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CATCH CROPS TO MITIGATE N LOSS AFTER WINTER FORAGE GRAZING: FROM PLOT TO PADDOCK

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Abstract

Recent research has shown sowing a catch crop can reduce nitrate leaching after simulated winter forage grazing. However, most of this research has been reported from lysimeter and small plot trials where the pragmatic considerations of drilling a crop in winter, and achieving a net economic benefit to the farmer, were not largely explored. We report the first-year results (2018) of a three-year sustainable farming fund project to upscale earlier research into farmers' paddocks by establishing a series of catch crop trials, post-grazing, on winter forage paddocks in Mid-Canterbury.

Two trials were situated at Hororata on a winter forage block on a shallow, stony Lismore soil (Pallic), and a third on a dairy farm at Te Pirita on a moderately-deep Waimakariri soil (Recent). Trials measured dry-matter (DM) yield, nitrogen (N) uptake and soil mineral-N (where possible). The Hororata trials (using oats only) compared differing cultivation and drilling treatments (conventional cultivation/drilling vs direct drill) on ex-kale and ex-fodder beet paddocks whilst the trial at Te Pirita considered differing catch crop species (oats, triticale and Italian ryegrass).

Trial establishment from early July to early August was aided by a relatively dry and mild month that provided favourable soil conditions for drilling, with the Hororata and Te Pirita trials being harvested mid and late November, respectively, at a similar time as the surrounding paddock was harvested for green chop silage. DM production and N uptake over both sets of trials ranged from 4-12 tonnes/ha and 100-360 kg N/ha, respectively, significantly reducing soil mineral-N levels.

Due to an application of pig effluent in June on the kale paddock, and cultivation before drilling the oats, soil N mineralisation rates were very high with over 400 kg mineral-N/ha measured in the top 15 cm of the soil profile. Soil mineral-N measurements were significantly lower for the fallow and direct-drill treatments suggesting lower N mineralisation rates. For the species trial, significantly more DM was produced by time of harvest in November for the oats, followed by triticale and Italian ryegrass (12, 10 &, 6 t/ha, respectively), and in N uptake (208, 183 & 140 kg N/ha, respectively).

Keywords

Tillage, cereals, direct drill, cultivation, oats, triticale, Italian ryegrass

Introduction

The growing of winter-feed crops such as kale and fodder beet over the summer months is a popular choice for dairy winter grazing management, particularly in the South Island regions of Canterbury, Otago and Southland. However, the grazing of these crops during winter delivers large volumes of cow urine to the soil surface when plant growth and uptake of the nitrogen (N) deposited is usually minimal and this can lead to large drainage losses of N as nitrate. Thus, winter forage grazing is recognised as a major potential contributor to a dairy catchment's N leaching losses. To preserve these low-cost winter feed systems in the face of more stringent nutrient regulation farmers need to demonstrate a reduction in this nitrate leaching potential.

Sowing a catch crop such as oats immediately following the winter forage grazing (WFG) period has been shown in small plot field trials (Malcolm *et al.*, 2016) and lysimeter studies (Carey *et al.*, 2016; Carey *et al.*, 2017) to significantly reduce nitrate leaching loss. However, it has not been shown in commercial winter feed cropping rotations, nor confirmed as a strategy that will consistently reduce, in most years, the high nitrate leaching potential of grazed winter forage paddocks. Although recent research has shown the potential of catch crops to reduce farmers' nitrate leaching losses, without good guidelines, the widespread adoption of such technology is unlikely if it cannot also be demonstrated as both economically viable and environmentally sustainable.

We report the first-year results (2018) for a series of trials in Mid-Canterbury as the first part of a three-year Ministry of Primary Industries' Sustainable Farming Fund project (SFF) to upscale the earlier research, establishing a series of catch crop trials, post-grazing, on commercial winter forage paddocks. The objectives are to show that sowing a winter catch crop is achievable and will reduce a farm's nitrate leaching footprint. The data and results from three years of on-farm trials will allow the development of good practice guidelines around the use of catch crops in winter forage grazing rotations and advise farmers for a range of soil types and climates, selection of tillage operatons, and crop species or mixes. The data will also be made available for a future update of OVERSEER® to improve predictive nitrate leaching estimates under winter forage grazing when a catch crop is used.

Materials and Methods

Trial sites

Two cropping trials were situated at Hororata on a winter forage block on a shallow, stony Lismore soil (Pallic), and a third on a dairy farm at Te Pirita on a moderately-deep Waimakariri soil (Recent) (Figure 1). The Hororata trials (using oats only) compared differing tillage treatments (conventional cultivation/drilling vs direct drill) on ex-kale and ex-fodder beet paddocks. Crop yields on these paddocks were 12 and 21.5 t DM/ha, respectively, and were grazed approximately over June-to-early July and mid-June-to-late July, respectively. The Hororata ex-kale paddock received an application of pig effluent (~200 kg N/ha) in June, prior to the pre-drilling soil sampling in July and also an application of urea (46 kg N/ha) in September. The Te Pirita trial compared different catch crop species (oats, triticale and Italian ryegrass) and prior to establishment was 1st year kale (16.4 t DM/ha) after long-term pasture. The paddock was grazed over May-to-June. Trials measured DM yield, N uptake and soil mineral-N (0-30 cm). Site establishment and harvest information is shown in Table 1.

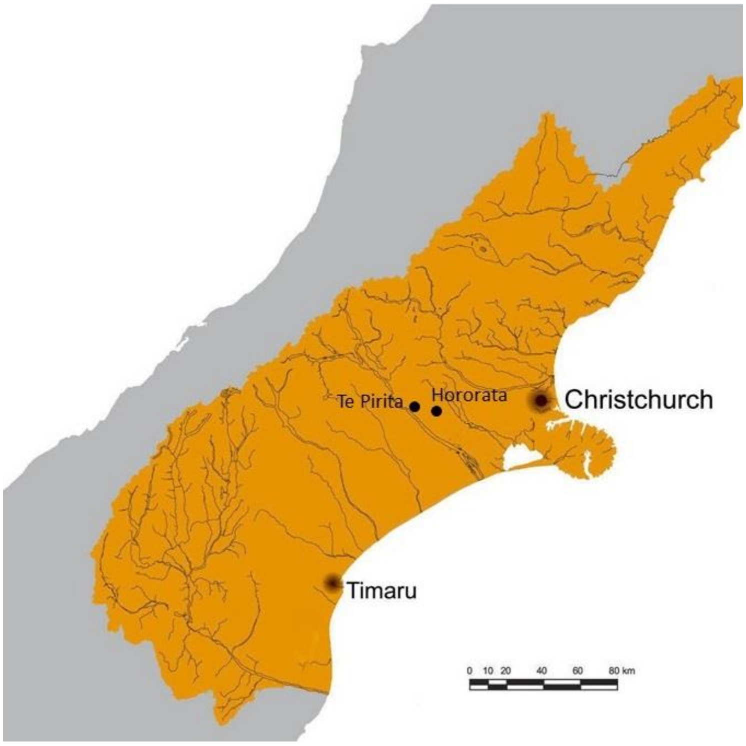

Figure 1. Location of Mid-Canterbury trial sites.

Table 1. Site and soil classification for each trial site.

Property	WFC [a]	Soil name (Class)	NZSC	Soil depth (cm)	Stone (%)
Hororata	Kale	Lismore (silt loam)	Pallic	0-15	2
				15-30	12
Hororata	Beet	Lismore (silt loam)	Pallic	0-15	1
				15-30	15
Te Pirita	Kale	Waimakariri (silt loam)	Recent	0-15	2
				15-30	6
				30-45	20

[a] Winter forage crop prior to trial establishment

Treatments

Each tillage or crop species trial plot was 6 m wide and 10 m long, with fallow plots 3 m wide left undisturbed. The two cropping trials at Hororata followed the same tillage treatment format comparing fallow with conventional cultivation/drilling and direct drilling. Cultivation involve a shallow grubbing (250 mm depth)/discing operation before drilling the oats (Milton) while the direct drill treatment used the drill only. The trial at Te Pirita was a catch crop species trial and compared fallow with Italian ryegrass (Asset AR37), triticale (Bolt) and oats (Intimidator). Cultivation across the whole paddock used a deep ripper (400 mm depth) discing operation followed by a further discing and then drilling. Drilling rates for oats and triticale ranged from 100-110 kg/ha, and for Italian ryegrass, 20 kg/ha, targeting 300 and 400 plants/m^2, respectively. The list of treatments, establishment and harvest dates, and tillage equipment used is shown in Table 2.

Table 2. List of trials and treatments

Trial	No.	Treatment	Tillage & harvest dates	Tillage equipment
Hororata ex-kale (tillage trial)	1	Fallow	Cultivated May 25	Bednar disc roller cultivator + John Deere 750a disc drill.
	2	Cultivation	Drilled Jul 7	
	3	Direct drill	Harvested Nov 8	John Deere 750a drill only
Hororata ex-fodderbeet (tillage trial)	1	Fallow	Cultivated Aug 5	Bednar disc roller cultivator + John Deere 750a disc drill.
	2	Cultivation	Drilled Aug 5	
	3	Direct drill	Harvested Nov 8	John Deere 750a drill only
Te Pirita ex-kale (species trial)	1	Fallow	Cultivated Jul 7	Sumo Quattro (6m) ripper/ Bednar swifter disc (8 m) + Horsch avatar drill
	2	Italian ryegrass	Drilled Jul 13	
	3	Triticale	Harvested Nov 20	
	4	Oats		

Measurements and data analysis

Climate measurements, (air temperature-Campbell Scientific CS107, soil temperature CS107B at 10 cm depth and rainfall -tipping bucket rain gauge, 0.2 mm resolution) were collected using a CS CR10X data logger from the Hororata site and compared with long-term data from nearby NIWA climate stations. Soil temperature data (5 cm depth) was also recorded hourly for the duration of each trial using soil temperature "buttons" (IButton Thermochron F5- Maxim Integrated) placed in half the plots (6-8 plots per trial).

Sites were soil sampled (6-10 augur holes per plot) to at least 30 cm depth (where possible) prior to drilling. These samples were frozen until analysed for mineral nitrogen. Samples were sieved following thawing and any major stone (>5 mm) was removed and weighed prior to extraction with 1 M KCl (modified from Blakemore et al. (1987)) for one hour and filtered. Analysis for ammonium and nitrate was by flow injection analysis (FOSS FIAstar 5000 triple channel analyser with SoFIA software version 1.30).

Plant counts were carried out for both trials in August involving three random 1 m counts for each plot. Dry-matter (DM) cuts were taken three-times for each trial through the growing period and samples taken for moisture (dried at 60°C) to calculate DM yield and for total-N analysis.

Results

Climate

Trial establishment at the Hororata and Te Pirita sites over July was aided by a relatively dry (35 mm less rainfall) and warmer month than average that continued through to August and provided favourable soil conditions for drilling. July and August air and soil temperatures (10 cm) for Hororata/Methven were considerably warmer than the long-term means (1997-2017) for the last 24 years (1-1.5°C greater) with trial site soil temperatures similarly warm (Figure 2). The spring month temperatures were closer to the long-terms means but October and November were considerably wetter than average (~50 and ~100 mm more monthly rainfall, respectively).

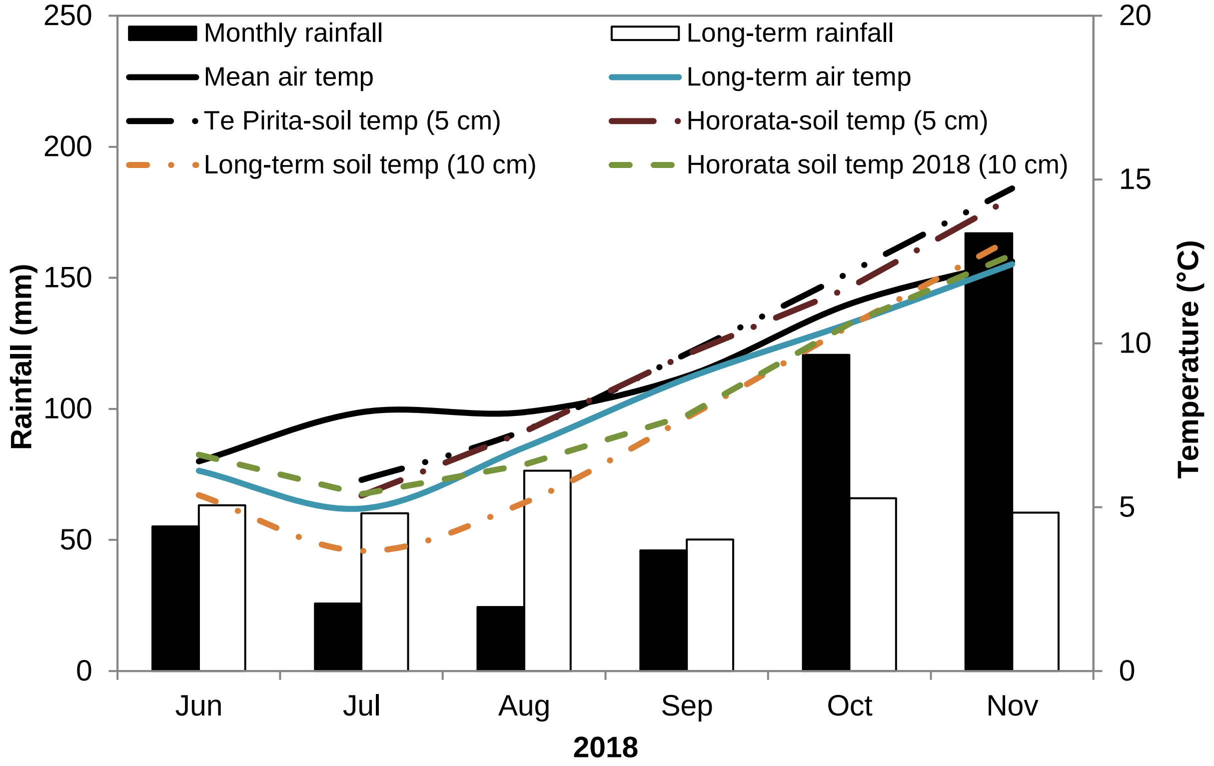

Figure 2. Mean climate data for Hororata (kale) and Te Pirita sites Jun–Nov 2018 compared with long-term means (1994-2017) for Hororata/Methven (where available).

Dry-matter production and N uptake

The cultivation treatment for each tillage trial produced greater plant counts on average (322 and 300 plants/m^2 for ex-kale and ex-beet sites, respectively) than under direct drill treatments, particularly in the ex-fodderbeet paddock (304 and 189 plants/m^2, respectively). This was also reflected in early DM yields for both trials although by the final harvest there was little difference in yield between the cultivated and direct drill treatments for either trial (Figure 3A).

There was, however, a very large difference in N uptake between the cultivation (363 kg N/ha) and direct drill (177 kg N/ha) treatments) for the ex-kale trial (Figure 3B). The major source of this high N uptake, apart from the urea applied to all ex-kale treatments in September (46 kg N/ha), appears to be from the mineralisation of the pig effluent applied in June prior to drilling in July and the warmer than average soil temperatures during the period (Figure 2). Unlike the cultivation treatment, soils under the direct drill and fallow treatments remained relatively undisturbed. Whilst there was an early and significant difference in N uptake between tillage treatments in the ex-fodder beet paddock trial, this did not persist and N uptake was largely similar by final harvest (Figure 3B).

Dry-matter production and N uptake for the Te Pirita catch crop species trial firmly favoured oats production, particularly early on (Figure 4A & B) where by mid-October 76 kg N/ha had been removed compared with 51 and 18 kg N/ha for triticale and Italian ryegrass, respectively. Dry-matter production for the oats reached 12 t DM/ha by final harvest, twice what was produced under Italian ryegrass whilst removing over 230 kg N/ha (no N applied).

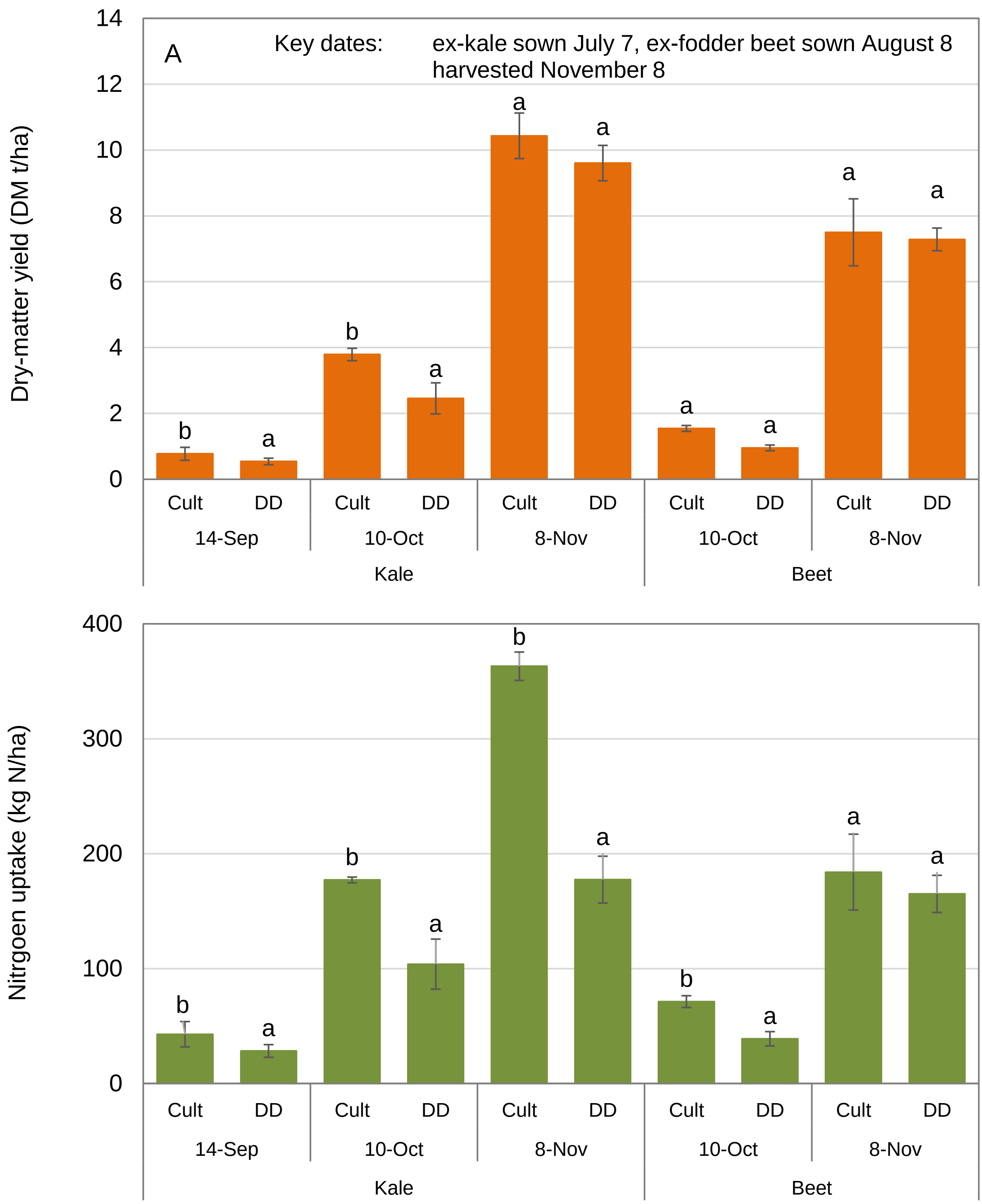

Figure 3. **Harvest DM yield (A) and N uptake (B) for Hororata ex-kale and ex-fodder beet tillage trials (Cult = cultivation and DD = direct drill). Uncommon letters denote significant differences within harvest dates at the 5% level (Duncan's multiple range test).**

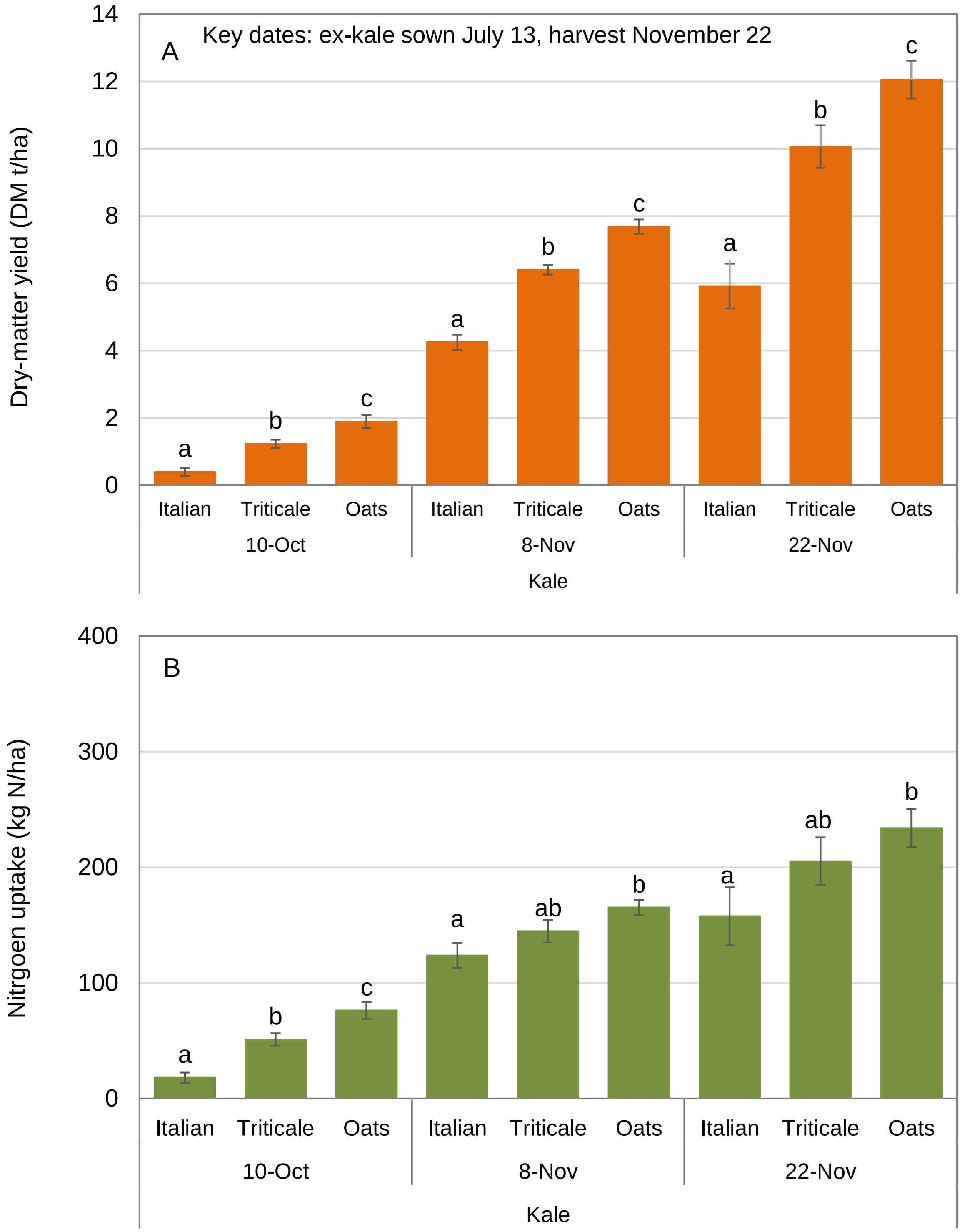

Figure 4. Harvest DM yield (A) and N uptake (B) for Te Pirita catch crop species trial (Italian = Italian ryegrass). Uncommon letters denote significant differences within harvest dates at the 5% level (Duncan's multiple range test).

Soil mineral nitrogen

There was considerable variation in soil mineral-N content pre-drilling between sites, most obviously in the Hororata kale site where cultivation and the application of pig effluent in the period prior to drilling the catch crop, resulted in a large mineralisation effect on soil N (Table

3). More than 400 kg N/ha was found residing in the top 15 cm depth of the cultivation treatment (at least 550 kg N/ha was estimated to be held in the top 30 cm depth of the soil profile but cannott be corroborated due to pre-drilling 15-30 cm samples not having been taken). Approximately half of this mineral-N was present as ammonium. Less mineral-N, however, resided in the undisturbed fallow and direct drill treatments with 125 and 91 kg N/ha extracted, respectively, in the top 15 cm, pre-drilling. No effluent or fertiliser was applied to the Hororata fodder beet and Te Pirita sites so mineral-N content, even in the cultivated treatments (all Te Pirita plots were cultivated except the fallow) was lower overall than the Hororata ex-kale cultivated treatments at 130-160 kg N/ha and 63-85 kg N/ha, respectively.

Post-harvest, soil mineral-N values declined considerably although fallow values were significantly 2-3 times higher than the tillage or species trial treatments (Table 3). The exception was the ex-kale cultivation treatment where, despite the removal of over 360 kg N/ha, still remained 50% higher than the fallow treatment (and 3-times the direct drill treatment). Generally, though, there was little difference between the ex-fodder beet tillage treatments or the catch crop species in terms of soil mineral-N by post-harvest.

Table 3. Soil mineral-N content (kg N/ha) in top 30 cm of the profile, pre-drilling and post-harvest, for Mid-Canterbury trial sites.

Trial		Pre-drilling			Post-harvest		
	Trt	**NH_4^+-N**	**NO_3^--N**	**[a] Min-N**	**NH_4^+-N**	**NO_3^--N**	**Min-N**
Hororata-Beet	Fallow	44 a	121 b	**164 a**	12 a	85 b	**97 b**
	Cultivation	52 a	107 a	**159 a**	10 a	23 a	**32 a**
	Direct drill	42 a	85 a	**127 a**	11 a	22 a	**33 a**
[b] Significance		ns			ns		
LSD (5%)		28					
[c] Hororata-Kale	Fallow	59 a	66 a	**125 a**	57 b	38 b	**95 b**
	Cultivation	206 b	202 b	**408 b**	52 b	96 c	**148 c**
	Direct drill	32 a	59 a	**91 a**	41 a	8 a	**49 a**
Significance							
LSD (5%)							
Te Pirita -Kale	Fallow	40 a	44 a	**84 a**	22 a	103 b	**125 b**
	Oats	23 a	39 a	**63 a**	27 a	17 a	**44 a**
	Italian RG	36 a	29 a	**65 a**	20 a	39 a	**60 a**
	Triticale	42 a	43 a	**85 a**	26 a	18 a	**44 a**
Significance							
LSD (5%)							

[a] Min-N = soil (ammonium-N + nitrate-N); [b] Significance level; ns = not significant, * p<0.05, ** p<0.01, *** p<0.001. Duncan multiple range test- letters not in common within a trial and column are significantly different at 5% level; [c] 15-30 cm samples not taken pre-drilling so comparisons between pre-drilling and post-harvest on 0-15 cm depth only.

Discussion

The advantages of using catch crops post-winter forage grazing were considerable in these series of trials. Not only were valuable amounts of feed produced (~$2000-$3000/ha) but each extracted in excess of 150 kg N/ha of soil-N, increasing the N efficiency of the winter forage system and reducing the nitrate leaching potential. Higher than average rainfall through October and November meant that N leaching losses from fallow treatments were potentially high and likely greater than from catch crop treatments despite the former's higher soil mineral-N content post-harvest. Without a catch crop, soil-N mineralisation still continues, especially if soil temperatures are greater at the surface due to a lack of canopy cover. Previous catch crop research in Canterbury and in growth chamber studies has shown that leaching losses under fallow are generally a third-to-a-half greater than where a cereal catch crop has been sown, even when soil mineral-N content remains greater (Malcolm et al., 2016; Carey *et al.*, 2018). This is because, as soil temperatures increase in a mild winter or with the advent of spring, soil-N mineralisation rates increase. The cultivation treatment in the Hororata ex-kale trial was an extreme case but demonstrated that these amounts can be substantial although this site is an outlier in terms of its effluent application history. Nevertheless, it does support that sowing the catch crop as soon as possible following the cessation of winter grazing is strongly advisable and corroborates earlier Canterbury research (Carey et al., 2016; Malcolm et al., 2016).

DM yields were similar to those shown in research plot trials for direct drilling treatments (Malcolm et al., 2016) and weren't significantly less than cultivation treatments by final harvest in November despite the latter's initial advantage over the direct drill treatments. Earlier research had suggested that cultivating the soil after fodder beet grazing aided oats establishment (Malcolm *et al.*, 2017) due to looser soil physical conditions promoting higher plant counts compared with the more compacted direct drill treatment soil conditions. Cattle grazing high yield winter forage crops can create more compacted soil conditions and reduce subsequent crop yields without intervention (Houlbrooke *et al.*, 2009). Nevertheless, one of the advantages in using cereals such as oats is their larger seeds enabling them to germinate relatively well despite poorer soil physical conditions.

The species trial at Te Pirita supported oats as the preferred catch crop species for both its greater DM production and N uptake. A yield range of 7.3-12.1 t DM/ha was recorded for all the oats treatments across the three trials, with triticale within the same range, and Italian ryegrass somewhat less (but able to be repeatedly grazed). At $0.20/kg DM, and establishment and growing costs of ~$300-600/ha (Askin & Askin, 2018) leaves a gross margin return to farmers in a range of $1000-$2000/ha (not including harvest costs). These profit margins have to be balanced, however, against a delay in establishing the next winter forage crop and some loss of potential yield. This may be important for fodderbeet crops that are typically sown by October to maximise yield. However, in a kale sequence, or a beet rotation entering a kale or restorative pasture phase, this is less important (DairyNZ, 2017). Nevertheless, these returns are encouraging and an incentive for farmers to use cereal catch crops within their winter forage crop rotations.

Conclusions

Inclusion of a catch crop in winter forage rotations in three Mid-Canterbury paddocks was successfully undertaken over a warmer and drier than average winter (2018). In the two Hororata tillage trials (ex-kale and ex-fodderbeet), cultivation/drilling increased DM yield and N uptake initially over direct drilling but by final harvest there was little difference in DM yield between either treatment for either ex-kale (9.6-10.4 t DM/ha) or ex-fodder beet paddocks (7.3-7.5 t DM/ha). In the ex-kale paddock, cultivation stimulated the rapid mineralisation of recently applied pig effluent resulting in very high soil mineral-N levels that exceeded those of both fallow and direct drill treatments. This also induced much higher N uptake (~360 kg N/ha) in the cultivation, compared with the direct drill, treatments (~177 kg N/ha).

In the Italian ryegrass, triticale and oats species trial, oats performed best in terms of both DM yield (6, 10 and 12 t DM/ha, respectively) and N uptake (158, 215 and 234 kg N/ha, respectively).

A wetter than average spring showed the value of a catch crop in a winter forage rotation where paddocks would otherwise lay fallow, with the resulting build-up in soil nitrate subject to increased drainage.

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