Establishment methods of oat catch crops after winter forage grazing

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Abstract

Catch crops sown directly after winter forage grazing can reduce the risk of nitrogen (N) leaching losses. In this study we tested the agronomic performance of oat (*Avena sativa* L.) catch crops, post-grazing, on a stony Balmoral/Lismore soil. In July 2016, two experiments were set up (approx. 200 m apart) near Lincoln, Canterbury, with three oat catch crop establishment method treatments at a 300 plants/m^2 target population: (i) conventional (surface grubbing, power harrow, roll then drill), (ii) direct drill, and (iii) broadcast, after surface grubbing. Both experiments, one ex-kale (*Brassica oleracea* var. *acephala* L.; Exp. 1) and the other ex-fodder beet (*Beta vulgaris* L. ssp. *vulgaris* var. *alba*; Exp. 2), had recently been grazed by pregnant non-lactating dairy cows in June/July. In Exp. 1, oat plant populations on 18 August (28 days after sowing, DAS) were near target in the conventional and direct drill treatments (276 and 261 plants/m^2, respectively) compared with the broadcast treatment of 123 plants/m^2. In Exp. 2, both direct drill and broadcast treatments resulted in relatively low populations (97–128 plants/m^2) compared with the conventional treatment (198 plants/m^2). At green-chop silage maturity (126 DAS) yields were between 7 and 10 t DM/ha in both experiments, with between 98 and 151 kg N/ha taken up by plants. Application of 50 kg N/ha in spring (as split plots) did not consistently improve yields; however, responses to N fertiliser in terms of herbage N concentration and N uptake were evident, indicating other factors potentially limiting production. The results from this preliminary trial suggest that successful oat stands can be established after grazing kale by either conventional or direct drill methods, whereas cultivation prior to drilling is probably important after fodder beet grazing.

Additional keywords: Catch crop, *Avena sativa*, winter grazing, forage crop, nitrogen leaching, kale, fodder beet

Introduction

Kale (*Brassica oleracea* var. *acephala* L.) and fodder beet (*Beta vulgaris* L. ssp. *vulgaris* var. *alba*) are single-graze forage crops that are widely used for wintering dairy livestock in New Zealand, particularly in the South Island (Edwards *et al*., 2014). However, land post-grazing typically remains fallow for three to five months until a new crop is established in spring. This poses a significant environmental risk of nitrogen (N) leaching losses for three main reasons: (i) high stocking densities result in a large amount of urine [source of most N leaching (Selbie *et al*., 2014)] deposition in concentrated patches; (ii) precipitation exceeds evapotranspiration in winter causing higher risk of drainage during the grazing period (McLaren and Cameron, 1996); and (iii) the absence of an active plant sink to take up residual N and water when N is at most risk of leaching (Malcolm *et al*., 2016a; 2015; Monaghan *et al*., 2007). In addition, in Canterbury in particular, most of the wintering occurs on light stony soils, which are particularly susceptible to leaching losses because of their low water-holding capacity.

Recent research has shown that N leaching losses from winter forage crop systems can be reduced when a catch crop is sown immediately after grazing. A study by Carey *et al*. (2016), using intact monolith lysimeters, indicated that oats (*Avena sativa* L.) sown after simulated grazing of forage kale could reduce N leaching losses by 18–46%. Similarly, in large field plots Malcolm *et al*. (2016b) reported that up to 230–240 kg N/ha was taken up from a simulated urine patch (400 kg N/ha applied in early July) by an oat catch crop sown in July or August, resulting in significant reductions in the amount of N remaining in the soil profile at risk of leaching. Additionally, Malcolm *et al*. (2016b) reported yields of 6–12 t DM/ha at green-chop silage maturity (late November), which are likely to compensate for any potential production losses if the sowing of a subsequent spring crop is delayed (Fletcher *et al*., 2011).

Nevertheless, the effectiveness of catch crops to mitigate N leaching losses was shown to largely depend on management (e.g. sowing time) and inter-annual weather variability (e.g. the timing and amount of rainfall) by long-term simulation experiments in Canterbury (Teixeira *et al*., 2016) and Waikato (Zyskowski *et al*., 2016). It is unclear how other management factors, such as establishment methods, can influence the production of catch crops sown after winter grazed forages. Soil conditions for catch crop establishment are often unfavourable after the grazing of winter forages due to soil pugging and compaction by livestock and remaining forage stubble. In this study, we investigate different methods of catch crop establishment considering soil preparation and sowing techniques after the grazing of both kale and fodder beet crops.

Materials and Methods

Site information

The trials were conducted at the Lincoln University Ashley Dene Research and Development Station (ADRDS) near Lincoln, Canterbury (43°39'S, 172°20'E). The soil was a free-draining Balmoral/Lismore stony silt loam [Mottled Argillic Pallic Soil (Hewitt, 2010); Udic Ustochrept (Soil Survey Staff, 1998)], which represents a typical soil type found on the Canterbury Plains.

Two independently-run experiments were set up. Experiment one (Exp.1) was established within a paddock that had previously been in kale (hereafter referred to as 'ex-kale'), while experiment two (Exp. 2) was within a previously grazed fodder beet paddock (hereafter referred to as 'ex-fodder beet'). The experiments were approximately 200 m apart on the same soil type, and previous crops were used for grazing pregnant, non-lactating dairy cows during June and July 2016. At the time of grazing, average dry matter (DM) yields were approximately 14.1 and 24 t DM/ha for kale and fodder beet, respectively. Kale was allocated at 12 kg DM per cow per day, while fodder beet was allocated at 8 kg DM per cow per day. Animals were also fed pasture silage as part of their daily diet. As a consequence of both yield and daily DM allocation throughout the winter period, the stocking density of livestock on the fodder beet (~50 cows/ha for 60 days) was considerably higher than on kale (~20 cows/ha for 60 days).

Trial design and treatments

Both experiments were arranged as randomised split plots, consisting of three main plot treatments and two subplot treatments, replicated five times. The main treatments were comprised of three different establishment methods (direct drill, conventional and broadcast) and the subplots of two N fertiliser treatments [with (50 kg N/ha on 28 October) and without Sustain urea fertiliser in spring] (Table 1).

On 19 July 2016, immediately after the experimental sites had been progressively strip-grazed over an approximate four-week period, 10 m x 4 m plots were established and grazing animals were excluded thereafter. The plots were arranged in parallel with the grazing strips, while the blocks were aligned in the direction of grazing, to account for any temporal variation associated with grazing.

In the conventional plots, the soil was Tyne grubbed, power harrowed and then Cambridge rolled. For the broadcast plots, only Tyne grubbing was performed before sowing. No soil preparation was imposed in the direct drill plots. All direct drill and conventional plots were then sown with ‘Milton’ oats on 21 July using a 2-m wide Taege drill (two drill passes per plot) at a seeding rate of 125 kg/ha (target population of 300 plants/m^2). Chain harrows were towed behind the drill. Broadcast plots were seeded by hand at the same sowing rate as those that were mechanically drilled and were subsequently lightly worked with a Tyne crumbler to improve soil-to-seed contact.

Table 1: Treatment structure of the experiments at Lincoln University Ashley Dene Research and Development Station (ADRDS) near Lincoln, in 2016. Both experiments were assessed independently following grazing of either kale (‘Ex-kale’) or fodder beet (‘Ex-fodder beet’).

Treatment	Establishment method	Nitrogen applied[1] (kg/ha)
1	Direct drill	0
2	Direct drill	50
3	Conventional	0
4	Conventional	50
5	Broadcast	0
6	Broadcast	50

[1]applied as SustaiN urea fertiliser on 28 October 2016

Measurements

On 18 August (28 DAS) the number of oat seedlings within two side-by-side rows of a randomly placed 1 m strip were counted. Two replicate counts per plot were performed. This information was used to calculate the plant population (plants/m^2).

Reflectance measurements were undertaken to assess canopy development after plants were fully emerged (commencing 43 DAS) on a fortnightly basis until canopy closure using GreenSeeker® (GS, Trimble Agriculture Division, CO, USA). Reflectance values on each measurement date were calculated from approximately 70 measurements obtained from a 10 m × 0.6 m area of each plot, at a height of about 0.6 m above the crop canopy. These values obtained were converted into a scaled normalised difference vegetation index (SC-NDVI) (Carlson and Ripley, 1997; Chakwizira *et al*., 2015).

Crop sampling measurements were performed on 13 October, 2 November and 24 November (approximate green-chop maturity stage) to determine biomass accumulation and N uptake. At the 13 October and 2 November samplings, only the 0 N fertiliser treatment plots were sampled, given the fertiliser was applied only five days prior to the second harvest; however, on 24 November samples were obtained from all plots. On each sampling occasion, above-ground biomass was measured in each plot from a single 0.5-m² quadrat. The crop was cut at ground level and fresh weight was determined. A subsample (approximately 400 g) was oven dried at 65°C for approx. 48 hours (or until a constant dry weight was achieved) to determine percentage dry matter (DM), then ground and analysed for total N content using a LECO CNS analyser (LECO Corporation, St Joseph, MI, USA). The product of the biomass yield and N concentration in the tissue gave the total herbage N uptake (kg N/ha) on each sampling occasion.

Soil mineral N [ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N)] was measured in all plots that did not receive N fertiliser on 2 November. Samples were obtained to a depth of 30 cm and passed through a 4-mm sieve. A well-mixed subsample of 5 g of sieved soil was taken and extracted with *2 M* KCl at a 1:5 soil-to-solution ratio. The filtered extract was analysed for NO_3^--N and NH_4^+-N content on a Lachat QuikChem 8500 Series 2 Flow Injection Analysis System (Lachat Instruments, Loveland, Colorado, USE; Keeney and Nelson, 1982).

Rainfall and mean air temperature data were collated daily, for the trial period between 19 July and 24 November 2016, from the Broadfield Ews NIWA weather station, located approximately 11 km from the experimental sites.

Statistical analysis

Differences in plant population, final DM yield, N uptake and soil mineral-N were assessed by an analysis of variance (ANOVA) using GenStat v. 17 (VSN International, Hemel Hampstead, UK). Significant interactions and main effects were separated using Fisher's protected least significant difference (LSD) tests (α=0.05).

Results and Discussion

The winter/spring period when the trial was conducted was notably drier than normal (Figure 1a). Between sowing (21 July) and the date at which crops were considered fully emerged (18 August), only 29 mm of rainfall had been recorded, equating to approximately half the average amount of rainfall recorded during the same months in prior years between 2000 and 2015 (NIWA, 2016). By the end of the trial a total of approx. 150 mm of rain had fallen, almost 70 mm less than the long-term mean. Aside from approx. 2°C cooler temperatures during the first three weeks of August, air temperatures were similar to the 2000–2015 historical average (Figure 1b).

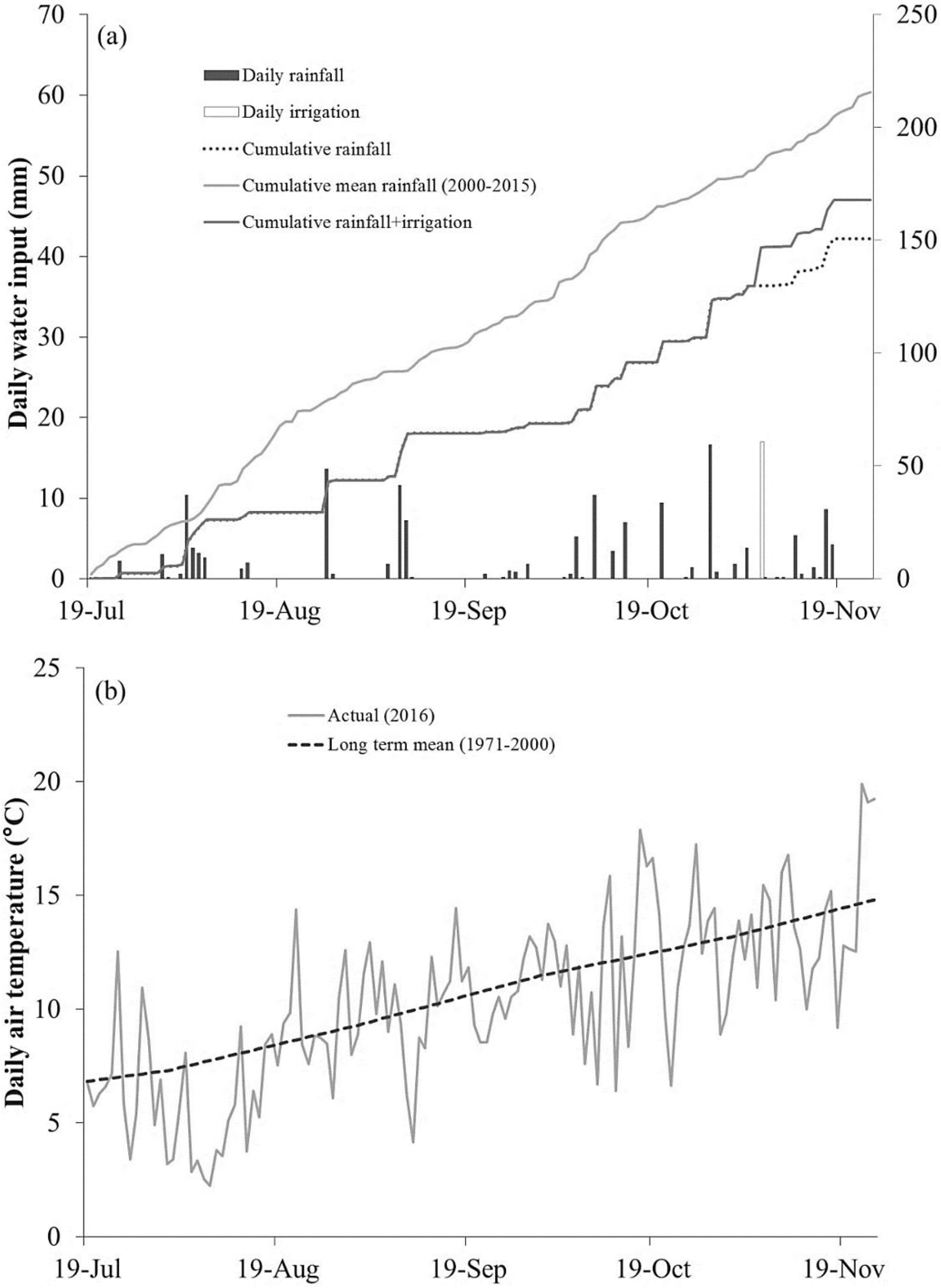

Figure 1: Rainfall/irrigation (a) and air temperature (b) patterns collated for the trial period (19 July to 24 November 2016) from the nearest NIWA weather station (Broadfield Ews, Lincoln) to the Lincoln University Ashley Dene Research and Development Station (ADRDS) trial sites.

By full emergence (18 August), there was evidence that the establishment method had a significant (*P*<0.01) effect on oat populations, in both experiments (Figure 2). Broadcasting oat seed resulted in significantly (*P*<0.05) lower plant populations than conventional methods resulting in approximately one third of the population targeted (300 plants/m^2) at sowing. This could be attributed to poor soil-seed contact, as well as potentially some bird damage due to a greater proportion of seed exposure compared with those plots that were drilled. In Exp. 1 (ex-kale), both conventional and direct drill methods of establishment resulted in near target plant populations (no statistical differences were observed between these two treatments). In Exp. 2 (ex-fodder beet), conventional methods of establishment resulted in significantly (*P*<0.05) higher plant populations than direct drill and broadcast (198 v. 128 and 97 plants/m^2, respectively). We speculate that this was due to the high stocking density of animals during fodder beet grazing causing significant compaction and soil damage. When direct drill plots were being established, it was noted in Exp. 2 that there was greater soil resistance, restricting the ability of the coulters to penetrate the soil. In the broadcast plots, even after surface grubbing, large clods of compacted soil remained on the surface of the ground, particularly in Exp. 2. The effects were also evident through until full canopy cover, with both direct drill and broadcast methods after fodder beet grazing resulting in slow oat canopy development compared with that in the conventional establishment treatment (Figures 3 and 4). For example, <50% canopy closure had occurred by 1 November in the direct drill treatment of Exp. 2 cf. ≥70% closure for all other treatments in both experiments (Figure 3).

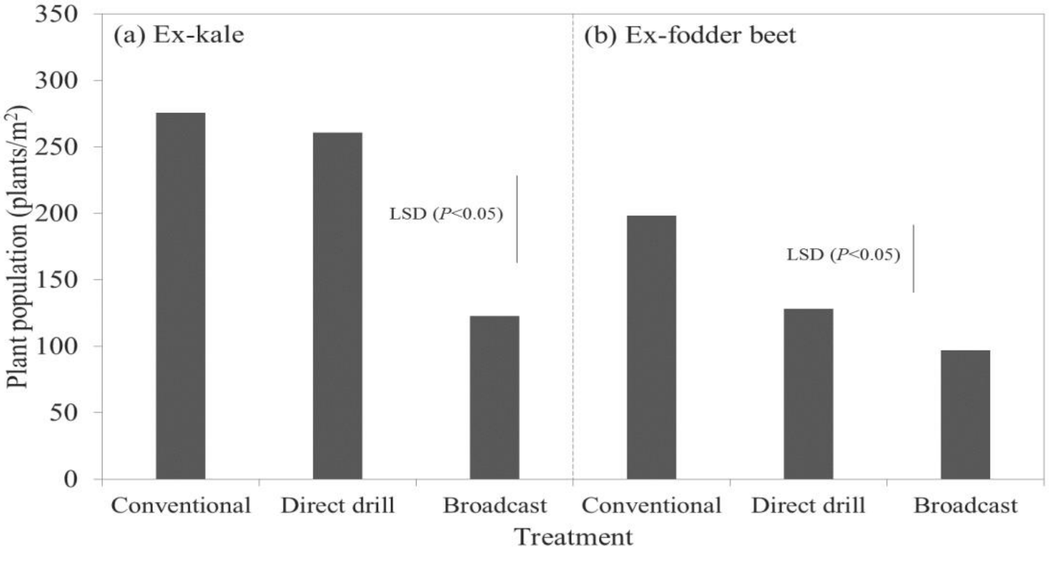

Figure 2: Plant population (plants/m^2) of oat catch crops sown on 21 July 2016 following grazing of either (a) kale ('Ex-kale') or (b) fodder beet ('Ex-fodder beet') by pregnant non-lactating dairy cows at Lincoln University Ashley Dene Research and Development Station (ADRDS), near Lincoln. Three establishment method treatments were imposed; conventional, direct drill and broadcast. The vertical bars represent the least significant differences (LSD) at the 5% level. Data from each of the trial sites were analysed independently.

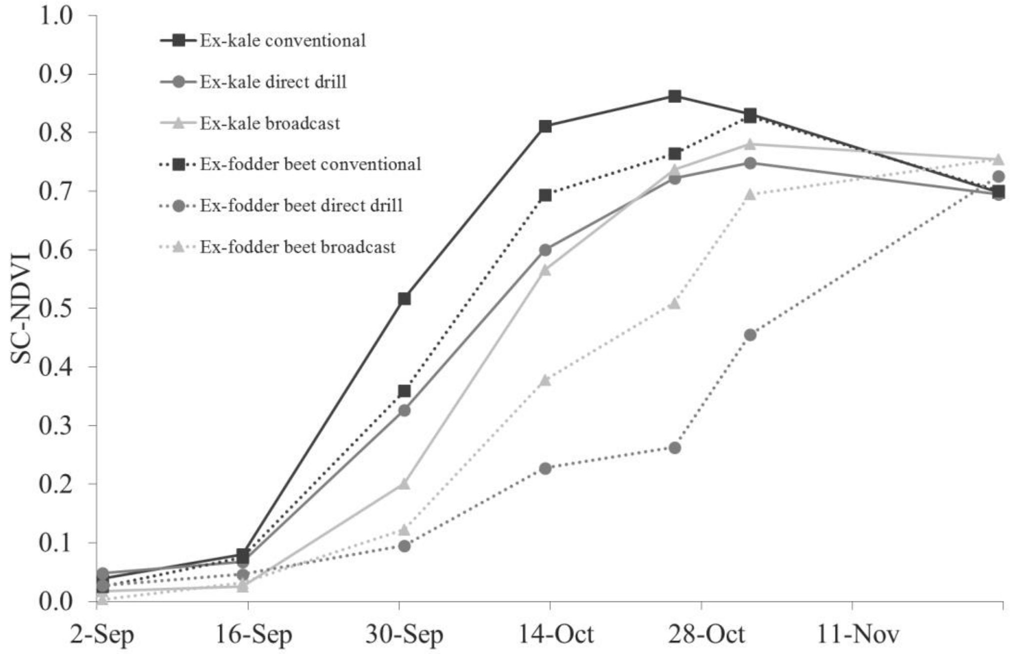

Figure 3: Proportional rate of canopy development (scaled normalised difference vegetation index, SC-NDVI) of oat catch crops sown on 21 July 2016 following grazing of either kale ('Ex-kale') or fodder beet ('Ex-fodder beet') by pregnant non-lactating dairy cows at Lincoln University Ashley Dene Research and Development Station (ADRDS), near Lincoln. Three establishment method treatments were imposed; conventional, direct drill and broadcast.

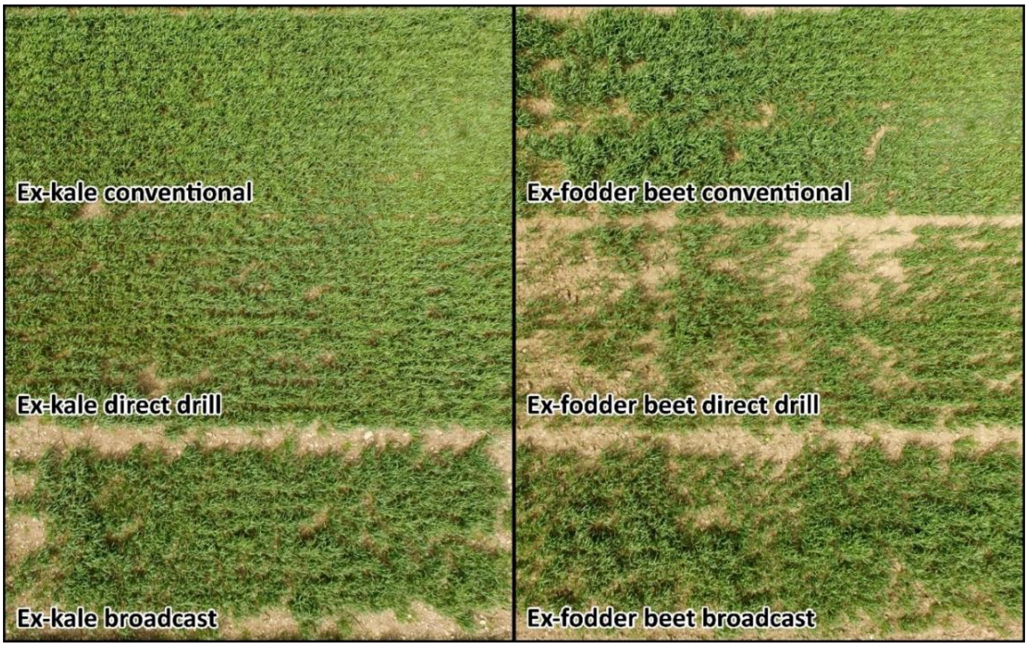

Figure 4: Aerial photographs (taken 1 November, 103 DAS) of representative plots for each establishment method treatment following grazing of kale ('Ex-kale', left) and fodder beet ('Ex-fodder beet', right) at Lincoln University Ashley Dene Research and Development Station (ADRDS), near Lincoln in 2016.

Although the plots prepared conventionally were visually similar at both sites, in general the oat plant populations in Exp. 2 were lower than in Exp. 1. This could be due to a number of reasons: (i) residual herbicide in the soil (there was considerably higher herbicide use on the fodder beet than on the kale); (ii) secondary plant compounds inhibiting germination, (iii) the chemical composition of animal urine; or (iv) soil structural differences. Indeed, for the direct drill treatments, soil compaction appeared considerably higher in the ex-fodder beet plots than in the ex-kale plots; however, for the other treatments there was no obvious explanation. Further work is therefore required to identify whether this was a real effect given the location ('ex-kale' and 'ex-fodder beet' were not true variables in the experimental design), and to determine the mechanisms for any differences observed.

More than half the biomass accumulated during the final three weeks of the trial (November; Table 2). This is consistent with the winter-sown oat catch crop data obtained by Malcolm *et al*. (2016b) under controlled conditions (i.e. no prior winter grazing), who reported that 54–72% of the biomass in simulated urine patches accumulated during the final 2–3 weeks. This was expected because of the particularly cool temperatures and the harsh winter environment under which the crops established. However, in terms of crop N uptake, there was a lower proportion of N that accumulated during the final three weeks than the respective biomass accumulations. For instance, at the 2 November sampling, 60–92 and 59–73% of the total N at green-chop had been taken up by the crops of the ex-kale and ex-fodder beet plots, respectively, in subplots that had received no additional N. Herbage N contents of the oats at the initial sampling on 13 October were between 3.8 and 4.6% for all plots in both experiments, which progressively declined as the crops matured. Similarly, Carey *et al*. (2016) showed an inverse relationship between DM yield and N content (y = -1193x + 5908; r^2 = 0.72, P<0.001) when oats were sown into monolith lysimeters in winter following simulated grazing of forage kale.

At green-chop silage maturity (24 November, 141 DAS), in subplots where no N fertiliser was applied, yields ranged from 7.7–9.6 and 6.8–9.0 t DM/ha under all main treatments for the ex-kale and ex-fodder beet plots, respectively. Despite the significant treatment differences observed for plant populations, final yields were not strongly affected by method of establishment. In Exp.1, there were no significant yield differences between the establishment treatments. In Exp. 2, however, conventional methods of establishment resulted in significantly (P<0.05) higher yields than both direct drill and broadcast methods, by 30 and 33%, respectively. As mentioned above, heavy soil compaction under fodder beet grazing is most likely to be the cause of these differences. This suggests that under similar climatic conditions, surface cultivation after fodder beet grazing may be necessary to ensure an even and more productive stand of oats; after kale grazing, both till and no-till options are potentially suitable before drilling on these soil types.

Table 2: Dry matter (DM) yield (t DM/ha), herbage nitrogen (N) content (%), herbage N uptake (kg/ha) and soil mineral N (N_{min}, kg/ha; sampled 2 November 2016) of oat catch crops sown on 21 July 2016 following grazing of either kale ('Ex-kale') or fodder beet ('Ex-fodder

Experiment	Establishment treatment	Yield (t DM/ha)			Herbage N content (%)			Herbage N uptake (kg/ha)			Soil N_{min} (kg N/ha)
		13-Oct	2-Nov[1]	24-Nov[2]	13-Oct	2-Nov[1]	24-Nov[2]	13-Oct	2-Nov[1]	24-Nov[2]	
1. Ex-kale	Conventional	1.61	4.52	10.25	4.03	1.94	1.42	64.7	87.4	146.4	27.2
	Direct drill	1.21	3.88	8.36	3.77	2.33	1.37	45.8	90.4	113.8	16.8
	Broadcast	0.60	2.70	7.92	4.87	2.76	1.71	29.4	72.7	136.6	31.3
	P value	*<0.001*	*<0.001*	*0.008*	*<0.001*	*0.004*	*<0.001*	*<0.001*	*0.001*	*0.013*	*0.616*
	LSD (5%)	*0.16*	*0.49*	*1.46*	*0.43*	*0.40*	*0.13*	*9.9*	*7.31*	*21.0*	*34.0*
2. Ex-fodder beet	Conventional	1.01	3.82	8.61	4.49	2.52	1.54	45.3	96.2	132.2	40.7
	Direct drill	0.35	2.20	7.09	4.19	2.90	1.75	14.5	61.0	123.2	47.8
	Broadcast	0.48	3.08	6.42	4.61	2.67	1.86	22.2	81.2	118.3	60.1
	P value	*<0.001*	*0.001*	*0.002*	*0.006*	*0.305*	*0.004*	*<0.001*	*0.013*	*0.346*	*0.415*
	LSD (5%)	*0.21*	*0.63*	*1.15*	*0.22*	*0.53*	*0.18*	*8.4*	*20.6*	*19.6*	*32.2*

beet') by pregnant non-lactating dairy cows at Lincoln University Ashley Dene Research and Development Station (ADRDS), near Lincoln. Both experiments were statistically analysed independently. LSD represents the least significant difference at the 5% level.

[1]sampling occurred in the 0 N fertiliser plots only, given fertiliser applications were made only five days prior to sampling,

[2]final harvest (green-chop silage maturity stage); includes the additional N fertiliser treatments as per Table 3 below, i.e. '+' and '–' fertiliser N treatments are combined averages.

Considering significant differences in plant populations were observed between some of the treatments, yet yields were not too dissimilar, it is logical to assume that a certain degree of compensation of yield components occurred in plots with lower populations. For example, in Figure 4 of Exp. 2 (ex-fodder beet) there appears to be a denser stand of oats in the broadcast plot than in the direct drill plot, where plant population was low (Figure 2). This could be the result larger plants (e.g. thickening of stems, larger leaves and/or greater numbers of tillers per plant). Compensation by oat tillers was illustrated in a grazing study by Duchini *et al*. (2014) where an inverse linear relationship between tiller population density and mass per tiller was observed. Importantly, yield component compensation may have potential feed quality implications in terms of metabolisable energy (ME) and digestibility, which were not considered in our study.

The application of N fertiliser to half of each of the main plots on 28 October resulted in small, and generally insignificant, increases in biomass production at green-chop silage maturity (Table 3). Nitrogen application did, however, result in significantly (P<0.001) greater N uptake at green-chop in Exp. 1 and near-significant (P=0.08) effects were observed in Exp. 2. The seemingly greater response to N fertiliser in Exp. 1 was probably due to lower amounts of N in the soil (0–30 cm depth) than in Exp. 2, which was evident (but not statistically confirmed) at the early November sampling (Table 2). This would suggest that other limiting factors, e.g. moisture, restricted the ability of the oats to accumulate further biomass. Indeed, the weather data shown in Figure 1 suggest that there was not only a drier than normal winter/spring, but probably insufficient irrigation was applied to the trial sites.

Additional to the trial was a 20 m long x 4 m wide plot set up within the fodder beet paddock as ‘proof-of-concept’, to investigate the option of broadcasting oat seed pre grazing. Oat seed, at 125 kg/ha, was broadcast by hand evenly over the top of fully established fodder beet plants, which were then grazed 2–3 days later. Emergence counts on 18 August indicated very poor emergence (<1%), which we attributed to heavy trampling by grazing animals as a consequence of the high stocking density.

Table 3: Effect of nitrogen (N) fertiliser (applied on 28 October 2016) on oat biomass production (t DM/ha) at the green-chop silage maturity stage (24 November 2016) following different establishment methods. Both experiments were statistically analysed independently following grazing of either kale ('Ex-kale') or fodder beet ('Ex-fodder beet'), at Lincoln University Ashley Dene Research and Development Station (ADRDS), near Lincoln. Oat crops were sown on 21 July 2016. LSD represents the least significant difference at the 5% level.

Experiment	Establishment treatment	N fertiliser applied (kg N/ha)	Herbage N content (%)	N uptake (kg/ha)	Yield (t DM/ha)
1. Ex-kale	Conventional	0	1.23	117.9	9.60
		50	1.61	174.9	10.89
	Direct drill	0	1.18	98.1	8.36
		50	1.55	129.6	8.36
	Broadcast	0	1.57	121.1	7.69
		50	1.84	151.1	8.14
	P value		*0.632*	*0.358*	*0.651*
	LSD (5%)		*0.19*	*29.7*	*2.06*
	Main effect means	0	1.33	112.4	8.55
		50	1.67	152.2	9.13
	P value		*<0.001*	*<0.001*	*0.323*
	LSD (5%)		*0.11*	*17.2*	*1.19*
2. Ex-fodder beet	Conventional	0	1.47	132.4	8.97
		50	1.60	131.9	8.25
	Direct drill	0	1.50	104.1	6.89
		50	1.99	142.4	7.28
	Broadcast	0	1.74	116.0	6.75
		50	1.98	120.6	6.10
	P value		*0.127*	*0.105*	*0.540*
	LSD (5%)		*0.25*	*27.7*	*1.62*
	Main effect means	0	1.57	117.5	7.54
		50	1.86	131.7	7.21
	P value		*<0.001*	*0.080*	*0.472*
	LSD (5%)		*0.14*	*16.0*	*0.94*

Conclusions

The main conclusions drawn from this trial are:

1. After kale grazing, both conventional and direct drill establishment methods can offer equally high plant populations and yields, compared with the seed broadcast method. After fodder beet grazing, conventional methods (cultivation pre drilling) may be important for establishing a successful stand of oats on these soils under similar climatic conditions.
2. By 15 October and 24 November in the nil N treatment, up to 65 and 132 kg

N/ha was taken up by the oats on average in both experiments, respectively, reducing the amount of N in the soil at risk of leaching.

3. Sowing an oat catch crop directly after winter grazing of either kale or fodder beet can result in significant feed benefits in late spring/early summer. At green-chop silage maturity (late November), yields were between 7 and 10 t DM/ha when no N was added.

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