Forages for Reduced Nitrate Leaching

Monitor farm report

FRNL Sheep and Beef Monitor Farms

FINAL REPORT 2019

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AgResearch

Forages for Reduced Nitrate Leaching is a DairyNZ-led collaborative research programme across the primary sector delivering science for better farming and environmental outcomes. The aim is to reduce nitrate leaching through research into diverse pasture species and crops for dairy, arable and sheep and beef farms. The main funder is the Ministry of Business, Innovation and Employment, with co-funding from research partners DairyNZ, AgResearch, Plant & Food Research, Lincoln University, Foundation for Arable Research and Manaaki Whenua-Landcare Research.

Executive Summary

- One Sheep and Beef monitor farm had very low nitrate leaching across the farm on average (< 20 kg N/ha/yr) and reducing that average was very difficult, although productivity gains were possible within current leaching levels.

- One Sheep and Beef monitor farm had steadily increasing nitrate leaching across the farm for the duration of the FRNL programme (from 20 up to 53 kg N/ha/yr). This was led by a staged investment in spray (centre pivot) irrigation, increased stocking rates and a strong trend away from beef and towards winter grazing of dairy cattle.

- The greatest source of nitrate leaching from sheep and beef farms was noted in paddocks of forage crop used for winter grazing of adult cows or adult bulls for beef (up to 377 kg/ha/yr). This was very dependent on soil type, irrigation and time of year.

- Catch crops following the forage crops emerged as the method with the greatest potential to reduce nitrate leaching on sheep and beef farms. Establishment was challenging given the very cold and sometimes very wet conditions, but economically useful yields of the catch crops for making silage were evident in the field.

- Soil maps have proven a good tool to assist in choosing heavy soils for establishing winter crops to retard nitrate leaching and hold nitrogen for a subsequent catch crop. Not all farmers have adopted this innovation.

- Although promising in a research setting, plantain did not persist under current sheep and beef grazing management and therefore could not be expected to decrease nitrate leaching without substantial changes to current grazing practices.

- Diverse pastures were only transient under sheep and beef grazing and rapidly transform to grass-dominant swards.

- Growing maize and grazing it *in situ* has been an interesting innovation on Highlands farm. It is a low nitrogen forage crop consumed in late summer and early autumn and can be followed with Italian ryegrass or other crops and we expect it would result in minimal nitrate leaching. However actual leaching is unknown and grazing of maize is not considered in the Overseer model

- Plantain might be useful to reduce nitrate leaching from paddocks grazed in autumn, if forage crops like rape were established with a large proportion of plantain, but it was not possible to experimentally test this.

- Catch crops have the greatest potential to reduce leaching, but even with favourable establishment, they will cover slightly more than 10% of area of the farms studied and therefore mathematically will struggle to reduce leaching by 20% across the whole farm.

Introduction

This report summarises data collected from the commencement on the Forages for Reduced Nitrate Leaching (FRNL) project from January 2015 until June 2019 on both Highlands (Cannington) and Glengael (Parnassus) farms.

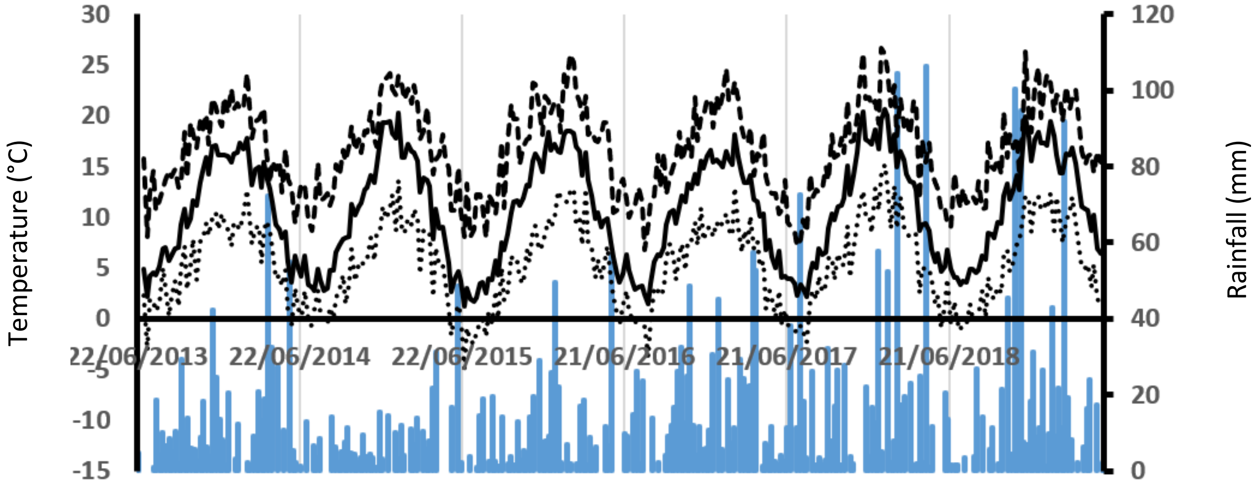
During the period, an initial monitoring project was established to determine pasture and forage crop production from the farms. When results from other projects within the wider FRNL program became available these were examined on the Sheep and Beef monitor farms. This included "catch crops" to capture nitrate from soils post-forage crops before leaching occurs. Plantain was found elsewhere to have several actions which lower the leaching of nitrate from soils when it is around 30% of the dry matter consumed. It was therefore of interest to examine plantain in pastures on the sheep and beef farms to see if the required proportion of dry matter could be attained and maintained. This report summarises the five years of the study and the highlights of the research.

Bill and Shirley Wright – Highlands

Climate

The figure below (Figure 1) shows the variability of rainfall during the six-year period to June 2019 while we have been monitoring Highlands. The weekly mean soil temperature is also shown along with maximum and minimum air temperatures. There is a clear seasonal rhythm in soil temperature which permits plant growth at a certain point depending on species, but soil moisture is the dominant determinant of plant growth on this dryland property. There were particularly low soil temperatures in 2015 and 2016 whereas in the winter of 2018 soil temperature was relatively warm. A warm wet soil in winter can increase the rate of nitrification and therefore leaching of nitrate. Summer and autumn of 2018 were relatively wet, and it was so wet early in the summer of 2019 that newly sown maize and fodder beet were drowned. For the research team this has given us a good range of conditions to study the farm, though we do sympathise with the farm owners continually adjusting to cope with the variable rainfall without irrigation on the farm.

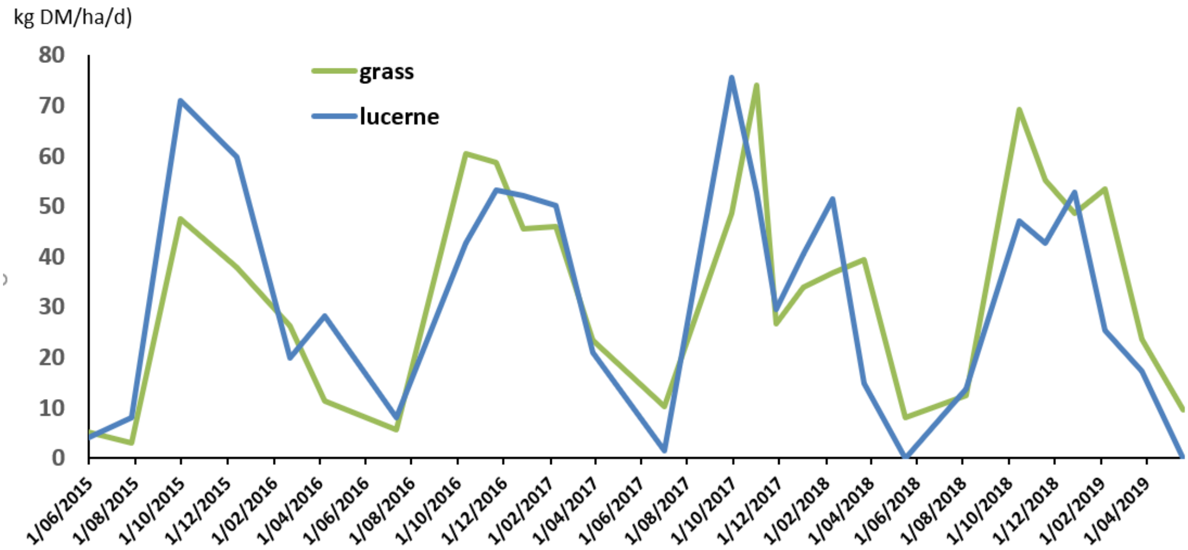
Figure 1. Weekly rainfall (blue bars), air temperature (max dashed line, min dotted line) and soil temperature (solid line) at Highlands from July 2013 to June 2019 based on interpolated weather data from NIWA's Virtual Climate Station Network (https://www.niwa.co.nz/climate/our-services/virtual-climate-stations)



Production

Shown in Figure 2 below is the seasonality of production of two pastures observed across a four-year period, whether lucerne or grass, dry matter production was strongly affected by temperature and soil moisture. Production from grass pasture was affected more by the drought in summer 2015-16 than was lucerne with its deep tap root, while in the wetter 2016-17 the reverse was true. In 2017 to 2018 both types of pasture produced very well, but in the very wet summer of 2018 to 2019 the lucerne was less productive.

Figure 2. Growth of grass-based and lucerne pastures on Highlands during 4 years to June 2019.



Plantain and its persistence

When discoveries about plantain were made in other parts of the FRNL program, we turned our attention from the grass and lucerne pastures in Figure 2 above, to more diverse mixtures including plantain. The following tables show the results from the pasture production in 2017 to 2018 and 2018 to 2019 (Table 1) collected from pasture cages located in five paddocks at Highlands. At least from these five pastures it seems that the young mixed pastures including plantain were very productive in comparison with the older grass or lucerne pastures. It is interesting to note in Table 2 and 3 and Figure 3 below that very little of the dry matter in those pastures was actually plantain.

Table 1. Total dry matter production (kg/ha) assessed using pasture cages from 12th September 2017 to 26th September 2018 and from then to 17th June 2019.

Name	Sown	Slope	Species	DM kg/ha	
				2017-18	2018-19
Coles cabbage tree	2012	flat	Ryegrass	10071	11198
Coles Patersons 1	2013	flat	Tall fescue	11872	9736
Coles pumphouse 2	2013	flat	Lucerne	10567	7357
Top bottom haybarn	2016	flat	Grass-w clover plantain	13425	10380
Back road flat	2017	flat	Grass-w clover plantain	16614	14182

Table 2. Herbage species composition (%DM) from pasture cages, average from 17th October 2017 to 26th September 2018.

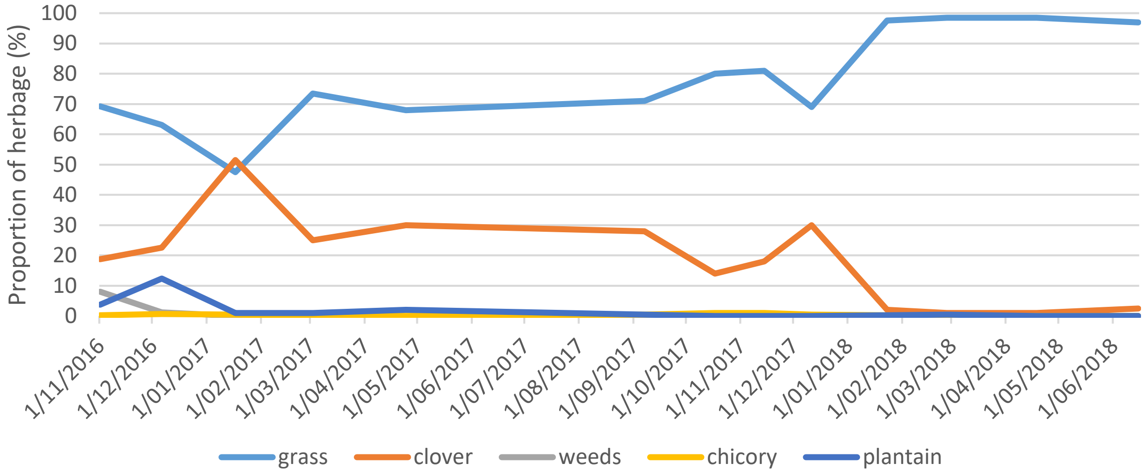
	Sown	Grass	Clover	Weeds	Chicory	Lucerne	Plantain
Ryegrass	2012	94	5	1	-	-	-
Tall fescue	2013	93	6	1	-	-	-
Lucerne	2013	-	-	11	-	89	-
Mix (autumn)	2016	91	9	-	-	-	-
Mix (autumn)	2017	85	13	-	1	-	1

Table 3. Herbage species composition (%DM) from pasture cages, average from 26th September 2018 to 17th June 2019.

	Sown	Grass	Clover	Weeds	Chicory	Lucerne	Plantain
Ryegrass	2012	93	6	1	-	-	-
Tall fescue	2013	91	6	3	-	-	-
Lucerne	2013	6		13	-	81	-
Mix (autumn)	2016	96	4	-	-	-	-
Mix (autumn)	2017	92	8	-	-	-	-

One of the pastures described above was a pasture mix which included plantain sown in autumn 2016 on Highlands (Figure 3) but had very small amounts of plantain on average across the season in 2017. When observed in 2018 little plantain remained (Table 2) with none in 2019 (Table 3). There was a good deal of seasonal variation (Figure 3), but plantain was never more than 13% of the herbage available. The plantain sown in 2016 only produced 2% of the dry matter in the pasture in 2017.

Figure 3. The changes in proportion of various plant species in a mixed pasture sown in autumn 2016 at Highlands.



Forage crop production

Forage crop yields recorded during the five years are shown in tables 4 and 5 below. For the most recent two years a breakdown of N leaching per paddock for kale and fodder beet crops is provided.

Table 4. Kale.

Paddock name	DM kg/ha	Area of paddock ha	**N leaching losses (kg N/ha**
2nd July 2015			
Pipeline	5965	6.79	
Near bottom hay barn	6020	3.20	
Stables	9285	1.92	
Crawfords Ram	6788	8.82	
2016			
13th May Kelynacks	8045	7.59	
8th June Middle Bottom Triangle	8846	6.45	
23rd May 2017			
"young grass"	11721	4.14	
Top and Bottom lucerne	8464	6.70	
Bottom River Flats	9490	4.19	
15th June 2018			
Bottom river flat	9409	4.19	25
Browntop hole	9891	6.10	15
Bottom Scotts	9115	3.93	25
18th June 2019			
Crawfords Ram	6848	8.82	67
James	3437	3.56	9
Hamish David	5906	5.69	24
Far sheep yards	5746	3.60	29
Bottom terrace	6104	2.69	25

Table 5. Fodder beet.

Paddock name	DM kg/ha	Area of paddock ha	**N leaching losses (kg N/ha)**
11th June 2015			
Top Silage pit	7283	4.94	
Browntop hole	9080	6.10	
School	4490	4.44	
13th May 2016			
Kelynacks (direct drilled)	17439	7.59	
Browntop hole (coated seed)	16586	6.1	
Browntop hole (bare seed)	15015	(6.1)	
1st June 2017			
Top Silage pit	8769	4.94	
Top flat	11171	6.50	
Kelynacks (ex fodder beet)	17081	4.00	
Kelynacks (ex kale)	23680	3.59	
15th June 2018			
Crawfords Ram	29540	8.82	36
Top silage pit	16870	4.94	38
18th June 2019			
Bottom sheep yards	11679	3.69	16.6
Near sheep yards	8654	3.48	16.6

Grazing of maize

The soils and climate at Highlands have been found suitable to grow maize on rainfall alone and it is used as a forage crop in late summer and autumn. This suits this dryland farm very well because fodder can be carried from spring and early summer into periods when there is an annual risk of drought. Some crops have been frosted shortly after sowing but recovered and in the most recent year a crop was drowned out shortly after sowing. However, considering these opposing risks the crop has given substantial yields some years (Table 6)

Table 6. Maize production assessed pre-grazing during the period we have observed Highlands.

Year	Paddock name	Date	DM kg/ha	Area of paddock
2015				
	Roundhill paddocks	16th Feb	10288	10.8
2016				
	Trees	2nd Feb	8653	8.64
	Trees	14th Mar	19727	(8.64)
	End of lane	12th Feb	7172	2.07
	Near Middle creek	14th Mar	11634	1.28
	Stables	14th Mar	9354	1.92
2017				
	Stables	1st Mar	4200	1.92
	Bottom triangle	11th Mar	13820	6.45
2018				
	James	26th Feb	22335	3.56
2019	Crop failed			

We must note that modelling nitrate leaching following grazing of a maize crop is not something Overseer has been programmed to do. We assume that since maize is low in protein, there will be low levels of nitrogen excreted in the urine, however the herbage yields have been such that a large number of cattle can be grazed on it and there may be a considerable amount of nitrate in the soil. The crop is consumed by early autumn and Highlands have found it best to use the crop early in the season because the stems resist grazing later. This means that another crop or pasture, often Italian ryegrass, can follow the maize and utilize the nitrogen. We consider this to be a more fruitful endeavour on this farm, with its high risk of summer-autumn drought than growing plantain pastures which have a much lower herbage yield. Specialist plantain pastures for autumn grazing were not evaluated in this farming system, if the environmental benefits were sufficient, novel approaches would be required to maintain plantain dominant pastures.

Catch crop experiment

Catch crop plots were sown in a paddock called "Browntop Hole". A kale forage crop had previously been grazed by R2 dairy heifers. The season prior to that it had grown annual ryegrass. The plot area was grazed two weeks prior to sowing, but the heifers were permitted on-going access to the plot right up to 1/8/2018. A range of different crops and two sowing dates were used, and three replicate plots were sown alongside replicated fallowed controls. Some crops were direct-drilled and other plots were given light cultivation. Immediately following sowing, the plots were covered with bird netting (because plots are vulnerable in a fallow paddock) and fenced to prevent cattle and vermin from grazing them. Slug bait was applied ten days after sowing.

The bird netting was removed on 10/9/2018 and germinated seedlings were counted. On the 18/9/2018 an extra treatment of barley was sown after the plots had been cultivated on that date. This date was similar to usual planting date for spring wheat at Highlands. All plots that had been sown on 1/8/2018, except oats were sprayed with Hussar and Partner herbicides, while the oats were sprayed with Barvel and MCPA. Neither fallow plots nor late sown barley were sprayed with herbicide during the course of this experiment.

On 25/10/2018 herbage was cut to ground level at 3 sites on each replicate across a 500 X 500 mm quadrat. Herbage samples were dried at 50°C to estimate dry matter and for chemical analyses. On 1/11/2018 each replicate was divided in half and "Sustain N" fertiliser was applied to one half of each plot, with the exception of the fallowed plots. Herbage samples were collected to ground level on 3 sites across a 0.72 m² quadrat.

Between the 14th and 19th of December soil samples were collected from 5 sites across all plots down to 900 mm deep using a 50 mm diameter soil core. Samples were screened through a 4mm sieve and stored at 4°C. Triticale, ryecorn and wheat plots had reached an appropriate stage for whole crop silage on 21/12/2018 and were harvested to ground level at 3 sites, again across a 0.72m² quadrat. Remaining plots were all harvested to ground level using the same method on 7/1/2019 when these had also reached an appropriate stage for whole crop silage.

As noted above this was a particularly wet year and soil moisture levels were high. The weekly rainfall and average soil temperatures are shown in Figure 1. Soil temperature dropped below 4°C in the winter and had begun to warm when these cereals were sown in August and continued to do so throughout the experiment. Soil moisture was good in November and December following unusually high rainfall and declined in January around the time the last harvests were taken.

The following tables (7 and 8) show establishment and subsequent production of the various cereal species at Highlands.

Table 7. Seedling establishment of catch crop species at Highlands on 10th September 2018.

Species	Timing	method	Count/m	Count/m²
Fallow			-	-
Ryecorn	Early	Tilled	32.67	217.8
Triticale	Early	Tilled	40.00	266.7
Wheat	Early	Tilled	27.33	182.2
Oats	Early	Tilled	26.67	177.8
Oats	Early	Direct drilled	18.67	124.5
Barley	Early	Tilled	33.67	224.5
Barley	Late	Tilled	*	*

***Note** late barley was not sown until the 19th of September

Table 8. Total dry matter production (kg/ha) assessed using quadrats within plots on three occasions during the growing season for a range of species and type and timing of sowing, and application of N in the growing season.

Species	timing	method	25/10/18	20/11/18		Final harvest	
				+N	No N	+N	No N
Fallow			-	-	1163		
Ryecorn	Early	Tilled	1189	7626	5392	10903	7695
Triticale	Early	Tilled	3000	7382	7061	16563	10276
Wheat	Early	Tilled	1419	5840	5186	12650	10550
Oats	Early	Tilled	1396	9571	7395	11555	11264
Oats	Early	Direct drilled	658	5712	4580	9702	7477
Barley	Early	Tilled	126	6289	5084	10686	8240
Barley	Late	Tilled	-	2468	2399	8744	7472

Light cultivation assisted seedling establishment and ultimate production from oats, where direct-drilled oats, that did not receive additional nitrogen fertiliser during the growing period, were one third less productive. Some weeds did establish on the fallow plots but this was removed with herbicide before final harvest. In this experiment triticale was most productive when additional fertiliser was applied during the growing period, but oats grown with some tillage and no added nitrogen were very productive at the final harvest. Ryecorn, triticale and barley sown early showed the greatest seedling establishment, but this was not reflected in yield at the final harvest where wheat and oats with lower seedling counts were very productive at a lower density.

Table 9. Proportion of total dry matter production (kg/ha) recorded as weeds at final harvest.

Species	timing	method	Final harvest +N	Final harvest No N
Fallow				
Ryecorn	Early	Tilled	8	10
Triticale	Early	Tilled	3	3
Wheat	Early	Tilled	17	10
Oats	Early	Tilled	5	4
Oats	Early	Direct drilled	18	10
Barley	Early	Tilled	17	6
Barley	Late	Tilled	13	15

A proportion of weeds was evident in all cereals, and although not harvested, there were some weeds in the fallow plots (Table 9). Late sown barley had a relatively high proportion of total dry matter as weeds. Direct drilling of oats allowed far greater weed invasion than observed with some tillage, again perhaps due to poor establishment. However, these crops were made into silage, with at most 18 kg of weeds and more than 2400 kg in all plots except fallow – weed growth was not a problem!

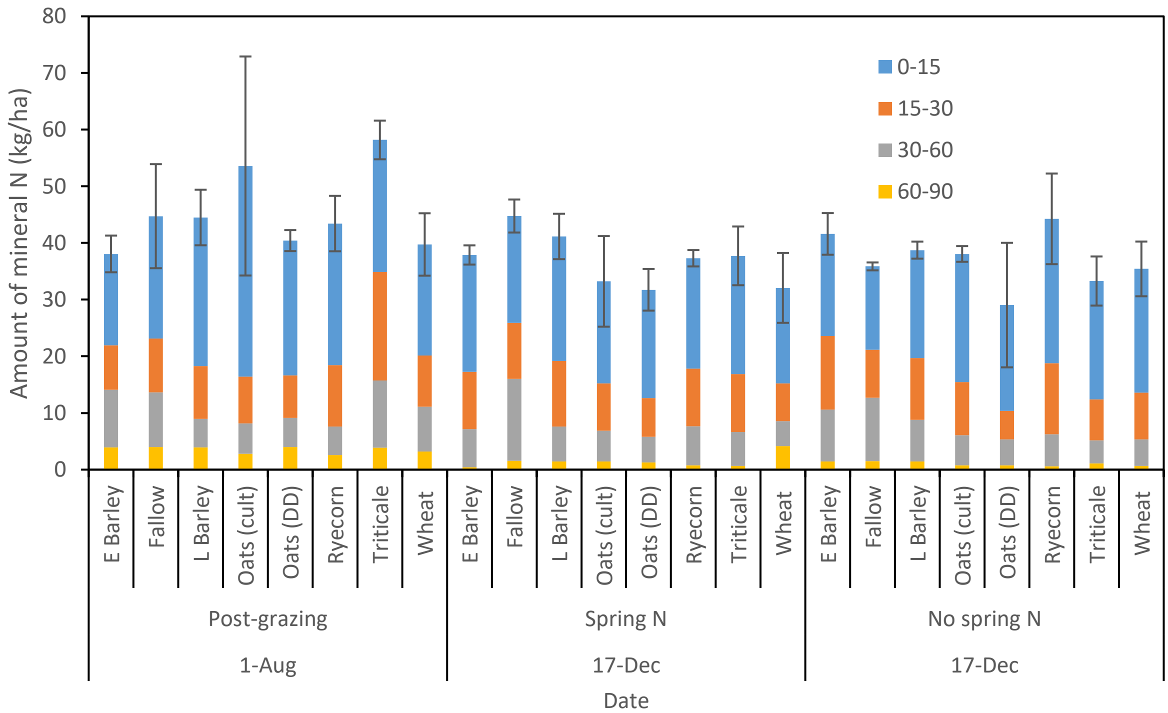


Figure 4. Mineral nitrogen in soil at various levels down to 900 mm under various species of catch crops compared with fallow plots (Courtesy of Brendon Malcolm at Plant and Food).

Figure 4 shows small differences between any of the catch crops and the fallow plot in terms of mineral nitrogen in the soil beneath them down to 900 mm. Although the amount of mineral nitrogen in the soil seemed lower under some species of catch crop, there was a great deal of variability in the measurements between plots and treatments. Average levels of soil mineral nitrogen in the entire soil profile were slightly lower at the final harvest (30 to 40 kg N/ha) than they had been around the time of sowing (40 to 60 kg N/ha). Adding fertiliser during the growing season increased soil nitrogen levels a small amount on average, but again variability was such that these conclusions were not strong. The fallowed plots exhibited more mineral nitrogen at 30 to 60 cm deep than cereal plots on average, and addition of nitrogenous fertiliser during the growing season exacerbated this. Oat plots that had been cultivated were lower in nitrogen at the end of the season than oats that had been direct drilled, but this was also true at sowing. By chance, plots that were sown with triticale were highest in soil nitrogen at the time of sowing and showed a reduction whether nitrogenous fertiliser was added during the growing season or not.

Perhaps the most significant finding from this work was that farmers who attended a field day on the catch crops gained a good deal of understanding about the ability of heavy soils to hold the nitrogen! This year was dry prior to sowing and very wet later which meant pugging was minimal, but farmers may need to solve their nitrate leaching problem first and develop methods to control soil damage rather than to grow winter forage crops on free draining soils because they are less likely to pug.

Nitrate leaching

The rainfall, types of soil, the plants and the livestock consuming them all interact to give nitrate leaching. For the years we have been studying Highlands, these results are summarised in Table 10. Nitrate leaching losses were low and moderately variable between years. More rain meant more dry matter production and more stock, which all conspired to give greater leaching in better seasons.

Table 10. Dry matter intake, stocking rates and resulting animal production from Highlands and the nitrate losses (in bold) estimated with Overseer 6.3.2.

	Highlands - South Canterbury				
	2014-15	2015-16	2016-17	2017-18	2018-19
Beef meat; kg	90,145	51,652	90,788	92,210	75,740
Sheep meat; kg	26,233	28,288	23,545	29,547	25,797
Wool; kg	7,463	6,784	7,114	8,767	5,551
Total animal production (kg)	*123,841*	*86,723*	*121,356*	*130,524*	*107,088*
Pasture production (kg DM/ha) *	6,909	5,641	8,307	8,425	8,345
Total Dry Matter Intake (DMI; kg)	2,598,127	1,601,312	2,573,473	2,674,706	2,334,215
DMI - overall (kg/ha)	7,217	4,448	7,149	7,430	6,484
Stocking rate (SU/ha)	13.3	9.4	13.3	14.8	11.7
N leaching losses (kg N)	6,027	4,715	6,498	7,136	6,900
N leaching losses (kg N/ha)	**15**	**12**	**17**	**19**	**18**
N leaching losses (kg N/kg product)	0.049	0.054	0.054	0.055	0.064

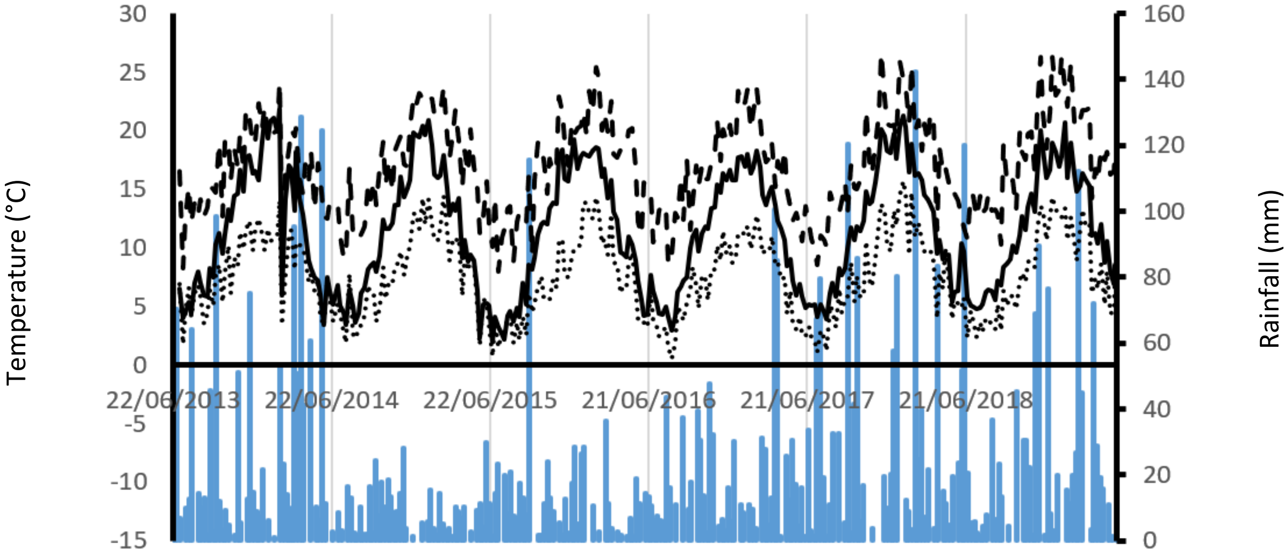
* Weighted average from Farmax (potential + fertiliser N boosted)

Blair and Amie Kirkland - Glengael

Climate

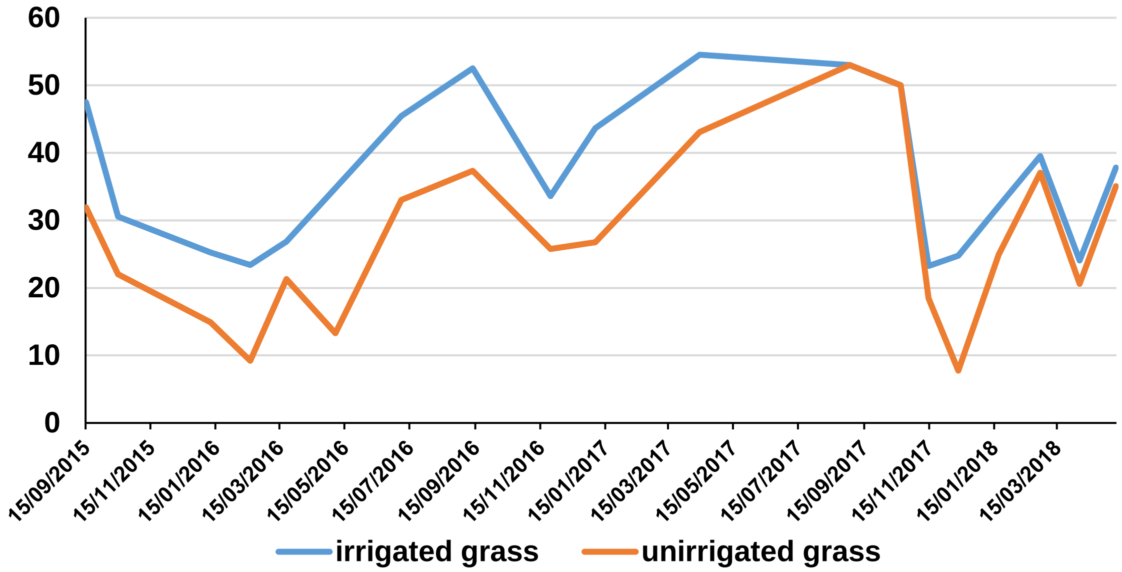
The rainfall during the six-year period to June 2019 while we have been studying Glengael is shown in Figure 5. Soil and air temperature are also shown and there was a strong seasonal rhythm in soil temperature with 2015 exhibiting the lowest and 2018 the warmest. All temperatures were slightly warmer than at Highlands. On Glengael, early 2014, 2017, 2018 and early 2019 were times of high rainfall. In comparison 2015 and 2016 were relatively dry years. This gave the research team a very good range to compare nitrate leaching, however this farm has irrigation and that has a marked effect on management of this farm and the ability to stave off droughts, and of course has a notable effect on stocking rates and nitrate leaching.

Figure 5. Weekly rainfall (blue bars), air temperature (max dashed line, min dotted line) and soil temperature (solid line) at Glengael from July 2013 to June 2019 based on interpolated weather data from NIWA's Virtual Climate Station Network (https://www.niwa.co.nz/climate/our-services/virtual-climate-stations)



Indeed, irrigation has continued to expand during the period we have studied this farm and some resultant changes in fencing of paddocks has led to challenges in modelling nitrate leaching of an ever-changing farm. In 2016 the area irrigated was 39% of the farm. Despite the availability of irrigation, soil moisture levels in two of the pastures we studied (Figure 6) showed soil moisture was quite low in summer and autumn of 2017 and 2018. Irrigation did not increase soil moisture to levels seen in the previous summer 2016 to 2017.

Figure 6. Average soil moisture assessments from two pastures at Glengael.



Production

Table 11 shows the pasture production and Table 12 shows pasture composition collected from pasture cages located in five paddocks at Glengael. One paddock of interest is Stable 2, which has a sloping portion (Slope) and a flat portion (Flat), all sown with the same mixture of grass, white clover and plantain. All these pasture paddocks produced very good herbage mass in the period they were measured, and of notable interest the mixed pastures produced more than those predominantly in grass whether irrigated or not.

Table 11. Dry matter production from pasture cages between 6th September 2017 and 6th September 2018 and from then until 28th May 2019.

Name	Water	Slope	Species	DM kg/ha	
				2018	2019
Wacca	irrigated	Flat	Grass	15082	12042
Mushroom 2	irrigated	Flat	White clover & chicory	20900	13456
Stable 2*	irrigated	Flat	Grass w clover plantain	16387	16641
Stable 2*	irrigated	Slope	Grass w clover plantain	15658	15777
Boomerang	unirrigated	Flat	Grass	7596	9722
Rutherford	unirrigated	Flat	Grass w clover plantain	8760	11433

*Stable 2 has flat and sloping terrain in one paddock which was sown with the same mixture of seeds.

Plantain and its persistence

The herbage composition of samples collected from pasture cages is shown in Tables 12 and 13 below. Where plantain was once thought of as a weed, it had not invaded pastures sown in 2012 in measurable amounts. Where plantain was sown, it was present and particularly in the unirrigated pasture. During the planning phase, while the research team were searching for suitable paddocks to study, it was noted that in one paddock ("Stable 2") that plantain prevalence was much greater (10%) on sloping ground (**S**) than it was on the flatter area (**F**) of the irrigated paddock (<1%). A higher prevalence on dry land and sloping land where the irrigation no doubt runs off, leads us to cautiously suggest that plantain will be more competitive on drier sites compared with the other species sown here. Yet half the amount of total herbage was produced on the sloping site compared to the flatter site. Lower total herbage production will lower nitrate leaching but will not boost productivity of the farm. When these pastures were examined again the following year, grass had become the dominant species in all swards with the exception of the paddock sown with only clover and chicory. Loss of clover and broadleaf species from these pastures would reduce herbage quality, and the impact of this is wider than the FRNL program alone.

Table 12. Herbage species composition (%DM) from pasture cage average from 17th October 2017 to 6th September 2018.

	Sown	Grass	Clover	Weeds	Chicory	Plantain
Irrigated						
Grass	2012	100	-	-	-	-
Clover, chicory	2017	1	75	-	24	-
F Grass, w clover, plantain	2017	90	9	-	-	1
S Grass, w clover, plantain	2017	67	23	-	-	10
Unirrigated						
Grass	2012	97	3	-	-	-
Grass, w clover, plantain	2016	31	25	-	-	44

F & **S** are flat and sloping terrain in one paddock which was sown with the same mixture of seeds.

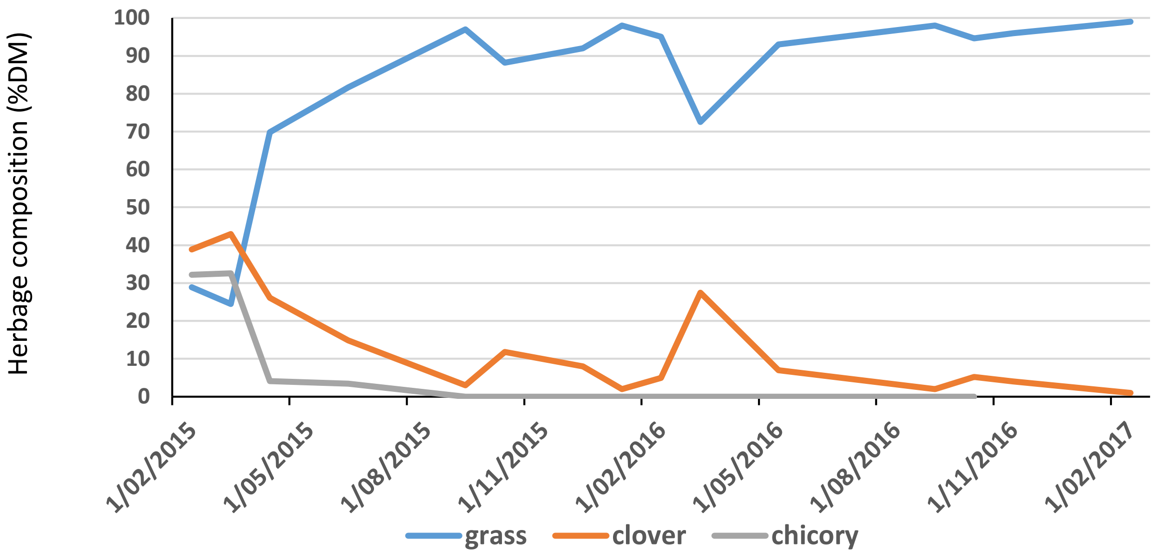
Table 13. Herbage species composition (%DM) from pasture cage average from 6th September 2018 to 28th May 2019.

	Sown	Grass	Clover	Weeds	Chicory	Plantain
Irrigated						
Grass	2012	99	1	-	-	-
Clover, chicory	2017	1	97	1	1	-
F Grass, w clover, plantain	2017	97	2	1	-	-
S Grass, w clover, plantain	2017	94	2	1	-	3
Unirrigated						
Grass	2012	91	9	-	-	-
Grass, w clover, plantain	2016	41	23	-	-	36

F & **S** are flat and sloping terrain in one paddock which was sown with the same mixture of seeds.

Figure 7 shows the species recorded in a pasture on Glengael during a two-year period to February 2017. Clover and chicory vanished from this pasture within two years of sowing. Disappearance of plantain, like the disappearance of chicory, may be a more generalised disappearance of herbs from sheep and beef pastures. Perhaps sheep or cattle grazing these pastures targeted the plantain or chicory and grazed them out, or the presence of nitrogen gave the grass a competitive edge in pasture ecology.

Figure 7 The species composition of a pasture sown with grass, clover and chicory



The flat and sloping areas of Stable 2 paddock were studied further during a two-year period (Figure 8). Plantain became a modest proportion of the herbage in late summer and early autumn on the sloping portion of this paddock. It was only during February, that the sloping area of the paddock produced 30% of the available herbage as plantain, the level at which it has been found to mitigate nitrate leaching, but the flat areas of the paddock had little. Also included on Figure 8 is an unirrigated pasture sown in 2016 with grass, white clover and plantain. For much of the period this paddock was studied, it produced sufficient plantain to make up 30% of the available herbage and could be expected to affect nitrate leaching. Plantain had re-established itself from seed following summer drought in this unirrigated paddock, where other species had not.

Figure 8 the proportion of plantain recorded in samples from three pastures on Glengael.

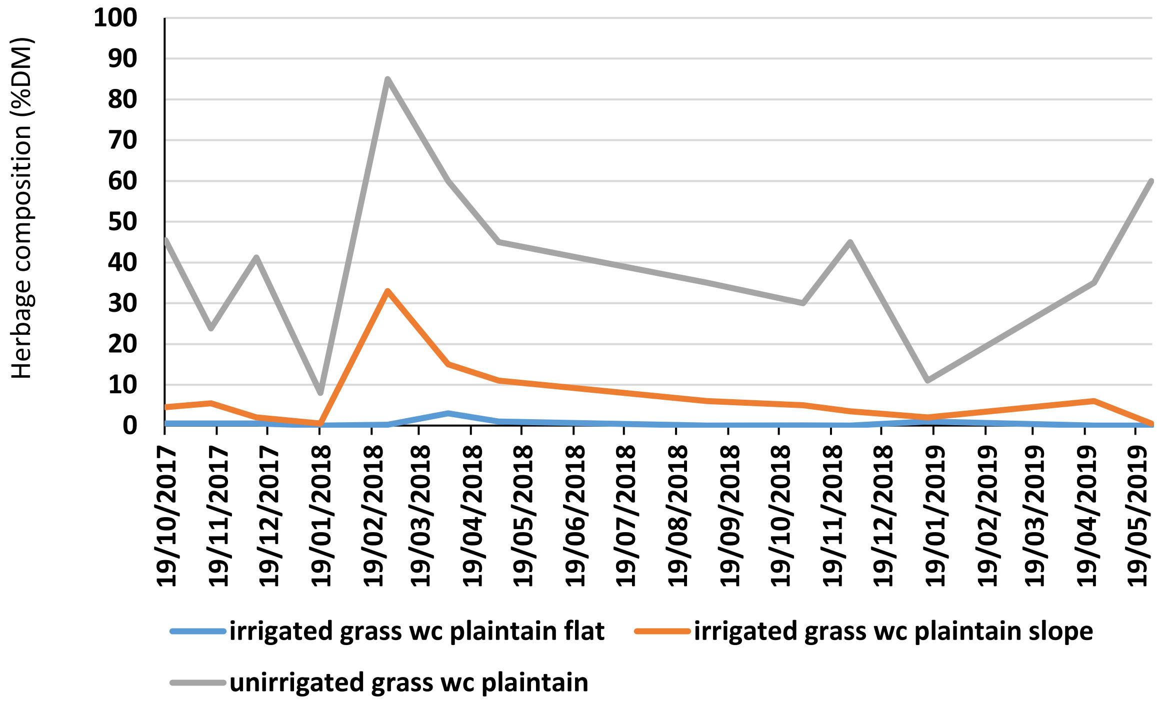


Figure 9. Pasture growth rates for irrigated vs unirrigated pastures on Glengael from September 2017 to the end of recording in May 2019.

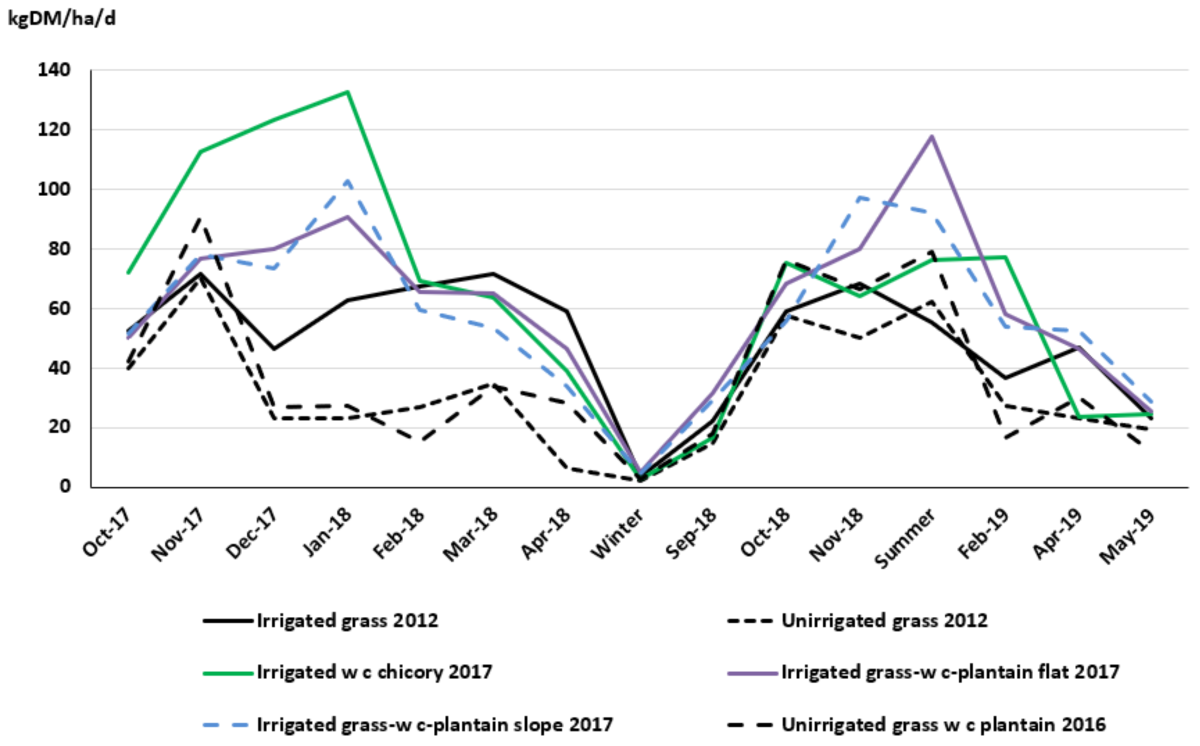


Figure 9 shows the growth rates of the various pastures from September 2017 until May 2019. Clearly there was little growth of any pasture mixture between the 9th of May and the 6th of September (winter), and without irrigation, production would have been lower in total and much more seasonal in 2018. Given the wet summer of 2018 to 2019 even unirrigated pastures were very productive throughout the year. Without doubt, white clover and chicory would be very good for finishing stock in the spring and summer, but other pastures are required to feed stock in autumn. The pastures containing plantain were relatively productive in autumn, but most would need a greater proportion of plantain in the herbage to mitigate nitrate leaching.

Forage crop production

Forage crop yields recorded for the five years are shown in Tables 14, 15 and 16 below. Large numbers of adult dairy cows arrive on the farm and are grazed on these forage crops during winter. Under irrigation on Glengael, fodder beet gives consistently high yields, whereas kale paddocks produce lesser amounts. However, these two species are sown in rotation with each other to minimise weeds and diseases.

Table 14. Fodder beet forage crop production (kg DM/ha) during the five years of observation at Glengael.

Paddock	Date	DM kg/ha	Area of paddock ha	N leaching losses (kg N/ha
Collard Pie	10/6/15	29521	4.08	
Railway pivot	13/5/16	24589	16.83	
Mushroom 1	13/5/16	26491	4.77	
Mushroom 2	13/5/16	29608	4.59	
Leader pivot	2/5/17	24139	9.61	
River pivot	2/5/17	25156	9.61	
Bridge	7/6/18	17570	7.41	252
Collard	7/6/18	33392	4.99	59
Half-moon and Highway	17/6/19	29977	4.47	37-58
Sisters	17/6/19	18357	4.63	14

Table 15. Kale forage crop production (kg DM/ha) during the five years of observation at Glengael

Paddock	Date	DM kg/ha	Area of paddock ha	N leaching losses (kg N/ha
Derry Hill	22/4/15	4286	5.10	
Derry Hill	1/4/16	10077	5.10	
Leader pivot (irrigated)	10/8/16	6090	7.40	
Leader (unirrigated)	10/8/16	4332	(7.40)	
Killer shed	2/5/17	11587	5.24	
Sisters	2/6/17	6748	4.15	
Railway pivot	7/6/18	16117	16.83	49 (irr) 8 (dry)
River pivot	7/6/18	10861	9.61	190 (irr) 109 (dry)
Railway pivot	17/6/19	8862	16.83	108 (irr) 53 (dry)
Bridge	17/6/19	7885	7.41	240
River pivot	17/6/19	8485	9.61	170

The nitrate leaching levels are shown for some paddocks in the two most recent seasons and in separate areas of some paddocks. Centre pivot irrigators create a circular area, or part of a circle which is irrigated, and paddock shapes mean that there are often areas which are not irrigated. Unirrigated areas are lower in yield, and theoretically lower in nitrate leaching. The Railway pivot for example gave an almost twofold difference in estimated N leaching between irrigated (108 kg N/ha) and dryland (53 kg N/ha) areas in the most recent season modelled. However, cattle redistribute this across the grazed area, depending on the break fencing pattern.

Glengael regularly sow and utilise forage crops that are grazed in the autumn. These include a range of species and can be sown on either dryland or irrigated paddocks. Some paddocks produce substantial yields, and in some cases the herbage was measured at two times. These paddocks either ceased being used for grazing or produced some regrowth post-grazing and were grazed again later. For example, a portion of the rape crop in the "Road paddock" was utilised in April 2018 and then allowed to recover and was grazed again in June. This giant rape produced a high total yield for this species and there was little difference in total yield between that which was grazed and recovered versus that which was grazed once. Nitrate leaching from an autumn grazed paddock might be caught by a subsequent crop or pasture but grazing in June 2019 was essentially a winter forage crop and would require a catch crop to reduce the extremely high nitrate losses form this area.

Table 16. Autumn forage crop production (kg DM/ha) during the five years of observation at Glengael

Paddock	Species	Date	DM kg/ha	Area of paddock ha	N leaching losses (kg N/ha)
Mushroom 1	Pasja	7/1/2015	6309	4.77	
Leader	Pasja	18/2/2015	6453	7.84	
Half pipe	Pasja	24/3/2015	10140	4.75	
Mushroom 2	Pasja	24/3/2015	6106	4.59	
Kerry's corner	Leafy turnip	12/2/2016	3318	1.42	
Hayshed	Leafy turnip	12/2/2016	1547	6.53	
Ram	Leafy turnip	12/2/2016	1435	6.01	
Derry Hill	Giant rape	21/3/2016	2083	8.08	
Killer shed	Giant rape	1/4/2016	3933	5.24	
Leader pivot	Maize	21/3/2016	9093	7.4	
Ram	Rape	2/5/2017	3121	6.01	
Top Gully	Rape	15/3/2017	3200	5.16	
Jundee	Rape	5/4/2017	3800	3.45	
Nimary	Rape	5/4/2017	3800	3.69	
Road	Giant rape	5/4/2018	8395	3.32	
Road	Giant rape	28/6/2018	14720	3.32	40
Collard	Giant rape	17/6/2019	6192	4.99	377
Road	Giant rape	17/6/2019	6679	7.5	201
Strip	Giant rape	17/6/2019	5998	4.65	160

Catch crops

Planting catch crops on Glengael was not dramatically successful in 2017. The primary reason was the extremely wet conditions. Milton oats and T100 triticale were sown on 5th July 2017 and 31st August 2017, within 9 and 16 days respectively, of dairy cows grazing of a 24-tonne crop of fodder beet. Cereal performance was assessed on 10th November 2017, the results from which are shown in Table 17.

Table 17. Performance of catch-crops sown immediately post- winter grazing of fodder beet at Parnassus assessed on 10th November 2017.

Cereal	plant counts (n/m2)	Survival* (%)	Composition (%) cereal	other	Herbage mass (kg DM/ha) cereal	other
Sown 5th July 2017						
control	0					
Oats	5	1.0				
triticale	1	0.2				
Sown 31st August 2017						
control	0		0	0	0	0
oats	147	25.2	100	0	2865	0
triticale	78	19.9	100	0	2215	0

*number of plants relative to seed sown.

As shown in Table 17 very few cereal plants survived the July sowing. Despite a poor survival of plants in the August sowing, more than 2000 kg/ha of dry matter were grown in just 71 days. Further catch crop trials were sown in 2018 in a paddock immediately adjacent to State Highway 1 called "Railway pivot". This paddock had grown a kale crop of 16 tonnes of dry matter that was grazed by adult dairy cows. The actual plot area was grazed 20 days prior to sowing, but the cows were permitted on-going access to the plot right up to sowing. Sowing occurred on 27/7/2018, and a barley cultivar "Monty" was direct-drilled at 140 kg/ha across three replicate plots (7 x 10 m) located alongside three replicate plots that remained fallow. The plots were fenced to exclude cattle and covered in nets to exclude birds. Slug bait was applied on 15/8/2018.

Seedling counts were undertaken on the 26/9/2018 and netting was removed from the crops at that time. The barley was sprayed with Barvel and MCPA on the 16/10/2018, and half of each fallow plot was sprayed at that time. Herbage was sampled to ground level from 3 quadrats of 0.25 m^2 in each plot on the 26/10/2018. Fertiliser (60kg N/ha in the form of "Sustain N") was applied to half of each plot containing barley on the 1st of November 2018. Herbage was again sampled to ground level using 3 quadrats of 0.72 m^2 from each plot of cereal with or without N, and 4 quadrats of the same size on both the sprayed and un-sprayed fallow plots (26/11/2018).

Soil samples were obtained from three sites per sub plot (barley with and without nitrogen fertiliser, fallow with and without herbicide). Soil samples were collected at three depths (0-150 mm, 150 – 300 mm and 300 – 600 mm). Given the very high prevalence of stones in this soil, the samples were taken with a spade and rocks were removed and it was not possible to sample deeper than 600 mm.

Seedling counts on September 26th showed reasonable establishment of the barley catch crop (Table 18). Between sowing in July and sampling in November, an average of 5529 kg DM/ha had accumulated on the plots sown with barley, with a little more (6226 kg DM/ha) on those treated with nitrogen fertiliser. Not all plots responded to nitrogen in the short period from 1st to the 26th November and there was a good deal of variability between plots reflecting the variable nature of the soils and conditions. The plots were removed to make way for a subsequent forage crop and were not taken to full crop silage stage.

Table 18. Seedling establishment on 26th September 2018 and dry matter production from catch crop and fallow plots on 26th October and 26th November (with and without added N fertiliser 1st November).

Plot	treatment	Seedling count/m²	DM (kg/ha)	DM (kg/ha)	
				+ N	No N
1	Fallow		-	-	-
2	Barley	152	1391	5383	6284
3	Barley	102	1441	5627	5403
4	Fallow		-	-	-
5	Fallow		-	-	-
6	Barley	123	1456	7669	4899

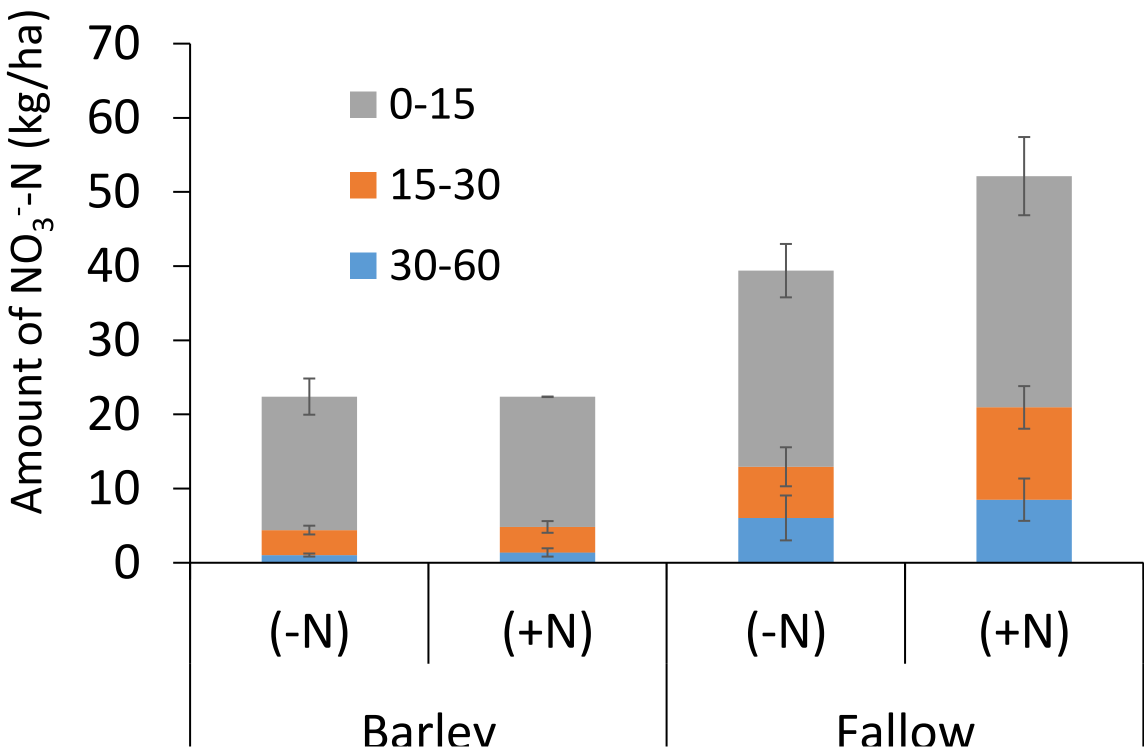


Figure 10. Nitrate levels in soil at various depths under a barley catch crop and fallowed ground on the 6th of December 2019. Half of each plot was fertilised with nitrogenous fertiliser (+N) or not (-N) during the growing season on November 1st. (Courtesy Brendon Malcolm, Plant and Food)

In figure 10 we can see lower amounts of nitrate in soil sampled at all depths between plots sown with barley and those that were left fallow. When nitrogenous fertiliser was added during the growing season it appears that it was quickly taken up by the barley, perhaps with a small increase in soil nitrate at 300 to 600 mm deep. In fallow plots, soil nitrate levels increased at all depths sampled if nitrogen fertiliser m added during the growing season. From other measurements not shown here there was almost 80 kg N/ha in the soil at sowing, but only 20 kg N/ha remained under the barley catch crop at harvest, while the fallow plots (without added N) contained 40 kg N/ha.

Nitrate leaching

Nitrate leaching increased dramatically on this farm during the period we have modelled it (Table 19). This increase was accompanied by a steady increase in the amount of dry matter produced and consumed on the farm (from 2.8 million kg up to 3.6 million kg). The area under irrigation also increased during the five years on Glengael, producing more herbage with an accompanying increase in stock density from 13 to 19 SU/ha. An increasing proportion of the dry matter was also consumed by dairy cows, at the expense of other classes of stock. Winter grazing of dairy cows comes at the worst possible time of the year for nitrate leaching.

Table 19. Dry matter intake, stocking rates and resulting animal production from Glengael and the nitrate losses (in bold) estimated with Overseer 6.3.2.

	Glengael - North Canterbury				
	2014-15	2015-16	2016-17	2017-18	2018-19
Beef meat [1]; kg	64,080	61,612	37,987	57,857	63,185
Sheep meat; kg	58,831	61,526	65,114	64,242	66,386
Wool; kg	15,458	15,000	15,186	15,377	15,715
Total animal production (kg)	*138,369*	*138,138*	*118,287*	*137,475*	*145,286*
Pasture production (kg DM/ha) [2]	7,282	7,646	9,933	12,438	11,503
Total Dry Matter Intake (DMI; kg)	2,820,611	3,187,959	3,312,786	3,131,522	3,640,429
DMI - overall (kg/ha)	6,567	7,414	7,704	7,283	8,466
Stocking rate (SU/ha)	13.5	13.6	14.5	16.2	19.1
N leaching losses (kg N)	10,895	10,101	11,087	16,919	20,214
N leaching losses (kg N/ha)	**20**	**23**	**25**	**38**	**45**
N leaching losses (kg N/kg product)	0.079	0.073	0.094	0.122	0.139

[1] "Beef" means both beef carcass and that leaving the farm as live weight gain on grazed dairy cattle.

[2] Weighted average from Farmax (potential + fertiliser N boosted)

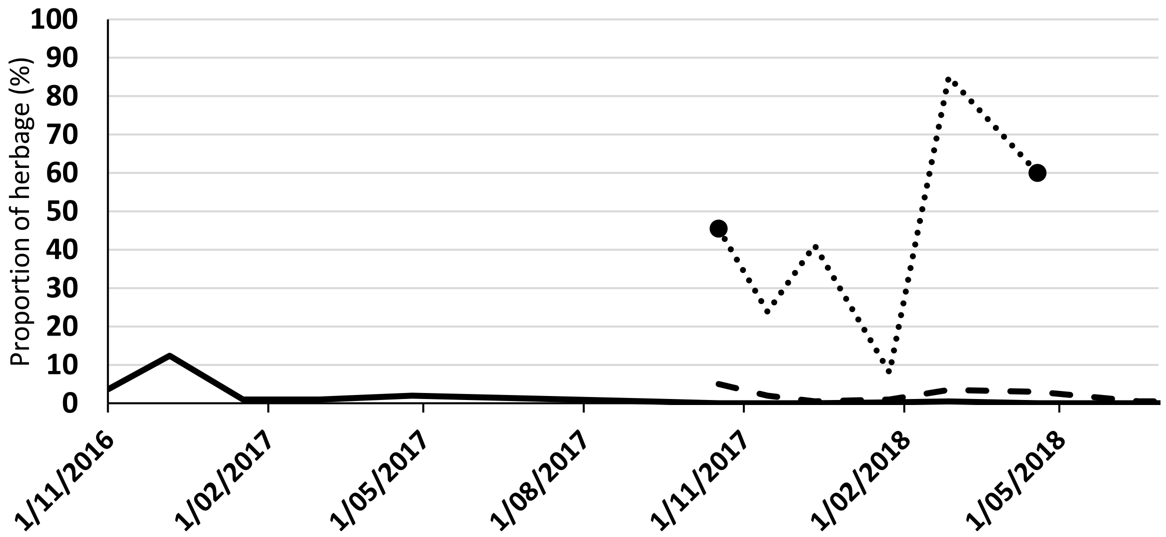
Discussion

With respect to the goal of Forages for Reduced Nitrate Leaching, working with these farms across a five-year period we did not reduce the amount of nitrate leaching from either farm. If we fitted a trend to the results from Highlands farm there would be a very small increase, but on Glengael nitrate leaching increased dramatically across the term of this project. This was disappointing to the research team since none of the promising new forage technologies decreased leaching sufficiently to reach the goal of a 20% reduction. The five years have seen dramatic changes in product prices for beef and lamb and an improving relationship with dairy grazing clients on Glengael. Highlands has seen few changes in infrastructure but large seasonal changes between droughts and very wet periods. Glengael on the other hand has rapidly expanded the area of irrigation during the period that we have worked with the farm. Although as noted from Figure 6, soil moisture levels continue to vary on Glengael, the farm can buffer against droughts often associated with this part of Canterbury.

Plantain and its persistence

Figure 11 shows the low proportion and rapid disappearance of plantain from mixed pastures where it was drilled on both farms, with the exception of the dry slope in one part of an irrigated paddock on Glengael. It is interesting to see plantain had persisted on more challenging sites with less competition at Glengael. This is not entirely unexpected of a flat broadleaf plant trying to compete against vigorous grasses. It will be interesting to review the other initiatives with plantain inside and outside the Forages for Reduced Nitrate Leaching program. No other paddocks exhibited substantial amounts of plantain on either farm, and certainly not at 30% of DM required to influence nitrate leaching.

Figure 11. Plantain as a proportion of the herbage available on two sites at Highlands (solid sown 2016, dashed sown 2017) and on a dry slope in part of an irrigated paddock on Glengael (dotted).



This leads us to suggest that plantain may be useful as a pure sward for grazing cattle in autumn on sheep and beef farms, and particularly dairy heifers. In sloping dry areas, it may persist and outperform other pasture species. Alternatively, it may be worthwhile investigating mixed drilling of plantain with crops like rape. This crop is often used on Glengael in autumn and has been found to leach relatively high amounts of nitrate under these circumstances on this farm (up to 377kg/ha/yr).

This could overcome the low herbage yield of plantain and the high nitrate leaching following the forage crop.

Catch crops

Catch crop trial sites were poorly established on both farms in 2017. There were very challenging circumstances for establishment including rock hard frozen ground at Highlands and persistent ponding of surface water at Glengael which destroyed the plots on one establishment date. However, better establishment conditions, and bird and slug protection led to better results in 2018. The crop plots were removed early at Glengael to make way for the establishment of the following forage crop but had reduced nitrate leaching at that stage. On Highlands, quite a different picture emerged in 2018. As noted above it was a warm winter with a very wet summer period up to the time the plots were harvested. We would have expected this to have led to a considerable amount of leaching in control plots, but it did not. This was a consequence of paddock choice for the forage crop on a heavy clay soil and subsoil that do not leach. Although the research team were disappointed with this outcome, the famers and attendees at a field day found this to be a most useful way to continue using forage crops without risking high nitrate leaching levels on their farm. The challenges around early establishment of the catch crop will remain, but the rewards in catch crop yields for silage and therefore cost effectiveness make earlier sowing worth consideration wherever and whenever possible. As far as the Forages for Reduced Nitrate Leaching project is concerned, this will be a very useful technology on sheep and beef farms that use forage crops and or graze dairy stock in winter, due to the time of year in which it is effective.

The research team learned much about establishing trial plots of cereal catch crops. Although well accustomed to trial plots for pasture species and mixes, the impact of birds and slugs on the establishment of small patches of cereal were not fully appreciated in 2017. Having acknowledged this failing, it is important not to dismiss the practice. Research is frequently guided by deadlines and dates, but farming must fit with and not fight with the environment. The alternative to a catch crop is to grow nothing and leave the soil fallow and lose nutrients as shown in fallow plots on Glengael. In 2018 we had considered taking a section of the very first part of the forage crop to be grazed and planting winter wheat to achieve the maximum capture of nitrate before it leached. Ideally this would have occurred before the shortest day. Given other organisational constraints and soil conditions this opportunity passed, and a different design was implemented but this is where catch crops can potentially have the greatest impact. The manager should be constantly looking for the opportunity to fence off an area and sow a crop that suits the soil, the environment and the time of year. Some of these things have been characterised and new information will become available in the future. Even in the Highlands experiment where there was no leaching in 2018, a yield advantage was observed in the earlier sowing. For similar costs, the nitrogen (and water) can be removed for a greater herbage yield.

On Glengael the catch crop plots were visited during growth at a field day, harvested twice and then removed to make way for the new forage crop. The remainder of the paddock had been cultivated to reduce weed infestation by the time of the field day visit, and weeds were very evident on the fallow plots. This experimental catch crop suggested between 5 and 6 tonnes of dry matter could have been grown during the period the rest of the paddock remained fallow. Robb Macbeth of DairyNZ prepared a gross margin analysis that suggested that around this level of production the catch crop on Glengael might yield more than $800 per hectare. For the range of crops, harvest dates, yields and treatments on Highlands, a gross margin calculation was prepared by Shane Maley of Plant and Food (Appendix 1 and 2). In that analysis, preparing green chop silage from late sown barley would technically lead to a financial loss (Appendix 1), although as noted in the footnote to the appendix this would not be considered for silage production under commercial farming conditions. Late sown barley has been the chosen crop and timing for this farm, early sown barley was more profitable but early sown triticale was the most profitable in this analysis. The owners of Highlands have noted that triticale performs well in their environment and following discussion of these results they are prepared to consider earlier sowing of triticale rather than late sown barley when conditions for drilling are appropriate. Whether the variety of cereals chosen here would achieve the same rankings in production relative to barley during a drier year are unknown.

Universally, the addition of nitrogen fertiliser to the catch crops improved yield, if only a slight advantage for oats on cultivated plots (291kg/ha) on Highlands. Adding Nitrogen fertiliser part way through the season may seem like an unusual strategy in a program called Forages for Reduced Nitrate Leaching. However, in vigorously growing crops in the spring with adequate rainfall, nitrate is unlikely to escape the root zone. On Glengael, the advantage from adding nitrogen fertiliser was only 697kg/ha given the very short period between adding the fertiliser and the final harvest to make way for the following forage crop.

The catch crop plots on Glengael exhibited less nitrate in the soil than the fallow plots at harvest, suggesting some of the soil nitrate between sowing and harvest was depleted by the crop. No doubt some nitrate would have leached from under the catch crop and we would need more detailed investigations to determine how much, however some was removed from the soil and “caught” by the crop. Indeed, the crop was able to take up additional nitrogenous fertiliser whereas in the fallow plots additional nitrogenous fertiliser quickly leached down through the soil profile. Not that we are suggesting N should ever be added to a fallow plot, but experimentally we could see more nitrate throughout the soil profile when it was. The catch crop plots on Highlands were less convincing in terms of the depletion of soil mineral nitrogen, with fallow plots exhibiting more mineral nitrogen at deeper levels in the soil profile. Compared with fallow plots, there was half the amount of nitrate under catch crops at Glengael, and a quarter the level of nitrate observed at sowing. However, the difference was less than one third at Highlands, and at much lower total concentrations. The soil at Glengael was very stony and would leach quickly, the soil at Highlands had a good deal of clay that would impede the flow of nitrates through the profile. However, there are some very stony soils on Highlands and catch crops may be useful on these.

Early sown barley yielded more than late sown barley in this year on Highlands, 768 kg more without the addition of nitrogen fertiliser, and 1942 kg more when fertiliser was applied during crop growth in November. Early sowing was not used at Glengael, but we might expect a similar response. Practice change from fallow followed by direct-drilled late sown barley, to minimise the fallow period and to sow earlier with a little cultivation and possibly triticale might improve yields. With respect to the goal of the current project, these crops could catch that valuable nitrate rather than see it leach to groundwater.

Nitrate leaching

Returning to the opening paragraph in this discussion. We have not been able to reduce nitrate leaching on these farms. We have identified that the forage crop paddocks, particularly those grazed in winter are the source of much of the nitrate leached from these two farms. Forage crops on Glengael produced somewhere between 15 to 20% of the dry matter intake on the farm, while imported supplements and home-grown supplements were negligible. On Highlands as little as 12% of dry matter intake was from forage crops in some years but up to 30% in 2016. Imported and home-grown supplements featured more on Highlands but were less than 5% of the dry matter intake at most. Reducing supplement feeding is unlikely to have a major impact on nitrate leaching on either farm. The forage crops are grown on a very small proportion (<10%) of these farms each year (30 hectares at Highlands and 44 ha at Glengael). Forage crop utilisation is condensed to a very short period of the year which along with autumn is one of the worst periods for nitrate leaching from the urine deposited during grazing. Pastures make up the largest proportion of both farms and these are grazed for much of the year. Pasture paddocks leach small amounts while forage crops leach significant amounts of nitrate. In at least one of those forage crops the Overseer modelling suggested 377 kg/ha/yr was leached from that paddock. It makes the most sense to focus effort on the forage crop paddocks and catch crops seem the most appropriate solution to the problem and a 20% reduction in leaching seems feasible on these areas. However, this may still fall short of the 20% reduction across the whole farm.

Appendix 1

Gross margins for green chop silage at Highlands (20 November)					
Cereal Species Treatment	**Yield (t DM/ha)**	**Revenue ($/ha)** *0.25c/kg DM*	**Input costs ($/ha)**	**Margin ($/ha)**	**Profit (c/kg DM)**
Milton Oats - N *Cultivated*	**6.9**	**1725**	**538**	**1186**	**17.2**
Milton Oats + N *Cultivated*	**8.0**	**2000**	**644**	**1355**	**17.0**
Milton Oats - N *Direct Drilled*	**4.7**	**1175**	**258**	**916**	**19.5**
Milton Oats + N *Direct Drilled*	**4.8**	**1200**	**364**	**835**	**17.4**
Early Barley - N	**5.2**	**1300**	**680**	**619**	**11.9**
Early Barley + N	**5.4**	**1350**	**785**	**564**	**10.4**
Late Barley* - N	**2.4**	**600**	**636**	**-36**	**-1.5**
Late Barley* + N	**2.3**	**575**	**741**	**-166**	**-7.3**
Triticale - N	**9.0**	**2250**	**616**	**1633**	**18.2**
Triticale + N	**9.3**	**2325**	**721**	**1603**	**17.2**
Wheat - N	**6.0**	**1500**	**601**	**602**	**15.0**
Wheat + N	**5.5**	**1375**	**708**	**668**	**12.1**
Ryecorn - N	**5.1**	**1275**	**548**	**726**	**14.3**
Ryecorn + N	**6.5**	**1625**	**671**	**953**	**14.7**

*Pre optimal green-chop

Appendix 2

Gross margins for whole chop silage (late December) at Highlands					
Cereal Species Treatment	**Yield (t DM/ha)**	**Revenue ($/ha)** *0.25c/kg DM*	**Input costs ($/ha)**	**Margin ($/ha)**	**Profit (c/kg DM)**
Milton Oats - N *Cultivated*	**10.8**	**2700**	**538**	**2161**	**20.0**
Milton Oats + N *Cultivated*	**11.0**	**2750**	**644**	**2105**	**19.2**
Milton Oats - N *Direct Drilled*	**10.0**	**2500**	**258**	**1516**	**21.4**
Milton Oats + N *Direct Drilled*	**8.2**	**2050**	**364**	**1685**	**20.6**
Early Barley - N	**7.7**	**1925**	**680**	**1244**	**16.2**
Early Barley + N	**8.9**	**2225**	**786**	**1439**	**16.2**
Late Barley - N	**6.3**	**1575**	**636**	**939**	**14.9**
Late Barley + N	**7.6**	**1900**	**741**	**1158**	**15.2**
Triticale - N	**10.0**	**2500**	**616**	**1883**	**18.8**
Triticale + N	**16.0**	**4000**	**721**	**3278**	**20.5**
Wheat - N	**9.6**	**2400**	**601**	**1798**	**18.7**
Wheat + N	**10.7**	**2675**	**707**	**1967**	**18.4**
Ryecorn - N	**6.9**	**1725**	**548**	**1176**	**17.1**
Ryecorn + N	**10.1**	**2525**	**671**	**1854**	**18.3**