Catch crops after winter grazing for production and environmental benefits

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Abstract

Grazing winter forage crops is an important management strategy for profitable livestock production in many New Zealand regions where there is commonly a pasture feed deficit during this period. However, the high stocking densities that are often associated with these systems can have negative environmental effects, such as nitrogen (N) leaching losses to groundwater. This field study investigated the potential biomass production and reduced risk of N leaching from establishing oats (*Avena sativa*) as a green-chop catch crop after winter-grazed forage kale (*Brassica oleracea* var. acephala) in Canterbury, New Zealand. Oat crops were direct-drilled on two sowing dates (early: 1 July 2015 and late: 1 August 2015) and were managed under high (400 kg N/ha) and low (0 kg N/ha) N load conditions, representing urine-patch and inter urine-patch areas. For the early-sown crops yields were 6.1 (low N) and 11.8 t DM/ha (high N) at final harvest (50% ear emergence) on 19 November 2015. For the late-sown crops yields were 6.7 (low N) and 10.1 t DM/ha (high N) at the same development stage (26 November 2015). By establishing oats as a catch crop in winter soil profile mineral-N (0-120 cm depth) was reduced by up to 86% (early) and 80% (late) in the high N (simulated urine-patch) treatments compared with the respective fallow treatment. These results indicated the technical feasibility of direct drilling oats as catch crops immediately after winter forage grazing, with likely production and environmental benefits such as the reduced risk of N leaching losses.

Additional keywords: oats, *Avena sativa,* nitrogen, leaching risk

Introduction

Winter forage crops such as forage kale (*Brassica oleracea* var. acephala L.) and fodder beet (*Beta vulgaris* L. ssp. *vulgaris*) are single-graze species and land typically remains in a fallow state for three to five months post-grazing until a new crop is established in spring (Edwards *et al*., 2014). The risk of nitrogen (N) leaching from urine-patches post-grazing is greatest during these winter and early spring fallow periods (Monaghan *et al.*, 2007; Malcolm *et al.*, 2015). This is due to the absence of an active plant sink to take up residual N and a high probability of soil drainage, as precipitation generally exceeds evapotranspiration in winter. It is therefore important to identify economically viable and practical on-farm mitigation options to ensure the long-term sustainability of winter grazing systems.

A lysimeter study by Carey *et al.* (2016) indicated that sowing a catch crop of oats (*Avena sativa* L.) could reduce the amount of N leaching loss by 18-46% in a winter forage crop system in New Zealand. Further, they found that the earlier the oats were sown following urine deposition, the greater the reduction in leaching loss. The importance of early sown catch crops was also reflected in a recent long-term simulation of crop growth and soil drainage in Canterbury (Teixeira *et al.*, 2016). In addition to the reduced risk of N leaching losses, there is also a potential benefit of increasing annual forage production by reducing the fallow period inherent to winter forage grazing.

Nevertheless, there are important agronomic questions around how early an oat catch crop can be established under field conditions following winter grazing, as well as associated production potential (Carey *et al.*, 2016). The oat catch crop has to successfully establish and develop under the cool winter temperatures and unfavourable soil conditions (e.g. soil pugging/compaction and remaining forage stubble) associated with the grazing of winter forages in Canterbury.

The main objective of this study was to determine the potential biomass production and N uptake of oat catch crops sown after a winter forage kale crop.

Materials and Methods

The trial was carried out at the New Zealand Institute for Plant & Food Research Limited, Lincoln (43° 83' S, 171° 72' E) on a well-drained deep (>1.6 m) Templeton silt loam (Immature Pallic (Hewitt, 2010); *Udic Ustochrept* (Soil Survey Staff, 1998)). The plant available water-holding capacity of these soils is approximately 190 mm/m of depth (Jamieson *et al.*, 1995). Physical characteristics of the soil have previously been reported by Martin *et al.* (1992).

Preceding this trial was a crop of forage kale which was sown during the previous spring and mechanically harvested and removed (to partially simulate grazing) in late June 2015. After the kale crop was removed, 2×10 m plots were marked out and arranged as a split plot design consisting of four replicates of six treatments, giving a total of 24 plots (Table 1). Soil cores from each plot (0-15 cm depth x 2.5 cm diameter) were taken from the site and analysed for basic soil fertility status and residual mineral N (Table 2). All basic nutrients were within acceptable ranges for forage production.

The trial consisted of three main plot catch crop sowing treatments; fallow (control), early-sowing (1 July 2015) and late-sowing (1 August 2015). The catch crop used was 'Milton' oats, which was direct drilled using a 2 m wide Taege drill at a seeding rate of 110 kg/ha. Within each main plot were two rates of N; 0 and 400 kg N/ha (Table 1). These N rates simulated inter urine-patch and urine-patch areas, respectively, of a winter-grazed kale paddock (Malcolm *et al.*, 2015; Carey *et al.*, 2016). All N load treatments were uniformly applied as solid urea (46% N) on 1 July 2015.

Irrigation was applied to all the plots on four separate occasions during the months of October and November to a depth of 105 mm. The trial area was also sprayed with Agritone (a.i. 720 g/l MCPA as dimethylamine salt in the form of a soluble concentrate) at 1.5 l/ha in 200 l/ha of water to control weeds. Aside from the N treatments imposed in respective plots, no other fertilisers were applied to the trial area (Table 2).

Table 1: Treatment structure of the winter catch crop field experiment at Plant & Food Research, Lincoln in 2015.

Treatment	Sowing date	Urea fertiliser[a] (kg N/ha)
1	Fallow	0
2	Fallow	400
3	July	0
4	July	400
5	August	0
6	August	400

[a]Simulated inter urine-patch (0 kg N/ha) and urine-patch (400 kg N/ha) areas.

Table 2: Initial soil fertility status of the general trial area of the winter catch crop field experiment at Plant & Food Research, Lincoln in 2015 prior to treatment applications. Sample depth 0-15 cm. All units are in 'MAF quick-test units' unless specified (Mountier *et al.*, 1966).

Soil property								
pH	Olsen P (mg/l)	CEC (me/100 g)	Mineral N (kg N/ha)	Anaerobically mineralisable N (kg/ha)	QT Ca	QT Mg	QT K	QT Na
6.2	26	16	6	59	9	11	7	8

Measurements

The number of emerged oat seedlings within two side-by-side rows of a randomly placed 1 m strip were counted three to four times after each sowing date, from when the first seedling began to emerge until a constant population was observed. This information was then used to calculate emergence percentage.

Biomass harvests were carried out on three to four occasions during the trial; 14 October, 5 November, 19 November and 26 November 2015 (late-sowing only). The final harvest for each sowing date was taken at the optimum green-chop silage stage (50% ear emergence/growth stage 51), which occurred on 19 November and 26 November for the early- and late-sowing treatments, respectively. The harvests involved randomly placing a 0.5 m^2 quadrat within each oat catch crop plot and cutting the herbage at ground level. Bulk samples were weighed fresh and subsamples were oven-dried at 60°C for 48 hours to obtain dry matter (DM) percentage for the calculation of DM yield. Subsamples were then finely ground using a Cyclone Sample Mill (Udy Corporation, Fort Collins, Colorado, USA) to pass through a 1 mm screen, and analysed for total N content using a LECO CNS analyser. The information was used to calculate N uptake from each plot/treatment. Roots were not sampled.

Two soil cores were obtained from each plot down to a depth of 1.2 m on 2 September, 6 November and 26 November 2015. The cores were divided into five depth horizons; 0-15, 15-30, 30-60, 60-90 and 90-120 cm. At each sampling date the soil samples from the same depth horizon within each plot were combined, passed through a 2 mm sieve, and analysed for total mineral N content by flow injection analysis (Gal *et al.*, 2004; Tecator Inc.).

Climate data [air temperature [Campbell Scientific (CS) 107], soil temperature (CS 107B) at 10 cm depth and rainfall (tipping bucket rain gauge, 0.2 mm resolution)] were collected using a CS CR10X data logger.

Statistical analysis

Differences in final DM yield, N uptake and soil mineral-N were assessed by an analysis of variance (ANOVA) using GenStat version 14 (VSN International Ltd, UK). Datasets were log-transformed where necessary to ensure homogeneity of residual errors.

Results and Discussion

Both total DM (Figure 1) and N uptake (Table 3) significantly (P<0.001) increased with N application. Under the simulated urine-patch treatments (400 kg N/ha applied), total DM yield from the catch crop treatments at final harvest was 11.8 t DM/ha (19 November harvest) and 10.8 t DM/ha (26 November harvest) for the July and August sowing dates, respectively (Figure 1). In addition, these same treatments took up 243 and 229 kg N/ha, respectively, which would have otherwise remained in the soil under fallow conditions and been at risk of leaching (Table 3). Although absolute differences in yield and N uptake between the sowing dates were non-significant with the earlier sown catch crop treatment, the green-chop silage stage (final harvest) was achieved one week before the later sown crop. By 19 November (final harvest of the July catch crop treatment) the July sown catch crop had yielded almost 3 t DM/ha more biomass than the August sown oat crop, and at the same time removed 43 kg/ha more N. Overall the yields measured for these winter sown oat crops were higher than those in the study of Carey *et al.* (2016) where crops were grown in lysimeters (2-4 t DM/ha). This difference might be because of the restrictive nature of barrel lysimeters in comparison with the field conditions of our study, coupled with seasonal differences. Nevertheless, in both studies oat crops were able to successfully establish and take up excess N during the winter period.

Under the simulated inter urine-patch treatments (0 kg N/ha applied) yields were significantly (P<0.001) lower reaching a maximum of 6.7 t DM/ha (August sown oats at 26 November). Lower yields were attributed to lower residual soil mineral N levels at the outset of the trial (<10 kg/ha; Table 2) and the comparatively low background N mineralisation from soil organic matter.

Between 83 and 96% of the final biomass was accumulated during the final five to six weeks of the trial, after mid-October (54-72% during the final two to three weeks in the simulated urine-patch treatments). Consequently, the largest proportion of N uptake was also observed during this period. The catch crops were slow to emerge and reach full canopy cover, with full emergence recorded on 17 August and 7 September for the early- and late-sown crops, respectively (data not shown). This was partially due to the early spring period being cooler than the long term average (Figure 2), with temperatures in September almost 1ºC cooler than the historical records. The poor physical structure of the over-cultivated soil at the site might have contributed to low soil temperatures due to excess moisture retention. These results highlight the dependence on prevailing weather conditions that largely determine the rate and timing of canopy closure and uptake of soil N of catch crops (Teixeira *et al.*, 2016).

Table 3: Total nitrogen (N) uptake by oats sown in July or August 2015 of the winter catch crop field experiment at Plant & Food Research, Lincoln. Values given represent the total accumulated N from sowing until the time of sampling (n=4).

Month of sowing	Fertiliser treatment[a] (kg N/ha)	Total N uptake (kg N/ha) 14 Oct	5 Nov	19 Nov[b]	26 Nov[b]
July	0	26.8	47.8	*55.4*	
	400	39.6	144.4	*242.8*	
August	0	18.8	34.4	60.6	*76.2*
	400	18.0	91.7	199.7	*228.5*
LSD (5%) (final harvests only)					59.5

[a]Simulated inter urine-patch (0 kg N/ha) and urine-patch (400 kg N/ha) areas; [b]values presented as 'italics' represent the final harvest as green-chop silage for both sowing dates.

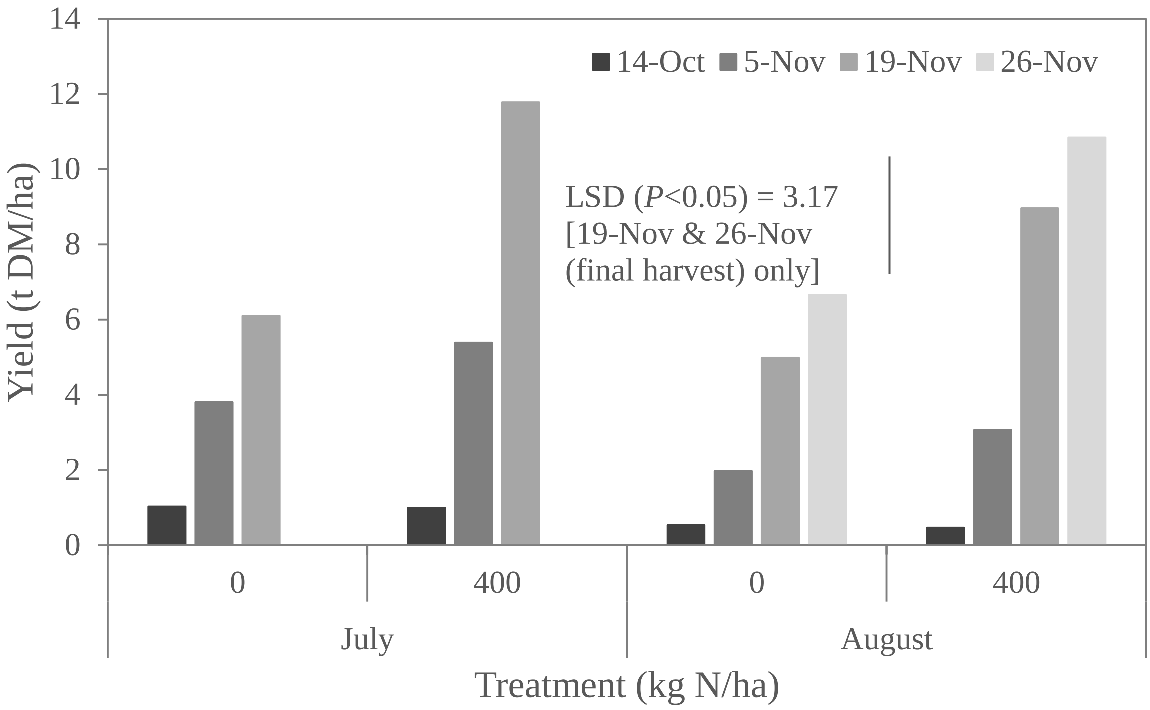

Figure 1: Sequential total dry matter (DM) yield of catch crop oats sown in July or August 2015 at Plant & Food Research, Lincoln. Vertical bar represents the least significant difference (LSD) at the 5% level (n=4).

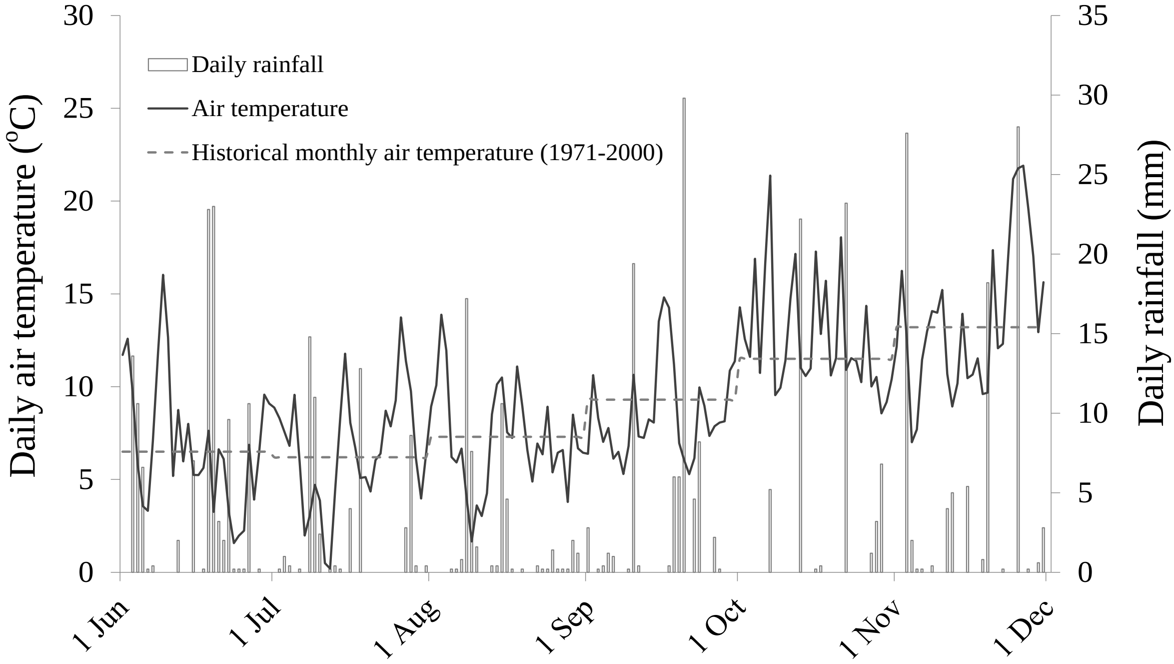

Figure 2: Daily average air temperature and rainfall at the winter catch crop oat trial site at Plant & Food Research, Lincoln in 2015 and the historical district air temperature recorded between 1971 and 2000.

Changes in the total amount of soil mineral N in the profile (0-120 cm depth) at various times during the trial period are shown in Figure 3. By 2 September 165-288 kg N/ha remained in the soil profile under the simulated urine-patch treatments. At this time, sowing a catch crop in either July or August significantly ($P<0.001$) reduced soil mineral N by approximately 33% compared to the fallow control.

The respective inter urine-patch (0 kg N/ha) treatments contained between 42 and 55 kg N/ha, indicating a net mineralisation amount of 45 kg N/ha on average during the period from the initial soil sampling on 9 June until 2 September. At the final soil sampling (26 November) total soil profile mineral-N (0-120 cm depth) was reduced by 86% (early) and 80% (late) in the simulated urine-patch treatments compared with the respective fallow treatment. By early November there was relatively low biomass production and N uptake. Most of the benefit of the oats occurred during the final 10 days of the trial, where soil mineral N was reduced on average by 185 kg N/ha in the simulated urine-patch catch crop treatments, and about 6.4-7.8 t DM/ha of new biomass accumulated. It is possible that on lighter, stony soils (to which 70% of the Canterbury Plains belong) the effectiveness of the winter catch crops begin earlier as a result of the ability of the soil to warm up more quickly throughout the day. A non-replicated proof-of-concept trial that we carried out after winter grazing in 2014 on a stony Balmoral silt loam soil showed that this may be the case, with almost double the amount of accumulated DM of oats by mid-October (sown 1 July and 1 August) compared with the respective treatments in this trial (unpublished data)

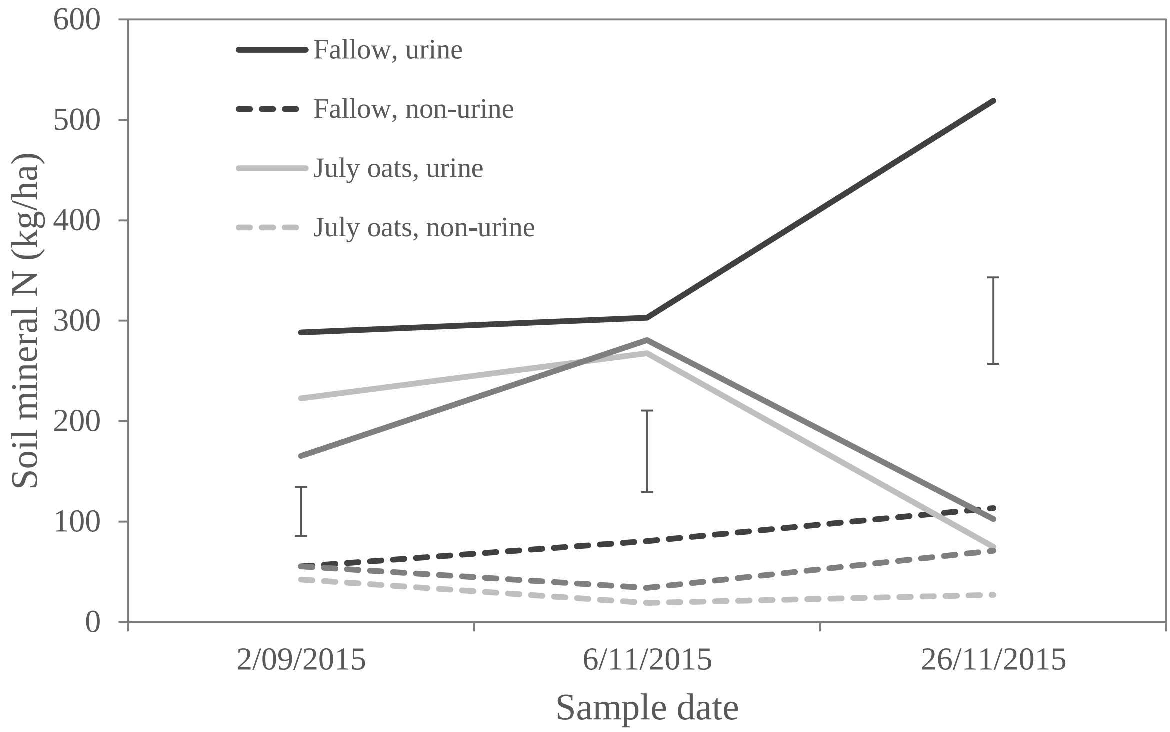

Figure 3: Total soil mineral N throughout the soil profile (0-120 cm depth) of the catch crop oat trial at Plant & Food Research, Lincoln in 2015 post fertiliser applications until the final biomass sampling for the simulated urine-patch (400 kg N/ha) and inter urine-patch (0 kg N/ha) treatments within each catch crop and fallow treatment. Vertical bars represent the least significant difference (LSD) at the 5% level (*n*=4)

The presence of a catch crop reduced the N amount in the deeper soil profile. Of the simulated urine-patch treatments (400 kg N/ha) 32-55% of the N in the profile was below 15 cm (i.e. 15-120 cm depth) during the final 10 days of the trial (Table 4). In absolute terms, the amount of N within this 15-120 cm depth of the profile, of the simulated urine-patch treatments, was 85 kg N/ha (August sown oats) and 99 kg N/ha (July sown oats) lower compared with the respective fallow treatment (158 kg N/ha) on average during these final 10 days (Table 4). In addition, soil mineral N deep in the soil profile (90-120 cm depth) was reduced by 75% (July sown oat) and 71% (August sown oat) in the simulated urine-patch treatments compared with the equivalent fallow treatment at the final soil sampling (data not shown).

These results indicate that sowing a winter catch crop of oats after winter forage grazing in Canterbury can have agronomic and environmental benefits. An additional yield of 6-12 t DM/ha was achieved during a growth period that for the most part would have otherwise been under fallow. During this period, approximately 55 to 240 kg N/ha were removed from the soil profile reducing the risk of N leaching. Nevertheless, there are important agronomic aspects to be considered for the use of oat catch crops after winter grazing. Firstly, most of the catch crop growth and potential for N uptake occurred late in the growth cycle (e.g. from early November on in this study). The effectiveness of catch crops is greater when weather and soil conditions favour early crop growth (e.g. warm years). Benefits will vary depending on when rainfall events occur, their magnitude and how fast catch crops develop. A large inter-annual variability of catch crop effectiveness was previously estimated for Canterbury climatic conditions (Teixeira *et al.*, 2016). Second, final harvests of the catch crop oats for green-chop silage did not occur until late November, which is four to six weeks after a spring crop would normally be sown in Canterbury. To ensure the economic viability of this management intervention for Canterbury production systems, it is important to assess if the additional biomass achieved from the catch crop oats would compensate potential losses in yield of the subsequent spring crop due to a late sowing (Fletcher *et al.*, 2011). Further work is required to validate our findings and to address these and other (e.g. establishment under variable post-grazing residue) practical 'on-farm' implications. Overall, our results highlight the importance of targeting conditions for fast establishment and growth of winter-sown catch crops.

Table 4: Sequential changes in soil mineral N status in the 15-120 cm depth zone after sowing and nitrogen (N) treatment applications of the winter catch crop field experiment at Plant & Food Research, Lincoln.

Month of sowing	Fertiliser treatment[a] (kg N/ha)	Soil mineral N (15-120 cm depth) kg N/ha			% of total profile		
		2 Sept	6 Nov	26 Nov	2 Sept	6 Nov	26 Nov
Fallow	0	36.3	44.6	71.5	67.0	54.2	63.3
	400	89.9	100.4	215.4	32.0	32.9	41.6
July	0	26.5	13.8	21.1	62.7	71.3	78.1
	400	66.9	83.2	34.5	29.9	32.4	54.7
August	0	37.5	22.5	29.8	67.6	65.0	64.8
	400	45.7	100.3	44.9	27.4	36.9	51.7
Level of significance (5%)							
	Sowing	0.015	0.081	<0.001	0.687	0.124	0.288
	Nitrogen	<0.001	<0.001	<0.001	<0.001	<0.001	0.024
	Sowing x Nitrogen	0.008	0.690	<0.001	0.218	0.300	0.824
	[b]LSD (5%)	17.3	33.1	29.9	8.8	14.0	25.4

[a]Simulated inter urine-patch (0 kg N/ha) and urine-patch (400 kg N/ha) areas;
[b] least significant difference.

Conclusions

The main conclusions drawn from this trial are:

1. Growing a catch crop of oats following winter forage crop grazing can have significant environmental benefits, by removing up to 243 kg N/ha of residual mineral N throughout the soil profile. The benefit will depend on the rate of growth of catch crops (and therefore the amount of N that is locked up during the winter and spring) and seasonal rainfall patterns.

2. Establishing a catch crop of oats during this cool period is agronomically possible and resulted in yields of 6-12 t DM/ha by

the end of November for green-chop silage.

3. Further work addressing the 'on-farm' practicalities of establishing a catch crop after winter grazing is required.

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