Effectiveness of winter cover crops to reduce nitrogen leaching losses in cropping systems in Waikato, New Zealand

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Abstract

A modelling study was undertaken to assess the impact of sowing date and soil water holding capacity (WHC) on the effectiveness of a winter triticale (*Triticosecale*) cover crop to reduce nitrogen (N) leaching losses in arable rotations in the Waikato region, New Zealand. The Agricultural Production Systems sIMulator (APSIM) was used to run multi-year simulations in response to daily weather variables for the historical Waikato climate from 1971 to 1999. Sowing dates considered were 15 March, 15 April, 15 May and 15 June for cover crops commonly harvested in late September before the establishment of a summer silage maize crop. A 'no cover crop' treatment was simulated as a fallow control. Two residual mineral N loads of 111 and 190 kg N/ha, and two soil water holding capacities of 144 mm and 315 mm down to 180 cm, were simulated. Cover crops were effective in reducing N leaching for both soils of varying WHC and N loads. Results showed that under Waikato climatic conditions early sowing dates can be expected to reduce the total amount of N leached (in relation to a fallow control treatment) from around 70% in the early (March) sown crops to 25% in the late (June) sown crops. Overall, this long-term simulation study confirms the benefits of cover crops to reduce N leaching losses over winter.

Additional keywords: catch crop, nitrogen uptake, nitrate, *Triticosecale*

Introduction

There are a number of summer crops grown in the Waikato region to support intensive dairy farming and reduce the risk of feed shortage during dry periods. These crops are typically harvested in late summer and autumn as conserved feeds (e.g. maize, cereal silage) or grazed in-situ (e.g. turnips, rape, kale, fodder beet). There is strong interest in nitrogen (N) use efficiency in these systems, and in particular, the potential impact these crops can have on N leaching losses in subsequent cropping sequences. Recent surveys have shown that residual soil mineral N measured in crops in autumn can be high. For example, residual mineral N across 95 maize fields sampled between 2005 and 2010 averaged 107 kg N/ha in the top 0.6 m (Johnstone *et al*., 2014), ranging from 23 to 375 kg N/ha. Excess soil mineral N may be caused by a combination of over-supply of N fertiliser during the season, higher than expected mineralisation of N from soil organic matter, lower than expected crop N demand

and/or return of N in crop residues. In addition, crops grazed in-situ will also have N returned to the soil in dung and urine. Soil mineral N under fallow conditions between crops is at risk to loss to leaching, creating inefficiency in N use and potential environmental concerns.

The use of winter cover crops is among the most effective management interventions to mitigate this risk (Thorup-Kristensen *et al*., 2003; Constantin *et al*., 2010; Carey *et al*., 2016; Teixeira *et al*., 2016). Cereals such as oat (*Avena sativa* L.) and triticale (*Triticosecale* Wittm. ex A. Camus.) are promising winter cover crop options as they grow actively during winter, can recover mineral N from deep in the soil profile and provide a high quality feed during the spring (Carey *et al*., 2016; Teixeira *et al*., 2016). However the potential benefit depends on when the crop is sown and the length of time it is grown. Dabney *et al*. (2001) showed in on-farm trials that delaying the sowing of cover crops reduces N uptake and biomass accumulation. An earlier study by Teixeira *et al*. (2016) showed in model simulations for Canterbury that the year-by-year leaching results were variable and highly dependent on weather. However these patterns have not been studied under warmer winter climates, with potentially deeper soils such as those in the Waikato.

The aim of this work was to investigate the effect of a cut-and-carry cereal cover crop for different autumn/winter sowing dates, soil water holding capacity (WHC) and initial residual mineral N loads on N leaching losses during the subsequent period up until the sowing of the maize crop in spring, for the Waikato climate.

Methods

The Agricultural Production Systems sIMulator (APSIM) version 7.7 (Keating *et al*., 2003; Holzworth *et al*., 2014) was used to test the effect of different autumn/winter crop sowing dates on cover crop growth, N uptake and N leaching. Simulations were performed using long-term downscaled (Tait *et al*., 2006) weather data at 5 km resolution collated from the NIWA Virtual Climate Station (VCS28720) for the period 1971 to 2000. This data provided a contiguous daily climate record for radiation, wind, rain, temperature and vapour pressure, enabling a more complete calculation of growth and evapotranspiration and showing the variation capable in this region

Each simulation began on 11 March with a fallow period followed by a triticale crop sown on one of four dates (15 March, 15 April, 15 May or 15 June) or a fallow treatment where no cover crop was sown. The 11 March initiation date of the simulation was selected to represent either the harvest of a maize silage crop or the grazing of a forage crop in late summer/early autumn (both common management options in the Waikato region). All triticale cover crops were harvested (cut-and-carry) on 30 September with the residue being incorporated into the soil. This was followed by a maize silage crop sown on 5 October. Key production details for the triticale and maize are summarised in Table 1. The simulations concluded when maize was harvested at silage maturity (assumed as 80% of thermal-time requirement to grain maturity), which varied by year depending on the climatic conditions.

Table 1: Distribution of mineral nitrogen (N) in soils at initiation of simulation for the median and heavy initial residual N loads. Each layer consisted of 1 kg/ha of ammonium-N.

Soil depth (cm)	Distribution of soil mineral N (kg N/ha)	
	Median load	Heavy load
0–15	55	100
15–30	20	30
30–60	20	30
60–90	7	14
90–120	5	10
120–150	2	4
150–180	2	4
Total	111	190

For each simulation we used two artificial soil types representing contrasting WHC common of light and heavy-textured soils: low = 144 mm and high = 315 mm, per 180 cm depth. The volumetric water content (v/v) values were set using profile drained upper limits of 0.22 (low) and 0.34 (high) with a lower limit (stress point) of 0.06. Soils were initiated with two nitrate-N loads (111 kg N/ha and 190 kg N/ha) to 180 cm depth and a water profile set to field capacity on 11 March each year, equilibrating the two soils for potential drainage. The initial N loading rates were taken from earlier unpublished work in the Waikato region (Johnstone *et al*., 2014) and represented a median and heavy residual mineral N load after commercial maize crops. The loads were distributed throughout the soil profile (primarily in nitrate-N form) as described in Table 2. These parameters were held constant for the contrasting WHC soils.

In total there were 2400 simulations covering 30 years of weather at one site. Key output variables included: biomass production, N uptake by the crops, drainage and N leaching passed at specified depths on a daily basis. The values were accumulated for each period of crop growth and fallow. R scripts were used to collate the data andgenerate the tables and graphs. Boxplots show median values, 25th percentile and 75th percentile (box) and maximum and minimum values.

Table 2: Summary of key production details used in the cover crop triticale and following maize crop simulations.

	Triticale cover crop	Spring maize
Planting date	15 March 15 April 15 May 15 June	5 October
Cultivar	‘Doubletake’	‘Pioneer 39G12’
Planting population (plants/m^2)	400	10
Fertiliser	Nil	240
Irrigation (mm)	Nil	40-160
Harvest date	15 September	Silage maturity (duration of development stage; 80% of thermal time from flowering to grain fill)

Results

Progressive delay of sowing of a cover crop from March to June reduced triticale yield to approximately 30% (Table 3) of the early sowings. Average simulated dry matter (DM) yields at the September harvest for the high WHC soil were 16.9, 10.7, 8.0 and 6.0 t DM/ha for the March, April, May and June sowing dates, respectively. By comparison, on the low WHC soil simulated DM yields at the September harvest were lower: 15.5, 9.2, 6.3 and 4.2 t DM/ha for the March, April, May and June sowing dates, respectively (Table 3). The difference between treatments (sowing date and N load) was as large as 4 t DM/ha in the driest years and as little as 1 t DM/ha in the wettest years. A higher initial N load increased the harvested yield for the earlier sown triticale but the effect diminished with later sowing (Table 3). The higher yield of early sown triticale was also reflected in N uptake by the crop (Figure 1, Table 4), with the early (March) sowings taking up about 150-200 kg N/ha from the soil compared with 70-170 kg N/ha for the June sowing. It is important to note that even the later sowings were effective at removing N from the soil that would otherwise be at risk of leaching. Triticale sowing dates and initial soil N load had little effect on the subsequent maize crop yield. The model predicted an average maize yield of 23 t DM/ha in all the well-irrigated and well-fertilised situations.

Table 3: Simulated biomass (t DM/ha) (mean, standard deviation, minimum and maximum) of a triticale cover crop grown in the years 1971-2000 in the Waikato, New Zealand.

Soil WHC	Nitrogen load	Cover sown (Month)	Biomass (t DM/ha) mean	sd	min	max
Low	Median	March	15.5	1.6	8.8	17.1
		April	9.2	0.9	6.6	11.1
		May	6.3	1.1	4.3	8.0
		June	4.2	1.2	2.2	6.3
		Fallow	-	-	-	-
	Heavy	March	16.7	1.4	10.8	18.3
		April	11.2	1.2	7.8	13.0
		May	7.6	1.4	4.9	9.8
		June	5.0	1.5	2.3	7.8
		Fallow	-	-	-	-
High	Median	March	16.9	1.0	13.7	18.8
		April	10.7	0.9	8.3	12.6
		May	8.0	0.8	6.1	9.3
		June	6.0	1.0	3.8	7.6
		Fallow	-	-	-	-
	Heavy	March	17.9	0.9	16.2	19.6
		April	12.8	1.0	9.9	14.4
		May	9.4	1.0	7.1	11.0
		June	7.0	1.1	4.3	8.8
		Fallow	-	-	-	-

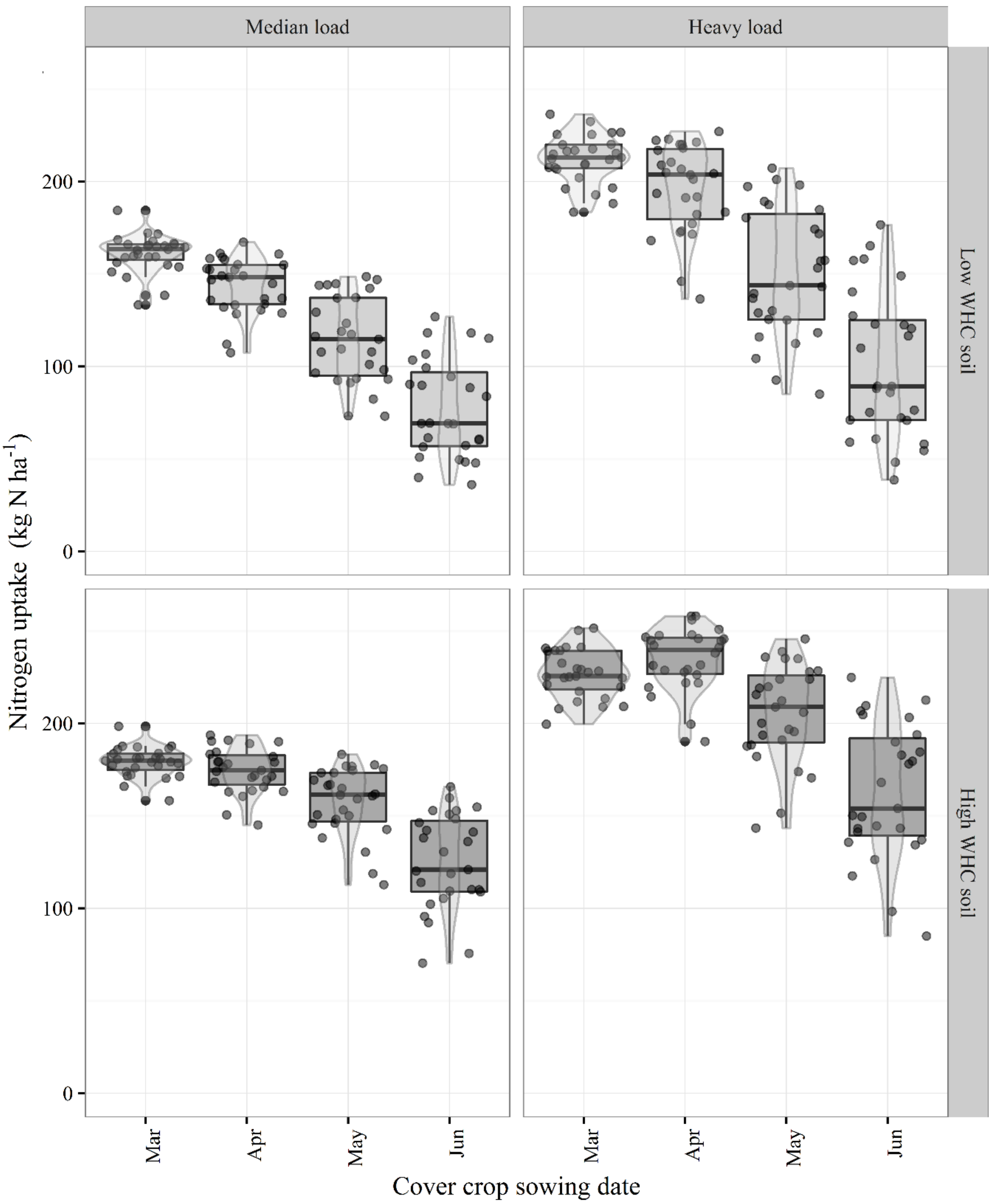

Figure 1: Simulated N uptake (kg N/ha) of a triticale cover crop sown at different sowing dates for the two contrasting water holding capacities (WHC) soils (low and high) and two different initial mineral N loads (median=111 kg N/ha, 0-1.8 m depth horizon; heavy=190 kg N/ha, 0-1.8 m depth horizon) in response to 30 years of historical weather for Waikato, New Zealand.

Table 4: Simulated nitrogen (N) uptake (kg/ha) (mean, standard deviation, minimum and maximum) of a triticale cover crop grown in the years 1971-2000 in the Waikato, New Zealand.

Soil WHC	Load	Cover sown (Month)	N uptake (kg/ha) mean	sd	min	max
Low	Median	March	161	10	133	184
		April	144	15	107	167
		May	114	23	73	149
		June	77	26	36	127
		Fallow	-	-	-	-
	Heavy	March	212	13	183	236
		April	196	24	137	227
		May	150	35	85	207
		June	100	40	39	177
		Fallow	-	-	-	-
High	Median	March	179	8	158	198
		April	174	12	145	194
		May	158	18	113	183
		June	125	26	70	166
		Fallow	-	-	-	-
	Heavy	March	227	13	200	251
		April	236	17	190	262
		May	206	27	143	246
		June	163	37	85	225
		Fallow	-	-	-	-

The higher biomass production and higher uptake of N by the triticale significantly contributed to the reduced cumulative predicted N leaching losses (Figure 2, Table 5). Where fallow conditions were tested the baseline leaching was particularly high. For example, average fallow losses were 187 (heavy N load) and 128 kg N/ha (median N load) for the low WHC soil, and 148 (heavy N load) and 104 kg N/ha (median N load) for the high WHC soils (Table 5). Early sown triticale in March reduced leaching by up to approximately 70% in the low WHC soil and approximately 80% in the high WHC soils. Delayed sowing of triticale decreased the effectiveness of the cover crop to reduce N leaching at a rate of 10-20% per month. However, even the late sowings reduced the predicted N leaching by approximately 50% compared with the fallow, confirming the beneficial effect of having continued N uptake during the winter/spring.

Table 5: Simulated nitrogen (N) leaching during winter (mean, standard deviation, minimum and maximum) under fallow and a triticale cover crop grown in the years 1971-2000 in the Waikato, New Zealand.

Soil WHC	N load	Cover sown (Month)	N leached (kg/ha) mean	sd	min	max
Low	Median	March	26	12	11	58
		April	37	11	12	57
		May	57	13	35	86
		June	59	17	25	94
		Fallow	128	24	74	159
	Heavy	March	49	21	18	98
		April	69	16	36	97
		May	94	19	66	140
		June	88	23	40	136
		Fallow	187	32	113	224
High	Median	March	14	6	5	34
		April	24	9	9	40
		May	45	14	25	77
		June	53	18	18	88
		Fallow	104	29	44	138
	Heavy	March	30	16	8	71
		April	47	16	20	73
		May	77	20	43	120
		June	80	26	28	127
		Fallow	148	39	66	197

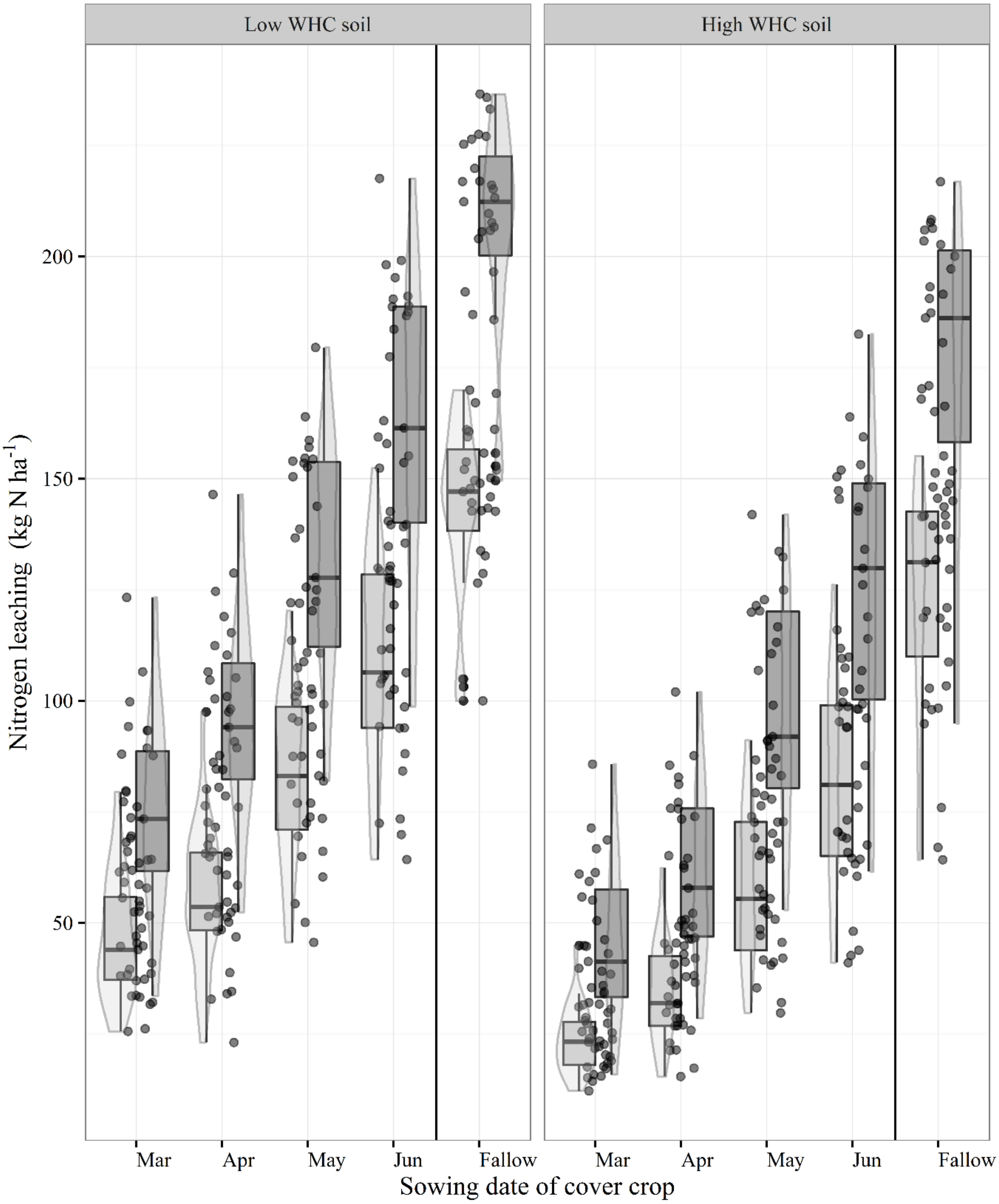

Figure 2: Simulated winter/spring N leaching (kg N/ha) of a triticale cover crop sown at different sowing dates for the two contrasting water holding capacities (WHC) soils (low and high) and two different initial mineral N loads (median=111 kg N/ha, 0-1.8 m depth horizon (lighter-shaded boxes); heavy=190 kg N/ha, 0-1.8 m depth horizon (darker-shaded boxes)) in response to 30 years of historical weather for Waikato, New Zealand.

Discussion

Simulations showed the potential for winter-sown cover crops to take up residual soil N and reduce cumulative N leaching losses following summer cropping. The magnitude of the N uptake by cover crops depended on sowing dates (March>April>May>June), soil WHC capacity (high WHC>low WHC) and initial mineral N loading (heavy>median). These results agree with the overall patterns simulated for cover crops grown under Canterbury climatic conditions (Teixeira *et al*., 2016), although cover crop yields estimated under Waikato conditions are considerably higher. This is because the mean winter air temperatures and solar radiation at lower latitude Waikato are about 1.2°C and 2.2 MJ/day, respectively, higher than Canterbury. The Waikato estimates of N leaching were higher than for the Canterbury study largely because the assumed initial mineral N loads were higher.Predicted N leaching losses in this Waikato study were 74-159 kg N/ha (median initial mineral N load, low WHC soil) and 44-138 kg N/ha (median initial mineral N load, high WHC soil) for the simulated fallow conditions, reducing to 11-58 kg N/ha for the early cover crops. These predicted figures for a March-sown crop are comparable with expected N leaching losses under permanent pasture (40-60 kg/ha) previously predicted (Vogeler *et al*., 2014) and measured (Shepherd *et al*., 2014) indicating that cover crops can also be an effective mitigation tool of N leaching in the warmer regions of New Zealand (e.g. Waikato). The positive effect of early-sown cover crops to reduce N leaching losses agrees with previous literature (Dabney *et al*., 2001; Teixeira *et al*., 2016) and implies mean reductions in N leaching for an early-sown cover crop in March of approximately 70-80%, and a late-sown cover crop in June of about 25%.

These results illustrate the importance of cultural practices and environmental conditions on the potential of winter cover crops to reduce N leaching losses. Further work is required for model validation purposes to ensure that the benefits outlined in this simulation study can be extrapolated to a field context.

Conclusion

This model study indicates the potential benefits offered by a winter cereal cover crop in Waikato, particularly in relation to mitigating N leaching losses. It confirms that the earlier the cover crop is sown, the more biomass is grown, then more N is taken up during the winter period, and consequently, the greater the reduction in the amount of soil N susceptible to leaching. An additional benefit of a cereal cover crop is as a source of feed during spring or as supplementary feed in later months. Similar to the leaching effect, the greatest benefits in terms of biomass production is when the cover crop is sown early. Although our simulations for late-sown cover crops suggest that these are still effective in reducing N leaching when compared to fallow, cost-benefit analyses must first be considered to ensure economic viability of sowing and processing the crop on-farm, as well as experiments showing the effectiveness of these sowings.

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