The Ballance Agri-Nutrients brassica calculator - improvement of the turnip model

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Abstract

Forage brassica calculators were developed to assist in the planning of nitrogen (N) and phosphorous (P) management for site-specific forage brassica production. These calculators are based on the PARJIB model which analyses and forecasts yield responses to nutrients. Previous validation of the calculators showed that simulation of the summer ('Barkant') turnips model was poor (RMSD≤28% (2.7 t/ha) (R^2=0.10). This was attributed to yield responses to P being masked by low yield potential due to factors such as poor crop establishment and other agronomic factors. To recalibrate the model, three turnip P response experiments were conducted in the 2012-13 season at sites (Southland, Manawatu and Central North Island) with soil Olsen P values between 5 and 17 mg/kg soil. Fertiliser P was either broadcast or banded at five rates (0-200 kg P/ha). There was a response to P fertiliser only at the site with the lowest soil P (Southland). At this site, the total dry matter (DM) yield at the final harvest increased with P supply, from 0.4 t/ha for the 0 kg P/ha crops to 10 t/ha for the 100 kg P/ha crops. This was associated with a 3-fold increase in plant population with P supply. However, the method of P application had no effect on either final DM yield or plant population, across the three sites. These and previous data were used to refit the PARJIB model to take into account soil P retention and reserve K. This approach explained a larger proportion of yield variation with an RMSD of <10% (0.23-1.1 t/ha) (R^2=0.65) compared to the initial validation. The turnip P response curve is now comparable to other brassica species and can be used with greater confidence for strategic N and P fertiliser recommendations.

Additional keywords: *Brassica campestris* subsp. *rapifera*, agronomic factors, 'Barkant' turnip, calibrated, nutrient requirement, PARJIB model, predicted yield, validated.

Introduction

Forage brassicas are widely used in New Zealand to supplement pasture fed at times of low growth or poor quality, caused by cool winter temperatures or summer droughts (Fletcher *et al.*, 2012). In New Zealand, nearly two-thirds of the land under arable crops annually (approximately 300,000 ha) is under forage brassicas (Dumbleton *et al.*, 2012). Bulb turnips (e.g., 'Barkant') (*Brassica campestris* subsp.

rapifera (Metzg.) Sinskaya) occupy about 36% of this area (White *et al.*, 1999).

Forage brassica crop establishment and subsequent growth are affected by nutrient availability, particularly for the key nutrients of nitrogen (N) and phosphorus (P). In commercial farming situations, forage brassicas are often sown into the lower producing paddocks as part of pasture renewal programme. These paddocks are often of low to moderate soil fertility status (McLaren and Cameron, 1996; Chakwizira *et al.*, 2009), ≤17 mg/kg Olsen P and ≤100 kg N/ha available mineralisable nitrogen (AMN). Thus optimum crop yields can only be obtained through application of N and P fertilisers. However, excessive application of N and its subsequent uptake by forage brassicas can lead to the accumulation of anti-nutritional compounds, such as nitrate-nitrogen (NO_3-N) (Fletcher and Chakwizira, 2012a; 2012b; Chakwizira *et al.*, 2014) with the potential risk of NO_3-N poisoning of grazing ruminant animals (Nichol, 2007). Moreover, Haynes and Williams (1993) reported that more than 70% of the ingested N is returned to the soil in urine. The implication is that the large amount of the N taken up by the turnips crops is potentially returned to the soil and lost through leaching (Di and Cameron 2002) late in autumn or early winter when drainage is high, causing environmental pollution. Furthermore, excess P increases the environmental risk of P loss in run-off events leading to eutrophication of surface water (Kleinman *et al.*, 2011). Fertiliser management strategies to optimise DM yield production without causing risks of environmental pollution, either through N leaching into underground water or P runoff onto surface water systems are needed.

The 'Forage Brassica Calculators' were developed by The New Zealand Institute for Plant & Food Research Limited (Plant & Food Research) (Wilson *et al.*, 2006) through funding from Ballance Agri-Nutrients. These calculators were calibrated (Wilson *et al.*, 2004; Zyskowski *et al.*, 2004), described (Wilson *et al.*, 2006) and validated against field data from a range of environments throughout New Zealand (Chakwizira *et al.*, 2011; 2012). However, simulations for bulb 'Barkant' turnip model were poor [R^2=0.10; RMSD=28.1% (2.70 t/ha)] (Chakwizira *et al.*, 2011). Often the calculator predicted the same yield for different treatments within sites, while observed yields differed widely (4-12 t DM/ha).

In general, brassicas grown in low phosphorus (P) soils respond to increasing P fertiliser inputs with a rapid gain in yield (where other nutrients are non-limiting). The response then levels off as potential yield is attained (Chakwizira *et al.*, 2009; 2010). The turnip calculator showed a decreasing yield response with increasing Olsen P levels in the soil, with some indication that yield responses to P may have been masked by low yield potential due to factors such as poor crop establishment.

This paper describes work to revise and retest the model using the results of three new P response experiments and the same historical data used previously (Chakwizira *et al.*, 2011; Fletcher *et al.*, 2011).

Materials and Methods

The earlier datasets (Chakwizira *et al.*, 2011; Fletcher *et al.*, 2011) were supplemented by results from experiments established at three low to moderate Olsen P sites. These sites were located at Owaka (46° 18' S, 169° 25' E) in Southland, Ashhurst (40° 17' S, 175° 43' E) in the Manawatu, and Ngaroma (38° 19' S, 175°

32’ E) in the central North Island (cNI). The soils at the three sites were Pallic, Yellow brown earth and Pumice, respectively (McLaren and Cameron, 1996). Before cultivation, the average Olsen P values for the paddocks at these sites were 5.6, 13.3 and 17 mg/kg soil, respectively (Table 1).

The experimental designs differed between sites, taking account of the differing soil fertility, slopes and paddock sizes. The designs were a Latinised column-row design at the Manawatu and cNI sites, and a randomised block design at the Southland site, all replicated three times. ‘Barkant’ turnip seed was sown at 2 kg/ha using a Taege drill with an Oyjord cone seeder. Sowing dates were 4 November 2012 for the Manawatu site, 12 December 2012 for the cNI site and 10 December 2012 for the Southland site. At all sites each plot was one drill width wide (1.35 m wide, 15 cm row spacing) by 10 m long. Average soil test results to 150 mm depth are shown in Table 1. This included P retention and reserve K at each site. This soil information was used to refit the fertiliser model PARJIB to help isolate the response to P.

Table 1: Average soil test[1] results for the sites.

Site	pH	Olsen P	K	Ca	Mg	Na	TBK	ASC	AMN
		mg/kg	----------------		me/100g		----------------	%	kg/ha
Manawatu	5.5	13.3	0.24	4.95	0.79	0.16	0.7	39.0	199.8
cNI	5.9	16.6	0.50	10.7	0.62	0.12	0.6	87.3	132.4
Southland	5.8	5.6	0.26	11.3	0.73	0.21	0.9	75.2	147.1

[1] Olsen P, anion storage capacity (ASC; P retention) and exchangeable cations were measured according to Cornforth and Sinclair (1984). Anaerobically mineralisable N (Keeney and Bremner, 1966) was used as a measure of readily available N. Reserve K (TBK) was measured according to Jackson (1985).

Five rates of P fertiliser, applied as triple superphosphate (21% P) were either broadcast prior to planting at 0, 50, 75, 100 and 200 kg P/ha or banded below the seed at 0, 25, 50, 75 and 100 kg P/ha. A banded rate of 200 kg P/ha was excluded as it was felt it could potentially damage the seedlings and a broadcast rate of 25 kg P/ha was considered too low to be effective. The control treatment received no P fertiliser. Base fertilisers comprised of 100 kg/ha potassium chloride (52% K and 48% Cl), 15 kg/ha Boronate (10% B) and 108 kg/ha urea (46% N) applied at all sites. An additional 150 kg N/ha was split, half applied at two dates at each of the three sites during the growing season to give a total of 200 kg N/ha. At all the three sites, no irrigation was applied; however the sites were selected because they typically receive adequate summer rainfall. Agrichemicals applied included pre-emergence herbicides such as Frontier (active ingredient 900 g/l dimethenamid EC) and magister (active ingredient 480 g/l clomazone EC) and the insecticide, diazinon 800 EC at all sites. At Southland, a molluscicide, mesurol®FS (active ingredient 20 g/l methiocarb) was also applied. Additional agrichemicals were applied as and when needed.

At the end of the season, dry matter yield was determined from 5×0.5 m^2 quadrats in each plot, on 29 January, 2013 for the Manawatu site, 7 March, 2013 for the cNI site and 2 May, 2013 for the Southland site. Plant fresh mass and density were determined in the field. Samples were dried in a forced air oven at 60°C until a constant weight was obtained. The Manawatu crop was harvested in late January, earlier than is normal for the region to minimise leaf loss from a beet yellow virus infection.

The new turnip calibration was conducted using both the current experiments and earlier datasets (2009-2013) (Chakwizira *et al.*, 2011; Fletcher *et al.*, 2011) from sites where background nutrient levels were clearly limiting crop growth and where variability from other factors (e.g., soil type variations and water availability) was least. For improved nutrient forecasting for the faster-growing summer turnips, the PARJIB model (Reid, 2002) was adjusted so that the supply of P and K reflected ASC and TBK (Table 1).

Data analysis

Analyses were carried out in GenStat (version 13, VSN International, UK). An estimate of the variation associated with the means was given by the least significant difference (LSD) at $\alpha=0.05$. A mixed model fitted with restricted maximum likelihood (REML) was used for the row-column design and analysis of variance (ANOVA) for the randomised block design. The two methods of P fertiliser application were compared using response curves, and also by ANOVA. The five rates were categorised as ‘control’ (no P fertiliser); ‘low’ (25 kg P/ha banded, 50 kg P/ha broadcast); ‘low/medium’ (50 kg P/ha banded, 75 kg P/ha broadcast); ‘medium/high’ (75 kg P/ha banded, 100 kg P/ha broadcast) and ‘high’ (100 kg P/ha banded, 200 kg P/ha broadcast). In the overall analyses for refitting the model in PARJIB, earlier datasets were reanalysed. For the former sites at Peel Forest (43° 35’ S, 171° 12’ E) in Canterbury, and Rahotu (39° 19’ S, 173° 54’ E) in Taranaki, measurements of ASC and TBK were not made in the original experiments, so fresh soil samples from these areas were collected and analysed. It was assumed that the difference in sampling time was not likely to be a major issue as these tests are more closely linked to texture than previous fertiliser management.

At all sites the yield of the best performing treatment was used instead of the potential yield to scale the yields as required for fitting PARJIB. This step was necessary as the crops at Southland and Manawatu experienced drought from January 2013. Furthermore, the Manawatu crop was harvested early, in late January to minimise leaf loss from a beet yellows virus infection.

Full data analyses for the turnip calculator have been described in Chakwizira *et al.* (2011). Briefly, simulated yields, modelled by PARJIB (Reid, 2002) were compared with actual plot yields measured from the final harvest for each site and year. A 1:1 line was used to determine the fit of the overall data for each crop. However, the validation applied here for the individual sites uses regression analyses of the linear form $y=a+bx$ between individual sets of actual (y) and predicted (x) data. The root mean square of the deviation (RMSD) and adjusted coefficient of determination (R^2) (Willmott, 1982; Willmott *et al.*, 1985) were used as measures of accuracy of the simulation. The RMSD will be reported both as a quantity of yield (t/ha) and fraction (%).

Meteorological conditions

The total rainfall for the experimental period was lower than the long-term average (LTA; NIWA, 2014) for each of the sites: 342 mm at Southland (LTA=590 mm), 150 mm at Manawatu (LTA=210 mm) and 166 mm at cNI (LTA=262 mm).

Results

Final dry matter (DM) yields were unaffected by the rate of P application at the Manawatu and cNI sites but increased ($P<0.001$) with P supply at the Southland site (Figure 1). The average DM yields were 6.4 t/ha for Manawatu (86 day crop duration), 9.8 t/ha for cNI (85 days) and 7.0 t/ha for Southland (143 days). These ranged from a low of 0.4 t/ha at the Southland site to a high of 13.4 t/ha at the cNI site. Final DM yield increased from 0.4 t/ha for the control (0 kg P/ha) to 10.1 t/ha for the 100 kg P/ha treatments at the Southland. However, the method of P application did not affect yield at any of the three sites.

Plant density at the final harvest at the Southland site was lower ($P<0.001$) for the control treatment (13 plants/m^2) compared with 36-40 plants/m^2 for all the treatments where P was applied. At final harvest, the bulb contributed to about 70% of the total DM yield and was unaffected by either the rate or method of P application.

At the Manawatu site, the P treatments had no effect on total DM yield, which averaged 6.4 t/ha. The plant density and proportion of the bulb to total DM averaged 46 plants/m^2 and 51%, respectively, and were unaffected by the fertiliser treatments. At the cNI site P treatments had no effect on total DM, plant density and bulb proportion of the total DM yield, averaging 9.8 t/ha, 40 plants/m^2 and 44%, respectively.

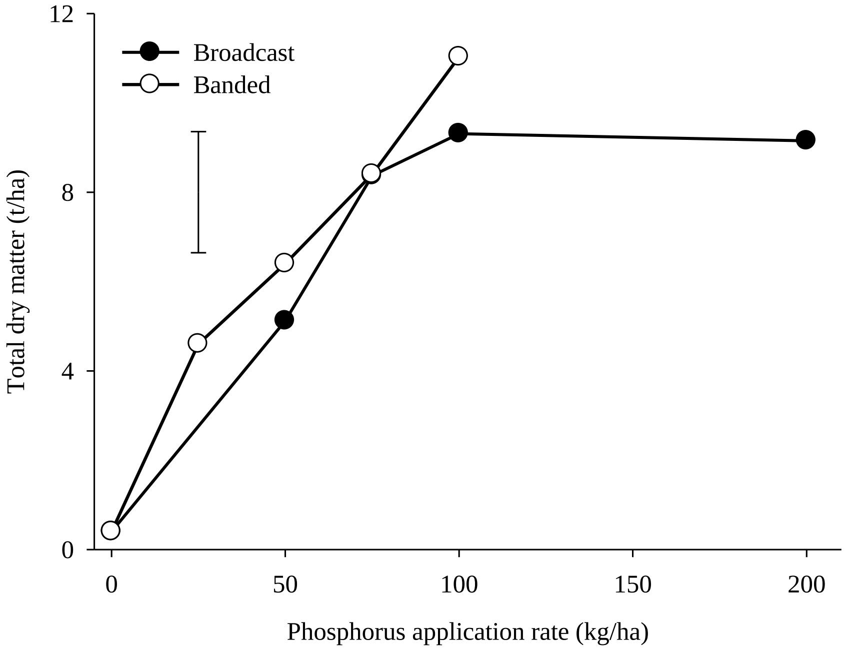

Figure 1: Total dry matter yield (t/ha) of ‘Barkant’ turnip crops grown in Southland under different rates (0-200 kg P/ha) and methods of P application (○, banded and ● broadcast) in the 2012-13 season. The vertical bar represents the least significant differences ($LSD_{0.05}$, with 16 d.f.).

The response to background P was variable for both the current and earlier experiments that were used for the calibration (Figure 2). In the current experiments, the response was strongest for the lowest Olsen P site (Southland). Furthermore, there was a strong response at Putaruru (Fletcher *et al.*, 2011), where the Olsen P levels were also low. However, at the other sites no trend was established, with strong responses at sites with moderately higher Olsen P levels (e.g., Peel Forest and Rahotu) than lower Olsen P (e.g., Taupo).

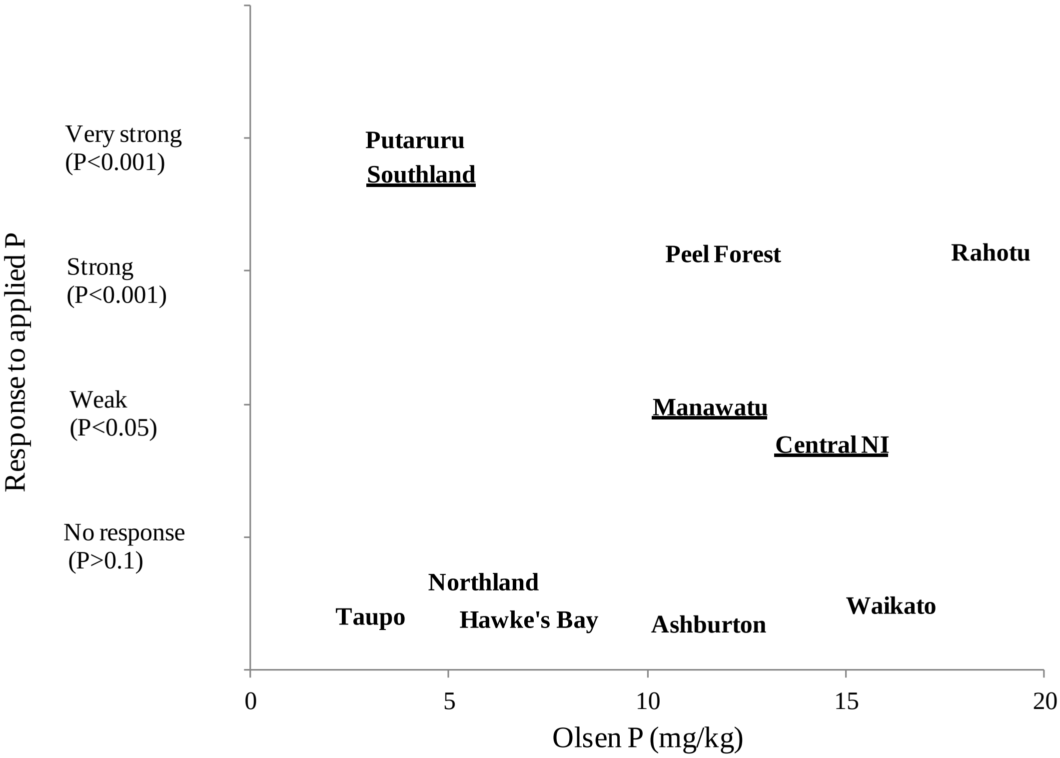

Figure 2: An aggregation of previous and current turnip yield responses to applied P fertiliser against background soil test values. The most recent experiments are underlined.

The final DM yield for Pirongia and Henderson sites (Waikato) and at Lincoln were reliably predicted by the turnip calculator (R^2=0.65; RMSD=7.6% (1.9 t/ha) (Figure 3). The calculator predicted the same yield for all the treatments except the control treatments for the Waikato sites, and at Lincoln all treatments including the control had the same predicted yield. However, the measured yield varied between 9.3 and 10.4 t/ha at the Lincoln site and 8.8-12 t/ha for the other sites, indicating that factors other than those modelled were affecting yield at these sites.

Overall yield prediction across the sites was generally good, with an RMSD of <10% (0.23-1.1 t/ha) (Table 2). This was also supported by moderate to high R^2 of 0.57 to 0.95 for 5 of the 6 data sets. However, the simulated yields were inconsistent for the control treatments of the Waikato sites; under-predicted at the Pirongia site (circle A; Figure 3), and over-predicted by about 40% at the Henderson site (circle B; Figure 3).

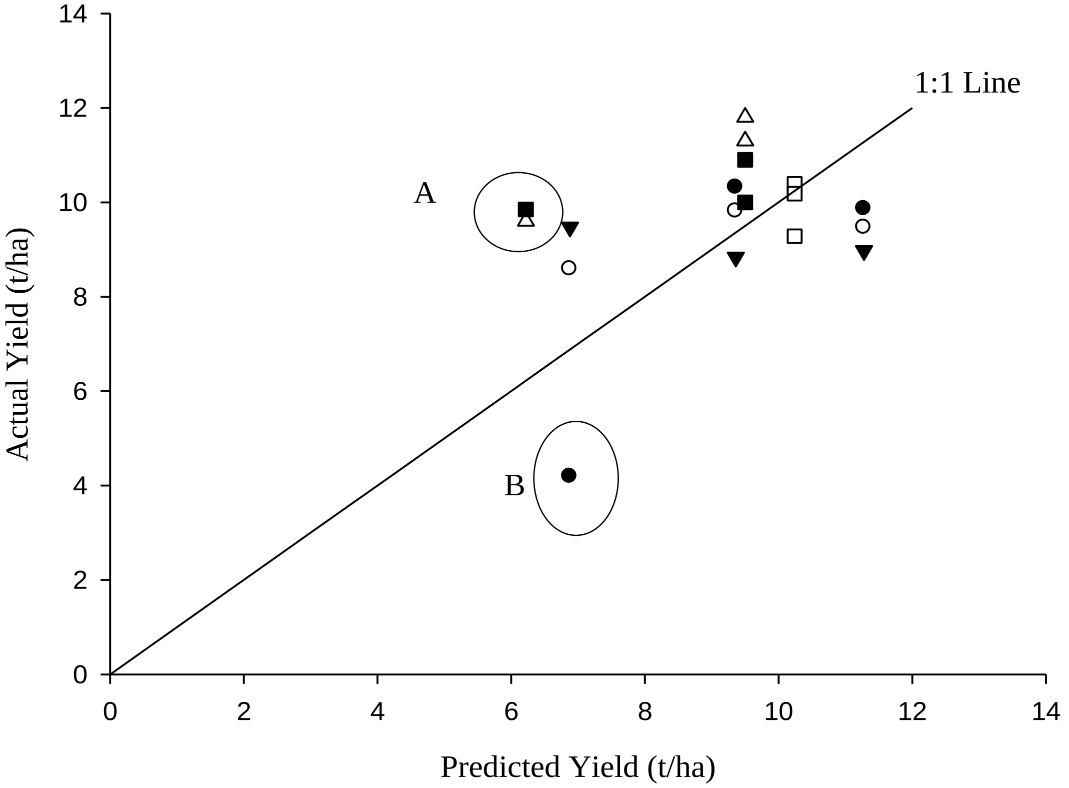

Figure 3: Relationship between predicted and actual yields for turnip crops grown in Waikato; Pirongia (2008): Δ CC and ■DD and Henderson (2009): ● DD, ○ CC(D) and ▼CC(B) and □ Lincoln (2010). [DD – no cultivation, seed drilled, CC(D) – cultivated, seed drilled and CC(B) – cultivated, seed broadcast]. The line of perfect agreement is also shown (denoted as 1:1 line). RMSD and R^2 values are shown in Table 2 for clarity.

Table 2: The root mean square of the deviation (RMSD) and adjusted coefficient of determination (R^2) for turnip crops grown at Waikato and Lincoln (Figure 3).

Site	RMSD (t/ha)	R^2
Pirongia cultivated	1.05 (9.7)[a]	0.95
Pirongia direct drilled	0.95 (9.0)	0.37
Henderson cultivated, seed drilled	0.75 (9.3)	0.76
Henderson direct drilled	0.60 (6.4)	0.56
Henderson cultivated, seed broadcast	0.83 (9.1)	0.63
Lincoln luxury N	0.23 (2.3)	-[b]

[a] Numbers in parenthesis are the percentage of RMSD.

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

Discussion

Despite a nationwide drought during the season, average DM yields from the three sites of between 6 and 10 t/ha when adequate P was applied were consistent with those reported elsewhere for both bulb and leaf turnips (Percival *et al.*, 1986; Chakwizira *et al.*, 2009; Fletcher and Chakwizira, 2012b). Futhermore, the DM yield response to P fertiliser varied with site, increased with P supply at Southland (Figure 1) but was unaffected at Manawatu and cNI sites. Dry matter yield was unaffected by the method of P application across the three new sites. Previous reports on effects of method of P application on forage brassica crops have been inconsistent. Dry matter yield increased when P was banded than broadcast for 'Pasja' (*Brassica rapa*; syn. *B. campestris*), a leafy turnip and kale (*Brassica oleracea* L. subsp. *acephala* DC) (Wilson *et al.*, 2006), while Chakwizira *et al.* (2009; 2010) found no difference in DM yield for the same crops, when P was either banded or broadcast at sowing. These inconsistencies were attributed to the initial Olsen P levels (Chakwizira *et al.*, 2009; 2010), as these authors reported results from a moderate Olsen P site (9-17 mg/kg soil) compared with 6 mg/kg of soil in Wilson *et al*. (2006). The lack of response to method of P application at Southland (Figure 1), a site with a low Olsen P (5.6 mg/kg; Table 1) suggests that the application of fertiliser P was more important than the method of application at this site. The lack of a response to method of P application at Manawatu and cNI site could be attributed to the moderate Olsen P levels (Table 1), which were similar to those reported in Chakwizira *et al.* (2009; 2010). The increase in DM yield with P supply at Southland could be attributed to the differences in plant population at the final harvest. Plant population was higher (36-40 plants/m^2) when P was applied compared with the 13 plants/m^2 for the control (0 kg P/ha) crops. This suggested that establishment of at least 36-40 plants/m^2 was important to achieve optimum DM yield. This was consistent with the minimum of 40 plants/m^2 reported for 'Green Globe' turnips by Adams *et al.* (2005). These plant populations were achieved when P was non-limiting in the current studies. The increase in plant population with P supply has been reported in other crops species, e.g., forage maize (Niamatullah *et al.*, 2011). The maximum yield was attained at 100 kg P/ha for the Southland site (Figure 1) which was higher than the 50 kg P/ha reported by Wilson *et al*. (2006) for leafy turnips.

The overall simulation for the refitted model for the turnip calculator (R^2=0.65) was good; with an RMSD of <1.1 t/ha (<10%) across the sites (Table 2). This was better than the relationship (RMSD≤28% (2.7 t/ha) (R^2=0.10) established in Chakwizira *et al*. (2011) and was within the <10% RMSD recommended by Kobayashi and Salam (2000). This was despite large variation in the actual yields of 4-12 t/ha (Figure 3) induced by method of sowing and fertiliser application. As the forage brassica models are intended for site-specific brassica production (Chakwizira *et al*., 2011), the predictions within each site (Table 2) were acceptable for 5 of the 6 data-sets (R^2=0.57-0.95; RMSD≤10%) and unacceptable for one dataset ((R^2=0.37; RMSD=9%). The model did not simulate the control treatments well in some of the experiments (circles A and B, Figure 3). Overall, these results show that the current turnip model is now sufficiently robust to predict N and P fertiliser requirements and hence, potential DM yields for the key regions where turnips are grown in New Zealand.

The fertiliser recommendations provided by the brassica calculator are based on average weather for different agro-ecological regions of New Zealand. Drier seasons could result in over-application of nutrients if the predicted yield is not reached. Where summer turnips are grown on irrigated light land, for example in Canterbury, care needs to be taken to irrigate little and often, to minimise high drainage and subsequent leaching of N. Medium to late-maturing turnip varieties such as ‘York Globe’ and ‘Green Globe’ are grown for winter feeding, mostly for bulb production. There is currently no provision in the calculator for these types.

Conclusions

The calculator is now sufficiently robust to determine predicted yield of bulb turnip crops grown at different agro-ecological regions of New Zealand. However, as the current version of the calculator is primarily designed for managing the capital fertiliser requirements, there may be need to improve them to include a capability for managing split application of N fertiliser during crop establishment, therefore enabling improved economic and environmental outcomes.

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