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Nitrogen management of North Island potato crops, 2005–08

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Contents

1 Executive summary

All those involved in the potato industry are committed to improving production, cutting costs and running environmentally sound operations. On-farm, even though one of the key operations is nitrogen (N) management, growers have lacked reliable guidance and are unsure how effective their current practices are.

Over 3 years, between 2005 and 2008, the N management of 18 North Island commercial potato crops was monitored through a Sustainable Farming Fund project, supported by HortNZ, potato growers, three regional councils, potato processors, consultants and a fertiliser company.

Main findings were that N management by growers always provided sufficient N to maximise yields but not enough account was taken of N already in the system, sometimes leading to undesirable N surpluses at harvest. Analysis of crop yields showed they were often below potential and that the main cause was usually a constraint other than shortage of N, most commonly a compacted layer in the soil and/or water stress.

The potato growing environments monitored in the project were wide-ranging. They included dry (<600 mm annual rainfall) east coast regions where irrigation is essential for economic yields and wetter (>1000 mm) Waikato and Manawatu regions, where irrigation is beneficial. Soils ranged from shallow (<30 cm to stones), alluvial Hawke's Bay soils to deep peat, volcanic ash and pumice soils in the central North Island. All crops were planted in spring and grown for the fresh and processed markets. Cultivars included Russet Burbank, Ranger, Agria, Moonlight, Fianna, Nadine and Rua. The amounts of mineral N in the soil when crops were planted ranged from 40 to 200 kg N/ha, and N mineralised from organic matter throughout the season varied from 20 to 160 kg N/ha. Amounts of N applied at planting in the monitored crops ranged from 80 to 150 kg N/ha.

Demonstration plots were set up within these 18 crops, with four treatments of different side dressing N applications ranging from 0 to 280 kg N/ha. To calculate the total crop and soil N balance, the amount of mineral N in the soil was measured to 60 cm depth before planting (and any N application) and at harvest. Final gross yield, tuber number, and tuber dry matter and N contents were measured at canopy death. N leaching beyond 80 cm depth under potato crops and over winter was measured at three sites in the Waikato.

In 13 of the 18 monitored crops there was no yield response to the N side dressings, because enough N was provided by the fertiliser at planting, N already in the soil and N mineralised during crop growth. Inadequate water supply limited yield in 16 of the 18 crops, even in some of the six crops that were irrigated. Insufficient rainfall and/or irrigation, coupled with soil constraints which limited rooting depth, compounded water stress and reduced yield below potential by 20 t/ha or more in some cases. No leaching was observed during crop growth in any of the 3 years, but between 20 and 120 kg N/ha was leached during the following winters.

The project aimed to investigate and improve N management with the help of the Potato Calculator (PC), a computer-based N management tool. However, the PC delivered much more than just advice about N management. It was able to help explain the wide range of crop yield differences (yields ranged from 30 to 90 t/ha gross), by isolating the effects of a range of management practices, of which N management was just one. While N supply is important, investigations showed that lack of water, soil constraints and time of planting could cause greater yield limitations than shortage of N.

2 Introduction

Potato growers aim to manage nitrogen (N) fertiliser effectively to ensure that just enough N is provided to meet the demands of crops and to optimise yield, but not to provide excess N which may be lost from the system. Growers aim to minimise losses because there are both economic and environmental costs associated with the losses.

In the past, N management has been guided by the use of petiole nitrate testing or crop walking to observe crop colour. However, recent investigations into these methods show they do not provide reliable advice on the future N requirements of a potato crop and may have led to over-fertilisation in some cases. Recently, the price of N fertilisers has increased dramatically. Urea cost $600 per tonne in 2007, rising to $700 per tonne in February 2008, with the most recent review setting the price at $920 per tonne. Regional councils are also encouraging effective N management to minimise the environmental impact of farming, and markets are also increasingly demanding that food be produced sustainably so buyers of potatoes are encouraging growers to adopt and demonstrate effective N management as part of this. All these factors have led to grower interest in a fresh appraisal of current N practices.

The current N management system is based on having most of the fertiliser (from 80–150 kg N/ha) in place early, so it is available to a growing crop later. Some is either incorporated during pre-plant cultivation or placed in a band under the seed potatoes as they are planted. This approach gets around the problem of later applications having to be surface broadcast and timed before predicted rain if the crop is un-irrigated. However, considering that a spring-planted crop takes up to 1 month to emerge and needs very little N (or water) during that time, there is a risk that after rain, some of this early N could be moved down the profile with draining water and lost.

The amount of N supplied by the soil is not usually part of the equation when scheduling N. This amount is a combination of N left over from the previous crop, N released from pre-plant cultivation, and N supplied by continuing mineralisation over the growing season. Soil-supplied N can make a significant contribution to overall N supply, especially where extra organic matter is present in the soil from the breakdown of pasture or crop residues (a previous cash crop and/or a cover/green manure crop).

One or more side dressings are applied later, depending on whether irrigation is available or rain is forecast. Crop appearance (green-ness) or petiole N levels are often used as indicators of N deficit. Neither of these indicators can predict N deficiency before it happens, or provide advice about how much N is needed to alleviate a deficit.

The purpose of this project was to investigate the effectiveness of current N management systems and suggest ways to improve the match between N inputs and crop requirements, making savings where possible. Seminars, workshops, reports and newspaper articles during the 3 years have presented growers with the findings from this work and, more importantly, have provided them with a better understanding of crop physiology and agronomy as they apply to a potato crop. This process has resulted in growers learning more about the relationships between a potato crop and its environment, and this has helped them to consider a greater range of factors affecting potato production.

This report contains a summary of principal findings from the 3 years of work, plus a more detailed report on the third year's results. Also included is a report about the use of cover crops as a way to deal with retaining and recycling N during winter months and a report about the effectiveness of using slow-release forms of N fertiliser for a potato crop in Canterbury.

3 Project impact in relation to original stated project outcomes

Original stated outcomes are in italics.

1. *In dollar terms, growers will be able to economise on the use of N, reducing the cost of fertiliser and maximising yields. For example in Waikato, potato growers apply up to 300 kg N/ha. If this could be reduced by between 50–100 kg/ha, the savings in this region alone would amount to at least $150–300k each year.*
2. *Minimise N pollution. Continuing with the Waikato example, approximately 70–140 tonnes less of N would end up in the environment. The eventual technology transfer to potato growers in other regions would see these savings rise.*

Five out of 18 crops in this study responded to side dressed N (point 2 in section 4 covers this in more detail). Even if 50% of crops in New Zealand were calculated to need no side dressed N (averaging 50 kg N/ha) then, out of 10,000 ha of total area, savings from 5000 ha could equate to 250 t of N per annum (or $380k at $700 per tonne Urea). Less N in the system will help to decrease the risk of adding to the contamination of ground and surface waters.

3. *Increased knowledge about the growth and development of potatoes for the community groups concerned. Growers of many crops often don't have the opportunity (or time) to consider the principles of crop physiology. Exposure to some of the science behind the mechanics of crop growth will help us to take on board new ideas for improved crop management.*

The issues and difficulties associated with achieving good N management of potato crops have had wide publicity over the past 3 years, through conferences, seminars, field days, on-farm discussions and articles in local papers and farming magazines. Some of the basic concepts behind how a potato crop responds to its environment have been presented. Growers now have more topical, localised information to refer to when making decisions about the N requirements of their crops.

One unexpected outcome of the study was the observation (through crop modelling) that some yields were limited by a shortage of water. For some crops this was a question of better managing irrigation schedules. In other cases, soil compaction appeared to reduce the volume of soil available for roots to exploit and therefore could be limiting water and N availability.

4. *Improved on-going communication between growers and regional councils in respect to understanding each other's requirements. Regional councils will benefit through the opportunity of being able to work alongside growers where they can better appreciate some of the issues faced by growers.*
5. *Improve local and international market access by using a system that demonstrates that we are growing our crops in an environmentally sustainable manner.*

Regional councils acknowledge that efficient N management is a difficult challenge for all crop growers, as every situation is unique. In the regions where the project's work was carried out, the councils are generally satisfied that potato growers are striving to manage nitrogen inputs efficiently. Growers continue to work hard to keep up with the increasingly tougher "clean green" demands from processors and consumers.

4 Main messages from 2005–08

Know how much N is in the soil at the start. This can significantly contribute to the crop's N requirement and represents fertiliser that does not need to be applied.

Over the 3 years, soil N at planting ranged from 40 to 200 kg N/ha, reflecting differences in prior paddock management (Table 1). Those with higher amounts (>100 kg N/ha) tended to be following previous crops of potatoes, maize and lucerne, or in one case (Matamata year 1, 239 kg N/ha) in a paddock which had been used for dairy shed run-off. In some cases the N had moved down towards 60 cm, having been in the ground all winter. N at this depth is at risk of being unavailable to a potato crop, since the roots are often unable to penetrate through compacted layers to reach this far. Low (below 50 kg N/ha) start N sites were not common and may have been a result of N loss from prolonged waterlogging on heavier winter-grazed soils. To measure initial N, take samples (at least 15 across a paddock) down to the predicted rooting depth of the crop. Where there is difficulty getting a spade through a zone in the soil profile, then potato roots will be restricted as well.

Table 1: Total N available (column 5, kg/ha) to the crop **prior to any side dressing applications**. Total N is made up of Soil N start (N already in the soil) + Planting fertiliser N + Min N (N mineralised over the season). The Surplus/Deficit is calculated by subtracting Crop Uptake (kg/ha) from Total N. The negative, bolded values are where a crop deficit was predicted.

N kg/ha	Soil N start (to 60 cm)	Planting fert N	Min N	Total N	Crop Uptake	Surplus/Deficit (+,-)
Year 1						
Matamata	140	80	118	338	313	+25
Hamilton	66	170	112	348	225	+123
Waharoa	239	100	20	359	201	+158
Year 2						
Matamata	107	100	30	237	228	+9
Matangi *	91	147	61	299	265	+34
Te Poi*	104	100	33	237	247	-10
Opiki *	92	72	20	184	131	+53
Ohakea	100	124	20	244	179	+65
Waipuk *	56	102	130	288	291	-3
Hastings	109	135	116	360	253	+107
Year 3						
Pukekohe	87	144	96	327	255	+72
Matamata*	78	0**	133	211	235	-24
Ohakune	106	150	20	276	169	+107
Opiki 1	194	120	115	429	137	+292
Opiki 2	41	103	162	306	167	+139
Waipuk	70	113	73	256	131	+125
Te Aute	41	120	20	181	145	+36
Canterbury	144	120	44	308	269	+39

*Denotes yield response to N side dressings. ** Trial area only.

Planting fertiliser N ranged from zero (Matamata, year 3 - trial area only) to 150 kg N/ha. The amounts applied did not relate to or necessarily complement the amount already in the soil, even though eight of the 18 sites had 100 kg N/ha or more, which could have supplied about one third to one half of the total crop requirement. N applied at planting time is at risk of being lost through leaching. Crop N use is nil before emergence, and then it only gradually needs N as it gains biomass.

All soils mineralise N though gradual breakdown of the organic matter (OM) pool. The size of the OM pool depends on soil type (for example, peat types have naturally higher levels) as well as the long-term farming history of a particular paddock. For example, in a study at Lincoln (Denis Curtin, pers. comm.), a silt loam with a 10 year pasture phase mineralised 300 kg N/ha between the beginning of September and mid February in one season, averaging 2 kg N/ha per day. The soil was then cropped for 4 years, after which time the mineralisation rate had dropped, the soil mineralising only 100 kg N/ha over the same time period.

Soil moisture and temperature can also affect mineralisation rates, where drier conditions slow microbial activity, and thus the breakdown of OM, and warmer conditions accelerate mineralisation.

In the 18 crops, mineralised N (Min N) was calculated using the low N treatments:

$$Min\ N = (N\ removed + N\ left\ at\ harvest) - (Start\ N + N\ applied)$$

N mineralised during potato crop growth ranged from 20–162 kg N/ha (Table 2). Crops with the lowest amounts of Min N were those with a relatively intensive cropping history and those grown without irrigation (Waharoa year 1, Matamata year 2, Te Poi year 2, Ohakea year 2, Ohakune year 3). Irrigation and/or longer pasture or lucerne phases helped increase the rate of Min N during potato growth in several crops (Waipuk years 2 and 3, Matamata years 1 and 3, Hamilton year 1, Hastings year 2). The Opiki peat-based soils have naturally higher OM levels, so were able to produce higher amounts of Min N than other soils.

Table 2: Amount of N mineralised over the potato growing season, whether irrigation was used (I = irrigation used, NI = non-irrigated), and a summary of cropping history.

N kg/ha	Mineralised N	Irrig.	Management effects on mineralisation
Year 1			
Matamata	118	NI	Previously in 3 years of lucerne
Hamilton	112	NI	Recently out of pasture
Waharoa	20	NI	Third year of potatoes, previously dairy
Year 2			
Matamata	30	NI	2 years lucerne, 2 years onions, maize
Matangi	61	NI	5 years maize, 2 years potato
Te Poi	33	NI	1 year potatoes, 3 years onions, maize
Opiki	20	NI	1 year potatoes, 5 years pasture, winter pugged by grazing cattle.
Ohakea	20	NI	20 years poor pasture
Waipuk	130	I	2 years grass, potatoes, wheat, pasture
Hastings	116	I	Potatoes, sweetcorn, grass, squash, potatoes
Year 3			
Pukekohe	96	I	Old pasture
Matamata	133	I	2 years maize, 2 years onions
Ohakune	20	NI	Long term cropping, some pasture
Opiki 1	115	I	Maize, long term pasture, peat soil
Opiki 2	162	NI	5 years pasture, winter pugged by grazing cattle, peat
Waipuk	73	I	Pasture, stony soil
Te Aute	20	I	1 year potatoes, winter cover crop, heavy soil
Canterbury	44	I	Long-term cropping

Some crops may not need side dressing.

Five of the 18 monitored crops responded to side dressed N (Table 1, denoted by an asterisk), with yield increases of between 1 and 7 t/ha (see reports from years 1 and 2 and Appendix I of this report). This was because enough N was available through
N already in the soil, fertiliser N applied at planting and N mineralised during the season. For three of these crops, N requirement was greater than the non-side dressed N supply (Waipuk 1, Te Poi and Matamata 3, the latter which had no N at planting). For the other two crops (Matangi and Opiki) N supply appeared to be sufficient yet a response to N was measured. In these cases it was likely that the crops' roots were unable to access all the N measured to 60 cm because of compaction (winter grazing of cattle on a peaty soil at the Opiki site) or water stress (dry conditions in the non-irrigated crop at Matangi).

Inadequate water supply can cause significant yield limitations.

Estimated potential yield losses (as indicated by the Potato Calculator, PC) of between 5 and 48 t/ha were identified in 16 of the 18 crops monitored (Table 3). These yield losses were associated with inadequate water supply, even in the irrigated crops. Water supply was limited not only by shortage of rain or irrigation, but also by subsoil compaction which prevented roots from reaching water stored further down the profile. Potential yield loss in the Matangi and Matamata year 2 crops was reduced by the fact that the crops were killed off early to control tuber size.

Crop water deficits typically began to accumulate from mid-December onwards as water use increased rapidly and rainfall became less frequent. If the crops' water balance is not monitored, this early deficit situation is not easily recognised (the crop can look fine) and as a result irrigation can begin too late. For some cultivars with vigorous top growth (for example, Moonlight) irrigation is sometimes deliberately delayed to discourage top growth.

Problems such as irrigation equipment failure and the inability of the irrigation system to get around the allocated crop areas soon enough often caused water shortage for the crop. Additionally, where soil compaction (at the surface or where there is a deeper cultivation pan) is severe, it can be physically impossible for the crop's root system to extract enough water to meet demand, causing the maturing crop to be in a permanent water deficit situation.

Table 3: Measured yield (t/ha), Potato Calculator-predicted yield if crop water demand was met (Yield with adequate water, t/ha), estimated yield lost from water shortage (Lost yield, t/ha), and whether irrigation was used (I = irrigation used, NI = non-irrigated).

	Measured grower yield	Yield with adequate water	Lost yield	Irrigation
Year 1				
Matamata	87	94	7	NI
Hamilton	78	90	12	NI
Waharoa	61	74	13	NI
Year 2				
Matamata *	70	72	2	NI
Matangi *	70	67	-3	NI
Te Poi	77	96	19	NI
Opiki	40	59	19	NI
Ohakea	49	78	29	NI
Waipuk	87	92	5	I
Hastings	65	82	17	I
Year 3				
Pukekohe	81	100	19	I
Matamata	80	88	8	I
Ohakune*	77	96	19	NI
Opiki 1	39	87	48	I
Opiki 2	59	82	23	NI
Waipuk	55	82	27	I
Te Aute	68	84	16	I
Canterbury	72	91	19	I

* Crop sprayed off to control tuber size.

Planting crops later than early to mid-November begins to limit yield.

The canopy needs to be closed by mid December (the longest day is 21 December) to take full advantage of radiation, which peaks at about this time. Even with optimum management, potential (predicted by the PC, nutrients and water non-limiting) yields will decrease with later planting (Figure 1). Earlier planting can also benefit yield by increasing crop duration through slower thermal time accumulation. This gives the crop more time to develop more/larger tubers.

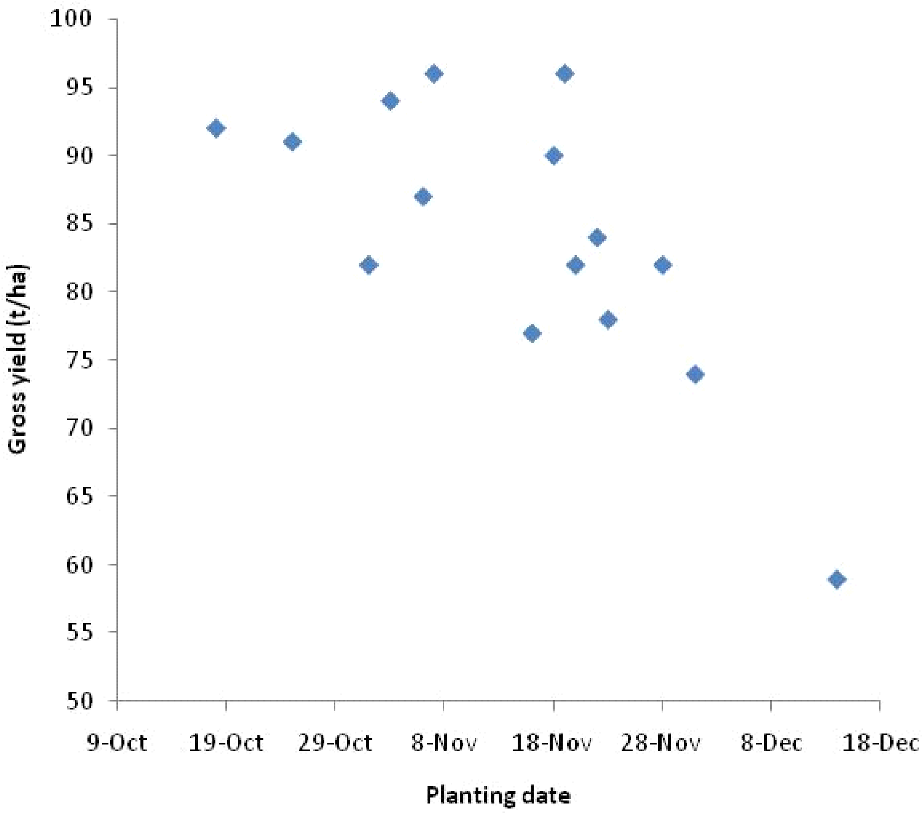

Figure 1. Potential yield (t/ha) of the test crops plotted against planting date.

N leaching is unlikely to occur during crop growth.

Drainage was measured (drainage lysimeters to 80 cm depth) in a Matamata crop in each of the 3 years of the project. Measurements were started at planting and continued past crop death, well into winter. The first two crops were rain-fed, the third crop irrigated.

Apart from a small amount of drainage (and leaching) that occurred around emergence of the crop in years 1 and 2, there was none during crop growth in each of the 3 years (Table 4).

Table 4: Comparison of drainage and rainfall (mm) during and after crop growth. Rainfall in year 3 includes irrigation. Autumn/winter drainage measurements ceased in early June for Year 1 and at the end of August for Years 2 and 3.

	Crop duration	Crop life		Autumn/winter	
		Drainage	Rainfall	Drainage	Rainfall
Year 1	1 Dec–26 Apr	92*	469	285	328
Year 2	7 Nov–11 Apr	8*	426	206	424
Year 3	16 Oct–31 Mar	0	440	1365	948

*Drainage occurred between planting and emergence.

Where more N is applied over and above crop requirement, more N will be either left in the soil or unaccounted-for in the system, eventually lost through leaching, denitrification, or volatilisation.

5 Materials and methods for Year 3 work

5.1 Sites, N treatments and cultivar evaluation

A five-replicate trial consisting of four rates of N (20 plots, each 5 rows by 12 m) was set up in seven potato crops; one each in Pukekohe, Waharoa, Ohakune and Hawke's Bay and mid-Canterbury and two in Manawatu (see Tables 5 and 6 and Appendix II for detailed site information). At each site, a trial was marked out with permanent flags after planting. Treatments were arranged in a randomised complete block design, with a different arrangement at each site. In some cases, replicates were split to allow tractor access for spraying fungicide or herbicide. Apart from a basal N application banded at planting by the grower, any further treatment N was applied by hand (as urea or calcium ammonium nitrate, CAN), individually to each plot, when the grower applied a side dressing to the rest of the paddock. The N rates were similar to those in the first 2 years of this project:

- Low N, no further N from planting.
- Grower N.
- Medium N, based on PC recommendations, but modified if these recommendations were the same as grower N.
- High N, twice medium N.

Since N is always put on at planting, pre-mixed with other nutrients, testing yield responses to varying amounts of N had to be based solely on side-dressed N applied after planting. However, there was one opportunity to test the effectiveness of planting N at the Matamata site. A base fertiliser mix containing no N was applied as usual over the whole area before bed-forming. During the cultivation operation when the moulds were formed and a suspension containing 8:8:8 NPK is normally injected, this fertiliser was withheld from the trial area. Later, when planting time was optimal for the grower, seed potatoes were planted into the existing moulds, including those of the trial.

An 8th trial was set up at a high soil pH site in the Hawke's Bay to investigate whether different types of N fertiliser affected yield, as some types can slow the rise of soil pH, high values of which can encourage common scab in potatoes (> pH 5.8). CAN (27% N), ammonium sulphate (21% N, known to reduce pH in the long term) and two rates of Urea (46% N) were applied as treatments.

In addition to the eight nitrogen trials, 10 cultivars (three replicates, each plot 9 m by four rows) were planted at a Lincoln site to monitor growth characteristics for use in the PC.

At all sites, N available in the soil was measured to 60 cm, generally across the trial area at the start and in each plot at harvest. Available mineral N may have been under-estimated at the Waipuk site. Sampling had to be carried out before the pasture had been ploughed under, due to the quick turn-around between cultivation and planting (1 day). Of the eight sites, five were irrigated.

Soon after planting, a range of soil physical properties was measured at two sites within each trial area. Soil samples were extracted from different depths and taken to the laboratory where saturation, field capacity, texture, bulk density and moisture measurements were made. Soil resistance every 5–10 cm deep up to 50 cm was measured in the field with a penetrometer.

Around the time of full canopy, plant rooting depth was measured at all sites by excavating a pit between two randomly selected plants in two random locations. Depth to the end of the majority of root exploration was recorded, as well as the depth of intermittent deeper roots.

After canopy death, final tuber yield was measured by digging, counting and weighing all tubers from 5 m by two rows in the middle of each plot. Tuber sub-samples from each plot of 300−500 g were retained for dry matter and N analysis.

Table 5: Site information and grower management for Pukekohe, Matamata, Ohakune, Canterbury.

Location	Pukekohe	Matamata	Ohakune	Canterbury
Previous crop	Old pasture	Maize	Pasture	Long-term cropping
Planting date	29 Oct 07	16 Oct 07	19 Nov 07	25 Oct 07
Cultivar	Rua	Moonlight	Nadine	Russet Burbank
Emergence date	18 Nov 07 (PC)*	16 Nov 07	3 Dec 07 (PC)	18 Nov 07 (PC)
Death date	Mid April	End March	Early April	End March
Plant spacing (cm)	39	25	37	30
Row spacing (cm)	83	70	86	92
Soil type	Patamahoe clay	Waihou gritty sandy loam	Ngaruhoe Ash	Chertsey silt loam
Soil features	Compacted layer at 30 cm	Compacted layer 15 cm. Perched water table 1.5 m	Compacted layer 15 cm.	Compacted layer 25 cm.
Available soil N at start (kg/ha to 60 cm)	87	131	106	144
N at planting (kg/ha)	144	90	150	120 (0 in trial)
N side dressing by grower (SD) (kg/ha)	81, 54	46,46,46,55	108	80,49
Date SD applied	21 Dec 07 22 Jan 08	26 Nov 07	27 Dec 07	4 Dec 07 31 Jan 08
SD days from planting	54,85	41	38	40,58
Irrigation no. and amount (mm)	6,185	8,184	Nil	11,315
Leachate tubes	-	√	-	-
Lysimeters	-	√	-	-
Nearest weather stn	Pukekohe (10 km)	On site	Ohakune (10 km)	Chertsey (2 km)

*(PC) As per Potato Calculator prediction.

Table 6: Site information and grower management for Manawatu (Opiki) and Hawke's Bay (Waipukurau and Te Aute).

Location	Opiki 1	Opiki 2	Waipukurau	Te Aute
Previous crop	Maize	Pasture	Grass	Potatoes
Planting date	6 Nov 07	20 Nov 07	1 Nov 07	22 Nov 07
Cultivar	Moonlight	Moonlight	Agria	Moonlight
Emergence date	27 Nov 07 (PC)*	9 Dec 07 (PC)	23 Nov 07 (PC)	10 Dec 07 (PC)
Death date	Mid April	Mid April	4 April, sprayed	End April
Plant spacing (cm)	25	27	29	30
Row spacing (cm)	90	90	90	90
Soil type	Opiki Humic silt loam	Opiki Humic silt loam	Takapau silt loam	Okawa silt loam
Soil features	Gleyed mottled zone below 60 cm	Plastic soil, compacted layer 25 cm	30 cm to gravel	No obvious impediments
Available soil N at start (kg/ha to 60cm)	194	41	13 (to 35 cm) just before turning under	41
N at planting (kg/ha)	120	103	113	120
N side dressing by grower (SD) (kg/ha)	36,41	30	41,41,20	62
Date SD applied	10 Jan, 30 Jan 08	27 Feb 08	9 Jan, 29 Jan, 9 Feb 08	29 Dec 07
SD treatments - days from planting	65,85	99	69,99,109	37
Irrigation no. and amount (mm)	4, 126	Nil	8, 186	5, 105
Leachate tubes	-	-	-	-
Lysimeters	-	-	-	-
Nearest weather stn	P North (20 km)	P North (20 km)	Waipukurau (10 km)	Te Aute

*(PC) As per Potato Calculator prediction.

5.2 Leachate tube and lysimeter installation

In year 3, drainage and leaching measurements were carried out for the Matamata crop. After the potatoes were planted on 16 October 2007, 12 drainage lysimeters were installed to 80 cm (from ridge top) in two replicates, and two leachate tubes (depth 80 cm) were installed in each of the 20 plots making up the trial (see Appendix V). N measured drainage water at these depths was considered lost to the crop and therefore leached. Leachate tubes can only be used to measure soil water N concentration at certain point in time, hence the advantage of lysimeters, which measure and retain all water. Of the 12 lysimeters, six were linked to a data logger, where drainage was recorded every half hour. The remaining six lysimeters were manual, meaning water had to be pumped from the pans below, the volume measured and a sample taken for N analysis. Samples for N analysis also had to be taken for the automatic lysimeters.

As with the previous 2 years, lysimeter drainage was measured manually and soil water samples were taken from the leachate tubes after a rainfall event big enough to cause drainage (monitored using the automatic lysimeters).

5.3 Winter mustard crop

An extension to this project enabled drainage and leaching to be measured beyond the original end date of 30 June 08, incorporating a cover crop on half of the original plots. The potato crop was harvested and the cover crop sown, leaving the drainage lysimeters underground.

Soon after the end of potato growth (13 May), soil was sampled to 60 cm for mineral N content, all leachate tubes were removed and potato yield was measured in each plot (5 m by 2 rows). The remainder of potatoes were harvested from the plots, by hand from around the lysimeters and by harvester over the rest of the trial. The area was cultivated by one tractor pass (grubber) and by hand rake around the lysimeters. The original plots were relocated and leachate tubes re-installed. Half of the plots were broadcast with 10 kg/ha mustard seed and 250 kg/ka sulphate super fertiliser (see plan, Appendix IV). Because of poor establishment the same plots (dry conditions, bird strike and slug damage) were re-sown with mustard (10 kg/ha) on 12 June 2008.

It should be noted that where the harvester was used to lift potatoes, all soil from the ridges was moved the length of the harvester belts and deposited on the ground in a new location. However, since soil mineral N levels from 0–60 cm depth through the ridges immediately prior to harvest were similar for all N treatments, the assumption is that harvesting had little effect on plot N under mustard.

6 Cultivar information for the Potato Calculator

The growth characteristics and yield of eight common New Zealand-grown cultivars and two North American cultivars were compared at Lincoln in a three replicate trial during the 2007–08 season (Table 7). Seed was procured from a number of sources (although no information about physiological age was collected). The cultivars were planted on 23 October 2007, in a Templeton silt loam previously in lucerne. The crop was moulded once, sprayed regularly to control canopy diseases and irrigated.

Variations in emergence, probably related to physiological age of the seed tubers, ranged from 25 (Nadine) to 36 (Umatilla) days. The date of tuber initiation was not recorded. Canopy development was monitored by taking weekly photographs in each plot until canopy death. Faster emergence and time to canopy closure/full canopy can give a cultivar the ability to capture more light and store more carbohydrates. Umatilla and Russet Burbank reached canopy closure 28 days from emergence, whereas Innovator, Agria and Fianna took a week longer.

All cultivars reached full canopy on about 8 January 2008, when Leaf Area Index (LAI) was measured. LAI describes the total area of leaves relative to one square metre of ground, for example an LAI of 4 is equal to 4 m^2 of leaf material. Due to shading of lower leaves, the optimum LAI value is around 3–4. Higher LAI values can indicate a longer duration crop, as leaves are being produced over a longer time period. In the trial LAI ranged from 4 (Nadine) to 6 (Moonlight), and a greater LAI generally indicated a taller canopy.

At full canopy, rooting depth was measured from ground zero (halfway between ridge top and furrow bottom) by digging one pit in each plot, down through the ridge between two potato plants. Most of the roots in all cultivars explored no further than 20–30 cm from the ridge top, at which point a compacted zone was noted. For some plants, not obviously cultivar-related, a small number of longer, thicker roots continued down another 20–30 cm.

Cultivar death dates ranged from 28 Feb 2008 (Nadine) to beyond 7 April 2008 (Rua, which was harvested with green tops). The majority of cultivars died off in mid March.

There were several reasons to suspect less than optimum growing conditions during the season, thus limiting potential yield. The crop experienced a degree of water deficit through most of January as adjacent crops were being harvested. Strong easterly winds after full canopy caused top damage and introduced some leaf disease and early death, particularly in Russet Burbank. Additionally, a compacted cultivation zone at about 30 cm probably limited root growth. For these reasons, developmental information from this trial cannot be used to confirm existing cultivar descriptions for the PC.

Given existing cultivar information, the PC was able to accurately predict death date and yield for Agria. It predicted death date for Umatilla and Russet Burbank but over-predicted yield, indicating that other constraints such as water stress and disease were not fully accounted for.

Cultivars which lived longer than predicted and yielded the same or more than predicted were Nadine, Shepody, Innovator and Moonlight, suggesting that the extra canopy duration gave greater yield.

Ranger and Fianna had longer duration canopies, but yielded less than predicted, even though thermal time from emergence to canopy death were very similar to the existing cultivar descriptions.

Table 7: Days to emergence, leaf area index (LAI) at full canopy, rooting depth of majority of roots (from ridge top), thermal time (TT) from emergence to canopy death (base temperature 0°C), the current setting in Potato Calculator for emergence to canopy death, and gross measured yield (t/ha) for 10 potato cultivars.

Cultivar	Days to emergence	LAI at full canopy	Rooting depth (cm)	TT to canopy death	Current PC setting	Gross yield t/ha	Predicted yield t/ha
Nadine	25	4.1	20	1696	1800	71	66
Umatilla	36	4.7	20	1658	2000	66	73
Shepody	29	5.2	26	1796	1600	69	65
Russet B	29	4.3	20	1796	2000	58	73
Innovator	29	4.5	20	1796	1600	65	65
Agria	29	5.0	28	2272	2000	78	77
Ranger	33	4.6	23	1960	2000	61	73
Rua	33	4.6	30	2159	2300	70	87
Moonlight	29	6.0	33	2226	2000	76	72
Fianna	29	4.6	23	2226	2200	73	83

The important parameters for describing a cultivar for use in the PC are canopy duration (°C days), maximum LAI and thermal time from crop emergence to tuber initiation. The existing description of Russet Burbank growth and development continues to provide a sound basis for explaining the majority of environmental responses of other common mid to late season cultivars grown in New Zealand.

The temptation is to modify these parameters for a cultivar, based on one or two seasons of observations, which may not hold true in other years. Variation in physiological age of the seed tuber is an important factor causing subsequent unexpected cultivar growth and development responses. This is not yet catered for in the PC. Additionally, any growth limitations caused by factors such as exposure to disease, high temperatures or unseen soil constraints may also contribute to incorrect information about a cultivar’s full potential.

7 Results

7.1 Yield response to applied N

Measured gross yields in the eight crops ranged from 36–90 t/ha (Figure 2), growers applying between 90–150 kg N/ha at planting and from 65–193 kg N/ha as side dressings (Table 5 and 6).

Comparing yields in the zero N plots with those in the grower N plots showed sometimes grower yields were higher and sometimes they were lower than the zero N treatments (Table 8). However, these differences were only statistically significant at two sites. At Matamata where no N was applied at planting, applying no side dressing N reduced yield by 12 t/ha (P<0.05) compared with the grower N treatment. At the Pukekohe site, there was an apparent depression in yield at the Grower rate of side dressed N. Damage to a higher proportion of Grower treatment plots by a travelling irrigator wheel may have caused this yield loss, and further statistical analysis could take this into account.

Lack of crop response to N side dressings at most of the sites indicates that N supply was sufficient to meet the crops' N demands to maximise yield. Since none of the crops reached potential yield (as calculated by the PC), then it could be assumed that the crops were unable to utilise the added N because water was limiting. Crops at sites in Pukekohe, Matamata, Ohakune, Opiki 1, and Canterbury all needed to produce about 105 t/ha (assuming tuber dry matter percentage of 22% and a tuber N content of 1.6% of dry weight) just to use up the fertiliser N, not counting N already in the soil at the start or N mineralised.

For un-irrigated crops, there is some justification for applying extra N as an insurance, as rainfall can be unpredictable. However, if irrigation is available, the opportunity is there to better coordinate nitrogen and water management to maximise yield economically.

Table 8: Yield gains or losses from side dressings (t/ha).

Gross yield (t/ha)	Low N (no side dressing)	Grower N	Side-dressing total (kg/ha)	Yield difference
Pukekohe	89	81	135	-8NS
Matamata	68	80	193	12*
Ohakune	78	77	108	-1 NS
Opiki 1	37	39	77	2 NS
Opiki 2	55	59	65	4 NS
Waipuk	56	55	102	-1 NS
Canterbury	74	72	129	-2 NS

*LSD 0.05, df = 12. NS = no significant difference.

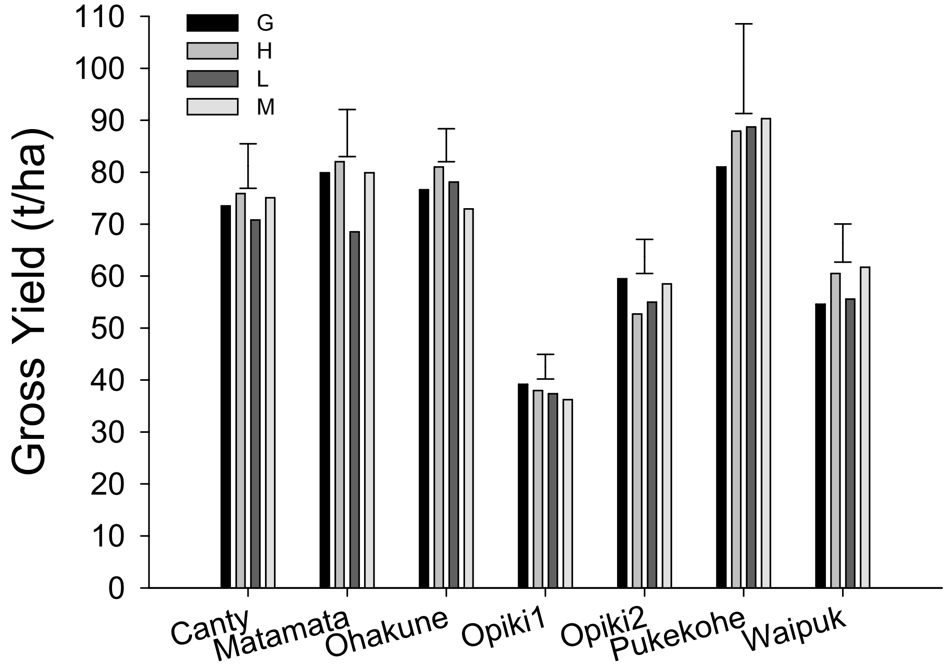

Figure 2: Gross yields (kg/ha), for each site and each N treatment. The vertical bars represent 5% LSD with 9 df for Pukekohe and 12 df for the other sites.

7.2 Yield components

Crops used in the project were grown for the fresh and processing markets, giving a range of cultivars monitored, including Nadine and Rua (fresh), Agria and Russet Burbank (fry), Fianna (crisp) and Moonlight (multi-purpose). As a result, tuber characteristics at harvest varied between crops.

Nadine tubers had the lowest dry matter (DM) content (averaging 13%, Russet Burbank had the highest at 23%) and because they were planted more closely in the rows, the highest tuber number per square metre (Appendix I). Tuber DM percentage can also be affected by factors other than the cultivar effect. Increasing rates of N can lower DM, as can wet conditions near the end of crop growth. This is because tubers continue to take up water and respire, especially if still attached to stem and roots. In some of the monitored crops with a leaner N supply (before side dressing application) there was a tendency for DM to be lower with the higher rates of N (in particular at the Canterbury site). This did not occur at sites where greater amounts of N were already in the soil after planting.

Plants in those crops grown for the processing market were planted further apart and were cultivars that produce larger tubers (Agria, Moonlight and Russet Burbank), and so had a larger average tuber size. Although no yield responses to N were measured in the Agria crop, the low N treatment canopy died off first and had a smaller average tuber size than at the higher rates of N.

At any one site, there was little effect of N rate on tuber N%, except at the Waipuk site where the low N treatment had a lower tuber N content. Tuber N content tended to be higher at some sites with higher rates of side dressed N. However, crops cannot be relied upon to "mop up" N surpluses and thus reduce any future N loss through over-application.

7.3 N balance, drainage and leaching at the Matamata site

The Matamata site was set up after planting with drainage lysimeters and leachate tubes. No N was applied at planting. Four rates of N were applied (see Appendix IV for layout details):

- No N, planting or no side dressing N.
- PC N, three side dressings totalling 138 kg/ha.
- Grower N, one amount of 90 kg N/ha just after planting to simulate N at planting, four further side dressings totalling 193 kg/ha, giving 283 kg N/ha.
- High N, three side dressings totalling 276 kg/ha.

N already in the soil (to 60 cm) just before planting averaged 78 kg/ha over the trial site. Mineralisation for the site was calculated using the final N balance (kg N/ha) from the No N treatment:

Mineralisation (top 60 cm) = (N removed by the tubers + N left) – (N at start + N applied), or

(167 + 44) – (78 + 0) = 133 kg N/ha.

The amount of N lost from the system can be calculated as the difference between the amount of available N and what is removed and left at the end of the season:

(Initial soil N + Min N + Fert N) – (harvest soil N + Crop N)

Amounts of N available (including the estimate of N mineralised) to the crop ranged from 211 to 494 kg/ha (no N and grower N treatments respectively). N left in the soil at harvest varied from 44 to 60 kg N/ha. N had either been taken up by the crop, moved further down the profile than 60cm or was lost in other ways. This calculation for the Grower treatment gives an unexplained N loss of 139 kg N/ha.

As with years 1 and 2, there was no significant drainage during crop growth (from emergence when the lysimeters were installed) at this site, and therefore no loss of N through leaching. Rainfall from planting to crop death (about 31 March 2008) was 256 mm, less than the first 2 years, because the region experienced a drought which started in the last half of 2007 and continued until April 2008. Even though it was irrigated, the crop experienced some periods of water deficit during December and January due to the late commissioning of a new irrigation system.

A mustard cover crop was planted in mid May on half of the original potato plots, to investigate its effectiveness in recycling surplus N, thus reducing N loss over winter. Emergence was initially poor and the crop had to be re-sown in mid June. By the beginning of August, the mustard crop was well established and while it had no measurable effect in reducing drainage, leaching was eventually less under the mustard than under fallow ground. (See Section 7 for the complete mustard report).

According to the automatic lysimeters, drainage at the site began on 16 April 2008 after 153 mm rain fell over 2 days, breaking the drought. From then until 9 October, 1080 mm rain fell in total. With no crop to intercept water, the pattern of water drained closely coincided with each rainfall event (Figure 3). However, the 12 lysimeters averaged 25% more drainage than measured rainfall (weather station on-site) indicating some lateral flows may exist under the site, which could channel extra water (and N from other plots) into the lysimeters (Table 9).

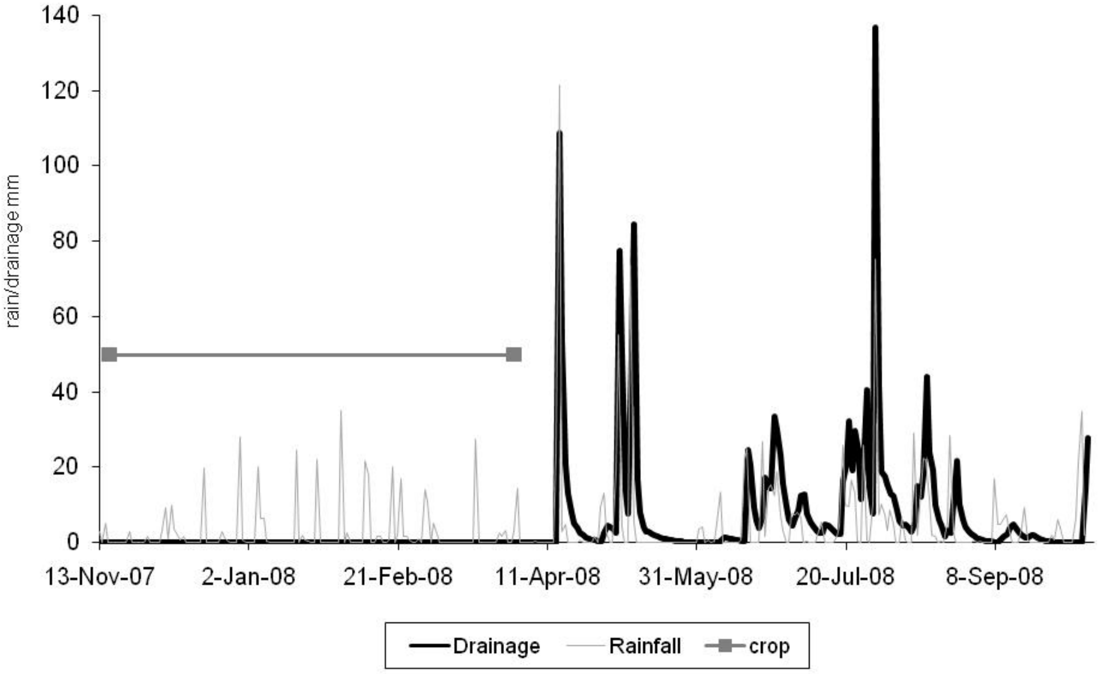

Figure 3: Crop growth, daily rainfall and drainage events, Matamata site.

Table 9: Comparing rainfall (mm) and drainage (mm) for each major drainage event.

Date	Rainfall (mm)	Mean drainage in 12 lysimeters (mm)
22 April 08	170	176
7 May 08	105	147
12 May 08	80	172
18 Jun 08	75	63
28 Jun 08	97	143
8 July 08	33	71
21 July 08	50	58
24 July 08	39	58
29 July 08	27	67
1 Aug 08	93	147
14 Aug 08	73	107
19 Aug 08	68	109
26 Aug 08	38	46
9 Oct 08	132	65
Total	1080	1430

Two methods were applied to estimate the amount of leaching below 80 cm from the different N application treatments, one using soil water N concentrations found in the lysimeters and one using those from the leachate tubes. In all, each treatment had 10 leachate tubes, giving better replication of N concentration values than three lysimeters. However, the solution collected in the tubes does not necessarily represent the N concentration of the drainage event because it is only sampled at one point during the event.

Drainage values used were calculated using the average value obtained from the manually measured water volumes from all 12 lysimeters.

When using the same drainage volumes for both methods, but corresponding N concentrations as measured in the water samples collected, more N was calculated to be leached through the lysimeters, as soil water N concentrations were higher. For the lysimeter method, greater differences also developed between the N treatments (Figures 4 and 5).

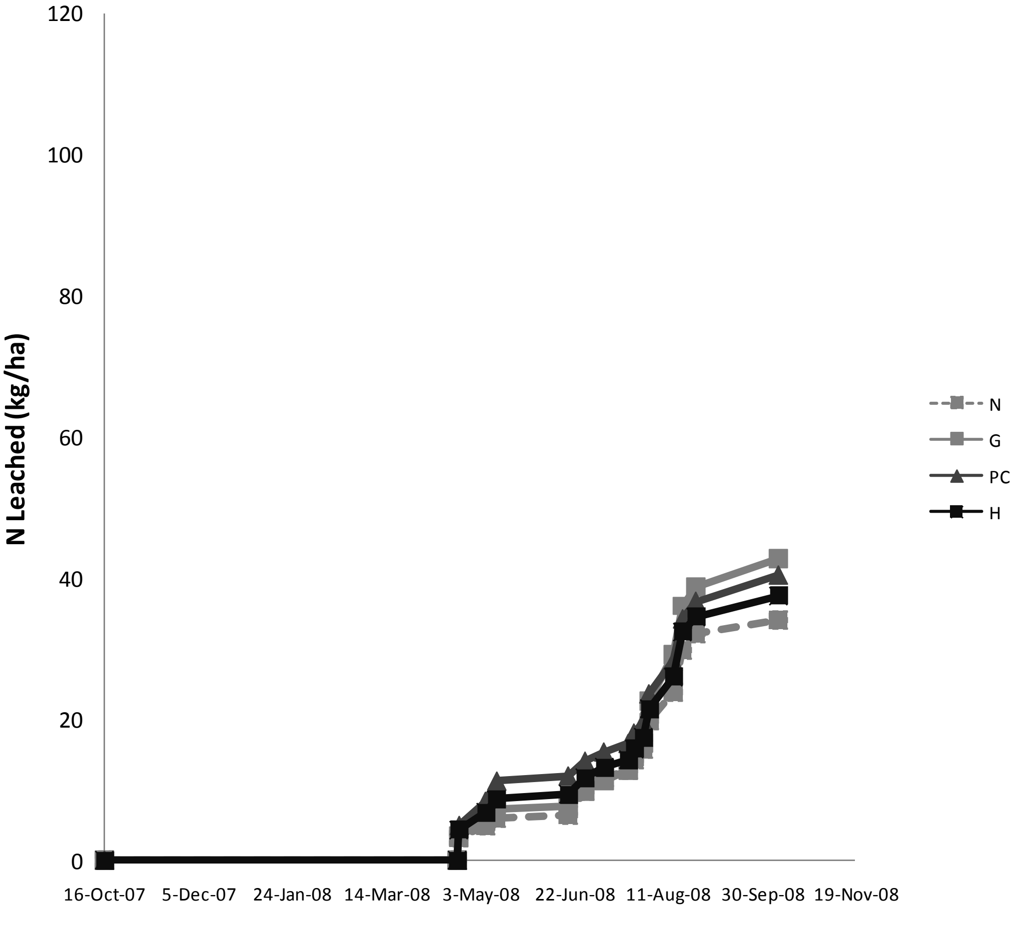

Figure 4: N leached (kg/ha) at the Matamata site, measured using leachate tube N concentration values. The treatments are N = No N, G = Grower managed, PC = PC managed, H = High N.

This indicates that the leachate tube method may have under-estimated leaching of surplus N, as drainage occurred quickly after the heavy rainfall events experienced. It is possible that any surplus fertiliser N still in the soil water, and not lost as a gas, largely passed the leachate tube collection cup zone before it could be measured. See Appendix III for a table showing N concentration, rainfall and drainage values along with dates fertiliser N was applied.

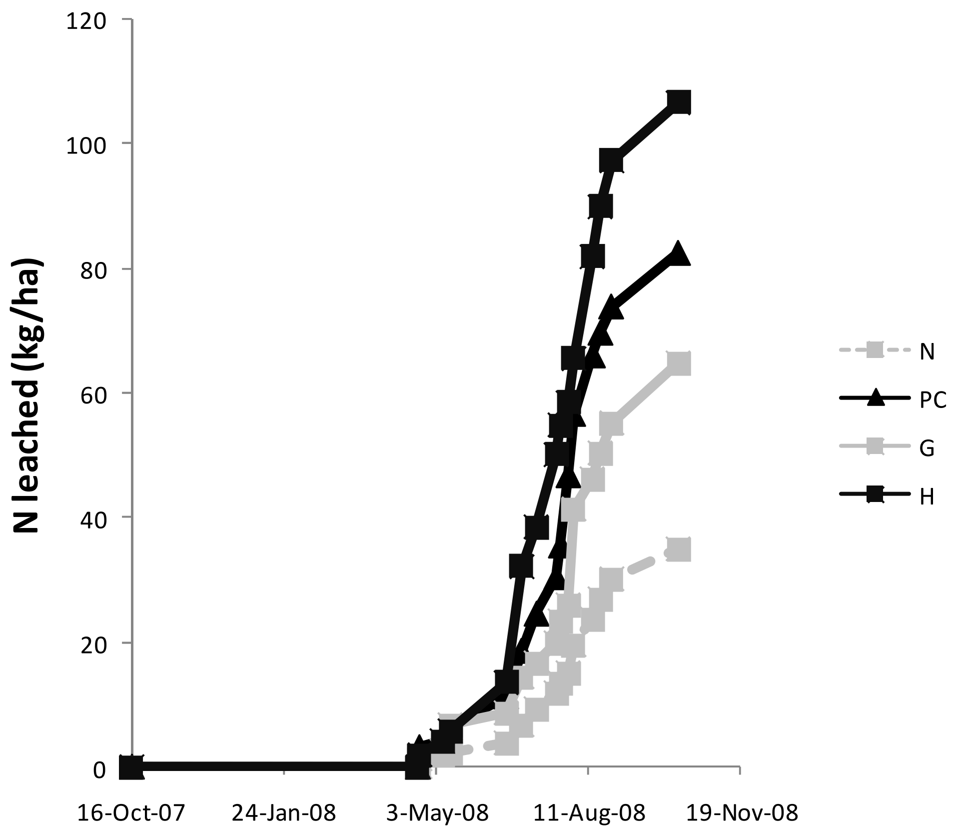

Figure 5: N leached (kg/ha) at the Matamata site, as measured using lysimeter N concentration values. The treatments are N = No N, G = Grower managed, PC = PC managed, H = High N.

7.4 Soil mineral N at harvest

Amounts of N left at harvest ranged from about 40–500 kg/ha (Table 10). Soil N measurements were made by sampling directly down through the ridges in two 30 cm increments, which gave an increased chance of striking any left-over banded N fertiliser that was applied at planting. Because the per hectare rate was concentrated in a band near the seed tubers, end of season soil measurements may have picked up a disproportional amount of N in a particularly dry season. This feature was not noted in the first 2 years. However, at sites where levels were high, a combination of higher N supply at the start, dry weather (the Ohakune and Opiki 2 not irrigated) and the banding of N fertiliser at planting may have all contributed.

Table 10: N left at harvest to 60 cm depth (kg/ha) for each site and each N fertiliser treatment. The Te Aute site had different types of N fertiliser applied (AS = ammonium sulphate, CAN = calcium ammonium nitrate, PC U = Potato Calculator guided urea,G U = grower-managed Urea).

Min N kg/ha	Low N	Medium N	Grower N	High N
Matamata (irrig)	44	54	60	54
Ohakune	336	417	463	325
Opiki 1 (irrig)	305	245	511	424
Waipukurau (irrig)	145	135	173	154
Opiki 2	160	253	199	266
Pukekohe (irrig)	67	75	98	85
Canterbury (irrig)	65	69	113	128
Fertiliser type	AS	CAN	PC U	G U
Te Aute (irrig)	62	50	52	70

7.5 Rooting depth and soil compaction

The first two years results showed that yields were not measuring up to PC predictions of potential yield, largely the result of inadequate water supply to the crop. During hand-harvesting of these crops, difficulty in digging much lower than the bottom of the ridge was noted and rooting depth was mostly between 25–40 cm (from ridge top). These depths were shallower than anticipated, given that potato roots are capable of getting down to well over 50 cm in optimum conditions.

A study in the UK (Stalham et al. 2007) showed that many soils used to grow potatoes in the UK are compacted to the extent that growth and yield are adversely affected. Many crops rooted freely near soil surfaces where the compaction resistance was less than 1 MPa, but this reduced with increasing compaction until root growth was low or non-existent at resistances of 3 MPa.

In year 3, a closer investigation of rooting depth and the relationship between this and possible soil compaction was undertaken. Just after planting, soil resistance at 10 cm intervals through the planted ridge (five random sites in the trial area) was measured using a penetrometer. Comparing relative penetration resistance values for different soil types and conditions can be misleading, as resistance is dependent on soil moisture content, soil texture, which differs widely from paddock to paddock. A compacted zone in the soil can be more easily penetrated by roots as it gets wetter.

In all paddocks monitored, penetration resistance was low in the ridges, but increased to often be at a maximum around the depth to where cultivation implements reach, to about 25–30 cm (from ridge top). In some cases, resistance was reaching the root-restricting levels found in the UK, at over 2 MPa. Two examples of different levels of compaction found in soils studied in this project are illustrated in Figure 9. Penetration resistance at the Matamata site was similar to that at Pukekohe up to about 35 cm, but a compacted layer measuring 2.1 MPa was detected between 30–40 cm, possibly caused by repeated cultivation to the same depth. Beyond this, resistance flattened off.

Problems with irrigation gear meant that watering of the Matamata crop did not start until early January, allowing the soil to dry out during December, perhaps compounding effects of any compaction. When measured at full canopy, not many roots were seen to be growing past the compacted zone at 30 cm. At the time of measuring penetrometer resistance, the Pukekohe soil was quite moist, helping to lessen the effects of compaction. Even though the clay soils in Pukekohe can get very hard when dry, for this crop the optimum irrigation management kept the whole profile wet from the start, ensuring that the crop's roots established deeply, so that many were measured reaching to more than 50 cm by full canopy.

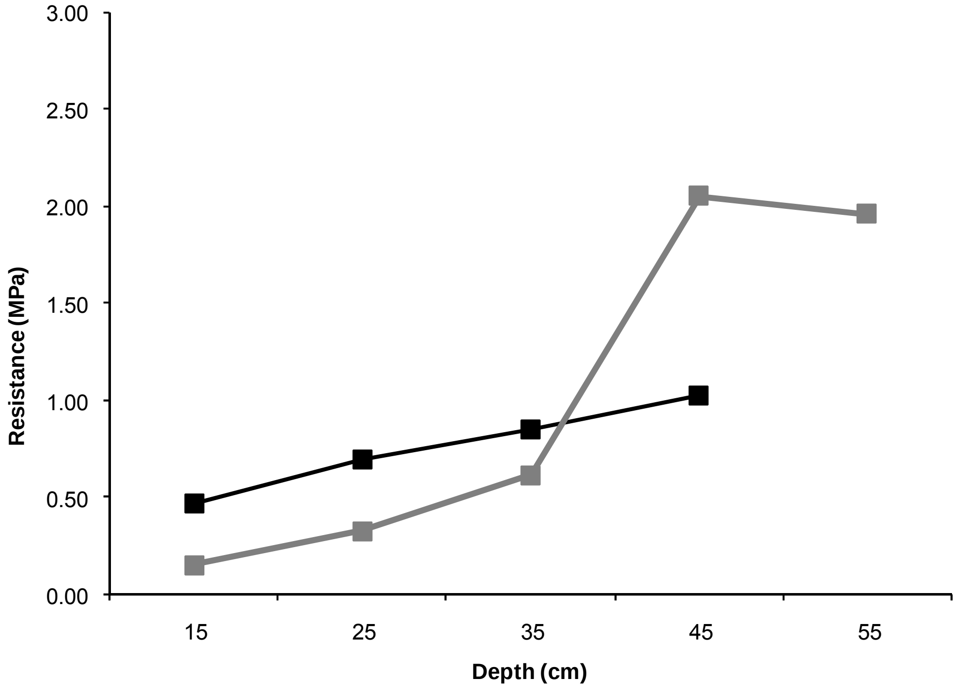

Figure 9. Soil resistance (MPa) at planting in 10 cm increments from ridge top. The black line represents a Patamahoe clay soil in Pukekohe (ridge height 15 cm), the grey line a Waihou gritty silt loam in Matamata (ridge height 25 cm).

7.6 Effect of N fertiliser type on yield and soil pH

At one Hawke's Bay site, high soil pH is a known feature and averaged 7.0 in the field monitored. On some soil types high pH can be a factor contributing to the presence of common scab on potatoes. Ideally, pH levels should be below 5.8 to reduce the risks of the crop contracting this disease (Richard Falloon pers. comm.). N fertiliser in the form of ammonium sulphate can help reduce pH if used over a number of years. The grower was interested to see if different forms of N would have a detrimental effect on yield.

One side dressing of ammonium sulphate (295 kg/ha, equivalent to 62 kg N/ha, applied on 29 December 2007) was compared with the same N rate of urea (135 kg/ha) and calcium ammonium nitrate, the usual grower choice (230 kg/ha). At harvest, pH was lower in the top 0–30 cm of the soil profile than at 30–60 cm across all fertiliser types, and lower where Urea was used (Table 11). However, the differences are of no practical significance and the grower did not expect to see an effect after one season. Yield was not affected (averaging 65–68 t/ha gross), mostly because N was not limiting and the side dressings were not needed by the crop. Common scab can also occur where conditions are dry, and this was not the case on this well-irrigated crop in a deep soil. No scab was noted in the crop at harvest.

Table 11: Side dressing amounts (kg/ha) applied to meet the 62 kg/ha grower requirement, with associated pH at two depths, measured at harvest.

Soil pH	N% of product	Amount of product applied as side dressing(kg/ha)	Soil depth	
			0–30 cm	30–60 cm
Ammonium sulphate	21	295	6.8	7.1
CAN	27	230	7.2	7.4
Urea	46	135	6.6	7.1
PC rate CAN*	27	170	7.3	7.5

* equivalent to 46 kg N/ha, recommended by the PC.

8 The role of cover crops in Waikato cropping rotations

8.1 Introduction

Cropped soil is at risk of slowly degrading, due to continuous crop removal decreasing soil organic matter levels and damage to soil structure by cultivation and harvesting equipment. A financial consequence of this is the increased likelihood of reduced crop yield and quality, quite apart from other environmental issues. However, there are opportunities to slow this process and one example is to plan for restorative (or cover) crops in between cash crops when possible, even in winter. These type of crops need to be easy to establish and to break down quickly when incorporated into the soil before the next crop. Some cash crop residues can also be useful. For example, maize stubble, along with its extensive root system, returns some organic matter, but N released during breakdown is still at risk of becoming leached over winter. Restorative or cover crops can be beneficial in a number of ways. They can:

- Mop up surplus N and retain it at the surface.
- Scavenge N quite deeply from below the potato root zone.
- Improve other nutrient recycling, remediation.
- Increase/protect organic matter.
- Keep weeds down.
- Slow drainage and therefore leaching.
- Increase infiltration.
- Harbour beneficial insects.
- Help break disease cycles.
- Help minimise erosion.
- Provide a cash crop (forage oats are an example).
- Break up compacted soil (for example radish has deep tap roots).

Mustard, a common winter cover crop in New Zealand, establishes rapidly, grows well, and breaks down easily in the soil. This latter characteristic means that the following crop is not usually adversely affected by a rough seedbed or N shortages caused by excessive organic matter breakdown. Collins et al. (2007) showed that mustard could produce about 6 t/ha biomass (dry weight) and take up about 120 kg/ha N of which about 30% (or 30–40 kg N/ha) was then recycled for the next crop. Collins et al. also suggested that C to N ratios related to cover crop breakdown are important. If they get too high (>20:1) N can become immobilised, reducing the initial N availability to the next crop. Some wheat and barley crop residues can have a C to N ratio above 80.

Cereals such as oats are likely to provide more organic matter, but large amounts of biomass can be difficult to incorporate back into the soil and may break down too slowly, using N resources in the process. The surplus can be sold as forage. However, *in-situ* grazing on winter-saturated ground is not recommended, as the soil structure is easily damaged. Additionally, stock would return a proportion of N as urine, susceptible to leaching. A cut and carry system could be considered, but would add cost and result in some compaction from harvesting equipment.

Cover crops with far-reaching tap roots, including radish, can penetrate compacted layers in the soil, leaving pathways for the roots of subsequent crops to follow. These crops can pull up nutrients from depths beyond the potato root zone and bring them back to the surface. They can also be useful for remediation of high P soils. For example, total P removal by above-ground radish parts reached 40 kg P/ha in 3 months (Weil 2007).

8.2 The Waikato situation

In the Matamata district, a common cropping rotation is a combination of maize, onions and potatoes, with a pasture phase at some point. As onion crops are planted in early winter, closely following a previous summer crop, there is no opportunity for a cover crop in this situation. However, between maize and potato crops and after onions, the land is sometimes managed in winter by growing a cover crop of mustard, oats or ryegrass.

To limit excess growth of cereal cover crops, oats are often planted where the previous potato or maize crop is harvested later in autumn. This way, biomass develops more slowly and is more easily returned to the soil in spring. Mustard can grow for longer and still be easily chopped and incorporated. Lack of thick ground cover by a cover crop during periods of heavy frosts is also an advantage as self-set potatoes are more easily destroyed.

8.3 Two winter cover crop demonstration trials

In early May 2007, one strip (about 80 m long by 5m wide) each of oats (sowing rate 100 kg/ha), mustard (12 kg/ha) and radish (5 kg/ha) was planted after potato harvest near Matamata. No fertiliser was added and soil N to 60 cm was measured at the start and just before incorporation (end of August) in the soil, when biomass was measured using eight random 1 m quadrats in each crop. Biomass samples were weighed fresh, and a sample oven dried at 60°C to ascertain dry matter, plant carbon and nitrogen percent.

Following potato harvest, mustard was established in mid May and June 2008 in half the plots of a potato N rate trial (including drainage and leaching measurements) at Waharoa near Matamata. Drainage and leaching from under fallow and mustard-covered plots were measured right through from earlier potato harvest. At the beginning of October, just before ground preparation for the next crop of potatoes, a 1 m quadrat of mustard (including roots) was removed from each plot and processed as for the 2007 trial.

Even though the mustard was sown immediately after potato harvest on 13 May 2008, a second sowing in June was needed to boost population numbers. Once established and growing strongly, the crop began to reduce the amount of N leached through the system (Figures 10 and 11) This was achieved by the crop taking up increasing amounts of N. Ideally, with better establishment, a crop could be more efficient in reducing N leaching further by removing N earlier.

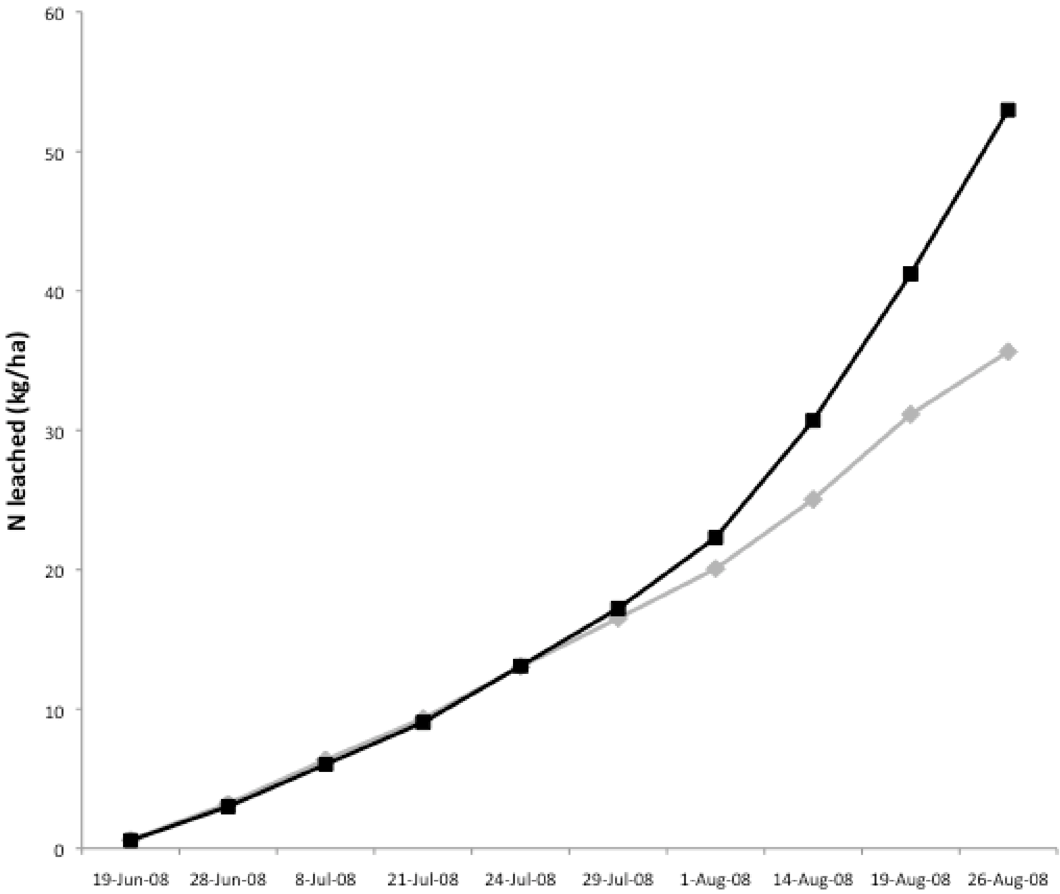

Figure 10. N leached (kg/ha) from under a winter mustard cover crop (grey line) and fallow ground (black line).

The quality of the mustard crops grown in 2007 and 2008 reflected the different soil N contents and growing conditions. The 2007 crop was grown in soil with high residual N and for a shorter time, giving it higher N content, less biomass, and lower C:N ratio (Table 12). The 2008 crop grew for a month longer and was more stalky, giving it a higher C:N ratio. However, both crops retained much of the N left behind by the potato crop.

Figure 11: Mustard crop at harvest, 9 October 2008.

The 2007 oat crop had the heaviest biomass at 9000 kg/ha and mopped up much of the residual N. By this stage, though, the crop was too bulky to work in directly, so was cut off near ground level as a forage crop to be fed off-site. Top-only biomass amounted to 5600 kg/ha and removed 127 kg N/ha, leaving 39 kg N/ha to be returned by lower stems and roots (data not shown). This system involved an extra tractor pass, risky at that time of year. If conditions were wet at optimum harvest time (for forage quality), then harvest would have to be delayed to avoid soil damage, and crop quality could deteriorate. Depending on how the crop was to be fed out, surplus N problems are being transferred from one situation to another, rather than solved.

The 2007 radish crop removed the most N at 239 kg N/ha, both through accessing N deeper in the profile (it possibly accessed some N below 60 cm, data not shown) and by having twice N concentration in the plant material than the other two crops. Additionally, the radish had the lowest C:N ratio, indicating that plant breakdown would be faster. Another benefit of radish is the existence of a strong tap root, which may be able to penetrate compacted zones through the soil profile, opening up cracks for the roots of subsequent crops to take advantage of.

Table 12: Start soil mineral N to 60 cm (kg/ha) when cover crops were planted, soil mineral N prior to cultivating in cover crop (kg/ha), plant uptake (kg/ha), whole crop biomass (DM kg/ha), C:N ratio and whole plant N% (by dry weight).

Cover crop (kg/ha)	Start N	End N	Plant uptake	Biomass (DM) at incorporation	C:N ratio	Whole plant N%
Mustard 07	143	40	113	5500	28:1	1.7
Oats 07	163	30	166	9000	19:1	1.6
Radish 07	150	68	239	6700	12:1	3.2
Mustard 08	53	6	75	7000	37:1	1.1
Fallow 08	52	26	0	0	N/A	N/A

9 Discussion and conclusions

As land-use intensifies and the risk of environmental damage from farm practices increases, potato growers are under pressure to prove that their N management minimises N leaching. Growers are also keen to optimise N use as N fertiliser costs rise. The aim of this project was to evaluate current N management systems across a range of North Island potato crops, and where needed, provide ways to help growers calculate crop N requirements more closely and consistently.

Findings from the third year reflect those of years 1 and 2, where the N requirement of the crop was largely met by the N supplied in the soil and the fertiliser N at planting, indicating that some side dressings could be dropped from the fertiliser program without yield loss. Alternatively, less N could be applied at planting and more as a side dressing when required, since the risk of N leaching is greater before the crop emerges.

Under favourable conditions, potato roots can reach 70 cm or more through the soil. In most of the crops under study, roots were restricted by a compaction layer at about 30 cm, thus reducing the ability of the plants to access more of the resources present further down. This has direct implications for N and water management of the crop. Increased root access would make more N available and decrease the risk of a situation where the soil is not able to supply enough water to a rapidly growing crop.

As with the first 2 years, no N leaching occurred in the third year during the growth of the potato crop. However, N was leached later during the winter, once the soil had been refilled with water and drainage began. More N was leached where more was applied during crop growth, but more significantly, more N was unaccounted for in the system where more was applied.

10 Acknowledgments

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Appendix I: Final tuber yield and other yield components

Treatment	Low N	Grower N	Medium N	High N	LSD (0.05)
Gross yield t/ha					
Pukekohe, Rua	89	81	90	88	NS
Matamata, Mlight	68	80	80	82	9*
Ohakune, Nadine	78	77	73	81	NS
Opiki 1, Mlight	37	39	36	38	NS
Opiki 2, Mlight	55	59	58	53	NS
Waipuk, Agria	56	55	62	60	NS
Canterbury, RB	74	72	75	76	NS
N type	Amm S	CAN	Urea	CAN PC	
Te Aute, Mlight	68	68	65	65	
Tuber number per m^2					
Pukekohe	48	48	43	48	NS
Matamata	29	34	35	29	NS
Ohakune	57	58	58	63	NS
Opiki 1	28	30	28	29	NS
Opiki 2	26	26	27	25	NS
Waipuk	25	28	27	28	NS
Canterbury	43	43	44	43	NS
N type	Amm S	CAN	Urea	CAN PC	
Te Aute	34	31	33	31	
Tuber weight g					
Pukekohe	142	127	131	131	NS
Matamata	204	202	197	213	NS
Ohakune	98	95	89	96	NS
Opiki 1	132	132	127	132	NS
Opiki 2	211	216	215	222	NS
Waipuk	200	232	217	224	23*
Canterbury	172	170	170	175	NS
N type	Amm S	CAN	Urea	CAN PC	
Te Aute	200	220	195	208	NS
Tuber DM%					
Pukekohe	20.0	19.2	19.7	18.3	NS
Matamata	18.2	17.6	18.0	17.3	NS
Ohakune	13.0	13.2	13.3	12.9	NS
Opiki 1	18.1	18.2	17.9	18.6	NS
Opiki 2	17.8	17.8	17.6	17.6	NS
Waipuk	15.6	14.6	14.9	15.3	NS
Canterbury	22.2	23.4	23.1	21.9	0.8*
N type	Amm S	CAN	Urea	CAN PC	
Te Aute	17.6	17.4	17.4	17.4	NS

Treatment	Low N	Grower N	Medium N	High N	LSD (0.05)
Tuber N%					
Pukekohe	1.47	1.63	1.50	1.62	0.10**
Matamata	1.37	1.68	1.56	1.60	NS
Ohakune	1.69	1.67	1.68	1.66	NS
Opiki 1	1.83	1.90	1.86	1.84	NS
Opiki 2	1.51	1.58	1.63	1.56	NS
Waipuk	1.29	1.65	1.53	1.57	0.16**
Canterbury	1.64	1.48	1.62	1.72	NS
N type	Amm S	CAN	Urea	CAN PC	
Te Aute	1.18	1.27	1.29	1.23	NS

Appendix II: Nitrogen treatments and total N supply

Treatment kg/ha	Low N	Grower N	Med N	High N
Pukekohe				
N in soil to 60 cm	87	87	87	87
N at planting	144	144	144	144
N side dressing	0	81,54	46	92
N mineralised	96	96	96	96
Total N supplied to crop	327	462	373	419
N removed at harvest	260	255	267	263
N left in soil	67	98	75	85
Matamata				
N in soil to 60 cm	78	78	78	78
N at planting**	0	90*	0	0
N side dressing	0	46,46,46,55	46, 46, 46	92, 92, 92
N Mineralised	133	133	133	133
Total N supplied to crop	211	494	349	487
N removed at harvest	167	225	235	226
N left in soil	44	60	54	54
Ohakune				
N in soil to 60 cm	106	106	106	106
N at planting	150	150	150	150
N side dressing	0	108	40	80
Total N supplied to crop*	256	364	296	336
N removed at harvest	173	169	162	174
N left in soil***	336	463	417	325
Opiki 1				
N in soil to 60 cm	194	194	194	194
N at planting	120	120	120	120
N side dressing	0	36, 41	72	108
N mineralised	115	115	115	115
Total N supplied to crop	429	506	501	537
N removed at harvest	124	137	122	130
N left in soil***	305	511	245	424
Opiki 2				
N in soil to 60 cm	42	42	42	42
N at planting	103	103	103	103
N side dressing	0	65	46	92
N mineralised	162	162	162	162
Total N supplied to crop	307	372	353	399
N removed at harvest	147	167	169	144
N left in soil***	160	199	253	266

Treatment kg/ha	Low N	Grower N	Med N	High N
Waipuk				
N in soil to 60 cm†	70	70	70	70
N at planting	113	113	113	113
N side dressing	0	41, 41, 20	41	82
N mineralised	73	73	73	73
Total N supplied to crop	256	358	297	338
N removed at harvest	111	131	140	145
N left in soil	145	173	135	154
Te Aute	Amm sulph	Urea	CAN	PC N
N in soil to 60 cm	42	42	42	42
N at planting	120	120	120	120
N side dressing	62	62	62	46
N mineralised	20	20	20	20
Total N supplied to crop	244	244	244	228
N removed at harvest	141	145	147	139
N left in soil	62	70	50	52
Canterbury				
N in soil to 60 cm	144	144	144	144
N at planting**	0	0	0	0
N side dressing	80	120, 80, 49	80, 46, 46	80, 92, 92
N mineralised	44	44	44	44
Total N supplied to crop	268	437	360	452
N removed at harvest	251	269	280	286
N left in soil	42	163	69	128

* Broadcast soon after planting.
** Only on the trial area.
*** High levels of N measured may have resulted from sampling through N remaining from a concentrated band of fertiliser applied at planting.
† Estimated, amount measured was 13 kg N/ha before poor pasture cultivated.

Appendix III: Concentrations of leached N, leachate tubes, Matamata

Date	Rainfall (mm)	Drainage (mm)	L	G	PC N	H
			(ppm)			
16 Oct 07			Crop planted			
19 Oct 07	17					
4 Nov 07	35					
9–16 Nov 07	10					
16 Nov 07	Crop emerged, moulded, lysimeters and leachate tubes installed					
26 Nov 07	N trts applied (kg/ha)		0	90*	0	0
12 Dec 07	N trts applied (kg/ha)		0	46	46	92
19 Dec 07	N trts applied (kg/ha)		0	0	46	92
8 Jan 08	N trts applied (kg/ha)		0	46	46	92
22 Jan 08	N trts applied (kg/ha)		0	46	0	0
12 Feb 08	N trts applied (kg/ha)		0	55	0	0
	Total N		0	283	138	276
31 Mar 08			Crop death			
26 Nov to 31 Mar 08	378		No drainage at 80 cm. Includes 184 mm irrigation			
Total	**440**	**0**				
22 Apr 08	170	176	1.8	1.9	2.8	2.5
6 May 08	105	147	0.5	1.2	1.9	0.9
12 May 08	80	172	0.6	0.7	1.5	1.1
19 Jun 08	75	63	1.1	0.8	0.8	1.0
28 Jun 08	97	143	3.6	2.3	2.1	2.4
8 Jul 08	33	71	1.8	1.7	1.6	1.7
21 Jul 08	50	58	1.9	3.1	2.6	2.2
24 Jul 08	39	58	2.7	2.6	2.3	2.4
29 Jul 08	27	67	2.1	2.6	2.3	2.4
1 Aug 08	93	147	3.3	5.3	3.1	3.1
14 Aug 08	73	107	4.4	6.7	5.6	5.7
19 Aug 08	68	109	6.5	5.7	5.8	5.9
26 Aug 08	38	46	3.2	6.0	5.1	3.2
9 Oct 08	132	65	2.9	8.7	6.4	5.5
Total	**1080**	**1430**				
Season total	**1520**	**1430**				

* Broadcast to approximate N at planting.

Appendix IV: Trial layout, Matamata

SFF Potato Nitrogen (N) Trial
Waharoa

N No N
G Grower N
PC Potato Calculator N
H High N

White squares winter mustard planted

Plot size: 5 rows x 12m