Effect of autumn regrowth interval and nitrogen fertiliser on dry matter yield and plant characteristics of six forage species

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Abstract

Cold temperatures and drainage increase nitrogen (N) losses from livestock production systems, so autumn management and forage type were investigated as strategies to mitigate N loss whilst meeting animal requirements. The effect of regrowth interval and fertiliser rate on plant dry matter (DM) yield, plant N and digestible organic matter in the DM (DOMD) was measured in six forage species over 4 weeks regrowth, in Canterbury in autumn 2015. As regrowth interval increased, herbage DM yield increased (from 180 kg DM/ha to 922 kg DM/ha, $P<0.05$) and N response rates were highest in perennial ryegrass and plantain ($P<0.05$). Herbage N% in autumn was high at >3.2% of DM and, in grasses and herbs, was positively associated with N application rate but negatively associated with regrowth interval ($P<0.001$). Delayed grazing by up to 4 weeks, under a moderate N regime, improved herbage quality and reduced herbage N% in autumn. These results suggest plantain is a suitable alternative to perennial ryegrass to reduce N losses without impeding farm production in autumn.

Keywords: chicory, plantain, perennial ryegrass, cocksfoot, white clover, red clover, nitrate leaching, nitrogen response rate

Introduction

Reducing nitrate leaching from agricultural land is an important goal for New Zealand farmers to ensure they are within environmental regulations developed by Regional Councils across New Zealand (Ministry for the Environment 2014). These regulations will require large reductions in nitrogen (N) inputs and outputs which may affect profitability.

Nitrogen fertilisers are often used in farm systems to maintain annual herbage production, however, their excessive use is discouraged due to the impact on N loss. Martin *et al.* (2017) compared the effect of N fertiliser on dry matter (DM) yield and N content (N%) in a suite of forages at a set regrowth interval, and found interactions between species and N fertiliser rate. The results suggested different species may benefit from different management strategies to achieve animal production targets under a regulated N loss regime.

Nitrate leaching in pasture-based dairy systems occurs largely from urine patches due to large quantities of mineral N deposited (Di & Cameron 2002). The risk of leaching is greatest in the autumn when cooler temperatures reduce plant N uptake and higher rainfall increases drainage of soil mineral N. Plant characteristics, such as annual growth and winter activity, have been identified to improve capture of soil N (Malcolm *et al.* 2014; Woods *et al.* 2016) as well as low herbage N% to reduce urine N (Woods *et al.* 2016). Both annual growth and plant characteristics can be altered using farm management practises; Bryant *et al.* (2012) showed interactions between regrowth stage and N fertiliser on herbage N%. However, the study was restricted to perennial ryegrass and found that herbage quality declined during regrowth, reducing milk yield (Bryant *et al.* 2014). As little information exists on the effect of regrowth on alternate forage plant characteristics, species such as plantain, chicory, clover and other grasses, may present an opportunity to reduce N losses without impeding quality. Therefore, the objective of the study was to compare the response of different forage species to N fertiliser rate and regrowth interval with respect to their forage characteristics which mitigate N loss and maintain farm production goals.

Methods

Experimental site and design

The current study was conducted 12 months after establishment, between 10 March and 7 April 2015. The experiment was a split-split-plot design with three blocks situated under irrigation on a free-draining Templeton fine sandy loam (Immature Pallic soil, Hewitt 2010) at the Lincoln University Research Dairy Farm, Canterbury, New Zealand (43º64’S, 172º46’E). Forage species (Table 1) were the main plot treatments (area = 37.8 m^2), N fertiliser rate (nil, medium and high) were the split-plot treatments (area = 6.3 m^2) and regrowth interval was the split-split plot treatment (area = 0.6 m^2). The N fertiliser rates were 0, 180 and 450 kg N/ha/year for grasses and herbs and 0, 156 and 389 kg N/ha/year for legumes.

Establishment and management

This study was part of a larger field experiment examining the role of N in alternative forages to

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reduce nitrate leaching. Details of establishment and management are described in (Martin *et al.* 2017). Briefly, the experimental area was established in March 2014 following cultivation. Control of herbage mass commenced in spring 2014 using only mower harvests, thus avoiding trampling and nutrient recycling of livestock. During the next 7 months harvest intervals in spring and summer for grasses and herbs were 32 and 26 days, respectively, and 41 and 35 days, respectively, for legumes to allow sufficient regrowth (Donaghy & Fulkerson 1998; Moot *et al.* 2003; Lee *et al.* 2015). N fertiliser was applied following each harvest as calcium ammonium nitrate (27: 0 :0 : 0; N : P :K :S), with the total annual N application rate split evenly throughout the year. Climate data was collected from Broadfields Meteorological Station, 1 km from the experimental area. Annual irrigation was 550 mm, applied between October and March.

Herbage measurements

Regrowth data was collected weekly between 17 March and 7 April 2015. Herbage yield, botanical composition and plant characteristics were determined by harvesting three quadrats (32 x 60 cm) per plot using hand shears, with an attachment set to 4 cm height to mimic grazing height. Harvesting occurred between 10:00 am and 12:00 pm and previously harvested areas were avoided. Herbage was kept in the shade, before being transported to the laboratory once all plots had been harvested. Two quadrats were oven-dried at 60 °C for 48 hours and weighed to determine herbage yield. The third quadrat was mixed and a sub-sample was frozen and freeze-dried for chemical analysis. Near-infrared spectrophotometry (NIRS, NIRSystems 5000, Foss, Maryland, USA) was used to determine plant characteristics, based on calibrations derived on experimental herbages (Martin *et al.* 2017). Herbage quality was measured as DOMD (digestible organic matter in dry matter) and N was measured as a % of DM. Any samples outside the calibration spectrum were analysed by wet chemistry using the same methods as Martin *et al.* (2017).

Statistical analysis

The split-split plot design procedure in GenStat, version 16 (VSN International 2013) was used to compare the fixed effect of forage species, N fertiliser regime, and regrowth interval on cultivars: herbage DM yield, N% and DOMD.

Results

Climate data

Average air temperature was 15.0 ºC from 10 March to 7 April 2015, this was 1.4 ºC higher than the long-term average in March/April (1981-2010). Minimum and maximum temperatures averaged between 10.7 ºC and 19.9 ºC. Rainfall was 20.8 mm from 10 March - 7 April, this was 24.7 mm below the long-term average for 1 month in March/April (1981-2010). Soil temperature (10 cm depth) was 15.5 ºC from 10 March - 7 April 2015.

Herbage DM yield

An interaction between N rate and regrowth interval (P<0.001) showed more rapid DM accumulation in high compared with nil N fertiliser treatments. Generally, there was a positive effect of both regrowth and N fertiliser rate on DM yield (Figure 1; Table 2). An interaction (P<0.001) between N fertiliser rate and species showed a positive response to N from herbs and grasses but no yield response to N fertiliser from legumes. Interaction between plant species and regrowth interval showed that there were large differences between species at beginning of the regrowth interval, however, by the end of the regrowth all species were similar in DM yield apart from plantain (Figure 1; Table 2; P=0.013). Response to N fertiliser was highest (P<0.05) in plantain and perennial ryegrass (23 kg DM/kg N) compared with chicory and cocksfoot (11 kg DM/kg N).

Nutrient concentration

The herbage N% of all treatments (sampled above 4 cm) was high, exceeding 3% of herbage DM. An interaction between N fertiliser and species revealed there was a positive relationship between N fertiliser

Table 1 Forage species sown and their functional group, scientific name, cultivar and sowing rate (kg/ha).

Forage	Functional group	Scientific name	Cultivar	Sowing rate (kg/ha)
Perennial ryegrass	Grass	*Lolium perenne*	One 50 AR37	20
Cocksfoot	Grass	*Dactylis glomerata*	Savvy	8
Chicory	Herb	*Cichorium intybus*	Choice	8
Plantain	Herb	*Plantago lanceolata*	Tonic	10
White clover	Legume	*Trifolium repens*	Kopu II	5
Red clover	Legume	*Trifolium pratense*	Sensation	10

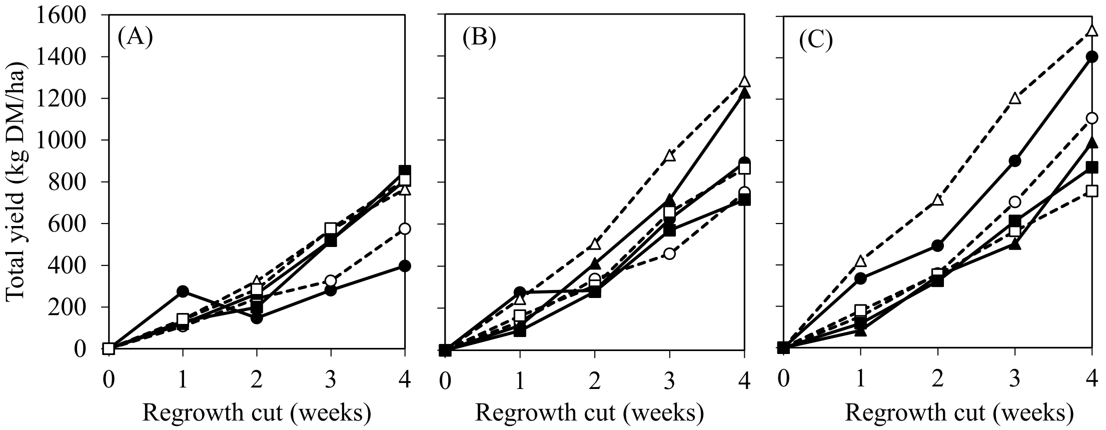

Figure 1 Effect of regrowth interval on herbage DM accumulation at three N fertiliser rates; nil (A), medium (B) and high (C), for six forage species: Perennial ryegrass (—●—), cocksfoot (- -○- -), chicory (—▲—), plantain (- -Δ- -), red clover (—■—) and white clover (- -□- -). Points are mean values.

Table 2 Average DM yield, plant N% and DOMD of six forage species at three N fertiliser rates over 4 weeks. LSD$_{0.05}$= least significant difference at the 5% level. Means followed by different letters denote the values are significantly different at the 5% level.

		Yield (kg DM/ha)		N % (% of DM)		DOMD (MJ/kg DM)	
Species	Chicory	509^{a}		4.0^{c}		77.5^{c}	
	Cocksfoot	438^{a}		4.0^{c}		70.3^{a}	
	Plantain	710^{b}		3.5^{b}		71.3^{ab}	
	Red clover	440^{a}		4.8^{d}		71.3^{ab}	
	Perennial ryegrass	526^{a}		3.2^{a}		73.1^{b}	
	White clover	471^{a}		4.8^{d}		80.0^{d}	
Regrowth interval (weeks)	1	180^{a}		4.1^{b}		70.6^{a}	
	2	343^{b}		4.3^{c}		73.8^{b}	
	3	624^{c}		4.1^{b}		75.0^{c}	
	4	922^{d}		3.8^{a}		76.9^{d}	
N fertiliser rate	Nil	390^{a}		3.8^{a}		73.1^{a}	
	Medium	535^{b}		4.0^{b}		73.8^{b}	
	High	626^{c}		4.3^{c}		75.0^{b}	
		P value	LSD$_{0.05}$	P value	LSD$_{0.05}$	P value	LSD$_{0.05}$
Species		**	98.3	**	0.158	**	1.755
N fertiliser rate		**	58.4	**	0.075	**	0.874
Regrowth interval		**	52.6	**	0.121	**	1.053
S x R		*	143.3	*	0.292	**	2.745
S x N		**	146.1	**	0.208	NS	2.362
R x N		**	96.8	*	0.194	NS	1.785
S x N x R		NS	239.6	NS	0.486	NS	4.487

DOMD, digestible organic matter digestibility; S, species; R, regrowth interval; N, N fertiliser rate; and NS, not significant. ** P<0.001; * P<0.01.

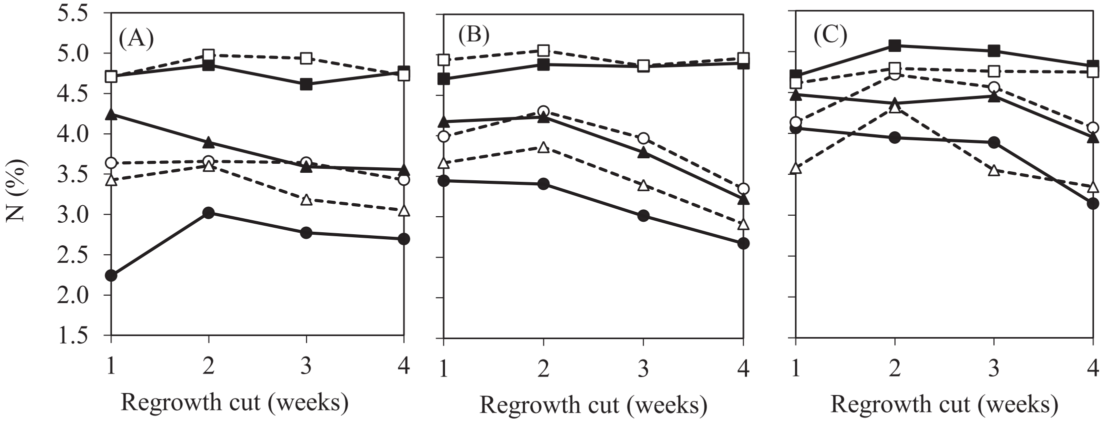

Figure 2 Effect of regrowth interval on plant N% at three N fertiliser rates; nil (A), medium (B) and high (C), for six forage species: Perennial ryegrass (—●—), cocksfoot (- -○- -), chicory (—▲—), plantain (- -Δ- -), red clover (—■—) and white clover (- -□- -). Points are mean values.

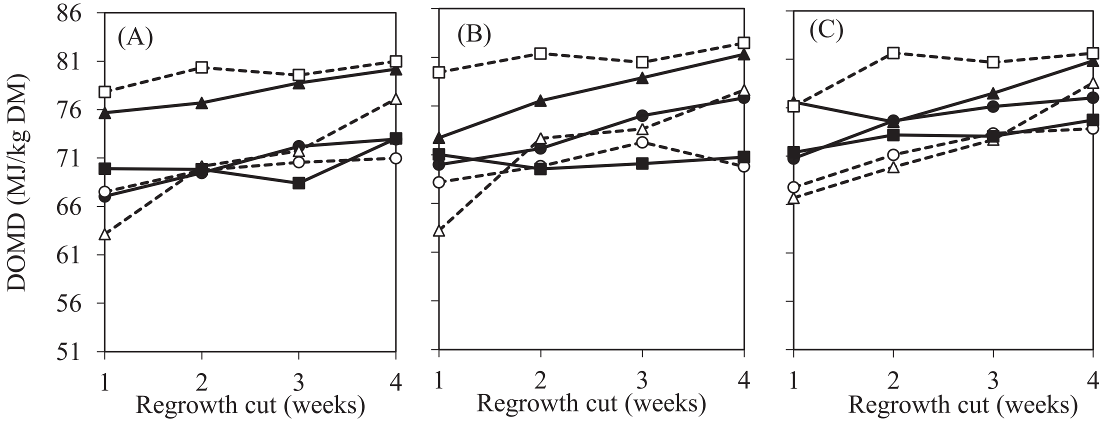

Figure 3 Effect of regrowth interval on DOMD at three N fertiliser rates; nil (A), medium (B) and high (C), for six forage species: Perennial ryegrass (—●—), cocksfoot (- -○- -), chicory (—▲—), plantain (- -Δ- -), red clover (—■—) and white clover (- -□- -). Points are mean values.

rate and N% for herbs and grasses, but no relationship for legumes which were always had high N% (Table 2; Figure 2). Similarly, there were interactions between species and regrowth on herbage N%. Within legumes, N% did not change with regrowth interval. In contrast, for both herbs and grasses the relationship between N% and regrowth was quadratic. During the first 2 weeks herbage N% increased then dropped by week 4 (Figure 2; Table 2; P=0.005).

An interaction (P<0.001) between regrowth interval and species showed that there was no change in DOMD of red clover, while for other species, DOMD increased from week one to four (Figure 3). Differences between N fertiliser rates found DOMD were significantly higher (P<0.001) at the high N fertiliser rates, compared to the nil N fertiliser rates (Figure 3).

Discussion

Herbage DM yield

It was found that highest DM yield was achieved when N fertiliser was used on plantain and chicory at the longest regrowth interval. These findings are similar to previous studies (Minneé *et al.* 2013; Martin *et al.* 2017). On the other hand, under nil fertiliser, DM yield was greatest for legumes, so species re-ranked when N was applied. The lack of N response from legumes was expected (McKenzie *et al.* 1999; Martin *et al.* 2017) due to their N-fixing ability which indicates N was not limiting growth. Differences in growth between species, as determined by DM yield with different N rates was probably due to differences in thermal requirements (^{o}C days) and hormonal signalling altering above- and below-ground partitioning of photosynthates in response to day-length and defoliation (Moot *et al.* 2003; Powell *et al.* 2007). The autumn N response results demonstrate that perennial ryegrass and plantain need less N to produce similar DM yields compared with cocksfoot or chicory (Moore *et al.* 1991; King *et al.* 2012).

Nutrient concentration

The second management concern was identifying strategies to reduce herbage N content, as this is positively associated with N intake and urine N loss (Moorby 2014). At the final regrowth cut, N% was highest in legume species, intermediate in cocksfoot and chicory, and lowest in plantain and perennial ryegrass. However, herbage N contents of over 3% N (18% crude protein), which exceed cow late lactation requirements for protein, reflects the risk of high urinary N losses, irrespective of species (Castillo 2001). These results show that N% was lowest at the final harvest due to N dilution rates in the plant cells as DM increases (Blaser 1964; Peyraud & Astigarraga 1998). Similarly, moderate N fertiliser rates resulted in lower N% compared with the high N rate. Although nil N fertiliser had the lowest herbage N content, the compromise in yield is likely to offset herbage N reductions.

The energy value (DOMD) of the herbage did not decline over the regrowth interval in any of the species, and remained high. This result was not expected as it was thought DOMD would generally decline (Buxton 1996; Rawnsley *et al.* 2002). The reason for a high DOMD throughout the regrowth was probably due to the time of year and the proportion of leaf in the herbage sampled above 4 cm. It is well documented, grasses harvested before the fourth leaf stage are higher in DOMD due to no leaf senescence (Donaghy & Fulkerson 1998). Leaf appearance interval (time taken for one leaf to fully expand) is influenced predominantly by temperature (Silsbury 1970) and soil moisture availability (van Loo 1992). The current trial ran in autumn when cooler temperatures occurred and consequently, leaf appearance rate was slower. As a result, at week four, the grasses were at the third leaf stage and leaf senescence did not occur. These results demonstrate that delaying regrowth to 4 weeks in autumn as a management strategy to reduce N losses, does not affect herbage quality and therefore farm production goals.

Conclusions

Any farm decision to reduce N is likely to be based around whether that decision also meets socio-economic goals. As feed costs are a major component of the farm system, decisions leading to changes which reduce feed supply are likely to limit adoption. The results of this study indicate delaying grazing of grasses, herbs and legumes up to 4 weeks in autumn increases DM yield, reduces herbage N content without compromising digestibility. The strong response to N fertiliser from plantain and perennial ryegrass suggests that a moderate N fertiliser regime would address economic and environmental goals. However, because there was little management factors could do to reduce N content below 3%, future strategies to further mitigate N loss through N intake should consider low N supplements.

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Further field evaluation of the controlled release nitrogen fertiliser Smartfert®

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Abstract

Five field trials were conducted over 2 years in which the effects of single applications of different rates of a controlled release nitrogen (N) fertiliser, Smartfert, on pasture production and pasture N concentration were measured, relative to the same rates of SustaiN. The 2016 trials also compared multiple applications of SustaiN with a single application of Smartfert. Pasture responses to SustaiN relative to the control generally occurred within the first one to three harvests following application and then declined and became negative in the later harvests. The pasture responses to Smartfert developed more slowly and were greatest after the third harvest. In terms of total production significant ($P<0.05$) responses to Smartfert relative to the same rate of N applied as SustaiN occurred in three trials. SustaiN significantly increase pasture production at one site relative to Smartfert. In three trials pasture production from single applications of Smartfert applied at 100 kgN/ha were the same and in one case better ($P<0.05$) than three consecutive applications of 33 kg N/ha of SustaiN. The soluble N fertilisers, urea and SustaiN, elevated the mixed-pasture N concentration relative to control and to Smartfert in the first harvest following application. The nitrogen use efficiency (NUE, kg DM/kg fertiliser N applied) of Smartfert was significantly greater ($P<0.05$) than for SustaiN in two trials.

Keywords: fertiliser, nitrogen, nitrogen use efficiency, pasture, Smartfert, urea, SustaiN

Introduction

New Zealand uses about 350 000 tonnes of fertiliser N annually (Fertiliser Matters 2010) most of which is applied in a readily available, water-soluble form, such as urea, ammonium sulphate or diammonium phosphate. The N in such products is subject to losses to the environment via: volatilisation (ammonium), denitrification (nitrogen and nitrous oxides gases), leaching (nitrate) and runoff (ammonium and nitrate).

There are international (Our Nutrient World 2013) and national (Ministry of Primary Industries 2013) initiatives to increase nitrogen (N) use efficiency (NUE), driven by both economic and environmental considerations and concerns. There are many ways to define and hence measure NUE and de Klein *et al.* (2016) have usefully defined three broad categories: Crop NUE, Animal NUE and Whole farm NUE. They defined the Crop NUE as the crop dry matter (DM) per unit of N input of which fertiliser NUE (kg DM/kg fertiliser N applied) is a subset.

Edmeades (2015) reported on the evaluation of Smartfert, a controlled release nitrogen fertiliser which, in three field trials, increased the NUE (kg DM/kg N applied) in pastures by between 5-50%, depending on the site and the rate of application.

In this paper the results from five further field trials are discussed focussing on the potential economic and environmental benefits and the NUE (kg DM/kg fertiliser N applied) of Smartfert.

Methods

Field Trials

Three field trials were conducted in 2014 and have been described earlier (Edmeades 2015). Mixed-pasture samples were collected at each harvest from these trials, either on a per plot basis (Taupo) or bulked over replicates (Rotorua and Northland) and have been analysed for total nitrogen concentration (N%). These results are reported in this paper.

Five further field trials were conducted, two in 2015 and further three in 2016. All these trials (mowing with clippings removed, plot size 2 x 6 m) were on clover-based pastures using standard management and measurements techniques (Lynch 1966). The trial designs and treatments, however, were changed between years driven largely by commercial rather than scientific considerations. For example, SustaiN (urea treated with a urease inhibitor), a proprietary product from Ballance AgriNutrients Ltd was used as the standard for comparison with Smartfert.

The two 2015 trials, one each in Northland and Rotorua, comprised six replicates of seven treatments: control, SustaiN 30 kg N/ha (SustaiN30), SustaiN 60 kg N/ha (SustaiN60), Smartfert 30 kg N/ha (Smartfert30), Smartfert 60 kg N/ha/yr (Smartfert60) and a 50:50 mix of SustaiN and Smartfert applied at 30 or 60 kg N/ha. The treatments were applied once at the commencement of the trials in September and the production measurements terminated after 6 harvests in either January or February. Pasture DM (kg DM/ha) was measured on a per plot basis, and for the Rotorua trial only, the mixed-pasture N concentrations were measured on samples bulked by treatments.

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