Investigating the potential of kale to remove soil potassium accumulated from farm dairy effluent application

B.R. THOMPSON[1], D.R. STEVENS[1] and I. KNOWLES[2]
[1]*AgResearch Ltd., Invermay Research Centre, Private Bag 50034, Mosgiel*
[2]*Telford Rural Polytechnic, 498 Owaka Highway, Balclutha*
bryan.thompson@agresearch.co.nz

Abstract
Potassium (K) build up in soils is a side effect of prolonged farm dairy effluent irrigation, and can result in animal health issues. A kale crop was planted to investigate its potential to take up K applied in farm dairy effluent. Removing the crop at maturity and feeding it elsewhere is a management option to reduce the build up of soil K that occurs when farm dairy effluent is applied to land at K loading greater than maintenance requirements. As winter approaches soils tend to become wetter than field capacity reducing the opportunity for mechanical harvesting. We examined the trade-off between the potential to damage soil and achieving maximum yield. Kale K concentrations increased in a linear fashion ($P<0.001$) with the increasing rates of K input applied from 1.98 to 3.90 g K/100g DM with no effect on dry matter yields, but removing up to 499 kg K/ha. Maximum yield (13 t DM/ha) was reached in late May when mechanical harvesting was still possible with little or no potential damage to the soil regardless of sowing technique (conventional tillage versus direct-drilled). This demonstrates the potential of a kale crop to remove high levels of K in farm dairy effluent in a cut and carry system.
Keywords: sowing technique, soil resistance

Introduction
Feeding of pastures or supplements high in strong dietary cations such as potassium (K) to the transition cow causes an increase in the incidence of milk fever (Goff & Horst 1997). The utilisation of farm dairy effluent (FDE) as a nutrient resource can increase the amount of these strong dietary cations in the soil (when inputs are greater than maintenance requirements) and subsequently in pastures or crops grown from these treated soils. Quantities of K from FDE varies widely from farm to farm (Longhurst *et al.* 2000) and also throughout the year (Roberts *et al*. 1992). The concentration of K in FDE has increased over time due to less water use during washout and increased intensity of dairy farming (with more cows through the shed) (Longhurst *et al.* 2000). Longhurst *et al.* (2000) found that K levels in FDE vary widely (as with other nutrients) with an average concentration of 370 mg K/L of FDE.

Soils on the Telford Dairy Farm Unit, near Balclutha have been irrigated with FDE for the last two decades which has resulted in high soil concentrations of K (Quick Test K 32) occurring in some areas. The areas with raised K soil concentrations are not grazed during the transition period (3 weeks pre-partum to 3 weeks post-partum) to avoid any possible metabolic disorders associated with dietary cation/anion difference (DCAD). Land application of FDE at heavy K loading rates (in excess to maintenance requirements) to other parts of the farm spreads this problem, potentially rendering more of the farm unavailable around calving.

Using kale to remove K from the soil also requires harvesting and storage of the crop for feeding elsewhere. This means that harvesting machinery must be able to remove the crop when conditions suit to prevent soil damage and harvesting difficulties. One approach to reducing soil damage or extending the window of harvest opportunity may be using direct-drilling, rather than conventional cultivation (Vanags *et al*. 2004), maintaining the original strength of the soil.

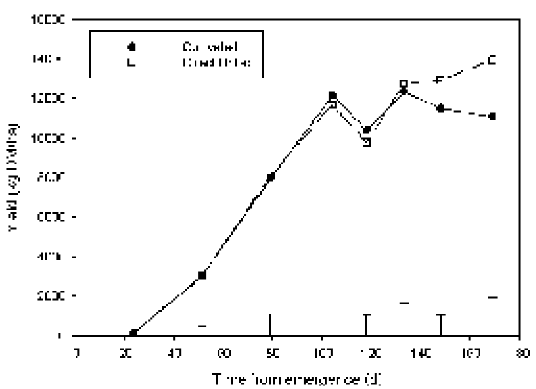
This trial investigated the potential of a forage kale (*Brassica oleracea* spp. *acephala*) crop to reduce high available K levels in the soil after 0, 2, 4 and 6 passes of the travelling irrigator used to apply FDE at the Telford Dairy unit. Soil physical properties and resistance to penetration for two sowing techniques were also investigated during autumn and early winter, to assess the potential to mechanically harvest the crop and remove K off the affected area. Trade-offs between kale yield and harvest dates and sowing techniques, and K concentration in the soil and sowing techniques were also investigated.

Methods
The experiment was carried out on the Telford Rural Polytechnic teaching farm (Lat. 46.2923 S, Long. 169.7299 E), Balclutha, in conjunction with the Telford Dairy demonstration farm project, that commenced in November 2008. The effects on kale yield of increasing rates of K in FDE were assessed in a 4 x 2 factorial design with four K rates (0, 80, 160 and 240 kg K/ha applied as muriate of potash) and two establishment techniques (conventional cultivation and direct-drilling) each replicated three times in 5 x 3 m plots. These K rates were equal to zero, two, four, and six

passes of the effluent irrigator as had been previously measured on the Telford Dairy unit (D. J. Houlbrooke pers. comm.). The growth of the crop, potential yield and soil strength was measured in a randomised block design comparing conventional cultivation with direct-drilling in eight replicates.

The paddock was double-sprayed 3 weeks apart, initially with Roundup Renew (5 L/ha, glyphosate 360 g a.i./L) and Granstar (40 g/ha, Tribenuron-methyl 750 g/kg) and secondly with Roundup Renew (2 L/ha, glyphosate 360 g a.i./L). Strips were ploughed on the 17 December 2008 then disced, levelled with Dutch harrows and rolled before direct-drilling and rolling. 'Caledonian' kale seed (5 kg/ha) was sown on 24 December 2008 with 300 kg/ha of Cropmaster brassica fertiliser (41.7, 46.2, 28.5 and 2.4 kg of N, P, K and S, respectively, plus 0.6% boron). Muriate of potash (KCl) (50% K) was applied (200 kg/ha) during March to increase K levels over the whole paddock as it was measured as being deficient in a kale herbage sample. The K treatments were applied as KCl in two applications on the 20th of February and the 20th of March to avoid plant damage. The soil type was a Te Houka deep silt loam classified as a Pallic soil using the New Zealand Soil Classification with an average pH of 5.8, Olsen P of 23, K Quick Test value of 3.4 and a incubation N of 187 kg/ha, as measured in March 2009 by NZ Labs, Ruakura.

Figure 1 The accumulation of dry matter yield of kale sown by direct-drilling or after conventional cultivation on 24 December.



Kale yield, soil strength and soil moisture to 30 cm was measured along two transect lines perpendicular to the sowing direction. Kale yield was measured monthly from January-March, and fortnightly from April-mid June using a single 1 x 0.3 m quadrat per plot. Sub-samples were taken back to the lab and dried at 60°C in a forced-air fan oven until a constant weight was reached.

Kale samples were analysed for chemical composition at the final harvest in June by NZ Labs, Ruakura. Soil chemical contents were also analysed at the end of the trial.

Soil strength was measured using a Scala dynamic cone penetrometer (Groundtest Equipment, Auckland) (Scala 1956) down to 30 cm to calculate soil resistance strength (MPa). Soil strength measurements were carried out periodically between April and June. Penetration data was converted to MPa using the formula adapted by Vanags *et al*. (2004).

Soil moisture content was measured in 10 cm increments down to 30 cm at each kale yield sampling. Samples were weighed pre- and post-oven drying to determine the moisture content. Soil bulk density and macroporosity were measured on 28th April at depths of 0-5, 15-20, and 25-30 cm using the methods of Drewry & Paton (2000).

Kale yield data were analysed using analysis of variance for each harvest, while data for the effects of K loading rate were analysed on the final harvest using analysis of variance (Genstat 2007). Analysis of soil resistance to penetration was performed on log transformed data using split-plot analysis of variance with time nested within treatment. This method was chosen because there was no evidence of autocorrelation (Genstat 2007).

Results

Kale yield did not differ significantly ($P>0.05$) between the two sowing techniques (Fig. 1) or between the two sites at any time and peaked at approximately 13 t DM/ha in early May. The application of extra K to the kale crop had no effect on kale yield (Table 1) but caused a significant negative linear decline ($P=0.04$) in DM content (13.3, 12.6, 12.7 and 11.7 % of DM for

Table 1 Effects of rate of K application on the yield and K uptake of a kale crop.

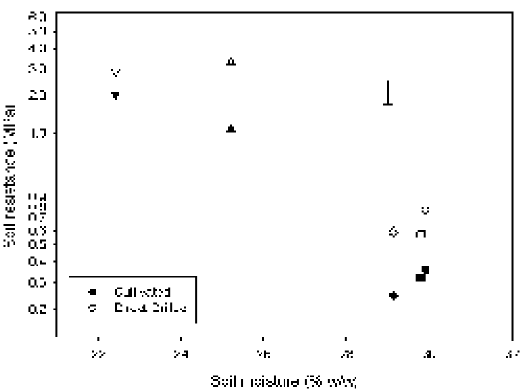
		K application rate (kg/ha)				
		0	80	160	240	SEM
Yield	(kg DM/ha)	12730	15280	14460	12650	1099
Dry matter content	(%)	13.3	12.6	12.7	11.7	0.50
Potassium content	(% of DM)	1.98	2.65	2.97	3.90	0.148
Potassium removed	(kg K/ha)	255	408	428	499	40

Table 2 Average soil physical properties for samples down to 30 cm for direct- drilled (DD) and cultivated (Cult) sowing treatments.

	0-5 cm		15-20 cm		25-30 cm		
	DD	Cult	DD	Cult	DD	Cult	SED
Dry bulk density (t/m^3)	0.98 d[1]	1.11 c	1.35 b	1.17 c	1.49 a	1.47 a	0.0261
Field capacity (% v/v)	44.4 a	39.9 c	39.3 c	42.1 b	36.5 d	37.6 d	0.802
Pores 30-300 microns (% v/v)	10.1 a	9.6 a	6.8 c	7.9 b	4.5 d	4.4 d	0.417
Pores >300 microns (% v/v)	7.8 a	7.9 a	2.0 c	5.2 b	1.6 c	1.5 c	0.778
Pores <30 microns (% v/v)	17.9 a	17.5 a	8.8 c	13.1 b	6.2 d	5.9 d	1.022

[1] Values with the same letter are not significantly different (P=0.05).

Figure 2 Cumulative penetration resistance of soil to 20 cm at different times in autumn for both cultivated and direct-drilled treatments as affected by soil moisture (data presented on a log transformed y axis).



treatments 0, 80, 160, and 240 kg of K, respectively). K application had a positive linear effect on K concentration (P<0.001, Table 1). The amount of K removed by the crop increased significantly (P<0.001) ranging from 255 kg K/ha with 0 kg K/ha applied to 499 kg K/ha with 240 kg K/ha.

The effects of cultivation method on soil moisture content varied significantly down the soil profile (P<0.001), being consistently higher at 0-10 cm in the direct-drilled treatments compared to conventional cultivation (29.1 versus 25.9%), but the trend reversed for 10-20 cm samples (23.5 versus 25.7%). Both treatments had similar soil moisture content at 20-30 cm (20.8%).

Soil physical properties (Table 2) differed down the soil profile with a significant (P<0.001) interaction between soil depth and treatment. The direct-drilled treatment had a lower bulk density at 0-5 cm and a greater bulk density at 15-20 cm than the cultivated treatment, while the bulk density at 25-30 cm was similar in both treatments. This effect was then repeated for soil water content at field capacity. The direct-drilled treatment also had a greater volume of medium sized pores (30-300 μm) in the 0-5 cm profile than the cultivated treatment, while the cultivated treatment had a greater volume of large pores (>300 μm) and small pores (<300 μm) in the 15-20 cm profile than the direct-drilled treatment.

Soil resistance differed significantly down to 20 cm for treatments (P<0.001) and sampling date (P<0.001) but this did not apply for depths between 20-30 cm. A significant interaction between treatment and time was found (Fig. 2) with the direct-drilled soils being stronger to 20 cm than the conventional cultivation soils at the first two measurement times, but not at the final three measurements (P=0.04). Soil moisture content provided a significant covariate effect (P=0.05).

Discussion

The kale yields recorded in this trial were similar to the potential that would be calculated by growing degree days (above 0^{o}C) (Brown *et al.* 2007), confirming that other environmental stresses such as drought and insect attack did not have a major impact on this crop. This highlights the rapid end to the growing season in this environment and confirms previous findings (Brown *et al.* 2007) that early sowing is an important feature of high yielding kale crops. The lack of a yield difference between establishment techniques again confirms the functionality of direct-drilling as a rapid and convenient establishment option that can allow ease of sowing when weather and soil conditions may prevent the use of conventional cultivation.

Kale demonstrated that it is capable of taking up available K from the soil reaching towards 500 kg/ha. Herbage K concentration of 1.98% in the control plots were similar to previous reports (Cornforth *et al.* 1978; Grace *et al.* 2000). A single silage harvest of 3 t of pasture may remove up to 105 kg K/ha at 3.5% K (Morton *et al.* 2004), while a whole crop cereal silage yielding 10 to 15 t/ha may remove between 200 and 250 kg K/ha depending on the crop (Khorasani *et al.* 1997). Kale yield was not affected by the differing quantities of K applied, with all treatments being above the recommended limiting requirements for growth, consistent with other research (Wilson *et al.* 2006).

The ability to take up large amounts of available K from the soil makes kale an ideal candidate for use in problematic areas where high K levels are of concern. The full potential to take up more K is untested as the relationship was linear and an upper limit was not found. This trial demonstrated that kale absorbed all of the K applied up to 240 kg/ha. The current effluent application system at Telford applies approximately 44 mm/ha at an average concentration of 375 mg K/L, resulting in average application rates of 165 kg K/ha. Even more K may be able to be harvested with earlier sowing as Brown *et al.* (2007) has shown sowing a month earlier would provide another 2 t DM/ha at this site, potentially removing another 70-80 kg K/ha.

To be successful at reducing the available K in the soil the kale would need to be harvested and utilised in a cut and carry system to avoid the excess K being re-applied to the soil by grazing *in situ*. This transfers the K to another area which can be managed by the farmer. A cut and carry system is only practical if machinery can be used at appropriate times for harvest, and so soils must be trafficable. Soil resistance to penetration was demonstrated to be considerably lower for cultivated soils down to 20 cm than for those direct-drilled, supporting the findings of Vanags *et al*. (2004). The lower soil resistance to penetration in the cultivated treatments can be attributed to reduced cohesiveness and the disruption of soil structure resulting from the cultivation while the direct-drilled treatments were comparatively undisturbed. This is reflected in the changed distribution of soil bulk density and soil pore sizes in the 0-5 and 15-20 cm profiles that were recorded.

Moisture content played an important role in determining soil resistance to penetration and as the season progressed and the soil moisture increased, the resistance decreased for both treatments. This decrease in soil resistance did not differ between treatments once field capacity was reached when damage to the soil may occur with trafficking. Analysis of the last 5 years of soil moisture data indicates that this region reaches field capacity between late April and mid May, depending on the season, so our recommendation for harvesting is around mid April. In this trial harvesting of the kale in mid April would have achieved near maximal yield while the soils in both establishment techniques would have allowed mechanical harvesting with minimal soil damage (direct-drilled 2.85 and cultivated 1.94 MPa penetration resistance).

To increase yields of kale and K removal planting earlier rather than harvesting later is recommended. This trial demonstrated the potential of kale to remove excess available K from the soil using a cut and carry system timed to minimise damage to soil structure without limiting crop yield. These results need to be confirmed by further research on soils that have accumulated high K after effluent application. The actual impacts of mechanical harvesting and their relationship to the soil resistance measurements taken also need to be confirmed.

ACKNOWLEDGEMENTS

The authors would like to thank Dairy NZ for financial support, Dr Roger Littlejohn for statistical analysis, and Telford farm and AgResearch Invermay staff for technical assistance.

REFERENCES

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

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

Drewry, J.J.; Paton, R.J. 2000. Effect of subsoiling on soil physical properties and dry matter production on Brown soil in Southland, New Zealand. *New Zealand Journal of Agricultural Research 43*: 259-268.

GenStat 2007. GenStat for Windows. VSN International Ltd, Oxford.

Goff, J.P.; Horst, R.L. 1997. Effects of the addition of potassium or sodium, but not calcium, to prepartum rations on milk fever in dairy cows. *Journal of Dairy Science 80*: 176-186.

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

Khorasani, G.R.; Janzen, R.A.; McGill, W.B.; Kennelly, J.J. 1997. Site and extent of mineral absorption in lactating cows fed whole-crop cereal grain silage or alfalfa silage. *Journal of Animal Science 75*: 239-248.

Longhurst, R.D.; Roberts, A.H.C.; O'Connor, M.B. 2000. Farm dairy effluent: a review of published data on chemical and physical characteristics in New Zealand. *New Zealand Journal of Agricultural Research 43*: 7-14.

Morton, J.D.; Roach, C.G.; Tong, M.J.; Roberts, A.H.C.

2004. Potassium in soil and pasture and leaching of cations on an allophanic soil in New Zealand. *New Zealand Journal of Agricultural Research 47*: 147-154.

Roberts, A.H.C.; O'Connor, M.B.; Longhurst, R.D. 1992. Wastes as plant nutrient sources: Issues and options. *In*: The use of wastes and by-products as fertilisers and soil amendments for pastures and crops. Eds. Gregg, P.E.H.; Currie, L.D. Massey University Fertiliser and Lime Research Occasional Publication Report 6.

Scala, A.J. 1956. Simple methods of flexible pavement design using cone penetrometers. *Proceedings of the second Australia-New Zealand Conference on Soil Mechanics and Foundation Engineering,* Christchurch, New Zealand. pp. 73-83.

Vanags, C.; Minasny, B.; McBratney, A.B. 2004. The dynamic penetrometer for assessment of soil mechanical resistance. *Super Soil 2004: 3rd Australian New Zealand Soils Conference*. http://www.regional.org.au/au/asssi/supersoil2004/s14/poster/1565_vanagsc.htm#TopOfPage

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