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Use of turnips to reduce potassium accumulation on areas receiving Farm Dairy Effluent

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Abstract

Land treatment of farm dairy effluent (FDE) on small areas of intensive of dairy farms has enriched soils with nutrients particularly K. Solving the problem solely by increasing the area allocated for land treatment requires large investment in pump, pipes and irrigator infrastructure. A less costly strategy, of sowing and grazing a summer turnip on the land treatment area in order to redistribute K to the pasture area is evaluated in this thesis. A survey (February 2006) showed that in the Manawatu region turnip crop yields (8 to 17t $DM.ha^{-1}$) provided profitable feed for dairy cows, were a suitable re-grassing strategy and if harvested, removed 350 to 700 kg K ha^{-1} from the soil. In the summer of 2005/06, a turnip (*Brassica rapa* cv. Barkant) trial was established after permanent pasture on a Pallic soil (pH 6.5, Olsen P 35.2 ug. g^{-1}, exchangeable K^{+} 0.7, Ca^{2+} 6.3, Mg^{2+} 1.4 me/ 100 g soil). The following treatments pre-plant fertiliser only (38 kg N ha^{-1}, 25 kg P ha^{-1} and 25 kg K ha^{-1}), pre-plant fertiliser plus side-dressed urea at 40 DAS (46 kg N ha^{-1}) and pre-plant fertiliser plus 5 x 10 mm FDE applications ($57kgha^{-1}$) all produced similar final dry matter yields (8 t DM ha^{-1}) at 100 days after sowing (DAS). Leaf was the largest component of dry matter and had higher K concentrations (4.6 and 6.8% K in the control and FDE treatments respectively) than bulb (3 and 4 %K in the control and FDE treatments respectively). The ratio of leaf to bulb dry matter however varied for each different treatment. Side-dressed urea and FDE treatments produced the largest leaf biomass and reached maximum yields earlier by 75 DAS and 64 DAS, respectively and generated more K removal at harvest (339, 428 & 537 kg K ha^{-1} at 75 DAS and 316, 372 & 490 kg K ha^{-1} at 100 DAS for pre-plant only, urea & FDE treatments, respectively).

The lack of yield response to N partially resulted from crop uptake of between 107 and 114 kg N ha^{-1} from mineralisable soil N. The dynamic N crop model N-able predicted that extra side-dressed N would not increase turnip yield but in the absence of pre-plant N (38 kg N ha^{-1}) the turnips would yield 7.4 t DM ha^{-1} at 100 DAS. The use of the N-able model demonstrated a need for a decision support model to assist farmers in choosing appropriate N fertiliser application rates.

A simple model was created to simulate how the grazing cow can transfer K from turnip paddocks (part of a FDE treatment block) to other parts of the farm. The model simulation of 490 cows on a mixed diet of 4kg DM turnips and 12 kg DM pasture predicted that the grazing of turnips (8t DM ha^{-1} crop) would result in the net transfer of significant quantities (>170 kg K ha^{-1}) of K from land growing turnips to other parts of the farm. To cause net transfer to occur the allocated turnip dry matter must be grazed in the shortest time possible and the cows returned to pasture after short milking times.

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Table of Contents

List of Tables

List of Figures

List of Plates

Introduction

1.1 Intensification of Dairying and the accumulation of potassium under land treatment of FDE

The intensification of dairy farming in New Zealand over the last 10 years has resulted in an increase in the average stocking rate of 10% i.e. from 2.48 cows ha^{-1} to 2.75 cows ha^{-1} (LIC, 2003/04). By 1999/00, the top 25% of farmers (herd size > 300 cows) had also increased the amount of supplementary feed purchased so that the average amount of supplement brought onto the farm was 670 kg DM cow^{-1} or 2069 kg DM ha^{-1} (Leslie, 2002). This increased use of supplementary feed and fertiliser has led to greater inputs of nutrients into dairy farm systems.

Increased stocking rate leads to the generation of greater volumes of farm dairy effluent (FDE). By 2003/04, approximately 63 million m^{-3} $year^{-1}$ of FDE was being generated (LIC, 2003). Mismanaged irrigation of FDE to land can create a number of problems (Bolan et al., 2004; Houlbrooke et al., 2004) including:

- High application rates generating runoff and drainage of partially treated FDE, which pollute surface and ground waters.
- Excessive FDE loads leading to N and K enrichment of topsoils increasing the risk to animal health, plant quality and soil quality.
- Nutrient enrichment of winter drainage water
- Wet easily, pugged soils
- Localized areas that receive higher rates of effluent which exceed the soil's infiltration rate. Therefore, patches of saturated soil, preferential flow of FDE through the soil profile, soil structure damage, poor plant growth, etc.

Therefore, nutrient enrichment on land receiving FDE becomes a potential risk. The nutrient concentration in FDE varies widely from farm to farm (Longhurst *et al.*, 2000) but typically the N, P and K concentrations range from 181 to 400 mg N l^{-1}, 40 to 80 mg P l^{-1} and 164 to 705 mg K l^{-1}, respectively (Longhurst *et al.*, 2000). Whilst high and poorly timed application rates of N and P in FDE can cause undesirable N and P enrichment of drainage (Houlbrooke *et al.*, 2004) and surface waters (Monaghan et al. 2004), the high concentration of K in FDE can cause excessive K accumulation in soils of areas that receive FDE. Paddocks that are irrigated with FDE at the appropriate N loading rate for regional council consent (150-200 kg N ha^{-1}) accumulate and presumably leach large amounts of K (Bolan *et al.*, 2004). This results in pastures on effluent paddocks with high K contents and reduced Mg and Ca contents (Bolan *et al.*, 2004). For example, the nutrient budgeting tool 'Overseer® Nutrient Budgets 2' predicted that K was added as effluent at rates of 354 and 154 kg ha^{-1} y^{-1} to the effluent areas of two dairy farms in North Otago (3.7 cows ha^{-1}, Lynch, 2006) and Waikato (4.7 cows ha^{-1}, Payze, 2006), respectively. The variation in concentration depended partially on the area of the effluent blocks on each farm. Cows left for a long time to graze these paddocks may suffer from metabolic disorders (Hypocalcaemia and Hypomagnesaemia).

Problems caused by application of FDE to wet soils are being addressed by FDE storage and deferred irrigation. This system is advocated by most regional councils (Houlbrooke et al., 2004). The management of deferred irrigation has been improved by the use of irrigators, such as the k-line system, that are able to apply small depths (less than 5 mm) of FDE to soils (Houlbrooke *et al.*, 2006). While such modification will minimise the risk of N and P loss to the aquatic environment, additional strategies are required to reduce the K loading and accumulation in soils.

1.2 Solution to this problem: Strategies to reduce the accumulation of K on areas receiving FDE

1.2.1 Extension of effluent area

The current criterion for applying FDE to land is based on Regional Council regulations for appropriate N loading of which 200 kg N ha^{-1} y^{-1} is the limit (Heatley, 1996). The land area recommended for FDE treatment is currently 4 ha per 100 cows (Heatley, 1996), but a new proposal suggests that the area should be based on the proportion of dung and urine that is collected from the herd. This can be estimated from the average time a cow spends off the paddock in the collecting yards and milking shed and/or feed pad (Hedley *et al*., 2004). To prevent K accumulation in soil, the annual K loading rate should not exceed the annual K maintenance requirement of grazed pasture. This requires irrigation of FDE to a larger proportion of the farm (30-40%) than is currently used to meet the N requirements (10 -15 %). A number of case studies where areas allocated for land-treatment of FDE are described below.

Hedley *et al*., (2004) described a farm in the Bay of Plenty with 580 cows and an original effluent area of only 19 ha. It was proposed to increase the FDE area to 43 ha (30% of the whole farm) to improve management of FDE. Nutrient application rates to the expanded area were reduced by up to 50%. Of course enlarging the effluent area requires increased expenditure on an upgraded irrigation system. In this case study, the predicted cost of installing additional irrigation on the 43 ha plus annual running costs was around $8917 per year, which allowed a saving of $9400 per year in fertiliser costs (Hedley et al., 2004).

Two dairy farm case studies (in North Otago and Waikato) used the Overseer® nutrient budgeting model to assess the impact of nutrient management recommendations on efficiency of nutrient use in, and nutrient loss from, the effluent blocks. The two farms, where the soil nutrients levels were already equal to or greater than optimum agronomic value for pasture, increased the area of effluent application up to the total farm area. The North Otago dairy farm reduced the application rates of nutrients by about 87%, by use of the new irrigation system. However, the predicted investment in the new irrigation system was very large (Lynch, 2006). On the other farm (Waikato) extending the application area to be equal to the whole farm area decreased the nutrient content applied to the effluent paddocks by about 53% (Payze, 2006). The difference in the sizes of the nutrient reductions in the two farms were due to the different stocking rate (3.7 and 4.7 cows ha^{-1}) and the size of the previous effluent blocks (25 and 85 ha).

1.2.2 Crop nutrient removal

Hedley *et al.*, (2002) proposed that the harvesting of silage, or hay, to remove K from the FDE area will avoid the need for excessively large land-treatment areas. For instance, Overseer® was used to simulate the ability of maize silage (spring planting) followed by barley/triticale (autumn planting) to remove nutrients for FDE paddocks on a Bay of Plenty farm (Hedley *et al.*, 2004). If these two crops yielded 27 and 5 ton DM ha^{-1}, respectively, the combined nutrient removal was predicted to be 414 kg N ha^{-1}, 61 kg P ha^{-1} and 288 kg K ha^{-1}. Annual grass silage harvesting in spring and summer, which yields a total dry matter production of 6 t DM ha^{-1}, will remove less nutrient at 187 kg N ha^{-1}, 27 kg P ha^{-1} and 133 kg K ha^{-1} (Hedley *et al.*, 2004). Another problem in using grass silage as a nutrient removal strategy is that in many areas of New Zealand, wet soils in winter and spring delay the commencement of 'safe' effluent irrigation to late spring and summer. The window of opportunity to harvest hay and silage is reduced and crop sizes of 3.5 to 5 t DM ha^{-1} are expected. Therefore, K extraction and removal can remain low relative to inputs in the FDE.

Summer crops such as maize and turnips offer the opportunity to produce larger amounts of dry matter with higher metabolisable energy content (Table 1.1) than conserved pasture (Table 1.2) and therefore are attractive as fodder crops for summer dry areas. In addition, for the same growing period, the higher yields of maize silage and turnips remove more nutrients than pasture silage (Table 1.2). Turnips, in particular, have higher tissue K concentrations (Table 1.1) and remove markedly more K when harvested (grazed). For example, at a yield of 10 t DM ha^{-1}, turnips extract 10% less N and P but 40% more K and S than a crop of maize yielding 18 t DM ha^{-1}. If the turnips and maize had similar yields (18 t DM/ha) then the turnips would remove 60% more N and P and 150% more K and S (Table 1.2)

Table 1.1 Nutrient content of different crops that could be grown to remove excess K from the soil

				Nutrients (%)					
	DM (%)	MJ ME/kg DM	CP (%)	N	P	K	S	Ca	Mg
Pasture Silage/Baleage	35	9.5	16.0	3.5	0.29	2.2	0.22	0.70	0.18
Maize silage	33	10.3	8.0	1.3	0.23	1.2	0.13	0.25	0.18
Turnip crop	10	12.5	13.0	2.1	0.37	3.0	0.33	1.75	0.23

Source: Holmes *et al.*, 2002. Milk production from pasture. Principle and practices.

Table 1.2 The effect of crop type and yield on the removal of K from the soil

		Nutrients (kg ha^{-1})			
	Yield t ha^{-1}	N	P	K	S
Pasture Silage/Baleage	2 - 4	70 - 140	6 - 12	44 - 88	4 - 8
Maize silage	18	234	41.4	216	23.4
Turnip crop	10	210	37	300	33
Turnip crop	18	378	66.6	540	59

[1] Source: The silage and baleage yields are from the Dexcel website (2006) www.dexcel.co.nz; the maize and turnip yields are from Holmes C. (Personal comm.).

Factors such as the timing of growth, available finance, and plant nutritive qualities would also affect farmers' decisions as to which crop to grow. At 0.08 – 0.12 $/kg DM, turnips have the lowest cost per kg DM produced. Therefore, turnips could be a "best option" for this new strategy of nutrient harvest by a crop because, unlike maize, they require no specialized machinery nor added contractors costs to plant and harvest (feed to cows). However, many dairy farmers prefer to buy maize silage rather than cultivate (Holmes pers com, 2005).

Table 1.3 Approximate cost per kg DM produced and the harvesting time of crops

	Cost $/kg DM	Harvest time (weeks)
Pasture Silage/Baleage	0.40 - 0.45	4 - 8
Maize silage	0.15 - 0.21	24 - 28
Turnip crop	0.08 - 0.12	10 - 12

Source: www.dexcel.co.nz

Forage crops such as turnips are grown for the following reasons:

- Provide a large quantity of high quality feed during summer months to increase milk production at this time (decreasing the fall in milk production that normally occurs at this time from 14 % to 7% month (McGrath *et al.*, 1998; Daniels, 1995).

- A pasture renewal strategy to introduce new productive pasture species free of endophytes, and clean the soil of pests, weeds and diseases;

- Improve soil structure and surface micro-topography by levelling or draining during the cultivation phase.

- Less stressful time for the farmer.

In addition, they could be sown on effluent areas and on/off grazed to aid the redistribution of effluent borne K around the other grazed areas of the farm.

1.3 Research Objectives and Thesis Structure

The objective of the research presented in this thesis is to provide more information on the role that a summer turnip crop could play in redistribution of K from soils that have been enriched with K by FDE application. This study involves a survey of turnip crops grown in the Palmerston North region, a field trial evaluating the K removal potential of Barkant turnips grown under FDE irrigation and two exercises in modelling the crop N requirement and K transfer by cows grazing a mixed diet of turnips and pasture.

This thesis has the following objectives:

- Review how intensive dairy farming increases the concentration of nutrients in effluent paddocks.
- Survey local turnip crops for yield and nutrient content at harvest.
- Measure the ability of turnips (*Brassica rapa* cv. Barkant) to take-up K under normal fertilization and FDE irrigation
- Use of N-able model to assess the amount of N fertiliser that is required to achieve high turnip yield.
- Build a simple model to evaluate the K transfer potential of different grazing strategies for cows on a mixed diet of turnips and pasture.

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Chapter 2

2.1 Brief review of FDE management in dairy farm systems

2.2 Environmental concern about effluent

The face of dairy farming in New Zealand dairy has changed in recent times as it has expanded and intensified. For example, dairy farm systems have traditionally been based on pasture production, however, for some farmers the use of relatively large quantities of supplements brought onto the farm has been profitable. During the past decade the number of cows and effective hectares used for milk production has increased about 37% (LIC, 2003). More than the 20% of farms now milk more than 300 cows and this has had a large effect on the economic success of these businesses.

Expansion and intensification of dairy farming have also increased inputs of fertiliser and outputs of farm dairy effluent (FDE). These trends have loaded farms and, in particular, FDE paddocks with large quantities of nutrients. About 63 million m^3/year of FDE is generated (LIC, 2003). Farm dairy effluent (FDE) can be raw or partially treated; the former comes directly from the yard via a sump, while the latter is stored in single or two ponds (Bolan *et al.*, 2004; Houlbrooke *et al.*, 2004a). Nutrient and solid concentrations in FDE have increased due to decreased volumes of wash-down water (Longhurst *et al.*, 2000). For example, nitrogen (N) concentration has doubled from 200 to 400 g /m^3 in the last 30 years (Longhurst *et al.*, 2000).

Nutrient rich FDE is potentially hazardous to the aquatic environment and therefore its discharge to waterways has been legally prohibited by most regional councils. Regional councils advocate land application of FDE in order to prevent the nutrient load of FDE from creating a major reduction in the quality of receiving surface waters. The nutrient rich status of FDE indicates that it could be useful as a natural fertiliser. The main goal of land application of FDE is to create a "closed cycle" of nutrients. If FDE applications are carefully managed, pasture will reuse the nutrients. However, this goal will not be achieved if FDE is mismanaged and FDE and the nutrients that it contains will enter receiving water bodies (Table 2.1).

Table 2.1 Problems caused by mismanagement of FDE application to the land.

Inappropriate use	Problems
Infrastructure, planning inadequate: total loading despite guidelines (overall application: area to small)	Land blocks with excessive nutrient enrichment causing enriched K (it is a potential problem) and N leaching and P run off
Scheduling of irrigation (irrigation on wet soils)	Direct drainage or run off of partially treated FDE
Application rate: irrigation speed, time and frequency of application (depths exceed – soil water deficit, depth exceed – deficit in plant root zone)	Enrichment of subsoil leaching or enriched nutrient loss in winter drainage.
Poor irrigation management (defining irrigator low priority (the width and uniformity of the distribution pattern)	Localized areas which receive higher rates of effluent exceeding the soil infiltration rates. Therefore, patches of over wet soil, soil structure damage, poor plant growth, etc.

If the problems associated with poor management of FDE are not treated effectively, the dairy industry could jeopardize its "clean green" marketing reputation and face economic repercussions. Therefore, since the introduction of the Resource Management Act (RMA) in New Zealand there has been substantial interest in looking for practical and sustainable land treatment strategies for FDE (Longhurst *et al.*, 2000). Researchers, farmers and government are working together to prevent the potential negative impacts of FDE mismanagement.

For instance, Environment Waikato changed its monitoring practices and enforcement processes (using prosecution) when it found that 57% of dairy farms did not comply with at least some of the rules for FDE application and, that 16% were seriously non-compliant. As a result, Environment Waikato has started using a helicopter ("Eye-in-the-Sky") to ensure that farmers comply with FDE management guidelines and avoid water pollution (Environment Waikato, 2005a, 2005b, 2005c).

2.3 Chemical composition of Farm Dairy Effluent

There are wide ranges in the physical and chemical compositions of FDE, even on the same farm due to differences in the source, treatment, storage, and collection time (Longhurst *et al.*, 2000; Wang *et al.*, 2004). Typically, FDE is made up of dairy cow excreta (10%), wash-down water (86%) teat washing (4%) plus other soil contaminants, (Houlbrooke *et al.*, 2004a; Longhurst *et al.*, 2000) which are collected from the farm dairy and yards (Table 2.2). Thus, FDE is a rich source of nitrogen (N), phosphorus (P), potassium (K) and smaller quantities of calcium (Ca), magnesium (Mg) and sulphur (S) (Bolan *et al.*, 2004; Houlbrooke *et al.*, 2004a; Longhurst *et al.*, 2000). Farm dairy effluent is not a balanced fertiliser (Bolan *et al.*, 2004; Longhurst *et al.*, 2000)

Generally, N and, to a lesser extent, P have been considered the major pollutants of ground and surface water through drainage and runoff processes from agricultural land (Bolan *et al.*, 2004; Houlbrooke *et al.*, 2004a; Longhurst *et al.*, 2000). Research with N fertiliser application, has indicated that N loss by leaching can be minimized if application rates are below 200 kg N/ha (Ledgard *et al*, 1996). On the basis of these findings, some regional councils limit FDE applications to land to the equivalent rate of 150 to 200 kg N ha^{-1} $year^{-1}$.

Table 2.2 Chemical and Physical characteristics of FDE from aerobic ponds

Characteristics	Range of nutrient content
Solids content	0.031 and 0.192% DM.
Nitrogen content	135 - 150 mg l^{-1} (Bolan et al., 2004; Houlbrooke et al, 2004c)
Seasonal variation of nitrogen (N)	N content of the FDE has the same seasonal pattern that lactation and pasture growth. (Rose from the start of lactation to peak during September/October then gradually declined again towards the end of the lactation)
Major elemental composition of FDE	Phosphorus: 22.1 - 25 mg l^{-1} (Bolan et al., 2004; Houlbrooke et al, 2004c) Potassium: 231 mg l^{-1} (Bolan et al., 2004) Calcium: 15.2 mg l^{-1} (Bolan et al., 2004) Magnesium: 11.5 mg l^{-1} (Bolan et al., 2004) Sodium: 54 mg l^{-1} (Longhurst et al. 2000) Sulphur: 65 mg l^{-1} (Longhurst et al. 2000)

When FDE is applied at the equivalent rate of 150 kg N/ha^{-1}, the maximum rate permitted by some regional authorities, the K concentration at this level is approximately two to three times (194 to 260 kg ha^{-1}) greater than the soil's maintenance K requirement (70 – 80 kg ha^{-1}) (Bolan *et al.*, 2004). Consequently, this level of FDE application is likely to cause an imbalance of basic cations in the plant/soil system and, in turn, animal health problems such as milkfever (hypocalcaemia) and grass staggers (hypomagnesaemia) can occur (Bolan *et al.*, 2004; Longhurst *et al.*, 2000), These problems can become critical during late autumn and early spring (Mason & Young 1999, cited in Wang *et al.*, 2004).

The excessive supply of K through long-term FDE application can result in luxury pasture uptake of K without affecting pasture yield (Bolan *et al.*, 2004) and nutritive value (digestibility, crude protein, fibre) (Morton et al., 2005). High K application rates in soil depressed plant uptake of sodium (Na), magnesium (Mg) and calcium (Ca) producing cation imbalances in the plant and the soil. The cations which are not taken up by plants are prone to leaching from the soil due to competition for soil exchangeable sites (Table 2.3) (McNaught, 1973). The magnitude of the leaching of these nutrients varies depending on the soil type, soil reserves and the season (Morton *et al.*, 2004.

Table 2.3 Mean concentration of K in herbage (grass and white clover) on N-K plots and percent changes in Ca, Na and P due to K fertiliser application (McNaught *et al*, 1973)

	% K	% of changes (189 kg K ha^{-1} applied)			
Season	No-K	K	Ca	Na	P
Spring 66	3.02	+18	-7	-42	0
Autumn 67	3.52	+ 9	-2	-28	-1
Spring 67	3.21	+ 5	-1	-21	-1

The application of Ca and Mg fertilisers could mitigate the depletion of these nutrients (Bolan *et al.*, 2004; Morton *et al.*, 2004) (Table 2.4). For example, gypsum and Epsom salt at levels of 20 kg Ca ha^{-1} and 20 kg Mg ha^{-1}, respectively, increased the concentrations of Ca and Mg in pasture at all levels of effluent application (Bolan *et al.*, 2004).

Table 2.4 Effect of dairy farm effluent application on exchangeable cations in soil (Taken from Bolan *et al*, 2004)

Effluent level (kg N ha^{-1})	Without Ca and Mg fertiliser addition			With Ca and Mg fertiliser addition		
	K	Ca (cmol kg^{-1})	Mg	K	Ca (cmol kg^{-1})	Mg
0	1.26	5.06	0.82	1.19	6.62	1.26
150	2.36	4.15	0.34	2.27	6.53	1.18
200	3.45	3.05	0.15	3.39	6.49	1.18

Bolan *et al.* (2004) stated that potassium-induced Ca and Mg deficiency in grazing animals occurs at different stages:

1. Competition for adsorption sites between Ca, Mg and K, due to excessive, application of K to the soil, producing leaching of Ca and Mg.

2. Luxury uptake by plants owing to the high concentration of K in soil solution, thus plants decrease the uptake of other cations, such as Ca and Mg, to maintain charge balance. Therefore, when the animal eats this plant, other cations are excreted from the animal's body because of competition for metallothionein protein in favour of K.
3. As clover takes up more Ca and Mg than grasses, the decrease in legume content of pasture swards under FDE irrigation (due to high N loadings) indirectly reduces the Ca and Mg ingested by grazing animals.

2.4 Best land-based wastewater treatment

Previous studies have shown that the quantity of nutrient loss would decrease if dairy farmers improved FDE management (Houlbrooke *et al.*, 2004a; Houlbrooke *et al.*, 2004b; Houlbrooke *et al.*, 2004c). As stated above, the method used currently by most farmers, and preferred by regional councils is the application of FDE to land. Nevertheless, when the effluent was applied at an unsuitable time, with high soil water content, significant volumes of effluent are lost as drainage and runoff (Houlbrooke *et al.*, 2004b).

Researchers have recently developed a feasible and sustainable land-treatment system for FDE called deferred irrigation (Houlbrooke *et al.*, 2004b) Deferred irrigation involves the storage of FDE in pond(s) and its strategic application (preferably from the aerobic pond) to the soil only when an adequate soil water deficit exists (Hedley *et al.*, 2005; Houlbrooke *et al.*, 2004b). At No 4 Dairy Farm, Massey University, deferred irrigation eliminated nearly all drainage and associated nutrient losses under FDE irrigation (Table 2.5) (Houlbrooke *et al.*, 2004c). A further design feature is the harvesting of conserved pasture, as hay or silage, from the treatment area to reduce the accumulation of nutrients in the soil-plant system; thereby, improving the quality of both the pasture and soil (Hedley *et al.*, 2002).

Table 2.5 The mean depth of farm dairy effluent (FDE) applied by the irrigator at each of the irrigation events, the soil moisture deficit at the commencement of irrigation, the average from all plots over three lactation seasons (2000/01 – 2002/03), and the maximum drainage from any single plot as a proportion of the applied FDE (i.e., representing the "worst case" scenario). -, no data (Taken from Houlbrooke *et al.* 2004c)

Irrigation date	Effluent applied (mm)	Estimated soil moisture deficit at start of irrigation (mm)	Average drainage (mm)
23 Nov 00[a]	27	66	-
6 Dec 00[a]	31	63	1.4
10 Apr 01[a]	8	195	0
10 Apr 01[a]	12	187	0
11 Apr 01[a]	25	175	0.1
16 May 01[a]	26	117	1.2
20 Aug 01[b]	9	30	0
24 Jan 02[b]	7	40	0
20 Feb 02[b]	9	34	0

[a] 2000/01 lactation season; [b] 2001/02 lactation season

A new modification to the deferred irrigation is the adoption of more stringent irrigation scheduling criteria: smaller depths of FDE are applied to minimise the risk of effluent moving below the root zone of the pasture (Hedley *et al.*, 2005). Therefore, plant uptake and soil immobilization processes would be maximized. However, the success of this modification depends on the storage pond capacity, daily monitoring of the soil water balance and an effluent block nutrient budget. By aiming to irrigate smaller depths, these guidelines could increase the number of days on which it would be safe to apply FDE while avoiding drainage and nutrient losses (Hedley *et al.*, 2005). For example, on a 490 cow dairy farm in the Manawatu with an effluent area of 20 ha, scheduling FDE irrigation depths at 10 mm d^{-1} over 4 ha and a pond storage capacity of 3000 m^3 were determined as safe practice to maintain the effective soil water balance in the pasture root zone and to storage FDE until a period of safe irrigation (Hedley *et al.*, 2005).

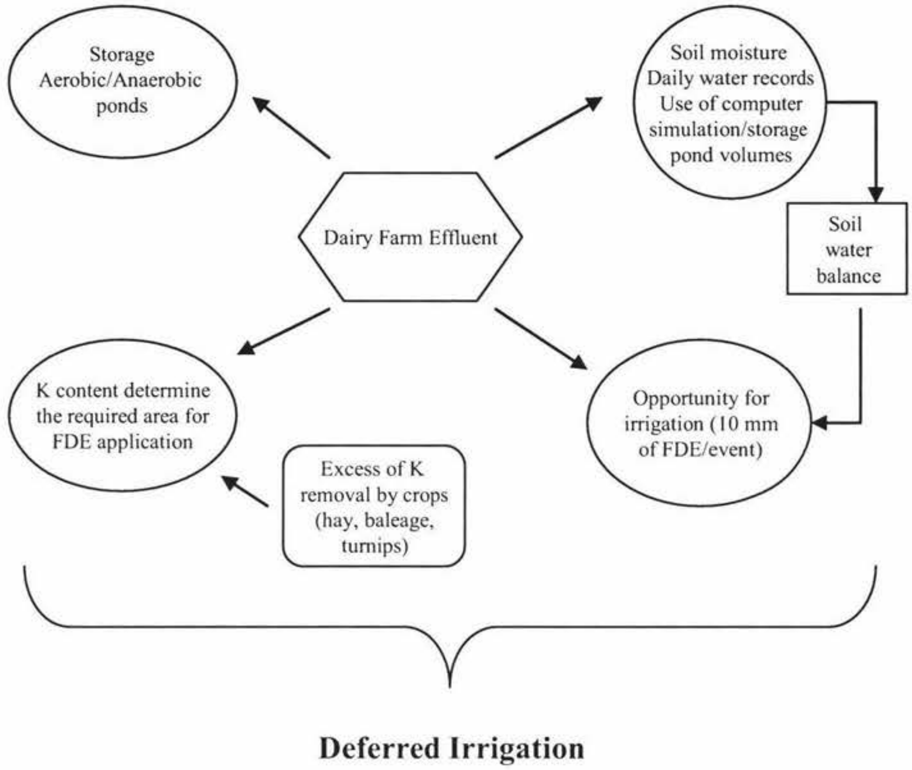

Figure 2.1 Key parameters and components for successful deferred irrigation of farm dairy effluent.

The management of deferred irrigation is based on soil water and nutrient balance models. However, if farmers do not take soil water and nutrient status into account (Figure 2.1) then, deferred irrigation will not be successful.

The combination of best management practices including the application of FDE to an area of appropriate size, right irrigation system, low FDE application rates and suitable rest periods will minimise the risk of N and P leaching, It will prevent ponding and surface runoff, and avoid physical deterioration of the soil. However, deferred irrigation is not able to overcome the enrichment of nutrients in the soil such as K.

2.5 Nutrient budgeting model

Researchers, consultants and farmers have been using a nutrient budgeting tool, Overseer® Nutritional Budgets 2, which allows them to identify the nutrient inputs in the form of supplement, fertiliser and effluent to the whole farm and individual blocks. This model helps farmers modify their fertiliser policy and select strategies which could help to save money and to minimise the impact of their farm on the environment. In the future, farmers may be required to submit nutrient budgets for their farming system to Regional Councils for auditing purposes (Hedley *et al.*, 2004).

This budgeting tool has allowed the effects of intensification in the form of nutrients going back into the effluent paddocks to be determined. Therefore, nutrient budgeting is identifying from the beginning the accumulation of nutrient and the changes in soil test values in effluent blocks.

The Overseer® model has been particularly helpful in identifying problems associated with the management of areas on the farm that receive FDE. On many farms, Overseer® identifies excessive N leaching and accumulation of K in the soil profile. These problems arise because the effluent areas are too small, and consequently, they must tolerate excessive applications of FDE. These problems can be dealt with in two ways. Firstly, by correctly assessing the area required for FDE irrigation, and secondly by using crops to remove nutrients from the effluent area.

2.5.1 Area required to reduce the loads of K and N

Regional Councils suggest that the amount of effluent applied to the land should be limited to a maximum of 200 kg N applied per ha annually; therefore the minimum land area recommended would be 4 ha per 100 cows (Heatley, 1996). However, a new guideline (Hedley *et al.*, 2004) for the appropriate size of effluent blocks suggests larger areas of 8 ha per 100 cows. This novel proposal is founded on the proportion of time cows spend on effluent collecting areas. If FDE is applied to a larger area, the metabolic disorders in animals due to potassium excess in pasture should be overcome (Hedley *et al.*, 2004).

For example, on a farm with 580 cows, in the Bay of Plenty the original effluent area was 19 ha (Hedley *et al.*, 2004). However, under the new proposal the area was increased to 43 ha (30% of the whole farm); therefore, the nutrient concentrations were reduced by up to 50%. Of course, enlarging the effluent area requires increased expenditure on a new irrigation system. In the farm above, the predicted cost of installing the irrigation on the 43 ha was around $8917/ year, which allowed a saving of only 6%, due to a reduction in fertiliser inputs (Hedley *et al.*, 2004).

Two dairy farm case studies (in North Otago and Waikato) used Overseer® to assess the impact of nutrient management recommendations on the efficiency of nutrient use and nutrient loss in the effluent blocks. Soil test values on the two farms were at optimum agronomic values for pasture. On both farms, the area to which effluent was applied was increased so that FDE was irrigated to the entire farm. By use of the new, extended irrigation system, the North Otago dairy farm reduced the quantity of nutrient going to the original FDE block by 87%. However, the predicted investment in the new irrigation system was large (Lynch, 2006). On the other farm (Waikato), extending the application area to cover the whole farm decreased the nutrient content going to the original FDE paddocks by about 53% (Payze, 2006). The difference in the sizes of the nutrient reduction in the two farms were due to the different stocking rate (3.7 and 4.7 cows ha^{-1}) and the size of the previous effluent blocks (25 and 85 ha).

2.5.2 Nutrient removal in crops

Hedley *et al.*, 2002 argued that the use of large areas of land for FDE application should be avoided, and that the investment in new irrigation equipment could be reduced by using annual crops that are capable of removing or harvesting large quantities of nutrients. The main idea underpinning the use of annual crops for nutrient removal is that the nutrients left after the crop is harvested should more closely match the nutrient requirement of the pasture, ensuring minimum nutrient loss to soil water (Heatley, 1996).

The Overseer® model was used to simulate a dairy farm in the Bay of Plenty, and to show that using maize silage followed by barley/triticale crops on the effluent blocks would yield 27 and 5 ton DM ha^{-1} respectively; the combined nutrient removal was 414 kg N, 61 kg P and 288 kg K per ha (Hedley *et al.*, 2004). Another crop proposal was the conservation of silage from an annual ryegrass (harvesting in spring and summer). This crop would produce a total of 6 ton DM ha^{-1} and remove fewer nutrients (55%) than the first option (Hedley *et al.*, 2004). However, growing pasture for silage would limit the safe FDE application period to late spring and summer, and this irrigation would in turn reduce the opportunities for harvesting of silage. As a result, the potassium extraction and removal would remain low relative to input rates in the FDE.

Summer crops such as turnips or maize yield large quantities of plant material. The cheapest crop for nutrient removal is likely to be turnips because cows can graze them, and with good grazing practices, it is possible to use the cows to redistribute nutrients from the FDE areas to other parts of the farm. However farmers are likely to be influenced by a number of factors including timing of growth, available finance, and plant nutritive qualities when selecting both the crop to grow and the extent of any such cropping. Holmes (personal comm. 2005) stated that the majority of commercial dairy farms prefer to buy maize silage rather than to grow it on farm. However, as a number of farms currently grow turnips, they could be a "best option" for this new strategy of nutrient removal by a summer crop.

2.6 Review of literature on turnips, their impact on the performance of intensive dairy farms and as a crop to reduce high K concentrations on effluent paddocks

2.7 Introduction

This section of the review discusses the potential role of turnips in sustainable land application of FDE. This review firstly examines published data on the agronomy of cultivars grown in New Zealand and the value of turnip as a fodder crop in dairy systems, and then considers the role of turnips for nutrient management of land irrigated with FDE.

2.8 Use of turnips on New Zealand dairy farms

New Zealand dairy farm systems are based on grazed pasture as the main, if not, the only source of forage. However, forage crops such as turnips are widely grown for the following reasons:

1. To provide a large amount of high quality feed during dry summer months to maintain milk production at the high levels McGrath *et al.*, 1998; Daniels, 1995)
2. As part of a pasture renewal programme to introduce new, more productive pasture species, free of endophytes. During cultivation, the incidence of pests, weeds and diseases in the soil is reduced.

3. As an opportunity to improve soil structure and surface micro-topography by cultivation and levelling during the seedbed preparation phase
4. To reduce stress on the farmer by providing a source of feed in dry summers.

Most of the research into the feeding of turnips to cows in New Zealand has been to determine the lactation responses, the opportunity costs, energy, protein and mineral status of lactating cows (Exton *et al.*, 1996; Clark *et al.*, 1996 & 1997; Shaw *et al.*, 1997; Harris *et al.*, 1998) with few studies of the nutrient status of the turnip plant. Similar experiments have been conducted in Australia and some of this work has determined the nutrient status of the plant.

2.9 Turnip yield and variety responses

The period between 1994 and 1996 was remarkable for the number of studies of turnip crops, with around 60% of the research done in this period (Table 2.6). Most of these studies have been conducted in the North Island. Turnip yields ranged from 0 to 19 t DM ha^{-1}. However, since Clark's report in 1996, the lowest yield has not been less than 6 t DM ha^{-1}. A national survey which covered New Zealand's 7 regions (Northland, Bay of Plenty, North Waikato, South Waikato, Taranaki, Southern North Island and South Island) and a Manawatu survey were carried out in 1994 – 1995. In this period turnip yields ranged from 0 – 15 t DM ha^{-1}, the variability caused by extreme weather (too wet or dry) conditions (Clark, 1995; Daniels, 1995). Both the National and the Manawatu surveys demonstrated that up to 80 and 50 % of the farmers, respectively, preferred Turnips (*Brassica rapa*) cv. Barkant and the average yields were 7.5 and 5.7 t DM ha^{-1}, respectively.

In 1999 - 2000 a survey in the South-western Victoria region of Australia determined that the most common turnip variety sown was Barkant, followed by three other turnip cultivars (Mammoth Purple Top, Vollenda and Rondo). The Barkant cultivar has both higher yield and quality (Eckard *et al.*, 2001; Jacobs *et al.*, 2001). This suggests this variety is able to adapt to a wide range of weather and soil conditions.

Table 2.5 Research and approximated turnip yield from 1994/95 to up to date.

Year	Location	Treatment	Range of yield t/ha	Author
		Yield trials		
1994/95	NZ survey	328 farmers surveyed	0 – 15.2 (7.5)[1]	Clark, 1995
1994/95	Manawatu (Tararua and South Wairarapa)	32 farmers surveyed	0.0 – 11.2 (5.7)	Daniels, 1995
1994/95	Manawatu (Tararua)	0,30,60 and 120 kg N/ha applied @14 DAS (days after sowing)	(5.3)	Daniels, 1995
1994/95 1995/96	TAR (Taranaki Agriculture Research Station)	0,25,50,100 and 200 kg N/ha applied after sowing	7 - 12 (11.5)	Pearson & Thomson, 1996
		Feeding trials		
1994/95 1995/96	Waikato	Turnip area: 5 -10%	6.2 - 11	Exton *et al.*, 1996
1995	TAR (Taranaki agriculture research Station)	4,5,8 kg DM/cow/d turnip allowance + basal pasture diet (10 kg DM/cow/d)	(9.3)	Clark *et al.*, 1996
1995/96	DAR (Dairy Research Corporation) Hamilton	0,4,8 kg DM/cow/d turnip allowance + summer & autumn intake	summer (12.2) autumn (13.3)	Clark *et al.*, 1997
1996/97	Grater Waikato and Hauraki Plains	Turnip area: 5 -10% + 60 kg N (30 kg at cultivation and 30 kg two months later	9.2 – 12.2	Shaw *et al.*, 1997
1996/97	DAR (Dairy Research Corporation) Hamilton	0,4,8 kg DM/cow/d turnip allowance + summer & autumn intake	summer (12.0) autumn (7.1)	Harris *et al.*, 1998
2003	Foot hills of Waikato's Mount Pirongia		(19)	Country –Wide Northen
2002	Waikato Survey	200 farmers surveyed	Best Practice	Wrightson Seeds 2005

[1] The mean of the yield is given in brackets.

2.10 Factors associated with yield

After 3 years (between 2002-2004) of analyzing and comparing yield data for Barkant turnip crops grown on 200 Waikato farms, Wrightson Seeds published the Barkant™ Best Practice Guide (www.wrightson.co.nz/assets/seeds/forage%20focus/) for establishing and growing high yielding Barkant turnip crops. This information and the survey data from 1995 agree that several factors are associated with yield variation, including; rainfall, fertiliser use (nitrogen and phosphorus), the number of days between sowing and grazing, and cultivation method.

In New Zealand the best sowing date is generally in early November. Crops sown after this period are likely to encounter moisture stress before they have begun to mature. The later a crop is sown, the more at risk there is in encountering dry soil conditions. Despite the wide range of yields, a high proportion of farmers grazed the turnips between 70 to 90 days after sowing, which could coincide with the maximum turnip growth rate (Pearson & Thomson, 1996) or with the farmers' need for extra feed. The maximum harvesting time should be about 120 days after sowing for Turnip-Barkant (Clark et al., 1996).

A farmer in Waikato achieved 19 t DM ha^{-1} of turnips (Table 2.6) following the Barkant best practice guidelines ("Country-Wide Northen," 2006). When fed at 5 kg DM $cow^{-1}day^{-1}$ as a supplement, milk solids production on this farm increased by 80 g MS/kg DM.

Even though the Best Management Barkant guide recommends that 50-100 kg N ha^{-1} is applied 3 – 4 weeks after sowing, two studies showed that there was no response in total turnip yield to increased levels of N and P application (Daniels, 1995; Pearson & Thomson, 1996). Pearson and Thomson. (1996) suggested that soils with total N concentrations greater than 0.63% and Olsen P values greater than 26 mg P l^{-1} were adequate for growing turnips. The high nutrient content and the lack of response to N fertiliser in this study could have been due to the fact that the experiment was established in a paddock where the pasture had been more than 20 years old. Even though the application of N fertiliser did not affect the total production, the bulb yield decreased and bulb N concentration increased at high levels of N. The increase in N content of bulbs was reflected in an increase in the nitrogen content of the whole crop (Pearson & Thomson, 1996).

2.11 Milk solids

The first studies (1994-1996) of responses in milk production to the feeding of turnips suggested that this practise was unprofitable (Exton *et al.*, 1996). Unpredictable weather (lack of rain), lack of planning at sowing (reduction of grazing area, decrease in pasture yield for silage due to early crop cultivation), and the costs of establishing and feeding this crop resulted in lower milk production and higher animal weight loss, even though in the second season of one experiment turnip production was high (10- 11.5 t DM ha^{-1}). Thomson *et al.* (1997) found that devoting 8% of the farm's area to turnips reduced; pasture cover, the quantity of conserved pasture, body condition score and annual milk solid production by 360 kg DM ha^{-1}, 180 kg DM ha^{-1}, 0.2 units and 0.2 kg MS ha^{-1}, respectively.

Later research has demonstrated that turnips can be a viable option to increase milk-solid yield (Table 2.7). However, growing turnips will not be economic if the feed supply from pasture remains high, i.e. pasture growth in summer is not moisture limited. As a result, the comparative cost of using nitrogen fertiliser to increase pasture growth during the time when the turnip crop would be grown, the magnitude of the pasture shortage and the costs of turnip establishment and feeding will determine the profitability of this crop (Clark *et al.*, 1997; Clark *et al.*, 1996; Harris *et al.*, 1998; Shaw *et al.*, 1997).

Comparisons have been made between turnips and other supplement feeds. Two years of experiments with sorghum and turnips showed that turnip cv. Barkant fed at a rate of 4 kg DM/cow/day increased milk solid production by 25 and 29% compared with a pasture diet only (Clark *et al.*, 1997; Harris *et al.*, 1998). However, sorghum at the same intake (4 kg DM/cow/day) increased milk solids by only 15 and 22%. Similar increases in milk solid production of 46% were found when combinations of barley and turnip were fed to cows (Moate *et al.*, 1998). However, milk solid production did not increase further when the turnip feeding rate was increased from 4 to 5 and 8 kg DM/cow/day (Clark *et al.*, 1997; Clark *et al.*, 1996; Harris *et al.*, 1998). Moate *et al*, (1998) also found that when cows were fed with 6 kg of turnips/day; milksolid production was the same as it had been when 4 kg DM had been fed. Therefore, cows could have achieved their maximum intake at one grazing. In addition, the intake of turnips might be limited due to their bulkiness and high water content. In Australia, the maximum turnip intake was 0.98% of liveweight (*Moate et al.*, 1996) and in New Zealand 0.88% of liveweight (Moate *et al.*, 1996), or about 4 kg DM for a Jersey cow or 5 kg DM for a Holstein Friesian at New Zealand (Holmes, pers. comm).

2.12 Effect of turnips on milk characteristics

Changing cows' diets, by increasing the intake of turnips, can change milk composition and therefore influence the value of the milk. Turnip ingestion can potentially modify the physical characteristics and nutritive value of the final dairy products. Thomson *et al.* (2000) reported that crude protein was not altered by turnip intake; however the casein/whey ratio (this ratio indicates the suitability of milk for cheese making) increased when cows were fed at increasing levels of turnip intake (0, 4, 8 kg DM/cow/d). Milk with a greater casein/whey ratio may produce a cheese with a firmer curd and a lower moisture content (Lucey, 1996 cited by Thomson *et al*, 2000).

The concentration of fat in milk decreased by only 2-5% in summer and by 6-9% in autumn when cows were fed turnips at 4 and 8 kg DM/cow/d respectively. Protein increased slightly by 0.5 to 3%, when levels of turnip feeding increased at 8 kg DM/cow/day (Clark *et al.*, 1997; Harris *et al.*, 1998). In a two-year experiment at DRC in 1996-1997, the supplementary feeding of 4 and 8 kg DM turnip/cow/day did not affect the milk characteristics and solid fat content (Harris *et al.*, 1998). While, on feeding turnips, milk fat content decreased from 5.5 to 5%, the short, medium and long-chain fatty acids increased and unsaturated acids decreased. This feature would result in butter that was less soft and spreadable when it was made from milk sourced from cows that had been fed turnips at 8 kg DM/cow/d (Thomson *et al.*, 2000).

2.13 Economic analysis of its use

As turnips are becoming an important supplementary feed, either as part of a re-grassing programme or as a high energy feed supplement when grass growth slows (either in the dry summer in the North Island or the cold winter weather in the South Island), farm systems modelling approaches have been used to determine if this forage crop is suitable for dairy systems. Using data from the national survey and the UDDER model, Clark (1995) predicted the financial break-even yields for the feeding of turnips. Turnip crops would be profitable if they yield approximately 10 t DM ha^{-1} in a season of average rainfall and 8 t DM ha^{-1} in dry year (Clark, 1995).

Some experiments have shown that turnips are unprofitable (Exton *et al.*, 1996); others have demonstrated positive responses in milk solids production only if pasture production is low. Therefore, the UDDER software was used to determine if the model could predict the same response as the original information. As a result, UDDER used specific information from the More Summer Milk program, Taranaki Agricultural Research Station and Dairy Research Corporation (TAR & DCR) trials and the break-even yields of turnip by UDDER. The combination of this information showed that the farm situation prior to feeding turnip was higher than occurred on-farm, thus, turnip utilization in the model was overestimated (Thomson *et al.*,1997). Therefore, Thomson *et al.* (1997) stated that farm system trials are required to determine accurately the impact of forage crops in dairy production systems.

Most of the analysis that suggests that growing turnips may be financially marginal or negative has been on a dry matter basis, of supplementing quantities of feed grazed for pasture i.e. kg DM ha^{-1}. However, as turnips is a high quality feed, Daniels (1995) stated that the financial analysis of turnip growing should be conducted on the basis of metabolic energy. In 1995, the cost of a crop of turnips yielding 5 t DM ha^{-1} and 13 MJME/kg DM was around 10 cent/kg DM. This compared favourably with the cost of pasture silage (9 to 13 cent/kg DM) when adjustments were made for differences in MJME/kg DM between these two feed sources.

Simulations with UDDER were used to measure the economics of a summer turnip crop using a model 100 ha farm in North Waikato ("Barkant™ best practice," 2005). Different scenarios were created using climatic data for dry (1999-2000) and wet (2003-2004) years. The cropping area ranged from 5 to 10% of the farm and turnip yield ranged from 5 to 15 t DM ha^{-1}. The model predicted that in a wet and dry summer, a crop of turnips with a yield of 12 t DM ha^{-1} returns \$2.00 and \$3.50 for each \$ 1 invested, respectively. This simulation exercise suggests that providing an adequate yield can be achieved, turnips can be profitable in any summer weather conditions. In this analysis, the economic break-even yields for turnip crops in a dry and wet summers was 7 t DM ha^{-1} and 8 t DM ha^{-1}, respectively. These relatively low threshold yields suggest that the decision to plant turnips holds little risk for a farmer ("Barkant™ best practice," 2005).

A Waikato farmer reports that turnips cost him 7 cents/kg DM and that the milk-solid response was 80 g MS/kg DM ("Country-Wide Northern," 2003). At \$3.60 milk payout and with 85% of crop utilised, this farmer had a net income of \$3318/ha. These figures did not include the financial benefits associated with pasture renewal. The cost of establishing the crop was $1290/ha ("Country-Wide Northern," 2003).

2.14 Approaches to use turnips with FDE application

2.14.1 Chemical characteristics

The potential of turnip crops to remove nutrients which have accumulated to excessive levels on land irrigated with FDE can only be assessed on the basis of data for crop yield, element concentration in plant material and hence nutrient uptake.

Table 2.7 Crude Protein (%) and metabolizable energy (MJME/kg DM) from New Zealand studies of turnips for dairy cows.

Cultivar	g MS/kg DM	CP (%)	MJME/kg DM	Author
Barkant	36- 39	Leaf:14.3 Bulb:13.3	Leaf & bulb: 12.2	Clark et al., 1996
Barkant	Not profitable			Exton et al., 1996
Barkant		Leaf:8.9 – 21.4 Bulb:5.7 – 17.5	Leaf: 13.0–13.9 Bulb: 13.2–13.9	Daniels., 1995
Barkant	Summer: 42.5 Autumn: 50.0	12 (whole plant)		Clark et al., 1997
Barkant:	72	10.8-10.9(whole plant)	13.6-14.3	Shaw et al., 1997
Barkant	Summer: 58.0 Autumn: 45.0	10.6 (whole plant)	12	Harris et al., 1998
Barkant				Wrightson Seeds 2005

So far, in New Zealand little information has been published on the nutrient concentration in the turnip plant in relation to soil fertility management. A few studies have measured the crude protein content and metabolizable energy in the whole plant and its components (Table 2.7), but not the mineral elemental composition. Some studies determined the effect of increased fertiliser N (0,25,50,100 and 200 kg N ha^{-1})

on turnip yield and the N concentrations in the leaves (2.02 – 3.55%), bulbs (1.24 - 2.22%) and whole plant (1.95 – 3.1%) (Daniels, 1995; Pearson & Thomson, 1996). The National survey and Manawatu survey provided information about the rate and type of fertiliser applied to turnip crops in 1995 but there was no data on paddock histories, soil type and soil fertility.

Australian research has demonstrated that turnips have a wide range of elemental compositions as well as dry matter yields due to soil fertility status and type and rate of fertiliser (Table 2.8). Concentration of crude protein and metabolizable energy were similar to values quoted in New Zealand studies; however, these values differ from those given by Holmes *et al.*, (2002). Holmes *et al.* (2002) reported a general chemical composition table of the most common feed in New Zealand. For example, values in crude protein (Table 2.8) ranged from 7 to 15% for bulbs and from 12.6 to 20.4% for leaves, and the whole plant from 9.4 – 14.3%. The largest values reflected the level of nitrogen fertiliser added and/or soil fertility.

Despite the wide range of crude protein concentrations, some of the Australian studies suggested that a turnips-only diet would be deficient in protein (Eckard *et al.*, 2001; Moate *et al.*, 1999), Therefore, additional high protein supplements (pasture, lupins or cotton seed) (Moate *et al.*, 1999) or addition of N fertiliser to the soil to increase the N in the leaf and bulbs was needed for an the animal diet with adequate protein levels. The addition of 10 kg N increased CP in leaf and root by 0.35 and 0.4%, respectively (Jacobs *et al.*, 2001).

The chemical composition of the turnip crops in Table 2.8 is compared with the chemical composition of feed for dairy cattle cited in Holmes *et al.* (2002). Overall, the metabolizable energy concentration is relatively constant ranging between 12.1 – 14.6 MJME/kg DM, P and Ca concentrations in bulbs had 30 and 50% less than the nutrient composition which was used as reference (Holmes *et al.*, 2002). K concentration was low in the 1994 – 1996 studies by Moate *et al.*, (1999), but in 2000 – 2002 K increased almost three times due to the effects of FDE studies of Jacobs *et al*, (2003, 2004) effects and K fertiliser application.

Table 2.8 Chemical characteristics of turnips grown in Australia

Year	t DM/ha and turnip variety	Plant part	CP	MJME/kg DM	P %	K %	Ca %	Mg %	Na %	Author
1994	6.0 Vollenda	Leaf Bulb	19.1 13.1	-	0.15 0.17	1.67 1.12	1.90 0.33	0.40 0.13	0.18 0.20	Moate et al., 1998
1994 1996	10.0 Barkant	Leaf Bulb	12.7 7.3	-	0.38 0.27	1.60 2.00	2.70 0.50	0.2 0.1	0.30 1.10	Moate et al., 1999
1995/96 1996/97	0.7 – 7.0 Barkant	Leaf Bulb	12.4 7.0	12.5 13.4	-	-	-	-	-	Eckard, 2001
1999/00	0.5-19.2 (5)	Leaf Bulb	15.4 13.9	13.5 14.6	-	-	-	-	-	Jacobs et al., 2001
1999/00 2000/01	Barkant	Whole plant	9.4-13.8	13.2-14.2	-	-	-	-	-	Jacobs et al., 2002
2000	9.8 Barabas	Leaf Bulb	20.4 14.0	12.1 14.0	0.26 0.30	6.18 3.84	2.38 0.40	0.71 0.16	1.18 1.14	Jacobs et al., 2003*
2000/01 2001/02	0.6 – 1.1 4.9- 9.2 Vollenda	Leaf Bulb	12.6-20.0 7.5 -15.7	12.1–13.7 13.6-14.1	0.23 0.30	3.5 3.3	2.5 0.8	0.68 0.23	1.20 1.30	Jacobs et al., 2004

*Research which evaluated the FDE effect in turnip yield.; the mean of the yield is given in brackets.

2.14.2 Response to irrigation

Farmers in the dry region of South–eastern Australia have been forced to look for alternatives to pasture for a supply of good feed for their cows in summer (Moate *et al.*, 1998 & 1999; Eckard *et al.*, 2001; Jacobs *et al.*, 2001). Turnips have become an option to alleviate feed scarcity in summer.

Turnips have been shown to utilize water efficiently. Yield increases ranging from 4.8 to 31.3 kg DM ha^{-1} mm^{-1} were achieved using irrigation water (Eckard et al., 2001; Jacobs et al., 2002). However, good practices, such as sowing at the correct time and using a good cultivation method, increase the water use efficiency (WUE) by turnips. Therefore, Jacobs *et al.* (2002) stated that soil moisture deficit would be overcome efficiently when water was irrigated to a soil which had a good cultivation method and during minimal rainfall. This avoided lower yield of turnips.

2.14.3 Responses to effluent

The first study of the application of FDE to turnips determined that increased rates of irrigated FDE (0, 16, 23, 33 mm ha^{-1}) increased turnip yield and the concentration of crude protein, potassium, calcium and sodium in leaves and bulbs (Jacobs *et al.*, 2003). A comparison between the nutrient concentration of turnips that received 16 mm ha^{-1} of FDE (Jacobs et al., 2003, Table 2.8) and the rest of the nutrient information in Table 2.7 shows that while the turnip yield under FDE irrigation was not increased, these plants took up larger amounts of nutrients, especially of K, Ca, Na. Crude protein concentration was also increased by the FDE application (Jacobs *et al.*, 2003). Therefore, FDE irrigation may help increase the crude protein concentration of turnips to levels more suited to lactating cows and turnip crops continues being a good option to remove high amounts of K from soils with high nutrient concentrations.

2.15 Summary

During the past decade, intensification on many of New Zealand's dairy farms has been profitable. This intensification has often been achieved through increased inputs of supplements and fertiliser. As a result of intensification, the quantity of FDE that is generated has increased. This has loaded those areas of the farm that receive FDE with large quantities of nutrients. In particular, there is a risk of K enrichment of soils that are irrigated with FDE.

Typically, farmers apply FDE to only a small proportion of their farm. Consequently, this area must cope with excessive quantities of FDE. Two alternatives have been proposed to address this problem. Firstly, farmers could more accurately assess the area required for land application of FDE. Most commonly, this will involve expanding the size of the FDE area. It is advisable to have FDE blocks that have an equivalent area of upwards of 8 ha per 100 cows rather than 4 ha per 100 cows, the benchmark value used in the past. However, an increased area requires extra expenditure and investment in the irrigation system; thus farmers have to be careful about the investment. The second possible solution involves using crops to remove nutrients from the effluent area (Hedley et al., 2005), leaving a soil nutrient status that is more closely matched with the nutrient requirements of pasture. This option would avoid the need for farmers to invest further in their irrigation system.

The agronomic information for turnips, particularly their large K requirement, suggests that their role as a crop to remove nutrients that accumulate in FDE areas warrants further exploration. In other words, turnip crops could be a cost effective alternative to reduce nutrient accumulation in soils that are irrigated with FDE.

So far, New Zealand studies have determined the effects of turnips on dairy production (lactation responses, the opportunity costs, energy, protein and mineral status of lactating cows), and their value as a fodder crop. Some Australian studies have measured the nutrient status of the turnip crops.

Studies conducted during the period 1995 to 2002, measured a range of responses (i.e. negative, zero and small) in animal production (milk solids, live weight and body condition) to turnips. However, many farmers find turnips useful as they have a short growing time, are easy establishment, provide a high quality feed for grazing cows and help relieve stress in the summer period. As farmers have become more experienced with the growing of turnips, crop yields have increased so that the mean production of a turnip crop is now approximately 7 ton DM ha^{-1}. This yield is the minimum value that turnips have to yield in order to produce a profitable crop in a dry/drought summer.

Turnips require good grazing management to minimize wastage. Turnips should be gradually introduced to the cow's diet and they should not comprise more than 1/3 of the daily ration to avoid animal health problems and changes to characteristics of some dairy products.

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Chapter 3

3.1 A survey of seven turnip crops growing in the Palmerston North area.

3.2 Introduction

Turnips have become an important supplementary feed on dairy farms. Their rapid, short summer growing season makes them an ideal crop to provide the high energy dry matter needed to supplement slow grass growth in the drier summers of the North Island. Turnip crops also play a key role in re-grassing programmes. The dairy farm systems model UDDER indicates that the break-even point for profitable summer feeding of turnips in the lower North Island is 7 ton DM ha^{-1} in a dry year and 8 ton DM/ha in a wet year.

In the introduction to this thesis (Chapter 1), turnips were identified as a forage crop capable of producing high DM yields that contain high concentrations of potassium K relative to mixed ryegrass/clover pasture. If these attributes are consistent and extend to turnip crops grown in the lower North Island, turnips would be an ideal crop for re-grassing farm dairy effluent (FDE) paddocks with K rich soils. Strategic grazing of turnips growing on FDE paddocks in summer months has the potential to transfer K away from such K rich soil to other parts of the farm thereby reducing the risk of K induced milk fever when cows graze FDE paddocks in early spring.

In New Zealand there is little published information on the effects of soil management on the nutrient concentration and yield of turnips. Australian studies, however, showed that K concentration in the whole plant comprises between 1.4 to 5.0 %, thus the expected removal would be between 84 and 490 kg K ha^{-1} (Moate et al., 1999; Jacobs et al., 2003). To assess the potential to use turnips as a crop to produce a profitable supplementary feed and remove excessive nutrients, seven turnips crops growing near Palmerston North were surveyed.

The research hypothesis is that crops of turnips grown in the Manawatu district produce economic yields and have high whole-crop K concentrations that, upon grazing, facilitate the recycling of K from FDE paddocks to the rest of the farm.

3.3 Objectives

- To survey yields of seven mature crops of summer turnip grown near Palmerston North and compare these values with the economic break-even point for turnip crops.
- To measure the nutrient composition of seven mature turnip crops grown near Palmerston North.
- To explore the relationships between soil nutrient status and nutrient concentrations in turnips.

3.4 Methods

3.4.1 Location and Soil Description

In summer 2006, seven turnips crops were selected for sampling on farms near Palmerston North in the Manawatu district. Two crop paddocks were sampled on Massey University's No 4 Dairy Farm. The locations of the farms are given in Table 3.1 using references from the New Zealand Map Series.

Table 3.1 Location of the survey farms.

		New Zealand Map Series			
Farms	**Soil Type**	**Series (1:50000)**	**Sheet**	**East**	**North**
Underwood	Tokomaru	260	24	2729400	6085600
Lynch	Tokomaru	260	24	2728900	6083600
Perry	Tokomaru	260	T 24	2732600	6085600
Massey No. 4 Pd 32	Tokomaru	260	T 24	2732100	6087700
Massey No. 4 Pd 73	Tokomaru				
Jackson	Manawatu	260	T 24	2743500	6096600
Blyth	Ohakea	260	T 24	2743500	6096600

3.4.2 Soil types

Most of the crops had been planted on the Tokomaru silt loam (Underwood, Lynch, Perry and No 4 dairy farm), but the crops on the Jackson and Blyth farms were on Manawatu and Ohakea silt loams, respectively.

Tokomaru and Ohakea silt loam are Pallic soils which have poor natural drainage, thus, artificial mole and pipe drainage systems are necessary. The former soil is from deep deposits of loess (derived from greywacke alluvium) that accumulated on the deeply-dissected and uplifted marine terrace (Molloy, 1998). The latter is a younger Pallic soil and the parent material is either loess blown from the rivers, or fine textured colluvium washed from higher terraces or hills. Both soils have profiles containing clay that is weakly to moderately developed and a fragipan in the subsoil. Unless these soil are artificially drained, the water table perches on the fragipan for much of the winter and spring periods (Scotter *et al.*, 1979; Cowie, 1978).

In contrast to the two previous soils, Manawatu silt loam is a well drained soil formed from fairly fine textured alluvium. In the first 23 cm of the profile there is a friable brown silt loam with moderately developed nut structure (Cowie, 1978).

3.4.3 Field sampling and laboratory procedure

Seven turnip crops in the Palmerston North area were sampled between 14th February and 6th March 2006. In consultation with the farmers, a turnip paddock was identified for sampling: most commonly this was the next area to be grazed. Within each paddock, sampling sites were selected on the basis of uniform turnip growth i.e. where they occurred; areas of patchy or inconsistent growth were avoided. There were three sampling sites (approximately 10 m x 10 m in area) in each paddock. At each sampling site, a quadrat was thrown randomly across the site. All of the turnips within the quadrat were pulled out by hand and placed in a bag i.e. both the bulbs and leaves. This process was repeated in each paddock so that there were three quadrats harvested for each paddock. Turnip samples from each quadrat were kept separate. From within the quadrat area where turnips were harvested, five soil samples were taken to 150 mm depth and stored in plastic bags for further analysis.

In the laboratory, sub-samples of the turnips from each quadrat were taken to measure the gravimetric water content (weighed wet and then oven-dried at 70°C overnight, and reweighed). The soil was dried at air temperature for four days and then passed through a 2 mm screen mill.

The harvested turnip material from each quadrat was separated into bulbs (which were washed to avoid soil contamination) and leaves. The fresh weights of both parts of the plant were recorded. From these plants, a sub-sample of 5 or 6 plants per each quadrat was taken to dry at 70°C at constant weight. This was used to determine % of dry matter and then ground through a 1 mm screen and stored for subsequent chemical analyses to determine nutrient characteristics. Total turnip dry weight (TDM) was found by summing the leaves and shoots dry weights. Final results were expressed as tonne of DM per hectare.

3.4.5 Soil and Plant Analysis

3.4.5.1 Soil analysis

Olsen P was determined in 1 g of air-dried sieved soil into a 50 ml polypropylene centrifuge tube, and then 20 ml of 0.5 M NaHCO3 solution was added. The solution and soil samples were shaken for 30 minutes, in an end-over-end shaker; afterwards they were centrifuged at 9000 rpm for one minute, and filtrated through Whatman No 41 filter papers. Inorganic P was then determined by the phosphomolybdate method of Murphy and Riley. (1962).

Soil Exchangeable cations were determined by leaching 1 g of soil (dried and sieved) with successive volumes of 1 M NH4OOCCH3- (Blakemore *et al.* 1987). Afterwards, all the leachate solution was made up to volume in a 50 ml volumetric flask. The cation concentrations were measured by atomic absorption spectroscopy.

Soil mineral N (ammonium-N and nitrate-N) was extracted from 3 g of soil which were shaken with 30 ml of 2M KCl for 1 hour to extract NH_4^+ and NO_3^- (Adamsen *et al.* 1985) and then sieved using Whatman No 42 filter papers, afterwards the solution was analyzed on a Technicon Auto Analyser II.

Soil pH: ten g of dried and sieved soil were mixed and stirred with 25 ml of distilled water. The solution was left overnight and then the suspension was measured using a Radiometer standard pH meter.

Total soil N and P: Following a Kjeldahl acid digest soil total N and P were carried out colorimetrically on a Technicon Auto Analyser II using the method of McKenzie & Wallace (1954).

3.4.5.2 Plant analysis

Total N and P and cations (K, Ca, Mg and Na) were determined for each component of the plant (bulbs and leaves).

Following a Kjeldahl acid digest, total soil and herbage N and P analyses were determined out colorimetrically on a Technicon Auto Analyser II using the method of McKenzie & Wallace (1954).

Following a Nitric acid digest and then dissolving the samples with 2 M HCl, cations (K, Ca, Mg and Na) were determined on an atomic absorption spectroscopy.

3.5 Results and discussion

Variation in turnip yield between the survey paddocks will be discussed first including a consideration of how differences in paddock management might have affected crop yields. After that, the K concentration in bulb and leaves and K removal rates are discussed. The potential of grazed turnips to facilitate the recycling of K from FDE paddocks to other parts of the farm will be considered.

3.5.1 Turnip yields

The variation in total turnip production between the surveyed paddocks (Table 3.2) was large (range from 7.98 to 17.21 tonnes DM ha^{-1}). Although the number of paddocks sampled were insufficient to allow a rigorous comparison between yields of the two cultivars (particularly of green globe as a monoculture), there was no obvious relationship between total yield and cultivar (Table 3.2). For example, the total yields of Barkant turnips in paddocks at No 4 Dairy (8 and 9 tonnes DM ha^{-1} respectively) were very similar to the total yield measured at the Jackson's farm (8.91 tonnes DM ha^{-1}) where the cultivar was Green Globe. A mixture of both cultivars yielded 9.8 and 12.7 tonnes DM ha^{-1} at the Perry and Blyth farms, respectively. On the other hand, the paddocks on the Underwood and Lynch farms, which had only Barkant had the highest total yields (upwards of 14 tonnes DM ha^{-1}). This variation in yields supports previous observations that factors other than cultivar will have the major influence on turnip growth in the lower North Island (See later discussion) (Daniels, 1995).

Likewise, the yields of bulbs and leaves for the survey paddocks were variable and did not show any clear relationship with cultivar. It would appear that a greater proportion of the total yield of the Green Globe cultivar is made up of bulb material than is the case for Barkant.

All of the total yields were greater than 7.5 tonnes DM ha^{-1}, the economic 'break-even' yield as determined by the UDDER model for a dry season such as 2005-2006 (Clark 1995). Three of the total yields exceeded 12 tonnes DM ha^{-1} which according to the "Barkant^{TM} best practice" (2005) returns \$3.50 for \$1 invested in dry summers respectively.

Table 3.2 Leaf, bulb and total dry matter production of Turnip crops surveyed in the Palmerston North area in March 2006

		Tonnes DM ha^{-1}		Range of total yields (t DM ha^{-1})
Farmers	Cultivar	Leaves	bulb	total
Underwood	Barkant	9.03	8.18	17.21
Lynch	Barkant	7.75	6.50	14.25
Perry	Barkant/Green Globe	4.81	7.87	12.68
No 4 Dairy Paddock 32	Barkant	5.05	2.94	7.98
No 4 Dairy Paddock 73	Barkant	5.60	3.44	9.05
Jackson	Green Globe	3.30	5.61	8.91
Blyth	Barkant/Green Globe	4.28	5.47	9.75

However, in some studies the financial analysis of turnips has been marginal or negative; Daniels (1995) stated that the costs should be analyzed on the basis of metabolizable energy. Thus, for a crop of 5 t DM ha^{-1} and 13 MJME/kg DM, in 1995 the cost was around 10 cent/kg DM which is similar to the cost of pasture silage at values of 9 to 13 cent/kg DM (adjusted for differences in MJME/kg DM). Therefore, farmers have to take into account the turnip quality compared with a poor summer pasture.

All the dry matter yields obtained in the Manawatu district's farms exceeded the economic break-points predicted by the UDDER model and the criteria suggested by (Daniels 1995).

3.5.2 Factors influencing yield

3.5.2.1 Soil nutrient status

Total turnip yield did not correlate with soil nutrient concentration in any of the survey paddocks. The soil nutrient values for each paddock are given in Table 3.3 and the optimum ranges for turnip growth are given in Table 3.4. Overall, the values for pH, Ca, Mg and Na in most paddocks were in the normal range. However, some paddocks had low values for exchangeable K and Olsen P. For instance, the paddocks on the Jackson, Blyth and Underwood farm had the lowest Olsen P (19.2, 21.5 and 20.2 ug g^{-1} soil, respectively), paddocks on the Lynch, Underwood, and No 4 Dairy farms had less than 0.4 meq K 100 g^{-1} soil (Table 3.4). Interestingly, the one paddock that had lower values for both Olsen P and K, the Underwood's, had the greatest total turnips yield. That less than optimum nutrient status in some paddocks did not constrain turnip yield can probably be attributed to the lower fertility requirement of turnips compared to other brassica crops (Kay and Hill, 1998).

Table 3.3 Soil pH, Olsen P, exchangeable cations and extractable nitrogen values for Turnip crops surveyed in the Palmerston North area in March, 2006.

Farmers	pH	K^+	Ca^{2+}	Mg^{2+}	Na^+	Olsen P	NO^-_3	NH^+_4
			(meq 100 g^{-1} soil)				(µg .g^{-1} soil)	
Underwood	6.4	0.4	8.1	1.3	0.1	20.2	1.3	4.5
Lynch	6.0	0.3	6.9	1.3	0.2	26.9	0.8	4.6
Perry	6.3	0.5	6.9	1.5	0.1	33.7	1.4	6.1
No 4 Dairy Paddock 32	5.9	0.3	6.4	1.3	0.1	34.0	2.0	5.1
No 4 Dairy Paddock 73	6.2	0.4	6.5	1.5	0.1	34.3	5.6	7.9
Jackson	5.9	0.5	6.2	1.4	0.1	19.2	2.2	5.2
Blyth	6.1	0.5	13.3	2.4	0.2	21.5	3.3	6.1

Table 3.4 Normal ranges of soil pH, Olsen P, exchangeable cations and CEC values recommended for optimum Turnip crop growth (source: Hill Laboratories)

	Unit	Normal Range
pH	-	5.4 -6.7
Olsen P	ug. g-1	30-80
K^+	meq 100 g^{-1} soil	0.5-1.0
Ca^{2+}	meq 100 g^{-1} soil	6.0-12.0
Mg^{2+}	meq 100 g^{-1} soil	1.0-3.0
Na^+	meq 100 g^{-1} soil	0.0-0.5
CEC	meq 100 g^{-1} soil	12.0-25.0

3.5.3 Climatic Conditions

3.5.3.1 Temperature and solar radiation

From November 2005 to March 2006, 306 mm rainfall fell in the Manawatu District, which was only 58% of the potential evapotranspiration for this period. Overall, the monthly average for rainfall, ET, solar radiation and Growing Degree Days (GDD) increased from November to December, and between January and March the magnitude of these climatic parameters decreased (Table 3.5). For instance, the amount of solar radiation and the number of GDD decreased by 65% and 17% from January to March, respectively. This reduction in solar radiation is likely to decrease the rate of turnip growth. Adams et al. (2006) stated that crop production is proportional to the total amount of radiation that is intercepted. However, the amount of heat and the cumulative GDD in the Manawatu region during the 2005-2006 season fulfilled the requirements for turnips, and this season had more GDD than the 32 year average (Table 3.5).

GDD is a good indicator to predict the effect of sowing time on when brassica reach maturity or maximum developmental stage (Adams *et al.*, 2006). For the calculation of GDD in Table 3.5, a threshold temperature of 4°C was used (White *et al.*, 1999).

In the surveyed turnip crops there was no effect of sowing time because from planting to harvesting dates there were small differences among farms (Table 3.6). All surveyed crops achieved GDD greater than 1400 except the crop grown in paddock 32 of The No. 4 Dairy Farm.

Table 3.5 Summary of monthly climatic data obtained from Palmerston North weather station, November, 2005 – March, 2006.

			Average air temperature °C			
Months (2005-06)	Rainfall (mm)	Potential ET (mm)	Maximum	Minimum	Solar Radiation (MJ/m^2)	GDD (°Cd)
Nov	53	102	18	10	326	299 (309)
Dec	119	114	23	14	335	442 (377)
Jan	54	131	23	13	384	440 (414)
Feb	40	106	24	14	309	408 (383)
Mar	40	76	21	11	233	365 (382)
Total	306	529	22	12	1587	1954

Rainfall, potential ET, Solar radiation and GDD (growing degree days) are monthly totals while air temperatures are the averages for the months. The number in bracket is the average month of 32 years.

Table 3.6 Total climatic data for farm obtained from Palmerston North weather station, Nov, 2005 – March, 2006.

Farmers	Rainfall (mm/period*)	Potential ET (mm/period)	Total Solar Radiation (MJ/m^2)/period	Total GDD[1] °Cd	DAS[2]
Underwood	263	477	1283	1500	109
Lynch	265	447	1340	1577	116
Perry	266	454	1369	1591	119
No 4 Dairy Paddock 32	263	391	1175	1359	100
No 4 Dairy Paddock 73	266	443	1333	1543	111
Jackson	269	462	1388	1627	122
Blyth	269	464	1396	1635	122

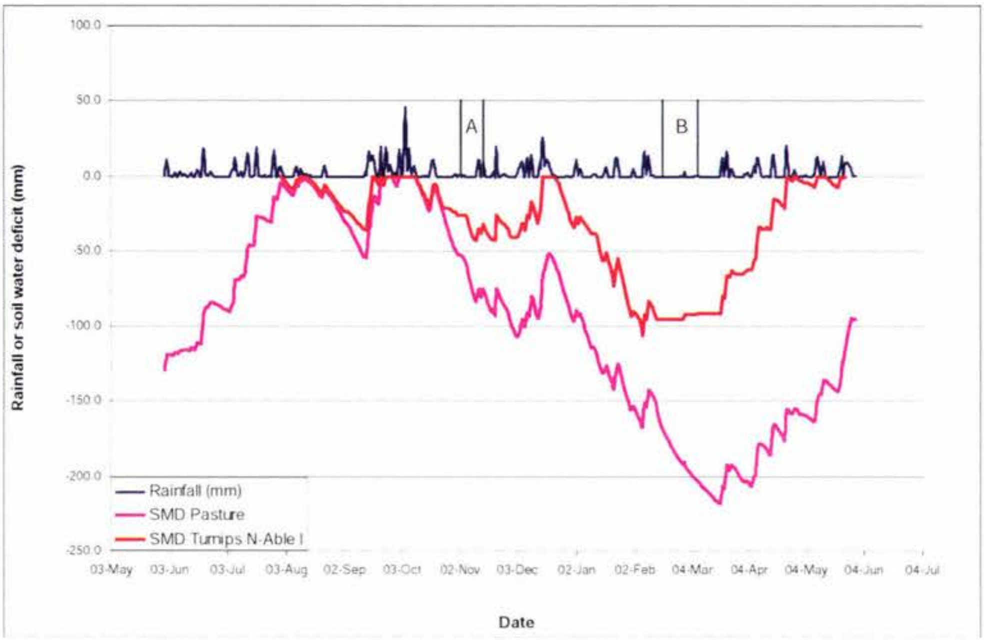
[1] GDD: Growing degree days; [2] DAS: days after sowing

* Period (it is the time that turnips had in the different farms from the sowing and the harvesting dates)

Therefore, under the same weather conditions, the different yield at each farm (Table 3.2) did not have any relationship with predicted water availability, evapotranspiration or growing degree days. In general, the overall climatic conditions were highly suited to turnips growth. Some studies (Collie et al., 1998; Adams et al., 2006) have demonstrated that sowing dates affect the total turnip yield and canopy closure, thus the effect of temperature and solar radiation influences the yield.

3.5.3.2 Plant available water

The N-able model was used to investigate the effects of soil moisture deficit on turnip yields in the survey paddocks. N-able predicts the soil water balance from inputs of daily rainfall, evaporation and estimates of soil moisture content at field capacity and wilting point. The model suggests that in the first week of February, the soil moisture deficit increased above 75 mm and so water stress began to develop (Moir *et al.*, 2000) (Figure 1). Following this date, evapotranspiration would have become limited. As a result, water limitation would play some role in yield variation. Nevertheless, although all of the turnip crops suffered from water limitation, there was no relationship between the size of the soil water deficit and turnip yields in the survey paddocks.



A: period of sowing date of all turnip crops; B: period of harvesting date of all turnip crops

Figure 3.1 Rainfall and soil water deficit obtained using N-Able and data from the Palmerston North weather station. Nov, 2005 – March, 2006.

In other words, planting date had no effect on yield. In part, this is due to the similarity in sowing dates for the survey crops i.e. all of these crops were sown during the first 10 days of November 2005. In a study of turnip crops with a mean sowing date of 10 November, Clark (1995) found no relationship between sowing date and yield. Crops sown in late October and early November (Clark, 1995; "Barkant^{TM} best practice," 2005) are likely to be able to utilize late spring rains efficiently. Good rainfall during the critical period of the first 30 days of growth is likely to result in rapid turnip growth and maturity by January.

Overall, the survey turnip crops grown near Palmerston North had small time differences in sowing dates and, therefore, there were no differences in climate (GDD, soil moisture deficit, rainfall and temperature) experienced by the crops. Consequently, climate factors could not be invoked to explain the large variation in yields between the survey crops.

3.5.4 Crop management

The effects of crop establishment practices and fertiliser management on the yields of the survey crops were also considered. Each of the six farmers managed their turnip crops differently (Table 3.7 & Table 3.8). Seed density varied from 3.5 kg ha^{-1} in Underwood's paddock to 1.0 kg ha^{-1} in the paddocks on the Jackson and Blyth farms. All sowing rates in the survey paddocks were in or close to the recommended range (1 – 3 kg ha^{-1}). Farmers commonly vary sowing rate according to; soil fertility, paddock preparation and sowing techniques, and if turnips are sown with other species (Ayres et al., 2002).

Plant density in the survey paddocks were between 34 to 95 plants m^{-2} for Barkant and between 31 to 56 plants m^{-2} for Green Globe and the mixture of Green Globe and Barkant respectively. These densities are comparable with the density of 55 plants m^{-2} measured in a Green Globe crop by Adams *et al.*, (2006). The variability in plant density (Table 3.7) between paddocks may have been due to the different ground preparation regimes and seed cultivation methods (Table 3.8).

A survey in 1995 demonstrated that sowing method (broadcast and drilling) and cultivation method (tillage) were not significantly associated with turnip yield (Clark, 1995). Clark (1995) measured a turnip yield of 10 tonnes DM ha^{-1} following establishment using a plough, power harrow and roller drill. Some Australian studies (Jacobs *et al.*, 2001; Jacobs *et al.*, 2002) determined that cultivation techniques had little effect on yields due to fact that they had little impact on soil moisture at sowing. However, the biggest consequence of cultivation method was in reducing weeds; thus, the cultivation practice helps to eliminate weed seeds, as a result they will not compete with turnips seedlings for water, nutrients and light.

The practice of using a mixture of turnip cultivars (the most common combination is Barkant & Green Globe) is due to the difference in the maturity rates of these cultivars. Barkant is an early maturing summer crop (60 - 90 days) with a high proportion of leaf material. On the other hand, the later maturing, frost tolerant Green Globe is good as a late-summer/autumn feed. Therefore, these cultivars complement each other, giving farmers greater flexibility in the timing of grazing and ensuring quality feed is available through the summer deficit period and on into autumn (Ayres *et al.*, 2002; "Barkant™ best practice," 2005; Dexcel, 2005).

Sowing dates for the survey crops were in the recommended period for turnips i.e. between late October and mid-November (Clark *et al.*, 1996; Ayres *et al.*, 2002, 2005; "Barkant™ best practice," 2005). The grazing varied in each paddock according to the cultivar, and the herds' feeding requirements. The paddocks of mixed Green Globe and Barkant, and Green Globe alone were grazed at 119 – 122 DAS, which was in the recommended harvesting time. The ideal harvesting time for Barkant is between 60 to 90 days after sowing when the crop has a high proportion of leaf material. In this survey, farmers also harvested this cultivar between 100 – 116 DAS. Mr. Curtis (Manager of No 4 Dairy Farm) stated that despite the fact that the leaves of the Barkant crop in the paddocks at No 4 Dairy were ready for grazing (at 75 DAS), as the bulbs were small, he delayed grazing for 15 or 25 days so as to get bigger bulbs. This suggests farmers are prepared to sacrifice leaf yield for bulb production.

The total rate of fertilization of the survey paddocks varied greatly especially for nitrogen (from 18 to 112 kg N ha^{-1}). However there seemed to be no clear relationship between rates of fertiliser and turnip yield. For example, paddocks 32 and 73 at No 4 Dairy received 88 kg N ha^{-1} (38 kg N ha^{-1} as basal fertiliser and 50 kg N ha^{-1} at 4-5 weeks after sowing), however their yields (8 and 9 tonnes DM ha^{-1} respectively) were no greater than other survey paddocks which received much less N fertiliser.

Table 3.7 Sowing and harvesting dates, varieties, days after sowing, seed and plant density, grazed area and grazing time for Turnip crop surveyed in the Manawatu Region, Nov, 2005 – March, 2006.

Farmers	Sowing	Harvesting	Seed density kg ha^{-1}	Plant density ($plant/m^2$)	DAS	Grazed area each day m^2/cow	**Grazing time (hour)**
Underwood	10/11/05	27/02/06	3.5	45.00	109	4.2	2
Lynch	04/11/05	28/02/06	1.8	95.00	116	4.6	2
Perry	07/11/05	06/03/06	1.8	30.63	119	7.65	4 (morning and night)
No 4 Dairy Paddock 32	06/11/05	14/02/06	2.0	40.00	100	4	3
No 4 Dairy Paddock 73	11/11/05	02/03/06	2.0	34.00	111	4	3
Jackson	01/11/05	03/03/06	1.0	52.23	122	5	1.5
Blyth	02/11/05	04/03/06	1.0	56.03	122	4.1	2

Table 3.8 Fertilization, seed cultivation method, and ground preparation for Turnip crop surveyed in the Manawatu Region.

	Nutrient application kg ha^{-1}							
Farmers	N	P	K	S	Ca	Fertiliser applied	Sowing method	Ground preparation
Underwood	24	15	19	12	164	700 kg ha^{-1} lime Quinphos Retain 7MS 10K 225 kg ha^{-1}	roller drill: 3.5 - 4 inches spacing	Plough, rotary hoe, leveller
Lynch	27	30	50	2	-	Cropmaster 11 250 kg ha^{-1}	roller drill: 3.5 - 4 inches spacing	Plough, rolled, rotary hoe, roller drill
Perry	43+69	28	28	22	-	Cropmaster 15 280 kg ha^{-1} urea 150 kg ha^{-1} when the plant were 8 cm	Broadcast	Plough, power harrow, leveller, roll with chain harrow behind roller.
No 4 Dairy Paddock 32	38+50	25	25	19	70	Cropmaster 15 250 kg ha^{-1} urea 108 kg ha^{-1} when the plant were 8 cm	Roller drill: 2.75 cm	Plough, spring tyne, power harrow + crumbler pacler, drill-Cambridge roller+ seed box + roll
No 4 Dairy Paddock 73	38+50	25	25	19	70			
Jackson	18	20		20	16	DAP 18:10:10:8 200 kg ha^{-1}	Broadcast	Plough straight under, spring tyne in front of leveller, Cambridge roller
Blyth	46	-	-	-	-	100 kg ha^{-1} urea at 4 weeks	Broadcast	Plough straight under, spring tyne in front of leveller, Cambridge roller

The total N rate used in the survey paddocks is in the range recommended by Wrightson Seeds ("Barkant™ best practice," 2005). In the pre-sowing and post-emergence periods, the N rate should be 30-40 kg ha^{-1} and 40-70 kg ha^{-1}, respectively. In a national survey, Clark (1995) found that farmers used N between 0-145 kg N ha^{-1}.

Eerens and Lane. (2004) during two seasons (2002-2004) in Taranaki and northern King Country found that the right time of herbicide and insecticide application had great impact on turnip yield, rather than the other determining factors (fertiliser type and rates, soil fertility) due to changes in management by farmer's experience. However, more than 60% of farmers who followed the best management practice turnip production protocol achieved high turnip yield (> 12 t DM ha-1) (Eerens and Lane, 2004).

Despite the large variation in dry matter production in the Manawatu survey, which was unexplainable, the yields were economic. As a result, further work is required to understand fully why the yields differed so much, but the final conclusion is that even the lowest yield was economic, when compared to the data of Hayward and Scott, (1993).

3.6 Turnip potential to remove K from paddocks

3.6.1 Plant nutrient concentrations

The concentration of K and N is greater in the turnip leaves than in the bulbs (Table 3.9 and 3.10). K and N concentration in the leaves were on average, 39% and 80% greater than those in the bulbs, respectively. On average, Ca, Mg concentrations in the leaves were 3.9 and 2.6 times greater than in the bulbs. However, the concentrations of P and Na were 6% and 22% greater in the bulbs than in the leaves respectively (Table 3.10).

Table 3.9 Soil type and nutrient concentration in leaves of Turnip crop surveyed in the Manawatu Region, Nov, 2005 – March, 2006.

Farms	Underwood	Lynch	Perry	32 Paddock	73 Paddock	Jackson	Blyth
			Leaf Nutrient concentration (%)				
K^+	4.7	3.5	4.2	5.5	4.4	4.6	5.0
Ca^{2+}	2.1	2.0	1.9	2.3	1.8	2.1	2.5
Mg^{2+}	0.4	0.4	0.5	0.5	0.5	0.4	0.4
Na^+	0.1	0.3	0.3	0.4	0.6	0.3	0.1
P	0.4	0.4	0.5	0.6	0.4	0.4	0.4
N	2.4	2.0	3.1	3.0	3.3	2.6	2.6

Table 3.10 Soil type and nutrient concentration in bulbs by Turnip crop surveyed in the Manawatu Region, Nov, 2005 – March, 2006.

Nutrient	Underwood	Lynch	Perry	32 Paddock	73 Paddock	Jackson	Blyth
			Bulb Nutrient concentration (%)				
K^+	3.5	2.3	3.2	3.2	3.4	4.2	3.8
Ca^{2+}	0.5	0.5	0.5	0.5	0.5	0.6	0.7
Mg^{2+}	0.1	0.2	0.2	0.2	0.2	0.1	0.2
Na^+	0.2	0.5	0.5	0.6	0.6	0.2	0.2
P	0.5	0.5	0.5	0.6	0.5	0.5	0.4
N	1.3	1.8	1.4	1.6	2.5	1.3	1.1

The nitrogen concentration in the leaves was significantly correlated (R^2 =74%) with the total mineral N content of the soil (Figure 3.4). When the mineral N content of the soil increased by 1 ug g^{-1}, the N concentration in the leaves increased by 0.129 % on average. Although a similar relationship between soil exchangeable K and plant K concentrations could not be investigated because the range of soil exchangeable K concentrations were so narrow (Table 3.3), the variation in plant K concentrations would tend to suggest that there was not a good relationship between soil and plant K values. The variation in plant nutrient concentration of P and cations showed no correlation across sites for Olsen P and exchangeable cations measured in the soils.

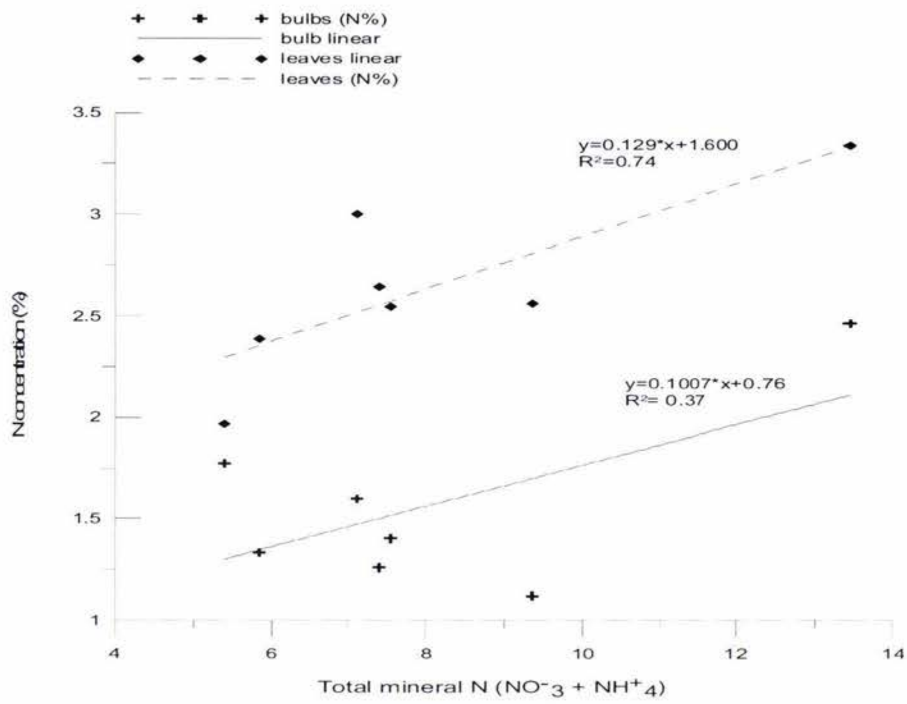


Figure 3.4 Soil total mineral nitrogen at harvest and nitrogen concentrations in turnips leaves and bulbs in the Palmerston North region during the season Nov, 2005 – March, 2006.

3.6.2 Nutrient removal

There was a marked variation in the quantity of nutrients removed in the leaves (Table 3.11), bulbs (Table 3.12) and the whole plant (Table 3.13) form the survey paddocks. This was not unexpected given the large range in turnip yields. K removal in the leaves varied from 152 kg ha^{-1} (Jackson) to 424 kg K ha^{-1} (Underwood). K removal in bulbs ranged from 94 kg K ha^{-1} (No 4 Dairy paddock 32) to 286 kg K ha^{-1} (Underwood). K removal in the whole plant ranged from 361 kg K ha^{-1} (No 4 Dairy paddock 73) to 711 kg K ha^{-1} (Underwood). This survey data illustrates the importance of yield to the removal of accumulated K from the soil.

The nitrogen was the other nutrient with high removal by turnips. The range was no greater than K removal; however, N removal in leaves ranged from 87 to 217 kg N ha^{-1} in Jackson and Underwood farms respectively. N removal in bulbs was noticeable less than leaves; it varied from 47 kg N ha^{-1} (No 4 Dairy paddock 32) to 115 kg N ha^{-1} (Lynch). N removal in the whole plant ranged from 158 to 326 kg N ha^{-1} at Lynch and Underwood farms respectively.

Table 3.11 Nutrient removals by leaves on Turnip crop surveyed in the Manawatu Region, Nov, 2005 – March, 2006.

Farms	Underwood	Lynch	Perry	32 Paddock	73 Paddock	Jackson	Blyth
				(kg ha^{-1})			
K^+	424	270	204	278	245	152	212
Ca^{2+}	185	158	91	116	98	69	107
Mg^{2+}	36	34	24	25	28	13	16
Na^+	12	22	16	18	32	9	6
P	36	31	24	30	24	14	19
N	217	153	150	152	187	87	110

Table 3.12 Nutrient removals by bulbs on Turnip crop surveyed in the Manawatu Region, Nov, 2005 – March, 2006.

Farms	Underwood	Lynch	Perry	32 Paddock	73 Paddock	Jackson	Blyth
Nutrient				(kg ha^{-1})			
K^+	286	148	255	94	116	236	208
Ca^{2+}	41	31	35	15	16	31	40
Mg^{2+}	11	10	12	5	6	8	9
Na^+	17	31	36	18	45	12	10
P	38	30	37	18	16	27	23
N	109	115	110	47	85	71	61

Table 3.13 Total Nutrient removals by the whole plant in Turnip crop surveyed in the Manawatu Region, Nov, 2005 – March, 2006.

Farms	Underwood	Lynch	Perry	32 Paddock	73 Paddock	Jackson	Blyth
Nutrient				($kg\ ha^{-1}$)			
K^+	711	419	459	372	361	387	420
Ca^{2+}	226	189	126	131	114	100	147
Mg^{2+}	48	45	35	30	34	21	26
Na^+	29	53	53	35	77	21	16
P	74	61	61	48	40	42	42
N	326	268	260	199	272	158	171

Of all the survey paddocks, the one on the Underwood's farm had the highest total removal of all nutrients except Na. The other survey paddocks however varied in the amount of nutrient removal due to differences in yield and nutrient concentration in bulbs and leaves (Table 3.13).

The importance of yield to K and N removal in turnips from the survey paddocks can be illustrated by plotting K and N removal as a function of turnip production (Figure 3.5). Figure 3.5 suggests that, on average, for every 1 tonne of turnips produced in the Palmerston North area 30.4 and 14.2 kg ha^{-1} of K and N were taken up by plants, respectively. On the other hand, the amount of Ca, P and Mg removed for 1 ton DM yield was 11.5, 2.44 and 3.5 kg ha^{-1}, respectively (Appendix 1).

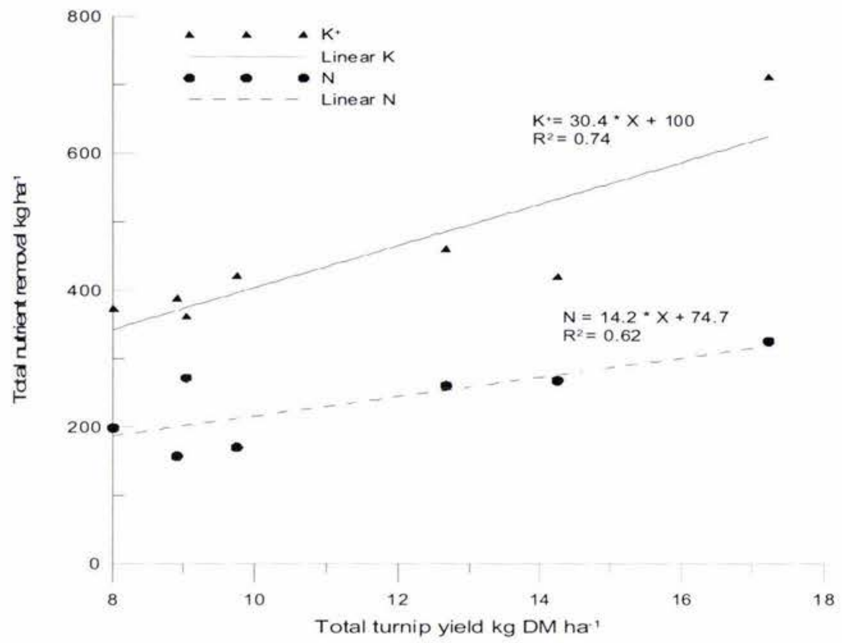


Figure 3.5 Total nutrient removal and turnip yield for K, and N in Turnip crop surveyed in the Manawatu Region, during the season Nov, 2005 – Mar, 2006.

3.7 Conclusions

Turnip yields in the surveyed paddocks near Palmerston North were between 8 and 17 t DM ha^{-1} during the season November 2005 – March 2006. This compares favourably with the predicted break-even yield for a dry year of 7 ton DM ha^{-1}. This yield information suggests that a summer turnip crop provides an economic solution to low summer grass production in this region.

Turnips have a high demand for K; however the nutrient removal was strongly affected by plant yield. Therefore, if a soil has high K concentration and there is no deficiency of other key nutrients, a moderate yielding turnip crop could remove substantial quantities of K. Growing a crop of turnips could be a very useful technique for reducing K accumulation on areas receiving FDE. However, certain management practices such as those related to ground preparation, sowing time, and harvesting time, could influence turnip production.

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Chapter 4

4.1 A field experiment evaluating growth and nutrient uptake pattern of turnips (*Brassica rapa* cv. Barkant)

4.2. Introduction

Previous studies (Clark, 1995; Daniels, 1995) and the survey of turnip crops grown near Palmerston North during the 2005/2006 summer (Chapter 3) have identified the ability of turnips to produce greater dry matter yields, with higher K concentrations, than pastures. These attributes are the basis of the research hypothesis being tested here, i.e. that turnips can be sown in paddocks used for FDE treatment to harvest the excessive quantities of K that accumulate in the soil of FDE paddocks. It is also suggested that with appropriate grazing management, the K taken-up by the turnips can be transferred from the FDE paddocks to other parts of the farm.

The seven turnip crops surveyed in Chapter 3 produced a wide range of yields indicating that K uptake by turnips will be dependent upon factors that influence crop growth. The magnitude of the soil water deficit and nitrogen availability are two variables which are likely to influence turnip yield. The application of N fertilisers may induce turnips to uptake greater amounts of K. FDE supplies water and is a rich source of K and N (Longhurst *et al.*, 2000). Consequently, irrigation of FDE to turnip crops may overcome summer water and N limitations thereby maximising yield or at least reducing variability in yields between years.

A field trial was conducted to evaluate the potential of Barkant turnips to remove K under FDE irrigation or with extra side-dressed nitrogen.

4.3 Objectives

1. To measure turnip growth rate, final yield and nutrient content as influenced by the application of additional urea and FDE.
2. To measure the uptake of soil nutrients and the depletion of soil nutrient supply by the turnip crop.
3. To provide information to assist farmers in the management of turnips to get crops of maximum quantity and quality and plant K removal.

4.4 Materials and methods

4.4.1 Trial Location and soil type

In the summer of 2005/06, a turnip (*Brassica rapa cv.* Barkant) trial was conducted on a mole-pipe drained Pallic soil (Tokomaru silt loam) in paddock 32 at Massey University's Dairy Farm No 4, Palmerston North. This Pallic soil has been formed on the deep deposits of loess, derived from greywake alluvium, that blanket the deeply dissected marine terraces on the east bank of the Manawatu River (Molloy, 1998). The Tokomaru silt loam is classified as an Argillic fragic Perch –gley Pallic Soil (Hewitt, 1998) or a Typic Fragiaqualf (Soil Survey Staff, 1998). The A horizon (0 - 250 mm soil depth) is a weakly to moderately developed, brown, silt loam; the B horizon (250 – 800 mm soil depth) is weakly developed, grey but strongly mottled, clay loam and the C horizon is a highly compacted, weakly–developed, pale-grey, silt loam fragipan, which creates a natural barrier to drainage (Scotter *et al.*, 1979a). For the 0-100 mm depth under sheep grazed pasture, the bulk density, saturated hydraulic conductivity and field capacity have been reported as 1100 kg m^{-3}, 32 mm day^{-1} and 45% v/v, respectively (Scotter *et al.*, 1979a).

The whole farm is located in a flat to easy/rolling landscape (c. 3% slope); however, the trial was situated on a flat site. The average annual rainfall is approximately 980 mm. The pre-cultivation vegetation at the site was a 7yr old mixed pasture of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*).

4.4.2 Cultivation and crop establishment

Farm staff began the process of preparing the trial paddock for the sowing of turnips on 15^{th} October, 2005. The previous pasture was sprayed with Roundup herbicide and ploughed under. Cropmaster 15 (250 kg ha^{-1}) was incorporated as a pre-plant fertiliser using a rotatiller. Barkant turnip seed was planted using a 2.5 – 3 cm width drill at 2 kg seeds per hectare on 6^{th} November, 2006.

At 36 days after seeding, plot areas were superimposed on the already established turnip crop. The research area consisted of 15 plots arranged in a completely randomized block design. Each plot was 5 m long and 2 m wide. The trial was blocked so as to account for increasing distance from a fence that could have influenced previous cultivation and cow grazing behaviour. The field experiment involved three treatments;

Control: pre-plant fertiliser only,

Urea: pre-plant fertiliser plus side-dressed urea at 40 DAS (46 kg N ha^{-1}) and

FDE: pre-plant fertiliser plus 5 x 10 mm FDE applications.

Each treatment had five replicates.

4.4.3 Soil and Plant analysis

Methods of soil and plant analysis are described in Chapter 3. Only if variations to those methods were used are they described in this Chapter.

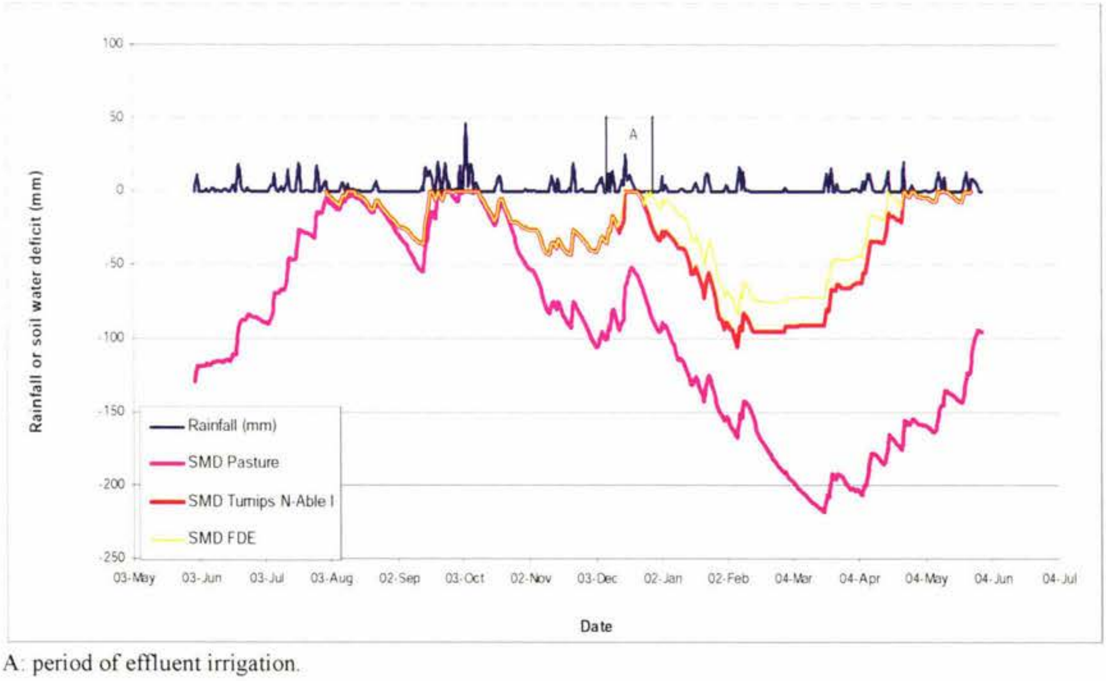
At 36 DAS, five soil cores (25 mm diameter and 0-150 mm depth) were taken from each plot. Sub-samples of moist soil were taken to measure the gravimetric water content (weighted wet and then oven-dried at 105°C overnight, and reweighed). The remaining soil was air-dried at 35°C, passed through a 2 mm sieve and used for soil chemical analysis. Further soil samples were taken from the trial at 58 and 75 DAS. Soil chemical analyses are described in Section 3.2 above.

4.4.4 Effluent irrigation and N application

Urea was applied to the nitrogen plots at 40 DAS. The fertiliser was broadcast manually on the plots at a rate of 100 kg Urea ha^{-1} (46 kg N ha^{-1}). This rate was taken from the 'Best Practice Barkant Crop' guide from Wrighston Seeds (2005). Table 4.1 shows the timing of FDE applications and the harvesting dates during the trial.

An attempt was made to (approximately) match the rate of N application to FDE plots with the rate added to the urea plots. To achieve this goal, the quantity of FDE required for each plot was estimated from an earlier measurement of the N concentration in FDE of 90 mg N l^{-1}. On the basis of this value, five effluent irrigations of 10 mm each were applied to the FDE plots. Each irrigation of 10 mm was applied using a watering can (Plate 1); a total of 100 litres of FDE was applied per plot at each irrigation. Applications of FDE were restricted to 10 mm each event to prevent applied nutrients from moving beyond the root zone of the turnip crop. The merit of irrigating relatively small depths of FDE is set out by Hedley *et al.* (2005). The soil water balance, which was predicted using the model of Scotter *et al.* (1979b), was used to schedule the FDE irrigations (Figure 4.1) so as to avoid any risk of FDE moving beyond the root zone, therefore, measurement of gravimetric water contents at 150 mm depth were done (Table 4.1). The greater gravimetric water contents maintained in the FDE treated plots relative to the control and urea treatments from 40 DAS onwards will be discussed later in this Chapter.

The model of Scotter *et al.* (1979b) predicted the soil water balance for pasture cover but the N-able model (Chapter 5) was used to predict the soil moisture deficit of the control and FDE treatments under the changing crop canopy of the turnip crop (using the potential evapotranspiration calculated by the Scotter model and temperature data for- Palmerston North). The period of cultivation and bare ground in the early stages of the turnip crop (late October- December) reduced water loss and created less water deficit in February for the maturing turnips than experienced by pasture (Figure 4.1).



A: period of effluent irrigation.

Figure 4.1 Soil water balance and FDE irrigation. Farm No 4 – Massey University.

Plate 4.1 Farm dairy effluent (FDE) irrigations during the season 2005/2006. Farm No 4 – Massey University.

Table 4.1. Harvest dates, and timing of FDE irrigations during the trial.

Activity	Date	FDE irrigation
sowing time	06/11/05	
Start of the trial	12/12/05	
	14/12/05	√
	16/12/05	√
1st harvest	19/12/05	
	23/12/05	√
2nd harvest	26/12/05	
	27/12/05	√
	29/12/05	√
3rd harvest	03/01/06	
4th harvest	09/01/06	
5th harvest	20/01/06	
6th harvest	14/02/06	

4.4.6 FDE nutrient concentrations

Samples of FDE were collected at each irrigation and analyzed for N and P using a Technicon™ auto analyzer after Kjeldahl digestion. K, Mg, Ca and Na were determined by atomic absorption spectroscopy after digestion of samples with nitric acid (GBC Avanta Ver. 133).

The concentrations of N, P and cations in the applied FDE are shown in Table 4.2. The FDE nutrient concentrations are very similar to those reported by Houlbrooke *et al.* (2004) and highlight the central problem that this thesis seeks to address – the relatively high K content of FDE. These nutrient concentrations are multiplied by the volumes of irrigated FDE to give application rates of nutrients to the plots, which are expressed in kg ha^{-1} in Table 4.3.

Table 4.2 Nutrient concentrations of FDE at point of application (FDE pumped from aerobic pond of a two pond system at Massey University's Dairy Farm No 4).

	N	P	K	Mg	Ca	Na
Application	Nutrients content (μg ml^{-1})					
1st	119	24	213	29	74	36
2nd	122	24	212	27	67	36
3rd	117	24	215	30	80	37
4th	105	21	207	23	92	37
5th	110	24	206	30	82	35

Table 4.3 Quantity of nutrients applied to plots in FDE (kg ha^{-1}).

	Nutrients kg ha^{-1}					
Application	N	P	K	Mg	Ca	Na
1st	12	2.3	21.3	2.9	7.4	3.6
2nd	12	2.4	21.2	2.7	6.7	3.6
3rd	12	2.4	21.5	3.0	8.0	3.7
4th	10	2.1	20.7	2.3	9.2	3.6
5th	11	2.4	20.6	3.0	8.2	3.5
Total	**57**	**11.7**	**105.4**	**14.0**	**39.5**	**18.1**

A total of 57 kg N ha^{-1} was applied in the 5 FDE applications, (Table 4.3) which exceeded the quantity of N added to the urea plots by 11 kg N ha^{-1}. The FDE was also a source of extra P, Mg, Ca and Na compared to the urea treatment. Notably the FDE applications applied 105 kg K ha^{-1} (Table 4.3).

4.4.7 Plant sampling

Turnip yield was measured on six occasions - at 43, 50, 58, 64, 75 and 100 DAS (Table 1). At the harvests on 43, 50, 58, 64 DAS, four plants were taken at random from the 50 cm boundary region of each plot (pulling out by hand). At the last two harvests, a quadrant (1 m long and 1 m wide) was used to sample plants from the centre of each plot. The plants were taken to the laboratory and the harvested material was separated into bulbs (washed to avoid soil contamination) and shoots before obtaining the fresh weight. From these plants, a sub-sample of 5 or 6 plants per plot was taken for measurement of % dry matter after drying at 70°C to constant weight. Total turnip dry weight (TDM) was measured by summing the leaves and shoots dry weights. Final results were expressed as tonnes of DM per hectare.

Plant samples from the 75 and 100 DAS harvests were ground through a 1 mm screen (Tecator Cyclotech sample mill) and stored in small plastic bags for chemical analysis.

4.4.8 Statistical analyses

Statistical analyses were performed by using the General Linear Model (GLM) software of the Statistical Analysis System (SAS Institute, 1999-2001). Data were analyzed by analysis of Variance (ANOVA) with a complete randomized design block. Least significant differences (LSD) at 5% were used to establish significant differences between treatment means.

4.5 Results and discussion

4.5.1 Dry matter yield and growth rate

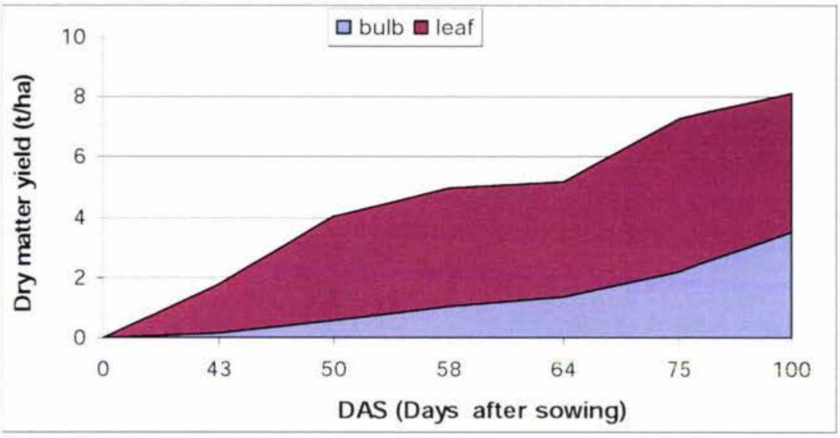
At the fifth harvest (75 DAS), the turnip yield of the FDE treatment was significantly ($P<0.05$) greater than the yields of either the control or urea treatments. However, at the final harvest (100 DAS) all treatments produced similar total dry matter yields of around 8 tonne DM ha^{-1} (Table 4.4). These trends in leaf and bulb yields are illustrated in Figure 4.2. In order to provide detail of turnip growth in the period 75 to 100 DAS, leaf and bulb yields for the 6 harvests were plotted and then fitted with a series of quadratic and linear equations, respectively (Figure 4.3). The final yields at 100 DAS were very similar for all treatments due to leaf death on all plots in the period 75 to 100 DAS, particularly on the urea and FDE treatments. This is seen in the leaf growth rates presented in Table 4.1 and in Figure 4.3a. The modelled lines in Figure 4.3 indicate that between 75 DAS and 100 DAS the turnips reached maximum yield and then leaf senescence commenced. In comparison, bulb growth rates were still high in the 75 to 100 DAS period.

Table 4.4. Total dry matter production in turnips Var. Barkant[1]. Farm No 4 – Massey University.

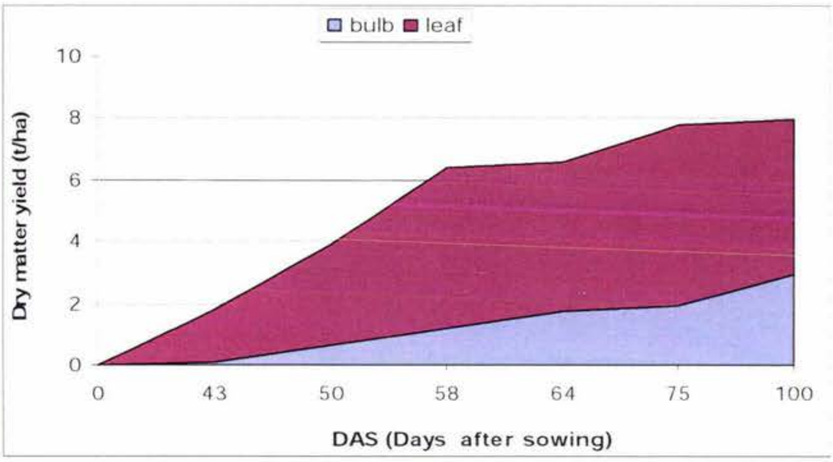
		Total ton DM ha^{-1}		
Harvest	days	Control[a]	Urea[b]	Effluent[c]
ns 1st	43	1.79	1.79	2.05
ns 2nd	50	4.01	3.92	4.28
ns 3rd	58	5.00	6.40	6.67
ns 4th	64	5.18	6.60	7.87
5th	75	7.27**b**	7.78**ab**	8.51**a**
ns 6th	100	8.12	7.98	8.44
**LSD 5th		0.85		

* Different letters in a given row differ significantly at the $P < 0.05$ level.
a Control: pre-plant fert.; **b** Urea: pre-plant fert. Plus 46 kg N ha^{-1} at 40 days after sowing; **c** pre-plant fert. Plus FDE; [1] Sowing date of the crop 06-11-05;
** Least significant difference ($P<0.05$); **ns**: no significance

a. Control



b. Urea



c. FDE

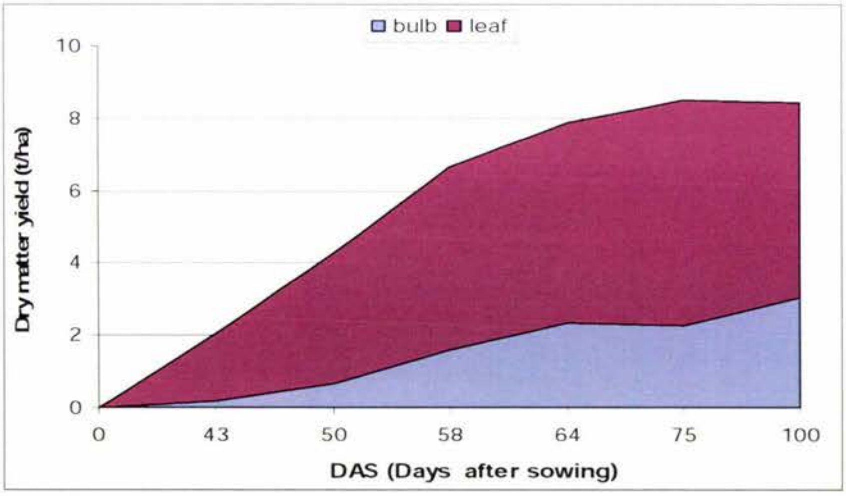


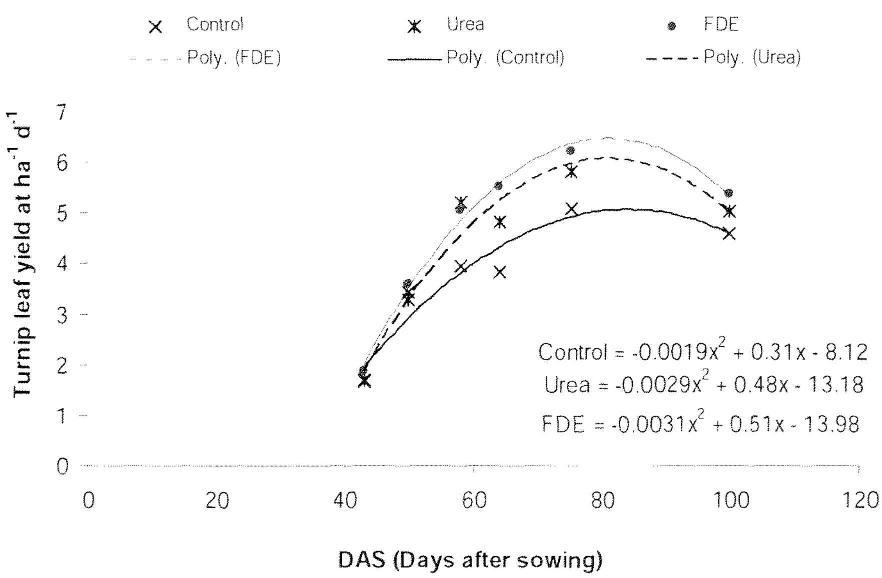
Figure 4.2 The development of leaf and bulb dry matter yield for Turnips (cv. Barkant) grown in the control (a), urea (b) and FDE (c) treatments at Massey University's No. 4 Dairy Farm – (Season 2005 – 06)

When the best fit quadratic equations describing leaf growth (Figure 4.3a) and the best fit straight line equations describing bulb growth (Figure 4.3a) are summed. The resulting product equation suggests that maximum yields on the control, urea and FDE plots were 7.91, 8.85 and 9.39 tonnes ha^{-1}, and were achieved at 99, 90 and 90 DAS respectively. Whilst these predicted yields are a function of the curves chosen to fit the data, the exercise is useful in suggesting that shorter intervals were required between yield measurements to confirm possible important treatment differences. For example the predicted maximum yields of the treatments suggest that if harvest date was flexible then the urea and FDE treatments may have yielded as much as 0.94 (12%) and 1.48 t ha^{-1} (19%) more turnips than the control, respectively.

The extra N applied in the form of FDE or urea, and the water component of the FDE increased yield at 75 DAS and secondly they helped these treatments achieve their maximum yield in a shorter period of time (90 days cf 99 days for the control). Interestingly, if a farmer wants to maximize the yield of turnips, grazing should be delayed until the end of the 60 – 90 day maturing period quoted by Wrightson. Other studies (Pearson *et al*, 1996; Clark *et al*., 1996; Daniels, 1995) have also shown that additional N applied as fertiliser (0, 25, 50, 100, 200 kg N ha^{-1}) may have no effect on yield, or the growth pattern of turnips (leaf, bulb and total DM).

In a series of experiments at the Taranaki Agricultural Research Centre (TARC), Pearson *et al*. (1996) and Clark *et al*. (1996) found that Barkant turnips attained maximum yield at 120 DAS with higher production (up to 10 ton DM ha) than the current trial at the Massey No.4 dairy farm. As in the current study, Clark *et al.* (1996) and Pearson *et al*. (1996) also noted that leaf yield peaked (at 91 DAS) but bulb yield continued increasing until the end of the experimental period (120 DAS). Pearson *et al*. (1996) stated that leaf yield could decrease due to canopy closure resulting in senescence and decay. As a result, the quantity of turnip available for utilization by grazing animals could decrease (Clark *et al.,* 1996). Both researcher groups suggested that turnips should be grazed between 80 to 120 DAS to minimize the risk of major losses from leaf senescence or bulb-rot and achieve maximum turnip yield. Two surveys undertaken in 1995 (New Zealand National and Manawatu surveys) found that the majority of the farmers harvested turnips between 70 to 90 DAS (Clark, 1995; Daniels, 1995).

(a)



(b)

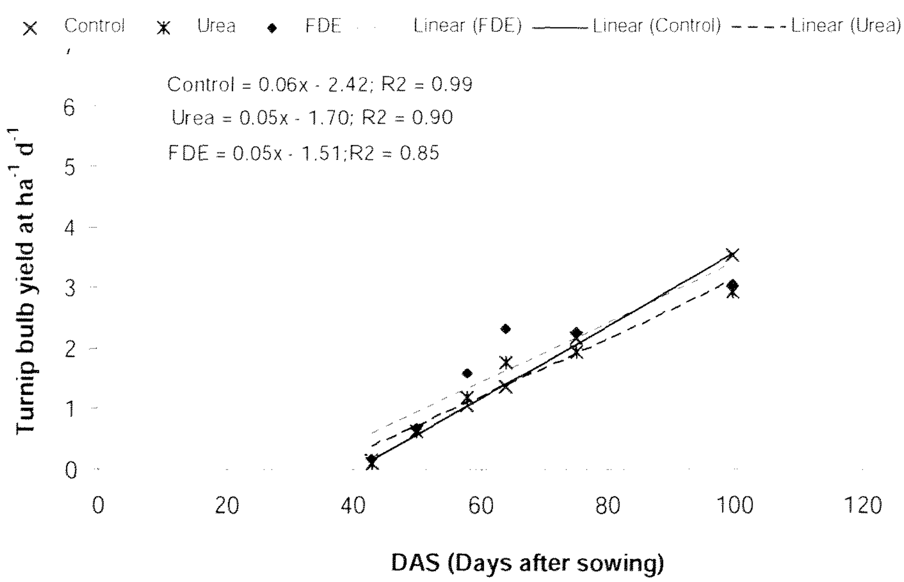


Figure 4.3 The dry matter yield (a), leaves (b) bulbs for Turnips (cv. Barkant) at Massey University's No. 4 Dairy Farm - (Season 2005 - 06)

From sowing to 58 DAS, leaf growth rates were generally much greater than bulb growth rates particularly for the urea and FDE treatments (Table 4.5). In contrast, following the harvest on 58 DAS, bulb growth rates were often greater than leaf growth rates, most noticeably in the period between the harvests on 75 and 100 DAS when, as noted above, the leaf growth rates on all plots were negative (See also decreasing leaf yield in Figure 4.2a). This means that at the end of the trial, the proportions of bulb to leaf material were smaller for the urea and FDE treatments (0.58 and 0.56, respectively) than for the control (0.76). Similarly, increases in applied N from 50 to 200 kg N ha^{-1} decreased bulb yield at 90 and 120 DAS in the experiments conducted by Pearson *et al.*, (1996) and Clark *et al.*, (1996).

Table 4.5. Leaf and bulb growth rates in turnips Var. Barkant. Farm No 4 – Massey University.

			Bulbs		Shoots		
				kg DM. ha^{-1} day^{-1}			
Harvest	DAS	Control	Urea	Effluent	Control	Urea	Effluent
1st	43	3	2	4	39	39	44
2nd	50	63	77	73	253	227	244
3rd	58	60	69	115	64	241	185
4th	64	50	95	120	-18	-62	80
5th	75	74	16	-5	115	91	62
6th	100	54	40	32	-20	-32	-34

Based on the information from the current trial and previous work by Clark et al. (1996) and Pearson *et al.* (1996), two key points concerning turnip yields arise. Firstly, the amount of N required to achieve maximum yield needs careful evaluation and monitoring. In some cases, the N requirement of a turnip crop could possibly be met by N already present in the soil as mineral N and mineralizable N. Secondly, in addition to increasing yields, N applications may help turnips achieve maximum yield earlier (particularly for leaves). Farmers need to account for this in the grazing plan and re-grassing programme. The role of N fertiliser will be examined in Chapter 5.

4.5.1.1 The advantage of attaining maximum yield early

As it takes approximately eight weeks to establish new pastures following the grazing of turnips, farmers must weigh the relative value of the decreasing growth rate of a mature turnip crop in summer against the growth rate of newly established pasture in autumn. If the turnip crop is left un-grazed for too long then grass production in the autumn will be compromised. The advantage of having turnip crops reach maximum yield earlier in the season can be illustrated using the data measured in this study.

For the period 50 to 75 DAS, leaf plus bulb growth rates were large compared to the typical growth rate of newly established pasture in autumn (e.g. 27 kg DM $ha^{-1}day^{-1}$). From 75 to 100 DAS, turnip growth rates on both the urea and FDE treatments (8 and -2 kg DM ha^{-1} d^{-1}, respectively) were less than the average pasture growth rates. Given this, it would be advantageous to re-grass these areas as quickly as possible. In comparison, for the period 75 to 100 DAS, the turnip growth rate in the control plots was 34 kg DM ha^{-1} d^{-1} suggesting that it would have probably been beneficial to leave these turnips growing until they reached the maximum measured yield of 8.12 t DM ha^{-1} at 100 DAS. This means that turnips receiving N or FDE could have been grazed approximately 25 days earlier than crops that received no N fertiliser. In other words, the FDE treatment has an advantage of 25 days. The importance of this will be discussed next.

Some simple land-use schedules are presented in Fig 4.4 for a range of grazing dates for turnips. It is assumed that, following a grazing period of one week, eight further weeks are required to cultivate and establish new pasture for its first grazing (Figure 4.4). Therefore, if the grazing of the FDE plots commenced in the second week of January (64 DAS), the newly established pasture on these plots could be grazed in the mid-March. The new pasture established on the control treatment could not be grazed until the end of April. If pasture growth rates average 27 kg DM ha^{-1} day^{-1} in March and April the FDE treatment has the potential to grow 675 kg DM ha^{-1} more pasture than the control treatment (after producing very similar quantities of turnips as the control treatment).

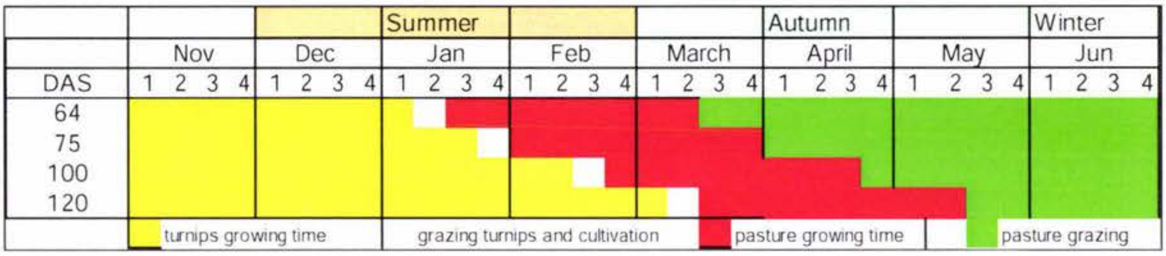


Figure 4.4 Land-use schedule to illustrate the advantage of early grazing of turnips and early re-grassing.

4.5.2 Plant Nutrient Concentration

At 75 and 100 DAS, a comparison between all leaf nutrient (Table 4.6) concentrations (except N) and bulb nutrient concentrations (except K, Na, P) were in the normal range (Table 4.7) found by Hill Laboratories (1998). The leaves maintained higher concentrations of nutrients than did the bulbs, the exceptions being P and Na. Potassium concentrations were approximately 70% greater in the leaf than the bulb for all treatments at both harvest dates. A comparison with Australian studies and the survey data in Chapter 2 (Table 2.7) showed that the turnips in the present field trial attained high concentrations of K, N and P in leaves and bulbs and low levels of Na. Climate, fertiliser type and rate of application, natural soil fertility, and season are all associated with the variation in mineral compositions (Jacobs *et al.*, 2003 & 2004), and are likely to account for the differences noted here.

Table 4.6. Nutrient concentration in turnip cv. Barkant[1] at 75 and 100 days after sowing Farm No 4 – Massey University.

Treatments	Control[a]		Urea[b]		Effluent[c]	
Time (days)	75[2]	100[3]	75	100	75	100
Element	Nutrient concentration in leaves (%)					
K^+	5.3Ac*	4.6Bb	6.1Ab	5.5Bab	7.1Aa	6.8Ba
ns Ca^{2+}	2.3	2.4	2.3	2.3	2.3	2.2
ns Mg^{2+}	0.4	0.5	0.4	0.5	0.4	0.5
ns Na^+	0.4	0.2	0.4	0.4	0.2	0.2
N	2.5	2.4b	2.6B	3.0 Aa	2.6B	2.9Aab
ns P	0.6	0.4	0.6	0.6	0.6	0.6
**LSD^K	0.8	1.4				
LSD^N		0.6				
(LSD^{Mg})		0.04				
Element	Nutrient concentration in bulbs (%)					
K^+	3.1	3.0b	3.7A	3.2Bb	4.1	4.0a
Ca^{2+}	0.4	0.5b	0.5	0.5b	0.5	0.6a
ns Mg^{2+}	0.1	0.2	0.2	0.2	0.2	0.2
	0.4	0.4	0.6	0.6	0.4	0.5
Na^+	1.4	1.1b	1.6	1.6a	1.4	1.5ab
ns P	0.5	0.5	0.6	0.6	0.6	0.6
**LSD^K		0.76				
LSD^{Ca2+}		0.06				
LSD^{Mg2+}		0.03				
LSD^N		0.56				

* abc values followed by different letter in a given row differ significantly at the $P<0.05$ level between treatments within period. **a** Control: no fertiliser; **b** Urea: 46 kg N ha^{-1}at 40 days after sowing; **c** Effluent: 5 applications during the trial.
* AB values followed by different letter in a given row differ significantly at the $P<0.05$ level between periods within a treatment. [1] Sowing date of the crop 06-11-05; [2] From the 5th harvest; [3] From the 6th harvest.
** The least significant difference ($P<0.05$); ns: no significance between treatments

In general terms, the concentrations of the major nutrients, apart from K (see below) in leaf and bulb showed little change between 75 DAS and 100 DAS (Table 4.6). It is expected that as the crop matures, nitrogen concentrations in both the leaf and bulb decrease (Greenwood and Draycott, 1989). However, increases in N fertiliser application, particularly side-dressed N, may maintain or increase the N concentration of leaves and bulbs as the crop matures (Jacobs *et al.*, 2004). In the present trial, the urea fertiliser treatment had greater leaf and bulb N concentrations at 100 DAS than the control. At 100 DAS, the N concentration in both the leaves and bulbs of the FDE treatment were not significantly ($P<0.05$) greater than the N contents of the plants in the urea and control treatments. However, this may have been a factor of the increased quantity of plant material grown under applications of FDE. Comparable responses to N were found by Pearson *et al.* (1996) for crops grown in two different years at two different sites using N fertiliser.

The addition of 105 kg K ha^{-1} in the FDE caused a significant increase in leaf and bulb K concentrations (Table 4.6). At 75 DAS, the K concentrations of leaf and bulbs for the FDE treatment were 34% and 32% greater ($P<0.05$) than K concentrations for control leaves and bulbs (respectively). Likewise at 100 DAS, the K concentrations for leaf and bulb on the FDE plots were 48% and 33% greater than concentrations of K in the leaf and bulb of control plots, respectively. At 75 and 100 DAS, the K concentrations of leaves on FDE plots were also significantly ($P<0.05$) greater than that on the urea plots and at 100 DAS the K concentration of bulbs on the FDE treatment was greater than the K concentration of bulbs on the urea treatment. In Australia, Jacobs *et al.* (2003) demonstrated that the application of FDE at different rates increased turnip dry matter yield, and plus K concentrations in leaves and bulbs.

Interestingly, N application in the urea treatment tended to stimulate higher K leaf concentrations although the only time that K concentration of plant material on the urea plots was significantly ($P<0.05$) greater (by 15%) than the control plots was for leaf material at 75 DAS. A similar response was measured at a dryland site (Western of Victoria) at 91 DAS when 50 kg N ha^{-1} increased the K concentration of leaves by 8 % in the first year and in the second year the N fertiliser increased the K concentrations of leaves and bulbs by 7 and 13%, respectively (Jacobs *et al.*, 2004).

It is particularly noteworthy that the K concentration of both leaf and bulb on all treatments decreased between and 75 and 100 DAS (Table 4.6). This will have major implications for K removal as discussed below.

The only other significant difference in nutrient concentrations was for the Ca, where the concentration in the bulb on the FDE treatments was significantly greater than the concentration in the bulb on both the urea and control treatments. In contrast, Jacobs et al. (2003) found that the application of FDE at different rates decreased Ca concentrations in leaves and increased in bulbs without significant differences at 101 DAS.

Table 4.7 Concentration of the major nutrients in turnip leaves determined by Hill Laboratories (1998)

	Normal Range
	%
Nitrogen	3.5-5.0
Phosphorus	0.30-0.70
Potassium	2.5-5.0
Sulphur	0.35-0.80
Calcium	1.80-4.00
Magnesium	0.30-0.60
Sodium	0.00-0.35

At both samplings (75 and 100 DAS), the effluent application did not significantly increase P concentrations of leaves or bulbs. In comparison, Jacobs *et al.*, 2003 found that the P concentration of turnips increased with increasing rates of FDE and that bulbs had more P than leaves.

4.5.3 Uptake and removal

Nutrient uptake by turnips is calculated by multiplying yield and nutrient concentration: it provides an estimate of the quantities of nutrients that can be removed per hectare by harvest or by grazing events. Nutrient uptake was much greater for leaves than bulbs on all treatments at both harvests. In all treatments, the amounts of nutrient removed by leaf tended to be lower at 100 DAS than at 75 DAS (Table 4.8). In contrast, the amounts of nutrient removed by bulbs tended to be higher at 100 DAS than at 75 DAS (Table 4.8). As leaf nutrient concentrations of K and dry matter yields were greater than corresponding measurements for bulbs, greater K removal per hectare occurred in the harvest at 75 DAS (Table 4.9). For N, P, Ca and Mg, the harvest date made less difference to the quantities removed.

Table 4.8 Nutrient removal at 75 and 100 DAS by leaves and bulbs in turnips cv. Barkant[1]. Farm No 4 – Massey University.

Treatments	Control[a]	Urea[b]	Effluent[c]	Control	Urea	Effluent
DAS		75[2]			100[3]	
Nutrient			kg ha^{-1} (Leaves)			
K^+	272c	357b	445a	211c	278b	366a
ns Ca^{2+}	115	134	141	110	116	121
Mg^{2+}	19b	22ab	23a	ns 21	25	26
ns Na^+	18	22	14	8	18	12
ns N	125	161	159	113	154	156
P	28c	35b	39a	22c	29b	32a
**LSD^K	69.8 kg K ha^{-1}			89.3 kg K ha^{-1}		
LSD^{Mg}	4.2 kg Mg ha^{-1}					
LSD^P	4.4 kg P ha^{-1}					
Element			kg ha^{-1} (Bulbs)			
ns K^+	66	71	92	104	94	124
ns Ca^{2+}	9	9	11	18	15	18
ns Mg^{2+}	3	3	4	6	5	6
ns Na^+	10	11	8	15	18	16
ns N	30	31	32	39	47	45
ns P	11b	11b	14a	18	16	18
LSD^P	2.6 kg P ha^{-1}					

* Values followed by the same letter in a given row do not differ significantly at the 0.05 level between treatments
[a] Control: no fertiliser; [b] Urea: 46 kg N ha^{-1}at 40 days after sowing; [c] Effluent: 5 applications during the trial.
[1] Sowing date of the crop 06-11-05; [2]From the 5[th] harvest; [3] From the 6[th] harvest.
** The least significant difference ($P<0.05$); ns: no significance between treatments

The K removals in leaves on the FDE were significantly ($P<0.05$) greater than that on the urea plots and control plots at 75 and 100 DAS (Table 5.8). This trend also occurs with total removal of the whole plant (Table 4.9). Additional side-dressing with nitrogen (urea treatment) resulted in greater total uptake of K (428 kg K ha^{-1}) at 75 DAS than the K uptake in the control treatment (339 kg K ha^{-1}, Table 4.9). Application of additional N, K and water in the FDE treatment allowed 58 % more K removal at 75 days than the K removed in the control treatment.

Interestingly, over the same growing period (100 DAS from 6 November), permanent pasture in an adjacent paddock accumulated a total of approximately 5000 kg DM ha^{-1} with measured leaf N and K concentrations of 2.9 and 2.6%, respectively. Thus, total K uptake by the permanent pasture was only 130 kg K ha^{-1} i.e., total K uptake by turnips on the control, urea and FDE plots was 2.4, 2.9 and 3.8 times greater than K uptake by pasture for the period corresponding to 100 DAS, respectively.

Table 4.9 Total Nutrient removal at 75 and 100 DAS by the whole plant cv. Barkant[1]. Farm No 4 – Massey University.

Treatments	Control[a]	Urea[b]	Effluent[c]	Control	Urea	Effluent
Time (days)		75[2]			100[3]	
Element			kg ha^{-1}			
K^+	339c	428b	537a	316b	372b	490a
ns Ca^{2+}	124	143	152	128	131	139
ns Mg^{2+}	22	25	27	ns 27	30	32
ns Na^+	28	34	22	23	35	28
ns N	156	192	192	152	201	201
P	39c	46b	53a	ns 40	45	51
**LSD^K	80.0 kg K ha^{-1}			107.7 kg K ha^{-1}		
LSD^P	4.7 kg P ha^{-1}					
LSD^{Mg}	4.3 g Mg ha^{-1}					

* abc values followed by different letter in a given row differ significantly at the $P<0.05$ level between treatments within period.
[a] Control: no fertiliser; [b] Urea: 46 kg N ha^{-1}at 40 days after sowing; [c] Effluent: 5 applications during the trial.
[1] Sowing date of the crop 06-11-05; from the 5[th] harvest; [3] from the 6[th] harvest.
** The least significant difference ($P<0.05$); ns: no significance between treatments

Research at the University of Connecticut evaluated the seasonal nutrient uptake of brassicas forages (Guillard *et al.*, 1989). They reported that under summer conditions, total plant uptake (especially for turnips) of K, Ca and Mg was significantly greater than in autumn. They also found nutrient uptake, particularly of K, was greater than available soil test values and added fertilisers. The high K removal in the current trial concurs with the results of Guillard *et al.* (1989).

4.5.4 Soil Nutrient Concentration

Soil samples (0-150 mm depth) were first taken from each plot at 36 DAS. While there was some variation between treatments, the mean soil test values (Table 4.10) for Olsen P, exchangeable cations and pH at the beginning of experiment were at or above the optimum soil test values for pastures and fell in the ranges recommended for optimum growth of turnips (Table 4.7).

Table 4.10. Soil pH, Olsen P, exchangeable cations and extractable mineral N in the top 0-150 mm soil depth at different times during the growth of turnips (var. Barkant)[1] grown at Massey University's No 4. Dairy Farm.

Treatments	Control[a]			Urea[b]			Effluent[c]		
Time (DAS)	36[2]	58[3]	75[4]	36	58	75	36	58	75
pH	6.5	6.4	6.4	6.4	6.5	6.4	6.5	6.5	6.5
ns Olsen P ug. g-1	35.2	29.9	28.2	31.8	31.8	34.0	36.7	35.4	33.5
K^+ me 100 g soil	0.7A	0.3Bb*	0.3Bb	0.7A	0.3Bb	0.3Bb	0.8A	0.5Ba	0.4Ba
ns Ca^{2+} me 100 g soil	6.3	6.2	6.1	6.3	6.4	6.4	6.3	6.4	6.5
ns Mg^{2+} me 100 g soil	1.4	1.2	1.3	1.4	1.4	1.2	1.5	1.5	1.4
ns Na^+ me 100 g soil	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2
ns NO^-_3 ug. g^{-1}	28.9A	3.7B	2.1B	37.6A	3.0B	2.0B	35.8A	3.8B	2.2B
NH^+_4 ug. g^{-1}	9.2A	10.6A	5.0Ba	7.8A	8.7A	5.1Ba	8.9A	10.9A	4.5Bb
**LSD^K		0.13	0.14						
LSD^{Na}			0.03						
LSD^{NH-4}			0.5						

* abc values followed by different letter in a given row differ significantly at the P<0.05 level between treatments within period.
a Control: no fertiliser; **b** Urea: 46 kg N ha^{-1}at 40 days after sowing; **c** Effluent: 5 applications during the trial.
* AB values followed by different letter in a given row differ significantly at the P<0.05 level between periods within a treatment. [1]
[1] Sowing date of the crop 06-11-05; [2] before establishing the experiment; [3] After the 3[rd] harvest; [4] after the 5[th] harvest.
** Least significant difference (P<0.05); ns: no significance between treatments

There were marked decreases in the concentrations of exchangeable K and total mineral nitrogen (NO_3^- and NH_4^+) during crop growth. These decreases were associated with the period of rapid plant growth between 36 to 64 DAS (Figures 4.5 and 4.6). Soil exchangeable K concentrations decreased significantly (P<0.05) by 0.4 meq 100 g soil, between 36 and 75 DAS on all treatments If we assume a soil bulk density of 1000 kg m^{-3} then the exchangeable K pool in the top 15 cm of control treatment soil decreased by approximately 230 kg K ha^{-1} from 36 to 75 DAS. This represents an amount equivalent to 69% of the total K removed by the turnip crop on the control plots (339 kg ha^{-1}, Table 4.9).

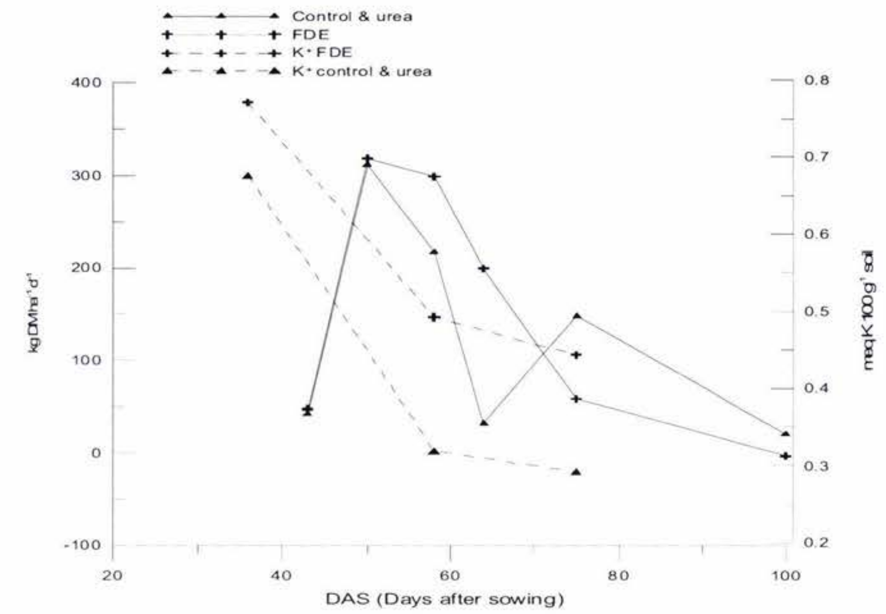


Figure 4.4 Change in growth rate of (total dry matter) turnip cv. Barkant and soil exchangeable soil K as days after sowing (DAS) increased. .

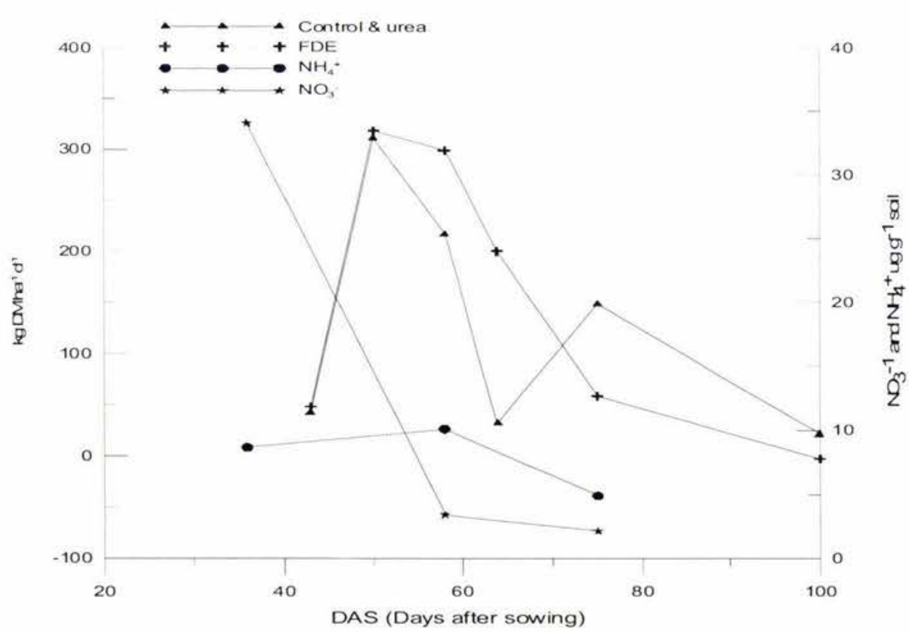


Figure 4.5 Change in growth rate of (total dry matter) turnip cv. Barkant and soil ammonium (NH^+_4) and nitrate –N (NO^-_3) content as days after sowing (DAS) increased.

At 36 DAS, extractable NO^-_3 (29 -38 μg N g^{-1} soil) contributed more than 75% of the total extractable soil mineral N. By 75 DAS, extractable NO^-_3 had been depleted to 2.1 ug N g soil $^{-1}$ and extractable NH^+_4 from 8-9 μg g soil^{-1} at 36 DAS to 5 μg g^{-1} soil at 75 DAS. The other exchangeable soil cations (Ca, Mg and Na) and Olsen P test values did not vary significantly through out the plant growth period.

Overall, potassium and soil mineral nitrogen (nitrate-N and ammonium-N) decreased over the period 36 to 75 DAS. Therefore, turnips require largest amount of these nutrients to have high yields.

Despite the growth rate in all treatments decreasing from 50 DAS, the FDE treatment had a greater growth rates from 50 DAS to 64 DAS, presumably because of extra nitrogen and potassium plus increased available water (Figure 4.1) of 50 mm of water applied as FDE.

The effectiveness of the FDE irrigation as a mean of maintaining higher soil moisture predicted in Figure 4.1 is supported by measure soil moisture contents Table 4.11. From the last irrigation (53 DAS), the moisture content of the top 0-150 mm of soil in the FDE treated soil remained above a gravimetric water content of 20% until 75 DAS. This is consistent with the lower predicted soil water deficit (11 mm) in the FDE plots after FDE irrigations (Figure 4.1). In the control and urea treatments, gravimetric water contents during this period were below 20% and consistent with predicted soil water deficit of 34 mm (Figure 4.1). Gravimetric water contents smaller than 20% in the surface of the Tokomaru silt loam correspond to stress point (Scotter at al., 1979a) and are likely to impose a restriction on evapotranspiration and thus limit plant growth rate.

Table 4.11 Harvest dates, soil gravimetric water content and timing of FDE irrigations during the trial.

	Soil gravimetric water (%)		
DAS	Control[a]	Urea[b]	FDE[c]
0			
36	35	35	35
38			
40	27	29	33
43	28	35	37
47			
50	26	32	33
51			
53			
58	19	19	24
64	20	19	25
75	19	16	18
100			

a Control: pre-plant fertiliser;
b Urea: pre-plant fertiliser. plus 46 kg N ha^{-1}at 40 days after sowing;
c pre-plant fertiliser. plus FDE; DAS: Days after sowing

4.6 Conclusions

At 75 DAS (6 November to 20 January), a crop of turnips cv Barkant, grown on a Pallic soil with no apparent soil fertility limitation (as diagnosed from initial soil test data or leaf analysis at 75 DAS) or severe water limitations and with a seed bed application of 38 kg N ha^{-1}, 25 kg P ha^{-1} and 25 kg K ha^{-1} managed a modest yield of approximately 7.3 ton DM ha^{-1}. A side application of 46 kg N ha^{-1} at 40 DAS did not significantly increase turnip yield above the control at the 75 DAS harvest. However, irrigation of 50 mm of FDE to turnips did significantly increase yield over the control at 75 DAS. Turnips on the control and urea treatments continued to grow during the period 75 to 100 DAS while the turnip yield on the FDE treatment declined so that there were no significant yield differences between the treatments at 100 DAS. It is suggested that N application will help turnips attain maximum production earlier in the season.

Relative to pasture growing at the same time of year the turnips produced 3000 kg ha^{-1} more dry matter and had much larger rates of K uptake, especially when fertilised with additional N or FDE.

The greatest accumulation of K in the crop of (339 -547 kg K ha^{-1}) was associated with a period when leaf biomass was at a maximum (in this experiment 75 DAS). This large accumulation of K in the crop, particularly when fertilised with FDE makes turnips cv Barkant ideally suited to manage K removal from paddocks where soil K concentrations have accumulated from past FDE application.

A number of benefits arise from fertilisation of turnips with FDE. There are reduced fertiliser costs when nutrient requirements of the turnip crop are met by the FDE. The combined application of nutrients and water was associated with the turnip crop meeting its yield ceiling at 64 DAS rather than at 100 DAS when FDE was not applied. This would allow grazing of turnips with higher leaf dry matter and benefits in improved feed quality plus an economical advantage. The economic advantage is derived when earlier re-grassing results in more autumn pasture available for grazing.

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Chapter 5

5.1 Towards improved Nitrogen fertiliser recommendations for Turnip crops using N-able model.

5.2 Introduction

Turnip crops have become a profitable alternative forage source to pasture in summer dry areas, particularly when associated with dairy farm pasture renovation (see Chapter 1). Their additional value as crop grown to redistribute K from paddocks used for FDE land treatment was also demonstrated (Section 6.3.3.4 Chapter 6). In this research (Chapter 4 section 4.4 and that conducted by others (Jacobs *et al.*, 2000 & 2003) it has been demonstrated that turnip yield and K uptake responds to increased crop available nitrogen but in a curvilinear (quadratic) manner. Above optimum rates of N do not lead to more dry matter production or K transfer. The problem is to predict what optimum rate of N fertiliser is required, particularly when ploughed out pasture will contribute large and varying amounts of mineralisable N susceptible to leaching and available for crop uptake.

Accurate prediction requires a dynamic crop N uptake model that considers site specific soil and climate data. A model that can simulate the mineralization of soil N and its contribution to crop uptake. No such model has been developed specifically for predicting soil and fertiliser N utilisation by fodder turnip crops in New Zealand.

In this Chapter, the N-able model (Greenwood, 2001), produced to model the N-response of field vegetable crops under diverse conditions, was chosen to simulate the turnip growth patterns and N uptake observed in the field trial described in section 4.3, chapter 4. Whilst the N able model has been validated with a number of vegetable crops (Greenwood, 2001, Yang *et al.* 1999, 2000 and 2001) there appears to be no published data on its use for fodder turnip crops.

Successful simulation of the actual turnip yields may indicate that such a model could be modified to offer decision support for nitrogen fertiliser recommendations for fodder turnip crops grown in New Zealand. The suitability of the model will also be evaluated by its ability to predict the soil mineral N content measured in the top 150 mm during the field trial (Table 4.6, Section 4.4).

5.3 Objective

To evaluate the ability of the N-able model to simulate the turnip growth and N uptake patterns observed in the Manawatu field trial and therefore evaluate the model's suitability to support decisions on the optimum fertiliser N requirements for fodder turnip crops.

5.4 Method

5.4.1 Model selection

A brief literature review indicated that N-able was the only freely available, crop simulation model that incorporated growth coefficients for turnips, and allowed prediction of soil N mineralization and nitrate leaching by using actual local daily climate data. A web version of the model is available at http://www.qpais.co.uk/nable/.

The simulation model was run on a standalone version obtained from Dr Clive Rahn, Horticulture Research International, Wellesbourne, Warwickshire, CV35 9EF, UK.

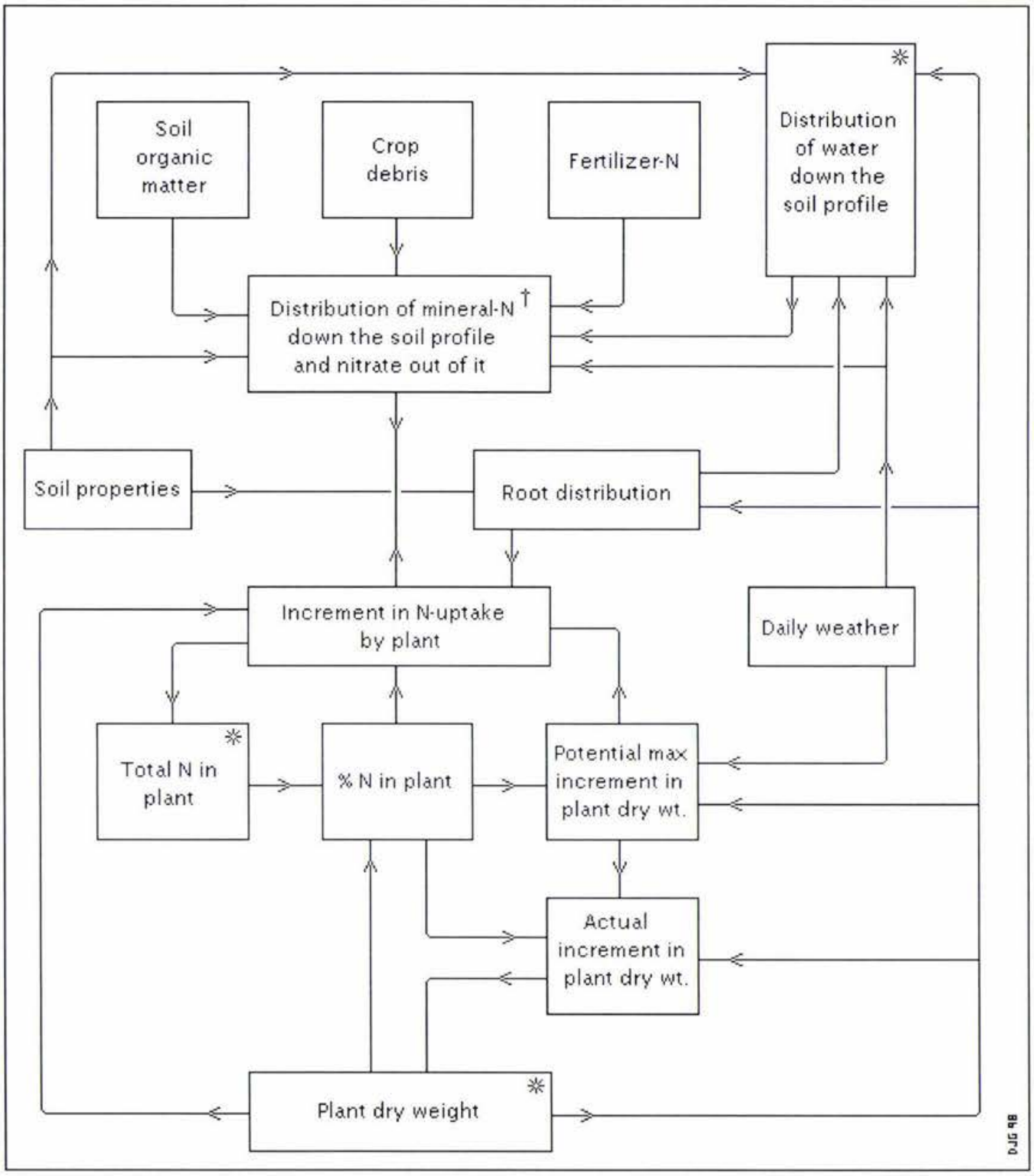


Figure 5.1 Flow diagram of N able model (with explanatory text from the web site)

The meanings of the symbols are as follows:
Boxes. Variable quantities or in some cases, such as 'Soil properties', groups of quantities.

Lines and arrows. The interdependence of the variables.

Asterisks(*). Variables the initial values of which are essential for running the model.

Dagger (†). Mineral-N is (ammonium+nitrate)-N.

Brief Explanation

The diagram is a simplification of the relationships between the more important variables in the model. The different components of weather are represented by a single box on the right hand side of the diagram and the various soil properties by a single box on the left hand side. Other variables concerning the soil are given in the upper part of the diagram and those concerning plants in the lower part.

The numerous processes in the model are represented by equations. These are solved for each day of the simulation and the variables updated accordingly. The main inputs to the equations used for calculating each variable are given by the sources of the arrows in the diagram. For example, the %N in the plant is calculated from the total N in the plant and plant dry weight.

A typical simulation run proceeds in 3 phases.

Pre-planting phase. In this phase only variables in the upper part of the diagram change. The model re-calculates for each day the decomposition of crop debris, the decomposition of soil organic matter, and the distribution of soil water. It also,, re-calculates their effects together with those the daily weather, various soil properties and the effects of any application of fertiliser, on the distribution and leaching of mineral-N down the soil profile.

Crop growth phase. In addition to the above, the model re-calculates, for each day, values of the variables in the lower part of the diagram. These are potential maximum increment in dry weight, root distribution, increment in N-uptake by the plant, total N in the plant, %N in the plant , actual increment in dry weight , and plant dry weight.

Post harvest phase. The operations for each simulation day are the same as in the Pre-planting phase (above).

For list of Model input parameters for the control, urea and FDE treatments see Appendices 5.1, 5.2 and 5.3. Appendix 5.3 shows that the FDE treatment was simulated by supplying the model with 5 N applications of 5 plus 5 irrigations of 10 mm at 38, 40, 47, 51and 53 DAS respectively.

5.5 Results & Discussion

5.5.1 Plant N uptake and dry matter yield

Simulated N uptake values for the three treatments had similar patterns to the observed data for (Figure 5.2a), the early and final stages of growth from 20th January, 2006, but the model could not simulate the higher rates of N uptake between mid-December and mid-January.

Similarly with yield prediction the model could not predict the 'S' shaped growth pattern over time (Figure 5.2b).

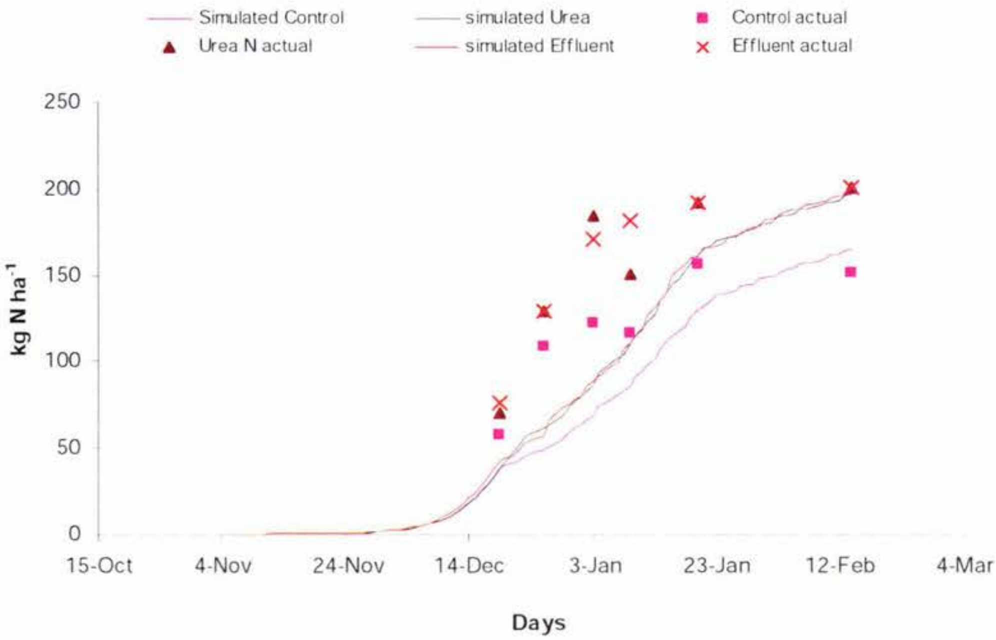
Despite the data and the simulated values indicating that N uptake by the turnip crop increased when sidedressed N fertiliser and FDE (N plus water) were applied (Figure 5.1), the model, however, predicted that their would be no significant gain in final DM yield by the addition of sidedressed urea or the FDE treatments (8.0 and 8.4 ton DM ha^{-1}). Suggesting that the farmer would be wasting the additional 46 kg N ha^{-1} because of the lack of response of yield. The measured yield data also support this model simulation.

The problem of poor simulation of the yield and N uptake of turnips in the mid growth period arises from the fact that the model has a J-shaped growth curve, which describes only the first and final phases of growth in the crops (Greenwood *et al.* 1987). It is recommended that the predictive growth equation for turnip is changed to an S shaped curve. A similar proposal to change the predictive growth equation to an S shape for lettuce (Yang *et al.*, 1999), cabbage and onion (Yang *et al.*, 2001) to better fit observed yield and N uptake data has been discussed in detail by Yang and others. Unfortunately there was not time to obtain the modified code for the N-able model to test its ability to better predict turnip yields and N uptake.

5.5.2 Soil N Mineralization rate

The turnip trial was established in a 7 year old paddock of grass and clover. The control yield and turnip N uptake at the final harvest (152 kg N ha^{-1}) indicates that the majority (See Table 4.9 section 4.4.3; N uptake of 152 kg N ha^{-1}; N applied at planting: 38 kg N ha^{-1}; thus, (152-38)/152 =~75%)) of plant N in the control was derived from soil N mineralization. The ability of the model to predict the amount of soil N mineralization and subsequent N uptake would be useful in estimating the residual N required from fertiliser. Therefore, simulations with different mineralization rates were conducted. The best fit of the control, urea and effluent treatments for N uptake was by using a mineralization rate of 0.5 kg N ha^{-1} d^{-1} (Figure 5.1). Using this soil N mineralization rate, the model also suitably predicts the soil nitrogen values over time (Figure 5.3) in the control plot, which decreased gradually driven by increased plant uptake during January (Figure 5.2).

a.)



b.)

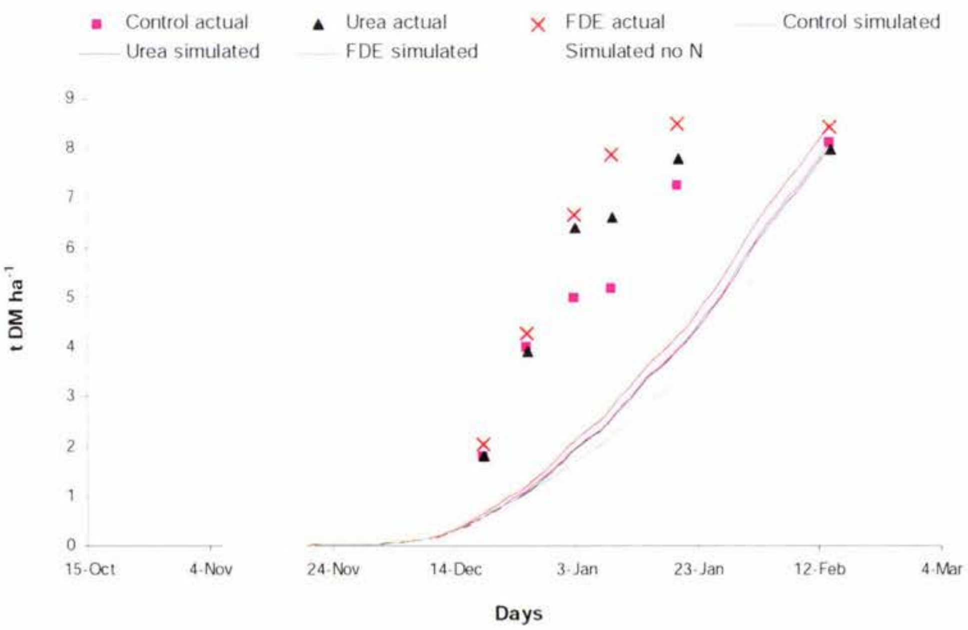


Figure 5.2 N-uptake (a) and dry matter yield (b) predicted (lines) and original data (symbols) of the three treatments Control (38 kg N ha^{-1} at planting), Urea (38 kg N ha^{-1} at planting plus 46 kg N ha^{-1} side-dressed and FDE (38 kg N ha^{-1} at planting plus 57 kg N ha^{-1} as FDE) and simulated yield without nitrogen application from the turnip trial conducted on the No.4 Dairy farm Massey University.

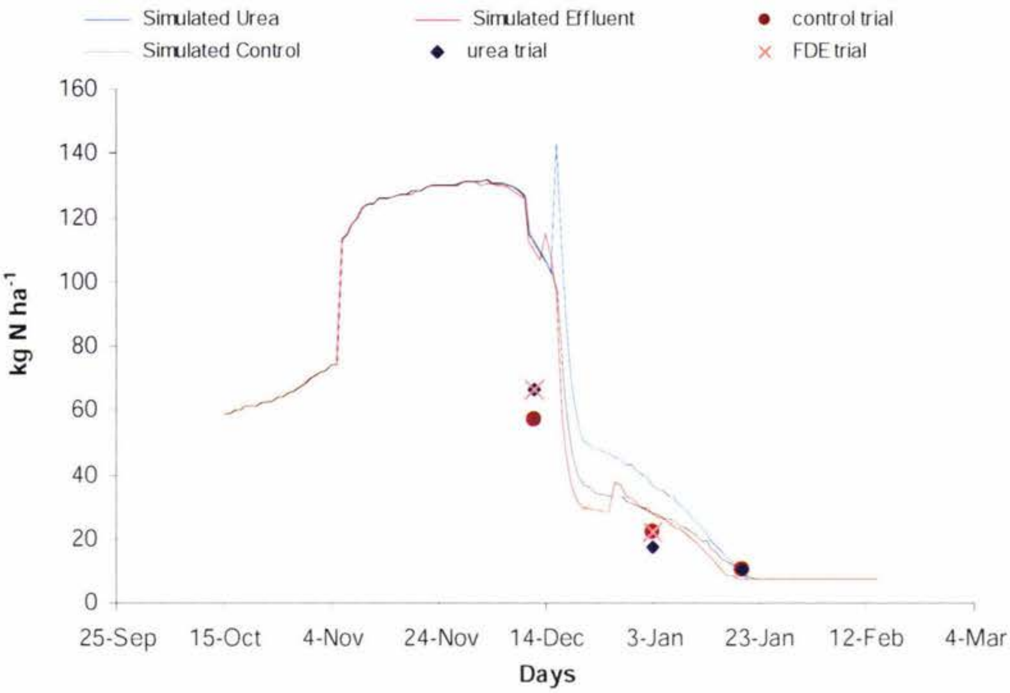


Figure 5.3 Simulated soil mineral nitrogen and average measured soil mineral nitrogen content in top 150 mm of the three treatments (control, urea and effluent) of the turnip trial.

Simulations, of the soil mineral N in control plot (with N at planting only) generated similar values and trends as the measured mineral soil nitrogen content (Figure 5.3). The soil mineral N increased gradually from the date of cultivation (15th October 2005) to 6th November due to mineralization of soil organic matter but then increases rapidly by 39 kg N ha^{-1} when the N is applied at planting. Another large increase is simulated when the side-dressed urea was applied on 16th December. Smaller increases are simulated when N is applied in the FDE irrigations on 14th and 16th December. Measured and simulated soil mineral values for all treatments (control: 38 kg N ha^{-1} as based fertiliser; Urea: 38 + 46 kg N ha; and FDE (38 + (5 x 11.4) kg N ha^{-1}) decreased from mid December onwards due to rapid plant uptake. Greenwood *et al.* (1989) stated that once the mineral-N had been taken up by the crop, N uptake by the crop is limited by the rate at which organic-N in soil is mineralized. The low soil mineral N values from mid-January to harvest in February add support to Greenwood's statement.

It is common that cereals grown in the first year after pasture show no response to fertiliser N applied (Metherell, 1989) owing to the soil supplying adequate N for crop uptake. In this trial the amount of soil N taken up turnips appears to range from 114 - 120 kg N ha^{-1} when fertiliser and FDE applied N is accounted for.

5.5.3 Discussion

Despite poor simulation of the turnips growth rates in the mid season the N able model provided a reasonable prediction of the final observed yields and soil mineral N contents. When the N-able simulation was conducted with no N fertiliser at planting the model predicted a simulated yield of 7.4 kg DM ha^{-1} and an N uptake of 142.2 kg N ha^{-1}. This simulation suggested that the small amount of N applied at planting (38kg N ha^{-1}) was essential to obtain 8 tonnes of dry matter under the climatic conditions of the Manawatu trial. It was also possible to demonstrate with the model that additional amounts of N did not produce higher final yields. However as mentioned in Chapter 4, section 4.4.3 additional N applied as urea increased the crop K removal by 89 and 56 kg K ha^{-1} at 75 and 100 DAS respectively. The additional N and K recovered in the crop would add to N and K transferred by cows in excreta to the pasture blocks (see later discussion).

The N-able simulation supports the measured trial data in predicting that turnips irrigated with FDE instead of urea side-dressing will attain the same yields and save expenditure on N fertiliser. At the same time the K removal by the FDE irrigated crop can be double that produced by urea application only. As a result, the time required to reduce K concentration in soils of FDE blocks will be shorter.

The N removal by turnips (152, 201 and 201 kg N ha^{-1} for the control, urea and FDE treatments respectively) was high compared with the amount of N fertiliser applied (38 kg N ha-1 in control, 38 kg N ha^{-1} + 46 kg N ha^{-1} in urea and 38 kg N ha^{-1} + 57 kg N ha^{-1} in FDE treatments) plus the initial soil mineral N (66 kg N ha^{-1}) in all the three treatments. This indicates a significant role for N mineralized during crop growth.

Experience gained from running the N-able model suggests that simple calculations normally used to determine how much fertiliser N is required to produce 8.0 ton DM ha^{-1} are not sufficiently accurate if they do not consider N mineralized during crop growth and mineral N capable of being exploited by developing crop roots.

For example:

1. Potential N in standing crop = 200 kg N/ha.
   (target Bulb yield x bulb N conc. + target shoot yield x shoot N conc)

2. Crop N uptake efficiency: 0.7 (estimate derived from Metherell 1989).

3. Total N required in root zone = 200/ 0.7 = 286 kg N ha^{-1}

4. Mineral soil nitrogen in seed bed at planting: 66 kg N ha^{-1} in top 150 mm. (Table 4.6, Chapter 4)

5. Fertiliser N = N required in root zone – mineral N in seed bed.
   = 285 - 66 = 220 kg N ha^{-1}

Which results in a serious overestimate of the fertiliser N requirement which N-able estimated as 38 kgN ha-1 to obtain the yield ceiling of 8 tonnes ha^{-1}.

5.6 Conclusions

A dynamic crop N model, such as N able provides a useful decision support tool to farmers trying to estimate how much and when to apply N to Barkant turnip crops to maximize yield and K uptake.

N able provides a method of assessing the contribution of soil mineralisable N to plant N uptake, which produces more conservative estimates of the crop fertiliser N requirement than simple calculations that consider only initial soil N and final crop N uptake.

The N able model should be evaluated further by testing an S-shaped turnip growth response model rather than the current J-shaped growth response model coded in the software.

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Chapter 6

6.1 Mass balance modelling of potassium transfers resulting from mixed grazing of turnips and pasture during a summer period in the Manawatu District.

6.2 Introduction

Over time land treatment of farm dairy effluent can lead to K enrichment of soils, especially when it is applied to small areas (Bolan *et al.*, 2004; Hedley *et al.*, 2002 & 2004). The hypothesis tested in this Chapter is that K accumulating crops such as turnips can be grown periodically on effluent block soils and controlled-grazed causing net transfer of K to other parts of the farm.

To provide quantitative information on the net amount of soil K that can be transferred when a summer turnip crop is strip-grazed as a partial diet for dairy cows, it was necessary to construct a simple model that quantified the nutrient transfers (Figure 6.1) Whereas, Overseer® Nutrient Budget 2 model has this capability for pastures and supplementary feed it does not yet give a robust description of nutrient flows from grazing a fodder crop. Currently, Overseer® does not allow the short term (less than 1 year) transfer of nutrients from a fodder crop block to adjacent pasture blocks to be calculated separately. In addition the default nutrient concentration for turnips, particularly K, are low (i.e. the default turnip K concentrations in Overseer® were lower than that found in turnip crops in the Manawatu survey (Section 3.5.1, Chapter 3) and in the trial conducted at No.4 Dairy Farm, Massey University (2% K vs 3.5 and 3.9% K, respectively).

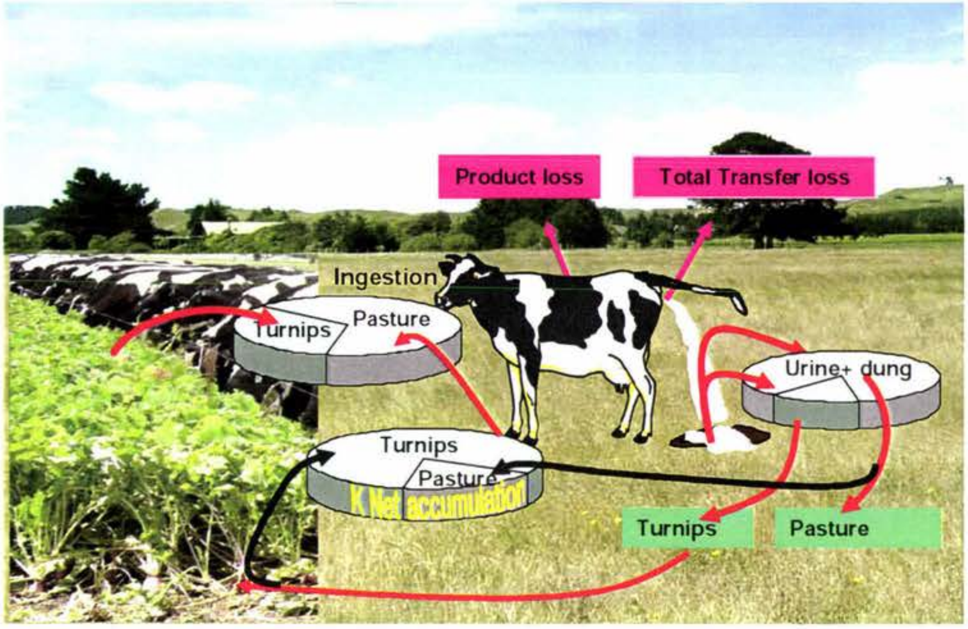

Figure 6.1 The potassium cycle of summer feed (turnips+pasture) in for dairy systems

Since Williams *et al.* (1990) modelled the transfer loss of K on a dairy farm; there has been no published information on the predicted K removal from grazed dairy pastures and certainly not from areas of fodder crop such as turnips. The simple mass balance model of Williams *et al.* (1990) was modified to estimate the daily transfer losses of K from the Massey University Dairy Farm No 4 caused by milking cows grazing a mixed diet of pasture and turnips.

6.3 Objectives

- To determine the amount of K ingested by cows from turnips and pasture paddocks in a summer period.

- To determine the product and transfer losses of K caused by the management of dairy cows and the total K returned in excreta to the turnip and pasture paddocks.
- To model the optimum grazing interval for a turnip block to maximize K removal.

6.4 Method (Calculation) assumptions

6.4.1 Case study Site No 4 Dairy

The studied farm represents one of the major dairying regions in NZ (Manawatu district). Table 6.1 gives details of the farm.

Table 6.1 General information for Massey No 4 Dairy farm for the summer period 2005-2006.

Manawatu (Dairy No 4 – Massey University)				
Summer rainfall period (2005/06)	306 mm			
N.Z soil group	Yellow –grey earth			
Order	Pallic soil			
Texture	Silt loam			
Number of cows	490			
Number of effective ha farm	192			
Mean milksolids/cow/ day[1]	1.0			
Liveweight gained kg/cow/d	0.5			
Nutrients	**N**	**Olsen P** ($ug\ g^{-1}$)	**Exchangeable** **K** (me 100g soil)	**Exchangeable** **Ca** (me 100g soil)
Initial soil test value		35	0.7	6.3
Fertiliser rate for turnips kg/ha	88	25	25	-

6.4.2 K loss model

The K loss model estimates the amount of K lost daily in animal product, in transfer to unproductive areas and K returned via dung and urine to the grazing areas. In the absence of more detailed information the model allocates excreta K to unproductive areas and grazing areas based on the proportion of time a cow spends in these areas. This assumption was also made by Williams *et al.* (1990). The model accounts for the grazing time for turnips, pasture and time out of paddock (raceways and milking shed/yards) in 24 hour period. The details of the equations involved are given below.

6.4.3 The development of parameters and algorithms in the model

6.4.3.1 K ingested by cows

The amount of K ingested was determined daily according to the cow's diet. In the studied farm, the cow's daily dry matter intake was comprised of 25% of turnips and 75% of pasture. Assuming that the respective K content in each feed was 3.90 % and 2.56 % respectively, then 34% of the dietary K was derived from turnips and 66% from pasture. The default K concentration for turnips was the average K concentration of turnip crops surveyed in the Manawatu district (Chapter 3).

The amount of K ingested by the cow from turnips is calculated from equation 1:

(1) $TuKI = TDM * (TK) / 100$

Where TDM = the daily dry matter ration of turnips per cow (kg DM/d).

TK = is the total K concentration of turnips (default 3.9% DM)).

The amount of K ingested by a cow from pasture is given in equation 2:

(2) $PKI = PDM * (PK) / 100$

Where PDM = the daily dry matter ration of pasture per cow (kg DM/d)

PK = is the total K concentration of pasture (default 2.6% DM))

The total K intake per cow per day is given in equation 3:

(3) $TKI = TuKI + PKI$ (kg K/cow/day)

6.4.3.2 K product losses

The amount of K lost from the farm via animal products is the sum of the losses that occur in milk-solids and live-weight gained by the cows (Table 6.2). These components were calculated separately (Equations 4 and 5) based on mean data for milk-solid production per day and milk-solid content in late lactation (Jan – March) and mean cow live-weight gained/day (Table 6.1).

Table 6.2 The default K concentrations for feed and products used in the simple K balance model (Summer period 2005/06)

	Milk[2]	Meat[2]	Pasture[1]	Turnips[1]	Grass silage[2]
			%		
N	0.6	2.2	2.89	1.87	2.56
P	0.103	0.64	0.41	0.49	0.29
K	**0.13**	**0.15**	**2.56**	**3.88**	**2.20**
Mg	0.01	0.05	0.24	0.33	0.18
Ca	0.13	1.4	0.47	1.58	0.68
Protein[3]	3.7				
Milk fat[3]	5.0				
Milk solids[3]	8.7				

1: The average turnips and pasture K concentrations are based on actual measurements on the No.4 farm
2: The average milk, meat and grass silage nutrient concentrations are taken from Holmes et al., 2002
3: The average protein, milk fat and milk solids nutrient concentrations are taken from Holmes et al., 2002

The amount of K lost by product loss of milksolids per day per cow is given in equation 4:

(4) $PLms = MS * (MsK / 100)$

Where MS = milksolids produced per day per cow mid-lactation (Feb-March) (kg MS/cow/d)

MSK = Mean concentration of K in the milk solids (default 0.13%MS)

The amount of K lost by product loss as live-weight gained (body tissue) per cow per day is given in equation 5:

(5) $PLmt = LwG * (LwK) / 100$

Where LwG = Live-weight gained per day per cow mid-lactation in summer period (Feb-March) (default 0.5 kg/cow/d)

LwK = Concentration of K in the body tissue (default 0.15%Lwt)

The total amount of product K losses is the sum of the losses produced by milk-solids and live-weight gained per cow per day given in equation 6:

(6) $TKPL = PLms + PLmt$ (kg K/cow/day)

6.4.3.3 K transfer losses

The amount of K transfer losses from the farm takes into account the destiny of excreta (dung and urine) and the time that the cows spend in raceways, milking shed and collecting yards (Table 6.3). These components were calculated separately (Equations 7, and 8) based on the difference of total K intake and total K product losses (milk and meat) by the average time that cows spend in the turnip and pasture paddocks at 24 hours basis.

The amount of transfer K loss in the raceways per cow per day is given in equation 7 (kg K/cow/day):

(7) $TLrw = (TKI - TKPL) * ART / 24$

Where $(TKI - TKPL)$ = total K returned in excreta per cow per day and ART = Mean time (h) spent by cows in the race ways result of the average time that the first cow + the last cow spend in the raceways for twice a day milking. (For the No. 4 Dairy this was 0.8 h);

24: number of hours per days.

The amount of transfer K losses in the milking shed and collecting yards per cow per day is given in equation 8: (kg K/cow/day)

(8) $TLmc = (TKI - TKPl) * AMT / 24$

Where AMT = Mean time (h) spent by cows in the milking shed & collecting yards; result of the average time that the first cow + the last cow spend in the milking shed & collecting yards in two milkings (For the No. 4 Dairy this was 2.6 h)

6.4.3.4 K returns in excreta

The total amount of K excreted by cows is the difference between the amount of total K intake from turnips and pasture and the total animal products losses.

The total amount of K that was lost by transfer to unproductive areas is based on the amount of time that the dairy cows spend in these areas (Williams et al., 1990). For example, a cow in one milking day can spend on average 1 hour on race ways and 2.5 hours in the milking shed, thus the cow could spend 15 % of day in unproductive areas (Table 6.3) therefore, 15 % of the excreta would be deposited there (Table 6.4). Time in the milking shed represents 11% of the transfer loss this is returned to the farm area allocated for FDE application.

The amount of dung and urine K deposited in the turnip paddock (kg K/cow/day) is given in equation 10:

(10) $RDUTp = (TKI - TKPL) * TGT / 24$

Where TGT = grazing time (h) spent by cows in the turnips paddocks

The amount of dung and urine K deposited in pasture paddock (kg K/cow/day) is given in equation 11:

(11) $RDUPp = (TKI - TKPL) * APT / 24$

Where APT = Grazing time (h) spent by cows in the pasture paddocks: $[24 - (ART + AMT + TGT)]$

6.4.3.5 Net Return per cow/day

The K returned in dung and urine per cow/day to turnip and pasture paddocks was estimated separately. It is based on the difference of the total K ingested on the diet (turnips + pasture) and the total product losses and the actual time the cows spent grazing in the turnip and pasture paddocks (RDUTp & RDUPp)(see equations 10 ,11, 12 and 13).

The net amount of K accumulated (kg K/cow/day) in turnip paddock is given in equation 12:

(12) $KAcTp = [RDUTp - (TDM * (TK) / 100)]$

The net amount of K accumulated (kg K/cow/day) in pasture paddock is given in equation 13:

(13) $KAcPp = [RDUPp - (PDM * (PK) / 100)]$

6.4.3.6 Net Returns per ha

To convert the units of (kg K/cow/day) to K removed or deposited per hectare (kg K ha^{-1}) was necessary to determine the number of cow-days required to graze a hectare of turnips. Therefore, the total yield turnips (8000 kg DM ha^{-1}) multiplied by a utilization factor (0.85 = 85%) was divided by the daily turnip intake per cow (TDM kg See Eq.14).

The net K returned to turnips and pasture paddocks was obtained by multiplying the total cow-days/ha and the net return of K to turnips and pasture per cow/day (Eq.15 and 16).

To determine the number of days for a herd to graze 1 ha of turnips the cow days are divided by herd size (Eq.17). For example, 3.5 days were needed for 490 cows to graze 1 ha of turnips with 8000 kg DM ha^{-1}.

The area of pasture required whilst grazing 1 ha of turnips was calculated by multiplying the herd size by the per cow pasture intake and the days taken to graze 1 ha of turnips divided by the grazeable pasture cover (Eq.18). If the grazeable pasture cover of the No 4 Dairy farm in this period is assumed to be 1800 kg DM ha^{-1}; therefore, 11 ha of pasture will be required to be grazed with 1 ha of turnip crop over a period of 3.5 days.

The number of cow-days per ha of turnip paddock is given in equation 14:

$$(14)\ \#\, cow-days/ha = \left[TDMY * UF \big/ TDM\right]$$

Where TDMY = Turnip yield kg DM ha-1 (at No.4 Dairy this was 8000 kg DM)

UF = Utilization factor (default 0.85) during grazing of turnip crops

TDM = the amount of turnip dry matter intake per cow/day

The net amount of K accumulated per ha of turnip paddock is given in equation 15:

$$(15)\ KAcTp/ha = (\#\, cow-days/ha) * RDUTp\,(kg/cow/day)$$

The net amount of K accumulated per ha of pasture paddock is given in equation 16:

$$(16)\ KAcPp/ha = (\#\, cow-days/ha) * RDUPp\,(kg/cow/day)$$

The number of days for a herd to graze one ha of turnip paddock is given in equation 17:

$$(17)\ TGD/ha = \left[\#cow-days/ha \big/ HSF\right]$$

Where HSF = Herd size farm (at No.4 Dairy this was 490 cows)

The number of pasture hectares needed to graze one ha of turnip paddock is given in equation 18:

(18) $TPha = \left[(HSF * PDM * TGD) / PC \right]$

Where PC = grazeable pasture cover (at No.4 Dairy this was assumed to average 1800 kg DM ha^{-1})

6.5 Boundary conditions of variable inputs and inputs for No. Dairy

6.5.1 Daily intake of turnips

Cows beginning to graze a turnip crop should have an acclimatisation period slowly increasing turnip intake. The range of grazing times for a turnip crop may vary from 1.5 to 4 hours per day; of course it depends on turnips and pasture availability. A maximum daily ration of 4 kg turnips DM can be eaten by one cow in three hours (Dexcel, Clark Dave. Person. comm. 2006).

Some studies have demonstrated that further increase in the feeding rate of turnips per day (more than 4 kg DM/cow/day) did not increase milk-solid production (Clark *et al.*, 1997; Clark *et al.*, 1996; Harris *et al.*, 1998). Moate *et al*, (1998) also found that when cows were fed with 6 kg of turnips/day; milksolid production was the same as it had been when 4 kg DM had been fed. Therefore, cows could have achieved their maximum intake at one grazing. However, these studies showed negative impacts in animal health when the cows were feeding at rate of 5, 6 or 8 kg DM/day.

Table 6.3 Assumptions used in the simple K balance model, based on information from the Massey University No.4 dairy farm in the summer period 2005/06.

Time in raceway/milking		
t1(hours)	First cow	0.3
t2 (hours)	Last cow	0.5
Average time/day		**0.8**
Time in shed and yards		
t1(hours)	First cow	0.4
t2 (hours)	Last cow	2.0
Average time/day		**2.4**
Yield turnip kg DM/ha		8000.0
Turnips allowance		
Time grazing turnips (h)		3.0
daily turnip intake kgDM/cow		4.0
daily grass silage intake kgDM/cow		0.0
Pasture allowance		
Time on pasture (h)		17.8
daily pasture intake kgDM/cow		12.0
Daily Total DM intake kg/animal		**16.0**
# of cows		490.0
# of ha		192.0
Liveweight gained kg/cow/d		0.5

6.6 Results

6.6.1 Case study summer grazing turnips at No. 4 Dairy

The model was used to estimate K losses and the K returns per cow and per hectare of turnips (8000 kg DM ha^{-1}) grazed at the Massey No 4 dairy farm (input data shown in Tables 6.1, 6.2 and 6.3). The model out puts are shown in (Table 6.4). When the daily cow dry matter intake was comprised of 12 kg DM pasture and 4 kg DM turnip DM, the total daily intake of K is 0.463 kg K/cow. The largest proportion (66%), is derived from the pasture at 0.307 kg K/day. Despite the lower (25%) DM intake from turnips, the K ingested from turnips was 34% of the total K intake. This was because turnips had higher K concentrations in their tissues (3.90 %) compared with pasture (2.6%).

Excreta returned to paddocks (0.388 kg K/cow/day) makes up 84% of K intake but as cows grazed turnips for only 3h per day then only 14.4% (0.056kg K/cow/day) of this was returned to the turnip paddock. As K ingested from the turnip paddock was 0.156 kg K/cow/day the turnip paddock K is depleted at a rate of 0.100 kg K/cow/day. If 490 cows take 3.5 days to graze per ha^{-1} of turnips then the turnip paddock is depleted by 170 kg K ha^{-1}. This results in a net positive return to pasture of 42 Kg K per ha turnips grazed. If grazeable pasture cover is 1800kg ha^{-1} then 490 cows eating 12 kg DM/day will require 11.3 ha^{-1} of pasture whilst grazing 1 ha^{-1} turnips (8000kg DM ha^{-1}) and the net K accumulation rate of the pasture is 3.7 kg K ha^{-1}.

Table 6.5 Daily transfers of potassium calculated by the simple model and expressed per cow and per hectare of turnips (grazed in 3.5 days by 490 cows at 4kgDM/cow/day).

	kg K/cow/d	kg K/ha of turnips eaten
Turnip intake	0.156	265
Pasture intake	0.307	522
Total K intake	**0.463**	**787**
Product loss		
PL milk	0.015	25.4
PL meat	0.001	1.3
Total K product losses	**0.016**	**27**
Transfer losses		
TLrw (raceways)	0.015	25
TLmc (milking shed/yards)	0.045	76
Total K transfer loss	**0.060**	**101**
K Returns in excreta		
RDUTp (turnip paddock)	0.056	95
RDUPp (pasture)	0.332	564
Net returns		
KAcTp (turnip paddock)	-0.100	-170
KAcPp (pasture)	0.025	42

PL: product losses; TLrw: transfer losses in raceways; TLmc: transfer losses in milking shed and collecting yards; RDUTp: Return of dung and urine in turnip paddock; RDUPp: Return of dung and urine in pasture paddock; KAcTp: Potassium accumulated in turnip paddock; KAcPp: Potassium accumulated in pasture paddock.

This simulation with the current information of the Dairy Farm No 4 shows that turnips crops are able to deplete K in short term from turnip paddocks without altering the grazing management of the whole farm.

6.6 2 General application of the model

6.6.2.1 Reduction of K transfer loss by reduced milking time

Transfer losses are a function of the time spent by cows in unproductive areas; therefore, the more time that the cows spend in these areas, the higher the K transfer loss. For instance, if a cow in one milking day which spends 3.2h compared with 1.6 h in the unproductive area, the cow will deposit 13.3 % and 6.7 % of the potassium returned via dung and urine in these areas.

To reduce the amount of nutrients which go to the farm dairy effluent and re-application to effluent paddocks, the ideal is to reduce the time spent by cows in the milking shed and collecting yards. Therefore, farmers have to plan carefully the movement and milking time of the herd during the day. A novel strategy in the herd management to reduce the milking time is to divide the size of the herd into small mobs (LIC, 2005). For instance, a farmer's experience in Waikato reduced the milking time of 500 cows from 4 to 1.5 hours (Livestock improvement, News and publications, 2005).

For example, at the Massey No 4 dairy farm during the experimental period (2005/06), the cows on average spent 2.4 hours per day (twice a day milking) depositing 10% of the excreta in the milking shed and collecting yards. The current area used for FDE application (14 ha) is only 6% of the whole effective farm area thus excessive K deposition on this area is expected. The model was used to estimate the K application rate to the effluent paddock (Table 6.5).

With 1 mob size of 490 cows and an average time in shed and yards of 2.4 hours and at 14 ha^{-1} for the effluent block the application rate of K was around 439 kg K ha^{-1} (Table

5.5). If the area is increased from 14 to 20 ha^{-1}, the K application rate reduces by 30%. When the herd is divided into two mobs and milking time is reduced to an average of 1.0 hour, then the K application rate to the effluent block is reduced by about 60%. Information on the impact of reducing milking time and increasing effluent area plus the amount of K potentially removed by grazing turnips (170 kg K ha^{-1}) could give some guidelines to the farmer for determining how many cropping years would be necessary to achieve a balance between soil nutrient and pasture requirement.

Table 6.5 Estimated K accumulation in the effluent block according to the milking time when the herd is in one mob of 490 or is divided into 2 mobs of 245 cows each.

Mob size	**Time[1]**	**Effluent Block Size (ha)**	
		14	**20**
		K kg/ha/y	
490	2.4[2]	439	307
245	2.0	365	256
245	1.5	274	192
245	1.0	183	128

1: The time that the cows spend in the milking shed and collecting yards
2: The current time in the milking time of the Farm No 4 with one mob of 490 cows.

6.6.2.2 Net transfer of K from turnip paddocks depends on time allowed for grazing

In general, the amount of K transferred to the pasture paddocks from the turnips paddocks depends on the time the cows are grazing the turnips (Table 6.6). Therefore, as grazing time increases on the turnip crops the K transferred from turnip paddocks and to pasture per ha of turnip grazed will drop.

The amount of K transferred to the pasture paddocks will decrease or increase depending on the daily turnip intake (Table 6.6, A & B; see table footnote) and the adjustment of the grazing time spent by cows in turnip paddocks. For instance, in the strategy A if time spent on turnip paddocks to consume the 4 kg DM daily ration is extended from 3 to 6 hours, the net amount of K transferred to pasture per ha of turnip grazed will be reduced dramatically (Table 6.6).

On the other hand, in the strategy B when longer turnip grazing times are associated with greater allocation of daily turnip DM (Table 6.6), the K transferred (kg ha^{-1}) from turnip paddock decreases only slightly and the K transferred to pasture per ha of turnip grazed increases. Therefore, the number of cow grazing days allocated per hectare of turnips affects the amount of K transferred from turnips, and the interaction of the two factors (cow-days/ha and allocation of turnip DM) influences the amount of K transferred to the pasture/ha of turnip grazed.

Table 6.6 Estimated K transferred from one hectare of turnips to pasture when time spent by cows in the turnip paddock (A) and time plus dry matter allocation (B) increases

A .Constant allocation of turnip DM at 4kg DM/cow/d			B. Variable allocation of turnip DM			
Time Spent in turnip paddock	K transferred (kg/ha^{-1})		Allocation of turnip DM	Cows-days/ha	K transferred (kg/ha^{-1})	
(h)	From turnips	To pasture/ ha of turnip grazed			From turnips	to pasture/ha of turnip grazed
3.0	170	42	4	1700	170	42
3.5	154	26	4.7	1475	168	57
4.0	138	20	5.3	1275	166	67
4.5	123	-6	6.0	1133	164	75
5.0	107	-21	6.7	1020	163	81
5.5	91	-37	7.3	927	161	85
6.0	75	-53	8.0	850	159	89

A: Modifying grazing time with a constant intake of turnip (4 kg/cow/day)

B: Modifying grazing time and allocation of turnip DM/cow/day

Using the information presented in Table 6.6 and variable assumed summer pasture covers (Table 6.7), the number of hectares of pasture needed for grazing varies greatly due to changes in the number of cow-grazing days per hectare of pasture. For example, the information in Table 6.7 was produced using a grazing time in the turnip paddock of 4.5 hours with the cows consuming 16 kg of Total DM/day with either 4 or 6 kg of DM turnips/cow/day and a turnip yield and a utilization factor of 8000 kg DM ha^{-1} and 0.85, respectively.

When the pasture cover increases, the area of pasture grazed decreases and there is no net transfer of K to the pasture (Table 6.7). Thus, the farmer should plan a K fertilization policy for the pasture. If however the cows are fed turnips at 6 kg DM, when the pasture cover increases, the area of pasture grazed decreases and there is net transfer of K to the pasture (Table 6.7) reducing the K fertiliser required on the pasture land.

Table 6.7 Estimated area (ha) to graze to transfer K to pasture paddocks per ha of turnip grazed (Turnip yield = 8000 kgDM ha^{-1}.

	4 kg turnips/day		6 kg turnip/day	
Assumed pasture cover	1700 cow/days 4.5 hour grazing		1133 cow/days 4.5 hour grazing	
DM/ha	hectare to graze	K kg/ha	hectare to graze	K kg/ha
1400	14.6	-0.38	8.1	9
1600	12.8	-0.44	7.1	11
1800	11.3	-0.49	6.3	12
2000	10.2	-0.54	5.7	13
2200	9.3	-0.60	5.2	15
2400	8.5	-0.65	4.7	16
2600	7.8	-0.71	4.4	17
2800	7.3	-0.76	4.0	19
3000	6.8	-0.82	3.8	20
3200	6.4	-0.87	3.5	21

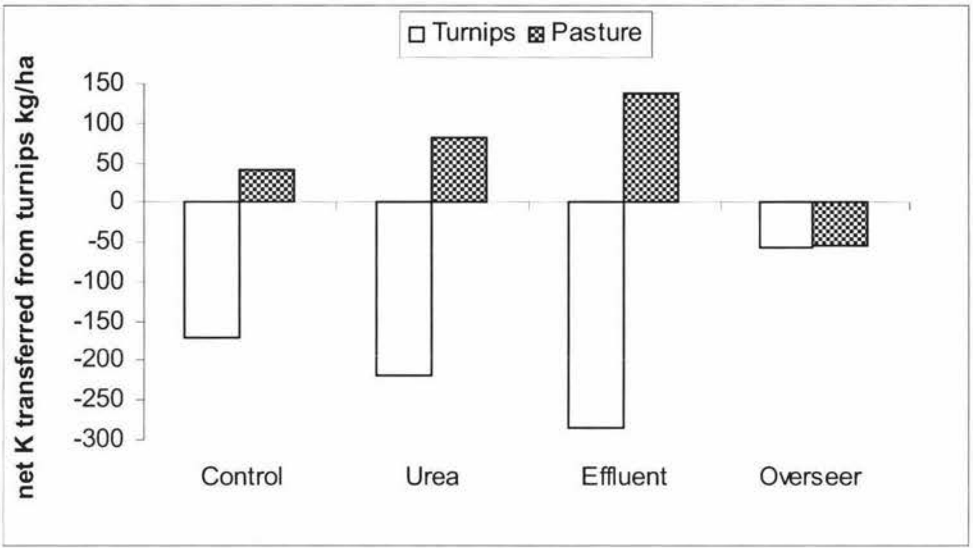

Figure 6.2 Estimated net K transferred from turnips paddocks to pasture paddocks per ha of turnip grazed as plant K concentration varies with fertiliser treatment (Control: 3.88% K, Urea: 4.66% K; FDE: 5.81% K)

6.6.2.3 Influence of Turnip K concentration on rate of K transfer

In the field trial (Chapter 4), turnips had different K concentration in their tissue (leaves and bulbs) depending on fertiliser treatment (Control: 3.88% K Urea: 4.66% K; FDE: 5.81% K). Therefore, the simple K model (using the default settings given in Table 6.3) was used to determine the net K returned from turnips to pasture per ha of turnip grazed with the K concentration being varied as per fertiliser treatment. The model output (Figure 6.2) showed that turnips from the urea and FDE treatments can transfer K at 26 and 65 % more than the control treatment. The default turnip K concentrations (2%K) from the Overseer® Nutrient Budgets model was used to compare the amount of K removed at a turnip yield of 8000 kg DM ha^{-1}, the outcome proved that Overseer® model is underestimating by about 66% the potential K transfer that turnip crops have in the lower part of the North Island.

6.7 Conclusions

A simple model was constructed that simulated the losses and net returns of K generated by cows grazing a mixed diet of turnips and pasture.

This model predicted that the grazing of a summer crop of fodder turnips can be managed to reduce soil K concentrations in land receiving FDE, with transfer of significant K to pasture paddocks.

To avoid recycling large amounts of K to the FDE treated land and maximise the K returned to pasture land the model indicated key management strategies were:

- Milking times should be minimised e.g. dividing the herd into smaller mob sizes.
- Grazing time to consume the allocated turnip dry matter should be minimised.
- Fertiliser treatment can be used to maximise K uptake by the turnip crop.

6.8 References

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Summary

In an effort to minimise nutrient losses to waterways under land application of farm dairy effluent (FDE), Regional Councils in New Zealand restrict the application of FDE to rates equivalent to 150 – 200 kg N ha^{-1}. However, when FDE is irrigated at these rates, large quantities of K are also applied, As a result, K is accumulating in the soil-plant system on FDE treatment areas on many dairy farms. The pasture grown on K-enriched soils poses serious risks to animal health. One obvious remedy to this difficulty is to increase the size of the FDE treatment area. However, expanding the FDE area is likely to be expensive and may not always be practicable. In some cases, FDE may need to be applied to the entire farm if application rates of K are to match maintenance requirements. A more novel solution to this problem is the use of crops with high K uptake, such as turnips, to harvest K. In turn, the K extracted by the turnips could then be redistributed to other parts of the farm by grazing cows. Turnip crops have the additional advantages of providing supplementary feed and playing a role in pasture renewal programmes.

The major objective of this thesis was to provide more information on the role that a summer turnip crop could play in redistribution of K from soils that have been enriched with K by FDE application.

To achieve this objective, firstly a survey of the yield and K uptake by turnip crops grown in the Palmerston North region was carried out (Chapter 3). The yields of the surveyed turnip crops ranged from 8 and 17 t DM ha^{-1} (growing from November 2005 – March 2006). All of the crop yields were greater than the economic break-even yield (7 ton DM ha^{-1}) for turnips grown in a dry year. The survey crops took up large quantities of K, indicating the suitability of turnip crops for soil K removal.

A field trial was conducted (Chapter 4) to study the patterns of turnip growth and K and N uptake. The treatments at the trial site were; control, (basal dressing of 38 kg N ha^{-1}

at sowing), urea (38 kg Nha^{-1} at sowing plus a side-dressing of 46 kg N ha^{-1} at 40 DAS) and FDE (38 kg N ha^{-1} at sowing plus 57 kg N ha^{-1} in 50 mm of effluent which was irrigated in 10 mm events between 41 and 54 DAS). The field trial supported the findings from the survey: turnip crops of moderate yields can remove large amounts of K. The turnips (cv Barkant) grown on a Pallic soil with optimum soil nutrient contents and basal fertilisation (38 kg N ha^{-1}, 25 kg P ha^{-1} and 25 kg K ha^{-}1) yielded 8 t DM ha^{-1} (control treatment) at 100 DAS. The yield on the FDE treatment was significantly greater than the control at 75 DAS. However, at the final harvest (100 DAS), there were no significant differences between yields of any of the treatments. Nevertheless, with the extra N, applied as nitrogen and FDE, turnips reached a yield of 8 t ha^{-1} earlier. The additional N applied in the urea and FDE treatments significantly increased K uptake on these treatments relative to the control at both 75 and 100 DAS.

The leaves on all treatments achieved maximum yield at the harvest on 75 DAS. Between 75 and 100 DAS, leaf yield on all treatments decreased as leaves senesced and died. K uptake by leaves was much greater than that by bulbs. Consequently, as the leaf yield declined between 75 and 100 DAS, so did total K uptake by turnips. This suggests that the timing of grazing will be important if the removal of K from FDE areas is to be maximised. Also nitrogen availability played a major role in yield and K uptake. Most crop nitrogen was derived from the mineralization of soil N. A dynamic crop N model is required to estimate this contribution of soil to crop uptake so that excessive N fertiliser is not applied.

In Chapter 5, the crop model N-able was employed to further explore N dynamics in the soil under turnips at the field trial. N-able predicted that substantial quantities of N were made available to the turnips by mineralization and only a small amount N applied at sowing (38 kg N ha^{-1}) was required to obtain maximum yield.

In Chapter 6, the transfer of K from the turnip paddock (part of a FDE treatment block) to other parts of the farm via the grazing cow was simulated using an adaptation of Williams et al. (1990) mass balance model of K transfer. The model simulation of cows on a mixed diet of 4kgDM turnips and 12 kg DM pasture predicted that the grazing of turnips would result in the net transfer of significant quantities (>170 kg K/ha) of K from land growing turnips to other paddocks on the farm.

The overall conclusion of the 4 separate pieces of work the survey, the field trial, evaluation of the nitrogen fertiliser requirement and the K transfer model is that Barkant turnip can be grown and fed to dairy cows as a profitable summer crop that when grazed, can result in net soil K transfer from the turnip paddock to pasture paddocks on the farm. To cause net transfer to occur the allocated turnip dry matter must be grazed in the shortest time possible and the cows returned to pasture after short milking times.

Further work

During the analysis of the current research, there have been some areas which were difficult to cover:

- Overseer® nutrient budget was not able to forecast accurately a K budget for fodder crops such as turnips because the model has default K concentrations for turnips that are too low and uses an annual time step. It would be helpful if Overseer® nutrient budgets software was recoded:
    - to take user defined herbage or fodder %nutrient content and
    - to simulate monthly changes in paddock management.

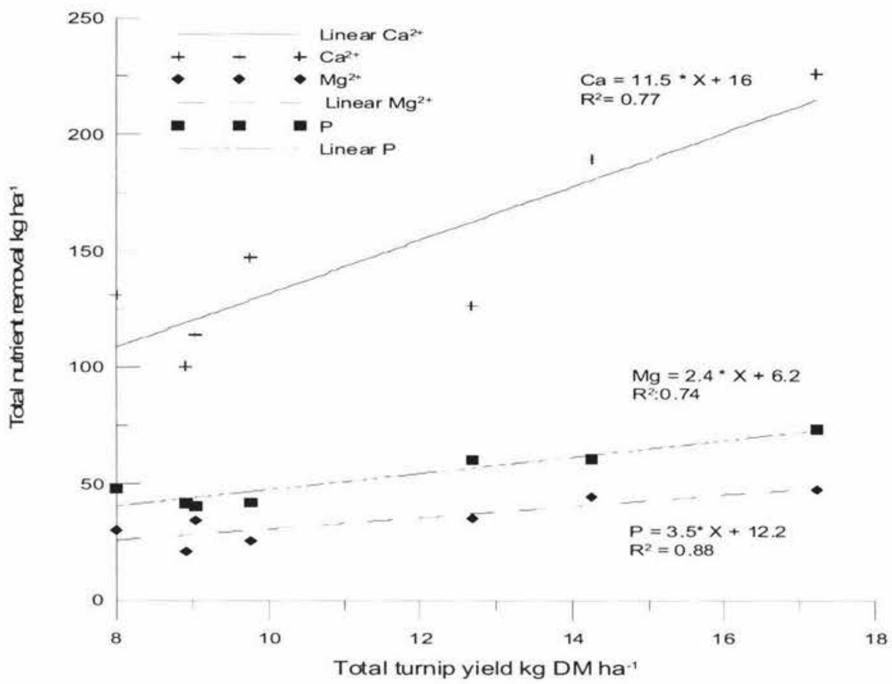
- To obtain a good simulation of turnip yield by the N-able model modification to the turnip growth equation from a 'J' to an 'S' type curve is required to fit with observed data.

- More extensive field data is required on turnip and pasture yields and nutrient concentrations when grown on FDE blocks. Only then will appropriate crop nutrient concentrations be generated for dynamic nutrient transfer modelling.

- In addition a full nutrient balance, including crop uptake and drainage N and K loss should be carried out to determine the environmental impact of a summer turnip crop followed by pasture renovation.

Appendix

Apendix 3.1. Total nutrient removal and turnip yield for Ca, Mg and P in Turnip crop surveyed in the Manawatu Region, during the season Nov, 2005 – Mar, 2006.



Apendix 4.1. Dry matter production of bulbs and shoots in turnip Var. Barkant. Farm No 4 – Massey University.

		Bulbs			Shoots		
				ton DM. ha^{-1}			
Harvest	days	Control[a]	Urea[b]	Effluent[c]	Control	Urea	Effluent
[ns] 1st	43	0.14	0.1	0.17	1.66	1.69	1.88
[ns]2nd	50	0.58	0.64	0.68	3.43	3.28	3.59
[ns]3rd	58	1.06	1.19	1.6	3.94	5.21	5.07
4th	64	1.36b*	1.76b	2.32a	3.83b	4.84b	5.55a
5th	75	2.17	1.94	2.27	5.10b	5.84ab	6.23a
[ns]6th	100	3.53	2.94	3.06	4.6	5.05	5.38
**LSD[4th]		0.64			0.96		
LSD[5th]					0.82		

* Values followed by the same letter in a given row do not differ significantly at the 0.05 level.
[a] Control: no fertiliser; [b] Urea: 46 kg N ha^{-1}at 40 days after sowing; [c] Effluent: 5 applications during the trial.
[1] Sowing date of the crop 06-11-05; ** Least significant difference (P<0.05); ns: no significance between treatments

Apendix 5.1 Input parameters for the Control treatment to simulate yield and N uptake

"Input Value"	"Definition"
0.35	"Field capacity ml water/ml soil 0-30cm layer"
0.38	"Field capacity ml water/ml soil 30-60cm layer"
0.40	"Field capacity ml water/ml soil 60-90cm layer"
5003 (05-06-06)	"Date when soil moisture deficit known"
0.00	"Soil moisture deficit mm "
5135 (05-10-13)	"Date when soil N sampled"
15	"layer size sampled cm"
1	"no of layers sampled"
66.00	"Mineral soil_N kg N/ha/sample layer 0 - 15cm"
5137 (05-10-15)	"Date of incorporation of previous crop debris"
2.50	"Dry weight of debris t/ha"
1.80	"%N in this debris"
24	"CROP:- Turnip "
5159 (05-11-06)	"Date of planting"
2.00	"Dry weight at planting kg/ha"
5259 (06-02-14)	"Date of harvest"
8.00	"Max Dry weight of total plant t/ha see detail"
5360 (06-05-26)	"Date when simulation ceases"
0	"Barrier to rooting depth cm"
1	"No of N applications (max=5)"
1	"No of treatment levels (max=20)"
5159 (05-11-06)	"Date when N applied"
38	"Amount of N applied kg/ha level 1 "
0	"IPORG=0 Debris removed/incorporated after TSTOP"
0	"Dry weight of debris t/ha level 1 "
0	"%N in this debris"
0	"No of applications of irrigation"
0.5	"Mineralisation rate kg N/ha/day"
11.8	"measured @ degrees C"
0.85	"Apparent recovery constant (REC)"
4	"Dry wt t/ha when roots in mid row point (WLRT)"
0	"Daily fractional disappearance of soil_N (BETA)"
0	"Soil_N kg/ha at which uptake is half max (KM)"
0.46	"Min conc of soil mineral_N kg/ha/cm (SMIN)"

* Julian years

Appendix 5.2 input parameters for the Urea treatment to simulate yield and N uptake

"Input Value"	*"Definition"*
0.35	"Field capacity ml water/ml soil 0-30cm layer"
0.38	"Field capacity ml water/ml soil 30-60cm layer"
0.40	"Field capacity ml water/ml soil 60-90cm layer"
5003 (05-06-06)	"Date when soil moisture deficit known"
0.00	"Soil moisture deficit mm "
5135 (05-10-13)	"Date when soil N sampled"
15	"layer size sampled cm"
1	"no of layers sampled"
66.00	"Mineral soil_N kg N/ha/sample layer 0 - 15cm"
5137 (05-10-15)	"Date of incorporation of previous crop debris"
2.50	"Dry weight of debris t/ha"
1.80	"%N in this debris"
24	"CROP:- Turnip "
5159 (05-11-06)	"Date of planting"
2.00	"Dry weight at planting kg/ha"
5259 (06-02-14)	"Date of harvest"
8.00	"Max Dry weight of total plant t/ha see detail"
5360 (06-05-26)	"Date when simulation ceases"
0 .00	"Barrier to rooting depth cm"
2	"No of N applications (max=5)"
1	"No of treatment levels (max=20)"
5159 (05-11-06)	"Date when N applied"
38.0	"Amount of N applied kg/ha level 1 "
5199 (05-12-16)	"Date when N applied"
46.0	"Amount of N applied kg/ha level 1 "
0.0	"IPORG=0 Debris removed/incorporated after TSTOP"
0.00	"Dry weight of debris t/ha level 1 "
0.00	"%N in this debris"
0.0	"No of applications of irrigation"
0.50	"Mineralization rate kg N/ha/day"
11.80	"measured @ degrees C"
0.85	"Apparent recovery constant (REC)"
4.00	"Dry wt t/ha when roots in mid row point (WLRT)"
0.0000	"Daily fractional disappearance of soil_N (BETA)"
0.00	"Soil_N kg/ha at which uptake is half max (KM)"
0.4600	"Min conc. of soil mineral_N kg/ha/cm (SMIN)"

Appendix 5.3 Input parameters for the FDE treatment to simulate yield and N uptake

"Input Value"	"Definition"
0.35	"Field capacity ml water/ml soil 0-30cm layer"
0.38	"Field capacity ml water/ml soil 30-60cm layer"
0.40	"Field capacity ml water/ml soil 60-90cm layer"
*5003 (05-06-06)	"Date when soil moisture deficit known"
0.00	"Soil moisture deficit mm "
5135 (05-10-13)	"Date when soil N sampled"
15	"layer size sampled cm"
1	"no of layers sampled"
66.00	"Mineral soil_N kg N/ha/sample layer 0 - 15cm"
5137 (05-10-15)	"Date of incorporation of previous crop debris"
2.50	"Dry weight of debris t/ha"
1.80	"%N in this debris"
24	"CROP:- Turnip "
5159 (05-11-06)	"Date of planting"
2.00	"Dry weight at planting kg/ha"
5259 (06-02-14)	"Date of harvest"
8.44	"Max Dry weight of total plant t/ha see detail"
5360 (06-05-26)	"Date when simulation ceases"
0	"Barrier to rooting depth cm"
5	"No of N applications (max=5)"
1	"No of treatment levels (max=20)"
5159 (05-11-06)	"Date when N applied"
38	"Amount of N applied kg/ha level 1 "
11.9	"Amount of N applied kg/ha level 1 "
12.1	"Amount of N applied kg/ha level 1 "
11.7	"Amount of N applied kg/ha level 1 "
21.4	"Amount of N applied kg/ha level 1 "
0	"IPORG=0 Debris removed/incorporated after TSTOP"
0	"Dry weight of debris t/ha level 1 "
0	"%N in this debris"
5	"No of applications of irrigation"
5197 (05-12-16) 10	"Amount of irrigation applied mm"
5199 (05-12-18) 10	"Amount of irrigation applied mm"
5206 (05-12-23) 10	"Amount of irrigation applied mm"
5212 (05-12-29) 10	"Amount of irrigation applied mm"
5212 (05-12-29) 10	"Amount of irrigation applied mm"
0.5	"Mineralization rate kg N/ha/day"
11.8	"measured @ degrees C"
0.85	"Apparent recovery constant (REC)"
4	"Dry wt t/ha when roots in mid row point (WLRT)"
0	"Daily fractional disappearance of soil_N (BETA)"
0	"Soil_N kg/ha at which uptake is half max (KM)"
0.46	"Min conc of soil mineral_N kg/ha/cm (SMIN)"

* Julian years

Appendix 5.4 Input parameters for simulating yield and N uptake without nitrogen as base.

"Input Value"	"Definition"
0.35	"Field capacity ml water/ml soil 0-30cm layer"
0.38	"Field capacity ml water/ml soil 30-60cm layer"
0.40	"Field capacity ml water/ml soil 60-90cm layer"
*5003 (05-06-06)	"Date when soil moisture deficit known"
0.00	"Soil moisture deficit mm "
5135 (05-10-13)	"Date when soil N sampled"
15	"layer size sampled cm"
1	"no of layers sampled"
66.00	"Mineral soil_N kg N/ha/sample layer 0 - 15cm"
5137 (05-10-15)	"Date of incorporation of previous crop debris"
2.50	"Dry weight of debris t/ha"
1.80	"%N in this debris"
24	"CROP:- Turnip "
5159 (05-11-06)	"Date of planting"
2.00	"Dry weight at planting kg/ha"
5259 (06-02-14)	"Date of harvest"
8.00	"Max Dry weight of total plant t/ha see detail"
5360 (06-05-26)	"Date when simulation ceases"
0.35	"Barrier to rooting depth cm"
1	"No of N applications (max=5)"
1	"No of treatment levels (max=20)"
5159 (05-11-06)	"Date when N applied"
0.01	"Amount of N applied kg/ha level 1 "
0	"IPORG=0 Debris removed/incorporated after TSTOP"
0	"Dry weight of debris t/ha level 1 "
0	"%N in this debris"
0	"No of applications of irrigation"
0.5	"Mineralisation rate kg N/ha/day"
11.8	"measured @ degrees C"
0.85	"Apparent recovery constant (REC)"
4	"Dry wt t/ha when roots in mid row point (WLRT)"
0	"Daily fractional disappearance of soil_N (BETA)"
0	"Soil_N kg/ha at which uptake is half max (KM)"
0.46	"Min conc of soil mineral_N kg/ha/cm (SMIN)"

* Julian years