Managing nitrogen during winter in organic and conventional vegetable cropping systems

P.H. Williams and C.S. Tregurtha

New Zealand Institute for Crop & Food Research Ltd,
Private Bag 4704, Christchurch

Abstract

Intensive vegetable crop rotations require inputs of nitrogen (N) to maintain high levels of production and crop quality. Managing N over the winter period is often the most difficult as plant growth is slow and the potential for nitrate leaching is high. Comparisons of N inputs and outputs in a range of winter crops showed that inputs usually exceeded N outputs. Leaching losses ranged from 11 to 246 kg N/ha. The highest leaching losses occurred when high rates of fertiliser N (300-350 kg N/ha) were applied to the crop at planting when the plants were too small to recover much of the applied N Leaching losses were also greater when the soil mineral N content at the start of the winter was high (e.g. 84 kg mineral N/ha in the 0-60 cm depth of soil compared with 39 kg N/ha). Mineral N contents at the start of winter ranged from 39 to 427 kg N/ha, depending on the previous crop history. The highest value was where compost was regularly used as a soil amendment. There is considerable scope to utilise N more efficiently in winter vegetable production systems by matching N inputs to crop demand and adjusting N inputs to allow for the amount of mineral N present in the soil at planting time.

Not all land under intensive vegetable production is used to grow crops over winter. Uncropped land may be left fallow or planted in a cover crop over winter. Rapidly growing species like triticale and oats can be sown as cover crops over winter. These crops will take up mineral N from the soil, and thus have the potential to reduce nitrate leaching losses. At the Aorangi trial site in the Manawatu, cover crops produced 14-18 t DM/ha between April and September and reduced nitrate leaching in the fallow plots from 38 kg N/ha to 13-20 kg N/ha. Leguminous crops can also be grown over winter to supply N to subsequent crops. At the Leeston trial site in Canterbury, lupins grown over the winter added 60 kg N/ha to the soil.

Additional key words: nitrogen fertiliser, compost, nitrate leaching, cover crops

Introduction

Intensive vegetable production in New Zealand covers an area of approximately 55 500 ha (Kerr *et al.*, 2002). In areas like Pukekohe, Otaki and Oamaru where soil type and climate are favourable, potatoes, spinach, cabbages, broccoli and other green vegetables are grown all year round. Up to three crops per year can be grown, usually with high levels of N inputs.

The winter period is often the most critical for managing N. Leaching losses can be particularly high during winter due to drainage from excess rainfall combined with high nitrate concentrations in the soil from winter fertiliser applications or left over from crops grown during the preceding summer/autumn. Leaching losses of >200 kg N/ha from winter vegetable crops have been recorded in Pukekohe and Levin (Spiers *et al.*, 1996; Williams *et al.*, 2000a; Francis *et al.*, 2002). Such losses represent both an economic loss of N from the farm and an environmental concern when the leached nitrate contaminates surface and ground water. Intensive vegetable production is thought to be the cause of the high nitrate concentrations (>10 µg nitrate-N/ml) recorded in some wells in Pukekohe (Selvarajah, 1999).

The N inputs are particularly high in winter vegetable crops (e.g. >300 kg N/ha; Wood, 1997) to compensate for perceived slower growth rates and plant N uptake. For conventionally grown crops, these N inputs are usually in the form of soluble N fertiliser. Being soluble, this N has a high risk of being leached over winter if not utilised by the crop. For organic farming systems, biological soil processes rather than soluble fertilisers are relied on to provide a source of mineral N to the crop. Thus, organic sources of N are applied to organic crops (e.g. compost and inclusion of legumes in the crop rotation) and the N is released to the crops via mineralisation. In both systems the challenge is to match the N inputs to crop demand to ensure the applied N is used efficiently by the crop, particularly over the winter.

Not all the land under intensive vegetable production is used to grow vegetables over winter. Some of the land may be left fallow or planted in cover crops that are ploughed down in spring. A range of species can be grown as cover crops. For example, when species like cereals and grasses are grown over the winter they can return large quantities of organic matter to the soil. They can also have an important role in managing the N fertility in the soil as they will take up mineral N left in the soil after crops grown in summer/autumn, thus reducing leaching losses (Francis, 1995). When cover crops are ploughed down, the N in the residues is released and can become available to the subsequent crop. Alternatively, growing legumes over winter can add N to the soil for the subsequent crop. This is particularly important in organic vegetable systems where N fixation is an important source of N.

This paper discusses ways of managing N in winter vegetable crops using the results from two field studies. In the first study, N inputs and outputs were measured from typical organic and conventional crops. In the second study a range of cover crops was grown over winter with the aim of determining their potential impact on N fertility. These crops included a range of legumes, cereals and grasses.

Materials and Methods

N inputs and outputs from winter vegetable crops

Inputs and outputs of N were measured at seven sites during winter 2002. Three of the sites were in broccoli crops and four were in potato crops. Also included are data for spinach and cabbage from Williams *et al.* (unpubl. data; 2003). The sites were chosen as being typical for the crops, and background details are given in Table 1. Note that the Pukekohe potato sites were next to each other. At one site the crop was grown with 469 kg N/ha applied as 319 kg N/ha at planting and 150 kg N/ha applied as a side dressing eight weeks later. This is typical of the current fertiliser practice for winter potatoes in Pukekohe. Potatoes at the other site were grown with 259 kg N/ha, applied as 109 kg N/ha at planting and 150 kg N/ha eight weeks later. This rate was used to demonstrate the impact of reducing the amount of N fertiliser applied at planting on crop yield and nitrate leaching. Both sites were managed in the same way and received the same rate of P and K fertiliser (200 kg P/ha and 200 kg K/ha).

Table 1 Location, soil type, planting and harvest dates for the crops used in the N input and output study.

Crop	Location	Soil type	Date planted	Date harvested
Broccoli	Oamaru	Waireka	2 April	7 August
Broccoli	Oamaru	Timaru	29 March	4 August
Organic broccoli	Otaki	Te Horo	6 April	30 July
Cabbage	Pukekohe	Patamahoe	12 May	17 September
Spinach	Pukekohe	Patamahoe	28 May	10 September
Potatoes	Oamaru	Waireka	5 June	2 December
Potatoes	Oamaru	Waireka	3 June	28 November
Potatoes	Pukekohe	Patamahoe	9 May	1 November
Potatoes	Pukekohe	Patamaohe	9 May	1 November

The amounts of fertiliser applied at the conventionally farmed sites, and meal and compost applied at the organic site along with the N content of these inputs were recorded. Soil, herbage and soil solution samples were taken from five replicate plots per site. Plots were 2 m x 1 m and were selected at random throughout the crop. Soil samples were taken to a depth of 60 cm at planting and harvest, and were analysed for KCl extractable nitrate and ammonium (Keeney and Nelson, 1982). The results of these analyses have been combined and are presented as soil "mineral N content" in this paper. Nitrate leaching losses were determined from soil solution nitrate concentrations and drainage estimations (Francis *et al.*, 1994). Soil solutions were obtained from ceramic solution samplers installed 60 cm below the soil surface. Two solution samplers were installed within each replicate per site (10 per site in total). Samples of soil solution were collected after each significant rainfall event (10-20 mm). The amount of drainage was calculated from a water balance based on the measured initial soil moisture, daily rainfall and evapotranspiration (Francis *et al.*, 1994). At harvest, above ground herbage on each plot was harvested by hand, weighed, subsampled and analysed for yield, dry weight and N concentration.

Cover crops

A range of cover crop species was grown in two field trials during 2001. One was on the Aorangi Research Station near Palmerston North. The soil was a Kairanga silt loam and the site had been left fallow for the previous 12 months. Prior to that the site was in pasture. The mineral N content of the 0-15 cm depth of soil was 66 kg N/ha when the trial was established (6 April 2001). The second trial was at Leeston in Canterbury on a certified organic mixed cropping farm. The soil type was a Temuka silt loam and the site had previously been in peas. The mineral N content of the 0-15 cm depth of soil was 45 kg N/ha at trial establishment (11 April).

There were 11 treatments replicated 4 times in a randomised block design, including a fallow where nothing was planted and the weeds were allowed to regrow. Treatments included 'Doubletake' triticale (*Triticosecale* spp.), '4723.4' triticale, 'Hokonui' oat (*Avena sativa* L.), 'Stampede' oat, 'Apollo' Italian ryegrass (*Lolium multiflorum* Lam.), 'Apollo' Italian ryegrass + vetch (*Vicia villosa* Roth), 'Apollo' Italian ryegrass + 'Huia' white clover (*Trifolium repens* L.), yellow sweetclover (*Melilotus officinalis* Pallis), blue lupins (*Lupinus angustifolius* L.) and 'Colenso' red clover (*Trifolium pratense* L.). At the Leeston trial, 'Otama' oats were grown instead of '4723.4' triticale because the latter was not expected to grow well in Canterbury. At both trial sites, the plots were 12 m x 2 m in size.

Nitrate leaching losses in the Aorangi trial were measured using the same technique outlined above. There was insufficient rain in Canterbury to warrant calculating leaching losses (only 283 mm fell over the April-October period in Leeston compared with 438 mm at Aorangi). At the Aorangi site, three ceramic solution samplers were installed per plot at 50 cm depth and samples of the soil solution were collected after each significant rainfall (approximately 20 mm). Due to time constraints, leaching measurements were made in 9 of the 11 treatments (i.e. not in the Doubletake triticale and Hokonui oat treatments).

The Aorangi trial was harvested on 19 September 2001 and the Leeston trial on 3 October. Samples of herbage (45 cm x 50 cm) were cut at ground level from each plot and weighed. Subsamples of the herbage were taken for herbage dissection, dry matter determination and N concentration.

Both trials were managed with no inputs to simulate conditions in an organic system. The weeds were not controlled in any way. Pest and disease incidence was minimal.

Statistical analyses

Data means and standard deviations were calculated for the N input and output trial using Genstat. While the samples were well replicated, the samples were collected from different geographic sites and it was not possible to make statistical comparisons. Data from the cover crop trials were analysed by ANOVA as a randomised block design using Genstat.

Results and Discussion

N inputs

The results of the analysis of N inputs are shown in Table 2. Data from spinach and cabbage crops collected in previous trials in Pukekohe have also been included in Table 3. Details of these trials are given in Williams *et al.* (unpubl. data; and 2003).

Inputs of N varied between crops from 59 kg N/ha in the Oamaru broccoli crops to 469 kg N/ha in the Pukekohe potatoes. The N fertiliser applied to the conventionally grown crops was in the form of a compound N:P:K:S fertiliser (containing typically 12-14% N). The N inputs on the organic crop comprised a mix of compost (20 t/ha @ 60.7 % N on a wet weight basis = 138 kg N/ha), certified fish and bone meal (58 kg N/ha) and certified liquid fish fertiliser (2 kg N/ha).

N losses

The amounts of N removed in harvested green vegetable crops ranged from 20 to 80 kg N/ha according to crop yield. The potato crops removed 37-108 kg N/ha. There were large differences in crop yield and N removed between the potatoes grown in Oamaru and Pukekohe. The Oamaru potato crops are aimed at the high value gourmet market and so are harvested at an earlier stage than the Pukekohe crops.

Leaching losses varied between sites according to drainage, soil mineral N content and the amount of N fertiliser applied. Losses were smallest from the Oamaru broccoli and potato crops (11-25 kg N/ha) where drainage was low (70-111 mm) and soil mineral N content at the planting was also low (39-58 kg N/ha). The other Oamaru sites also had low drainage but the soil mineral N contents were higher (84-177 kg N/ha) and so leaching losses were higher (65-94 kg N/ha). Winter drainage at Pukekohe sites was much greater (373-428 mm) than in Oamaru. In these sites leaching losses were greatest where soil mineral N content was large at planting and/or high N fertiliser rates were applied (e.g. Pukekohe cabbage and spinach). Where soil mineral N levels at planting were low (e.g. Pukekohe potato), leaching losses were increased where high rates of N fertiliser were applied at planting (171 kg N/ha leached from 469 kg fertiliser N/ha compared with 111 kg N/ha leached from 259 kg fertiliser N/ha). Very high leaching losses occurred from crops grown with 400-469 kg N/ha fertiliser because the majority (309-350 kg N/ha) was applied at planting. At this stage the plants were too small to recover significant amounts of N, consequently large amounts of fertiliser N accumulated in the soil leading to large potential leaching losses.

Table 2 Amounts of N applied in inputs, removed in the harvested crop, leached and present in the soil at planting as mineral N.

Measurement	Oamaru		Otaki	Pukekohe		Oamaru			Pukekohe
	Broccoli	Broccoli	Organic broccoli	Cabbage	Spinach	Potatoes	Potatoes	Potatoes	Potatoes
Yield (t/ha)	2.6	2.8	8.1	37	13	16	14	28	26
Soil mineral	39	84	427	101	204	58	177	41	46
content									
(kg N/ha)	59	59	218	150	400	111	120	469	259
N inputs (kg N/ha)	21	25	38	80	40	32	37	108	103
N removed in crop									
(kg N/ha)	111	94	315	384	428	70	82	373	373
Drainage (mm)	11	91	180	178	246	25	65	171	111
Nitrate leached									
(kg N/ha)									

In the organic crop, all of the N applied was in organic forms so it was not readily leached. Thus, we may have expected leaching losses to be less than in conventionally grown crops. However, the soil test at the start of the trial shows that a large amount of mineral N (427 kg N/ha) had accumulated in the soil, presumably mineralised from previous organic N inputs. The amount of mineral N in the soil was considerably more than the N requirement of the broccoli crop and so leaching losses occurred with the high drainage measured at this site (315 mm).

The balance of N inputs and outputs shown in Table 2 suggest that inputs greatly exceed outputs at most sites. Consequently N is not being efficiently cycled. Improvements could be made through better consideration of the amounts of N applied in fertilisers and composts, and recycled via crop residues.

Managing N fertiliser

It is possible to reduce the amount of N fertiliser applied and reduce leaching losses while still achieving high yields by improving the utilisation of the fertiliser by the crop. In particular, care should be taken with the amount of N applied at planting. While vegetable crops appear to need some N for establishment, applying more N than can be taken up by the small plants is inefficient. Comparing the data for the two Pukekohe potato sites shows that reducing the amount of N applied at planting by 200 kg N/ha had little effect on yield, but reduced the amount of N leached by 60 kg N/ha. Similar results have been obtained in potatoes (Martin *et al.,* 2001; Williams *et al.,* 2000a) and spinach (Williams *et al.*, 2003).

Crop residues

For green vegetable crops, only approximately 50% of the above ground crop is removed with the outer leaves and stems left behind on the soil surface. Vegetable crop residues have a relatively low C:N ratio (e.g. 14:1-19:1) and so can mineralise rapidly upon incorporation (e.g. within one month; Berry *et al.*, 2002). Assuming a harvest index of 50% for vegetable crops, the data in Table 2 suggest approximately 21-25 kg N/ha could become available to the subsequent crop from decomposing crop residues. This could provide a significant proportion of the N required by the subsequent vegetable crop.

Compost

The compost used on the organic broccoli crop added 138 kg N/ha. The C:N ratio was 57:1, suggesting that it would be relatively slow to decompose and the main contribution of the compost is to the soil organic N pool (Berry *et al.*, 2002). However, the soil mineral N content at the organic site when the crop was planted, was very high, suggesting that mineralisation of organic N was readily occurring. This N may have come from previous compost applications, residues from the previous crop or even the previous green manure crop.

Cover crops

The cereals established rapidly following planting in the autumn, and large amounts of dry matter (14-18 t DM/ha) were produced by the triticale and oat cover crops in the Aorangi cover crop trial (Table 3). Smaller amounts were produced by the ryegrass alone or in mixtures (8-10 t DM/ha). The lupins established poorly and accounted for only 18% of the total dry matter. Similarly the clovers established poorly as they were probably sown too late in the autumn. Clovers accounted for <1% of the dry matter production in the clover treatments. The cereal and ryegrass treatments had a significant impact on reducing nitrate leaching with losses of 13-20 kg N/ha compared with 38-51 kg N/ha leached from the fallow and legume plots.

Table 3 Yield of grass/cereal, weed, legume and amount of nitrate leached from winter cover crops at Aorangi, Manawatu.

Cover crop	Sowing rate (kg/ha)	Grass/cereal yield (t DM/ha)	Weed yield (t DM/ha)	Legume yield (t DM/ha)	Total yield (t DM/ha)	Amount of nitrate leached (kg N/ha)
Doubletake triticale	140	17.8	0	0	17.8	NM
4723.4 triticale	140	15.3	0	0	15.3	13.3
Hokonui oat	110	14.3	0	0	14.3	NM
Stampede oat	110	13.7	0	0	13.7	20.5
Apollo Italian Ryegrass	25	8.3	0	0	8.3	28.9
Apollo+vetch	15+3	8.7	1.0	0.2	9.9	17.6
Apollo + white clover	15+3	11	0	0	11.0	18.8
Yellow sweet clover	3	0	4.8	0	4.8	32.5
Blue lupin	190	0	4.7	1.0	5.7	41.1
Red clover	5	0	3.5	0.2	3.7	50.5
Fallow		0	5.0	0	5.0	37.6
$LSD_{5\%}$		2.84	1.79	0.36	3.37	14.9

NM = not measured

Dry matter yields in the Leeston trial were lower than in Aorangi (Table 4). The triticale, oat and ryegrass all produced 4.1-7.0 t DM/ha and these yields were significantly higher than those from the fallow plots by about 2 t DM/ha. As at Aorangi, the clovers did not establish well although the vetch and lupins grew well. The lupins grew particularly well, accounting for 57% of the 5.6 t DM/ha produced. The vetch accounted for 16% of the total DM production. The triticale had the highest N uptake

although it was not statistically higher than the oat N uptake. Lupins also had a high N uptake, presumably due to fixation of N rather than uptake of soil mineral N. It was estimated that the lupins fixed 60 kg N/ha and the vetch fixed 40 kg N/ha. The other legumes did not produce enough DM to warrant estimating N fixation.
Measurements of dry matter production, N uptake and nitrate leaching were made from cover crops grown on the Otaki organic property (unpublished data). The results showed that an oat crop grown between May and October produced 5 t DM/ha, recovered 80 kg N/ha and resulted in a leaching loss of 27 kg N/ha. The leaching loss can be compared with the 180 kg N/ha leached from the adjacent broccoli crop (Table 2).

Table 4 Yield of grass/cereal, weed, legume and nitrogen uptake in winter grown cover crops at Leeston, Canterbury.

Cover crop	Sowing rate (kg /ha)	Grass/cereal yield (t DM/ha)	Weed yield (t DM/ha)	Legume yield (t DM/ha)	Total yield (t DM/ha)	N uptake (kgN/ha)
Doubletake triticale	140	6.6	0.2	0	6.8	155
Otama oat	110	4.3	0.6	0	4.9	142
Hokonui oat	110	3.2	0.9	0	4.1	98
Stampede oat	110	5.5	0.9	0	6.4	119
Apollo Italian ryegrass	25	5.5	0.7	0	6.2	96
Apollo+vetch	15+3	5.1	0.2	1.0	6.3	147
Apollo+white clover	15+3	6.5	0.4	0	7.0	120
Yellow sweetclover	3	0	0.2	0	2.3	51
Blue lupins	190	0	2.4	3.2	5.6	146
Red clover	5	0	1.7	0.2	1.9	48
Fallow		0	2.2	0	2.2	96
$LSD_{5\%}$		1.07	0.73	0.14	1.23	44.3

Conclusions

Results from these studies and others (Francis *et al.*, 2002; Williams *et al.*, 2000a; unpubl. data; 2003) show that leaching losses can be very high from both conventional and organic winter vegetable crops (>150 kg N/ha). Leaching is highest when levels of soil mineral N are high, when winter vegetable crops are planted and when rates of N fertiliser applied at planting exceed the immediate needs of the crop plants. More efficient utilisation of N over winter can be achieved by:

- matching N inputs to crop uptake by reducing the amount of soluble N applied at planting and applying strategic side dressings,
- measuring the soil mineral N content at planting to identify the background level and adjust N inputs accordingly. Currently routine soil tests do not include mineral N analyses, but there are significant benefits in carrying out these analyses,
- taking account of the N content of composts and crop residues when determining N inputs for a crop,
- sowing rapidly growing cover crops like triticale or oats in the autumn instead of leaving the land fallow over winter or growing winter vegetable crops. These cover crops can scavenge N from the soil and have the potential to reduce nitrate leaching.

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