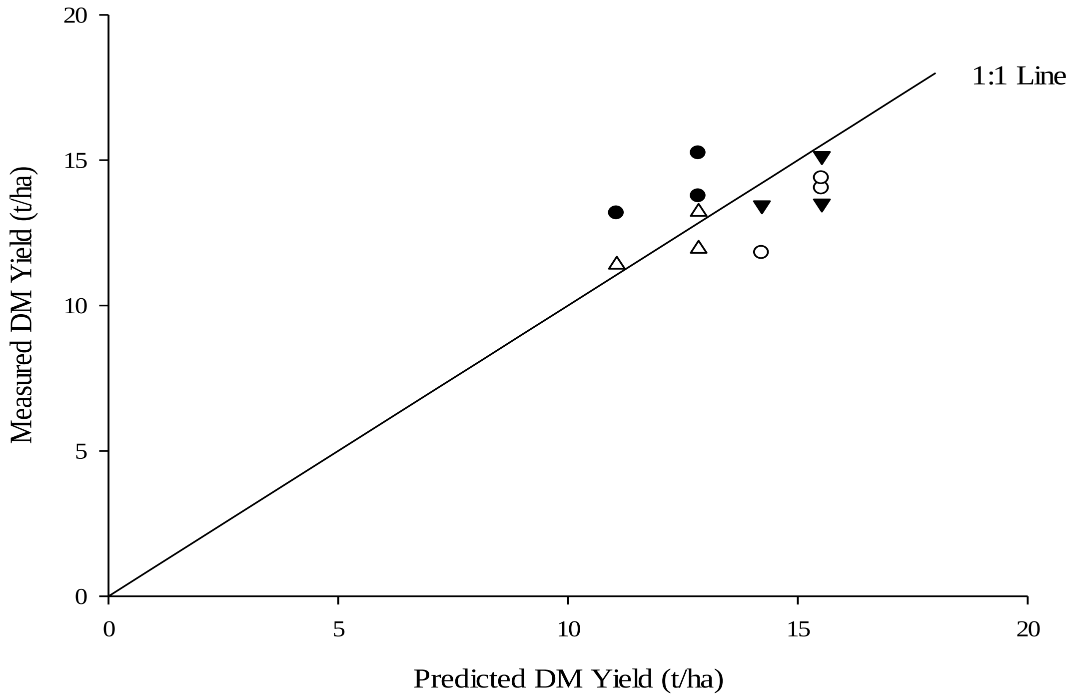

Figure 2: Measured versus predicted dry matter (DM) yields for swede crops grown at Gore, Southland, (Experiment C) in 2007-08 (● Conventional tillage vs. Δ Ridging) and in 2008-09 (○ Conventional vs. ▼ Ridged). 1:1 line perfect agreement.

Table 5: The root mean square of the deviation (RMSD, t/ha and percentage (%) and adjusted coefficient of determination (R^2) for swede crops grown at two sites (Experiment C, Figure 2) in Gore.

Site	Method of sowing	RMSD		R^2
		t/ha	%	
Gore 2008	Conventional	0.64	3.6	0.52
Gore 2008	Ridged	0.20	1.3	0.56
Gore 2009	Conventional	0.42	2.4	0.27
Gore 2009	Ridged	0.59	3.6	0.99

Discussion

Kale DM yields of 9 to 18 t/ha across experiments was consistent with those reported in the literature (Wilson *et al*., 2006; Chakwizira *et al*., 2009; Chakwizira *et al*., 2010; Chakwizira *et al*., 2011a). These results reflected the diversity of agronomic management and site potentials expected from these species. However, for the leafy, short statured kale cultivars 'Kestrel' (Fletcher and Chakwizira 2012a; 2012b) and 'Regal' (Chakwizira *et al*., 2010) yields were consistently lower at ≤13 t/ha. Measured DM yield for swede crops were ≥3 t/ha lower than the potential yield of 18-20 t/ha reported by de Ruiter *et al*. (2009) and also reflected the diversity of agronomic management of brassica crops at the farm level.

The simulation for kale crops (R^2=0.42) was fair. As 73% of the points on the graph are within the <10% RMSD recommended by Kobayashi and Salam (2000), the low fit for the overall simulation was attributed to the over prediction at the Wilson's Crossing and Lincoln sites (Experiment B and C, Figure 1). The low measured yields at Wilson's Crossing were attributed to significant moisture deficits and higher mean temperatures (Table 3). The site only received 80% of the long-term average rainfall and had a 2°C higher mean temperature. This was experienced between January and February, at a time when radiation was high. This restricted crop growth rate and therefore the potential dry matter accumulation was lower than expected. The pre-season prediction by the calculators was not expected to accurately predict yield under unfavourable or uncharacteristic weather. However, this scenario shows the model can be used to estimate the potential yield loss caused by moisture stress assuming all other factors affecting yield are minimised. Chakwizira and Fletcher (2012) have reported a 24% and 36% yield reduction in forage turnips (*Brassica rapa* L. var. *rapa* L. syn. *Brassica campestris* ssp. *rapifera* (Metzg.) and rape (*Brassica napus spp. biennis.* Schubl. & G. Martens) crops, respectively, when irrigated to 67% of the control (fully irrigated) crops. These authors also reported yield loss of up to 55% for both crops when irrigated to 33% of the control. The low yield at Lincoln in 2010 may be attributed to cultivar differences. Kestrel kale, a short statured cultivar with higher leaf: stem ratio (Gowers and Armstrong 1994; Adams *et al*., 2005) was planted at this site compared with the medium to tall cultivars Regal (Chakwizira *et al*., 2010) and Gruner (Gowers and Armstrong 1994) kale used in other sites. Overall, the kale model was sufficiently robust to provide accurate N and P fertiliser requirements.

A reasonable agreement between measured and predicted yield (R^2=0.54) was obtained for swede crops. The higher swede yield when P was banded than broadcast in 2008 was consistent with other results on swedes (Chakwizira *et al*., 2011a) and other forage brassica crops (Wilson *et al*., 2006). However, in 2009 banding was only superior when crops where ridged. Response to banding under moisture stress (2008, Table 3) has been reported for swedes (Chakwizira *et al*., 2011a) and other crops (Grant *et al*., 2000). The swede model consistently predicted lower yields for the control crops. This is reasonable as the background soil fertility was low to moderate at these sites (Table 1). The data sets used here were from Southland only and therefore data from other swede producing regions (Chakwizira *et al*., 2011a) such as Otago and the central North Island of New Zealand are required to determine consistency of prediction. The swede model was able to provide N and P fertiliser requirements to maximise yields for these crops.

Dry matter yield for the conventionally sown crops was higher ($P<0.05$) than ridged crops in 2008. Scott (1971) showed that conventionally sown swede crops can produce more DM yield (>40%) than ridged crops. The differences in the current experiment can be attributed to the moisture deficit experienced (Table 3) at this site. Furthermore, swede crops sown on ridges were sown at 610 mm row spacing (Stephen and Kelson, 1974; Stephen and Kelson, 1975) compared with 150 mm (Chakwizira *et al*., 2011a) for the conventionally sown crops. The ridged crops failed to close their canopies, therefore were not capturing all of the incoming radiation. Open canopies would also lead to loses of available soil moisture from the exposed soil surfaces. The combined effects of loss of radiation and moisture may have resulted in reduced yields in a relatively dry year (Table 3).

These forage brassica models are intended for site-specific brassica production (Chakwizira *et al*., 2011b). The predictions within each site were acceptable for kale ($R^2 \geq 0.70$; RMSD≤12%) and variable for swedes ($R^2 \geq 0.27$; RMSD≤4%). These results show that the current kale and swede models are sufficiently robust to predict N and P fertiliser requirements and hence, potential DM yields for the key regions were both crops are grown in New Zealand. However, both kale and swede models could be enhanced by the inclusion of modules to predict the impact of agronomic practices (Chakwizira *et al*., 2011b), such as method of P fertiliser application, and the impact of water stress. Other factors, such as diseases and pests and other nutrient deficiencies, may also limit yields to below potential.

Chakwizira *et al*. (2011b) commented that the current versions of the calculators are primarily designed for managing the capital fertiliser requirements and they cannot be used for in-season decision making in terms of N fertiliser rates and timings. There is still scope to improve the versatility of the calculators to include a capability for managing split application of N fertiliser during crop establishment, therefore enabling improved economic and environmental outcomes.

Conclusions

The calculators are sufficiently robust to predict N and P requirements for forage kale and swede crops over a range of sites in New Zealand.

More research is needed on the effects of methods of brassica crop establishment, P application and moisture stress effects on yield before these factors are included in the calculators.

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