LANDSCAPE LOGIC
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Assessing the risk of nutrient loss under intensive crop production in the Panatana catchment, Tasmania

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Cover photo: Three views of the Panatana cachment.

LANDSCAPE LOGIC is a research hub under the Commonwealth Environmental Research Facilities scheme, managed by the Department of Environment, Water Heritage and the Arts. It is a partnership between:

- **six regional organisations** – the North Central, North East & Goulburn–Broken Catchment Management Authorities in Victoria and the North, South and Cradle Coast Natural Resource Management organisations in Tasmania;
- **five research institutions** – University of Tasmania, Australian National University, RMIT University, Charles Sturt University and CSIRO; and
- **state land management agencies in Tasmania and Victoria** – the Tasmanian Department of Primary Industries & Water, Forestry Tasmania and the Victorian Department of Sustainability & Environment.

The purpose of Landscape Logic is to work in partnership with regional natural resource managers to develop decision-making approaches that improve the effectiveness of environmental management.

Landscape Logic aims to:

1. Develop better ways to organise existing knowledge and assumptions about links between land and water management and environmental outcomes.
2. Improve our understanding of the links between land management and environmental outcomes through historical studies of private and public investment into water quality and native vegetation condition.

Assessing the risk of nutrient loss under intensive crop production in the Panatana catchment, Tasmania

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Executive summary

The Panatana catchment in central north Tasmania (~41°12'S, 146°26'E) is one the most intensively cropped catchments in the state due to a favourable climate, productive soils and ready access to various agricultural processing and port facilities. The high rates of irrigation and fertiliser use in the catchment, combined with typically high annual rainfall totals and soils that have high infiltration rates and rapid permeability, create conditions that are conducive to high drainage and nitrogen leaching losses below the root zone.

The objectives of this study were to use simulation modeling to: 1) explore the likely impact of current management practices on the N balance under intensive vegetable-based cropping and dairy systems over a 25 year period; 2) enhance our understanding of the potential for N loss to ground water, and; 3) identify feasible and viable practices for reducing N loss.

Key findings are:

- Crop water supply (i.e. effective rainfall + effective irrigation) exceeds crop water use (i.e. soil water evaporation + transpiration) for all crops grown across the 7 crop-based farms;
- The surplus between crop water supply and crop water use results in substantial (i.e. >100 mm) average seasonal drainage figures for each crop;
- Crop N demand is close to crop N supply (i.e fertiliser N + soil nitrogen fixation) for all rotation elements with the exception of potato which has an average surplus of 89 kg N/ha;
- Surplus soil N should be taken into account when determining fertiliser rates for following crops in the rotation;
- Potato is the 'leakiest' of all crops with an average loss of 29 kg N/ha (up to 4 times greater than other crops);
- The potential exists for substantial seasonal N leaching losses from all elements of the crop rotations;
- Whole-farm N loss from the dairy operation (up to 203 kg N/ha) far exceeds that from any of the crop-based farms (up to 35 kg N/ha) due to much higher irrigation rates (560 mm/year), N input rates (330 kg N/ha) and drainage rates (670 mm/year);
- Modelled farm N loss rates for the dairy farm are much greater than catchment scale estimates for dairying (~25kg N/ha/year) while the corresponding loss rates for intensive cropping are comparable;
- Deficit-based irrigation and reduced N fertiliser rates appear to have the potential to generate significant financial savings through reduced input costs and reduced offsite N loss while maintaining current levels of production.

Contents

Acknowledgments

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Introduction

The Panatana catchment in central north Tasmania (~41°12'S, 146°26'E) is one the most intensively cropped catchments in the state due to a favourable climate, productive soils and ready access to various agricultural processing and port facilities. Rotations are typically comprised of up to 5 different annual crops and a pasture phase of between 2–5 years in duration.

The potential for high yields under these growing conditions and the high value of some of the crops (e.g. potato, poppy) has encouraged farmers to invest heavily in new irrigation infrastructure (e.g. dams, low pressure pivot irrigators) to overcome crop water deficits during the summer months. While irrigation application rates are often high, the timing of irrigation is rarely based on soil moisture deficit technology. This, combined with high annual rainfall totals (long-term average of ~768 mm/year, Figure 1) and soils that have high infiltration rates and rapid permeability (Cotching 1995) creates conditions that are conducive to high drainage rates.

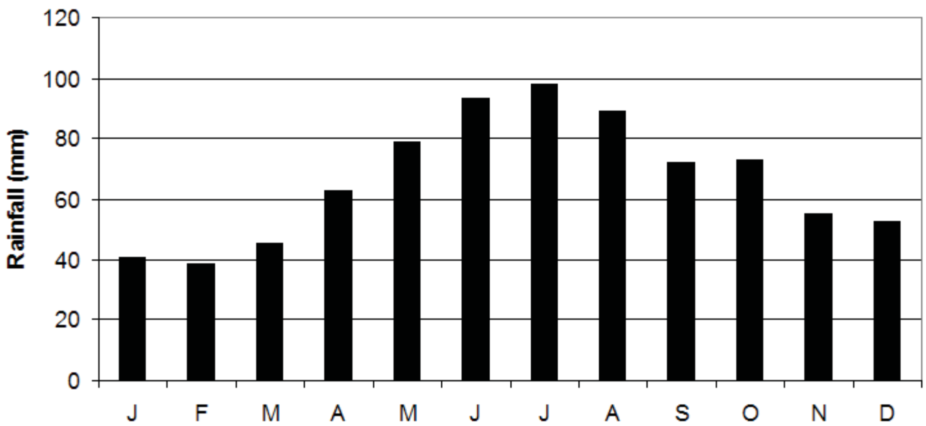
While fertiliser rates are often based on pre-plant soil and tissue analysis and the likely demand of the crop, there is a tendency to adopt a 'precautionary' approach to high value crops such as potato with rates typically in excess of demand. Figure 2 compares measured pre- and post-crop soil mineral N concentrations to a 70 cm depth for a range of crops grown in the Panatana catchment over the 2008/2009 season and suggests high residual levels of mineral N, especially after potato crops. Clearly there is potential for this surplus soil N to be lost through leaching events.

The fate of nitrogen and water in these systems is complex and influenced by a wide range of inter-dependent factors including seasonal climate, chemical and physical soil properties, crop management practices, crop sequence and the levels of residual nutrients and water carried over from previous crops. Computer simulation models which capture the key biophysical processes and the interactions between management, climate, soil and crop components provide a means to help understand how these resources move through these system, the potential for off-site nutrient loss, and to explore the potential implications of different management practices on nutrient fate.

The objectives of this study are to explore via model simulation:

(1) the impact of current management practices on the N balance under intensive vegetable-based cropping and dairy systems;
(2) enhance the understanding of the potential for N loss to ground water, and;
(3) identify feasible and viable practices for reducing N loss.

Figure 1.
Monthly rainfall totals for Devonport Airport (average 1889–2009).



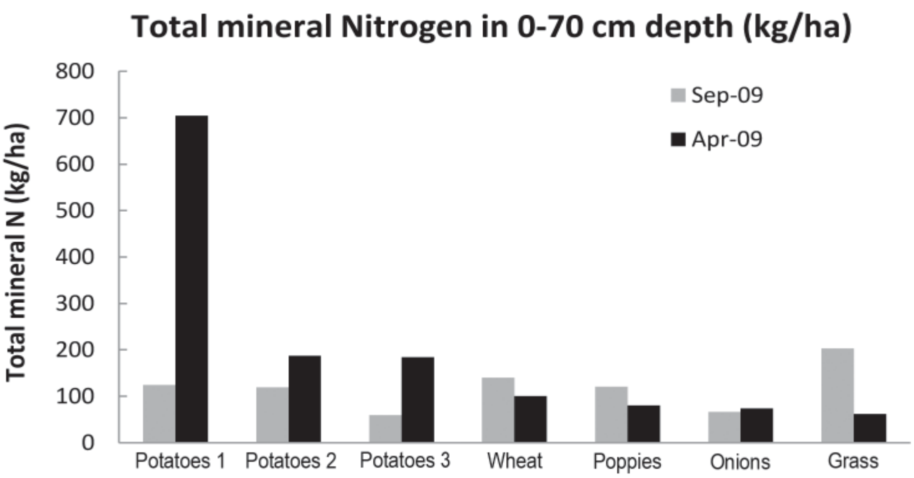


Figure 2.
Pre- (grey bars) and post- (black bars) crop soil mineral N contents to 70cm depth for a range of crops grown in the Panatana catchment over the 2008/2009 season.

Method

Collection of baseline farmer information/data

The study was based on 8 farms selected to represent the typical range of soil, crop and management practices prevailing across the Panatana catchment. The 8 farms include 7 crop-based operations and 1 dairy operation (the only dairy in the catchment). A variety of farm management, soil and climate information was collected for each farm for the purposes of: a) understanding the farming systems in question; b) calibrating/validating the APSIM (Agricultural Production Systems Simulator, Keating et al 2003) and DairyMod (Johnson *et al.* 2008) modelling tools and; c) developing performance baselines against which to compare alternative management practice.

Interviews were conducted with each farmer to collect key management details relating to crop sequence, cultivar selection, crop establishment (e.g. sowing date, seeding rate), nutrient management, irrigation management, tillage practices and residue management. Farmers were also asked to provide estimates for crop yield to enable comparison with simulated values.

One soil on each farm was fully described and characterised to a depth of ~120cm. Drained upper limit (DUL) was determined during winter following a period of significant rainfall and subsequent period of drainage. Samples were collected at this time for gravimetric determination of moisture content and bulk density across at least 4 soil layers. Crop lower limit (CLL) was also determined gravimetrically from samples collected post harvest in late summer. Samples were also collected for laboratory-based chemical analysis of pH, organic carbon, electrical conductivity and nutrient content (i.e. mineral N, Ca, Mg, Na, K, ESP) via the CSBP Soil and Plant Laboratory in Perth (Wesfarmers).

Long-term daily temperature, radiation and rainfall data for the Devonport (41.7°S, 147.1°E) was sourced from the SILO database (www.bom.gov.au/silo). This station is within 10km of the case study farms and is assumed to adequately represent the climate characteristics of the farm.

APSIM modelling of crop-based farms

Data/information collected from the crop-based farms (Farm 1–7, Appendix B) during the benchmarking activity was subsequently used to calibrate and parameterise the farming system model APSIM.

APSIM (version 6.1) simulates agricultural production systems by combining modules describing the specific processes within the system under investigation. In this study, the soil water module SoilWater (Probert *et al.* 1997), the soil nitrogen module SoilN (Probert *et al.* 1997), and the surface residue module SurfaceOM (Probert *et al.*, 1997) were linked with a range of crop modules relevant to the farming systems in the study area. Each of these crop modules simulate growth and development in response to climatic, soil and management inputs. For crops not currently captured within the APSIM framework, surrogate crops were used (i.e. navy-bean for fresh bean, broccoli for cauliflower). New APSIM crop models were used to simulate potato (Ridwan-Saleh 2009) and poppy (Lisson 2006) growth and production. Irrigation design and management attributes are simulated via the Irrigate and WaterSupply modules. All other management details are specified via the Manager module. For comprehensive descriptions of each of these modules see the relevant link in the APSIM website: www.apsim.info/apsim.

For the purposes of these simulations, pivot based irrigation equipment (i.e. low pressure overhead) were assumed to have a delivery efficiency of 90% (BSES 1998). That is, 90% of applied irrigation enters the root zone and is available for crop uptake (i.e. effective irrigation). Traveller based systems were assumed to have a delivery efficiency of 70%.

For each farm, a series of model runs offset by one year were conducted such that each element of the crop rotation was simulated in every year of the 26-year period from 1980 to 2005. This is based on the assumption that in any given year, most farmers will have each element of the rotation represented (in different paddocks). The 26 year simulation period enables consideration of long-term system impacts (i.e. carry-over from year to year) and the effects of seasonal climate variability.

'Ground truthing' of model performance was based on comparisons between model and farmer estimates of yield. For crops such as broccoli and poppy, where the model does not simulate yield, comparisons were made between simulated and published regional above-ground biomass figures. It should be noted that APSIM has been extensively validated in other systems interstate and overseas and there is no reason to suspect that the underlying principles upon which it is based are any different in this new environment. Return visits were made to each farm to clarify management/design details and to confirm that model estimates for yield and water usage were in reasonable agreement with farmer expectations.

DairyMod modelling of the dairy farm (Farm 8, Appendix B)

DairyMod is a biophysical pasture-simulation model for Australian grazing systems (Johnson *et al.* 2008). It includes modules for pasture growth and utilisation by grazing animals, water and nutrient dynamics, animal physiology and production and a range of options for pasture management, irrigation and fertiliser application. Up to 100 independent paddocks can be defined which can have different soil types, nutrient status, pasture species, fertiliser and irrigation management, but are subject to the same climate. Management options include commonly used rotational grazing management strategies and continuous grazing with fixed or variable stock numbers. The model also incorporates a range of rotational grazing management strategies that are used in Australia and includes options for conserving pasture.

The irrigation options allow irrigation in response to plant water status, soil water deficit, rainfall deficit (difference between accumulated potential evapotranspiration and rainfall), as well as regular intervals or specified dates. For each of these strategies, the amount of water, or target soil water content can be prescribed, as well as rules for the timing of irrigation within the day and throughout the year. The focus in this study was on nitrogen and the nutrients phosphorus (P), potassium (K) and sulfur (S) were considered to be non-limiting.

Model simulations were run over the whole farm using the climate data from 1970–2008.

Analyse the impact of current farming practice on the nutrient and water balances.

Analysis of model output from the baseline runs for each farm was used to quantify the extent of water and nitrogen leakage from these systems and to better understand the mechanism and source of these losses. The final step was to identify and analyse a number of practicable, alternative management options that have the potential to reduce nutrient and water loss while maintaining productivity.

Results and discussion

Case farm management

Key management details for the 8 case farms are summarised in Appendix B. Rotations for the 7 crop-based farms are comprised of up to 5 annual crops including a range of vegetable crops (i.e. potato, broccoli, fresh pea, green bean), poppy and wheat. All rotations on these crop-based farms have a pasture phase of between 2–6 years in duration and fodder ryegrass is commonly grown in-between summer crops to reduce drainage and to provide valuable winter feed for stock.

For most crops and on most farms, nitrogen fertiliser is typically applied at sowing and as a top-dressing later in the season. While fertiliser application rates are often prescriptive, most farmers utilise pre-season soil testing and in-season tissue nutrient results to modify their regimes. The highest N fertiliser application rates are for potato with up to 479 kg N/ha applied across basal and top-dress applications (Farm 3, Appendix B). The one dairy farm operation applies 100 kg N/ha/yr as fertiliser plus an additional 230 kg N/ha/yr in the form of supplementary grain feed.

All farms use irrigation water sourced from on-farm dams and river resources to offset summer deficits. Most of the farmers have made (or are in the process of making) the transition from high pressure traveller delivery equipment to low pressure overhead technology. Just one of the eight farmers uses soil moisture monitoring to schedule irrigation. The remaining farmers operate fixed schedules delayed only when water runs out or when there are significant rainfall events prior to the scheduled irrigation event. The highest application rates are for potato with up to 28 irrigation events of 15 mm each (Farm 7). The dairy farm applies approximately 16 irrigation events of 35 mm at regular 10 day intervals over the November–February period. Across all farms there is a focus on minimising tillage and, where possible, retaining crop residues in order to maintain soil health and nutritional status.

Soil characteristics

Key soil physical and chemical characteristics are summarised in Appendix A.

Comparison of model versus observed yield/biomass estimates

There was acceptable agreement between simulated yield and the estimates provided by farmers for each of the crop types (Table 1). In the case of broccoli and poppy, APSIM does not simulate yield so comparisons were made between modelled and published (total above ground) biomass values for crops grown under similar conditions.

Crop water use and supply

Simulated water and nitrogen balance component results are summarised in Appendix C. Crop water supply, which is the sum of effective (i.e. that portion of rainfall that enters the profile) rainfall + effective irrigation, exceeds crop water use (i.e. soil water evaporation + transpiration) for all crops grown across the 7 crop-based farms (Figure 3). The surplus is greatest for crops (i.e. pasture, wheat and ryegrass) that span the winter months when rainfall totals are highest and ET losses are low.

Drainage

The surplus between crop water supply and crop water use results in substantial average seasonal drainage figures for each crop (Figure 4). While the highest losses occur for the over-wintering elements, leakage from summer crops still exceeds 100 mm, attributable to the large irrigation volumes

*Table 1. Comparison of model yield and biomass estimates (range shown from 1980 to 2005) with measured farmers and published estimates (*Chung, 1986, **Boersma 2009).*

Crop	Farmer/published estimate	Model estimate
Potato (FW tuber/ha)	55–65	58–65
Bean (t bean/ha)	14–18	13–19
Pea (t grain/ha)	4–7	6.1–6.8
Maize (t silage/ha)	12–20	21
Wheat (t grain/ha)	4–6	4.2–4.8
Poppy (t biomass/ha)	6–12*	6.6–10.8
Broccoli (t biomass/ha)	6–11**	6.2–11
Irrigated dairy pasture (t biomass/ha)	14–16	12.5–16.6

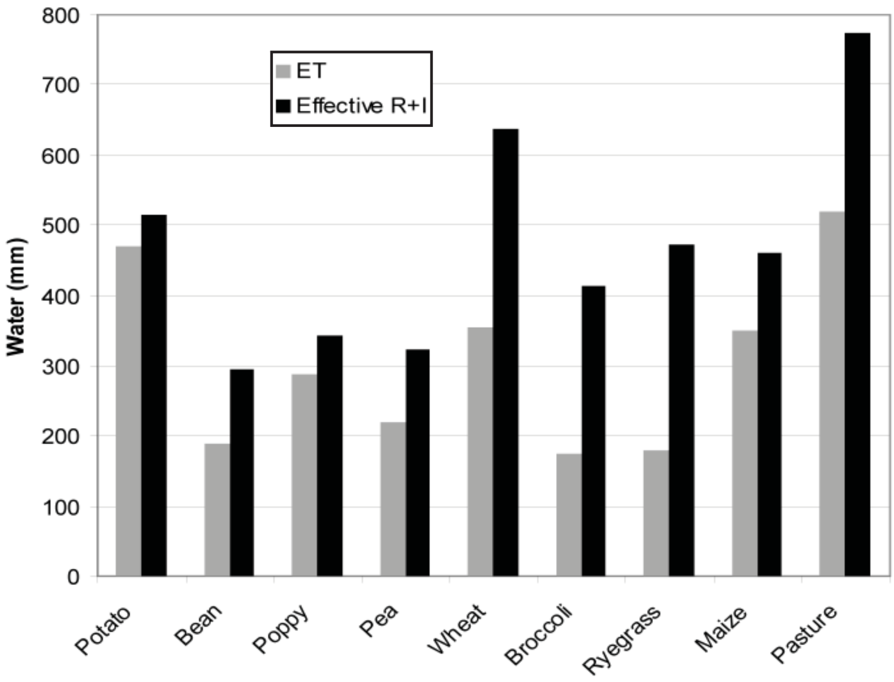


Figure 3.
Seasonal crop water use (evapo-transpiration, grey bars) and crop water supply (effective rainfall + effective irrigation, black bars). Results are averages calculated across all 7 crop-based farms and all years of the simulation period (1980–2005)..

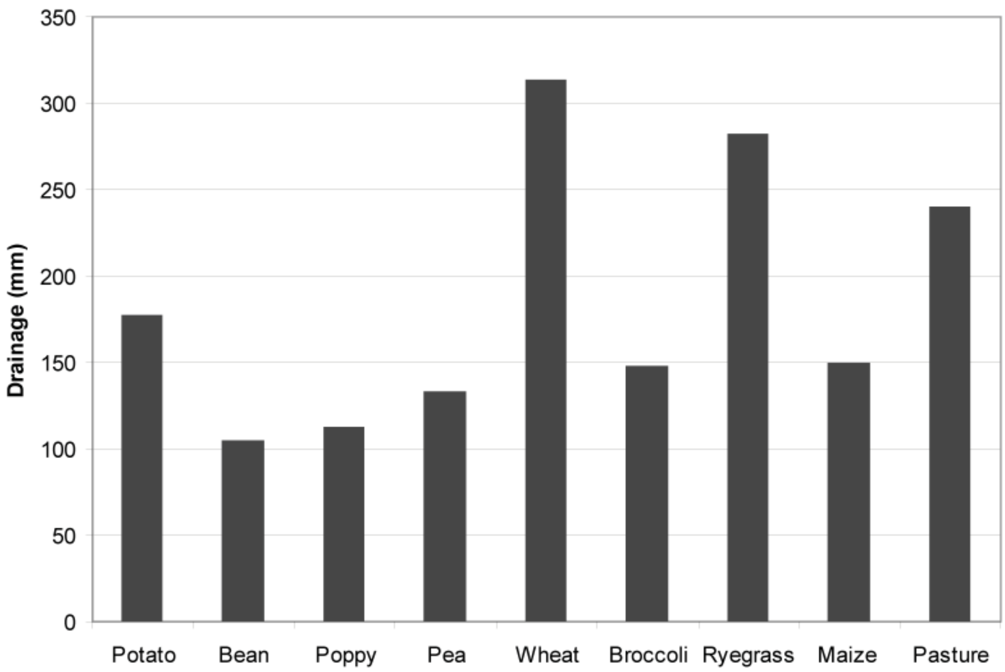


Figure 4.
Seasonal average crop drainage for each crop. Results are averages calculated across all 7 crop-based farms and all years of the simulation period (1980–2005).

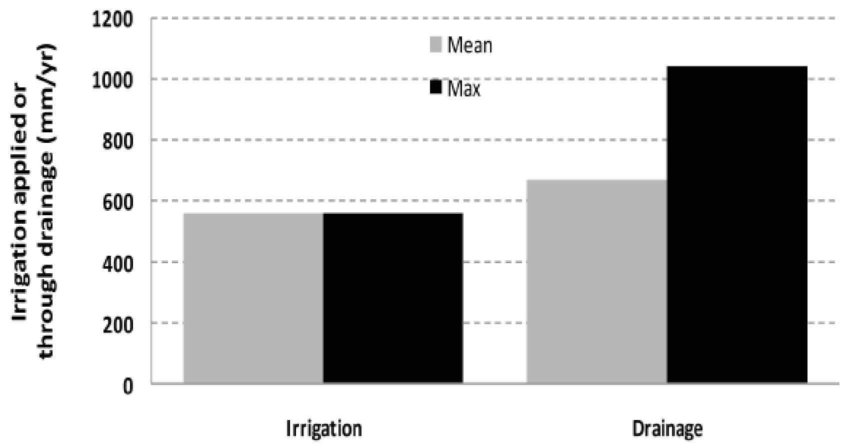


Figure 5.
Irrigation and drainage on the dairy farm. Results are averages calculated across all years of the simulation period (1960–2008).

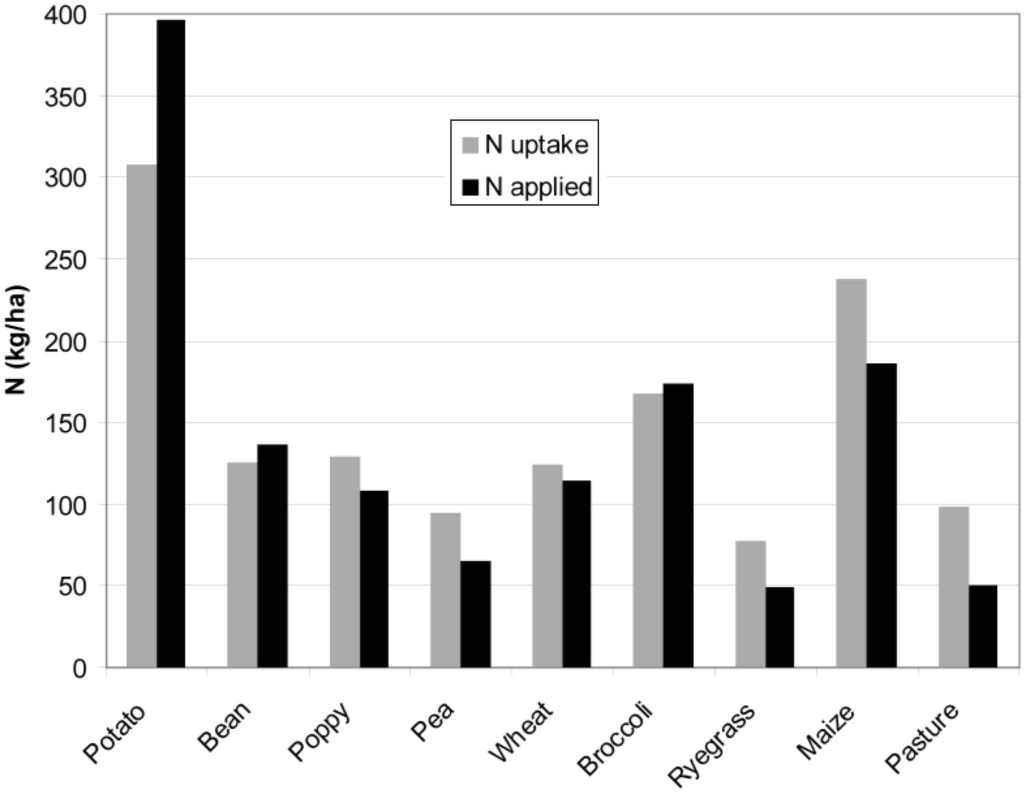


Figure 6. Seasonal crop nitrogen uptake (grey bars) and crop nitrogen supply (i.e. fertiliser N + nitrogen fixed in the soil, black bars). Results are averages calculated across all 7 crop-based farms and all years of the simulation period (1980–2005).

that are applied and the absence of deficit based irrigation scheduling. By comparison, the irrigation and drainage results for the dairy farm (Figure 5) are much higher than those for any of the crops shown in Figure 4.

Crop nitrogen demand and supply

Crop N demand is close to crop N supply (i.e. fertiliser N + soil nitrogen fixation) for all rotation elements with the exception of potato (Figure 6). For crops where demand exceeds supply, the deficit is met by soil mineral N reserves (i.e. pre-existing or mineralised over the life of the crop). Where supply exceeds demand, the deficit is carried over in the soil to the following season and should be taken into account when determining fertiliser rates.

Simulated potato crop N uptake (i.e. total biomass N) across the 6 case farms growing potato, range from 4.20 kg N/t FW tuber to 5.52 kg N/t FW tuber (average 1980–2005). These values compare favourably with previously published N uptake figures for potato crops grown under similar conditions in NW Tasmania i.e. 5.13 and 4.59 kg N/t FW tuber

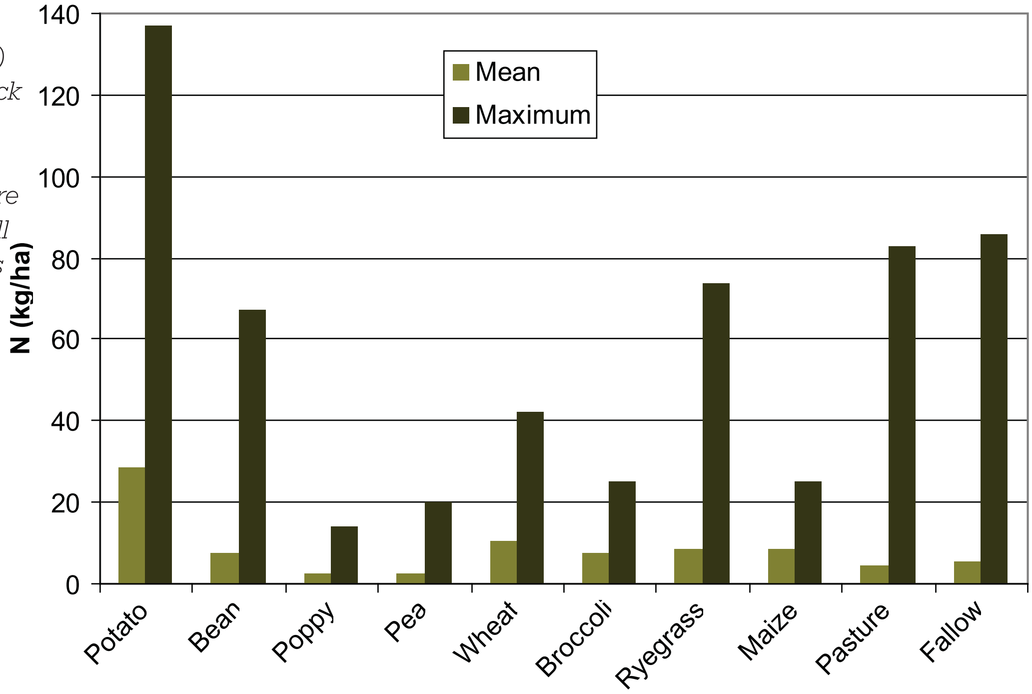
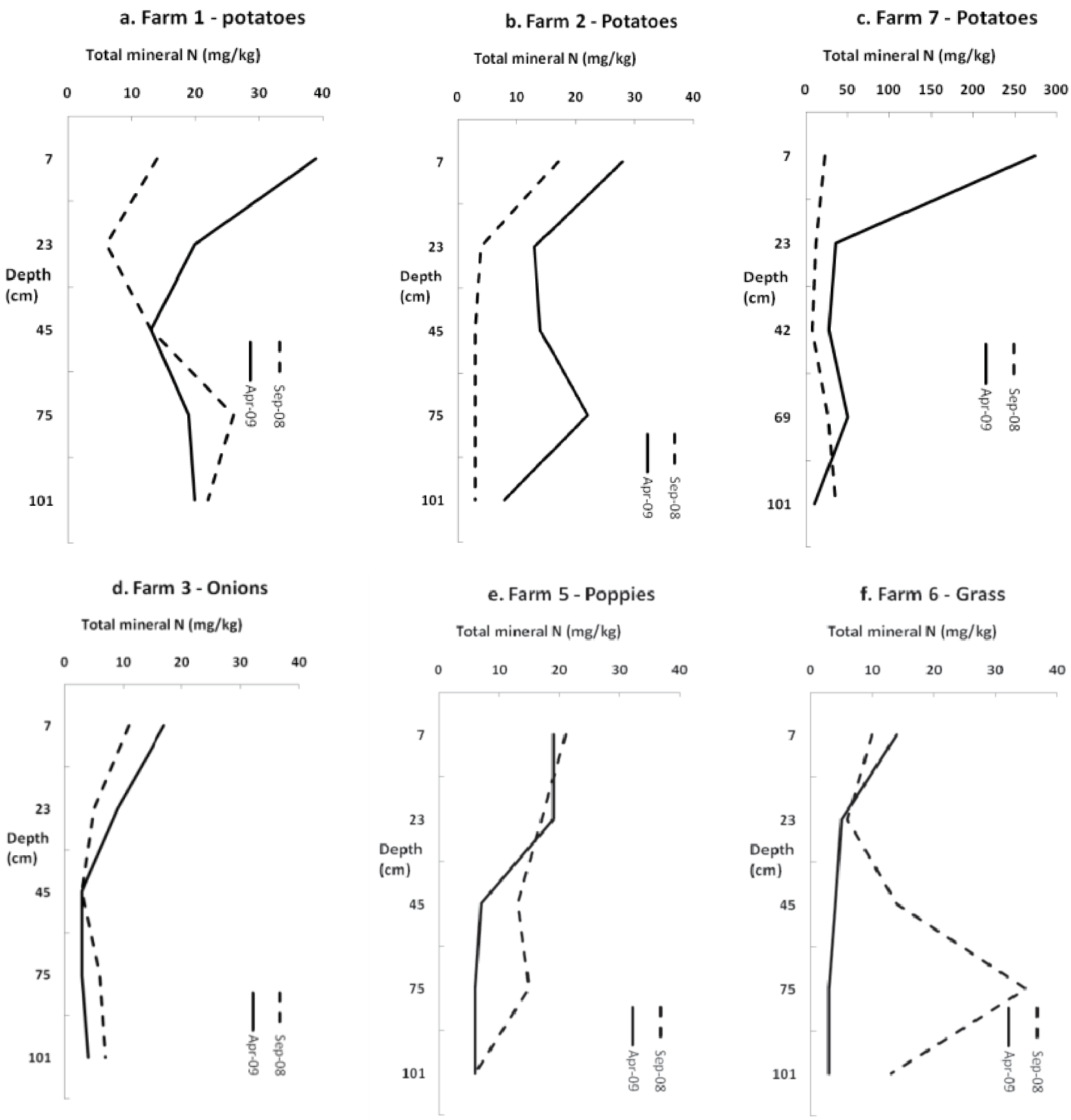


Figure 7. Seasonal, average (grey bars) and maximum (black bars) N loss via leaching below the root zone. Results are calculated across all 7 crop-based farms and all years of the simulation period (1980–2005).



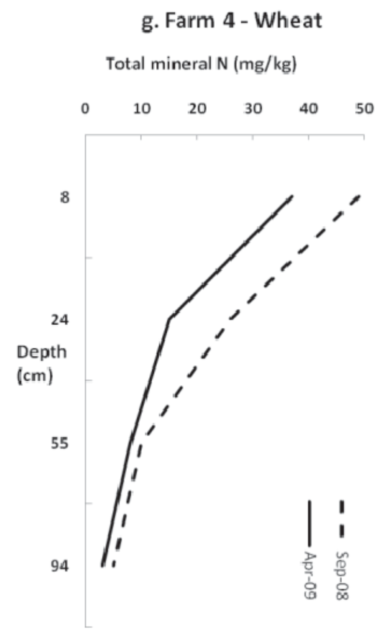


Figure 8. Soil mineral N concentration (mg/kg) before and after the 2008–2009 growing season..

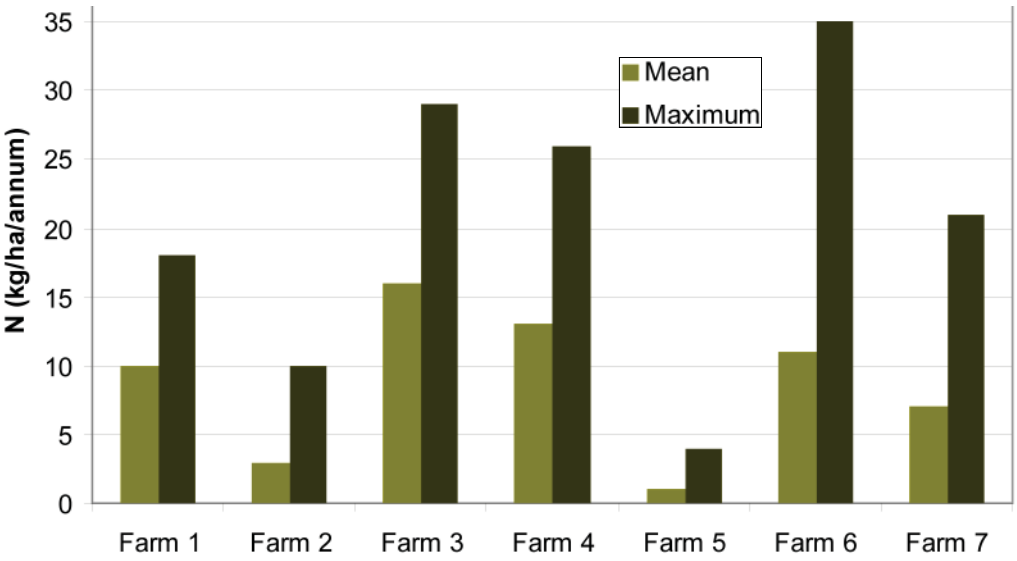


Figure 9. Whole farm average (light green bars) and maximum (dark green bars) N loss via leaching below the root zone for the crop-based farms. Results are calculated across all years of the simulation period (1980–2005).

(ServeAg 2007). When averaged across all farms and years, modelled seasonal N uptake is 308 kg N/ha and total N supplied as fertiliser is 397 kg N/ha. This gives an average surplus N supply for potato crops of 89 kg N/ha (Figure 6). Any mineralisation of N that occurs within the soil over the course of the season will add further to this surplus.

Simulated nitrogen leached from the root zone

Figure 7 shows modelled average and maximum seasonal N lost through leaching, calculated across all crop-based farms and years of the simulation period. Not surprisingly, given that it has the highest crop nitrogen surplus, potato is the 'leakiest' of all crops with an average loss of 29 kg N/ha, compared with <10 kg N/ha for all other crops. The maximum N loss figures shown in Figure 7 illustrate the extent of spatial and temporal variability in seasonal N leaching loss, and the potential for substantial seasonal N leaching losses from all elements of the rotation. For example, heavy rainfall following fertiliser application may lead to high losses in some years.

Measured pre- and post-season soil N concentrations

The measured soil mineral N concentrations before and after the 2008/2009 cropping season (Figure 8) show that potato crops left a considerable residual of soil N after the crop (Figure 8 a, b & c) with the excessive soil N values on farm 7 due to supplementary fertiliser applied prior to the following crop. It is also evident that a 'bulge' of mineral N is in the soil at 70 cm depth which is below the potential root zone (60 cm). Soil N concentrations in surface soils are much more closely aligned pre and post cropping season (Figures 8d, e, f and g). A subsoil 'bulge' in N is evident on 2 of the sites (Figures 8e and f) which is below the potential root zone and is likely to have been leached over subsequent winter rainfall events.

Whole-farm N loss

By aggregating APSIM model results from the off-set runs for each crop (i.e. paddock) for each year of the simulation period, it is possible to come up with an estimate for the annual 'whole farm' N loss through leaching from the crop-based farms (Farms 1–7, Figure 9). These results illustrate the substantial variability in N leakage across the case farms with average N loss ranging from 1 to 16 kg N/ha and maximum loss from 4 to 35 kg N/ha. There are many factors which influence the whole farm N loss including soil physical characteristics (e.g. water holding capacity), paddock history/crop sequence, crop management (e.g. fertiliser and irrigation) and seasonal climate variability. For example, Farm 3 has the highest N loss for the crop-based farms, attributed to having the lowest soil water holding capacity of all farms coupled with high rates of N fertiliser (e.g. 480 kg N/ha for potato). In contrast, Farm 5 has the lowest N loss for the crop-based farms, a high soil PAWC and no potato in the crop rotation.

The simulated, average whole-farm N loss from the dairy operation of 132 kg N/ha (max 203 kg N/ha) far exceeds that from any of the crop-based farms due to much higher irrigation rates (560 mm/year), high N input rates (330 kg N/ha) and drainage rates (670 mm/year).

While the N loss figures for the crop-based farms are comparable to catchment-scale N generation estimates recorded in other research undertaken in

Table 2. Results for alternative potato management on Farm 3 and current management on Farm 1.

Scenario	Baseline (current)	+ Deficit-based irrigation scheduling	+Deficit-based irrigation + reduced N	Farm 1
Basal N (kg N/ha)	215	215	100	154
Topdressing (kg N/ha)	5 X 54kg N as urea	5 X 54kg N as urea	5 X 37kg N as urea	5 X 80kg N as urea
Irrigation (mm)	260	174	172	198
Minimum interval (days)	11	5	5	5 (deficit based)
Amount per event (mm)	26	13	13	13
Drainage (mm)	135	52	51	57
N leached (kg N/ha)	53	6	3	1
Tuber yield (tFW/ha)	56	56	56	63
Fertiliser cost ($/ha)*	1782	1782	1157	–
Irrigation cost ($/ha)**	377	252	249	–

* *Assuming basal fertiliser cost of $550/t DAP (18% N) = $3.06/kg N as DAP, topdress fertiliser cost of $620/t urea (46%N) = $3.40/kg N as urea, fertiliser application cost of $50/ha DAP (basal) and $35/ha urea (top-dress). Source: David Addison.*

** *Assuming irrigation water cost of $100/ML and irrigator operating cost of $45/ML.*

Landscape Logic (~17 kg N/ha/year, Figure 10), the corresponding dairy farm N loss figures (132 kg N/ha/yr) are far greater than the catchment scale estimates for dairying (~25 kg N/ha/annum; Figure 9) (Broad 2008).

Options for reducing nitrogen loss in the crop-based farms

The above results indicate that of all the crops grown, the highest average rate of N loss occurs under potato. Similarly, of the 7 crop-based farms, Farm 3 exhibits the highest rate of average N loss but these losses are much less than those from the dairy operation. With this in mind, some exploratory 'what if?' modelling was conducted to explore the potential impacts of various management options for reducing N loss from the potato crop of Farm 3 and from the dairy operation (Farm 8).

The first scenario for Farm 3 involved the introduction of deficit-based irrigation and a schedule involving the application of less irrigation more often (Table 2). That is shifting from the current management of applying 26 mm (effective irrigation) at fixed 11 day intervals to a schedule where irrigation (13 mm effective irrigation) is applied once the soil water deficit reaches 13 mm (at no less than 5 day intervals). These changes acted to reduce the average seasonal drainage (across 7 seasons) from 135

Table 3. Summary of dairy model outputs under current practice plus alternative management practices. Figures are long-term averages calculated from 1960–2008 (ranges are shown in parentheses).

	Baseline (current)	+ Deficit-based irrigation scheduling	+ Deficit-based irrigation + N scheduling	+ Deficit-based irrigation + N applied every rotation
Fertiliser N (kg/ha/y)	100	100	147 (96–214)	310
Supplementary feed (t DM/ha/y)	8	8	7.7	7.6
Irrigation (mm/y)	560	270 (133–388)	275	280
Drainage (mm/y)	670 (273–1042)	378	377	376
N leached (kg N/ha/y)	132 (66–203)	116 (30–218)	113 (29–213)	239 (50–404)
Pasture utilized (t DM/ha/y)	14.8	14.9	15.8	15.9

mm to 52 mm and N loss below the root zone from 53 kg N/ha to 6 kg N/ha while maintaining crop yield at 56 t FW/ha.

Variable irrigation costs (i.e. water cost plus irrigator operating) will vary substantially between farms depending on the source (i.e. farm dam, river, bore) and type of irrigator equipment. For the purposes of this analysis, water cost was assumed to be $100/ML and irrigator operating costs $45/ML. Based on these figures the financial saving in shifting to a deficit based system equates to approximately $125/ha. Of course, this saving will need to be balanced against increased fixed costs associated with new irrigation infrastructure (e.g. soil moisture monitoring equipment).

Given the apparent surplus of fertiliser N applied to potato crops on these farms and the reduction in N loss associated with the introduction of deficit-based irrigation, the second scenario involved reducing fertiliser N rates – the basal rate from 215 kg N/ha to 100kg N/ha and the topdress rates from 115 kg urea/ha to 80 kg urea/ha. These changes led to a substantial savings in fertiliser cost of $525/ha, a small reduction in N loss down to a negligible 3 kg N/ha, but importantly did not result in any reduction in yield. Obviously these impacts are site specific and will vary with season, soil type and paddock history. However, they serve to illustrate the potential for these simple, feasible management changes to generate financial savings via reduced input costs and reductions in offsite N loss, while maintaining current levels of productivity.

The practicality of these changes in potato management are illustrated by current management practice on Farm 1 (Table 2). The manager of this farm has already shifted to a deficit based (sprinkler system) similar to that described in scenario 2. While still applying surplus levels of N fertiliser, he has also opted to reduce the basal N fertiliser rate and spread the remaining N across 5 separate topdress events. Modelling of this farm indicates that average N loss is just 1 kg N/ha and drainage losses 57 mm for a yield of 63t/ha.

Options for reducing nitrogen loss on the dairy farm

As for the crop-based farms, the first scenario considered for the dairy farm involved the introduction of deficit-based irrigation or shifting from the current management of applying 31.5 mm (effective irrigation) at fixed 10 day intervals to a schedule where irrigation is applied to replenish 90% of the soil's field capacity, once the soil water deficit (rainfall – potential evapotranspiration) reaches 15 mm. This resulted in a mean irrigation application total of 270 mm/y. These changes acted to reduce the average seasonal drainage from 670 mm to 378 mm and N loss below the root zone from 132 kg N/ha to 116 kg N/ha while maintaining pasture yield at ~15 tDM/ha/y (Table 3). The second scenario incorporated scheduling N fertiliser application to when the pasture was in N deficit during peak growth periods i.e. spring and early summer, with scheduled irrigation. This scenario requires additional N fertiliser to be applied compared to current management, but the scheduling of application to plant demand resulted in a reduced potential for N leaching. The third scenario incorporated application of 30 kg/ha N fertiliser after each pasture grazing with scheduled irrigation. This practice is currently practiced on some dairy farms in Tasmania, particularly pasture based feeding regimes, but results in potential extremely high levels of N leaching of 239 kg N/ha.

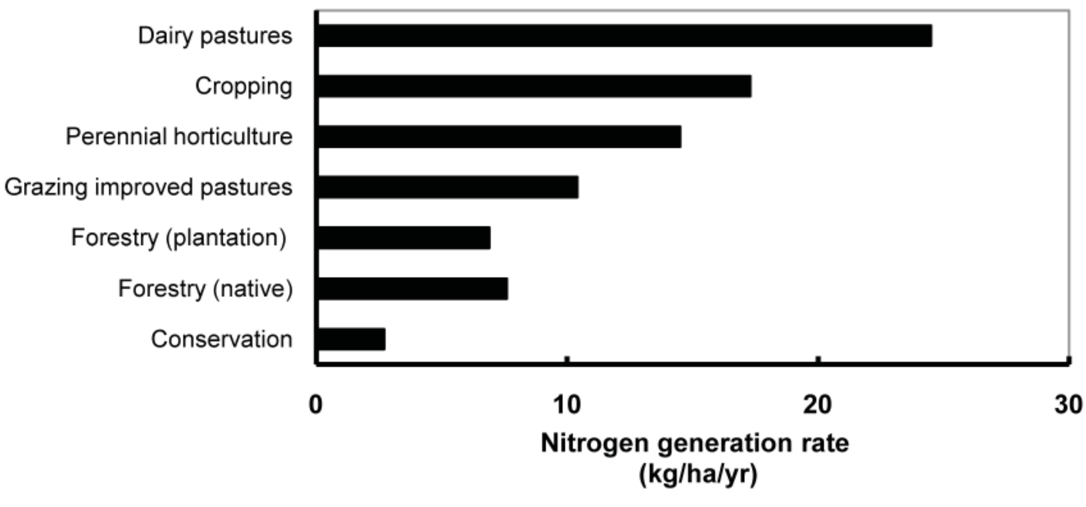


Figure 10. Catchment scale nitrogen generation rates for a range of land uses in Tasmania (Broad 2008).

Conclusions

Crop water supply (i.e. effective rainfall + effective irrigation) exceeds crop water use (i.e. soil water evaporation + transpiration) for all crops grown across the 7 crop-based farms;

The surplus between crop water supply and crop water use results in substantial (i.e. >100 mm) average seasonal drainage figures for each crop;

Crop N demand is close to crop N supply (i.e. fertiliser N + soil nitrogen fixation) for all rotation elements with the exception of potato which has an average surplus of 89 kg N/ha;

Surplus soil N should be taken into account when determining fertiliser rates for following crops in the rotation;

Potato is the 'leakiest' of all crops with an average loss of 29 kg N/ha (up to 4X greater than other crops);

The potential exists for substantial seasonal N leaching losses from all elements of the crop rotations;

Whole-farm N loss from the dairy operation (up to 203 kg N/ha) far exceeds that from any of the crop-based farms (up to 35 kg N/ha) due to much higher irrigation rates (560 mm/y), N input rates (330 kg N/ha) and drainage rates (670 mm/y);

Modelled farm N loss rates for the dairy farm are much greater than catchment scale estimates for dairying (~25 kg N/ha/year) while the corresponding loss rates for intensive cropping are comparable;

Practicable management options such as deficit-based irrigation and reduced N fertiliser rates have the potential to generate significant financial savings via reduced input costs and reductions in offsite N loss, while maintaining current levels of productivity.

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Appendix A: Soil descriptions

Case Farm 1

Grid reference: 457265E 5434871 N
Australian Soil Classification: Brown Dermosol
General Landscape Description: Irrig potatoes
Site Description: Gently sloping plain
Geology: Alluvium

Soil Profile Morphology

A11	0–15 cm	Very dark brown (10YR2/2); Heavy clay loam; moderate fine subangular blocky structure; moderately weak consistence (moist); few medium iron/manganese nodules; abrupt smooth boundary.
A12	15–27 cm	Very dark brown (10Y2/2); Light clay; moderate fine & medium s angular blocky structure; moderately weak consistence (moist); common medium iron/manganese nodules; sharp smooth boundary.
B2g1	27–51 cm	Yellowish brown (10YR5/4); Heavy clay; massive parting to weak medium subangular blocky structure; very firm consistence (moist); very few fine distinct reddish brown (5YR4/6) & very few medium faint light brownish grey (10YR6/2) mottles; abrupt smooth boundary.
B2g2	51–87 cm	Yellowish brown (10YR5/4); Heavy clay; massive parting to weak medium subangular blocky structure; very firm consistence (moist); many coarse prominent light brownish grey (2.5Y6/2) mottles; common distinct slicken sides; gradual smooth boundary.
Cg	87–120+ cm	Grey (2.5Y6/0); Heavy clay; massive; very firm consistence (moist); common medium prominent brownish yellow (10YR6/6) mottles; common distinct slicken sides.

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Ca	Mg	K	Na	Total	PBI
																Meq/100g					
A11	0–15	1.48	0.31	0.39	0.08	6.3	5.5	0.07	2.33	0.20	7	7	112	354	9.2	10.2	2	0.21	0.75	12.52	360
A12	15–27	1.46	0.26	0.38	0.12	6.1	5.2	0.07	1.85	0.17	3	3	41	355	15.2	9.18	2.8	0.29	0.74	13.01	596
B2g1	27–51	0.95	0.16	0.55	0.39	6.2	5.5	0.29	0.76	0.11	9	4	6	63	14.3	16.6	13.43	0.64	0.16	30.86	840
B2g2	51–87	0.97	0.39	0.57	0.18	5.6	5.1	0.39	0.43	0.07	22	4	2	85	59.1	11.03	18.75	0.67	0.18	30.63	818
Cg	87–120	1.04	0.60	0.54	0	5.1	4.4	0.23	0.31	0.06	19	3	1	79	23.2	6.57	16.17	0.62	0.17	23.53	306

** PAWC = (DUL-CLL bar) x100*

Case Farm 2

Grid reference: 455520E 5432689N
Australian Soil Classification: Red Ferrosol
General Landscape Description: Irrig potatoes
Site Description: Gently sloping low hills
Geology: Basalt

Soil Profile Morphology

A1	0–24 cm	Dark brown (7.5YR3/4); Clay loam; Moderate medium angular blocky parting to strong very fine subangular blocky structure; moderately firm consistence (moist); very few subangular gravels; abundant very fine roots; many white fungal masses; sharp smooth boundary.
B1	24–45 cm	Yellowish red (5YR4/6); Light clay; strong medium subangular blocky plus moderate very fine subangular blocky structure; moderately weak consistence (moist); many very fine roots; many white fungal masses; abrupt smooth boundary.
B2	45–88 cm	Red (2.5YR4/6); Light medium clay; moderate medium subangular blocky parting to weak very fine subangular blocky structure; moderately weak consistence (moist); few very fine roots; clear wavy boundary.
B3	88–120 cm	Yellowish red (5YR4/6); Medium clay; moderate medium subangular blocky structure; moderately firm consistence (moist); many coarse faint dark red (2.5YR3/6) mottles; few subangular gravels.

Horizon	Horizon Depth cm	Bulk density Mg/m³	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Ca (Meq/100g)	Mg	K	Na	Total	PBI
A11	0–15	1.40	0.37	0.36	0	5.7	5	0.07	4.31	0.30	7	10	259	291	9	10.6	1.67	0.64	0.2	13.13	529
A12	15–24	1.40	0.37			5.8	5	0.06	2.66	0.20	1	3	68	151	16.1	7.66	1.03	0.32	0.16	9.07	499
B1	24–45	1.50	0.29	0.35	0.06	5.3	4.7	0.08	1.16	0.09	1	2	12	79	31.3	3.78	0.54	0.18	0.12	4.62	1792
B21	45–88	1.21	0.42	0.42	0	4.9	4.2	0.09	0.36	0.03	1	2	6	59	166	3.6	0.38	0.13	0.19	4.30	1351
B22	88–120	1.18	0.50	0.46	0	4.9	4.3	0.10	0.57	0.07	1	2	5	54	136	4.51	0.53	0.14	0.21	5.39	17

** PAWC = DUL-CLL*

Case Farm 3

Grid reference: 439807E 5447259N
Australian Soil Classification: Aeric Podosol
General Landscape Description: Irrigated cropping
Site Description: Rolling low hills
Geology: Tertiary sediments

Soil Profile Morphology

A11	0–14 cm	Black (10YR2/1); Loamy sand; weak fine subangular blocky structure; moderately weak consistence (moist); common very fine roots; abrupt smooth boundary.
A12	14–29 cm	Black (2.5Y2/0); loamy sand; massive parting to weak medium subangualr blocky structure; very weak consistence (moist); few very fine roots; sharp smooth boundary.
A21	29–43 cm	Light brownish grey (10YR6/2); Sand; single grain; very weak to loose consistence; abrupt wavy boundary.
A22	43–80 cm	Grey (10YR5/1); Sand; single grain; loose; sharp wavy boundary.
Bs	80–120+ cm	Dark reddish brown (5YR3/4); Coarse sandy loam; massive; very strong consistence (moist); few medium distinct red dark reddish brown (5YR2.5/2) mottles.

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Meq/100g: Ca	Mg	K	Na	Total	PBI
A11	0–14	1.45	0.05	0.25	0.20	5.7	4.6	0.12	2.7	0.20	7	4	229	404	20.4	6.73	0.76	0.93	0.06	8.48	63
A12	14–29	1.48	0.12	0.22	0.10	5.8	4.8	0.06	2.72	0.17	3	2	147	58	6.2	7.6	0.75	0.13	0.1	8.58	23
A21	29–43	1.69	0.07	0.11	0.04	5.8	5.1	0.03	0.1	0.01	2	1	13	14	3.2	0.75	0.07	0.02	0.03	0.87	2
A22	43–80	1.58	0.06	0.10	0.04	5.5	4.9	0.02	0	0.01	5	1	5	15	4.1	0.52	0.05	0.02	0.07	0.66	717
Bs	80–120	1.45	0.05	0.25	0.20	5.2	4.7	0.04	0.97	0.04	5	2	2	25	19.8	0.38	0.05	0.06	0.04	0.53	745

Case Farm 4

Grid reference: 459012E 5436613N
Australian Soil Classification: Black Vertosol
General Landscape Description: Dryland wheat
Site Description: Floodplain
Geology: Alluvium

Soil Profile Morphology

A11	0–16 cm	Black (2.5Y2/0); Medium clay; strong very fine granular plus moderate fine polyhedral structure; very weak consistence (moist); many very fine roots; abrupt smooth boundary.
A12	16–33 cm	Black (2.5Y2/0); Heavy clay; moderate medium polyhedral parting to moderate very fine polyhedral structure; moderately firm consistence (moist); common very fine roots; clear smooth boundary.
B2g	33–77 cm	Very dark grey (5Y3/1); Heavy clay; strong medium polyhedral structure; very firm consistence (moist); few faint clay skins; common very fine roots; gradual wavy boundary.
Cg	77–110+ cm	Dark reddish grey (5R/1); Heavy clay; massive parting to weak medium prismatic structure; moderately firm consistence (moist); many coarse prominent strong brown (7.5Y4/6) mottles; few very fine roots.

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Ca (Meq/100g)	Mg	K	Na	Total	PBI
A11	0–16	0.73	0.24	0.40	0.16	6.2	5.3	0.09	7.26	0.68	35	14	148	227	14.7	23.98	15.45	0.51	0.51	40.45	390
A12	16–33	0.99	0.36	0.43	0.07	5.8	5	0.07	4.91	0.53	17	9	98	119	7.9	20.44	10.91	0.27	0.51	32.13	375
B2g	33–77	1.06	0.39	0.51	0.12	5.8	4.6	0.04	2.15	0.22	5	5	27	76	6.5	11.92	13.97	0.17	0.4	26.46	391
Cg	77–110+	1.11	0.22	0.42	0.20	5.8	4.9	0.06	0.95	0.07	3	2	34	33	26.1	5.27	3.56	0.07	0.3	9.20	527

** PAWC = DUL-CLL*

Case Farm 5

Grid reference: 456953E 5430439N
Australian Soil Classification: Red Ferrosol
General Landscape Description: Irrig poppies
Site Description: Gently sloping low hills
Geology: Basalt

Soil Profile Morphology

A1	0–25 cm	Dark brown (7.5YR3/2); Clay loam; strong fine subangular blocky structure; very weak consistence (moist); few subangular gravels; few very fine roots; sharp smooth boundary.
B1	25–45 cm	Dark brown (7.5YR3/4); Clay Loam; strong medium subangular blocky structure; moderately weak consistence (moist); few subangular gravels; few very fine roots; abrupt smooth boundary.
B21	45–86 cm	Dark reddish brown (5YR3/4); Light clay; moderate medium subangular blocky structure; moderately firm consistence (moist); many subangular gravels; few very fine roots; clear wavy boundary.
B22	86–120 cm	Dark brown (7.5YR4/4); Medium clay; weak medium subangular blocky structure; very firm consistence (moist); common coarse distinct dark reddish brown (2.5YR3/4) plus few medium distinct yellowish brown (10YR5/4) mottles; common subangular gravels.

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Meq/100g					PBI
																Ca	Mg	K	Na	Total	
A11	0–15	0.90	0.21	0.37	0.16	6.6	6	0.17	4.95	0.36	11	10	190	189	7.1	25.0	2.87	0.42	0.22	28.47	612
A12	15–25	1.11	0.21	0.44	0.23	6.6	6	0.14	4.76	0.34	12	5	174	180	10.8	23.8	2.82	0.4	0.25	27.27	634
B1	25–45	1.08	0.30	0.41	0.11	5.8	5.1	0.11	2.07	0.19	9	4	25	35	28.4	9.85	1.58	0.1	0.2	11.73	863
B21	45–86	1.18	0.34	0.45	0.11	5.6	5	0.11	1.12	0.11	12	3	6	32	62.8	6.66	1.71	0.07	0.17	8.61	886
B22	86–120	1.26	0.37	0.51	0.14	5.6	4.9	0.10	0.47	0.06	3	3	5	30	113	3.12	4.06	0.06	0.28	7.52	1149

** PAWC = DUL-CLL*

Case Farm 6

Grid reference: 441586E 5447267N
Australian Soil Classification: Brown Dermosol
General Landscape Description: Dryland pasture
Site Description: Gently sloping plain
Geology: Alluvium
Water table at 80 cm (August)

Soil Profile Morphology

A11	0–13 cm	Dark brown (7.5YR3/4); Clay loam; strong fine subangular blocky structure; moderately weak consistence (moist); common very fine roots; abrupt smooth boundary.
A12	13–26 cm	Dark brown (7.5Y3/4); Light clay; moderate medium angular blocky structure; moderately firm consistence (moist); very few medium iron/manganese concretions; few very fine roots; abrupt smooth boundary.
B1t	26–48 cm	Dark yellowish brown (10YR4/4); Medium clay; weak medium angular blocky structure; moderately firm consistence (wet); few very fine roots; clear wavy boundary.
B2g	48–80 cm	Yellowish brown (10YR5/4); Medium clay; massive; very firm consistence (wet); common coarse prominent light brownish grey (10YR6/2) mottles; many coarse iron/manganese concretions; clear wavy boundary.
Cg	80–100+ cm	Light yellowish brown (2.5Y6/4); Heavy clay; massive; very firm consistence (wet); very few medium prominent yellowish brown (10YR4/6) mottles.

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Ca (Meq/100g)	Mg	K	Na	Total	PBI
A11	0–13	1.42	0.19	0.40	0.21	7.3	6.6	0.09	2.3	0.20	4	6	139	152	12.4	11.7	1.81	0.32	0.26	14.09	252
A12	13–26	1.55	0.23	0.38	0.15	6.2	5.4	0.06	1.76	0.16	3	3	24	26	31.9	5.3	1.06	0.07	0.33	6.80	249
B1t	26–48	1.80	0.28	0.34	0.06	6.5	5.7	0.06	0.19	0.04	11	3	6	22	23.1	2.7	1.98	0.04	0.25	4.97	280
B2g	48–80	1.53	0.28	0.47	0.19	6.2	5.4	0.07	0.36	0.05	29	6	3	37	12.1	4.9	18.65	0.08	0.66	24.29	408
Cg	80–100	1.72	0.40	0.40	0.00	6.3	5.1	0.05	0.17	0.01	8	5	2	36	10.2	6.5	22.08	0.07	1.39	30.04	248

** PAWC = DUL-CLL*

Case Farm 7

Grid reference: 457666E 5440232N
Australian Soil Classification: Red Ferrosol
General Landscape Description: Irrigated cropping
Site Description: Moderately sloping low hills
Geology: Basalt

Soil Profile Morphology

A1	0–32 cm	Dark reddish brown (5YR2.5/2); Clay loam; strong fine & medium subangular blocky structure; firm consistence (moist); common very fine roots; abrupt smooth boundary.
B1	32–58 cm	Dark reddish brown (5YR3/3); Light clay; strong medium subangular blocky structure; stiff consistence (moist); few very fine roots; clear smooth boundary.
B21	58–92 cm	Dark reddish brown (2.5YR3/4); Light medium clay; strong medium subangular blocky structure; moderately firm consistence (moist); few very fine roots; clear smooth boundary.
B22	92–120 cm	Dark red (2.5YR3/6); Light medium clay; moderate medium subangular blocky structure; moderately firm consistence (moist).

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Meq/100g Ca	Mg	K	Na	Total	PBI
A1	0–15	1.19	0.38	0.48	0.10	5.9	4.9	0.08	5.55	0.44	19	4	318	725	27.3	14.9	2.76	1.85	0.33	19.79	830
	15–32	1.06	0.32	0.45	0.13	5.9	5	0.08	5.68	0.39	7	5	51	328	31.8	14.5	2.93	0.83	0.4	18.63	951
B1	32–58	1.06	0.32	0.41	0.09	6.4	5.4	0.07	2.59	0.20	5	3	16	87	41	14.7	2.68	0.2	0.57	18.13	1016
B21	58–92	1.21	0.43	0.45	0.02	6.5	5.8	0.11	0.98	0.11	25	2	8	46	57.2	9.05	2.61	0.1	0.61	12.27	1213
B22	92–120	1.23	0.47	0.50	0.03	6.5	5.8	0.11	0.66	0.10	33	3	8	63	84.4	5.45	5.05	0.13	0.48	11.11	257

** PAWC = DUL-CLL*

Case Farm 8

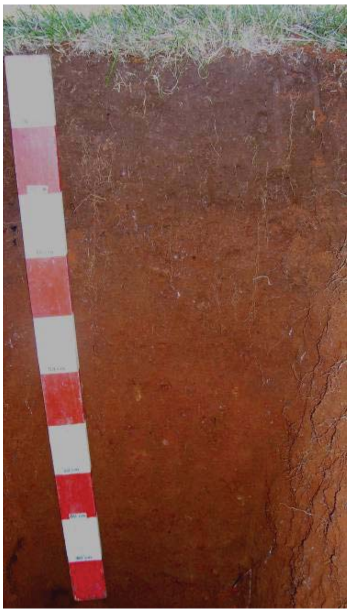
Grid reference: 458018E 5435745N
Australian Soil Classification: Red Ferrosol
General Landscape Description: Dryland pasture
Site Description: Gently sloping low hills
Geology: Basalt

Soil Profile Morphology

A1	0–21 cm	Dark reddish brown (5YR3/3); Clay loam; strong fine subangular blocky structure; moderately firm consistence (moist); many very fine roots; abrupt smooth boundary.
B1	21–40 cm	Dark reddish brown (2.5YR2.5/4); Light clay; strong fine subangular blocky structure; moderately firm consistence (moist); common very fine roots; clear smooth boundary.
B2	40–93 cm	Dark reddish brown (2.5YR3/4); Light clay; strong medium subangular blocky plus moderate fine subangular blocky structure; very firm consistence (moist); few very fine roots; gradual smooth boundary.
B3	93–120 cm	Dark reddish brown (2.5YR3/4); Medium clay; moderate coarse subangular blocky parting to weak fine subangular blocky structure; very firm consistence (moist); very few medium manganiferous soft segregations.

Horizon	Horizon Depth cm	Bulk density Mg/m^3	CLL v/v	DUL v/v	PAWC* v/v	pH water	pH CaCl2	EC dS/m	Org C %	Total N %	Nitrate N (mg/kg)	Ammon N (mg/kg)	Avail P (mg/kg)	Avail K (mg/kg)	Avail S (mg/kg)	Exchangeable Cations Ca	Mg	K	Na	Total	PBI
																Meq/100g					
A1	0–21	1.11	0.28	0.44	0.16	5.9	5.3	0.14	5.26	0.49	15	10	143	283	9.7	15.0	6.84	0.64	0.49	22.98	453
B1	21–40	1.21	0.29	0.41	0.12	5.9	5.4	0.15	1.23	0.17	6	6	24	151	60.7	7.68	2.82	0.34	0.56	11.40	638
B2	40–65	1.21	0.29	0.41	0.12	6.3	5.7	0.17	0.57	0.10	11	4	12	82	78.1	7.83	1.51	0.19	0.59	10.12	763
	65–93	1.21	0.30	0.41	0.11	6.5	5.9	0.15	0.54	0.09	12	2	9	64	65.5	7.94	1.61	0.15	0.69	10.39	1214
B3	93–120	1.24	0.35	0.48	0.13	6.6	6	0.12	0.19	0.02	3	2	11	60	72	5.77	3.2	0.14	0.55	9.66	1283

** PAWC = DUL-CLL*



Appendix B: Case study farm management details

Crops are listed in chronological order from first to last crop in the rotation. Details are based on farmer interviews.

Case Farm 1: David Addison

	Sowing	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Potatoes	October 10	1920 kg 9/16/8/4 at planting. 125kg urea/ha as topdress at 30 DAS, 50 DAS, 64 DAS, 78 DAS, 92 DAS	Deficit based Interval between events (days): 5 days Irrigation period: 30–110 DAS Amount per event: 15mm applied Equipment: solid set (potatoes only)	1 passes	Burn
Beans	December 10	500 kg/ha of 9/15/13 at sowing & 200 kg urea as topdress 30 DAS	Number irrigations: ~9 Interval between events (days): 7 days Irrigation period: <60 DAS Amount per event: 30mm applied. Equipment: LPO	2 passes	Incorporate
Ryegrass	Early April	310kg/ha 18/20/0 at planting	One event as establishment	1 pass	Spray-off
Poppies	September 10	400 kg/ha 6/19/5/1 at sowing 120 kg/ha urea as topdress (70 days after sowing).	Number irrigations: ~5 Interval between events (days): 7 days Irrigation period: 50–80 DAS Amount per event: 30mm applied Equipment: LPO	2 passes	Incorporate
Ryegrass	Mid-February	310kg/ha 18/20/0 at planting	One event as establishment	1 pass	Spray-off
Broccoli	September 10	750kg/ha 12/11/13 at planting. 125kg/ha urea as topdress (applied 40 days after sowing).	Number irrigations: ~7 Interval between events (days): 7 days Irrigation period: <42 DAS Amount per event: 30mm applied. Equipment: LPO	2 passes	Mulched for green manure
Wheat	March 1	310kg/ha 18/20/0 at planting. 125kg/ha urea as topdress (applied late September).	One event as establishment	1 pass	Incorporated
Pasture (2 years)	March 30	Nil	One irrigation at establishment of 30mm applied (24mm effective). Equipment: gun	1 pass	Grazed and sprayed off at end.

Case Farm 2: Robert Addison

	Sowing	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Potatoes	October 1	500kg/ha 9/15/13 pre-sow 1400kg/ha 9/15/13 at sowing 500kg/ha urea split across 5 topdressings (30, 45, 60, 90, 120 DAS) Muriate of potash – 125kg/ha	Number irrigations: ~9–10 Interval between events (days): 8 days Irrigation period: 30–110 DAS Amount per event: 35mm applied (26mm effective) Equipment: gun	2 passes	Burn
Peas	September 10	400kg/ha of 3:15:13	Irrigation 'season': 50–100 DAS Number irrigations: 3–4 Interval between events (days): 14 days Amount per event: 35mm Equipment: gun	2 passes	Incorporate
Ryegrass	April 1	310kg/ha 18/20/0 at planting	25mm at establishment	Direct drill	Spray-off
Poppies	September 10	370kg/ha 14/16/11 at sowing 100kg/ha urea as topdressing (70 DAS).	Irrigation 'season': 50–80 DAS Number irrigations: 4 Interval between events (days): 14 days Amount per event: 35mm Equipment: gun	2 passes	Incorporate
Pasture (3 years)	March 30	15kg N/ha at establishment. 100kg/ha urea on September 1 each year	One irrigation at establishment of 30mm applied (24mm effective). Equipment: gun	1 pass	Grazed and sprayed off at end.

Case Farm 3: Shane Radford					
	Sowing	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Wheat	March 1	310kg/ha 18/20/0 at planting. 125kg/ha urea as topdress (applied late September).	One event as establishment and one October. Amount per event: 30mm applied (26mm effective) Equipment: LPO	1 pass	Incorporated
Ryegrass	Early April	310kg/ha 18/20/0 at planting	One event at establishment	One pass	Spray-off
Potatoes	October 1	1655kg/ha of 13/3/19/11 575kg/ha urea split across 5 topdressings (30, 45, 60, 90, 120 DAS)	Number irrigations: 11 Interval between events (days): 11 days Irrigation period: 30–135 DAS Amount per event: 30mm applied (26mm effective) Equipment: LPO	2 passes	Incorporate
Ryegrass	Early April	310kg/ha 18/20/0 at planting	One event at establishment	One pass	Spray-off
Poppies	September 15	250kg/ha 14/16/11 at sowing in 2002 125kg/ha urea as topdressing (80 days after sowing)	Number irrigations: 3–4 Interval between events (days): 14 days Irrigation period: 50–80 DAS Amount per event: 30mm applied (26mm effective) Equipment: LPO	2 passes	Incorporate
Wheat	March 1	310kg/ha 18/20/0 at planting. 125kg/ha urea as topdress (applied late September).	One event as establishment and one October. Amount per event: 30mm applied (26mm effective) Equipment: LPO	1 pass	Incorporated
Pasture (4 years)	March 30	15kg N/ha at establishment. 100kg/ha urea on September 1 each year	One irrigation at establishment + 4 irrigations (October–December) of 30mm applied (26mm effective). Equipment: LPO	1 pass	Grazed and sprayed off at end.

Case Farm 4: Paul Badcock					
	Sowing	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Beans	December 10	500 kg to ha of 9/15/13 at sowing & 200 kg urea as topdress 30 DAS	Number irrigations: ~7 Interval between events (days): 14 days Irrigation period: <60 DAS Amount per event: 20mm applied (18mm effective) Equipment: traveller	2 passes	Incorporate
Potatoes	October 1	1655kg/ha of 13/3/19/11 Top-dress of 140kg urea per ha (7 weeks after sowing)	Number irrigations: 15 Interval between events (days): 6 days Irrigation period: 30–125 DAS Amount per event: 20mm applied (18mm effective) Equipment: traveller	3 passes	Incorporate
Wheat	April 1	56kg N/ha at planting. 125kg/ha urea as topdress (applied late September).	One event at sowing + 2 in June/July Amount per event: 20mm applied (18mm effective) Equipment: traveller	1 pass	Incorporate
Poppies	September 10	250kg/ha 14/16/11 at sowing 120kg/ha urea as topdress (70 days after sowing).	Number irrigations: ~4 Interval between events (days): 14 days Irrigation period: 50–80 DAS Amount per event: 20mm applied (18 mm effective) Equipment: traveller	2 passes	Incorporate
Pasture (6 years)	March 30	15kg N/ha at establishment. 100 kg/ha urea on September 1 each year	One irrigation at establishment of 20mm applied (18mm effective). Equipment: traveller	1 pass	Grazed and sprayed off at end.

Case Farm 5: Rick Rockliff					
Crop	*Sowing*	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Poppies	September 10	500 kg/ha 14/16/11 at sowing. 75 kg/ha Urea (if need to boost early frame size) 125kg/ha urea at Running Up (70 days after sowing).	Number irrigations: ~4–5 Interval between events (days): 14 days Irrigation period: 50–80 DAS Amount per event: 30mm applied (24mm effective) Equipment: gun/lateral	2 passes	Burn stubble then incorporate
Ryegrass	April 1	310kg/ha 18/20/0 at planting	30mm at establishment	Direct drill	Spray-off
Beans	December 10	500 kg/ha 8–16–8 at sowing.	Number irrigations: 6 – 7 Interval between events (days): 10 days Irrigation period: 20–80 DAS Amount per event: 10mm early up to 25mm late (100 – 130 mm applied overall) Equipment: gun/lateral	2 passes	Baled and sold
Wheat	May 15	375 x 9–15–13 at sowing. 2 x 125 kg/ha Urea topdressed (Mid Sept + early Oct).	One only in October	2 passes	Incorporate
Ryegrass	April 15	310kg/ha 18/20/0 at planting	30mm at establishment	Direct drill	Spray-off
Poppies	September 10	500 kg/ha 14/16/11 at sowing. 75 kg/ha Urea (if need to boost early frame size) 125kg/ha urea at Running Up (70 days after sowing).	Number irrigations: ~4–5 Interval between events (days): 14 days Irrigation period: 50–80 DAS Amount per event: 30mm applied (24mm effective) Equipment: gun/lateral	2 passes	Burn stubble then incorporate
Ryegrass	April 15	310kg/ha 18/20/0 at planting	30mm at establishment	Direct drill	Spray-off
Peas	September 1	250 kg/ha 9–15–13	Number irrigations: ~4 Interval between events (days): 14 days Irrigation period: 50–100 DAS Amount per event: 30mm applied (24mm effective) Equipment: gun/lateral	2 passes	Baled and sold
Pasture (2 years)	March 30	15kg N/ha at establishment. 80kg/ha urea on October 1 each year	One irrigation at establishment of 30mm applied (24mm effective). Equipment: gun/lateral	1 pass	Grazed and sprayed off at end.

Case Farm 6: Matt Ryan

	Sowing	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Beans	December 10	500 kg to ha of 9/15/13 at sowing & 200 kg urea as topdress 30 DAS	Number irrigations: ~9 Interval between events (days): 7 days Irrigation period: <60 DAS Amount per event: 30mm applied (24mm effective) Equipment: LPO	2 passes	Incorporate
Ryegrass	April 1 (18 months)	300–440kg/ha of 4/6/7 in September	20mm at establishment	Direct drill	Spray-off
Potatoes	October 1	9:14:17:1 basal application at 1500kg/ha 4 urea applications of 125kg/ha per event at 30, 51, 72, 93 DAS	Irrigation 'season': 30–110 DAS Number irrigations: ~16 Interval between events (days): 4 Amount per event: 25mm (20mm effective) Equipment: gun	2 passes	Incorporate
Ryegrass	April 15	Nil	Nil	Direct drill	Spray-off
Poppies	September 10	500kg/ha 14/16/11 at sowing. 250kg/ha urea as topdressing (70 DAS).	Irrigation 'season': 50–80 DAS Number irrigations: 4 Interval between events (days): 11 Amount per event: 25mm (20mm effective) Equipment: gun	2 passes	Incorporate
Broccoli	March 4	1000kg/ha 14/16/11 at planting. 180 kg/ha urea as topdress (40 DAS)	Irrigation 'season':<42 DAS Number irrigations: 6 Interval between events (days): 7 Amount per event: 25mm. Equipment: gun	3 passes	Incorporate
Maize	November 1	900 kg/ha of 14/16/11 at sowing. 250kg/ha 23/0/25 at 60 DAS	Irrigation 'season':10–120 DAS Number irrigations: 13 Interval between events (days): 14 Amount per event: 25mm Equipment: gun	2 passes	Incorporate
Pasture (2 years)	March 30	15kg N/ha at establishment. 100kg/ha urea on September 1 each year	One irrigation at establishment of 25mm applied (20mm effective). Equipment: gun	1 pass	Grazed and sprayed off at end.

Case Farm 7: Stuart Greenhill

Crop	*Sowing*	*N fertiliser*	*Irrigation*	*Tillage*	*Residue*
Potatoes	September 1	2400kg 14/16/11 at planting. 125kg urea/ha as topdress (applied 9 weeks after sowing).	Number irrigations: ~28 Interval between events (days): 3 days Irrigation period: 30–110 DAS Amount per event: 15mm applied (13mm effective) Equipment: LPO	2 passes	Incorporate
Broccoli	March 25	1000kg/ha 14/16/11 at planting. 180 kg/ha urea as topdress (40 DAS)	Number irrigations: ~4 Interval between events (days): 8 days Irrigation period: <42 DAS Amount per event: 30mm applied (24mm effective) Equipment: gun	2 passes	Incorporate
Poppies	September 15	400kg/ha 6/19/5/1 at sowing 128kg/ha urea as topdress (80 days after sowing).	Number irrigations: ~3 Interval between events (days): 14 days Irrigation period: 50–80 DAS Amount per event: 30mm applied (24mm effective) Equipment: gun	1 passes	Incorporate
Ryegrass	March 15	310kg/ha 18/20/0 at planting	25mm at establishment	Direct drill	Spray-off
Beans	December 10	150 kg to ha of 10.17.8.1 & 200 kg to ha of single super	Number irrigations: ~6 Interval between events (days): 7 days Irrigation period: <60 DAS Amount per event: 30mm applied (24mm effective) Equipment: gun	3 passes	Incorporate
Pasture (grass) (5 years)	March 30	15kg N/ha at establishment. 290kg/ha 17:15:19 late August + 100kg/ha urea on October 15 each year	One irrigation at establishment of 30mm applied (24mm effective). 2 irrigations in November to mimic pyrethrum (pasture used as surrogate for this). Equipment: gun	1 pass	Grazed and sprayed off at end.

Case Farm 8

Location: Moriarty
Farm size: 88 ha
Cow number: 240
Average cow lactation (days and milk produced): 9000 l
Supplementary fed grain: 2 t/cow
Nitrogen fertiliser applied: 100 kg applied once in spring with other fertilizer + 30kg/ha of urea applied twice during the growing season
Calving: Spring & autumn
Irrigation: 35 mm every 10 days from November to March, until water runs out

Appendix C: Summary results for case farms

Farms 1–7: Results are average crop season (sowing to harvest) totals calculated across all years of the simulation (1980–2005). Pasture results are calculated on a per annum basis.
Farm 8: Results are calculated over a 12 month period with the distribution over the simulation period (1970–2008) presented in percentiles, maximum, minimum and an overall average.

Case Farm 1: David Addison

Crop rotation	Potato	Fallow	Bean	Fallow	Ryegrass	Fallow	Poppy	Fallow	Ryegrass	Fallow	Broccoli	Fallow	Wheat	Fallow	Pasture	Fallow
Fertiliser N input (basal) (kg N/ha)	154.0	0.0	45.0	0.0	56.0	0.0	24.0	0.0	56.0	0.0	90.0	0.0	56.0	0.0	0.0	0.0
Fertiliser N input (topdress) (kg N/ha)	288.0	0.0	92.0	0.0	0.0	0.0	55.0	0.0	0.0	0.0	58.0	0.0	58.0	0.0	0.0	0.0
Total input N (kg N/ha)	442.0	0.0	159.4	0.0	56.0	0.0	79.0	0.0	56.0	0.0	148.0	0.0	114.0	0.0	0.0	0.0
N leached (kg N/ha)	–1.1	–12.6	–24.9	–0.3	–22.2	–1.1	–5.5	0.0	–2.4	–0.2	–11.3	–0.8	–11.4	–0.2	–2.9	–0.3
Denitrification (kg N/ha)	–9.4	–0.4	–3.6	0.0	–2.2	0.0	–0.4	0.0	–0.6	0.0	–1.5	0.0	–2.4	0.0	–0.5	0.0
N Uptake (kg N/ha)	–349.1	0.0	–138.1	0.0	–91.7	0.0	–109.7	0.0	–80.3	0.0	–107.2	0.0	–127.8	0.0	–51.6	0.0
N fixation (kg N/ha)	0.0	0.0	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall (mm)	233.9	638.7	123.5	35.5	384.7	24.7	262.9	26.2	440.6	24.7	230.1	116.8	652.4	111.9	767.7	122.9
Rainfall runoff (mm)	–11.6	–45.7	–8.6	–3.0	–15.6	–1.2	–9.1	–0.6	–10.7	–1.1	–12.1	–1.6	–22.8	–1.4	–40.0	–8.1
Rainfall effective (mm)	222.3	592.9	114.8	32.5	369.1	23.5	253.9	25.6	429.9	23.6	218.0	115.2	629.6	110.4	727.7	114.8
Irrigation effective (mm)	198.0	0.0	237.2	0.0	24.0	0.0	144.0	0.0	24.0	0.0	168.0	0.0	24.0	0.0	22.2	0.0
Irrigation runoff/loss (mm)	30.5	0.0	59.3	0.0	6.0	0.0	36.0	0.0	6.0	0.0	42.0	0.0	6.0	0.0	5.5	0.0
Irrigation applied (mm)	228.5	0.0	296.5	0.0	30.0	0.0	180.0	0.0	30.0	0.0	210.0	0.0	30.0	0.0	27.7	0.0
Total water input (mm)	462.4	638.7	420.0	35.5	414.7	24.7	442.9	26.2	470.6	24.7	440.1	116.8	682.4	111.9	795.4	122.9
Drainage (mm)	–56.6	–153.6	–209.0	–2.3	–217.4	–19.8	–178.8	–0.6	–256.5	–20.1	–220.8	–10.7	–350.5	–10.4	–372.5	–52.8
SW evaporation (mm)	–179.2	–339.5	–89.6	–23.8	–88.5	–12.2	–165.8	–30.7	–87.7	–11.6	–151.7	–94.3	–182.2	–90.7	–310.1	–73.3
SW Uptake (mm)	–298.8	0.0	–93.8	0.0	–27.1	0.0	–112.3	0.0	–40.6	0.0	–61.4	0.0	–141.7	0.0	–84.9	0.0

Case Farm 2: Robert Addison

Crop rotation	Potatoes	Fallow	Peas	Fallow	Ryegrass	Fallow	Poppy	Fallow	Pasture	Fallow
Fertiliser N input (basal) (kg N/ha)	171.0	0.0	15.0	0.0	56.0	0.0	52.0	0.0	15.0	0.0
Fertiliser N input (topdress) (kg N/ha)	230.0	0.0	0.0	0.0	0.0	0.0	46.0	0.0	46.0	0.0
Total input N (kg N/ha)	401.0	0.0	62.6	0.0	56.0	0.0	98.0	0.0	61.0	0.0
N leached (kg N/ha)	–17.7	–8.3	–7.8	–0.1	–3.3	–0.1	–2.0	0.0	–1.7	–0.1
Denitrification (kg N/ha)	–20.2	–1.0	–1.3	–0.2	–4.9	0.0	–2.8	0.0	–2.1	–0.1
N Uptake (kg N/ha)	–315.5	0.0	–90.1	0.0	–71.3	0.0	–104.3	0.0	–73.4	0.0
N fixation (kg N/ha)	0.0	0.0	47.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall (mm)	250.4	456.9	227.5	97.1	404.2	25.5	260.6	103.5	779.7	90.7
Rainfall runoff (mm)	–15.1	–38.1	–16.0	–6.1	0.0	–0.9	–10.5	–4.0	–37.3	–7.4
Rainfall effective (mm)	235.3	418.8	211.5	91.0	404.2	24.6	250.1	99.5	742.3	83.3
Irrigation effective (mm)	259.0	0.0	104.0	0.0	24.0	0.0	104.0	0.0	21.2	0.0
Irrigation runoff/loss (mm)	90.0	0.0	36.0	0.0	6.0	0.0	36.0	0.0	6.0	0.0
Irrigation applied (mm)	349.0	0.0	140.0	0.0	30.0	0.0	140.0	0.0	27.2	0.0
Total water input (mm)	599.4	456.9	367.5	97.1	434.2	25.5	400.6	103.5	806.9	90.7
Drainage (mm)	–140.3	–100.6	–128.0	–9.5	–265.3	–20.2	–135.3	–7.8	–354.6	–42.2
Soil evaporation (mm)	–188.9	–205.7	–166.8	–79.6	–84.7	–12.6	–164.1	–76.7	–300.5	–51.3
SW Uptake (mm)	–274.1	0.0	–45.6	0.0	–24.6	0.0	–112.5	0.0	–156.7	0.0

Case Farm 3: Shane Radford

Crop rotation	Wheat1	Fallow	Ryegrass1	Fallow	Potato	Fallow	Ryegrass2	Fallow	Poppy	Fallow	Wheat2	Fallow	Pasture	Fallow
Fertiliser N input (basal) (kg N/ha)	56.0	0.0	56.0	0.0	215.0	0.0	56.0	0.0	35.0	0.0	56.0	0.0	15.0	0.0
Fertiliser N input (topdress) (kg N/ha)	58.0	0.0	0.0	0.0	265.0	0.0	0.0	0.0	58.0	0.0	58.0	0.0	46.0	0.0
Total input N (kg N/ha)	114.0	0.0	56.0	0.0	480.0	0.0	56.0	0.0	93.0	0.0	114.0	0.0	61.0	0.0
N leached (kg N/ha)	–14.3	–0.5	–5.7	–0.1	–64.0	0.0	–9.3	–0.3	–2.8	0.0	–8.9	–0.6	–11.3	–0.3
Denitrification (kg N/ha)	–3.0	0.0	–0.9	0.0	–8.2	0.0	–1.5	0.0	–0.7	0.0	–2.4	0.0	–1.6	0.0
N Uptake (kg N/ha)	–111.1	0.0	–29.6	0.0	–325.1	0.0	–74.2	0.0	–126.4	0.0	–108.2	0.0	–87.0	0.0
N fixation (kg N/ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall (mm)	652.4	116.8	424.7	48.0	250.4	32.2	397.4	36.3	254.7	65.7	652.4	102.9	753.7	30.3
Rainfall runoff (mm)	–24.7	–1.0	–12.0	–2.4	–12.2	–0.2	–12.8	–1.6	–8.5	–0.7	–23.5	–1.4	–31.4	–1.9
Rainfall effective (mm)	627.7	115.9	412.7	45.6	238.1	32.0	384.6	34.7	246.2	65.0	628.9	101.5	722.4	28.4
Irrigation effective (mm)	52.0	0.0	26.0	0.0	260.0	0.0	26.0	0.0	78.0	0.0	52.0	0.0	148.0	0.0
Irrigation runoff/loss (mm)	8.0	0.0	4.0	0.0	40.0	0.0	4.0	0.0	12.0	0.0	8.0	0.0	22.8	0.0
Irrigation applied (mm)	60.0	0.0	30.0	0.0	300.0	0.0	30.0	0.0	90.0	0.0	60.0	0.0	170.8	0.0
Total water input (mm)	712.4	116.8	454.7	48.0	550.4	32.2	427.4	36.3	344.7	65.7	712.4	102.9	924.5	30.3
Drainage (mm)	–394.1	–12.8	–290.3	–27.4	–150.6	0.0	–185.8	–26.4	–111.1	–1.1	–345.3	–9.3	–457.5	–5.3
Soil evaporation (mm)	–184.4	–88.6	–95.9	–29.8	–186.3	–17.5	–85.5	–20.2	–161.8	–57.2	–194.3	–87.2	–269.9	–17.3
SW Uptake (mm)	–133.6	0.0	–12.1	0.0	–274.9	0.0	–24.7	0.0	–121.5	0.0	–128.8	0.0	–145.7	0.0

Case Farm 4: Paul Badcock

Crop rotation	Bean	Fallow	Potato	Fallow	Wheat	Fallow	Poppy	Fallow	Pasture	Fallow
Fertiliser N input (basal) (kg N/ha)	45.0	0.0	215.0	0.0	56.0	0.0	35.0	0.0	15.0	0.0
Fertiliser N input (topdress) (kg N/ha)	92.0	0.0	64.0	0.0	58.0	0.0	58.0	0.0	46.0	0.0
Total input N (kg N/ha)	159.0	0.0	279.0	0.0	114.0	0.0	93.0	0.0	61.0	0.0
N leached (kg N/ha)	–4.8	–17.9	–42.1	0.0	–13.5	–8.4	–2.2	0.0	–4.9	–0.1
Denitrification (kg N/ha)	–4.9	–1.8	–15.1	0.0	–3.1	0.0	–1.0	0.0	–1.4	0.0
N Uptake (kg N/ha)	–141.3	0.0	–276.7	0.0	–130.0	0.0	–105.0	0.0	–99.3	0.0
N fixation (kg N/ha)	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall (mm)	141.2	477.7	250.4	66.7	622.6	531.2	262.9	64.4	764.7	48.5
Rainfall runoff (mm)	–4.0	–21.2	–9.4	–1.1	–12.0	–3.9	–5.1	–1.1	–15.9	–1.8
Rainfall effective (mm)	137.2	456.4	241.0	65.6	610.5	527.3	257.8	63.4	748.8	46.7
Irrigation effective (mm)	124.6	0.0	267.9	0.0	50.1	0.0	72.0	0.0	16.6	0.0
Irrigation runoff/loss (mm)	10.0	0.0	30.0	0.0	6.0	0.0	8.0	0.0	2.0	0.0
Irrigation applied (mm)	134.6	0.0	297.9	0.0	56.1	0.0	80.0	0.0	18.6	0.0
Total water input (mm)	275.8	477.7	548.3	66.7	678.7	531.2	342.9	64.4	783.4	48.5
Drainage (mm)	–84.9	–167.6	–154.3	–0.6	–282.0	–250.9	–104.6	–3.2	–345.3	–3.0
Soil evaporation (mm)	–94.1	–241.2	–186.7	–37.6	–191.1	–199.2	–169.0	–57.9	–267.1	–38.6
SW Uptake (mm)	–100.4	0.0	–286.3	0.0	–175.5	0.0	–108.3	0.0	–173.8	0.0

Case Farm 5: Rick Rockliff

Crop rotation	Poppy1	Fallow	Rye1	Fallow	Bean	Fallow	Wheat	Fallow	Rye2	Fallow	Poppy2	Fallow	Rye3	Fallow	Pea	Fallow	Pasture	Fallow
Fertiliser N input (basal) (kg N/ha)	70.0	0.0	56.0	0.0	40.0	0.0	35.0	0.0	56.0	0.0	70.0	0.0	56.0	0.0	15.0	0.0	15.0	0.0
Fertiliser N input (topdress) (kg N/ha)	58.0	0.0	0.0	0.0	92.0	0.0	83.0	0.0	0.0	0.0	58.0	0.0	0.0	0.0	0.0	0.0	37.0	0.0
Total input N (kg N/ha)	128.0	0.0	56.0	0.0	155.1	0.0	118.0	0.0	56.0	0.0	128.0	0.0	56.0	0.0	67.7	0.0	52.0	0.0
N leached (kg N/ha)	–0.7	0.0	–0.6	0.0	–0.2	–0.1	–4.4	–0.1	–1.1	0.0	–0.5	0.0	–0.7	0.0	–0.5	0.0	–1.6	–0.1
Denitrification (kg N/ha)	–4.0	0.0	–3.1	0.0	–4.0	–0.5	–6.7	0.0	–3.0	0.0	–3.1	0.0	–3.5	0.0	–1.5	–0.4	–4.9	0.0
N Uptake (kg N/ha)	–141.7	0.0	–36.7	0.0	–134.9	0.0	–128.4	0.0	–20.0	0.0	–93.9	0.0	–43.6	0.0	–100.5	0.0	–120.7	0.0
N fixation (kg N/ha)	0.0	0.0	0.0	0.0	23.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.7	0.0	0.0	0.0
Rainfall (mm)	262.9	94.0	542.4	46.8	141.2	93.7	561.2	129.7	358.3	39.3	262.9	94.0	322.1	52.6	252.0	98.8	763.3	39.3
Rainfall runoff (mm)	–12.4	–3.2	–19.1	–2.1	–4.7	–12.0	–26.3	–2.3	–5.9	–1.3	–8.9	–4.9	–15.6	–2.5	–16.1	–6.4	–29.9	–3.6
Rainfall effective (mm)	250.5	90.8	523.3	44.8	136.5	81.7	534.9	127.4	352.4	38.0	254.0	89.1	306.5	50.1	235.9	92.4	733.3	35.7
Irrigation effective (mm)	96.0	0.0	24.0	0.0	93.2	0.0	24.0	0.0	24.0	0.0	96.0	0.0	24.0	0.0	95.1	0.0	22.2	0.0
Irrigation runoff/loss (mm)	24.0	0.0	6.0	0.0	23.3	0.0	6.0	0.0	6.0	0.0	24.0	0.0	6.0	0.0	23.8	0.0	5.5	0.0
Irrigation applied (mm)	120.0	0.0	30.0	0.0	116.5	0.0	30.0	0.0	30.0	0.0	120.0	0.0	30.0	0.0	118.8	0.0	27.7	0.0
Total water input (mm)	382.9	94.0	572.4	46.8	257.8	93.7	591.2	129.7	388.3	39.3	382.9	94.0	352.1	52.6	370.9	98.8	791.0	39.3
Drainage (mm)	–114.7	–5.1	–303.3	–7.5	–34.8	–24.3	–259.0	–14.0	–256.6	–28.8	–140.5	–7.5	–181.6	–35.6	–138.8	–7.1	–374.6	–22.5
Soil evap (mm)	–164.2	–71.8	–168.4	–35.8	–97.2	–47.4	–192.1	–75.1	–52.7	–14.6	–164.8	–72.7	–83.6	–27.3	–176.1	–82.0	–276.5	–20.2
SW Uptake (mm)	–139.7	0.0	–44.5	0.0	–98.6	0.0	–193.7	0.0	–6.7	0.0	–99.1	0.0	–12.7	0.0	–50.5	0.0	–129.3	0.0

Case Farm 6: Mat Ryan

Crop rotation	Bean	Fallow	Rye	Fallow	Potatoes	Fallow	Rye	Fallow	Poppy	Fallow	Broccoli	Fallow	Maize	Fallow
Fertiliser N input (basal) (kg N/ha)	45.0	0.0	0.0	0.0	145.0	0.0	0.0	0.0	70.0	0.0	140.0	0.0	126.0	0.0
Fertiliser N input (topdress) (kg N/ha)	92.0	0.0	15.0	0.0	240.0	0.0	15.0	0.0	115.0	0.0	83.0	0.0	60.0	0.0
Total input N (kg N/ha)	159.0	0.0	15.0	0.0	385.0	0.0	15.0	0.0	185.0	0.0	223.0	0.0	186.0	0.0
N leached (kg N/ha)	–7.9	0.0	–13.8	–0.3	–16.6	–0.1	–14.7	–3.4	–5.0	0.0	–8.3	0.0	–6.5	–1.2
Denitrification (kg N/ha)	–3.1	0.0	–1.6	–0.1	–8.2	0.0	–0.2	–0.1	–1.2	0.0	–4.8	–0.3	–5.1	–0.1
N Uptake (kg N/ha)	–150.3	0.0	–100.8	0.0	–339.5	0.0	–39.4	0.0	–222.8	0.0	–206.5	0.0	–237.4	0.0
N fixation (kg N/ha)	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall (mm)	141.2	9.2	669.7	58.8	250.4	56.7	322.1	78.1	260.6	27.7	294.0	286.0	208.9	67.4
Rainfall runoff (mm)	–7.1	–0.9	–28.3	–3.3	–13.9	–1.6	–10.3	–3.3	–9.4	0.0	–22.2	–6.6	–16.3	–2.8
Rainfall effective (mm)	134.1	8.3	641.3	55.5	236.5	55.1	311.8	74.8	251.2	27.6	271.8	279.4	192.6	64.6
Irrigation effective (mm)	213.2	0.0	20.0	0.0	320.0	0.0	0.0	0.0	79.2	0.0	119.2	0.0	266.9	0.0
Irrigation runoff/loss (mm)	53.3	0.0	5.0	0.0	80.0	0.0	0.0	0.0	19.8	0.0	29.8	0.0	66.7	0.0
Irrigation applied (mm)	266.5	0.0	25.0	0.0	400.0	0.0	0.0	0.0	99.0	0.0	149.0	0.0	333.7	0.0
Total water input (mm)	407.8	9.2	694.7	58.8	650.4	56.7	322.1	78.1	359.6	27.7	443.0	286.0	542.6	67.4
Drainage (mm)	–167.8	–0.2	–338.9	–27.3	–179.9	–0.6	–116.6	–47.2	–88.1	–0.3	–126.6	–168.4	–149.7	–25.1
Soil evap (mm)	–97.5	–6.2	–212.4	–38.0	–188.2	–28.0	–89.4	–38.3	–158.4	–31.1	–83.4	–122.8	–152.5	–16.9
SW Uptake (mm)	–101.1	0.0	–134.0	0.0	–298.3	0.0	–10.8	0.0	–181.2	0.0	–79.5	0.0	–196.0	0.0

Case Farm 7: Stuart Greenhill

Crop rotation	Potato	Fallow	Broccoli	Fallow	Poppy	Fallow	Ryegrass	Fallow	Beans	Fallow	Pasture	Fallow
Fertiliser N input (basal) (kg N/ha)	336.0	0.0	90.0	0.0	24.0	0.0	56.0	0.0	15.0	0.0	15.0	0.0
Fertiliser N input (topdress) (kg N/ha)	58.0	0.0	58.0	0.0	55.0	0.0	0.0	0.0	0.0	0.0	46.0	0.0
Total input N (kg N/ha)	394.0	0.0	148.0	0.0	79.0	0.0	56.0	0.0	47.6	0.0	61.0	0.0
N leached (kg N/ha)	–44.1	0.0	–3.5	0.0	–0.1	0.0	–0.6	0.0	–0.3	0.0	–1.9	–0.1
Denitrification (kg N/ha)	–38.4	0.0	–14.9	–0.1	–1.5	0.0	–4.2	–0.1	–0.7	0.0	–5.7	–0.1
N Uptake (kg N/ha)	–241.7	0.0	–189.3	0.0	–90.9	0.0	–80.9	0.0	–62.5	0.0	–155.1	0.0
N fixation (kg N/ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.6	0.0	0.0	0.0
Rainfall (mm)	311.3	31.0	401.2	86.8	226.1	26.9	596.5	46.8	146.2	24.6	776.1	126.2
Rainfall runoff (mm)	–23.0	0.0	–31.8	–2.0	–6.9	–0.2	–17.7	–1.9	–6.6	–3.7	–33.8	–8.2
Rainfall effective (mm)	288.3	30.9	369.4	84.8	219.1	26.7	578.8	45.0	139.6	20.9	742.2	118.0
Irrigation effective (mm)	320.5	0.0	96.0	0.0	96.0	0.0	24.0	0.0	142.2	0.0	68.3	0.0
Irrigation runoff/loss (mm)	49.3	0.0	24.0	0.0	24.0	0.0	6.0	0.0	35.5	0.0	17.1	0.0
Irrigation applied (mm)	369.8	0.0	120.0	0.0	120.0	0.0	30.0	0.0	177.7	0.0	85.4	0.0
Total water input (mm)	681.1	31.0	521.2	86.8	346.1	26.9	626.5	46.8	323.9	24.6	861.5	126.2
Drainage (mm)	–280.7	0.0	–151.0	–54.1	–115.1	–2.3	–347.2	–5.9	–113.8	–7.0	–368.6	–71.7
Soil evap(mm)	–221.1	–26.6	–98.3	–35.6	–153.4	–31.8	–141.2	–34.6	–101.3	–13.4	–271.4	–56.8
SW Uptake (mm)	–248.0	0.0	–79.9	0.0	–93.3	0.0	–96.5	0.0	–67.3	0.0	–197.1	0.0

Case Farm 8: Ian Hortle

Treatment	Summary	Milk produced (L/ha)	Pasture intake (t DM/ha)	Cut yield (t DM/ha)	Concentrate intake (t DM/ha)	Irrigation inputs (mm/ year)	N fertilizer (kg N/ year)	Forage intake (t DM/ha)	Supplementary feeding (t DM/ha.year)	Forage balance	N leached (kg N/ ha.year)	Through drainage (mm/ year)
Current practice	10th percentile	21677	10.9	2.1	5.7	560	100	1.9	7.6	–6.1	85	465
Current practice	25th percentile	21721	11.1	3.1	5.8	560	100	2.0	7.8	–5.1	103	560
Current practice	50th percentile	21794	11.3	3.5	5.9	560	100	2.1	8.1	–4.5	121	669
Current practice	75th percentile	21880	11.4	4.1	6.0	560	100	2.2	8.2	–3.8	172	749
Current practice	90th percentile	21999	11.6	4.5	6.1	560	100	2.3	8.4	–3.3	193	949
Current practice	Mean	21815	11.3	3.5	5.9	560	100	2.1	8.0	–4.5	132	670
Current practice	Max	22123	11.8	4.8	6.2	560	100	2.5	8.6	–2.9	203	1042
Current practice	Min	21568	10.8	1.7	5.6	560	100	1.8	7.5	–6.5	66	273
Irrigation Scheduling	10th percentile	21732	10.9	2.9	5.7	198	100	1.9	7.7	–5.3	66	222
Irrigation Scheduling	25th percentile	21781	11.2	3.3	5.8	240	100	2.0	7.8	–4.8	81	276
Irrigation Scheduling	50th percentile	21885	11.3	3.6	5.9	280	100	2.1	8.0	–4.3	108	389
Irrigation Scheduling	75th percentile	21919	11.5	4.0	5.9	305	100	2.2	8.2	–3.9	150	477
Irrigation Scheduling	90th percentile	21965	11.6	4.3	6.0	330	100	2.4	8.3	–3.6	174	563
Irrigation Scheduling	Mean	21853	11.3	3.6	5.9	270	100	2.1	8.0	–4.4	116	378
Irrigation Scheduling	Max	22109	11.7	4.5	6.0	388	100	2.5	8.5	–3.0	218	732
Irrigation Scheduling	Min	21499	10.8	2.5	5.6	133	100	1.8	7.5	–5.9	30	66
Scheduled N and Irrigation	10th percentile	21747	11.0	3.2	5.6	203	106	1.7	7.3	–4.7	66	219
Scheduled N and Irrigation	25th percentile	21781	11.2	3.9	5.6	241	131	1.9	7.5	–4.0	78	282
Scheduled N and Irrigation	50th percentile	21912	11.5	4.3	5.7	286	147	1.9	7.7	–3.4	107	387
Scheduled N and Irrigation	75th percentile	21979	11.7	5.0	5.8	311	164	2.1	7.9	–2.6	144	475
Scheduled N and Irrigation	90th percentile	22064	11.9	5.6	5.9	335	180	2.2	8.1	–2.0	168	560
Scheduled N and Irrigation	Mean	21892	11.5	4.4	5.7	275	147	2.0	7.7	–3.3	113	377
Scheduled N and Irrigation	Max	22184	12.1	6.1	6.0	393	214	2.3	8.2	–1.1	213	728
Scheduled N and Irrigation	Min	21522	11.0	2.9	5.4	138	96	1.6	7.0	–5.1	29	64
Rotationally applied N	10th percentile	21765	11.0	3.4	5.5	208	300	1.7	7.2	–4.5	141	220
Rotationally applied N	25th percentile	21826	11.2	3.9	5.5	245	304	1.8	7.3	–4.0	178	281
Rotationally applied N	50th percentile	21951	11.5	4.5	5.6	289	311	1.9	7.5	–3.1	216	387
Rotationally applied N	75th percentile	22070	11.7	5.1	5.8	316	315	2.1	7.8	–2.5	289	473
Rotationally applied N	90th percentile	22118	11.8	5.7	5.8	341	319	2.2	8.0	–1.6	362	556
Rotationally applied N	Mean	21943	11.4	4.5	5.6	280	310	1.9	7.6	–3.1	239	376
Rotationally applied N	Max	22171	12.0	6.2	5.8	394	337	2.3	8.1	–1.1	404	730
Rotationally applied N	Min	21571	10.9	2.9	5.4	140	285	1.6	7.0	–4.9	50	64