PARAMETER DEVELOPMENT FOR ADDING FODDER CROPS TO OVERSEER® NUTRIENT BUDGETS. KALE AND TURNIPS

Chakwizira, E[1]*, de Ruiter J.M.[1], Brown. H[1], Wheeler, D.M[2] and Shepherd, M[2].

[1]*TheThe New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Christchurch, 8140*
[2]*AgResearch, Ruakura Research Centre, Hamilton*
** Corresponding author Email: Emmanuel.Chakwizira@plantandfood.co.nz*

Abstract
The OVERSEER® nutrient budget (*Overseer*) is a decision support model that helps users to account for nutrient inputs, transfers and losses within farming systems.The current version of the model covers three main farming systems: pastoral, arable, and horticultural cropping. The arable and horticultural cropping modules have recently been upgraded to enable more realistic handling of the effects of event timing (sowing, fertiliser, irrigation) on nutrient balances. However, this enhancement has not been as widely tested as the pastoral module and does not include parameterisations for forage brassicas. Forage brassicas account for nearly two-thirds of cropping land use (~300,000 ha) in New Zealand so it is important that *Overseer* is expanded to include these crops for use in nutrient budgeting and policy and management planning. The fodder crop model was based on the arable crop model structure, and the parameters for forage brassicas were derived from published papers or experiments conducted by The New Zealand Institute for Plant & Food Research Limited (PFR). Expert opinion was used when data were lacking. Mean dry matter yields for kale crops were around 12 t/ha while those for turnip crops were 6–8 t/ha. The data also suggested that plant tissue macro-nutrient concentrations of roots and residues were generally lower than those of grazed tops, except for phosphorus (P). For example, the nutrient concentrations of 4% nitrogen (N), 0.3% P and 4% potassium (K) for the grazed tops while they were 2.5% N, 0.3% P and 2% K for kale crop residues. Crop utilisation was predicted to decrease with increasing yields. Higher yielding crops were more likely to suffer greater trampling losses. Lower utilisation of higher yielding kale crops was also caused by higher stem:leaf ratios and associated lower digestibility. Parameters derived for brassicas will be used to establish a fodder crop module in *Overseer*.

Key words: coefficiency, harvest index, metabolisable energy, thermal time, biomass yields

Introduction

Nutrient budgeting is useful for assessing the sustainability of nutrient use in farm systems and for highlighting potential environmental impacts (Wheeler *et al.* 2003). OVERSEER® nutrient budgets (*Overseer)* were developed to assist on-farm decision support. They comprise inputs, transfers and losses of nutrients associated with farm systems. The model was developed initially to guide nutrient management in pastoral farms (Ledgard *et al.* 1999). It has since been expanded to improve nutrient use efficiency and estimate nutrient outputs to the environment (Ledgard *et al.* 2001; Wheeler *et al.* 2006) for arable, vegetable and fruit cropping systems (Cichota *et al.* 2010).

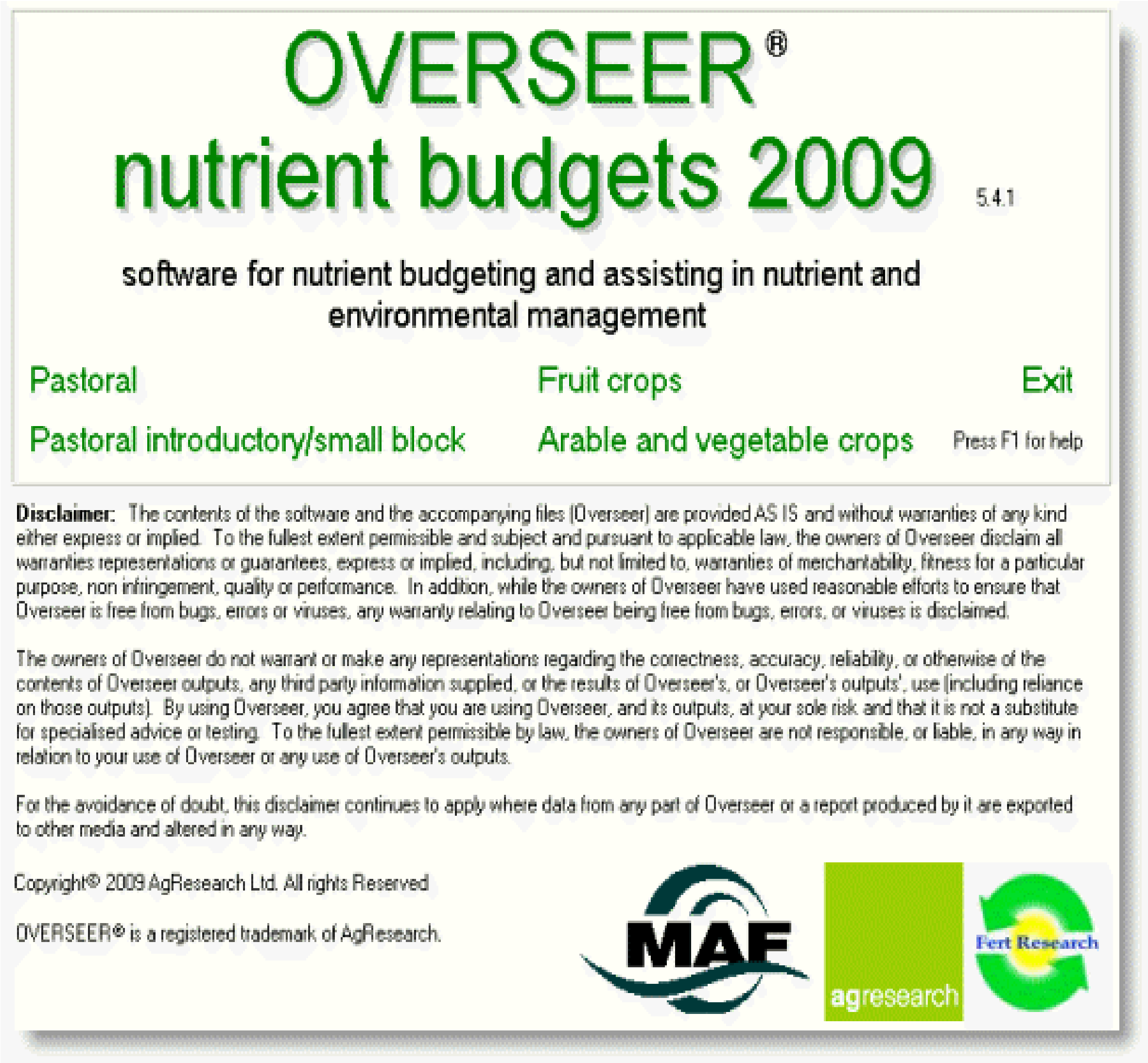

Figure 1: *Overseer* nutrient budgets main menu (Anonymous 2010c).

The current version of the model comprises separate components for pastoral, arable and horticultural cropping (Figure 1). A proposed new version will integrate data on pastoral, fodder crop and arable cropping blocks. This single model will allow arable cropping farms to be modelled more effectively. The methods used in the crop model are reported by Cichota *et al*. (2010). The fodder crops will use the same model and similar methods to determine parameter values.

The objective of this paper is to describe parameterisation of the new fodder crop model. The fodder crops described are kale (*syn.* Chou Mollier, *Brassica oleracea* spp. *acephala*) and bulb turnips (*Brassica rapa* spp. *rapifera* syn. *B. campestris*, e.g. `Barkant' or 'Globe' cultivars).

Crop parameters

Parameters for kale and turnips were derived from a range of sources (Table 1). These were grouped into two categories. Firstly, commonly used variables such as dry matter (DM) yield, metabolisable energy (ME), nutrient content of plant parts and harvest index were mostly derived from the literature. Where data were not available expert opinion was used to define value ranges. Harvest index was used as a surrogate for calculating utilisation. The second group of coefficients was specific for defining mechanisms for the advanced tool and was not available in the literature. The approach used here was to fit relationships to data from replicated experiments conducted at PFR over the past 10 years. Where data were incomplete in the literature or not available from experimentation, assumptions were made from crops with similar growth characteristics (Table 1) and adjustments were made to account for crop duration and timing of maximum cover. Literature sources were from New Zealand and overseas experiments.

The model of Cichota *et al*. (2010) required inputs for the following variables and parameters for each crop:

- Typical yields (t/ha)
- Proportion of DM (%DM)
- Metabolisable energy (MJ ME/kg DM)
- Tissue nutrient concentration for partitioned DM (roots, stem & leaves)
- Tissue nutrient concentration for grazeable and residual partitions
- Biomass coefficients (X_o_biomass, b_biomass)
- Crop canopy cover coefficients (X_o_cover, a_cover and b_cover)
- Harvest index coefficients (a_harvest, b_harvest)
- Thermal time coefficients (monthly averages).

In practice, DM yields for kale and turnips in New Zealand vary widely, from total crop failures to more than 20 t/ha. This can be attributed to various agronomic effects such as timing of sowing (Adams *et al.* 2005), cultivar choice (Gowers & Armstrong 1994; Mortlock 1975), soil fertility (Hayward & Scott 1993; Wilson & Maley 2006; Wilson *et al.* 2006) and crop protection practices (Addison & Welsh 1994). Yields (Table 2) used here are the typical, across agro-ecological zones of New Zealand. Typical metabolisable energy levels (ME; the portion of digestible energy retained within the animal body; Tulley *et al*. 2009) and percent DM were derived from Nichol *et al*. (2003).

The main driver for plant growth was considered to be light interception. However, the alternative driver of thermal time (accumulated heat available for crop growth; Morrison *et al.* 1989) was a useful concept for mediating canopy development processses and therefore indirectly influencing light capture. The use of thermal time means that data from crops grown in different environments can be standardised. It influences leaf appearance and expansion (Collie & McKenzie 1998), which in turn influence light interception. Reports in the literature suggest that brassica crops produce DM yield at about 800–1100 kg DM/100^{o}Cd (Adams *et al.* 2005; Chakwizira *et al.* 2011; Scott & Pollock 2004). Delaying sowing reduces the accumulated thermal time and hence the total DM yield produced.

DM yields were modified using data from specific individual crop experiments:

- Kale (Chakwizira *et al.* 2009; Chakwizira *et al.* 2010; de Ruiter *et al.* 2009; Gowers & Armstrong 1994; Percival *et al.* 1986; Stephen 1975; Stephen & Kelson 1974; Stevens & Carruthers 2008; Wilson *et al.* 2006)
- Bulb turnips (Clark *et al.* 1996; Harper & Compton 1980; Percival *et al.* 1986; Turk *et al.* 2009).

The DM content and ME values were set from published data (Chakwizira 2008; Clark *et al.* 1996; Judson & Edwards 2008; Nichol *et al*. 2003).

Plant tissue mineral concentration information (Table 1) was mainly derived from New Zeaalnd literature (Barry *et al.* 1981; Cornforth *et al.* 1978; Grace *et al.* 2000; Nichol *et al.* 2003) and supplemented with overseas data (Guillard & Allinson 1989; Jones 1959; Wiedenhoeft & Barton 1994).

Table 1: Sources of crop variables.

				Mineral concentration content (%)												
	DM attributes			*Grazeable products*							*Residues*					
	Yield	%DM	ME	N	P	K	Ca	Mg	Na	Cl	N	P	K	Ca	Mg	Na
Kale	PFR (P) Lit (L)	P L	L	L	P L	P L	P L	P L	P L	L	L	L	L	L	L	L
Bulb turnips	P L	P L	L	P L	P L	P L	P L	P L	P L	SW	P L	P L	P L	P L	P L	FB

Key:
PFR (P) – Historical data from PFR
Lit (L) – Data from literature
SW – Assumed to be the same as for swedes
FB – Assumed to be the same as for fodder beet (Jones 1959; Goh & Magat 1989)

Data from experiments conducted by PFR were used in some instances where published data were not available. This included derived biomass coefficients (Figure 1), crop cover coefficients (Figure 2) and harvest index (Figure 3) from data collected between 2002 and 2010.

Normally, harvest index (HI) refers to the harvestable yield of a crop (usually the reproductive sink such as seed, grain or fruit fraction) as a proportion of the total yield. For brassicas used as animal feed, the HI was assumed to be equivalent to the proportion of the crop utilised as animal feed. The HI was plotted against a range of yields for each crop to determine harvest coefficients (a_Harvest and b_harvest).

Both biomass (X_o_biomass and b_biomass) and crop cover (X_o cover and b_cover) coefficients were calculated from PFR data (Fletcher & Chakwizira 2011; Fletcher *et al.* 2010) by plotting biomass (Figure 1) and crop cover (Figure 2) from all treatments against accumulated thermal time (calculated from monthly average temperature). A sigmoidal function was fitted to these relationships to determine the values of X_o and b for each crop. The same function was used, irrespective of experimental site and sowing times. However, specific parameters varied depending on the crop type because of variation in growth duration and pattern of growth, including the rate of canopy closure, the pattern of DM accumulation and the proportion of crop utilised.

Both the pattern of crop cover and relative biomass accumulation were quantified in relation to thermal time (averaged per month; °C-month) using a sigmoid function. Most of the data used to determine kale coefficients were derived from nine experiments carried out at PFR between 2002 and 2010 and reported in recent papers on the growth and development of brassica crops (Brown *et al.* 2007; Chakwizira *et al.* 2010 & 2011; Fletcher *et al.* 2007; Wilson & Maley 2006; Wilson *et al.* 2006).

Results and discussion

Yield, DM and ME content

DM yield shown in Table 2 defines the typical yield and energy levels of feed available for allocation to the animals. Yields were higher for kale than turnips but ME was similar.

Table 2: DM and quality variables for kale and turnip crops used to extend *Overseer* nutrient budgets.

Crop	Variable		
	Yield	%DM	ME
Kale	12	16	12
Bulb turnips	8	12	13

Within turnips, data from sales literature suggested that there were differences in DM yields and ME. Better yield and quality was reported from globe cultivars compared to cv. Barkant. However, yield data from replicated experiments (Adams *et al.* 2005; Jung *et al.* 1986; Percival *et al.* 1986) and reviewed literature (Anonymous 2010a; Anonymous 2010b) showed little difference in these variables. The data from PFR experiments comparing `Barkant' and `Green Globe' turnips also show little differences in yield and quality, although there were differences between these cultivars in the time to final grazing (maturity) (Percival *et al.* 1986; Anonymous 2010b). Maturity range was 60–90 days for `Barkant' and 90–120 days for `Green Globe'. We assumed that all cultivars were similar for the purpose of nutrient budgeting, at least until sufficient data can be obtained to justify separating them.

Both kale and turnip crops are grazed *in situ* when they reach maturity and therefore no regrowth is included in the derivation of the parameters. Kale can be fed out as cut and carry, which affects its utilisation efficiency. However, no data were available to confirm its use in cut and carry situations and effects on utilisation. Therefore, we have assumed all kale crops are fed *in situ.*

Nutrient contents

Nutrient content is related to the quality of the feed but is not usually considered the main measure of quality. Table 3 shows the typical nutrient levels of grazeable and residual herbage for both kale and turnips. Minerals of grazeable products are invariably higher than in residues. Nutrient levels are critical for animal health because both excess and deficient nutrient levels can negatively affect animal thrift (Nichol *et al.* 2003). For example, excess N (nitrate levels of >2000 mg/kg) can lead to nitrate poisoning and red water disease in ruminant animals. This is related to elevated blood levels of s-methyl cysteine sulphoxide (SMCO). Nutrient deficiency also affects animal health. For example, low Mg in the diet (< 2 g Mg/kg diet; Mayland *et al.* 1990) can lead to hypomagnesaemia or hypocalcaemia, which lead to metabolic diseases. Low levels of micro-nutrients (Barry *et al.* 1981) such as copper and iodine during cow pregnancy can cause poor viability of newborn stock or still birth.

Table 3: Nutrient contents parameters for kale and turnip crops to extend OVERSEER® nutrient budgets.

Parameter	Mineral concentration content (%)												
	Grazeable products							*Residues*[1]					
	N	P	K	Ca	Mg	Na	Cl	N	P	K	Ca	Mg	Na
Kale	4	0.3	4	3	0.3	2	2	2	0.3	2.2	1	0.3	1
Bulb turnips	3	0.4	3	2	0.2	1	1	1	0.3	2	0.4	0.2	0.2

[1]Residuals are mostly stems and few leaves for kale and bulb rinds for turnips

Biomass coefficients

The relationship between potential yield and thermal time for individual experiments was used to derive the biomass coefficients. Coefficients for turnips were derived from only two experiments carried in Canterbury and will therefore need further validation in other regions.

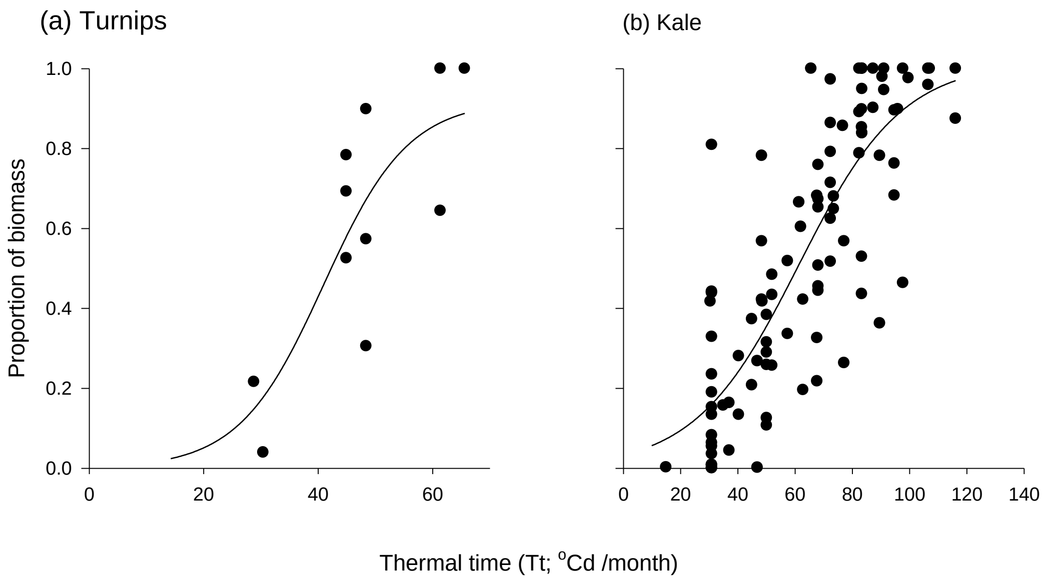

Figure 1: Proportion of biomass in relation to accumulated thermal time for turnips $Y=\frac{1}{1+e^{(-x-42)/7.4}}$ and kale $Y=\frac{1}{1+e^{(-x-61.2)/18}}$ (see Table 4 for summary of coefficients).

Table 4: The biomass coefficients for forage brassica crops.

Crop	X_o_Biomass	b_ Biomass
Kale	61.2	18.0
Bulb turnips	42.0	7.4

Turnips mature earlier than kale (Figure 1). Calculated thermal time (°Cd/ month; NIWA, 2011) to maturity (Percival *et al.* 1986) was 66 °Cd/ month for turnips and 105 °Cd/ month for kale.

Crop cover coefficients

Calculating crop cover coefficients was important because crop cover affects crop transpiration and is a significant variable in whole crop water balance, soil drainage and, therefore, N leaching. The rate of transpiration is determined by crop cover, which is estimated from specific crop cover coefficients and thermal time. The crop cover coefficients define how quickly crop leaf area develops relative to ground area. The pattern of crop cover was quantified in relation to thermal time (averaged per month; °C-month) using a sigmoid function. Time to full cover shown here was similar to ~ 28°Cd-month (Collie & McKenzie 1998) and ~ 34°Cd-month (Chakwizira *et al.* 2011) reported for turnips and kale, respectively. Time to full canopy closure affects the total amount of radiation accumulated by the crop and therefore the total DM produced by the crop. Radiation capture is more efficient with earlier closure of the crop canopy. The rate of crop cover development (Figure 2) was related to the duration to maturity (Figure 1).

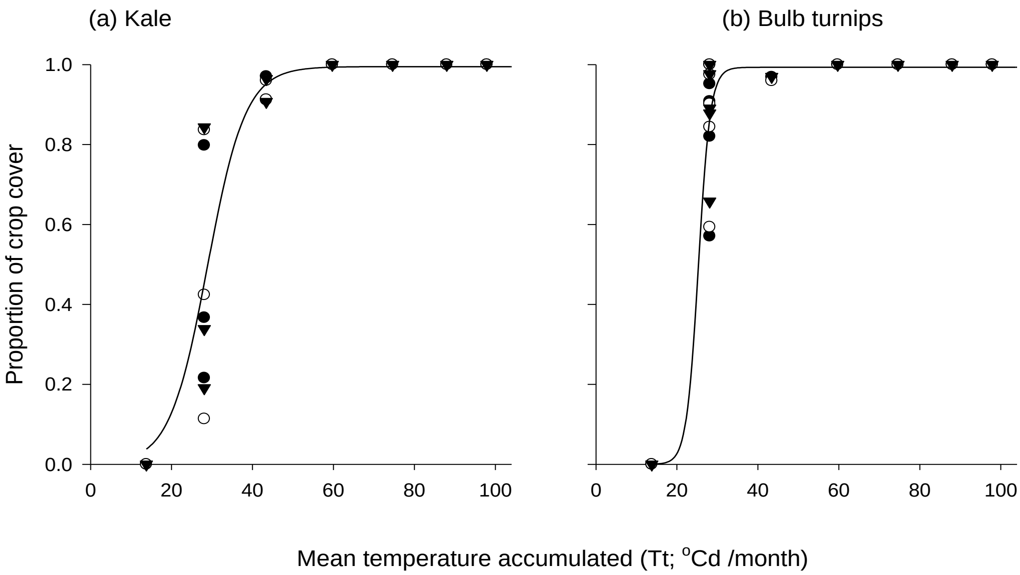

Figure 2: Crop cover in relation to accumulated thermal time for kale Y=$\frac{1}{1+e^{(-x-28.9)/4.68}}$ and turnips Y=$\frac{1}{1+e^{(-x-25.3)/1.48}}$ (see Table 5 for summary of coefficients).

Table 5: Cover development coefficients for forage brassica crops.

Crop	X_o_cover	b_cover
Kale	28.9	4.68
Bulb turnips	25.3	1.48

Table 5 shows that turnip crops had lower values for the coefficients than kale crops.

Harvest coefficients

Normally, harvest index (HI) refers to the harvestable yield of a crop (usually the reproductive sink such as seed, grain or fruit fraction) as a proportion of the total yield. For brassicas used as animal feed, the HI was assumed to be equivalent to the proportion of the crop utilised as animal feed. The HI was plotted against a range of yields for each crop to determine harvest coefficients (a_Harvest and b_harvest).

For both kale and turnips there was a negative relationship between HI and total DM yield (Figure 3). The ranges of yields shown in Figure 3 were derived from field measurements as follows:

- 7–15 t/ha for kale (Chakwizira *et al.* 2009, 2010; Gowers & Armstrong 1994; Judson & Edwards 2008; Wilson *et al.* 2006)
- 5–11 t/ha for turnips (Adams *et al.* 2005; Clark *et al.* 1996; Collie & McKenzie 1998).

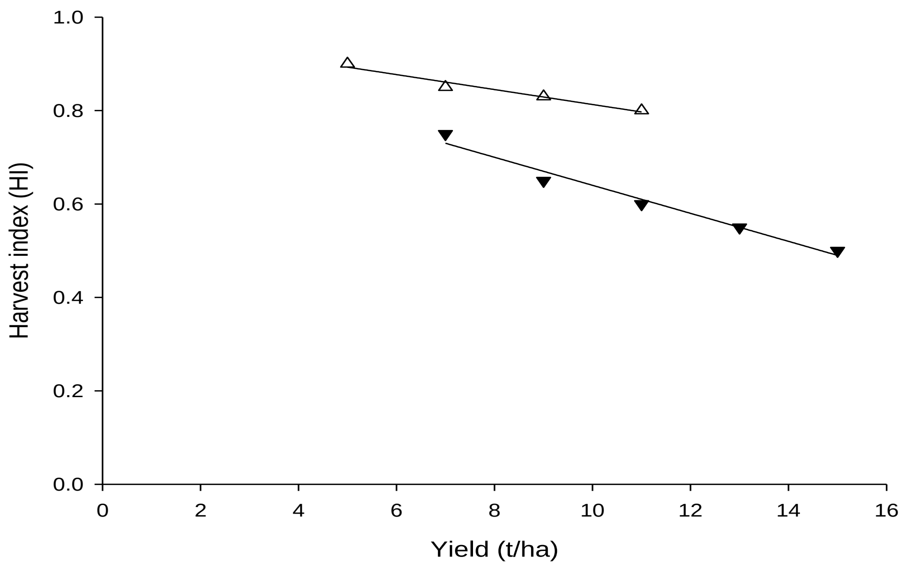

Figure 3: Harvest index in relation to total dry matter yield for kale (▼) and turnips (Δ) (see Table 3 for details).

Table 6: The harvest coefficients for forage brassica crops.

Crop	a_Harvest	b_Harvest	Equation
Kale	0.94	-0.03	Y=-0.03x +0.94
Bulb turnips	0.97	-0.016	Y=-0.016x +0.97

Using a range of crop yields, we were able to relate the parameters from the fitted regression (a_HI and b_HI) to the proportion of the crop utilised. The level of utilisation is specified by the user, enabling a more objective and accurate estimation of residue returns rather than using a constant HI. Figure 3 shows little change in HI as yield increased for turnips compared with kale. This relationship was negative because higher yielding crops are more likely to have greater trampling losses and/ or residuals. Gowers & Armstrong (1994) reported that ‘leafy’ kales produce low DM (about 10 t/ha) but have higher utilisation (> 60%) compared with the ‘giant’ kales (> 14 t/ha) with low utilisation (< 40%). This difference can be attributed to the proportion of stems for the crops as reported by Judson & Edwards (2008).

Conclusion

When deriving crop coefficients we have not included the regrowth potential. Both turnips and kale are assumed to be grazed once only at maturity. Also, there is a need to further investigate whether DM yield and other parameters vary among turnip cultivars. At present, there are insufficient data to define differences adequately within species and therefore how the effects of nutrient management can guide cultivar choice. The effects of feeding kale crops as cut and carry on animal utilisation and consequences for nutrient management need to be explored.

References

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

Addison, P.J.; Welsh, R.D. 1994. Furathiocarb seed treatment for the control of sprigtails on seedling brassica. *New Zealand Weed and Pest Control Conference 47*: 135-138.

Anonymous 2010a. DairyNZ farmfact. Turnips - Growing a high yielding crop. DairyNZ. www.dairynz.co.nz/file/fileid/4361,

Anonymous 2010b. DairyNZ farmfacts. Barkant Turnips – Feeding the crop. DairyNZ. www.dairynz.co.nz/file/fileid/4361,

Anonymous 2010c. Quick start guide: OVERSEER® nutrient budgets model www.agresearch.co.nz/overseerweb/files/introduction-to-overseer.pdf.

Barry, T.N.; Reid, T.C.; Millar, K.R.; Sadler, W.A. 1981. Nutritional evaluation of kale (*Brassica oleracea*) diets. 2. Copper deficiency, thyroid functions and selenium status in young cattle and sheep fed kale for prolonged periods. *Journal of Agricultural Science, Cambridge 96*: 269-282.

Brown, H.E.; Maley, S.; Wilson, D.R. 2007. Investigations of alternative kale management: Production, regrowth and quality from different sowing and defoliation dates. *Proceedings of the New Zealand Grassland Association 69*: 29-33.

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

Chakwizira, E.; de Ruiter, J.M. 2009. Southland winter feeding programme- evaluation of options. Report Report No 2355 prepared for DairyNZ. The New Zealand Institute for Plant & Food Research Limited. 50 p.

Chakwizira, E.; Fletcher, A.L.; de Ruiter, J.M.; Meenken, E.; Maley, S.; Wilson, D.R. 2009. Kale dry matter yield responses to nitrogen and phosphorus application. *Agronomy New Zealand In Press*:

Chakwizira, E.; Moot, D.J.; Scott, W.R.; Fletcher, A.L. 2011. Leaf development and light interception of kale crops supplied with different rates of banded and broadcast phosphorus (P) fertiliser. *Crop and Pasture Science* In Press.

Chakwizira, E.; Moot, D.J.; Scott, W.R.; Fletcher, A.L.; Maley, S. 2010. Establishment and dry matter production of kale supplied with banded or broadcast phosphorus (P) fertiliser. pp. 311-316. In: Proceedings of the 4th Australasian Dairy Science Symposium. Eds. Edwards, G. R.; Bryant, R. H. National Dairy Alliance, Lincoln University, Christchurch, New Zealand. www.sciquest.org.nz/elibrary/edition/5362.

Cichota, R.; Brown, H.E.; Snow, V.O.; Wheeler, D.M.; Hedderley, D.; Zyskowski, R.F.; Thomas, S. 2010. A nitrogen balance model for environmental accountability in cropping systems *New Zealand Journal of Crop and Horticultural Science 38*: 189-207.

Clark, D.A.; Howse, S.W.; Robyn, J.; Johnson, J.; Pearson, A.J.; Penno, J.W.; Thomson, N.A. 1996. Turnips for summer milk production. *Proceedings of the New Zealand Grassland Association 57*: 145-150.

Collie, B.N.; McKenzie, B.A. 1998. Dry matter accumulation of three turnip (*Brassica campestris* L.) cultivars sown on five dates in Canterbury. *Proceedings of the Agronomy Society of New Zealand 28*: 107-115.

Cornforth, S.; Stephen, R.C.; Barry, T.N.; Baird, G.A. 1978. Mineral content of swedes, turnips and kale. *New Zealand Journal of Experimental Agriculture 6*: 151-156.

de Ruiter, J.M.; Fletcher, A.L.; Maley, S.; Sim, R.E.; George, M.; Tabley, F.J.; Gillespie, R. 2009. 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.

Fletcher, A.L.; Brown, H.E.; Wilson, D.R.; Maley, S. 2007. Forage production and nitrogen uptake of kale. Pp. 335-342. In: Proceedings of the 3rd Australasian Dairy Science Symposium. Eds. Chapman, D. F.; Clark, D. A.; Macmillan, K. L.; Nation, D. P. 3: National Dairy Alliance, Melbourne, Australia.

Fletcher, A.L.; Chakwizira, E. 2011. Developing a critical nitrogen dilution curve for forage brassicas to manage N and crop quality. *Grass and Forage Science.* In Press.

Fletcher, A.L.; Sinton, S.M.; Gillespie, R.; Maley, S.; de Ruiter, J.M.; Sim, R.E.; Meenken, E. 2010. Drought response and water use efficiency of forage brassica crops. *Agronomy New Zealand.* In Press.

Goh, K.M.; Magat, S.S. 1989. Sodium chloride increases the yield of fodder beet (*Beta vulgaris* L.) in two New Zealand soils. *New Zealand Journal of Agricultural Research 32*: 133-137.

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

Grace, N.D.; Craighead, M.; Watt, B. 2000. The macro- and micro-element content of swedes and kale in Southland, New Zealand, and the effect of trace element-amended fertilsers on their Co, Se and Cu concerntrations. *New Zealand Journal of Agricultural Research 43*: 533-540.

Guillard, K.; Allinson, D.W. 1989. Seasonal-variation in chemical-composition of forage brassicas.1. Mineral concerntration and uptake. *Agronomy Journal 81*: 876-881.

Harper, F.; Compton, I.J. 1980. Sowing date, harvest date and the yield of forage brassica crops. *Grass and Forage Science 35*: 147-157.

Hayward, G.D.; Scott, W.R. 1993. The effect of fertiliser type on brassica establishment and yield. *Proceedings of the Agronomy Society of New Zealand 23*: 35-41.

Jones, D.J.C. 1959. Studies of the chemical composition of kales and rapes 1. The kales. *Journal of Agricultural Science 52*: 230-237.

Judson, H.G.; Edwards, G.R. 2008. Survey of management practices of dairy cows grazing kale in Canterbury. *Proceedings of the New Zealand Grassland Association 70*: 249–254.

Jung, G.A.; Byers, R.A.; Panciera, M.T.; Scaffer, J.A. 1986. Forage dry matter accumulation and quality of turnips, swede, rape, Chinese cabage hybrids and kale in Eastern USA. *Agronomy Journal 78*: 245-253.

Ledgard, S.F.; Thorrold, B.; Petch, R.A.; Young, J. 2001. Use of OVERSEER® as a tool to identify management strategies for reducing nitrate leaching from farms around Lake Taupo. Pp. 187-194. In: Precision tools for improving land management Eds. Currie, L. D.; Loganathan, P. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand, .

Ledgard, S.F.; Williams, P.H.; Broom, F.D.; Thorrold, B.; Wheeler, D.M.; Willis, V.J. 1999. Overseer™ – A nutrient budgeting model for pastoral farming, wheat, potatoes, apples and kiwifruit. Pp. 142-152. In: Best soil management practices for production Eds. Currie, L. D.; Hedley, M. J.; Horne, D. J.; Loganathan, P. Occasional Report No 12. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Mayland, H.F.; Greene, L.W.; Robinson, D.L.; Wilkinson, S.R. 1990. Grass tetany: A review of magnesium in the soil-plant-animal continuum. Pp. 29-41. In: Proceedings of the 25th annual Pacific Northwest Animal Nutrition Conference, 6–8 November. Vancouver, British Columbia.

Morrison, M.J.; McVetty, P.B.E.; Shaykewick, C.F. 1989. The determination and verification of a baseline temperature for the growth of westar summer rape. *Canadian Journal of Plant Science 69*: 455-464.

Mortlock, C.T. 1975. An assessment of some forage crops in South Canterbury. *Agronomy New Zealand 5*: 17-19.

Nichol, W.; Westwood, C.; Dumbleton, A.J.; Amyes, J. 2003. Brassica Wintering for Dairy Cows: Overcoming the Challenges. *South Island Dairy Event:* 154-172.

Percival, N.S.; Bond, D.J.; Hunter, R.M. 1986. Evaluation of new forage brassica cultivars on the central plateau. *Proceedings of the Agronomy Society of New Zealand 16*: 41-48.

Scott, W.R.; Pollock, K.M. 2004. Do plants respond to Invercargill show day. *SIDE Proceedings:* 33-43.

Stephen, R.C. 1975. The influence of sowing date on marrow stem kale production. *Proceedings of the Agronomy Society of New Zealand 5*: 27-28.

Stephen, R.C.; Kelson, A. 1974. The effects of early and late ploughing and nitrogen application on swede and kale production. *Proceedings of the Agronomy Society of New Zealand 4*: 60-62.

Stevens, D.R.; Carruthers, A.Y. 2008. Can nitrogen fertiliser applied before sowing increase brassica yields in a dry environment? *Proceedings of the New Zealand Grassland Association 70*: 31–36.

Turk, M.; Albayrak, S.; Balabanli, C.; Yuksel, O. 2009. Effects of fertilisation on root and leaf yields and quality of forage turnip (*Brassica rapa* L.). *Journal of Food, Agriculture and Environment 7*: 339-342.

Wheeler, D.M.; Ledgard, S.F.; de Klein, C.A.M.; Monaghan, R.M.; Carey, P.L.; McDowell, R.W.; Johns, K.L. 2003. OVERSEER® nutrient budgets – moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association 65*: 191-194.

Wheeler, D.M.; Ledgard, S.F.; Monaghan, R.M.; McDowell, A.M.; de Klein, C.A.M. 2006. OVERSEER® nutrient budget model – what it is, what it does. Pp. 231-236. In:

Implementing sustainable nutrient management strategies in agriculture. Eds. Currie, L. D.; Hanly, J. A. Occasional Report No 19. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealnd.

Wiedenhoeft, M.H.; Barton, B.A. 1994. Management and environment effects on *Brassica* forage quality. *Agronomy Journal 86*: 227-232.

Wilson, D.R.; Maley, S. 2006. Nitrogen balance for kale. In: Proceedings of the 13th Australian Agronomy Conference. Perth, Western Australia. www.regional.org.au/au/asa/2006/poster/systems/4550_wilsondr.htm

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