Crop sequences for high productivity and reduced environmental effects in New Zealand dairy forage systems

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Abstract

Recent intensive dairy forage production in New Zealand's South Island has increased input costs and the risk of nutrient leaching. Crops are increasingly being used for grazing on runoff land comprising short term rotations between pasture phases. This study defined the productivity limits and the scale of nitrogen (N) loss in two crop sequences typical of farm operations designed to maximise the biomass yield. Two crop sequences comprising kale (cv. Gruner), forage triticale (cv. Doubletake) and Italian ryegrass (cv. Feast II) were compared for productivity, soil water and soil N use over two seasons. Each sequence was either provided with low N inputs (typical grower inputs but sufficient for maximum yield) or excessively high N (double the low N) treatments. Maximum water use occurred while the crops were growing rapidly between January and April. Nitrogen management in the low N treatment in both triticale and kale resulted in only small amounts of N not recovered from soil in the winter period. Soil mineral N accumulation was higher under the triticale than the kale but the threat of N loss by leaching only occurred in the first season because of wetter soil conditions. Under high fertiliser N application rates there were some N losses unaccounted for and higher N residuals in the soil indicated luxury uptake of N. Kale was considered a better 'cut and carry' crop than triticale for minimising soil mineral N levels because of its higher capacity for N uptake.

Key Words

Forages, dairy runoff, water and nitrogen balance

Introduction

Production of crops for year-round supplementation of pasture is becoming increasingly accepted in dairy systems in the South Island of New Zealand. The demands for additional feed are primarily for (1) wintering stock and (2) for early spring and autumn feeding when there is pasture shortage, reduced feed quality or lower animal productivity (Clark et al. 2007). Use of intensively grown forages during winter has implications for sustainable land use because of poor utilisation and the detrimental effects of animals on soil quality (Field et al. 1985). There is also the potential for excess nitrogen accumulation and leaching losses from cropped soils, especially during wet periods (Lilburne et al. 2003; de Klein and Ledgard 2001). Nitrogen leaching may occur during crop growth or when returns by animals exceed the capacity of the soil to retain nutrients (Silva and Cameron 1999). Alternatively, 'cut and carry' systems may reduce the nitrogen loading compared with grazed systems (de Klein and Paton 2000). Higher crop productivity usually means increased costs and increased fertiliser use with potential detrimental impacts on the environment. Sustainable practices include the replacement of minerals removed in a cut and carry (or silage) system to maintain the mineral balance in the soil (de Klein and Ledgard, 2001).

The aim of this study was to define the scale of potential soil nutrient (N) losses and biomass production in two crop sequences. These sequences are typical of cut and carry farm operations designed to maximise the biomass yield in short term rotations between pasture phases in Canterbury (New Zealand) dairy farms.

Methods

A trial area at Lincoln, New Zealand (43.83?S, 171.72?E) comprised two crop sequences (Figure 1) consisting of either cv. Doubletake multigraze triticale (TL) or cv. Gruner kale (KL) in the winter period.

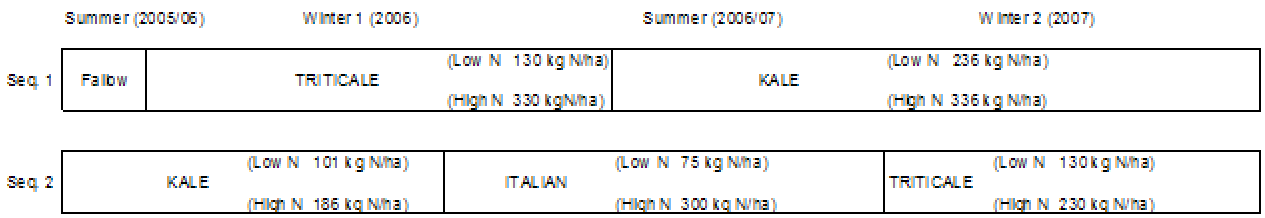

Figure 1. Cropping sequences and N fertiliser inputs.

This was a crossover design with either KL following TL (Sequence 1) or TL following KL, with cv. Feast II short-term tetraploid Italian ryegrass (IT) used as a bridge crop (Sequence 2). The period of winter cropping was of primary interest for water and nitrogen monitoring. This design means that the repeat crops over time were not true replicates because of their differing crop histories. In Sequence 1, TL was sown on 24 Feb 2006 into a fallowed seedbed using a Taege drill. The crop was removed on 19 October as a ‘green chop’ cereal, cultivated by grubbing and power harrowing, then sown to KL on 26 Oct 2006, and harvested on 15 Aug 2007. In Sequence 2, KL was sown at 4 kg/ha on 3 Nov 2005 and removed on 3 Jul 2006. IT ryegrass was sown on 1 Sep 2006 and cut three times before establishing TL on 1 Mar 2007. TL was cut twice (16 May and 14 Aug) and then saved for whole crop silage harvest on 15 Jan 2008. Treatments were sown in a RCBD design with three replicates. Plot size was 45 m x 4.0 m (15 cm row spacing). Each plot was randomly split into two nitrogen treatments and managed to provide a ‘high input’ treatment (High N) and a typical farmer ‘moderate management’ (Low N). The N treatments were adjusted as required during crop growth by monitoring the ‘low input’ treatment to ensure no growth restriction, and then doubling the N inputs for the High N treatment. N fertiliser applications for the respective crop sequences are given in Figure 1. Nitrogen was applied as urea (46% N) except for compound (NPKS) fertiliser at sowing.

Soil water

A single neutron probe access tube was installed in each plot shortly after crop emergence and measurements of soil water were made approximately monthly to 1 m depth. Measurements were suspended during the winter period when soil moisture was at or near field capacity. Irrigation water was applied regularly during spring and summer to ensure there were no water deficits. A water balance was calculated for each crop using Penman potential evapotranspiration and adjusting for irrigation and rainfall. Neutron probe measurements were used to initialise soil water content at the beginning of each measurement period. Leaching was determined as excess profile soil water above 360 mm calculated to a depth of 1.2 m. Crop water use was determined for successive neutron probe measurement periods by calculating the change in profile water content, adjusting the water balance for leaching, and deducting the accumulated rainfall and irrigation during the period.

Soil and crop sampling

A basic MAF soil test (N, P, K, S, Mg and Na) was taken at sowing for each crop; monitoring of total N, Olsen P and soil S indicated high (N, P) or adequate (S) soil fertility throughout the experiment. Sampling dates for NH_4^+ and NO_3^- content and potentially mineralisable N (0-15, 15-30 cm depths) coincided with biomass harvests. At the end of each crop cycle, soils were sampled to 120 cm depth and partitioned into 30 cm sections. Two 0.5 m^2 quadrats were taken from each plot for biomass determination approximately every 3 weeks. A subsample of ~500 g FW was dried at 100?C for 24 hours for %DM content. Another 200 g FW sample was dried (60?C) and ground to pass a 1 mm sieve (Udy mill) for total plant N (LECO CNS 2000 analyser).

Results and Discussion

Biomass and nitrogen uptake

Accumulated biomass in Seq.1 was less than in Seq. 2 primarily because of the initial summer fallow. Kale (Seq. 2), sown in November, produced a yield in excess of 23 t/ha under both ‘Low N’ and ‘High N’ management (Figure 2). Kale had taken up more than 90% of its N by the first harvest in late January irrespective of N treatment. The High N treatment grew under conditions of ‘luxury N uptake’ as the crop accumulated more N than was required for growth. There was no harvest date effect (P>0.05) for N uptake in KL in Seq. 2, although, concentrations of N in the tops was different (P<0.05) for the low and high N treatments. Conversely, kale N uptake did change over time (P<0.001) in the second season (Seq. 1) in KL. This latter crop was grown after previous TL and therefore the residual soil fertility was lower. A lower KL yield in Seq. 1 also suggested a soil N limitation which reduced N uptake and yield.

The February 2006 sowing of TL produced up to 11.2 t/ha biomass from two cuts in winter and a final green chop cut in October. There was only a small increase in crop yield for High N treatments in both crop sequences (Figure 2). The concentration of N in the herbage of High N treatments was however consistently higher than in the Low N treatment (Table 1) for all crops except KL in Seq.1. Under both low and High N treatments, crop growth was considered to be not limited by nutrients other than N. Fertiliser N was probably used inefficiently in the High N TR1 treatment due to losses to groundwater when fertiliser N was not taken up by the crop.

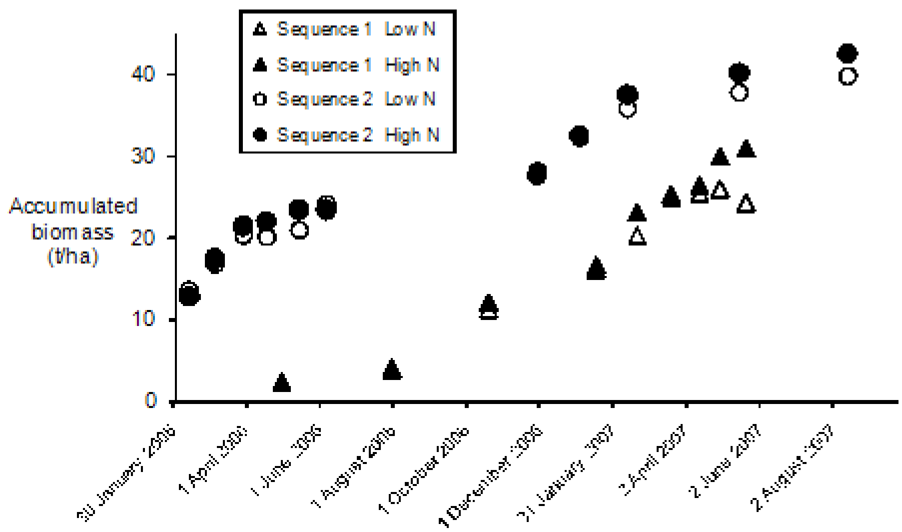

Figure 2. Accumulated biomass for crop sequences 1 and 2.

Table 1. N content of herbage at crop maturity and crop N uptake in sequences 1 and 2.

	Sequence 1		Sequence 2		LSD (5%), (df)	Interaction (Harv. x N)
Crop	Low N	High N	Low N	High N		
Herbage nitrogen (%)						
Triticale	1.15 [b]	1.97 [b]			0.135 (28)	*P*<0.05
Kale			1.36	2.03	0.072 (58)	*P*<0.05

Italian			1.79 [a]	2.57 [a]	0.199 (28)	*P*<0.05
Kale	1.62	1.80			0.150 (58)	NS
Triticale			2.10 [b]	2.77 [b]	0.164 (28)	NS
Nitrogen uptake (kg N/ha)						
Triticale	226.7	333.6			133.4 (2)	*P*=0.075 [e]
Kale			330.6	414.4	32.5 (58)	NS
Italian			209.5 [c]	354.3 [c]	86.0 (2)	*P*=0.078 [e]
Kale	210.5	366.7			25.4 (58)	*NS*
Triticale			108.7 [d]	176.3 [d]	131.0 (2)	*P*=0.041 [e]

[a,b] Means over three and two cuts, respectively; [c,d] accumulated N uptake over three cuts and two cuts, respectively;

[d] period ending 14 Aug; [e] Significance level for N treatment effect only.

Soil water balance

Soil water monitoring showed there was almost complete recharge during the winter of year 1, although deficits were greater under the KL (Figure 3). This was a result of the higher extraction of KL during the summer and autumn and its earlier planting date. The second winter was drier, with max deficits reaching 153 mm and 99 mm for KL and DT in June before winter rain in July.

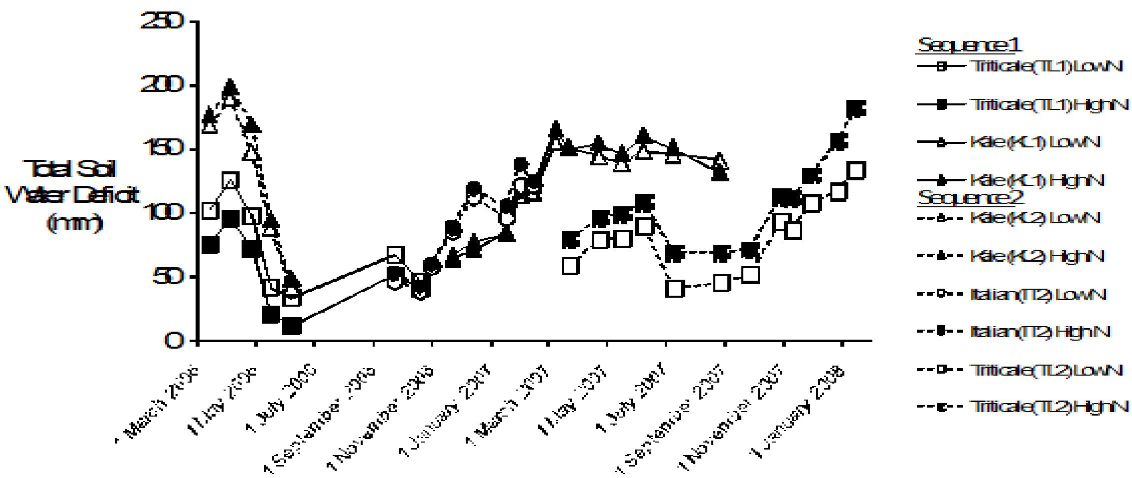

Figure 3. Pattern of soil water deficit for crops in Seq.1 (solid lines) and Seq. 2 (dashed line).

Soil nitrogen balance

At harvest of the first crops in the respective sequences (mid-October for TL and early July for KL), there were low concentrations of mineral N remaining in the soil. Both crops effectively utilised the available pools of soil N either present during early development, supplied as fertiliser or derived from soil mineralisation. Potentially mineralisable N in the 0-30 cm depth was close to 100 kg/ha throughout the winter period for the first crops in both sequences. Levels declined to <20 kg/ha at the end of the second winter. Mineral N levels were low. For example, High N TL plots had 51 kg N/ha remaining in the top 30 cm and only 14 kg N/ha in the Low N treatment. Under KL, in Seq.2, the soil contained up to 150 kg N/ha of available mineral N in the top 30 cm. By the end of the season, the extractable mineral N was lowered to 16 and 15 kg N/ha in the top 30 cm for the Low and High N treatments. Similarly, mineral N was low after the Italian bridge crop, with less than 30 kg N/ha remaining.

In the second winter, the pattern of soil mineral N under Seq.1 and Seq.2 crops were similar to the previous year, with less than 50 kg N/ha available in either Low N or High N treatments (for both KL and TL). In both seasons, it was apparent that most of the N available was taken up. As the first season was wetter (Figure 3) there was greater likelihood of N losses due to leaching. Mean leaching calculated using the water balance in the first winter was 222 mm under TL and 186 mm under KL.

Soil N balance showed there was more N unaccounted for under the TL crop in the first winter with up to 134 kg N/ha (Seq. 1) potentially lost to groundwater in the High N treatment. The N balance under high N in the second winter year was -39.4 kg/ha (Seq. 2). The negative value in year 2 occurred because a relatively high amount of residual soil N (142 kg N/ha) was recovered at harvest, that may otherwise have been leached in a wet year. Under Low N fertilisation in year 1, the N unaccounted for was less (15 kg N/ha). Similarly, 59 kg/ha of mineral N was recovered under kale in year 2 (KL1). Kale crops in both crop sequences had net negative N balance, meaning that more N was bound in crop biomass or present as soil mineral N at harvest than was accounted for in pre-season mineral N plus fertiliser N applied. Concentrations of N in soil leachates were not measured.

Conclusion

Although a crop situation was created that could cause potential leaching of water and nutrients out of the root zone, the only treatment showing excessive leaching losses (134 kg N/ha) was for triticale grown under high N in year 1. A low N treatment indicative of conservative N management did not create an N leaching problem in either a wet year (year 1) or a dry year (year 2). There were no recorded leaching events in year 2. In triticale, the High N fertiliser applications were well in excess of the plant N requirements. Kale crops were significantly more effective than triticale for utilising soil N reserves during the winter period, mainly because of the earlier timing of biomass accumulation (autumn vs late winter). Cut and carry cropping systems with high yield potentials appear effective for mopping up excess soil N.

Acknowledgements

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