Dairy wintering systems in Southern New Zealand

Quantification and modelling of nutrient transfers and losses from contrasting wintering systems

---

A thesis
submitted in partial fulfilment
of the requirements for the degree of

Doctor of Philosophy
in
Soil Science

at Massey University, Palmerston North, New Zealand

Jane Chrystal

2017

Abstract

Traditional dairy wintering practice in the lower South Island of New Zealand has been to graze brassica crops *in situ*. This practice has been under increasing scrutiny from local Regional Councils due to the relatively high nitrogen (N) leaching losses from this component of the whole farm system. Alternative wintering options to reduce N leaching losses that are currently available to farmers (such as barns and permanent wintering pads) are high cost and involve a large capital investment. In this work a new wintering system (termed a 'portable pad') was developed for use on support blocks (which can be located many kilometres from the milking platform) as an interim measure for reducing N leaching losses that is low cost and low input. This system is designed as a mitigation strategy that is available for use immediately while research investigates more permanent solutions. This system is a hybrid of the traditional crop grazing system and an off-paddock system, where effluent is captured. It makes use of the advantages of each of the original systems utilising the low cost feed source of the brassica crops, grazed *in situ*, while also utilising the benefits of duration controlled grazing with its associated effluent capture and irrigation at low rates.

The aim of the research was to generate whole system N leaching loss values for each of the three farm systems investigated (crop wintering, deep-litter wintering barn, and portable pad). Field and laboratory research was conducted to fill identified knowledge gaps such that system N loss values could be estimated. *OVERSEER* Nutrient Budget software tool was used in conjunction with measured and modelled (APSIM) data to simulate whole farm N leaching loss values for the three farm systems investigated. Nitrogen leaching losses from the portable pad and barn systems were between 5 and 26 % and between 13 and 26 % lower, respectively, than the crop wintering system.

Dedication

For Gorg

08.06.1920 – 26.02.2016

Acknowledgements

This thesis represents the end of one journey and the beginning of another. If there is one thing that I have learnt it's that no matter how well you plan and prepare for a journey there are unexpected twists and turns that are thrown at you along the way. How you learn from, and deal with, these challenges is as much of a learning experience as the thesis topic itself. Robert Service says it perfectly in his poem "The Quitter" which has been on the wall above my computer for the duration of my PhD.

The Quitter

When you're lost in the Wild, and you're scared as a child,
And Death looks you bang in the eye,
And you're sore as a boil, it's according to Hoyle
To cock your revolver and . . . die.
But the Code of a Man says: "Fight all you can,"
And self-dissolution is barred.
In hunger and woe, oh, it's easy to blow . . .
It's the hell-served-for-breakfast that's hard.

"You're sick of the game!" Well, now, that's a shame.
You're young and you're brave and you're bright.
"You've had a raw deal!" I know -- but don't squeal,
Buck up, do your damnedest, and fight.
It's the plugging away that will win you the day,
So don't be a piker, old pard!
Just draw on your grit; it's so easy to quit: It's the keeping-your-chin-up that's hard.

It's easy to cry that you're beaten -- and die;
It's easy to crawfish and crawl;
But to fight and to fight when hope's out of sight --
Why, that's the best game of them all!
And though you come out of each gruelling bout,
All broken and beaten and scarred,
Just have one more try -- it's dead easy to die,
It's the keeping-on-living that's hard.

Firstly, I would like to acknowledge AgResearch for funding my PhD, and express my gratitude to my managers, Drs Richard Muirhead and Bram de Vos, who saw the value in supporting me and convincing the 'powers-that-be' that I was worth supporting both financially and professionally. Without this backing I wouldn't have been able to do this project.

Secondly, to my supervisors who have motivated, encouraged, inspired, and at times dragged and pushed me along on this journey. It has been an honour to work with such passionate, professional scientists.

Professor Mike Hedley, my chief supervisor, thank you so much for your support, guidance and enthusiasm. I always came away from our meetings not only inspired, enthused and aware of just how much I had to learn; but also of how much I had learnt already.

Associate Professor Dave Horne, for your reassurance on my ability to make it to the end of this journey, and indeed the next leg of the journey, whenever I rang you during an "I'll never get there" moment. Thank you.

Dr Ross Monaghan (whose office was located next to mine for the duration of my PhD), I thank you for suffering the constant and daily questions, queries, and requests for confirmation that I was on the right track. Thank you for guiding me along on this journey with humour, encouragement, a good dose of "keeping-it-real", and a lot of red pen. I may, just may, have figured out the correct use of the colon and semi-colon by the end of this; here's hoping.

Thank you to my colleagues at Invermay, especially the Nutrient Losses to Water and Atmosphere group. Your enthusiasm for your research is infectious, and the camaraderie in our team is unique and something to be valued.

To the Technical Team: Stuart Lindsay, Tom Orchiston, Alison Rutherford, Chris Smith, Tash Styles, Sonya Walker and Wayne Worth. Thank you all for your assistance with field work, sample collection and sample analyses. Without your assistance this project would not have been possible.

To Mum and Dad, thank you for teaching me the importance and value of education and continuing that education throughout life. To Mum, Dad, Matt, Sarah, Gorg, Kate, Alasdair and the extended family, thank you for your support and encouragement even if you're still unsure exactly what my PhD topic is!

Finally I'd like to thank my husband Gregor and our wee family, Louisa, Elise and Mackenzie. I couldn't have done this without you. You've been there supporting and encouraging me the whole way. It hasn't been easy with a young family (which is now one member bigger than when I set out, welcome Mackenzie!) but because of your support I made it to the end, we made it to the end. They say it takes a community to raise a child, the same can be said about completing a PhD.

I am excited to begin the next journey and to continue my work in agricultural research. I hope that for many years to come my children can continue to tell their teachers and friends that their Mum's job is (in the words of my 9-year-old daughter), "doing something with cow poo".

Table of Contents

Abstract iii

Dedication iv

Acknowledgements iv

Table of Contents vi

List of Figures xii

List of Tables xxii

List of abbreviations xxvii

1. Research Introduction 1

1.2 Overarching hypotheses for literature review 4

1.3 Structure of this PhD 4

1.4 Gaps in knowledge and researchable problems 5

- 1.4.1 Winter crop systems 5
- 1.4.2 Winter off-paddock systems 7
- 1.4.3 A potential new system – Portable pad 8

1.5 Authors contribution to the different research projects 9

- 1.5.1 Specific P21 objectives that related to this thesis and its relationship to further work 10
- 1.5.2 Author’s contribution to the work in this thesis. 11

2. Review of the literature regarding dairy wintering systems used in southern New Zealand and the associated nutrient losses to the aquatic environment. 13

2.1 Introduction. 13

2.2 Dairy cow winter management Systems 13

- 2.2.1 Current wintering options: Crop, shelters/barns, off-paddock systems 14
- 2.2.2 Animal welfare measurements and issues 16
- 2.2.3 Costs of systems 28

2.3 Stand-off systems and the volumes of effluent they generate 30

- 2.3.1 Estimating effluent volume and characteristics 30
- 2.3.2 Factors that determine storage requirements 34
- 2.3.3 Effluent land application options 35
- 2.3.4 Risk around application of FDE to artificially drained soils 37

2.4 Principles of nutrient and contaminant transport from land to water 37

- 2.4.1 Water movement through soils 37
- 2.4.2 Nutrient movement – pathways of N and P loss to receiving waters 40
- 2.4.3 Impact of each system on the aquatic environment 43

2.5 Issues associated with wet grazed pasture soils – soil strength, contaminant losses in drainage, and applying effluent to wet soils. 48

2.5.1 The impact of grazing wet pasture soils on soil strength 48

2.5.2 The impact of grazing wet pasture soils on drainage 48

2.5.3 The impact of effluent irrigation on pasture soils grazed when wet 49

2.5.4 Impact of each system on soil, plants, production 49

2.5.5 Wintering issue within the context of the whole dairy system 52

2.5.6 Summary of the particular challenges associated with each wintering system 53

2.6 Development of a knowledge framework 53

2.7 Gaps in the research 54

2.8 Proposed area of research 56

3. Volumes and nutrient concentrations of effluent products generated from cows in the loose-housed wintering barn with woodchip bedding 57

3.1 Abstract 57

3.2 Research site and Farm characteristics 57

3.3 Identification and monitoring of effluent and manure streams 58

3.4 Methods of measuring liquid and solid effluent volumes, and obtaining samples for analysis 60

3.4.1 Effluent system 60

3.4.2 Rainfall collection areas 61

3.4.3 Monitoring sites (Figure 3.2) 62

3.4.4 Effluent analysis 63

3.5 Results from the effluent monitoring and sample analysis 64

3.5.1 Rainfall 64

3.5.2 Effluent volumes and nutrient characteristics 64

3.6 Discussion of the effluent volume and nitrogen concentration results 71

3.6.1 Volumes and nutrient concentrations for different streams 71

3.7 Conclusions 73

3.8 Acknowledgements 73

4. Nitrogen losses from winter grazed crop on stony soils: the use of a channel lysimeter to measure N leaching under restricted (6 hr) and unrestricted (24 hr) grazing 75

4.1 Abstract 75

4.2 Introduction 75

4.3 Methods 76

4.3.1 Channel lysimeter establishment 78

4.3.2 Custom modification of drainage flow measurement system 80

4.3.3 Grazing events 84
4.3.4 Sample collection and analysis 85
4.3.5 Soil water balance 86
4.3.6 Statistical analysis 91
4.4 Results 91
4.5 Discussion 99
4.5.1 The use of lined trenches as channel lysimeters 99
4.5.2 N leaching losses 100
4.6 Conclusions 104
4.7 Acknowledgements 104
5. Portable pad technology and trial 105
5.1 Abstract 105
5.2 Introduction 106
5.3 Methods 108
5.3.1 Trial site 108
5.3.2 Animal Ethics 109
5.3.3 Stage 1 pad design and establishment 109
5.3.4 Stage 2 pad and experimental design 111
5.3.5 Stage 2 measurements 114
5.3.6 Statistical analysis 121
5.4 Results 121
5.4.1 Stage one results 121
5.4.2 Stage two results 123
5.4.3 Costing of portable pad technology 136
5.5 Discussion 137
5.5.1 Portable pad as a concept to capture the effluent deposited 137
5.5.2 Portable pad use and the ability to maintain animal welfare. 141
5.6 Conclusion 141
5.7 Acknowledgements 142
6. Low depth winter applied effluent application 143
6.1 Abstract 143
6.2 Introduction 143
6.3 Methods and Materials 148
6.3.1 Field site selection 148
6.3.2 Field site establishment 149

6.3.3 Installation of the low depth sprinkler system 150
6.3.4 Frost control 153
6.3.5 Treatments 153
6.3.6 Soil sampling 155
6.3.7 Drainage and effluent sample analysis 155
6.3.8 Data analysis 156
6.3.9 Soil water balance 157
6.4 Results 157
6.4.1 Climatic results and soil data 157
6.4.2 Drainage compared with computed soil water balance (SWB) 159
6.4.3 Drainage results 162
6.4.4 Cost of irrigation infrastructure required to implement the low rate, low depth concept 165
6.5 Discussion 166
6.6 Conclusions 168
6.7 Acknowledgments 168
7. Simulation modelling of low rate and low depth winter applied effluent application 169
7.1 Abstract 169
7.2 Introduction 170
7.3 APSIM modelling methods 171
7.3.1 The APSIM model 171
7.3.2 Drainage in SWIM2 175
7.3.3 *Validation file* - modelling the field experiment 177
7.3.4 Modelling LRLD irrigation of effluents 178
7.3.5 Portable Pad Scenario methods 185
7.4 APSIM modelling results 186
7.4.1 Drainage volume results 186
7.4.2 Simulation pipe drainage discharge concentrations 187
7.5 Discussion of modelling *validation file* of LRLD trial data 190
7.6 Results of *FDE Scenario*: Applying FDE to land over winter using a low rate, low depth system 191
7.7 Discussion of simulated *FDE application* 193
7.8 Results from simulating the higher effluent N concentrations of barn effluents 193
7.9 Discussion of simulating higher effluent N concentrations equivalent to barn effluents 195
7.10 Results of simulating a *Portable pad scenario* 197
7.11 Discussion of Portable pad scenario 200

7.12 Summary of all scenario discussions 200

7.12.1 Rule of thumb for estimating N losses from use of the LRLD system 201

7.13 Conclusions 204

7.14 Acknowledgments 204

8. Simulation modelling and comparison of the N leaching losses from three different wintering systems 205

8.1 Abstract 205

8.2 Introduction 205

8.3 Methods 206

8.3.1 Models used 207

8.3.2 System scenarios tested 207

8.3.3 *Farmax* modelling file generation 207

8.3.4 *OVERSEER* modelling file generation 208

8.3.5 Scenario variations 213

8.4 *OVERSEER* Results 214

8.4.1 Portable pad results 219

8.5 Identifying disparity between measured, APSIM-modelled, and *OVERSEER* N leaching losses 220

8.5.1 N leaching losses from winter-applied effluent using the low rate, low depth technology 220

8.5.2 Altering crop losses to represent urine data from Chapter 5 and data from the literature 222

8.6 Combined Source Method 231

8.7 Discussion 234

8.7.1 Discussion of the predicted N leaching losses from the three contrasting wintering systems 234

8.7.2 Discussion of the financial cost of the portable pad and barn systems 235

8.7.3 Practical implications of the portable pad 237

8.7.4 Discussion of the *OVERSEER* model 237

8.8 Conclusions from ‘Combined Source’ 239

8.8.1 Scenarios that were poorly modelled by *OVERSEER* 240

9. Conclusions and future research priorities 242

9.1 Summary of research focus and the overarching hypotheses 242

9.2 Main findings of this research 242

9.2.1 Portable Pad 243

9.2.2 Deep litter barn (as an example of an existing off-paddock system) effluent and bedding 245

9.2.3 Traditional crop system – cow lying times 245
9.2.4 Whole system comparison 246
9.3 Priorities for future research (in no particular order) 246
9.3.1 Portable pad 246
9.3.2 N leaching from grazing winter crops 247
9.3.3 Wintering barn 248
9.3.4 OVERSEER model 249
9.3.5 Urine sensors 249
10. References 250
11. Appendices 264
11.1 Trial 2: Barn bedding moisture 264
11.1.1 Introduction to the barn bedding moisture trial 264
11.1.2 Methods of monitoring and measuring moisture content in a wintering barn woodchip bedding 264
11.1.3 Results of barn bedding moisture monitoring 266
11.1.4 Discussion on barn bedding moisture 268
11.1.5 Recommendations for farmers 268
11.2 Trial 3: Effects of applying dairy wintering barn manure of differing C:N ratios directly to pasture on N mineralisation and forage growth 270
11.2.1 Abstract 270
11.2.2 Introduction to the Incubation study 270
11.2.3 Methods for Incubation study 271
11.2.4 Results and Discussion of the Incubation Study 273
11.2.5 Conclusion of the Incubation Study 274
11.2.6 Summary 275
11.2.7 Acknowledgements 275
11.3 Low depth winter applied effluent application - P, SS and *E.coli* results 276

List of Figures

Figure 1.1. A conceptual diagram of the relationship between the different experiments and chapters of this PhD. The new wintering system is shown by the red dashed lines. 6

Figure 2.1. Simplified diagram of the components of the hydrological cycle that relate to soil water. 39

Figure 2.2. Transport pathways involved in the transfer of N and P from land to water in agricultural systems. The presence and relative size of each letter indicates the importance of that pathway. Adapted from: McDowell *et al* (2016) 40

Figure 2.3. The Nitrogen Cycle in agricultural systems. Source: H.J. Di and K.C. Cameron (2002), figure 1. 43

Figure 2.4. Transport pathways involved in the transfer of N and P from land to water in a winter cropping scenario. The presence and relative size of each letter indicates the importance of that pathway. Adapted from: R. W. McDowell *et al* (2016). 45

Figure 2.5. Transport pathways involved in the transfer of N and P from land to water in wintering barn scenario. The presence and relative size of each letter indicates the importance of that pathway. Adapted from: R. W. McDowell *et al* (2016) 46

Figure 2.6. Conceptual Southland rainfall (30- year-average from Gore; Blue bars) and estimates of relative drainage (orange bars) taken from measured drainage in Southland literature (Monaghan *et al.* 2009; Smith *et al.* 2012). The green boxes represent the timing of winter grazing events and winter crop paddock cultivation. 49

Figure 2.7. A knowledge framework outlining the key components of, and interactions between, different types of dairy wintering systems in the Southern South Island of New Zealand. The solid lines represent existing systems. The dashed red line represents the proposed system identified and investigated in this PhD. 55

Figure 3.1. Telford barn and effluent system. A. Telford wintering barn and feeding alley, B. purpose-built collection pond and C. small weeping wall in collection pond with wider than normal slats. 60

Figure 3.2 Diagram of the Telford farm effluent and manure measuring sites. These are: 1) FDE, 2) silage pad leachate, 3) effluent draining through the wintering barn bedding, 4) effluent scraped from the feed pad and concrete cleaning strip, 5) barn bedding, and 6) collection pond effluent. Effluent is then pumped via pipe ‘7’ to a large weeping wall for storage in the main effluent ponds. 62

Figure 3.3. Sampling equipment for monitoring of the effluent flows associated with the Telford Barn: (A) sediment trap established to measure the leachate from the silage pad, (B) tipping bucket measuring the leachate from the silage pad tipping bucket in the monitoring bunker recording the total number of tips, (C) cover over the monitoring bunker located at the end of the Wintering Barn, and (D) tipping bucket in the monitoring bunker recording the total number of tips. 63

Figure 3.4. Total monthly volumes of the different effluent streams generated from the wintering barn over two complete winters of monitoring (2013 and 2014). 65

Figure 3.5. All effluent streams entering the Telford effluent collecting pond; scaled for the 110 cows of the RES herd. 66

Figure 3.6. Comparison of rainfall (red lines, mm day^{-1}) and drainage (L day^{-1}) from the wintering barn (blue bars) during 2013 (a, b, c) and 2014 (d, e). The months when the cows were in the barn 24 hours a day are shown in graphs b and e. 67

Figure 3.7. Daily rainfall (red lines) and wintering barn drainage volumes (blue bars) for the period of June – August 2014 when cows were in the barn 24 hours a day. The blue arrow depicts a period of time when there was no rainfall and yet drainage was recorded. 68

Figure 4.1. Location of trench plots for the Otama channel lysimeter experiment. The site sits adjacent to the Mataura River, north east of Gore Township 76

Figure 4.2. Soil profile for a Riversdale soil at the site of the Otama experiment (0-700 mm depth 77

Figure 4.3. Photos of the establishment of the Otama channel lysimeters, November 2012. Photos are: A. Measurement of channel location, B & C. Excavation of channels, D. Lysimeter channel, E, Measuring fall in channel, F. Plastic liner with drainage pipe and pea gravel, G. Connecting drainage pipe to collection chamber, H. Filling in channel lysimeters, I. Site after completion with drainage chambers visible. 80

Figure 4.4. Photos of the sampling pits and tipping buckets in 2013. Photos are: A. sampling and drainage pit with drainage pipe connected, B. Altering the sampling pit to make it deeper, C. Tipping bucket in position in the sampling pit, D. Tipping bucket. 81

Figure 4.5. Photos of the enlarged sampling pits in 2014. Photos are: A. Pipe directing drainage into tipping bucket located in larger sampling pit, B. Composite sample container located below the base of the pit, C. View of the whole sampling pit. 82

Figure 4.6. Diagram of the Submersible pump used at the Otama trench site. (Amended from Orchiston, T, 2015) 83

Figure 4.7. Submersible pump in use at the field site for the 2015 drainage season. 83

Figure 4.8. A, 2013 grazing of kale at Otama site; B, 2013 site post grazing. Plot on left was a 4 hour plot and plot on right was grazed for 24 hours. 84

Figure 4.9. Monthly average air temperature (°C, 9 am) from the Gore weather station for 2015 (red line) and the 30-year-average from years 1980-2010. Grazing occurred on the 30th June (Green arrow) and the duration of the trial and drainage monitoring was 5th May until 23rd October (grey arrows and bar). Average air temperatures didn't exceed 6°C until mid-September (dashed blue lines). 91

Figure 4.10. 2015 monthly rainfall figures for: the trial site (Site; measurements from 10 April to 18 Dec, missing data replaced with Gore NIWA data), NIWA Gore weather station number 5778, and 30-year-average data 1981-2010 for the Gore NIWA weather station number 5778. 92

Figure 4.11. Drainage volumes and weather data for the Otama experimental site for the period of measurement in 2015. Daily rainfall and dual crop evapotranspiration (ET_C) are plotted along with SWB-predicted cumulative drainage (160 mm). 92

Figure 4.12. Daily evapotranspiration values from Gore met station data (ET_0; blue dots) and calculated using the dual crop coefficient (ET_C; crosses) method described by Allen *et al* (1998). Values reported are from the start of the recorded 2015 drainage period until the end of drainage measurements (May 1 – October 31) 93

Figure 4.13. Cumulative drainage from the 8 field plots from the first recorded drainage event (1st May) until the 31st October 2015 when drainage recording stopped. The SWB prediction for drainage is shown by the black dashed line. 94

Figure 4.14. Average drainage nitrate-N (NO_3-N) concentrations: 24 hour (red line) and 6 hour grazing treatments (blue line). Cumulative rainfall is shown by the green line and cumulative drainage by the purple line. Grazing occurred on the 30th June (green arrow). The date of the first peak in concentration post-grazing is 12/8/16 and the second peak is 16/10/16. The cumulative drainage at the point of grazing was 92 mm and is shown by the bottom blue dashed line, the final drainage value was 174 mm, represented by the top blue dashed line. 96

Figure 4.15. Average drainage Ammonium-N (NH_4-N) concentrations: 24 hour (red line) and 6 hour grazing treatments (blue line). Cumulative rainfall since the previous sampling is shown by the black bars. Grazing occurred on the 30th June (green arrow). The date of the first peak in concentration post-grazing is 12/8/16 and the second peak is 16/10/16. The cumulative drainage at the point of grazing was 92 mm and is shown by the bottom blue dashed line. The final drainage value was 174 mm, represented by the top blue dashed line. 97

Figure 4.16. Cumulative nitrate-N leached (kg/ha) for each plot from the first leachate sampling (6st May 2015) until the last leachate sampling (19th October) before drainage recording stopped (31st October). Dashed lines represent the 6 hour grazing treatment and solid lines are the plots grazed for 24 hours. Values are generated from measured drainage volumes and measured concentrations. Three plots have not been included due to their low captured drainage volumes, suggesting a physical fault in the trench. 98

Figure 4.17. Cumulative ammonium-N leached (kg/ha) for each plot from the first leachate sampling (6st May 2015) until the last leachate sampling (19th October) before drainage recording stopped (31st October). Dashed lines represent the 6 hour grazing treatment and solid lines are the plots grazed for 24 hours. Values are generated from measured drainage volumes and measured concentrations. Three plots have not been included due to their low captured drainage volumes, suggesting a physical fault in the trench. 98

Figure 4.18. Average cumulative drainage for in-field channel lysimeters at Otama, grazed for either 6 or 24 hours. Grazing occurred on the 30th June (green arrow) and peak nitrate-N concentrations in drainage occurred on 16th October (black arrow) after 0.93 and 1.02 pore volumes of drainage occurred for the 6 and 24 hour treatments, respectively 101

Figure 4.19. SWB predicted drainage for the Otama channel lysimeter site from 1 May 2014 until June 2015. Green arrows depict the grazing events and the orange arrow the timing of cultivation of the crop paddock. The dashed blue lines represent increments of one pore volume of drainage. 102

Figure 4.20. Experimental results for the Otama experiment: 6 hour (yellow crosses) and 24 hour (blue crosses) grazing treatments on a Fodder Beet crop. Results are compared to those by Monaghan *et al.* (2013) in the years: 2006 (red dot), 2007 (green dot) and, 2008 (grey dot). Compared data represents a one 24-hour grazing event on kale. 103

Figure 5.1. Trial locations for two stages of portable pad field experiments and paddocks on the Invermay deer farm grazed by cows during the second stage experimental period. 108

Figure 5.2. Photos of initial portable pad trial. A. pad layout with impermeable liner and 3 surfaces, B. Kura matting, C. rolled rubber, D. impermeable liner, E. bunding of sides, F. final pad, G. cows on matting, H. cows on Cowmax™ 110

Figure 5.3. Photos of winter portable pad establishment. A. the site prior to pad establishment, B. creating a base for the pad, C. the pit dug to house storage for the liquid effluent. 112

Figure 5.4. Schematic diagram of the portable pad design 113

Figure 5.5. Portable pad showing side bunding and electric fence (Kura matting is shown stacked on the left of the photo). 114

Figure 5.6. Attachment site for Hobo logger used to record cow lying times. The logger is housed in a pouch which is then attached to the leg by a strap and velcro (shown above). .. 116

Figure 5.7. Urine sensor attached to a cow and cow cover for urine data collection 118

Figure 5.8. Chain measurement of determining a quantitative value for determining surface roughness for crop paddocks 119

Figure 5.9. 'De Crap ItTM scraper used to scrape solid effluent from the portable pad 121

Figure 5.10. Mob average daily lying times for cows on the Stage 1 portable pad trial surfaces of Cowmax™ and Kura matting. 123

Figure 5.11. Rainfall during the main portable pad experimental period (2013). Red boxes denote the periods when the urine sensors were used. 124

Figure 5.12. Daily swede intake and residual per cow averaged for the Control mob (a) and the Pad mob (b). 126

Figure 5.13. Relationship between swede allocation and swede intake of cows grazing swedes in winter. Both the 24-hour and 6-hour grazed results are presented. Intake is increased as allocation increases ($P < 0.001$) 127

Figure 5.14. Body condition score of cows at start, mid and end-points of the portable pad trial for both the Control (n=20) and Pad cows (n=20). The goal of a 0.5 gain in BCS is shown by the green bar. 128

Figure 5.15. Average daily lying times of cows in two alternative winter management systems, traditional crop grazing and restricted crop grazing plus stand-off. Values are averaged over the animals in each mob with loggers (total 20 animals) and compared with daily rainfall (mm). Blue dotted line depicts the minimum recommended daily lying time. 129

Figure 5.16. Measured bouts of lying down of cows either in a winter crop grazing system or the portable pad system; (a) average number of lying bouts per day and (b) the average number of minutes per bout. 130

Figure 5.17. Average amount of nitrogen excreted at different times during a 24 hour period for Control animals (average of 393 events from 14 cows). An average urine concentration of 8.4 g N per urination event. The arrow depicts the time when cows were offered a new swede break. The orange bar is the period of time that *ad lib* baleage or hay was offered. . 133

Figure 5.18. Average amount of nitrogen excreted at different times during a 24 hour period for Pad animals (average of 200 events from 14 cows). An average urine concentration of 8.6 g N per urination event. The blue box depicts the period of time cows were on the crop paddock and the orange bar the time *ad lib* baleage or hay was offered. 134

Figure 5.19. Surface roughness class for crop paddocks grazed by Control (24-hrs-a-day grazing) and Pad (6-hrs-a-day grazing) mobs and daily rainfall for the measurement period of 25th June until 23rd July 2013. 134

Figure 5.20. Diagram depicting nitrogen cycling in the portable pad system. Inputs (feed and rainfall) and outputs resulting in effluent, urine and dung deposited either on the pad or the paddock over the two month field experimental period. 139

Figure 5.21. Diagram depicting nitrogen cycling in the traditional crop wintering system. Inputs (feed and rainfall) and outputs resulting in urine and dung deposited on the paddock over the two month field experimental period. 140

Figure 6.1. Map of the lower South Island of New Zealand depicting the locations of the Southland and South Otago regions whose climate data is presented in Table 6.2. (Source: Topomap) 145

Figure 6.2. Cross-sectional diagram of the drainage plot structure at the Telford trial site. A drainage pipe is located at 70 cm depth lain on a clay pan. 40 cm of pea gravel sits above the drainage pipe with 30 cm topsoil above that. The sides of the plot were lined with plastic. 149

Figure 6.3. Photos of (A) the collection pit (A) and (B) tipping buckets and sample collection containers. Note that the stilling wells in the photo were removed prior to the trial commencing. 150

Figure 6.4. Schematic diagram of half the low depth experimental site depicting the irrigated and non-irrigated areas of each plot. 151

Figure 6.5. Photos of the effluent irrigation system including the storage tanks and shed to house the generator (A), the timers used to control application depths to each plot (B), collection of a composite FDE sample (C), flow meter (D) and irrigation nozzle (E). 152

Figure 6.6. Daily average soil temperature (0-10 cm depth) for the experimental site. 158

Figure 6.7. Average daily soil moisture for the experimental site 158

Figure 6.8. Soil water balance results from the whole plot area. Application depths were modelled as the average application over the whole plot. Thus, application depths of effluent were 1, 2, 2, 3 and 5 mm for the 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments, respectively. Modelled using corrected Met data (see Table 6.11) 160

Figure 6.9. Average whole plot treatment drainage results and individual whole plot results compared with whole plot SWB modelled results for the period of 21 June 2012 until 8 September 2012. Each treatment is plotted separately: (a) Control, (b) 2 mm daily, (c) 2 mm, (d) 5 mm, (e) 7 mm, and (f) 12 mm effluent applied to the irrigated area daily unless rainfall exceeded 4 mm in the preceding 24-hours. 161

Figure 6.10. Modelled (SWB) and measured drainage for Control (a) and 1 mm daily (b) treatments using the experiment site rainfall data for the period 13-16 July 2012, the time period is indicated by the red boxes. 162

Figure 6.11. Analyte concentrations in drainage and effluent from the irrigated area of the treatment plots. Drainage concentrations were calculated based on measured values that were corrected for background drainage from untreated plot areas: (a) ammonium-N, (b) NO2 + NO3 , (c) Mineral-N (ammonium-N plus NO3 + NO2-N), (d) Dissolved organic nitrogen (DON). DON was not measured in the effluent applied. 163

Figure 6.12. Nitrogen losses in drainage over 92 winter days in response to varying effluent application depths. 165

Figure 7.1. Schematic representation of the nitrogen cycling processes within the *SoilN* module (within the large blue box) and interactions with other modules (*AgPasture* and *Surface OM)* and manager scripts (*Fertigation Continuous)*. Adapted from, Probert *et al.* (1998), page 7. 173

Figure 7.2. Source Verburg *et al.* (1996) page 3. Components of the soil water and solute balances addressed by SWIM2; P = precipitation, R = runoff, I = infiltration, U_w = water uptake, U_S = solute uptake, T = transpiration, E = evaporation, D = drainage, L = solute leaching, Ir = irrigation/fertigation, N = nutrients/fertiliser, ΔS = storage, S = solute source/sink 177

Figure 7.3. Monthly long-term average rainfall data for the three South Island locations used in the APSIM simulation of LRLD irrigation of effluent. 180

Figure 7.4. Measured and modelled cumulative drainage from the artificial drains of the LRLD experiment site for the different treatment application depths. Error bars represent one standard deviation. (Unadjusted $R^2 = 0.93$ for model's explanation of measured values). 187

Figure 7.5. Measured and modelled ammonium-N (NH_4-N) concentrations in the captured drainage from artificial drains under different effluent irrigation depths. Treatments were: (a) Control (nil effluent), (b) 1 mm daily irrespective of rainfall rule, (c) 1 mm, (d) 2 mm, (e) 3 mm, and (f) 5 mm. Treatments c, d, e & f were subject to a rainfall rule where no application of effluent occurred if there had been ≥ 4 mm rainfall in the preceding 24 hours. 188

Figure 7.6. Average concentrations of ammonium-N measured in drainage (◆) and APSIM-modelled results prior to (■), and following (▲), lowering *exco* in APSIM to better account for ammonium-N losses via preferential flow pathways. 189

Figure 7.7. Measured and modelled nitrate-N ($N0_3$-N) concentrations in the captured drainage from artificial drains under different depths of low depth effluent irrigation. Treatments were: (a) Control (nil effluent), (b) 1 mm daily, (c) 1 mm, (d) 2 mm, (e) 3 mm, and (f) 5 mm. Treatments c, d, e & f were subject to a rainfall rule where no application of effluent occurred if there had been ≥ 4 mm rainfall in the preceding 24 hours. 190

Figure 7.8. APSIM simulated Nitrogen leaching losses from daily effluent applications of 2 mm day $^{-}$1. Effluent concentration was 200 mg L^{-1} NH_4^+-N, 0.60 mg L^{-1} NO_3^-N, 400 mg L^{-1} organic-N and the maximum total load per hectare was 84.1 kg N. Once the maximum load was reached applications moved to another paddock. Application periods (7 days) for each paddock (1-10) are indicated by the horizontal bars. The soil used in this simulation scenario was a Tokomairiro silt loam and the climate data was NIWA climate data for Telford, New Zealand for the year 2000. Annual rainfall was 751 mm in 2000. 194

Figure 7.9. Cumulative total N leaching from the first 3 paddocks, of a Tokomairiro soil, to receive effluent. Comparison is made between a dry climate (yellow lines), an average climate (blue lines), and a wet climate (red lines). Paddock 1 (solid lines) received effluent 1-7 June 2000, paddock 2 (dashed lines) received effluent 8-14 June 2000, and paddock 3 (dash, dot lines) received effluent 15 – 21 June 2000. 195

Figure 7.10. Cumulative total N leached from paddock 1 for two different climates (dry – solid line; wet – dashed line) and 5 different soil types; the heavy soils: Tokomairiro (grey), Waikoikoi (yellow), Pukemutu (green) and the stony soils: Gore (red) and Lismore (blue) soils. Simulation year was 2000. 196

Figure 7.11. Depth of rain falling on each effluent application area following the first day of effluent application for that area. Year was 2000 and the rainfall region was Telford. 197

Figure 7.12. Simulation of average N leaching losses and total land areas required when the effluent collected from a portable pad system (100 cows wintered) is directly irrigated to adjacent pasture using a low rate, low depth effluent irrigation system. Results compare three soil types (Tokomairiro – 'Toko', Lismore – 'Lis', Gore), three rainfall regions (L-rain, M-rain, H-rain) and three effluent concentrations (L-eff, M-eff, H-eff). A further scenario (reduN) of a lower total N load ha^{-1} was simulated for the low rainfall region. 199

Figure 7.13. Decision tree of the relative risks of N leaching losses associated with applying the low rate low depth irrigation system under different scenarios. Red is high risk, Amber some risk, Green low risk. Low concentration effluent (Total N around 100 mg N L^{-1}) would be similar to FDE, high concentration similar to effluent obtained from a portable pad (around 2000 mg N L^{-1}). Early application in the first 2 weeks of June and late application from 15 June onwards. This assumes a constant maximum N load over the scenarios. 202

Figure 7.14. (a) The relationship between number of pore volumes (to 45 cm) drained and total N lost in drainage (averaged over 10 years) in poor/imperfectly drained soils, $R^2 = 0.9355$, and (b) the relationship between the number of pour volumes drained and the total N lost in drainage in stony, freely drained soils, $R^2 = 0.3002$ 203

Figure 8.1. *OVERSEER* predictions of whole farm losses for the 4 farm wintering system scenarios modelled over four soil types (two shown in the figure; poorly drained Pukemutu and stony Gore soils) and for two climates, Telford rainfall region with 717 mm annual rainfall (a) and Woodlands rainfall region with 1156 mm annual rainfall (b). 215

Figure 8.2. Screen print of *OVERSEER* crop rotation table (a) and N pools graph (b) for first year cow crop block from the base farm scenario of a stony Gore soil and a Woodlands rainfall climate (1156 mm yr^{-1}). The first 12 months the paddock is in pasture, conventional cultivation and crop sowing occurs in November of the first year, grazing occurs during June-Aug of the second year, it remains fallow for September and October, then cultivated using minimum till in the second November for a second-year winter crop. 224

Figure 8.3. Screen prints of *OVERSEER* generated 'Change in N pool graphs'. Graphs are of the wintering crop blocks for both the base scenario and the pad scenario under a Woodlands climate and on a Gore soil type. Both first and second year cropped paddocks are shown. The pad scenario depicts a restricted grazing scenario where cows graze 6-hours-a-day compared to the base farm scenario where they graze 24-hours-a-day. Note the graphs on the left have a Jan-Dec scale whereas the graphs on the right have a Nov-Oct scale. 225

Figure 8.4. Plotted values of percentage N leached against N application load in urine deposited by cows grazing forage crops. Values are from fodder beet (red and green points; 11 months of measurements) and kale (blue points; 9-10 months of measurements) lysimeter experiments conducted on a Balmoral stony soil (Malcolm *et al.* 2015; Malcolm *et al.* 2016). Rainfall (r) and drainage (d) values for the individual trials are depicted on the graph. The dashed green line represents the percentage loss from an applied N load of 418 kg N ha^{-1}. 229

Figure 8.5. Comparison of *OVERSEER* predicted and 'Combined Source' values for the base and portable pad scenarios. Results are presented for the Pukemutu and Gore soil types and under a Telford (a; 717 mm rainfall yr^{-1}) and Woodlands (b; 1156 mm rainfall yr^{-1}) climate. . 232

Figure 8.6. Whole farm system losses for the base, portable pad and barn scenarios. *OVERSEER* values are replaced with 'Combined Source' predicted losses for crop blocks and blocks receiving LRLD effluent. Results are presented for the Pukemutu and Gore soil types and under a Telford (a) and Woodlands (b) climate. 233

Figure 11.1. Diagram of wintering barn and sampling location points. 1-3 represent high traffic areas, 4-6 are medium traffic areas and 7-9 are low traffic areas. 265

Figure 11.2. Average bedding moisture content of night, medium and low traffic areas within the Telford wintering barn in winter 2014. 266

Figure 11.3. Barn bedding moistures, over time, at different locations throughout the barn and at two depths at each location. A top layer of the bedding was removed on 15/7/14 and replaced with a layer of fresh bedding. The moisture of the bedding removed was 73% and the bedding added was 62% (top two blue lines). The bottom blue lines show the moisture % (54% and 56% of the bedding stored to go in to the barn for the next season. 267

Figure 11.4. Loose-housed barn with bark and sawdust bedding on (a) the first day of winter (mid-May) and (b) mid-July. 267

Figure 11.5. Barn surface condition at the end of winter (Aug) for A) low and B) highly trafficked areas 268

Figure 11.6. Fresh barn bedding from two different sources. Wetter and larger woodchips on the left; drier and smaller, more uniform chips on the right. 269

Figure 11.7. Percentage net mineralisation of applied manure N during laboratory incubation of soil amended with manure that had been applied fresh or stored for periods of 2.5 months (short), 12 months (long) or fresh amended with urea (+N) during trial establishment. Results were adjusted to account for the net mineralisation in the control treatment and for the N added as urea to the +N treatment. Variation in s.e.m was high over days 1-14 (average 21%) but lower for the remainder of the trial (average s.e.m was 6% for days 21-100). 274

Figure 11.8. Calculated concentrations of TP, DRP, SS and *E. coli* in leachate and effluent. Leachate concentrations were calculated based on measured values that were corrected for background drainage from untreated plot areas. 277

Figure 11.9. Phosphorus losses in leachate over 92 winter days in response to varying effluent application depths. 280

Figure 11.10. Total measured *E. coli* loss in leachate over 92 days of winter in response to daily effluent applications of varying depths (2012). 280

List of Tables

Table 2.1. A summary of the, primarily New Zealand based, literature related to the effects of climate, space allowance, surface type, surface moisture on the lying times of dairy cows 25

Table 2.2. Reported capital costs of establishing wintering barns 29

Table 2.3. Measured values for effluents 32

Table 2.4. The amounts of nitrate leaching measured under crop wintering trials 47

Table 3.1. Concreted areas of the Telford farm that contribute rainfall runoff to the effluent system 61

Table 3.2. Tests and method of analysis conducted on barn bedding samples at a commercial laboratory. 64

Table 3.3. Effluent streams and products entering and leaving the effluent collection pond in 2013 and Jan-Aug 2014 (m^3). Actual figures measured or calculated and also figures calculated per cow. 70

Table 3.4. Annual quantities and nutrient concentrations of Nitrogen for the different effluent sources generated from a loose-housed wintering barn 71

Table 4.1. Channel lysimeter treatment (6 or 24 hour grazing), crop sown, and date of grazing for the Otama experiment. 84

Table 4.2. Number of sample collected per month for each of the trial years. 85

Table 5.1. Table of events for the period of time lying time loggers were used to monitor cow movements 116

Table 5.2. Chain test classification criteria adapted from the work of Saleh (1993) and used in an AgResearch SOP for a measurement of soil roughness using a chain test. 120

Table 5.3. Pros and Cons of the different surfaces trialled for use as a portable pad surface 122

Table 5.4. Laboratory results for ME, TKN and DM of feed components 124

Table 5.5. Feed intakes of swede and supplement of the Control and Pad mobs for the duration of the trial. 125

Table 5.6. Overall and monthly average mob lying times for cows either grazing swedes 24/7 (Control) or cows held on a portable pad for 20 (June) or 18 (July) hours per day and grazing swedes *In situ* the remainder of the time (Pad). 129

Table 5.7. Mob average lying bout data. Average number of bouts per day and average bout duration (in minutes). 131

Table 5.8. Urinary measurement data for cows and days where there was a 24-hour period of data recorded 132

Table 5.9. Nutrient concentrations of solid effluent scraped from the pad and sampled from the scraped pile weekly. Values reported on a day matter basis (samples n = 9) 135

Table 5.10. Nutrient concentrations of liquid effluent collected from the pad and sampled from the storage tanks weekly. (samples n = 9) 136

Table 5.11. Cost of portable cow wintering pad technology (assume 9 m^2 cow-1 including bunding) 137

Table 6.1. Winter growth rates and milk production in different regions of New Zealand (DairyNZ 2011). 144

Table 6.2. 30-year average climate data for Southland (1-8) and South Otago (9, 10) sites, 1970-2000. The map location reference numbers can can be seen on the map in Figure 6.1 (NIWA 2015a) 145

Table 6.3. Comparison of effluent storage requirements for winter-generated effluent with and without the use of a low depth effluent application to pasture over winter 147

Table 6.4. Site climate and pasture growth rate data during the experimental period (2012) 148

Table 6.5. Block randomisation of the 18 experimental plots 153

Table 6.6. Volumes and loads of nitrogen applied to treatments. Values represent cumulative loads per hectare applied over the 92 day season (and average load applied per application in brackets) and were derived from eight composite effluent samples taken during the season. 154

Table 6.7. Dates that drainage and effluent samples were taken and the number of days in each sampling period for the low depth effluent application experiment 156

Table 6.8. Monthly rainfall for June, July and August from a range of sources: data recorded at the experiment site in 2012, local NIWA met station (No. 5867) data for 2012 and, 30-year average rainfall data from the same met station for four 30-year periods. 157

Table 6.9. Volumes of FDE applied and drainage from the plots during the experimental period 159

Table 6.10. Comparison of measured verses SWB predicted drainage totals for effluent applications to land of a range in treatment application depths 159

Table 6.11. Rainfall values recorded at the field site for the dates 13 July until 16 July and the met station data used to replace the questionable field site values. 162

Table 6.12. Average nitrogen concentrations of the applied effluent and drainage from the control, 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments. NO_3-N, nitrate-N; NH_4^+-N, ammonium-N, DON and dissolved organic N..164

Table 6.13. Mineral-N, TP, DRP, SS and *E. coli* yields in drainage from the plots and total amounts applied for the period 18 June until 12 September 2012. 165

Table 6.14. Figures adapted from estimates provided by Logan Bowler (DairyNZ) for the cost to build a pond of 1189 m^3. Fixed costs are marked with an asterix, a non-liner relationship between cost and pond size was assumed following L Bowler's advice 166

Table 7.1. Climate data from three lower South Island locations of differing annual rainfall patterns. Sites were selected to represent a low. Medium and high rainfall region within Southland. Annual rainfall, site co-ordinates and average daily temperature are given........179

Table 7.2. Physical characteristics of the 6 soils (7 scenarios including 2 versions of Waikoikoi soil; with and without drains) taken from Smap datasheets prepared by Landcare Research www://smap.landcareresearch.co.nz/home. FDE, farm dairy effluent 182

Table 7.3. Attributes of the soils used for simulations of effluent irrigation. Hydraulic properties for the Tokomairiro_LRLD soils were taken from field measurements conducted on-site (see text above). Values for the other soils were based on data from the New Zealand national soils database (NZ NSD), complemented with pedotransfer functions (PTFs) (Cichota *et al.* 2013b; Vogeler *et al.* 2011) . K_{SAT}, saturated hydraulic conductivity; PAW, plant available water..183

Table 7.4. List of factors used to generate base and simulation runs, using APSIM, for low rate, low depth application of effluent to land (LRLD). Underlined figures are the factors used for extrapolation of the base simulation to the wider range of soils and climates. 184

Table 7.5. APSIM model outputs of N leaching losses and percentage losses of N applied for daily applications of farm dairy effluent (FDE) to land over winter (FDE scenario) Average values are over 10 years, min and max values are the lowest and highest annual losses from the 10 years modelled. 192

Table 7.6. Simulation of effluent concentrations generated by a portable pad under different rainfall inputs. Calculated concentrations of effluent N for three rainfall regions: Low 701 mm yr^{-1}, Med 908 mm yr^{-1}, and High 1082 mm yr^{-1} and the resulting N load (kg N ha^{-1}). The land area required for 100 cows if applications occur from June 1 until August 10 are presented. Scenario names are used in the headings for Figure 7.12 and Figure 7.13. 198

Table 7.7. APSIM model outputs of N leaching losses per 100-cows and effluent applied (kg N 100-$cows^{-1}$). The percentage of N applied N lost in drainage are given. Results are presented for three rainfall regions (low, med, high), three soil types (Tokomairiro, Lismore, Gore) and for four scenarios (Low, med and high effluent concentration with 80 kg N ha^{-1} max load and a reduced N max load). 199

Table 8.1. Monthly pasture growth rates used for *Farmax* modelling (kg DM/ha/day) (Dalley & Geddes 2013) 208

Table 8.2. Outputs from *Farmax*. Those used as inputs for *OVERSEER* are marked with an asterix 209

Table 8.3. Farm block managements for base farm, those that change in portable pad or barn scenarios are marked with an asterix 211

Table 8.4. Simulated values for silage fed and utilised by dairy cows in a wintering barn. Values differ between the predicted values in *Farmax* and the allowed value in *OVERSEER*. The resulting change in cow BCS over the winter period as predicted by *Farmax* in response to the different feed levels is presented. The target change in BCS was +0.5. 212

Table 8.5. Regional climate data predicted by *OVERSEER* using the 'climate station tool' 213

Table 8.6. Screen prints of *OVERSEER* nutrient budget scenario reports for Nitrogen. Nitrogen added to and lost from the system for the base, pad and barn scenarios for both the Telford (717 mm rainfall yr^{-1}) and Woodlands (1156 mm rainfall yr^{-1}) climates are presented for (a) the Pukemutu soil and (b) the Gore soil........ 217

Table 8.7. Values for N loss to water derived from APSIM modelling (Chapter 7; Figure 7.12) to improve predictions of N leaching losses from LRLD effluent application to land in winter at a low (Telford; 717 mm) and a high (Woodlands; 1156 mm) rainfall. Applications of effluent to a poorly drained Pukemutu soil and a freely drained Gore soil occurred for 70 days, from 1 June until 10 August. *OVERSEER*-predicted N losses for the young stock block (with the addition of winter applied effluent using LRLD) and predicted values accounting for the APSIM modelled results for LRLD are given........ 221

Table 8.8. Description of non-urine patch losses from winter grazed brassica crops. A comparison between *OVERSEER* modelled results and measured results in the literature of; crop type, non-urine patch N leaching losses, rainfall input, drainage volume, and reporting period........ 224

Table 8.9. *OVERSEER* predicted N leaching losses (kg N ha^{-1} yr^{-1}) from winter crop paddocks split into 'leaching - urine patches' and 'leaching – other' losses. Values for the portable pad and base farm scenarios are presented. 231

Table 8.10. *OVERSEER* and 'Combined Source' predictions for nitrate losses (kg N ha^{-1} yr^{-1}) for the whole farm. Results are for 3 farm wintering system scenarios (Base, Pad and Barn). Also 2 soil scenario variations (Pukemutu and Gore) and 2 climate scenario variations; a low rainfall region (Telford; 717 mm rainfall) and a high rainfall region (Woodlands; 1156 mm rainfall). 234

Table 8.11. Partial budget of estimated costs (per cow) related to working expenses differ between the two systems. Where costs are similar they have not been included (e.g. labour). 236

Table 11.1. Woodchip bedding surface management strategies adopted during 2012-2014 period on Telford farm and their effectiveness at minimising barn bedding moisture and longevity. 269

Table 11.2. Details of experimental treatments imposed in the laboratory Incubation (soil amended with cow barn manure) using carbon-based wintering barn manure. 272

Table 11.3. Chemical attributes of the three barn bedding manures (stored for different periods of time) used in a laboratory Incubation experiment designed to measure net rates of N mineralisation in soil amended with cow barn bedding material. 273

Table 11.4. Average nutrient concentrations of the applied effluent and drainage from the control, 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments. NO_3-N, nitrate-N; NH_4^+-N, ammonium-N, DON, dissolved organic N; TP, total phosphorus; DRP, dissolved reactive phosphorus; SS suspended sediments; counts of *E.coli*, Escherichia coli. 278

Table 11.5. Mineral-N, TP, DRP, SS and *E. coli* yields in drainage from the plots and total amounts applied for the period 18 June until 12 September 2012. 279

List of abbreviations

ACTH	Adrenocorticotrophic hormone
Ad lib	Ad libitum
APSIM	Agricultural Production System SIMulator
AWHC	Available water holding capacity
BCS	Body condition score
BMP	Best management practice
C	Carbon
C:N	Carbon:Nitrogen ratio
Ca	Calcium
CEC	Cation exchange capacity
CON	Control herd
CRH	Corticotrophin releasing hormone
DCD	Dicyandiamide
DIP	Dissolved inorganic phosphorus
DM	Dry matter
DON	Dissolved organic nitrogen
DRP	Dissolved reactive phosphorus
E.coli	*Escherichia coli*
EB	Exchangeable bases
ET	Evapotranspiration
ES	Environment Southland
FDE	Farm dairy effluent
FMO	Faecal micro organism
HPA	Hypothalamic-pituitary-adrenal axis
in situ	In the original place
K	Potassium
KCl	Sodium chloride
K-line	™ a flexible hose line and sprinkler pod irrigation system
LRLD	Low rate, low death
LW	Liveweight
Mg	Magnesium
Mineral N	Ammonium-N + nitrate-N
MJME	Metabolisable energy
MPN	Most probable number
MS	Milksolids
N	Nitrogen
N_2O	Nitrous oxide
NH_4^+	Ammonium
NO_3^-	Nitrate
OM	Organic matter
OPT	Optimal herd
ORC	Otago Regional Council
P	Phosphorus

P21	Pastoral 21 research programme
PAW	Plant available water
QT	Quick test
RES	Restricted herd
RI	Refractive index
S	Sulphur
SR	Stocking rate
SS	Suspended sediments
SU	Stock unit
SWB	Soil water balance
TBS	Total base saturation
TKN	Total kjeldahl nitrogen
TSE	Total solids

1. Research Introduction

Winter is an important season in New Zealand pastoral dairy farm systems. This represents the period of late pregnancy, when cows are not milking, arranged to coincide with the winter period with nil or slow pasture growth. In the southern South Island 'Wintering' usually occurs in a 10-week period from late May until calving in early August (Monaghan *et al.* 2013). At this time, pasture growth rates for Southland average 11 kg DM ha^{-1} day^{-1} in June and 6 kg DM ha^{-1} day^{-1} in July (DairyNZ 2011). In response to these low pasture growth rates in winter farmers have traditionally grazed cows on brassica crops. This involves removing cows from the pastures of the milking platform, often to a support block that can be many kilometres from the milking platform with its associated sheds and stand-off areas, with the aim of increasing pasture covers for the start of spring and to have cows at targeted body condition scores (BCS) for calving and early lactation. In addition, this support block can be leased land rather than owned so the option of capital investment in permanent stand-off structures or effluent storage is not always available. The benefits of this wintering system are that the brassica crop is a relatively low-cost feed that can be grazed at high stocking densities and provides a reliable winter feed source. Additionally, it does not require high capital inputs. There are however, disadvantages to this system. Grazing at high stocking densities during winter, combined with high winter rainfall and excessively free-draining soils, or fine textured soils and sloping land, can result in high contaminant losses (Nitrogen (N), Phosphorus (P), *E.coli*, suspended sediment(SS)) to water (Chrystal *et al.* 2012; Monaghan *et al.* 2002; Orchiston *et al.* 2013; Smith *et al.* 2012). Concern over these contaminant losses to water, particularly from Regional Councils and regulatory bodies, has resulted in increasing use of off-paddock systems, such as barns or stand-off pads, for dairy cow wintering. These systems have the benefit of removing cows from paddocks at a time of the year when the risk of contaminant loss to water is high. Effluent is captured and stored and thus able to be applied to land at more favourable times of the year. However, wintering barns and standoff facilities generate large volumes of manure and effluent products that must, at some point, be managed (Houlbrooke *et al*, 2012). The characteristics of the manure and effluent, and their immediate nutrient values, differ between and within systems (Longhurst *et al*., 2012) and they are not easily estimated or calculated. While off-paddock wintering systems (e.g. Barns) are able to reduce the contaminant losses from the wintering component of the system if the farm production is not increased, it has been reported that in the majority of situations this is not the case (Newman & Mashlan 2015). This is because in response to the high capital costs of building an off-paddock wintering facility, farmers generally increase their farm production (increased cow numbers or production per cow) to help off-set this cost. In a survey of 14 farms Journeaux and Newman (2015) conclude that intensifying the farm to make the barn profitable results in “a rapid erosion of the environmental benefits”.

Thus, it can be seen that existing wintering systems in southern New Zealand, both on and off-paddock, have their individual advantages and disadvantages. Currently there is no simple solution available to farmers to reduce the environmental impact of, or easily change their, wintering systems. Thus it is important that researchers seek alternative solutions while, at the same time, provide information and mitigation strategies for existing wintering systems. In periods of low cash surpluses for dairying, high-cost solutions for reducing contaminant losses in winter are particularly unappealing to farmers. Therefore, a low-cost stand-off that reduces contaminant losses to water, whilst utilising the low cost brassica crop as a feed source, is urgently sought. This PhD aims to develop such a system and then compare and contrast N leaching losses from the new system, the existing crop system and an example of an off-paddock system (deep-litter wintering barn).

i. A brief comparison between the New Zealand dairy system and regulatory environment and examples of overseas systems

In order to fully understand the need, or benefit, for alternative wintering systems it is helpful to have an understanding of the New Zealand dairy industry and the regulatory environment, in relation to contaminant losses, that farmers’ are operating under and how these differ to dairy systems overseas. The New Zealand dairy industry is an unsubsidised, predominantly pastoral-based, seasonal supply industry that operates under a low-cost, low-input, low-intensity system. This compares to the more intensive housed systems found overseas in countries such as the USA, UK and Europe. New Zealand cows are smaller and lower producing that the Holstein Friesians found overseas (Horan *et al.* 2004). They are ideally suited to the NZ system which requires them to walk long distances, calve annually and efficiently convert pasture into milk. For a New Zealand dairy farm to successfully run an intensively housed system requires a complete change in the farm system including the genetics of the livestock (March *et al.* 2017).

Ideally, in response to high nutrient losses to water from the wintering component of the NZ brassica crop system, to bring all animals indoors, at least during winter, to get them off-paddocks. However, this requires a large capital input and in an unsubsidised environment this often results in intensification of the system to justify the cost of the structure (Journeaux and Newman, 2015). In addition, intensive housed dairy systems and the feed supply activities required to support them can have greater negative environmental impact compared to pastoral based systems. A lifecycle assessment (LCA) was conducted on two Irish dairy systems comparing a grass-based dairy system to a confinement system. That work indicated that the grass-based system can have a lower environmental impact than the confinement system per litre of milk produced or farmed area (O'Brien *et al* 2012). The higher environmental impact from the confinement system came from the higher resource use, the production of concentrate food compared to pasture, and the storage of manures. Another desktop study compared ammonia emissions from a pasture based NZ system with a confinement system in the UK and found that N input was 1.7 times higher in the UK system than the NZ system with more sources of ammonium losses identified in the UK system (57 vs 24 kg N ha^{-1} ammonium losses) predominantly from the housing phase, specifically manure storage (Jarvis & Ledgard, 2002).

In terms of incentives or methods for ensuring environmental targets are met, New Zealand has historically worked on a best management practice (BMP) and voluntary system for meeting environmental targets. However, since the introduction of the National Policy Statement on Freshwater Management there is more of a mandatory requirement for farmers to meet baseline (or higher) water quality targets as set at a national level but implemented regionally by regional councils. In comparison both the UK and the US encourage compliance via a number of methods including voluntary and mandatory methods as well as financial incentives for farmers (McDowell *et al* 2016). No financial incentive schemes are available in New Zealand for farmers meeting or exceeding nutrient limits.

ii. An outline of the regulatory environment in southern New Zealand

In terms of regulatory bodies, the two regional councils relevant to this body of work are Environment Southland (ES; www.es.govt.nz) and the Otago Regional Council (ORC; www.orc.govt.nz). At the time that this work commenced there was no mandate on N leaching or contaminant losses to water from ES. However, they had indicated that there would be possible restrictions coming in the future. Environment Southland, as part of their 'Water and Land 2020 & Beyond' project, separated the Southland region into nine physiographic zones to better understand the causes of water quality variations (Environment Southland, 2016a). This allowed them to identify and target higher risk areas. The current proposed plan for Southland (under Rule 20 – Farming; Environment Southland, 2016a, p49) will change dairy farming from a permitted activity to a 'not permitted activity' in the three most at risk zones. Gradually, between 30 May 2018 until 30 May 2020, consent will be required for dairy farming and intensive winter grazing in all zones, where it will be a discretionary activity that needs to meet compliance standards. This means that farmers wishing to carry out these practices will be required to comply with a number of rules including; (1) obtaining a discharge consent for effluent that specifies the maximum number of cows for the property, (2) no increase in the number of cows beyond the maximum number in the discharge consent, (3) a Management Plan must be prepared and implemented and, (4) the area is not in the Alpine physiographic zone. In addition to the rules regarding dairy farming and intensive winter grazing there are further rules specifically related to intensive winter grazing (Rule 21 – Intensive winter grazing; Environment Southland, 2016a, p52). These involve the requirement that all farmers prepare and implement a Management Plan, no intensive winter grazing is to occur in alpine zones, another 2 high risk physiographic areas are allowed only 20 ha of intensive wintering grazing and the rest of Southland is allowed only 50 ha before a consent is required. In order to intensively graze in winter on land areas greater than these it is deemed a 'restricted discretionary activity'. In contrast, the ORC is setting limits for nitrogen, phosphorus and *E. coli* for different locations within Otago (ORC, 2014). In terms of nitrate leaching, their rules relate to a N leaching value determined by the nutrient budgeting tool *OVERSEER* (Wheeler *et al*, 2003) and the limits are: 15 kg N ha^{-1} yr^{-1} for a yellow mapped Nitrogen Sensitive Zone, 20 kg N ha^{-1} yr^{-1} for an orange mapped Nitrogen Sensitive Zone, and 30 kg N ha^{-1} yr^{-1} for remaining areas. The ORC have not stipulated how farmers' are to farm their land as long as the annual average losses of N leached from the system do not exceed the values listed above.

1.2 Overarching hypotheses for literature review

1. A knowledge framework can be developed that quantitatively characterises key components of, and the interactions within, different types of dairy wintering systems in the Southern South Island.
2. This framework can be utilised to identify gaps in knowledge and develop management strategies that deliver reduced environmental and improved economic outcomes.

The literature review in Chapter 2 has focused on published research and reports that provide a quantitative description of wintering systems and experimental and modelling studies that have been undertaken to assess the impact of nutrient losses from these systems on environmental quality. A large range of gaps in system design and quantitative data have been identified. Three of these areas have been chosen as research objectives for this PhD study.

1.3 Structure of this PhD

This PhD was structured with the end target of being able to compare and contrast N leaching loss from three different wintering systems. The three systems were:

1. Traditional winter crop
2. An example of a barn system (a deep litter barn with a woodchip bedding was selected).

3. A new system that would be developed that incorporated grazing of a brassica crop along with a period of confinement to an off-paddock structure (portable pad).

The resulting work is presented in this thesis:

- Chapter 2. A review of the literature.
- Chapter 3. A wintering barn effluent stream quantification and characterisation.
- Chapter 4. Nitrogen losses from winter grazed crop on stony soils: the use of a channel lysimeter to measure N leaching under restricted (6 hr) and unrestricted (24 hr) grazing.
- Chapter 5. Two field experiments investigating the portable pad concept.
- Chapter 6. A field experiment investigating contaminant losses in drainage water from liquid effluent applied to pasture during winter using a low depth irrigation system. N leaching losses are presented in this this chapter. Phosphorus, suspended sediment and *E. coli* losses are in presented in Appendix 11.3.
- Chapter 7. Extrapolation of the results from Chapter 6 to include low rate and low depth irrigation to a number of soils and climates, using APSIM modelling.
- Chapter 8. Modelling and comparison of three wintering systems: crop, wintering barn with woodchip bedding, and portable pad, using *Farmax* and *OVERSEER*.

A conceptual diagram of the general PhD structure and content is depicted in Figure 1. The relationship between experiments and chapters along with the associated research questions are shown. Two experiments that were conducted are included as appendices as they were not critical for the modelling component of this thesis.

1.4 Gaps in knowledge and researchable problems

1.4.1 Winter crop systems

Winter grazing on crop is seen by many as an undesirable activity with respect to water quality (Section 2.4.3.1), soil physical damage (Section 2.5.4.1) and animal welfare (Section 2.2.2.2). However, for farmers, there are many benefits offered by winter brassica crops. For example brassica crops grown on stony, excessively drained soils often yield well and there is reduced soil physical damage (when compared to fine textured soils). Winter brassica crops are used as part of the pasture rotation and do not require the same capital input or staffing during winter that many off-paddock systems require. Due to the financial and social reasons why farmers choose to winter cows on brassica crops rather than in off-paddock systems it is important to continue to develop mitigation strategies to help reduce contaminant losses (particularly losses of N to ground water) from this system. It is important that these mitigation options still enable farmers to graze brassica crops *in situ*, are low cost, but are able to reduce contaminant losses to water. The **aim** of this section of work is to quantify the losses of N to ground water from excessively free-draining soils (Chapter 4) and to develop a method of restricted duration grazing to reduce these losses of N (Portable Pad trial, Chapter 5).

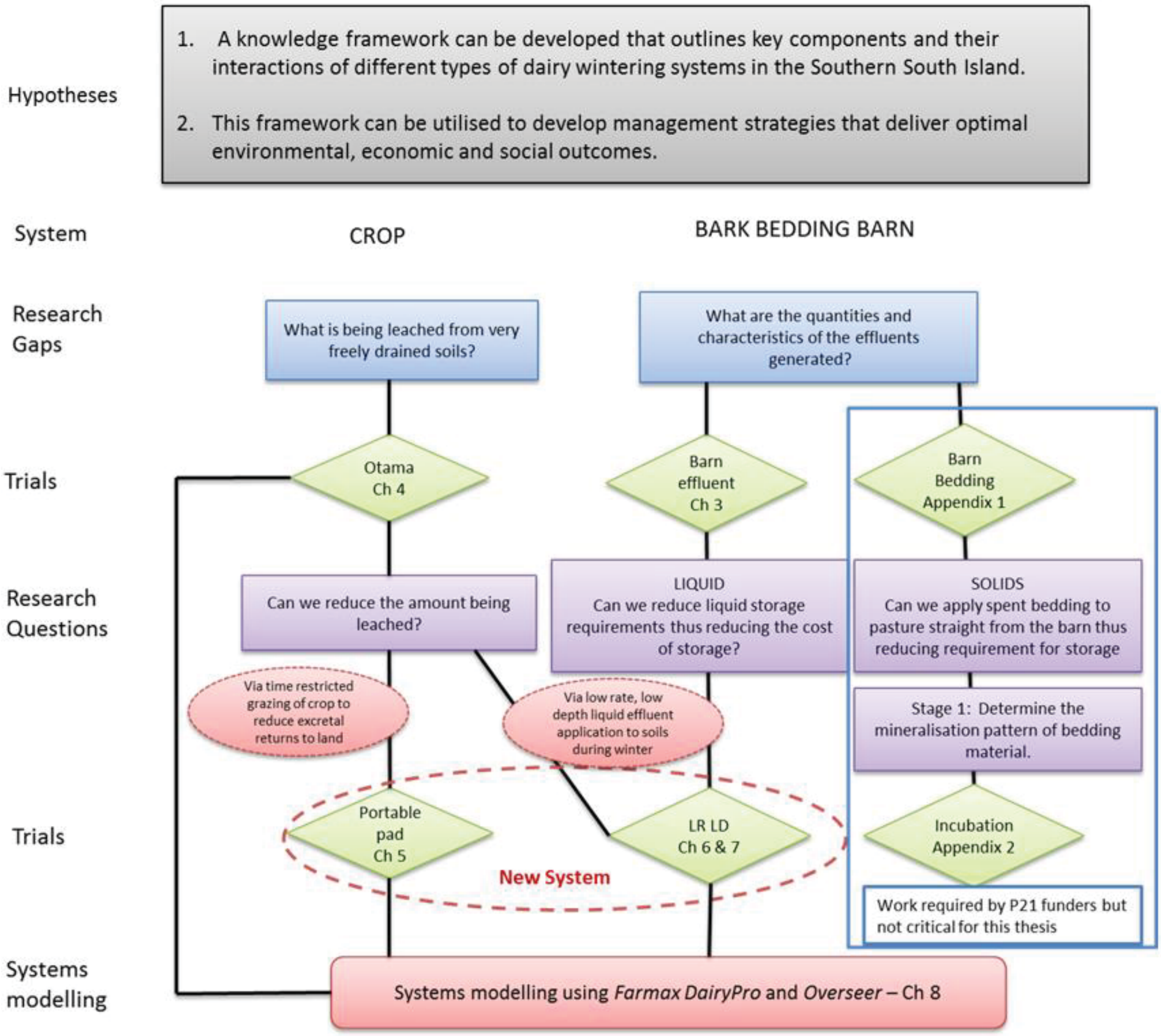


Figure 1.1. A conceptual diagram of the relationship between the different experiments and chapters of this PhD. The new wintering system is shown by the red dashed lines.

1.4.1.1 Research questions

1. What are the losses of N to ground water from winter grazing of crops on excessively free-drained soils? (Chapter 4).
2. Is it possible to reduce the losses of N from winter grazed crops grown on excessively freely-drained soils by development of a mitigation strategy? (Chapter 8 – bringing together results from Chapters 4, 5, 6 and 7).

1.4.1.2 Specific research objectives

1. Quantify losses to water from winter grazing of brassica crops on stony excessively-drained soils.

1.4.2 Winter off-paddock systems

Off-paddock systems are used to house dairy cows over winter for a variety of reasons including an attempt to reduce nutrient losses to the environment. There is little information regarding the amount of effluent and manure (hence forth referred to as 'effluent' to describe both liquid and solid products) produced by these off-paddock systems or the characteristics of the effluents produced and thus their fertiliser value. This creates problems identifying the size of effluent storage required and the best management practice when utilising the effluents in land application for their fertiliser value. This question is addressed for one particular off-paddock barn type (loose housed barn – with a deep-litter woodchip bedding) in the wintering barn effluent chapter (Chapter 3). Use of off-paddock systems can generate a liquid effluent stream that must be responsibly managed. This effluent must be stored and then either applied to land or exported. The capital cost of building new, or increasing storage capacity of existing, ponds poses the risk of some farmers opting to apply liquid effluent to land over winter rather than store it until conditions are more favourable for land application. One **aim** of this section of work is to develop a method of applying liquid effluent to land over the winter period in a way that reduces contaminant losses to ground water and is a system that is financially and practically feasible. This is addressed in the Low Depth trial outlined in Chapter 6 where N leaching losses are presented (P, SS and *E.* coli loss data is presented in appendix 11.3) and investigated further in Chapter 7 where APSIM modelling was conducted to investigate N losses from winter applied liquid effluent (using a low rate, low depth application technique) over a range of soil types and climates.

1.4.2.1 Research questions

3. What are the volumes and nutrient concentrations of winter captured effluent from different wintering systems? (Chapter 3).
4. What is the fate of nutrients applied during the winter as liquid effluent? (Chapters 6 and 7)

1.4.2.2 Specific research objectives

2. Quantify the volume and nutrient concentration of effluents generated in two contrasting wintering systems (an existing deep litter barn, and the proposed portable pad).
3. Quantify losses to water of contaminants (N - Ch 6; Phosphorus, suspended sediment and *E. coli* – Appendix 3) from winter applied liquid effluent, when managed with low depth irrigation technology. Extrapolate the field results of N leaching losses from a low depth irrigation field experiment, using APSIM, to include low depth and low rate over a number of soil types and climates.

1.4.3 A potential new system – Portable pad

As part of this PhD the potential of a system that makes use of the benefits of the crop wintering system and also the benefits of an off-paddock system will be investigated. The benefits of the crop are that is it a cheap feed source that cows can graze *in situ*. It is also valuable as part of the pasture rotation. As it is possible for cows to consume their daily crop intake in much less than 24 hours it may be possible to take them off-paddock for the remainder of the day and capture their excreta, thus making use of the benefits of an off-paddock system in reducing nutrient losses to water. However, because crop paddocks change from year-to-year (often as part of the pasture renewal programme, and to avoid pests and diseases caused by continual cropping) and are often on a Support Block (often leased) many kilometres from the Milking Platform, it is not always feasible to have them located near to a fixed wintering facility. The high capital cost of a permanent wintering facility may also be a deterrent to many farmers.

The new innovative system is the development of a Portable Pad technology where a low cost, low input system (that meets animal welfare requirements and enables the capture of excretal nutrients during the winter) is developed (presented in Chapter 5). The plan is for this technology to incorporate two main aspects:

1. An impermeable liner to capture effluent overlain by a suitable surface for cow comfort and durability (Chapter 5),
2. A low rate effluent irrigation system for the safe return of liquid effluent to land (Chapters 6 & 7).

Benefits of the proposed system include the low set-up costs, the ability for farmers to use low-cost winter brassica crops for winter feeding, and the portability of the system enabling farmers to re-locate the pad around their farm in different years as the crop paddocks used for winter brassicas change.

The new system is then compared to a crop and a barn scenario in a final modelling chapter (Chapter 8) where the three systems are modelled in *Farmax* and *OVERSEER* and N losses to water are compared. Modelled analysis results are supplemented with experimental data where it was found that modelled results did not match measured or where the *OVERSEER* model did not have the capacity to model new systems components (such as the low rate, low depth application of effluent to land over winter).

1.4.3.1 **Research questions**

5. Are there alternatives to current wintering systems?
6. Can the different wintering system N leaching losses be compared?

1.4.3.2 **Specific research objectives**

5. Develop a new low-cost alternative to wintering off-paddock that utilises the brassica crop as a feed source.
6. Provide N leaching loss values for three contrasting wintering systems: crop, wintering barn and new system.

1.5 Authors contribution to the different research projects

This PhD project was supported by AgResearch (50%) and funding from the Pastoral 21 research fund (P21) under Objective 4 – '*Next Generation Dairy Systems - Southland*' (50%). For this reason there was a significant body of work that was required to be conducted to meet agreed Pastoral 21 project objectives.

The hypotheses for the P21 '*Next Generation Dairy Systems - Southland*' were that: "reduced environmental footprints and increased profit can be achieved on Southland & Otago dairy farms by pursuing 2 broad strategies:

1. Implementing a set of management practices that optimise the current production system that relies on a forage brassica crop for animal wintering. These practices include increasing cow feeding allowances over winter, using short rotation ryegrasses and whole crop cereal silage to increase feed availability, calving later and strategically grazing critical source areas to minimise farm runoff.
2. Utilising off-paddock systems (a loose housed barn) to add value to the farm business by protecting soils and animals during wet periods, thus increasing pasture growth rates and animal performance whilst also avoiding the deposition of animal excreta to pastures or crops during high risk times of the year."

1.5.1 Specific P21 objectives for component research contributed to by this thesis

Objectives for July 2013 – June 2014 included:

1. *"Evaluate the merits of applying liquid effluent generated from a wintering barn (and its associated infrastructure) to grazed pastures, during winter, using low-rate, low-depth application methods."*

And

2. *"Refine the decision principles and* ***management*** *of the barn that will allow maximum value to be extracted from the loose housed barn facility used by the Restricted Grazing herd."*

Objectives for July 2014 – June 2015 included:

3. *"Complete a second year of measurements evaluating the merits of winter-applied effluent, generated from a wintering barn and its associated infrastructure, to grazed pastures using low-rate and low-depth application methods. A more concentrated effluent typical of that derived from a covered barn facility will be used and compared with findings from 2013 when pond effluent was applied to the experimental plots."*

Objectives 1 and 2 above dictated the direction of the work required to be conducted under the contract with the funding supplier. Objective 1 resulted in the low depth field experiment and the low rate low depth APSIM modelling work presented here in chapters 6 and 7, respectively. This work led to further work conducted by Dr Seth Laurenson under objective 3 above. Objective 2 (specifically, the **management** required) resulted in three experiments investigating aspects related to the wintering barn and the associated manures. Only the quantities and characteristics of effluents and manures work is included in the body of the thesis (Chapter 3). This data was to be used when investigating the low rate low depth irrigation concept. The volumes and concentrations of effluents produced are required for modelling purposes. The remaining two trials required by the investors and conducted by the author (barn bedding moisture and an incubation trial investigating the mineralisation rate of barn bedding) are included in the appendices as they were not required for the modelling systems analysis in this thesis.

Additional support from AgResearch PreSeed funding provided for the two portable pad experiments and AgResearch funded the authors time for the modelling required in Ch 8 and writing.

1.5.2 Author's contribution to the work in this thesis.

Chapter	Funding	Authors contribution (Project management was conducted by the author for all trials)	Constraints
Chapter 3 Barn	P21	Established monitoring protocol, established sampling schedule, under took sample collection in conjunction with other AgR staff. Sample analysis was conducted by the author and other Invermay based Technicians for *E. coli* and Phosphorus plus the extractions for mineral N analysis. Mineral N analysis was conducted by Stuart Lindsay at AgResearch Ruakura.	The requirement to measure quantities and characteristics of effluents and manures was set by the P21 research team. Continuing changing of farm staff, relying on farm staff to capture some information, some reluctance by farm staff for science involvement, all posed difficulties in the successful collection of data.
Chapter 4 N leaching on stony soils	AgResearch	Design and establishment of the trenches was done as a team. Sample collection was done by the author and others. The site is a full day return trip from Dunedin so samples were collected by other staff who were passing the site and by staff based at the Woodlands campus as this was closer. Design of the submersible pump was done by Tom Orchiston, AgResearch, as part of an AgResearch Curiosity Fund project. Site disestablishment was conducted by a team including the author.	Initial funding constraints requiring a last minute change from submersible pump to tipping buckets. Considerable distance to the site (over 2.5 hours' drive each way).
Chapter 5 Portable pad	AgResearch PreSeed	Design of pad dictated by author with help from farm staff in the practicalities of building it. The majority of the monitoring was conducted by the author with specialist help for animal handling, urine sensor use and where more than one person was required.	Requirement to use existing crop paddocks on the Invermay farm which restricted location of the pad. Trial disestablishment was not conducted by the author due to being on Maternity Leave.

Chapter 6 Low depth field experiment	P21	Trial design concept was established as a team, trial establishment and sample collects were a team effort with the author co-ordinating the trial and selecting the irrigation system for use. The pumping system and remote dial up was established by Tom Orchiston (AgResearch) and Scott Technical. Sample analysis was conducted by the author and other Invermay based Technicians for *E. coli* and Phosphorus plus the extractions for mineral N analysis. Mineral N analysis was conducted by Stuart Lindsay at AgResearch Ruakura. Site disestablishment was conducted by a team including the author.	Using an existing trial plot. Distance to the trial site and time constraints combined with an initial need to manually start the irrigation pumps meant that a high application rate system was required
Chapter 7 LRLD APSIM modelling	P21	Help from Dr R Cichota in building the base APSIM model and in learning how to use APSIM. Scenario testing conducted by the author.	
Chapter 8 Modelling	AgResearch	100% own work	

2. Review of the literature regarding dairy wintering systems used in southern New Zealand and the associated nutrient losses to the aquatic environment.

2.1 Introduction.

This review covers the literature related to dairy wintering systems in southern New Zealand focusing on the losses of contaminants, predominantly Nitrogen (N), to water. The review begins by describing the current wintering systems in use in southern New Zealand, for example traditional brassica crop grazed *in situ* and off-paddock systems such as wintering barns and wintering pads. Next animal welfare, relevant to cow wintering, is reviewed. Animal welfare is an important consideration when assessing the success of a farming system as it is important not only that environmental losses are minimised, but also that animal welfare is not negatively impacted. There is a large body of literature relating to the welfare of animals that is relevant for wintering systems, however, there is a scarcity of literature pertaining to the welfare of cows in a practical farming situation without heavily controlled conditions. The review then focuses on off-paddock systems and the generation of effluent products. Volumes and characteristics of effluent generated by the different systems are reviewed although, again, there is scant literature available. The review then focuses on losses of N and phosphorus (P) to water. Firstly a brief description of the principles of water movement through the soil is given, followed by examining the N cycle in soil and the principles of nutrient transport from land to water focusing on N and P losses. Following this, quantification of the measured N and P losses from different systems is given. While it is acknowledged that sediment and *E. coli* losses are also contaminant losses to water from wintering systems, they are not covered in this review. The impact of each wintering system on soil, plant and production is briefly reviewed. The main body of the literature review culminates in the development of a knowledge framework, which outlines the key components, and their interactions, in different types of wintering systems in the southern South Island (Hypothesis 1; Chapter 1, section 1.2). Finally gaps in the literature are identified and a brief outline of the proposed area of research concludes the chapter.

2.2 Dairy cow winter management Systems

Grazing brassica crops is currently the most common practice in southern New Zealand for wintering dairy cows. This system produces a disproportionately large fraction of total farm contaminant losses (N, P, suspended sediment (SS) and faecal microorganisms) to the environment (Monaghan *et al.* 2007b). There are alternative off-paddock wintering systems available that involve standing cows off paddocks (e.g. wintering pads, loose-housed barns, free-stall barns) that may considerably reduce losses of these contaminants to the environment. These systems are complex and varied with a range of options in: wintering facility structure, bedding type, effluent storage system, effluent treatment system and the method of return of effluent products to land. In this section the different wintering systems are outlined (Section 2.2.1), in addition the animal welfare issues related to each system are investigated (Section 2.2.2) as are the relative costs of some of the systems (Section 0).

2.2.1 Current wintering options: Crop, shelters/barns, off-paddock systems

2.2.1.1 Crop wintering – the most common system used historically and currently

Brassica crop wintering is described by Monaghan *et al.* (2013) as an "animal practice (that) normally occurs over a 10 week period during winter and is seen as a cost-effective strategy for providing required amounts of winter feed and avoiding animal treading damage to soils and pastures during wet and cool winters in southern New Zealand." The reason that this strategy has been developed in southern New Zealand is that it protects the availability of pasture on the milking platform and "the condition of cows in the spring" (Beukes *et al.* 2011). The problem with the current wintering system of grazing brassica crops *in situ* is that these systems are becoming increasingly less acceptable from an environmental perspective (Beare *et al.* 2006; Clark *et al.* 2007; McDowell *et al.* 2003b; Monaghan *et al.* 2007a). It has been estimated that the brassica wintering component may potentially provide 60% of the total dairy system N leaching loss, from only 15% of the whole farm system area (Monaghan *et al.* 2007b). These large losses from the wintering component of the system arise partly from urinary N deposited onto the grazed crop area (usually bare soil) during the winter when grazing occurs and plant uptake of N is low (Beukes *et al.* 2011; Monaghan *et al.* 2013), and partly from large amounts of residual mineral N in the soil after crop establishment in the spring (Beukes *et al.* 2011; Monaghan *et al.* 2013). Urinary N losses from a grazed swede crop (with baleage supplement) have been measured and were 68 % and 76 % of N intake under standard and high feeding allowances, respectively (Stevens *et al.* 2011). The N intake of the two treatments was 270 and 282 g cow^{-1} day^{-1} for the standard and high groups, respectively. Crop yield was 12 t ha^{-1} and comprised 28 % leaf at a crude protein of 24.7 and DM of 13.3 %, and 72 % bulb at a crude protein of 8.2 % and DM of 11.4 %. Feed allowances were 8.1 and 10.6 kg DM cow^{-1} day^{-1} of swede for the standard and high treatments, respectively, and 4 kg DM cow^{-1} day^{-1} of baleage (to both treatment groups) containing 16.7 % crude protein and 27 % DM (Stevens *et al.* 2011). The urinary N concentration measured was 4.33 and 4.46 g L^{-1} for the standard and high treatments, respectively. Total N excreted (urine and dung) was 90 and 94% of the N intake and the difference was assumed to be contained in an increase in the BCS of the cows accumulation of N in the mammary gland and developing foetus (Stevens *et al.* 2011).

In addition to losses of N, loss of P and SS to surface waters can be increased by crop grazing practices (McDowell 2006). Winter grazed brassica crops also have limitations in terms of: animal welfare (where reduced lying times have been recorded (Dalley *et al.* 2012; Fisher *et al.* 2003)), and public perception (Goulter 2010).

2.2.1.2 **Pasture – an alternative grazed system**

Wintering on pasture is defined as "a wintering system based on autumn saved pasture supplemented with conserved feed"(Dalley *et al.* 2014). This system is not common in this region due to limited available land of a suitable soil type and the risk of a reliable feed supply. Farmers that do use this system tend to be on lighter soils where the risk of soil treading damage is less.

2.2.1.3 **Alternative wintering systems for Southland – Off paddock systems**

In Southland there is an increasing use of off-paddock systems to provide shelter during winter, to remove the need for winter forage crops, and to provide containment and control of effluent discharges into the environment. However, there is little regional data related to the environmental risks and benefits of these systems. These off-paddock systems include feed-pads, stand-off pads and herd shelters and these systems remove cows from pasture or crop for periods ranging from a few hours a day to 24-hours a day over the entire winter period. Studies conducted in other regions of New Zealand have shown that removing stock from pasture or crop during the winter months reduces soil damage and N, P and *E.coli* losses to water (Luo *et al.* 2008b; Luo *et al.* 2008c; McDowell *et al.* 2003a). Beukes *et al* (2011) have modelled 4 scenarios for Southland covering the wintering options of; crop, pasture, roofed structure and uncovered wintering pad. This modelling work examined the financial performance of the different scenarios over a 35 year period, however they did not model nutrient losses from the different systems.

i. Wintering pad

This is an unroofed area that is specially built to hold cows' 24-hours a day for the winter period. The wintering pad consists of a lying area covered in a bedding material that is free-draining over an impermeable base so that effluent is collected and stored (DairyNZ 2014). There is an adjacent feeding area where conserved feeds are fed. This is often a concrete strip alongside the pad with a feeding alley or it may be a self-feeding silage stack on a concrete pad. This area also drains to an effluent storage area.

ii. Loose housed barn – slatted concrete floor

Dalley *et al* (2014) define this as "a fully covered facility, usually with a plastic film over a frame type roof and a concrete slatted floor covering an effluent holding bunker, large enough to hold the effluent/manure for extended periods”. There are variations in these barns including the use of rubber mats over the slats, or straw over the concrete or mats. Cows are fed on a concrete strip alongside the barn.

iii. Loose housed barn – bedding material.

This is another example of a fully covered facility with a variety of roofing types. The base is a carbon-based soft bedding such as straw, bark, woodchips or sawdust (Journeaux & Newman 2015). Liquid effluent is absorbed in the bedding and any excess drains through to an effluent collection system. Manure is collected in the bedding material and ‘fresh’ bedding is required to be added frequently to reduce the moisture content of the bedding. Feeding is via a concrete feeding strip adjacent to the facility. Effluent from the feeding alley must be captured and stored.

iv. Free-stall barn

“A fully covered facility (with) a concrete floor area for cows to move around freely and an area providing individual spaces (cubicles - stalls) for cows to lie down on a softer surface”(Dalley *et al.* 2014). The barn design is such that excreta lands on the concrete lane areas and is scraped to an effluent storage area.

2.2.2 **Animal welfare measurements and issues**

There is no universal definition of animal welfare (DairyNZ 2009) however the New Zealand Veterinary Council defines it as “The state of well-being in which an animal is in reasonable harmony with its environment, has adequate fulfilment of physical, health, and behavioural needs and is not subjected to unnecessary or unreasonable pain or distress” (Anon (2006) referenced in DairyNZ 2009). It could be added to that definition that an animal is in a state of well-being in which it is maintaining adequate productivity.

Assessing animal welfare is an important consideration when analysing the success of an existing animal system, when developing a new system or when comparing systems. Assessing the welfare of dairy cows in winter is a large and complex field, however, the purpose of this section of the literature review is to narrow the investigation to suitable measurements of symptoms of acute and chronic stress that can be used in field trials to determine a level of risk associated with a particular wintering system. When looking at the literature there are common metrics to assess if there is risk to a dairy cows health and wellbeing.

These include;

- Normal activity (lying times, feeding times, stride length, gait score)
- Body Condition Score (BCS) or body weight

- Biochemical assays (plasma cortisol levels, metabolic activity, hypothalamic-pituitary-adrenal axis (HPA))
- Skin thickness
- Faecal cortisol levels
- Milk quality (mastitis)

Risks to the health and well-being of a dairy cow in a wintering system include:

- Climate (temperature, rainfall, wind speed, snow events)
- Availability of shelter
- Space allowance
- Bedding surface type
- Bedding surface moisture
- Feed allocation, feed type

2.2.2.1 Metrics to assess welfare risk

i. Relationship between two common metrics: Biochemical assays and Lying times

The hypothalamic-pituitary-adrenal axis (HPA) is "one of the primary adaptive mechanisms in response to adverse conditions or noxious stimuli" (Fisher *et al.* 2002). The HPA axis is a set of influences and interactions among the hypothalamus, the pituitary gland and the adrenal gland. The interactions among these organs is a major part of the neuroendocrine system that controls reactions to stress (Smith & Vale 2006). Hormones involved in the HPA axis are the adrenocorticotrophic hormone (ACTH) the corticotrophin releasing hormone (CRH) and cortisol and these can be measured by taking a blood sample from the animal. An initial short-term response to stress is an increase in cortisol secretion which is the body's way of mobilizing body reserves to cope with the stress and to regulate inflammatory response to an injury (Fisher *et al.* 2002). A long-term response to stressful stimuli results in "increases in glucocorticoid concentrations which has a detrimental effect on immune system function and growth"(Fisher *et al.* 2002). From a farming perspective these responses to stress will result in a reduction in production efficiency so it is in the best interests of a farmer to ensure their animals are free from stress, particularly chronic stress. In reviewing the literature there are studies where HPA axis hormones have been measured as a response to restricted lying times (Fisher *et al.* 2002; Tucker *et al.* 2007). Fisher *et al* (2002) found that lying restricted cows had increased basal plasma cortisol concentrations, reduced ACTH and cortisol responses after corticotrophin releasing hormone (CRH) challenge, and an increase in the plasma cortisol/ACTH ratio thus concluding that the restricted lying times resulted in a stress response by the animals.

Across the literature cow lying times (h/24h) is a common, important metric to determine the relative welfare of the animals under particular conditions. Eight hours lying within a 24-hour period is deemed the industry minimum acceptable period to meet the welfare requirements of a dairy cow. This figure is from the Dairy Cattle code of welfare, 2010, booklet that states under General Information "Research shows that cows prefer to lie down for between 8 and 13 hours each day" (MAF 2010). Other than the study of Fisher *et al* (2002) where the figure of 8.1 h day^{-1} was observed in unrestricted cows and related to a non-stress blood hormone response compared to 3.9 h day^{-1} in the lying deprived animals where there was a blood hormone stress response measured, it is difficult to find data to show at which time point dairy cows become stressed.

ii. Normal activity

Stride length and gait score can be used as an indication of the level of cow comfort on a particular surface (Schütz & Cox 2014) and also the risk of hoof injury or lameness.

Feeding times can be influenced by a number of factors in including weather and cow lying times. Schutz *et al* (2010) have shown that cows will restrict their feed intake by 62% when exposed to wind and rain as they sacrifice feeding time for shelter. Cows with restricted lying times during stand-off periods have been shown to sacrifice grazing time in preference for lying times (Fisher *et al.* 2003).

iii. Body Condition Score (BCS) or live weight.

Body condition score (BSC) is a strategic tool for both commercial herd management and research that is used internationally. Different countries have different scales with New Zealand using a 10 point system. A change in a cows BCS over a period of weeks can be used as an estimate of the cows nutritive intake relative to its dietary requirements. The period prior to calving (winter time on most New Zealand dairy farms) is a period of concern as the condition of the cow at calving has an impact on her lactation production and ability to get back in calf (Roche *et al.* 2004). In New Zealand a cow with a score less than 3.0 is considered emaciated while a cow with a score greater than 7.0 is considered obese. The industry aim is to have mature cows at a BCS of 5.0 at calving as cows calving at a BCS less than this will produce less milk and have an increased likelihood of reproductive problems (Macdonald & Roche 2008). BCS can be measured by a trained assessor as a relatively easy, non-invasive indication of the risk to an animal's welfare.

Animal live weight is a more difficult measurement to assess risk to the welfare of an animal when conducted on pregnant cows close to calving (winter period). Cows may increase in live weight but decrease in body condition as the pregnancy progresses.

2.2.2.2 **Wintering systems**

When narrowing the focus of cow welfare to the winter period and winter related farming practices the systems that are focused on are those where animals are outdoors (grazing crop or pasture) or potentially housed indoors or on an off-pasture system (e.g. crop, wintering pad, stand-off pad). There are a number of risks that potentially affect the welfare of an animal. The exposure of the animal to potential stressors can influence the cumulative length of time a dairy cow will lie down for within a 24-hour period. Stressors and lying times vary between systems and there are a number of New Zealand relevant bodies of work that investigate these; some of which will be outlined in Table 2.1. Cow lying times is another easy-to-measure, non-invasive indication of animal stress that has been observed as a response to many different factors as outlined in the sections below.

i. Pasture and outdoor systems in general

It is generally accepted that the New Zealand practice of grazing dairy cows outdoors does not compromise the lying behaviour of the animals under acceptable weather conditions (Fisher *et al,* 2003). This is evidenced by the work of Dalley *et al* (2012) where they recorded an average lying time of 11.9 hours with none of the observed animals not reaching the minimum recommended 8 hours day^{-1} (Table 2.1). In this body of work the authors recorded cow lying times on pasture, in winter, under a normal commercial situation with no experimental manipulation of the animals or the environment (other than the attachment of a logger to the leg of the cows). The recorded period was one week and the weather conditions, although not recorded at the site but taken from a nearby NIWA climate station, were mild with mean temperature of 6°C, wind speed of 8.9 km h^{-1} and only an average rainfall of 1.77 mm day^{-1}. A similar result was reported by Schutz *et al* (2015) where lying times of 11.2 hours day^{-1} on pasture were measured (Table 2.1). These periods on pasture, reported by Schutz, followed cows spending a week on a simulated stand-off system (on a range of surfaces) and this period on pasture was termed a "recovery" period. This figure may have a component of animals lying down as compensation of reduced lying times during the stand-off period.

New Zealand winter weather conditions can influence the lying times of cows outdoors (Schütz *et al.* 2010; Tucker *et al.* 2007; Webster *et al.* 2008). As well as impacting cows wintering on pasture and crop this also influences cows wintered on outdoor wintering pads and stand-offs. In a trial by Webster *et al* (2008) cows were exposed to a week of cold and wet conditions while on pasture and compared to cows housed indoors. Amongst other things they looked at lying times over 16 hours a day (1600 to 0800h; Table 2.1). While this data shows us the difference in lying times between the housed animals and those exposed to the cold and wet conditions it does not give an accurate value for the number of hours per day that an animal would lie down under these cold and wet conditions under normal farming practice (without yarding for experimental manipulations). The results do show that the animals exposed to the cold and wet conditions spent significantly more time standing than those housed indoors (P <0.001). Animals exposed to cold wet conditions lay down for 3.4 hours within that 16 hour monitoring period compared to the housed animals lying down for 8.2 hours (Table 2.1). In this study the authors found a reduction in white blood cells and suggest that the cold and wet stress resulted in this potential reduction in immunity and that this, combined with the reduction in lying times, could be more severe than in reduced lying time alone.

Schutz *et al* (2010) investigated the effects of short-term exposure to wind and rain on the behavioural and physiological responses of dairy cows. They found that cows will seek shelter in preference to feeding when exposed to rain. Cows appeared to be more adverse to rain or a combination of wind and rain than to wind alone. Cows were in a pen where weather treatments were simulated. The area of the pen allowed for 6 m^2 per cow, however half the pen was sheltered whereas the other half was not. This meant that in adverse conditions where animals sought shelter there was only the area of 3 m^2 per cow to lie down. 85% of all lying behaviour was in the sheltered area. There was a significant effect of the imposed weather treatments on lying times; although there was no treatment were animals were exposed to the wind and rain without shelter available. However, the lying times of 4.4 - 1.1 h compare well to the 3.4 h/16 h that Webster *et al* (2008) recorded and the 3.6-4.5 h Tucker *et al* (2007) reported (Table 2.1). Interestingly, this reduced lying time result in response to seeking shelter to avoid wind and rain is not seen in response to shade provided during a New Zealand summer. Tucker *et al* (2008) looked at varying degrees of shade on the behaviour of lactating dairy cows. They found that there was no effect on the lying time of cows under the conditions they measured suggesting that it is likely the temperatures were not high enough to cause a heat stress response. Their recorded lying times for cows ranged between 8.8 h and 9.5 h during summer with an average air temperature of 19.5°C and cows grazed on pasture with 5.25 m^2 cow^{-1} (Table 2.1).

ii. Crop

Historically, in southern New Zealand, dairy cows have been wintered on brassica crops grazed *in situ*. There is limited literature related to welfare measurements of dairy cows winter grazing brassica crop. However, particularly relevant to this present study is the work conducted by Dalley *et al* (2012). Here cow lying times were recorded under a range of wintering systems in southern New Zealand. A number of cows within a commercial herd were monitored for a period of 7 days using lying time loggers. Of particular interest were reported figures of the percentage of the cows not achieving the 8 hour recommended minimum daily lying time. This was the only literature found that recorded this metric along with the mob average lying time. Three crop farms were monitored and it appears from this data that the weather is a significant contributing factor to the lying times of animals on crop. While the crop paddocks all achieved an average of 8 hr day^{-1} (8.1-10.5h) the monitoring period for the farm with the lowest average daily lying time (plus 57% of the animals didn't reach the 8 h day^{-1} minimum) occurred during a week that was cold and wet (Table 2.1). Mean temperature was 4.1°C, rainfall during the 7 day period was 102.7 mm and mean wind speed was 25 km h^{-1} with a max gust of 60 km h^{-1}. The weather data was taken from regional data measurements rather than site specific data. Interestingly, a similar range in crop lying times was reported by Stewart (2002). Here three Southland commercial farms were monitored (12 cows per farm) for a period of 24 hrs. Average lying time was 11.17 h/24 h and ranged from 8.3 – 14.2 h (Table 2.1). Farmers did note that although the crop paddocks can become very muddy the cows were observed to lie close to the crop where the surface was drier than the rest of the paddock. Unfortunately, the weather conditions and a measurement of how muddy the crop paddock surface was during the monitoring period, was not reported.

iii. Woodchip

A New Zealand study looking at the effects of shelter and body condition on the behaviour and physiology of dairy cattle bedding on woodchip surfaces in winter found a significant effect of cow BCS on lying times (Tucker *et al.* 2007). The study compared cows with a low BCS (4 out of 10) with cows of a high BCS (9 out of 10) housed indoors on woodchip or outdoors on woodchip and subjected to artificial rain and wind to simulate cold and wet winter conditions. The cows with the lower BCS spent more time eating and less time lying compared to the cows with the high BCS in both the indoor and outdoor treatments. In addition, the authors found a significant difference in the lying times between the indoor and outdoor treatments. Cows indoors lay on average 11.2 -12.7 h. This compared to cows outdoors in winter conditions lying for an average of 3.6 - 4.5 h (Table 2.1). These results are in contrast to those found in other trials where lying times on outdoor woodchip pads were at least 11 hours per day (Dalley *et al.* 2012; Fisher *et al.* 2003; Schütz & Cox 2014). Comparing the trials to gain an understanding of the differences shows that per cow space allowance isn't likely to be the cause of the reduced lying times. Space allowance ranges from 4.9 m^2 per cow (in the Schutz *et al* 2014 trial where cows lay for an average of 11.2 hours) to 12 m^2 per cow when lying times averaged 11.2 hours per day (Dalley *et al* 2012). Cows in the Tucker *et al* (2007) study with the reduced lying times had 10 m^2 per cow. The different weather conditions appear to be the cause of the reduced lying times reported by Tucker *et al* 2007. In that trial animals on the pad were exposed to continuous winter conditions using sprinklers and fans that created 30-79 mm rainfall per day and temperatures were as low as -9.9°C with the wind chill factor (Table 2.1). The work by Dalley *et al* (2012) and Schutz & Cox (2014) reported low rainfall amounts and mild temperatures. While the trial conducted by

Fisher *et al* (2003) (where lying times were 11.9 hrs) applied 25 mm of simulated rainfall each day to the woodchip pad this was applied during the three hours that the animals were on their pasture break. Thus the effect of the wet bedding was simulated but not the effect of the rainfall on the animal.

Tucker *et al* (2007) highlight in their discussion the contrast between their lying time results and other literature. Their results show reduced lying times in cold conditions when compared to other International research results of increased lying times of cows in response to cold conditions due to the “heat-saving advantages associated with lying”. They reference the work of (Gonyou *et al.* 1979) as resulting in increased lying times of steers. The temperatures in that experiment were as low as -40°. These findings are not particularly relevant to New Zealand systems as they do not get the low temperatures with dry conditions that are found in other parts of the world. Other work that showed increased lying times in dairy heifers in response to a cold climate, provided a dry bedding area (Redbo *et al.* 2001). Tucker *et al* (2007) do point out the possibility that the wet ground conditions may have resulted in their observation of decreased lying times of the outdoor animals. This suggestion would appear to be supported by the findings of Webster *et al* (2008) of reduced lying times by cows exposed to cold and wet conditions.

iv. Outdoor Other

As well as effects of climate on lying times as reported under the outdoor systems of pasture, crop and woodchip pad there are a number of other surfaces used in an outdoor situation. A common New Zealand farming practice is to stand dairy cows off pasture during adverse weather conditions (for example periods of heavy rainfall). There are a range of surfaces that farmers utilise during this practice. Although this practice is not specifically a wintering system, as it relates to a short-term solution to adverse weather, the comparison between surfaces is potentially relevant as some of these surfaces are used in off-paddock wintering systems. For the surfaces investigated, the stand-off time or time on the surfaces was a short-period, not for the whole winter. On only one other outdoor surface did animals reach the 8 hour minimum lying time (along with woodchip) and that was 24 mm rubber matting (Table 2.1; Schutz & Cox 2014). Surfaces that did not reach the 8 hour minimum were: concrete (Table 2.1; Fisher *et al.* 2003; Schütz & Cox 2014), gravel-surfaced farm laneway (Fisher *et al.* 2003), small paddock (Fisher *et al.* 2003) and 12 mm rubber matting (Schütz & Cox 2014). In the trial conducted by Fisher *et al* (2003), the authors commented that by the end of the 4 days both the laneway and the paddock were very muddy and that while cows lay for longer on the concrete than the laneway, or the paddock, they did have reduced gait length compared with laneway and paddock animals. They also reported lower bodyweights and higher faecal glucocorticoid metabolic concentrations (suggesting a stress response on concrete) compared with the woodchip pad and paddock. The authors concluded that animals require a surface that is both well drained and comfortable. While only the woodchip and 24 mm rubber surfaces achieved the recommended 8 h minimum it has been suggested by Fisher *et al* (2002) that while stress-induced increase in blood cortisol can be seen in cattle during a short period of lying deprivation the same does not happen if the lying deprivation continues for a longer period of time and it may be that while the behavioural response (i.e. reduced lying times) can be observed there is a "physiological down-regulation" (i.e. the hormone response to the stress is not maintained over time). This would be good to keep in mind if the behavioural observations of cow lying times during winter (an extended period of time exposed to cold and wet conditions) are less than the minimum 8 hours.

Along with surface type and moisture impacting animal lying times the per cow space allowance can also have an impact. A New Zealand trial investigated the effect of space allowance on lying time of pregnant, non-lactating dairy cows held on rubber matting for 18 hrs day^{-1} with grazing for 6 hrs day^{-1} (Schütz *et al.* 2015). They found that cows in this situation should have a space allowance of at least 4.5 to 6 m^2 per cow. When cows had more space available they spent more of their lying time lying on the pad and less lying on pasture during their 6 hours daily feeding break. When cows were space limited they compensated for shorter lying times on the pad by lying when at pasture and this could potentially impact cow bodyweight and production due to a reduction in feeding time, particularly if animals are not offered feed during the off-paddock time.

v. Indoor systems

While the effect of climate is minimised by housing animals indoors there are other factors that influence cow lying times. These include bedding surface type, bedding surface moisture and animal space allowance. Cow surface types have been covered in the section on outdoor systems above. Bedding surface moisture level trials indicate that regardless of season (Reich *et al*, 2010) dairy cows prefer dry bedding over wet bedding (Fregonesi *et al.* 2007; Reich *et al.* 2010) evidenced by longer lying times on dry bedding compared to wet bedding although all lying times reported were over the 8 hour recommended minimum daily lying time. In research that gave animals a free choice of stalls with dry or wet bedding the cows spent 12.5 hrs day^{-1} lying in the dry stalls and only 0.9 hrs day^{-1} in the wet stalls (Table 2.1). Interestingly, the authors commented that while all cows increased the period of time lying down when in dry stalls compared to wet stalls, the magnitude of the difference varied widely between cows from only 40 minutes day^{-1} for one animal to 11 hrs day^{-1} for another. A further interesting point was that the additional time spent not lying was not spent eating with no significant difference between the time spent eating between groups (Fregonesi *et al.* 2007).

Space per cow can also impact cow lying times. Schutz *et al* (2015) conducted a controlled trial keeping all other conditions constant and concluded that animals on rubber mats required a space allowance of between 4.5 to 6.0 m^2 per animal when held on the matting for 18 hours per day with 6 hours per day grazing over a long period of time (for example the winter period). In contrast the trial conducted by Dalley *et al* (2012) monitored cows in a number of commercial situations rather than in a controlled trial. There were a range of indoor wintering systems investigated consisting of a Herd Home, a loose-housed barn, and a free-stall barn. There was a range in average lying times of off-grazing systems of between 8 and 9.7 hrs cow^{-1} and this range appears to be due to a combination of stocking density, surface type and possibly weather conditions. The cows in the herd home lay for 8 hrs day^{-1} with 63% of cows not achieving 8 hours. They had 3 m^2 cow^{-1} and the week the measurements took place was cold with a very high rainfall and snow events. These animals were also housed on a concrete slat floor overlain with a layer of straw. The cows in the loose-housed barn had a space allowance of 5.2 m^2 cow^{-1} and lay for an average of 8.5 hrs day^{-1} with 37% not achieving the 8 hr target. The lying times for these animals may have been influenced by the wet bedding conditions of a sawdust deep-litter bedding. Animal in the free-stall lay for an average of 9.7 hrs day^{-1} with only 10% not reaching the 8 hour target. These animals had 8 m^2 cow^{-1} and the barn had rubber matting as the bedding surface (Table 2.1). The free-stall design results in a drier bedding surface due to the design feature created to capture excreta in the laneways rather than on the bedded areas.

2.2.2.3 **Summary of animal welfare concerns in relation to different wintering systems**

The literature shows that animals exposed to different wintering systems in terms of climate, bedding surface type and moisture level, and space allowance are at risk of a reduction in their wellbeing. There are a number of animal based metrics that can be measured to gain an understanding of the risk of a negative impact on the wellbeing of the animal. When undertaking a trial comparing animal farming systems it is important to record some measures of the risk to animal welfare. In terms of this present study I have selected cow lying times as one metric to measure as there are a wide range of influences that impact lying times and it is a relatively non-invasive and low cost measurement to take. BCS is another metric that is important over the winter period to help set up a cow for the following lactation season and mating. Other options of biochemical assays, body skin thickness, body temperature and faecal cortisol levels require yarding of the animals and expertise in the collection of the data. For the purpose of the trial work in this present study it was felt that monitoring lying times and BCS over the winter period would assist in characterising the influence of the system on the animals' wellbeing.

Table 2.1. A summary of the, primarily New Zealand based, literature related to the effects of climate, space allowance, surface type, surface moisture on the lying times of dairy cows.

Reference	*Lactation state*	*Ave temp (°C)*	*Rainfall*	*Wind speed (kph)*	*Lying surface*	*Recording method*	*Lying time h/day*
Pasture							
(Webster et al. 2008)	Non-lactating, not pregnant	3.4	72 mm h^{-1}	7.1	Pasture 10 m^2/cow	Instantaneous scan sampling over 16 hrs	3.4 h over 16 h
(Fisher et al. 2003)	Non-Pregnant, Non-lactating		25 mm/day plus 76.5 mm during rep 1 or 28 mm during rep 2		Small paddock 30 m^2/cow	24 h video recordings using time-lapse	6.9 h
(Tucker et al. 2008)	Mid-lactation	19.5	6.2 mm/d	4.6	Pasture	Instantaneous scan sampling	8.8-9.5 h
Karin E. Schütz et al., 2015)	Pregnant, non-lactating	9.7	5.5 mm/9 d period		Pasture	Logger	11.2
(Dalley et al. 2012)	Pregnant, non-lactating	6.0	1.77 mm/7 day period	8.9	Pasture	Loggers for a 7 day period on 10 cows	11.9 h (0 % less than 8 h)
Crop							
(Dalley et al. 2012)	Pregnant, non-lactating	4.1	102.7 mm in 7 day period	25.2	Kale crop	Loggers for a 7 day period on 10 cows	8.1 h (57% less than 8 h)
(Dalley et al. 2012)	Pregnant, non-lactating	6.1	4.06 mm in 7 day period	10.7	Swede crop	Loggers for a 7 day period on 10 cows	9.6 h (0 % less than 8 h)
(Dalley et al. 2012)	Pregnant, non-lactating	6.1	4.06 mm in 7 day period	10.7	Fodderbeet	Loggers for a 7 day period on 10 cows	9.8 h (11% less than 8 h)

Reference	***Lactation state***	***Ave temp (°C)***	***Rainfall***	***Wind speed (kph)***	***Lying surface***	***Recording method***	***Lying time h/day***
Crop continued							
(Dalley et al. 2012)	Pregnant, non-lactating	6.1	4.06 mm in 7 day period	10.7	Swede (farm2)	Loggers for a 7 day period on 10 cows	10.5 h (0 % less than 8 h)
(Stewart et al. 2002)	Pregnant, non-lactating	Not reported	Not reported	Not reported	Crop – 3 commercial farms	24 hr video recording 10 min scanning	11.2 h ave, range 8.3-14.2h
Outdoor: Woodchip							
(Tucker et al. 2007)	Non-pregnant, non-lactating	4.9 with wind chill -9.9	mm/d 30-79		Outdoor – woodchip 10 m^2/cow	Instantaneous scan sampling	3.6 h – 4.5 h
(Dalley et al. 2012)	Pregnant, non-lactating	6	1.77 in 7 day period	8.9	Wintering pad – bark chips. 12 m^2/cow	Loggers for a 7 day period on 10 cows	11.2 h (0% less than 8 h)
(Schütz & Cox 2014)	Pregnant, non-lactating	8.0	6.2 mm		Woodchip pad 4.9 m^2/cow	Lying time loggers	11.2 h
(Fisher et al. 2003)	Non-Pregnant, Non-lactating	7.8-17.3 and 9.1-19.0	25mm/day plus 76.5mm rep1 or 28 mm rep 2		Woodchip pad 11 m^2/cow	24 h video recordings using time-lapse	11.9 h
Indoor: Woodchip							
(Tucker et al. 2007)	Non-pregnant, non-lactating	5.6 with wind chill -3.1	Indoor		Indoor – woodchip 70 cm 10 m^2/cow	Instantaneous scan sampling	11.2 h – 12.7h
Outdoor: Other							
(Fisher et al. 2003)	Non-Pregnant, Non-lactating		25mm/day day plus 76.5mm rep1 or 28 mm rep 2		Gravel-surfaced laneway 11 m^2/cow	24 h video recordings using time-lapse	5.7 h
(Schütz & Cox 2014)	Pregnant, non-lactating	8.0	6.2 mm/d		Concrete 4.9 m^2/cow	Lying time loggers	3.3 h

Reference	***Lactation state***	***Ave temp (°C)***	***Rainfall***	***Wind speed (kph)***	***Lying surface***	***Recording method***	***Lying time h/day***
Outdoor: Other continued							
(Fisher et al. 2003)	Non-Pregnant, Non-lactating		25mm/day day plus 76.5mm rep1 or 28 mm rep 2		Concrete yard 4 m^2/cow	24 h video recordings using time-lapse	7.0 h
(Schütz & Cox 2014)	Pregnant, non-lactating	8.0	6.2 mm/d		12 mm rubber matting over concrete 4.9 m^2/cow	Lying time loggers	6.9 h
(Schütz & Cox 2014)	Pregnant, non-lactating	8.0	6.2 mm/d		24 mm rubber matting over concrete 4.9 m^2/cow	Lying time loggers	8.1 h
(Schütz et al. 2015)	Pregnant, non-lactating	9.7	5.5 mm/d		24 mm rubber matting range of space allowances 3 m^2/cow – 10.5 m^2/cow	Continuous recording by logger	7.5 – 13.8 h
Indoor: Commercial scale							
(Dalley et al. 2012)	Pregnant, non-lactating	Indoor			Herd Home, slatted-floor, 3.7 m^2/cow	Loggers for a 7 day period on 10 cows	8.0 h (63% less than 8 h)
(Dalley et al. 2012)	Pregnant, non-lactating	Indoor			Loose housed barn, sawdust, 5.2 m^2/cow	Loggers for a 7 day period on 10 cows	8.5 h (37% less than 8 h)
(Dalley et al. 2012)	Pregnant, non-lactating	Indoor			Free stall barn, rubber matting, 8 m^2/cow	Loggers for a 7 day period on 10 cows	9.7 h (10% less than 8 h)

2.2.3 Costs of systems

There is limited literature comparing and contrasting the costs of different wintering systems. The literature available is summarised in Table 2.2. The most relevant work is by Beukes *et al* (2011) where the authors undertake a modelling analysis comparing different wintering systems. The relevant comparison is between the brassica crop and the wintering barn. The authors modelled an operating profit of \$599 and \$743 ha^{-1} for brassica crop and wintering barn, respectively. In the year 2006/7 the net income was \$6202 and \$6188 ha^{-1} for the crop and barn scenarios, respectively while farm working expenses were \$4387 and \$4215 ha^{-1}. Models were run over a 30 years of climate data and for cows on crop an average increase in energy requirement of 17 % over June-August was estimated to account for the cow's energy requirement to maintain a constant body temperature in winter. The analyses were conducted keeping farm area, cow numbers and per cow production the same for all scenarios. The big difference in expenses between the crop and barn scenarios were the support block and cropping expenses.

Capital costs of wintering barns vary depending on the type and location of the barn. DairyNZ surveyed 34 barns and obtained information on their financial and environmental performance. The results of the original 34 farms have summarized in a number of publications (Journeaux & Newman 2015; Newman & Journeaux 2015; Newman & Mashlan 2015). In addition to the 34 farms there is a value for a slatted floor barn and a generic value used by Beukes in his analysis which was averaged from values published in the December 2009 Dairy Exporter. The capital plus machinery costs are summarized in Table 2.2 and range from \$540 - \$3,300 cow^{-1}. The costs of additional effluent requirements are largely unreported in the literature. Macdonald *et al.* (2014) gave a good analysis of the volumes of effluent generated and the costs to apply those products to land. In the work by Journeaux and Newman (2015) and Newman and Journeaux (2015) the authors captured the information relating to the cost of effluent storage additional to the existing system when a barn was built. They then combined this value into the barn structure values as it was deemed an integral part of the barn.

Table 2.2. Reported capital costs of establishing wintering barns

Region	***Year***	***Type***	***Cost ($/cow)*** ***Structure + machinery***	***Effluent system***	***Reference***
Southland		Free-stall	$2,300	Combined in barn cost	1, 2
Southland		Free-stall	$3,300	Combined in barn cost	1, 2
Southland	2009	Generic	$1,500	Not mentioned	3
Canterbury	2015	Free-stall	$1,150	Combined in barn cost	2
Canterbury	2015	Free-stall	$540	Combined in barn cost	2
Canterbury	2015	Free-stall	$950	Combined in barn cost	2
Waikato	2014	Woodchip	$943	Assumed 18 mthly replacement of bedding costing $48 cow^{-1}. Application of bedding to land costs $17.20 cow^{-1} barn-empty^{-1}	4
Waikato	2014	Slatted floor	$1507	Concrete bunker below floor cost to empty is $20 cow^{-1} yr^{-1}	4
Waikato	2015	8 farms (5 Herd Homes and 3 Redpaths)	Ave $1,844 range $934 - $2,524	Combined in barn cost	1, 2
Bay of Plenty	2015	Compost barn	$1,966	Combined in barn cost	1, 2

References: 1 (Journeaux & Newman 2015); 2 (Newman & Journeaux 2015); 3 (Beukes *et al.* 2011); 4 (Macdonald *et al.* 2014)

2.3 Stand-off systems and the volumes of effluent they generate

2.3.1 Estimating effluent volume and characteristics

2.3.1.1 Quantities

There is little available in the literature relating to the quantities of effluent generated by wintering systems. Recent component work conducted by van der Weerden *et al.* (2014) looked at gaseous losses from cow manure from different housed wintering systems. They highlighted that fact that there are a number of factors such as climate, storage method, management (feed offered, bedding material, proportion of liquid drained off) that will vary the characteristics of the manures generated by the wintering systems they investigated. They point out that there is unlikely to be a 'typical' manure associated with different systems however they present calculations on the potential volumes of manure generated by different systems. They assume 60% of the liquid fraction of manure for each system goes to the FDE pond. Over an 80 day winter, they calculated the total amount of manure generated for each system to be 482 kg dry weight per cow for bunker, 271 kg for weeping wall and 857 kg for deep litter (van der Weerden *et al.* 2014). This is estimated to be 2.77 m^3 cow^{-1} for the bunker system, 2.29 m^3 cow^{-1} for the weeping wall and 3.83 m^3 cow^{-1} for the deep litter barn (Van der Weerden 2014). A similar value for a deep litter barn was reported by Macdonald *et al.* (2014) who measured 3.6 m^3 cow^{-1}, although this was calculated on an 18 month period before the barn bedding was required to be replaced.

i. Effect of a roof on volumes of effluent generated

Beukes *et al* (2011) point out that unroofed standoffs capture the rainfall and thus "significantly increase the amount of effluent that has to be managed compared with a housed system." Luo *et al* (2008) make the same comment regarding the use of a roof to reduce the volume of effluent generated. They also suggest that "roofing a stand-off may also reduce drainage losses of nutrients because excreta nutrients would be expected to have more time in close contact with C-rich materials, allowing higher rates of absorption and immobilisation." (Luo *et al.* 2008a)

2.3.1.2 Characteristics

Effluent products can be characterised and defined based on their solids content; <5% dry matter (DM) is farm dairy effluent (FDE), 5-15% DM is slurry and >15% is solid manure (Longhurst *et al.* 2012).

i. FDE – solids content < 5%

A review of published data on the chemical and physical characteristics of FDE in New Zealand was published in 2000 (Longhurst *et al.* 2000). The average composition of FDE comprised only 10% dairy excreta and the remaining 90% was from the milking process and milking shed (e.g. teat washings, wash-water). Because of this large input of water from the milking shed it can be expected that the effluent from a wintering system will be more concentrated and of a lesser volume. The solids content of the FDE over 63 sites averaged 0.90% and ranged from 0.04 to 5.2%. Post 2000 there are four main references related to the volume and characteristics of winter generated effluent and these publications relate to three separate bodies of work (Table 2.3). In 2003/4 40 farms throughout NZ were case studied and an average nutrient concentration and DM% was given for similar wintering systems (Longhurst *et al.* 2006b).

ii. Slurry – solids content 5-15 %

Houlbrooke *et al.* (2011a) measured the composition of slurry from 12 Herd Homes. The average chemical compositions are outlined in Table 2.3. This appears to be the only literature measuring slurry characteristics from wintering systems in New Zealand.

iii. Solid manure – solids content >15 %

Longhurst *et al.* (2006) reported field measurements and manure nutrient content in Herd Home bunker material when different substrates were used in the bunker to absorb manure. The materials used were soil, wood shavings and a combination of the two as bunker material (Longhurst *et al.* 2006a). They found that the nutrient concentration of N and sulphur (S) decreased as storage time increased (measured at 3, 6 and 9 months). Soil bunker material resulted in the lowest loss of N (33% compared to 70% lost from raw manure, 67% from wood shavings and the same from soil + wood shavings). This work was conducted relatively early on in the use of the Herd Home concept. The first Herd Home was in use for the 2002/3 season and this trial was conducted in early 2006. Nine years on, at the time of writing this review, bunker absorbency media is not widely used particularly in Southland where the whole area of the bunker is required to capture the manure.

In comparison to bunker manure with no added substrate (as is now common practice in Herd Homes) carbon-rich pads can have very high DM% content, especially if covered. Published values range from 28-46% DM (Longhurst *et al.* 2012; Longhurst *et al.* 2006b).

Table 2.3. Measured values for effluents

Source	*Bunker/ bedding material*	*Effluent treatment*	*DM (%)*	*TN (% in DM)*		*P (% in DM)*	*K (% in DM)*	*S (% in DM)*	*C (% in DM)*	*C: N ratio*	*Ref*
Herd Home	Raw manure		32	1.59		0.72	3.78	0.47	21	13	1
Herd Home	Soil		64	0.82		0.29	0.62	0.15	9.2	11	1
Herd Home	50% Soil + 50% WS		57	0.57		0.17	0.54	0.11	13.8	24	1
Herd Home	Wood shavings (WS)		33	1.73		0.5	2.79	0.41	42.8	25	1
FDE		Pond	<1.0	0.045		0.006	0.035				2
Feed pad or stand-off pad		Storage pond	<0.5	0.025		0.003	0.03				2
Stand-off pad	Soft surface		25-30	0.35		0.3	0.2				2
Stand-off pad	Hard surface	Scraped or mechanically separated	15-20	0.45		0.1	0.3				2
Covered barn			20-50	.45-.6		.05-.1	0.5	0.7			2
Source	*Bunker/ bedding material*	*Effluent treatment*	*DM (%)*	*TN (kg/t)*	*Mineral-N (kg/t)*	*TP (kg/t)*	*TK (kg/t)*		*Org C %*	*C: N ratio*	*Ref*
Herd home shelter (average)	Manure		23	5.6	1.56	1.41	6.67		9.7		3
Herd home dairyland (ave)	Manure		27	7.4	1.03	1.97	7.59		9.7		3
Feed pad or stand-off pad (ave)		Scraped	26	5.9	0.35	1.28	7.69		8.3		3
Wintering pad (ave)	Carbon-rich		34	3.9	0.4	1.1	6.6		11.6		3

Table 2.3. Measured values for effluents continued

Source	*Bunker/ bedding material*	*Effluent treatment*	*DM (%)*	*TN kg/m3*	*Mineral-N kg/m3*	*TP kg/m3*	*TK kg/m3*		*Org C %*		*Ref*
Herd home slurry	Manure		11	4.31	1.67	0.99	6.43		3.7		4
Wintering barn		Scraper	8.1	3.19	1.38	0.8	4.24		3.1		4
Liquid from Herd Home	Manure		1.8	0.92	0.59	0.13	4.13				4
FDE		Stirred pond	1.7	0.62	0.15	0.13	0.38		0.6		4

Reference:

1. (Longhurst *et al.* 2006a)
2. (Longhurst *et al.* 2006b)
3. (Longhurst *et al.* 2012) & (Houlbrooke *et al.* 2011a)
4. (Houlbrooke *et al.* 2011a)

Luo *et al* (2008a) measured N loss from a bark or sawdust based stand-off pad where cows were on the pad 18 h day^{-1}. They measured N in drainage from the pad during the winter (12 weeks) when cows were on the pad. They continued measuring leachate from the pad once the cows had been permanently removed. They found that about 4% of the ingested N was lost in drainage during the period the cows were on the pad. Only small amounts were found in drainage when cows were not using the pads. Gaseous losses during the period the cows were on the pad were 2.5% of the deposited excreta for the sawdust pad and 0.3% for the bark pad.

Therefore they suggest that “between 90 and 94% of the deposited excreta N may be accumulated in pad materials, or could have been lost through ammonia volatilisation”.

They, recommend the use of a bark or sawdust lined stand-off pad as a promising winter management practice. They suggest that the majority of N is retained in the bedding with relatively small amounts lost in drainage or to gaseous emissions. However, they make no comment on the availability of product if it was to be used widely. Measured values of nutrient in the bedding for a deep litter barn were 10.8 kg of N, 5.4 kg of P and 3.6 kg of K per cow for the 3.6 m^2 cow^{-1} material produced (Macdonald *et al.* 2014).

2.3.2 **Factors that determine storage requirements**

The storage requirements for effluent will depend on a number of factors:

1. Cow numbers and the accumulated period of time cows are held in standoff facilities will directly influence the volume of dung and urine generated (Longhurst *et al.* 2006b).

2. The wintering standoff system. Roofed, or no roof, type of bedding and existence and type of effluent processing (e.g. solids separation) will influence the type and volume of storage required (pond for liquid, concrete pad for solids) (Houlbrooke *et al.* 2011a).

3. Annual rainfall. This influences the volume of effluent generated from unroofed facilities and uncovered storage areas. In addition, it influences the period of time that it is safe to apply effluent to land. Thus high rainfall areas require greater storage as they are required to store effluent for longer periods of time (van der Weerden *et al.* 2014).

4. Consent conditions. Requirements will vary depending on Regional Councils. (Environment Southland, 2016a; ORC, 2014).

There is an online Dairy Effluent Storage Calculator freely available for public use that takes into account points 1-4 and produces a required storage volume for a particular scenario. http://www.massey.ac.nz/~flrc/required/FDE%20Calculator/Obtain_DESC.html

2.3.3 Effluent land application options

Houlbrooke *et al* 2004 states that "the aim of land application of effluent is to utilise the soil/plant system to absorb, filter and breakdown all waste components of applied effluent, so as to minimise the risk of high nutrient loads and harmful micro-organisms draining into sources of fresh water." It can also be added that it aims to utilise the fertiliser value of the effluent applied. Thus the method of application and the timing of the effluent application must be such that the potential benefits are maximised and the cost minimised as often the cost of application outweighs the nutrient value. There are a number of different methods of applying liquid effluent or FDE to land. These are:

(1) Travelling irrigator. These are small, self-propelled irrigators that are low maintenance and can apply effluent at a range of depths due to their range in operating speeds (http://www.rainer.co.nz/effluent/spreaders/).

(2) Low-rate sprinkler system is a more recent method that is becoming increasingly common (Monaghan *et al.* 2010).

(3) Where existing border-dyke systems are located on free-draining soils it may be possible to flood-irrigate FDE, "however the risk of environmental pollution is high" (Houlbrooke *et al.* 2004b).

(4) Slurry tanker is another method of spreading FDE pond slurry. A tanker is used to periodically remove FDE slurry from the storage pond and then apply to land (http://www.nevadanz.co.nz/tankers).

(5) Soil injection is one method commonly used in Europe but not used regularly in New Zealand. This method involves the placement of effluent directly into the soil (Houlbrooke *et al.* 2004b).

With any irrigation "the soil moisture status of the land receiving application must be considered because during periods when rainfall exceeds evapotranspiration (usually May to October) soil water is at, or close to, field capacity and water may move freely through the soil profile" (Houlbrooke *et al.* 2004b). On reviewing the literature Houlbrooke *et al* (2004) found that under spray irrigation (travelling irrigator) on wet soils the leaching losses were as great as 30% of applied effluent volume.

There is already a literature review on the land treatment of farm-dairy effluent in New Zealand and this review does not seek to duplicate that work (Houlbrooke *et al.* 2004b). Here the aim is to focus on the two most common forms of land application of FDE: travelling irrigator and low-rate sprinkler system. An experiment was published in 2010 (after Houlbrooke's 2004 review) and was conducted between 2001 and 2003 to compare losses of contaminants in overland flow or from mole-pipe drainage from FDE applied by either a travelling irrigator or a low-rate (K-line) sprinkler system (Monaghan *et al.* 2010). The two experimental sites were in Otago and on the same Waikoikoi silt loam. One site had mole and tile drainage while the other had a slope and a history of overland flow problems. The authors aim was to "determine if a low-rate sprinkler system (K-line) could decrease the losses of FDE from overland flow or preferential flow pathways, which together contribute most losses from these soils". They also compared losses of FDE nutrients and faecal micro-organisms (FMO) in subsurface drainage. The targeted application depths for both irrigators were 8-12 mm, however the actual depths were 3-12 mm for k-line and 12.5-20 mm for travelling irrigator. The application rate of the k-line was between 0.6-4.3 mm hr^{-1} and there was only one measurement for application rate of the travelling irrigator (27 mm hr^{-1}). Irrigation events were timed so that FDE was applied when soil was close to field capacity so as to induce subsurface mole and tile drainage. The application dates were May, June, Aug, Sept and Nov. Monaghan *et al* (2010) found that the concentrations of N, P and *E.coli* in the drainage when effluent was applied via low-rate sprinkler was less than 2% of the effluent applied. This compared to between 2 and 14% of the N, P and *E.coli* of the applied effluent exiting via mole and tile drainage under a travelling irrigator. When they modelled the annual losses in mole and tile drainage they found that the use of a low-rate sprinkler system applying FDE at a depth of 4 mm resulted in a reduction of contaminants in mole and tile drainage and also a reduced FDE storage requirement compared to a travelling irrigator. They concluded that the "key advantages of the low-rate sprinkler system over a travelling irrigator are the ability to apply small depth often and at low rates; this allows for greater flexibility in scheduling effluent application when there is a soil water deficit and also for greater infiltration of effluent into the soil to filter and retain potential pollutants" (Monaghan *et al.* 2010). Houlbrooke and Monaghan (2010) praise the low-rate sprinkler systems for their "ability to reduce the risk of exceeding the soil's infiltration capacity" and increased likelihood of the applied nutrients being retained in the root zone. In addition, the chances of preferential flow are decreased which, in turn, increases the volume of the applied FDE that is able to travel through smaller soil pores via matrix flow resulting in greater attenuation of effluent contaminants (Houlbrooke & Monaghan 2010).

While the work described thus far looks at the land application of FDE (liquids of 0-5% DM) there are also dairy manures and slurries that are applied to land. Slurries (5-15% DM) are semi-liquid and can be sprayed, under pressure, to land via a slurry tanker. Solid manures cannot be pumped and sprayed and are usually applied to land by muck spreaders. The other option for solid manures is a tip truck where a tractor is fitted with a back blade for spreading (Houlbrooke *et al.* 2012).

2.3.4 Risk around application of FDE to artificially drained soils

Applying effluent to artificially drained soils increases the risk of contaminant losses to water in the presence of preferential flow pathways (described further in Section 2.4.1) in the soil and reduces the time effluent is held in the soil matrix (Scott *et al.* 1998). Houlbrooke *et al.* (2004a) found under a single 25 mm application of FDE applied to soil at near field capacity, 40% of applied effluent left the profile as mole and pipe drainage and 30% as runoff.

A Field experiment was conducted in the Waikato using water with a dye added to determine the infiltration rate and pattern of water applied at different rates. Two soils (a well-drained Horotiu and poorly drained Te Kowhai) were irrigated with water containing a dye at a range of application rates (5, 10, 15, 20 mm h^{-1}) using a “drip-type rainfall simulator”. Twenty minutes after irrigation, soil was sampled vertically at 25 or 50 mm intervals to assess the movement of the irrigated dye through the soil profile (McLeod *et al.* 1998). They found the infiltration pattern was uneven in both soils due to preferential flow. This preferential flow was increased in the poorly drained soil and also at greater application rates. In order to minimise leachate into the subsoil it was necessary to maintain irrigation at ≤ 10 mm hr^{-1}. They investigated whether pulsed application at higher application rates would avoid preferential flow and thus keep irrigation in the topsoil, however, this was not the case.

2.4 Principles of nutrient and contaminant transport from land to water

The wintering systems described in sections 2.2 and 2.3 all lead to an impact on the aquatic environment via nutrient losses to water. To understand this, an understanding of how water and nutrients move through soils is required. As this study focuses primarily on N losses to water, an understanding of the N cycle in agricultural soils is necessary. Therefore this section is split into three areas; (1) the movement of water through soils, (2) the movement of nutrients through the soil, and (3) the impact of the different wintering systems on the losses of contaminants to water

2.4.1 Water movement through soils

The basic principles of water movement through soil and the hydrological cycle are described in this section and are depicted in Figure 2.1 and Figure 2.2. Water applied to the soil surface either enters the soil matrix where it is stored in micropores approximately < 30 µm in diameter, whereas large macropores (> 30 µm in diameter) remain aerated providing drainage provided there is no impediment to hydraulic conductivity. If an impediment exists these pores temporally fill and the soil would be saturated with water. The balance of water stored in the soil is generally explained by the following equation:

Equation 2.1 $\Delta W = Pe + I - R - D - RO - T - ET$ (all units in mm)

Where:

ΔW = the change in water storage
Pe = rainfall
I = irrigation
R = deep drainage
D = is charge from drains
RO = surface runoff
T = interflow
ET = evapotranspiration

A soil water balance (SWB; e.g. equation 2.1) generates an estimate of the surplus water available for loss as drainage or surface runoff (Figure 2.1). A SWB uses readily available data of daily rainfall, daily potential evapotranspiration and available water holding capacity (AWHC)(Woodward *et al.* 2001). Detailed descriptions of the generation of a SWB for a cropping scenario is outlined in Section 4.3.5 and for a pasture in Section 6.3.9.

Surface runoff is most commonly generated: (i) by rainfall events of high intensity but low frequency (McDowell 2012), (ii) when soil is saturated, (iii) where there are impermeable soils without artificial drainage, (iv) where there is sloping ground combined with excess surface water or slow infiltration rates, and (v) soils with a damaged soil structure (e.g. pugging). Water at the soil surface is potentially lost via evaporation but once the water is in the soil profile it is available for plant uptake and potential loss via evapotranspiration, otherwise it is available to infiltrate the soil. Excess water then leaves the soil profile as drainage (Figure 2.1 and Figure 2.2), either deep drainage or a combination of deep and artificial drainage if installed. Surplus rainfall is often lost via a combination of these different pathways. As an example, Monaghan *et al.* (2016) found that 25% of estimated surplus rainfall was lost as runoff and 62% as mole-tile drainage on a Pallic soil in Southland. Interflow (Figure 2.1) is where water moves laterally through the topsoil. This occurs naturally in permeable soils or via artificial drainage if such systems are present. All drainage eventually makes its way to open bodies of water (Figure 2.1).

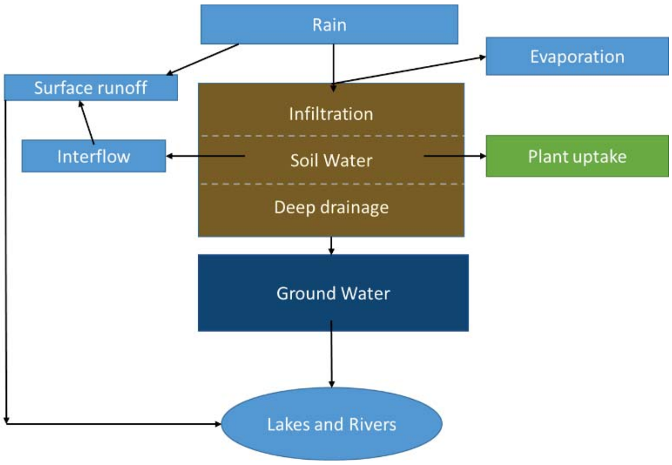


Figure 2.1. Simplified diagram of the components of the hydrological cycle that relate to soil water.

i. Drainage in permeable soils – matrix flow

Drainage in permeable soils is more uniform than in poorly-drained soils. The uniform drainage of water through a saturated soil profile is termed matrix flow. The rate of this flow of water through micropores within and around the soil aggregates (as opposed to rapidly around the aggregates) is influenced by the soil structure. Fine and uniformly structured soils have a faster flow of water than soils with blocky, platy or prismatic aggregates (Bowler 1980).

ii. Preferential flow

Preferential (or bypass flow) flow occurs when water moves through the soil profile in a non-uniform way. This can be natural cracks in the soil, worm holes, or through the fissure network created by a mole plough (Monaghan & Smith 2004). This preferential flow rapidly transports water and any surface applied nutrients or contaminants, through the soil matrix allowing little time for filtration, plant uptake or nutrient transformation (Monaghan & Smith 2004). McLeod *et al* (1998) found that preferential flow in a poorly drained clay loam, under overhead irrigation, was increased at higher irrigation application rates. This has implications for effluent application on soil susceptible to preferential flow.

iii. Artificial drainage in slow draining or impermeable soils

Mole-pipe drainage is common in the southern South Island of New Zealand on impermeable and slow draining soils (Figure 2.2). The system involves fissures or cracks created by the mole plough that permit rapid drainage that is collected by a mole channel which then flows to a main tile line where drainage is removed from the soil profile (Monaghan & Smith 2004). This system of artificial drainage increases the rate at which water moves through the soil. Houlbrooke *et al.* (2008) found that this function requires specific farm management practices to minimise losses of effluent contaminants.

They found that scheduling effluent irrigation for when soils are not saturated reduced the risk of contaminant losses via artificial drainage induced preferential flow.

2.4.2 Nutrient movement – pathways of N and P loss to receiving waters

Most elevated losses of N and P to water begins with an enriched source area being mobilised. This can result from nutrient input (e.g. fertiliser) or mobilisation of nutrients already in the system. The enriched sources of N and P and loss pathways in a pastoral farming system are depicted in Figure 2.2. These include: cultivation of pastures for pasture renewal, fertiliser spreading, effluent application, dung and urine deposition. Losses to water are in surface runoff and drainage.

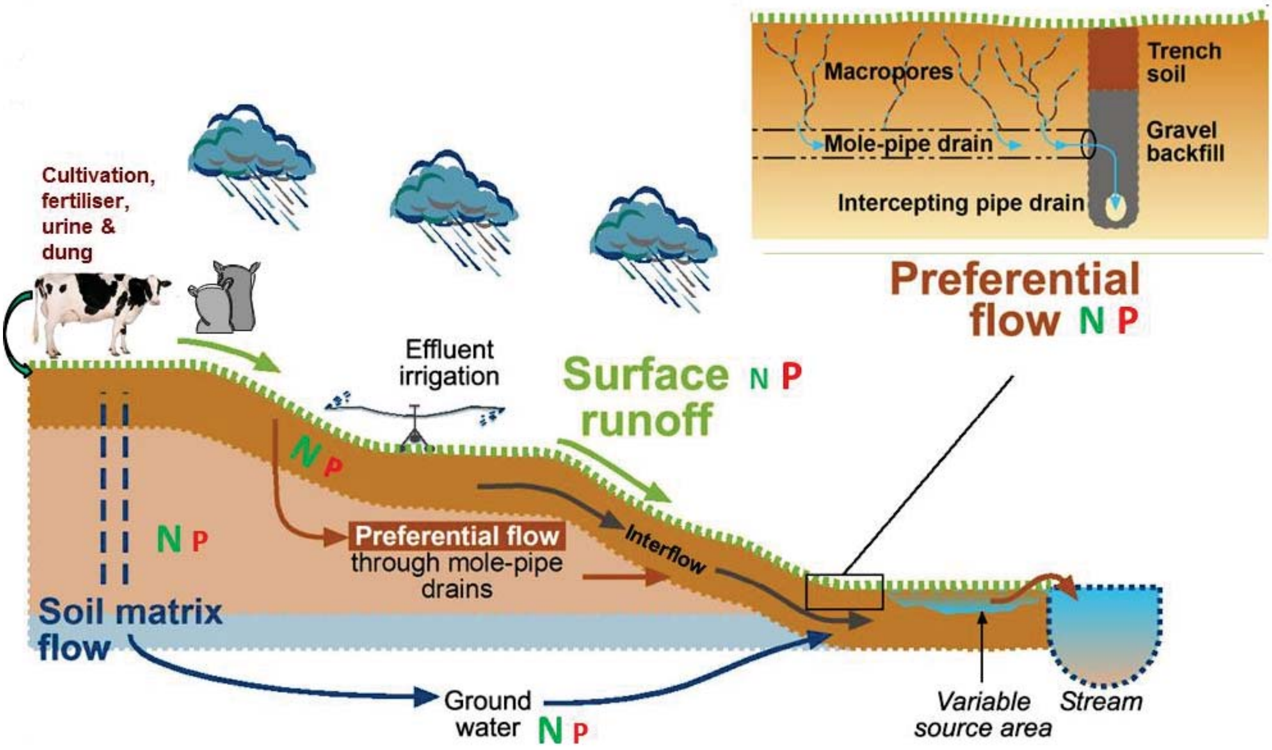


Figure 2.2. Transport pathways involved in the transfer of N and P from land to water in agricultural systems. The presence and relative size of each letter indicates the importance of that pathway. Adapted from: McDowell *et al* (2016)

This study focuses primarily on N losses to water therefore, P losses are covered only briefly.

2.4.2.1 Phosphorus loss to receiving waters

P losses to waterways are via surface or subsurface flows (Figure 2.2). The main loss pathway for P is in surface runoff as P is strongly adsorbed to soil particles. P losses in drainage are small and tend to be dominated by rainfall events of low intensity but high frequency which tend to force dissolved inorganic P (DIP) into subsurface flow. Once there, depending on the soils sorption capacity, small amounts (<2 kg P ha^{-1} yr^{-1}) of DIP can be lost via drainage systems (if present) or through the soil matrix flow into receiving ground waters (Figure 2.2) (McDowell 2012; McDowell *et al.* 2016). The forms of P lost vary depending on land use and soil characteristics. In surface runoff from grazed pastures and non-cultivated soils there is little sediment thus the small amount of P lost is in the form of readily available DIP (or as analysed, dissolved reactive P; DRP) (McDowell 2012). Cultivated soils induce erosion and the loss of particulate-bound Total P (TP). This form of P is not as readily available but can become available over the longer term. In a field experiment measuring overland and subsurface N and P losses from grazed pasture on drained and undrained soils Smith and Monaghan (2003) found greater overland losses of P from undrained soils than drained. Annual losses of TP were 230 g ha^{-1} for undrained compared to 30 kg ha^{-1} for drained. Losses of DRP were lower at 56 and 8 g ha^{-1} for undrained and drained, respectively. Concentrations of P in the runoff peaked at 5.6 mg TP L^{-1} and 3.2 mg DRP L^{-1} for the undrained treatment and 4.6 mg TP L^{-1} and 2.9 mg DRP L^{-1} for drained.

2.4.2.2 **Nitrogen Loss to receiving waters**

To understand the loss of N to receiving waters, it is necessary to understand the N cycle in agricultural systems (Figure 2.3). The majority of the N leaching losses from grazed agricultural systems are in the form of nitrate-N (NO_3^-)(McDowell *et al.* 2011; Monaghan *et al.* 2016; Monaghan *et al.* 2007b). Nitrates are generated in the soil by microbial nitrification of ammonium ions. The ammonium ions are generated from decomposition and hydrolysis of either, soil organic matter, inputs of fertiliser or recycling of grazing animal dung and urine. The dominant forms of N in different sources entering the soil are: urea in urine (Selbie *et al.* 2015), ammonium-N in effluent (NH_4^+) (Monaghan & Smith 2004), and fertiliser N is mostly applied to pastures as urea or NH_4 based fertiliser. Shortly (1 day) after grazing or fertiliser application concentrations of NH_4 forms of N in the soil are usually high because urea hydrolysis of N in the soil is rapid. NH_4 concentrations in soil stay high for approximately 2 weeks because nitrification is a slower process requiring growth of microbial populations. If NH_4^+ ions appear in drainage waters they are an indication that soil has preferential drainage flow pathways or waters are anaerobic. This is because NH_4^+ ions undergoing slow matrix flow are likely to be adsorbed strongly by soil cation exchange capacity (McLaren & Cameron 1994).

The majority of N loss is via leaching rather than surface runoff. This is because (i) nitrate (NO_3^-) is generated in soil and (ii) is not adsorbed by positively charged soil surfaces. Leaching of nitrate occurs when there is nitrate present in the soil in excess of plants requirements at a time when there is drainage occurring. Thus losses can be high during winter brassica crop grazing as urine is deposited on to bare soil where there are no plants available for N uptake and also at a time when drainage events occur frequently.

2.4.2.3 Measurement of N leaching losses

Losses of nitrate in drainage differ temporally and spatially and thus system, or paddock, scale losses can be difficult to accurately measure. There are a number of methods for measuring N leaching losses. (1) Measurements using lysimeters can record losses under urine patch and under inter-patch areas (non-urine) and then these losses can be extrapolated to paddock scale. A number of lysimeter studies have used this approach to measure losses under pasture (Cameron & Di 2004; Di & Cameron 2002; Di & Cameron 2003; Di & Cameron 2004; Di *et al.* 2009; Menneer *et al.* 2008), however, there are few data sets looking at losses under grazed brassica crops (Malcolm *et al.* 2015; Malcolm *et al.* 2016). (2) Another method, suited for soils with impeded subsoil drainage (clay pan), utilises artificially drained plots where the drainage is captured by mole and pipe drainage systems and volumes measured at "end of pipe". These are used in an attempt to capture the drainage from an area that represents the whole paddock. Again there are a number of field plot experiments measuring losses from under grazed pasture (Christensen *et al.* 2010; Monaghan *et al.* 2002; Monaghan *et al.* 2005; Monaghan *et al.* 2009; Monaghan *et al.* 2016) and only a few pertaining to winter crop grazing (Beare *et al.* 2010; Monaghan *et al.* 2013). (3) The third method to measure nitrate leaching losses is to install porous ceramic cups in the soil at a depth below the root zone (e.g. 60 cm for pasture) in a paddock. The cups are placed under tension and draw free water samples from the soil to be representative of dissolved N concentrations in drainage. A soil water balance model is required to estimate the drainage depths associated with the free water samples. Losses under pasture have been measured using ceramic cups in the North Island (Sprosen *et al.* 2009) and in the South Island losses under winter crop grazing have been measured using this method (Smith *et al.* 2012).

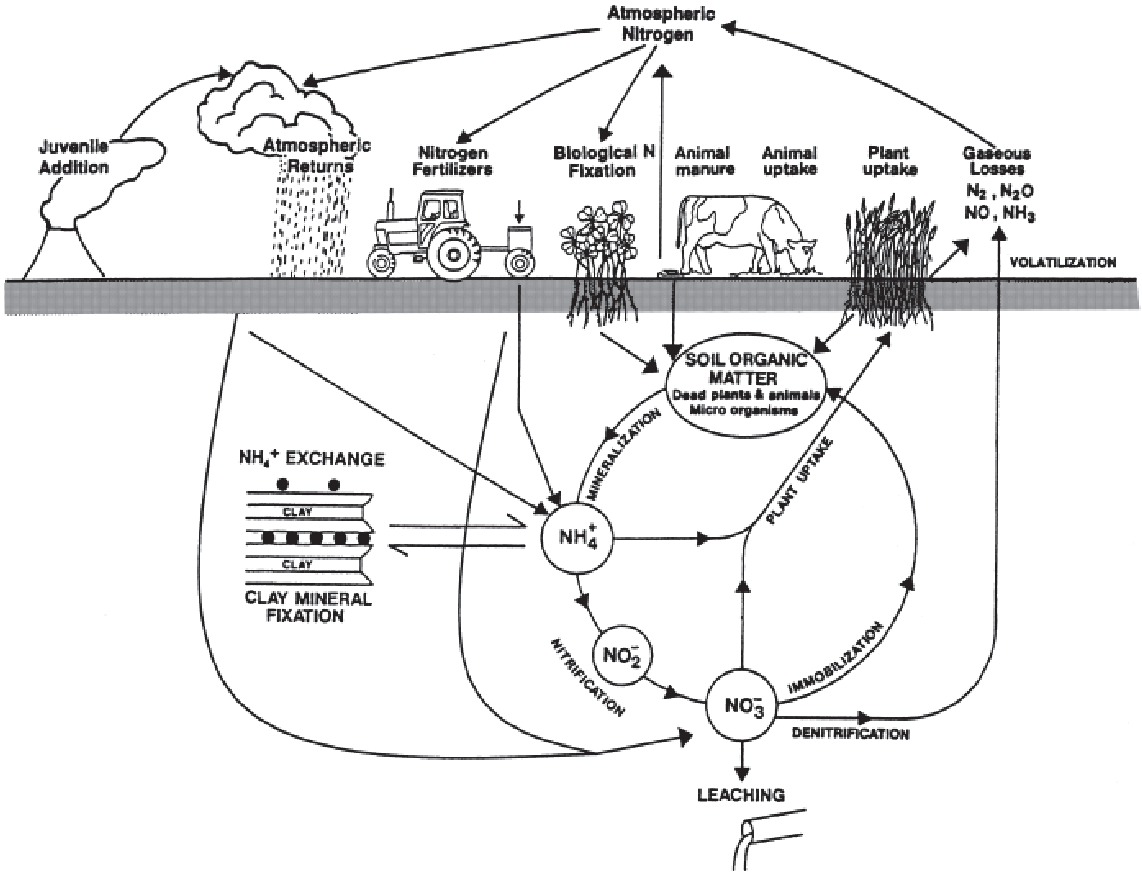


Figure 2.3. The Nitrogen Cycle in agricultural systems. Source: H.J. Di and K.C. Cameron (2002), figure 1.

2.4.3 Impact of each system on the aquatic environment

2.4.3.1 Crop nitrogen losses to water

Current knowledge (and existing data sets) of the N leaching losses from wintering dairy cattle on brassica crops in New Zealand is summarized in Table 2.4. The common analyte measured was nitrate-N in leachate although methods of capturing drainage varied. Of particular relevance to the present study was the work conducted by Smith *et al*, (2012) at Five Rivers in Northern Southland. The soil type was a slightly gravelly silt loam that is classified as having a severe vulnerability for nutrient leaching to groundwater. Ceramic cups were used to measure N leaching of winter grazed brassica crops in a field trial where cows grazed the crop over the plot area during a 10-day period in winter. Cows were not back fenced which means that cows were able to move freely over previously grazed soil which had the potential to increase the urine spots deposited on these areas. Results obtained over the 3 year experiment averaged 57 kg nitrate-N ha^{-1} yr^{-1} leached (range, 2.7 – 108 kg N ha^{-1} yr^{-1}). This compares to 153 kg nitrate- N ha^{-1} yr^{-1} obtained by Shepherd *et al* (2012) using ceramic cups on a free draining pumice in the Central Plateau, North Island, New Zealand. Both these trials were field trials measuring leaching from plots in a grazed paddock as part of a normal dairy farm system. Cows had free access to/from the plots and the paddocks were strip grazed in both trials. In the Central Plateau trial they included a plot in each treatment that was not grazed. The purpose of this was to separate out N leaching due to urine deposition and grazing from N leaching due to soil organic matter mineralisation caused by crop establishment. Forage was manually harvested. On the non-grazed plots measured losses in both years of the trial were about 120 kg N ha^{-1} yr^{-1} less than the grazed plots (approximately 12 and 53 kg N ha^{-1} yr^{-1} for the two years measured) suggesting that approximately 78% of the recorded nitrate leaching in drainage was from the grazing of the crop and the remainder from crop establishment and manual harvesting. Lysimeter work conducted by McDowell and Houlbrooke (2008) found a significant difference in urine and non-urine treatments and they suggest that animals are the predominant driver for nitrate loss from crop wintering. Recent work by Malcolm *et al* (2015, 2016), using lysimeters, also shows a significant difference between urine and non-urine treatments under kale and fodder beet grazing. Differences of 180 and 347 kg N ha^{-1} losses under kale crop receiving urine at two different loads, 500 and 700 kg N ha^{-1} urine patch, respectively. Non-urine patch losses were measured at 33 kg N ha^{-1}. Losses from the fodder beet experiment were lower than under kale and the differences from urine patches were 54 and 73 kg N ha^{-1} for the two years of the experiment where non-urine patch losses were 10 and 11 kg N ha^{-1}. The N urinary load for the fodder beet work was 300 kg N ha^{-1} per urine patch.

Work conducted at Woodlands in Southland (Monaghan *et al* (2013)) was on hydrologically isolated plots where winter grazing of crop was simulated, this trial resulted in a similar average N loss to water as the work conducted at Five Rivers (Smith *et al* (2012); Woodlands 52 kg nitrate-N ha^{-1} yr^{-1}compared to Five Rivers 57 kg nitrate-N ha^{-1} yr^{-1}).

Figure 2.4 highlights the loss pathways from a winter crop grazing. Crop paddocks require cultivation and fertiliser at establishment. Then at grazing there is urine and dung deposited to bare ground when there is little plant uptake. In Southland there is a percentage of winter crop grazing that occurs on stony free-draining soils.

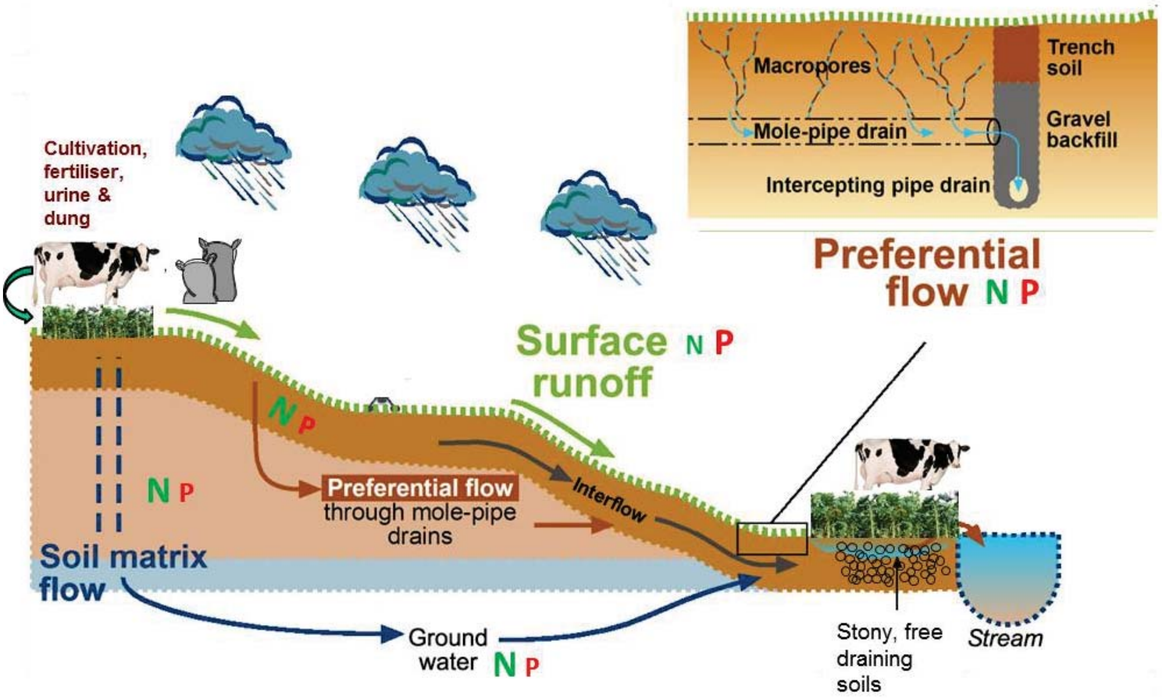


Figure 2.4. Transport pathways involved in the transfer of N and P from land to water in a winter cropping scenario. The presence and relative size of each letter indicates the importance of that pathway. Adapted from: R. W. McDowell *et al* (2016).

2.4.3.2 **Off-paddock system impact on the aquatic environment**

Studies conducted in other regions of New Zealand have shown that removing stock from pasture or crop during the winter months reduces soil damage and N, P and *E.coli* losses to water (2007; Luo *et al*. 2008a; Luo *et al*. 2008b; McDowell *et al*. 2003). However a full system analysis should be conducted to take into account the increased effluent captured and required to be exported, or most commonly, applied to land.

Figure 2.5 depicts the N and P loss pathways of a wintering barn scenario. Winter grazing is eliminated as are the cultivation and fertiliser associated with the winter crop paddock establishment. Winter deposits of urine and dung are also eliminated. The use of the barn does, however, generate effluent which requires storage and does, at some point, require land treatment. There is also additional storage required for winter feed which should, in the case of silage, be on a concrete pad where leachate is collected.

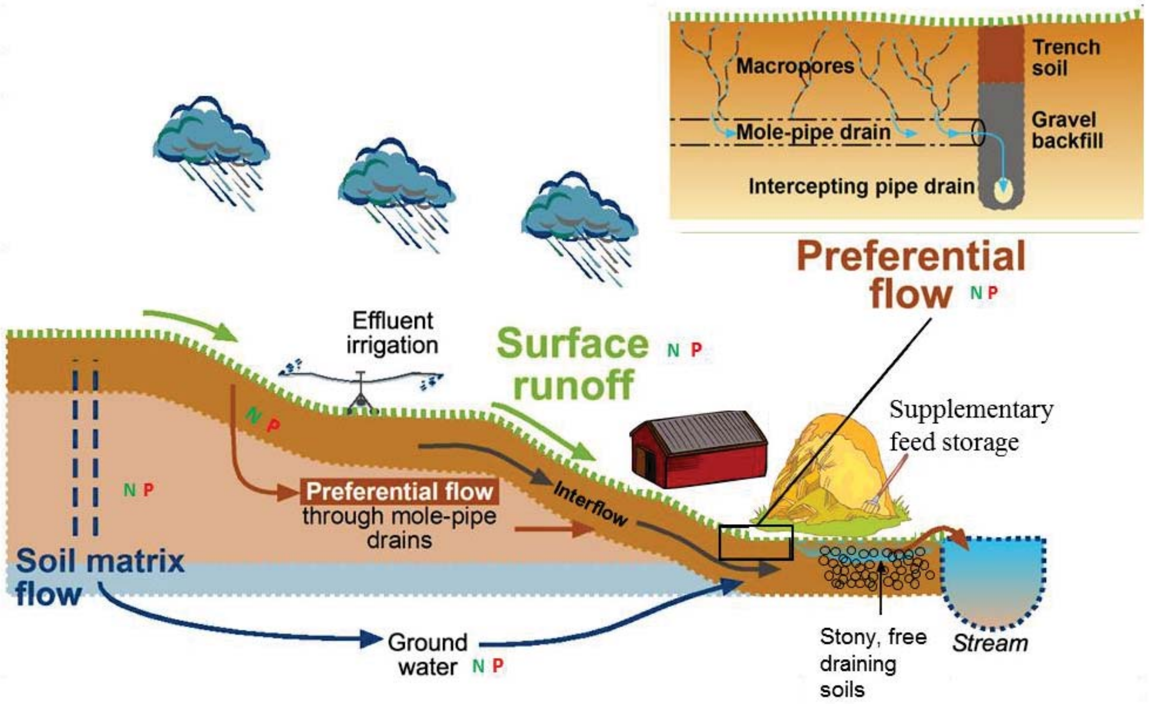


Figure 2.5. Transport pathways involved in the transfer of N and P from land to water in wintering barn scenario. The presence and relative size of each letter indicates the importance of that pathway. Adapted from: R. W. McDowell *et al* (2016)

Table 2.4. The amounts of nitrate leaching measured under crop wintering trials

Location	**Method**	**Soil type**	**Crop**	**Nitrate-N loss** **kg NO_3^-N ha^{-1}**	**Reference**
Five Rivers, Southland	Ceramic cups, grazed	Slightly gravelly silt loam	Swede/fodder beet	Ave 57 kg NO_3-N ha^{-1}	(Smith *et al.* 2012)
Central Plateau, North Island	Ceramic cups, grazed	Free draining pumice	Swede/kale	Ave 153 kg NO_3-N ha^{-1}	(Shepherd *et al.* 2012)
Woodlands, Southland	Plots, simulated grazing	Silt loam (Pallic)	Kale	Ave 54 kg NO_3-N ha^{-1}	(Monaghan *et al.* 2013)
North Otago	Lysimeter	Timaru silt loam	Triticale	Higher for urine than no urine up to 250 mg/L	(McDowell & Houlbrooke 2008)
Lincoln, Canterbury	Lysimeter		Pasture	98	(de Klein *et al.* 2010)
Lincoln, Canterbury	Lysimeter	Balmoral stony silt loam	Kale	213 and 380 kg NO_3-N ha^{-1} for 500 and 700 kg N ha^{-1} urine. 33 kg NO_3^-N ha^{-1} for non-urine	(Malcolm *et al.* 2015)
Lincoln, Canterbury	Lysimeter	Balmoral/ Lismore stony silt loam	Fodder Beet	64 and 84 kg NO_3^-N ha^{-1} for urine applications of 300 and 250 kg N ha^{-1}. 10-11 kg NO_3^-N ha^{-1} for non-urine patches	(Malcolm *et al.* 2016)

2.5 Issues associated with wet grazed pasture soils – soil strength, contaminant losses in drainage, and applying effluent to wet soils.

2.5.1 The impact of grazing wet pasture soils on soil strength

The commonly used indicator of soil aeration is macroporosity. A reduction in soil macroporosity values (expressed as the percentage of pores > 30 µm) one measure commonly used to assess soil damage and compaction with values of 10-12 % being a threshold, below which some researchers believe soil physical conditions may limit plant growth (Carter 1988; Carter 1990). Drewry, (2004) published work suggesting that the probability of lower pasture yields increases as macroporosity decreases in the range of 5-22% at 0 – 5 cm and 4 – 18% at 5 – 10 cm. In a review of the literature related to the effect of soil compaction on pasture yield and soil physical characteristics Drewry *et al.* (2008) concluded that while the effects of pugging are apparent, the effects of soil compaction are less apparent. Restrictions in pasture production as a result of soil compaction alone are less than with soil compaction and surface disturbance (pugging) (Drewry *et al.* 2008). A number of authors recommend implementing restricted grazing practices and removing cows from pasture when the risk of soil damage is high in an effort to reduce soil damage and restricted pasture growth (Laurenson & Houlbrooke 2014; Orchiston *et al.* 2013; Singleton & Addison 1999). In comparison Houlbrooke *et al.* (2009a) found the restricted grazing did not result in a significant difference in soil properties or pasture production compared with grazed. They concluded that grazing events at times deemed 'safe' but when soil water content was greater than the plastic limit probably resulted in treading damage and compaction.

2.5.2 The impact of grazing wet pasture soils on drainage

Winter crop grazing occurs at a time when the risk of drainage is high. This can be seen in the conceptual graph (Figure 2.6) of the 30-year-average rainfall from the Gore weather station (NIWA 2015a) and an estimate of relative drainage taken from some Southland experiments where a soil water balance was used to check the accuracy of the drainage volumes measured (Monaghan *et al.* 2009; Smith *et al.* 2012). The graph shows that the period of the year that cultivation occurs is also a potential period of drainage in Southland.

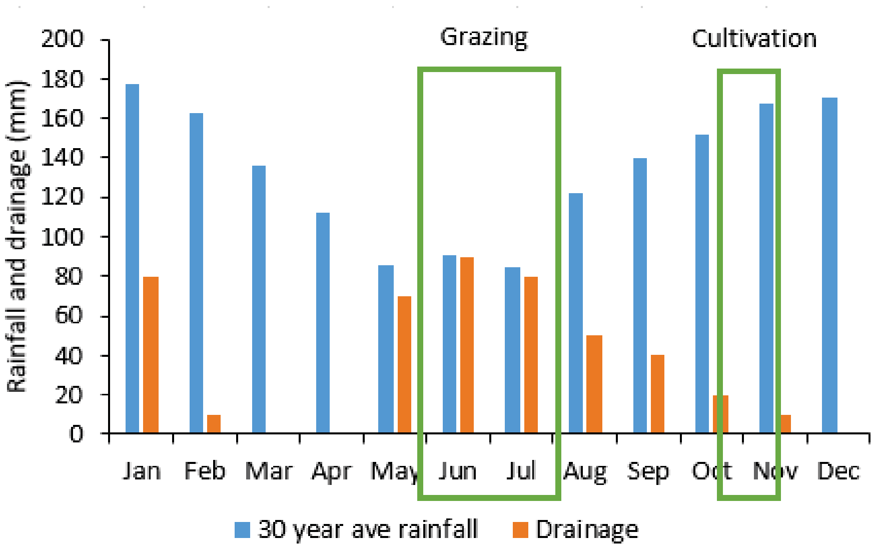


Figure 2.6. Conceptual Southland rainfall (30- year-average from Gore; Blue bars) and estimates of relative drainage (orange bars) taken from measured drainage in Southland literature (Monaghan *et al.* 2009; Smith *et al.* 2012). The green boxes represent the timing of winter grazing events and winter crop paddock cultivation.

2.5.3 The impact of effluent irrigation on pasture soils grazed when wet

Applying effluent to wet soils will increase the drainage and runoff volume and dissolved and particulate loss of N, P and *E. coli* in drainage and surface runoff (Houlbrooke *et al.* 2008; Monaghan & Smith 2004). Soil compaction resulting from grazing when soils are wet reduces infiltration rates of any applied effluent. The result of this is the increased potential for effluent to be lost in overland flow. Additionally, surface ponding can occur which is unacceptable in Southland under effluent application consent rules (Anon. 2010). The management response to reduce these risks is to apply effluent at a lower rate and/or depth.

2.5.4 Impact of each system on soil, plants, production

2.5.4.1 Impact on soil

i. Crop

Winter crop grazing can have a significant impact on soil as the grazing occurs over winter, an inherently wet time of year, and at high stocking densities (Drewry & Paton 2005; Houlbrooke *et al.* 2009b). Winter grazing causes soil compaction and pugging, particularly on soils that are imperfectly or poorly drained (see section 2.4.3.1 for further description). Soil compaction has a negative impact on nutrient and water transport through the soil as well as future pasture production (Houlbrooke *et al.* 2011b). Large reductions in soil macroporosity were measured in a field experiment investigating the impact of grazing dairy cows on a winter forage crop of swedes and kale (Drewry & Paton 2005). Macroporosity values measured by Drewry & Paton (2005) were 15.5% in ungrazed crop, 12.2% in established pasture, 12.8% on-off crop grazing, 9.6% strip grazing with a back fence, and 8.6 % traditional practice of strip grazing with no back fence. In addition, steps can be taken in crop establishment to reduce the potential severity of winter-grazing induced soil compaction. No-tillage or direct drill establishment of winter crops has been shown to reduce soil compaction during grazing of crop paddocks coming out of pasture (Thomas *et al.* 2008; Thomas *et al.* 2004). In comparison, experimental work conducted in North Otago, on plots following four years of consecutive winter crop grazing, found that non-inversion tillage (mechanical loosening of the soil; tillage without soil inversion) occurring in December, six months following the winter grazing, increased pasture production and soil macroporosity compared to no tillage (Laurenson & Houlbrooke 2014).

ii. Wintering barn

There is little in the literature regarding the impact of wintering barns on soils. However, the assumption is that by eliminating the winter grazing component of the system the resulting soil compaction is also eliminated. Interestingly, recent work investigating the benefits to pasture production resulting from removing cows from wet pastures during the milking season showed improved soil structure (total porosity) but no improvement of pasture production and no modelled financial benefit (Laurenson *et al.* 2016). However, for the modelling analysis additional feed was required in the brassica scenario to keep cow production the same in all scenarios.

2.5.4.2 **Impact on plants**

i. Crop

The impact of brassica crop grazing on plants is via the resulting soil compaction reducing subsequent pasture growth rates. There appears to be no literature available measuring the impact of winter crop grazing on subsequent pasture production.

ii. Wintering barn

The impact of a wintering barn on plants is that cows are completely removed from the paddock over winter. Thus soil compaction, resulting in reduced pasture production, at this time of the year is eliminated. The barn also gives management options to the farmer for taking cows' off-paddock at other times of the year when the risk of soil compaction is high. However, recent research on a Pallic soil in Southland suggests that while soil compaction is reduced, by taking cows off paddock at risky times of the year, there is no impact on pasture production (Laurenson *et al.* 2016). In comparison Houlbrooke *et al.* (2009a) found no change to soil compaction (on a Pallic soil) from removing cows during wet periods, but improved pasture production on non-grazed areas.

2.5.4.3 **Impact on farm production**

i. Crop

Winter grazing has the advantage of being a relatively low-cost wintering option. However, financial analysis suggests that winter brassica crop grazing is the least profitable winter management strategy (Beukes *et al.* 2011). The modelling work of Beukes *et al* (2011), suggests that the climate and exposure to bad weather may result in a lower BCS which can, in turn, result in lower production.

ii. Wintering barn

Modelling analysis comparing four different Southland based wintering strategies (brassica crop on a support block, pasture grazing on support block, stand-off pad, and wintering barn) found that the wintering barn scenario had the highest operating profit ($743 ± 122/ha compared with $599 ± 212/ha for brassica) and the lowest climate-induced risk (Beukes *et al.* 2010; Beukes *et al.* 2011).

The use of a wintering barn often results in an increase in farm production. This is often as a result of a change to the system to cover the capital costs of the barn rather than a direct result of the barn structure itself. However, this was not the strategy employed by Beukes *et al* (2011). Their cow numbers and per cow production remained the same. In contrast, case study research conducted by Newman and Journeaux (2015) found 8 of the 14 farms investigated increased cow numbers post barn addition and 100 % of the farms increased per cow milk solids production post-barn.

The use of a wintering barn has the potential to reduce the energy required by the cow for thermoregulation during exposure to cold winter conditions (in comparison to cows on crop). Thus feeding the same amount of feed results in an increase in cow BCS or, alternatively, less feed is required to achieve the same BCS as cows on a winter crop. In their multi-system analysis Beukes *et al* (2010) assumed an average increase in daily demand of 17% for cows grazing brassica crop.

2.5.4.4 Gaseous losses of Nitrogen (nitrous oxide)

i. Crop

Although this study does not compare gaseous losses of N from different wintering systems it is important to note that this is another pathway for the loss of N from the system and that nitrous oxide (N_2O) is a greenhouse gas. Gaseous N_2O losses from a winter grazed kale crop were measured in Southland and equated to 3.6 and 1.5 kg N ha^{-1} yr^{-1} in the two years studied. These losses were over the period June – November and the greatest fluxes occurred when soils were wet and in urine patches (Monaghan *et al*. 2013; Smith *et al*. 2008). This compared to a total loss of 7.9 kg N ha^{-1} yr^{-1} measured on a swede crop in South Otago in 2011 (van der Weerden & Styles 2012). These results were also for the period June-November.

ii. Wintering barn

Gaseous emissions associated with these systems are poorly understood. Nitrous oxide emissions from the stored effluent generated by a wintering barn were found to increase as the period of storage increased (van der Weerden *et al.* 2014). They found, in their component experiment, that N_2O emissions associated with land application of the stored manure were less than the emissions during the storage phase. However, they state that field scale research is required for verification at the farm scale.

2.5.5 Wintering issue within the context of the whole dairy system

The wintering component of the whole dairy system is an important one. This is the period of late pregnancy when the resulting cow body condition can have an impact on her production during the following season and also on her ability to get into calf again. In terms of environmental impact, the nutrient losses from the traditional crop wintering system provide a disproportionately large fraction of the whole farm losses (Chrystal *et al.* 2012; Monaghan *et al.* 2007b). There is little literature available that looks at the whole farm system from production, environmental and financial aspects and compares farms that have different wintering systems. It is important to assess the whole farm as reductions in losses from some areas due to a farm system change, may result in increased losses in other areas. It is important to assess whether ‘pollution swapping’ is occurring or whether the system change is resulting in a true reduction in total system losses.

2.5.6 Summary of the particular challenges associated with each wintering system

In summary the main challenges associated with each system are:

i. Crop

1. Risk of damage to soil (soil compaction, pugging) from high stocking densities at times of the year when soils are wet.
2. High contaminant losses to water via surface runoff and leaching
3. Thermal challenge:
    a. Risk of reduced animal production.
    b. Risk of reduced crop yields.
4. Animal welfare concerns:
    a. Reduced lying times in response to wet and cold conditions

ii. Wintering barn

1. High capital cost
2. Animal welfare issues:
    a. Increased risk of mastitis
    b. Increased lameness
    c. Reduced lying times in response to reduced area per cow and/or wet bedding.
3. Effluent storage requirement
4. Effluent management requirement
5. Resulting increased productivity potentially eliminating any environmental gains.

2.6 Development of a knowledge framework

This review of the literature pertaining to existing dairy wintering systems in southern New Zealand was used to develop a knowledge framework that outlines the key components, and interactions, of different types of dairy wintering systems in the southern South Island New Zealand (Figure 2.7). This framework highlights the complexity of off-paddock dairy wintering systems and represents some of the more common system components within existing dairy wintering systems. There will, however, be many more variations and other unique systems in use.

This framework has identified a lack of systems currently available that utilise the low cost brassica crop but incorporate some form of off-paddock system (Figure 2.7). This study looks to develop a low-cost wintering system that fills this gap (red dashed lines in Figure 2.7).

2.7 Gaps in the research

The main gap identified by drawing together the literature into a visual summary (knowledge framework; Figure 2.7) was that there is currently no low-cost system that grazes cows on winter brassica crop for a proportion of the day while confining them to a low-cost stand-off or loafing area that captured effluent. This lead to the idea that a system that incorporated the brassica crop but had an area where animals were contained and where effluent was captured and stored could be developed. Ideally the system would be low cost so a method of applying the liquid effluent to land during winter was investigated to reduce the storage requirement. This concept was named the "Portable Pad System" and the related work is outlined in this document;

1. Chapter 4 investigates the reduction in N leaching losses on stony soils under the restricted grazing (6 hours day^{-1}) compared to traditional grazing (24 hrs day^{-1})

2. Chapter 5 investigates the development of a pad that meets the requirements of low-cost and acceptable animal welfare conditions.

3. Chapters 6 and 7 investigate the potential to apply liquid effluent captured on the pad to land on a daily basis over the winter using low rate, low depth irrigation technology.

In terms of gaps in the knowledge of existing systems this review of the literature highlighted a number of gaps. Upon further investigation the majority of these gaps can be grouped under the broad heading of 'Manure Management'. There has been considerable work done on wintering system design and identifying the different systems available, there has been a lot of work investigating animal management and welfare and some work modelling the economics of the different wintering systems.

However, there remains a lack of information in the area of 'Manure Management'. This can be broken down into:

1. The volumes and properties of effluent products generated and captured by different off-paddock systems (Chapter 3).

2. Management of bedding surfaces (which are a manure source), to optimise animal health and welfare, minimise financial cost, and generate a useful nutrient source (Appendix 11.1).

3. Knowledge of the availability to plants of nutrients from different manure sources, such as barn bedding, when applied to land (Appendix 11.2).

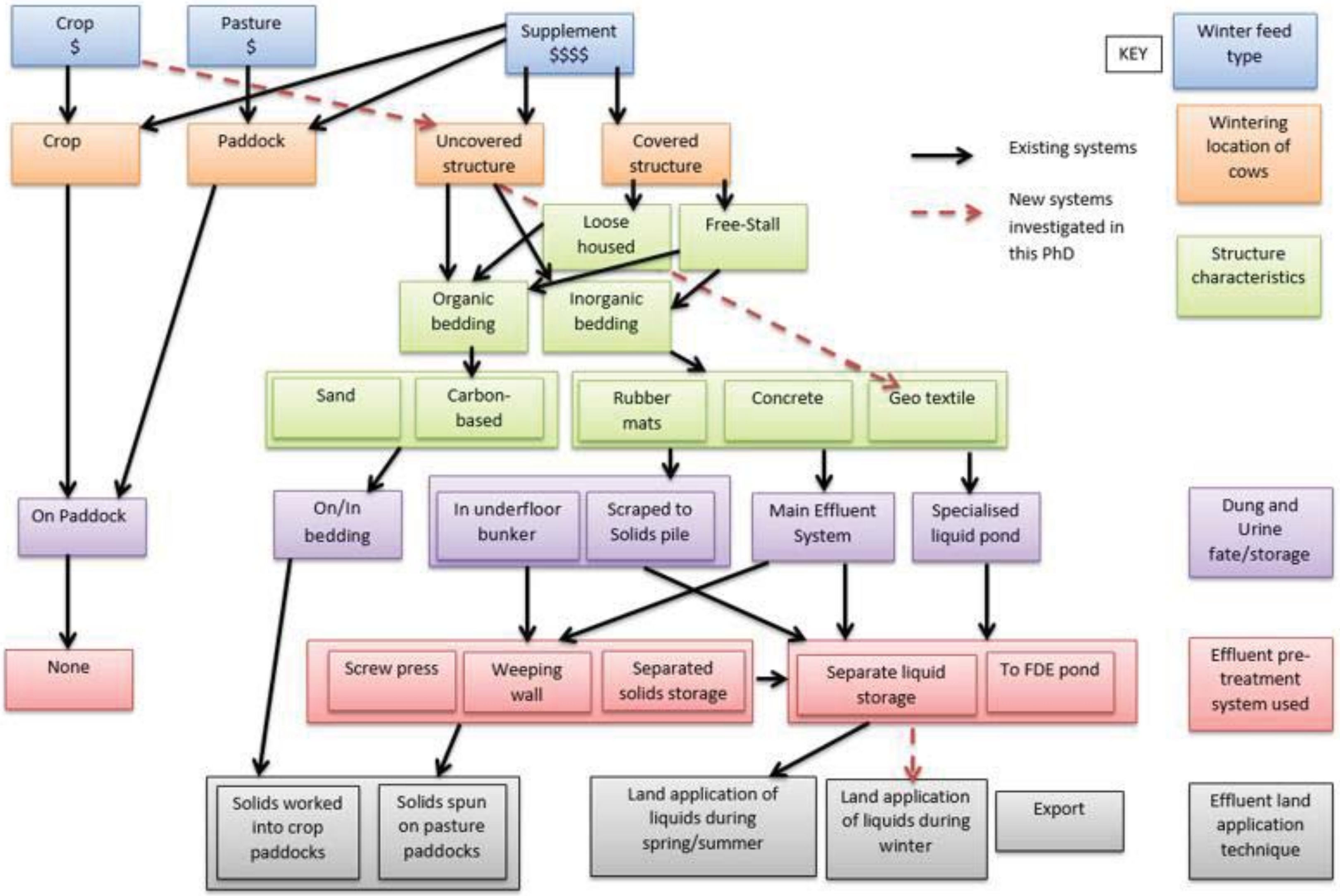


Figure 2.7. A knowledge framework outlining the key components of, and interactions between, different types of dairy wintering systems in the Southern South Island of New Zealand. The solid lines represent existing systems. The dashed red line represents the proposed system identified and investigated in this PhD.

These first gap has been addressed for a deep litter barn in Chapter 3 of this work. Areas 2 and 3 are in the appendices as the information is not required for the modelling comparison of the three systems conducted in this thesis.

Increasingly Regional Councils and dairy co-operatives require wintering systems to be both environmentally and animal welfare compliant. Very little research has addressed the environmental problems in conjunction with an evaluation of the system implications. Adopting what are considered to be environmental mitigation strategies will impact on other key aspects of the whole farm system such as farm management, labour demand, animal welfare, production levels, financial issues, and social issues. It will be important for future research to look at the impact of wintering systems at a whole farm system level if it is hoped to encourage farmers to adopt environmental mitigation strategies.

2.8 **Proposed area of research**

There is a need to develop a winter management strategy and system that is a low cost alternative to traditional brassica crop wintering systems. A system that takes advantage of the benefits of off-paddock wintering without the high-capital cost. In addition, any new strategy needs investigation into whole system implications, not just environmental losses. Animal welfare, financial and labour demand implications will have an impact on farmer uptake of any proposed system.

It is important for any new system to be compared to the examples of the existing crop and off-paddock wintering systems. Any gaps in knowledge of existing systems (such as the volumes and quantities of effluents generated by off-paddock systems) must be filled to accurately compare systems. Chapter 3 deals with the knowledge gap related to wintering barn effluent products.

Chapter 4 addresses the gap in the literature pertaining to N leaching under winter grazed crops on excessively freely drained soils. Chapter 5 investigates the new and novel portable pad concept developed in response to the gap identified in the knowledge framework of existing wintering systems (Figure 2.7). Chapter 6 presents results from a field experiment of low depth winter applied effluent to land. This concept is built on further in Chapter 7 to present modelled data of low rate and low depth winter applied effluent to a range of soil types under a range of climates. Chapter 8 presents estimates of whole farm N leaching losses from three different wintering systems: traditional brassica crop, portable pad, and wintering barn. This analysis uses a mix of results from *OVERSEER* nutrient budget simulations supplemented with measured and modelled (APSIM) results from the literature and also from the data presented in Chapters 3 to 7.

3. Volumes and nutrient concentrations of effluent products generated from cows in the loose-housed wintering barn with woodchip bedding

This research has been summarised in a paper published in the FLRC conference proceedings 2016. Chrystal, J., Monaghan, R., Hedley, M., & Horne, D. (2016). Volumes and nutrient concentrations of effluent products generated from a loose-housed wintering barn with woodchip bedding. Paper presented at the Integrated nutrient and water management for sustainable farming, Massey University, Palmerston North, New Zealand (Chrystal, J. *et al,* 2016) .

3.1 Abstract

In southern New Zealand there has been an increase in the use of off-paddock wintering systems as an alternative to the traditional approach of grazing winter brassica crops. These off-paddock systems capture and store effluent products that differ in their characteristics depending on the particular system used. The volumes generated and nutrient characteristics of the effluents produced are poorly defined and this means that the associated nutrient values are not easily estimated. The effluents and manures produced by a loose-housed deep litter wintering barn utilising woodchip as a bedding material were sampled and the volumes and nutrient concentrations measured. Effluent and manure products from 5 sources were monitored: drainage through the barn bedding, effluent scraped from the feeding alley, farm dairy effluent (FDE) from the dairy shed and yard, leachate from the silage pad, and the used barn bedding. Total amounts of nutrient per cow from all captured effluent sources in the dairy farm system were equivalent to: 38.4 kg N cow^{-1} year^{-1}, 9.6 kg P cow^{-1} year^{-1} and 56.1 kg K cow^{-1} year^{-1}. This equates to an annual fertiliser value of $136 cow^{-1}. The manure products with the highest nutrient concentrations were associated with dung and urine deposition in the feeding alley and on the barn bedding. The largest volumes of effluent were generated by the FDE from the dairy shed and yard, and rainfall falling on the concrete area of the milking yard, feeding alley and silage pad. The total volume of effluent captured by the pond system was equivalent to 4.2 m^3 cow^{-1} winter^{-1} (of which 3 m^3 cow^{-1} comes from the barn system) and the volume of spent bedding represented 7.4 m^3 cow^{-1} winter^{-1}.

3.2 Research site and Farm characteristics

The experiment was conducted on the Telford Rural Polytechnic dairy farm located near Balcultha, South Otago (latitude -46° 17'; longitude 169° 43'; 17 m above sea level). The property milks 650 cows on a 221 ha milking platform with an additional 188 ha for young stock, wintering and support (total 409 ha). At the time of these studies the farm was running three different farming systems (farmlets) for the P21 research programme. Briefly, these farmlets were: (1) a ‘Control’ (CON) where there was no change to the current farming system, 430 cows were milked on 142.5 ha (stocking rate (SR) 2.9 cows ha^{-1}); cows were winter grazed on brassica crops (44 ha), (2) ‘Optimal Feeding’ (OPT) where 110 cows were milked on 39.2 ha (SR 2.8 cows ha^{-1}) and calving was 2 weeks later than the CON herd to better align with pasture production; Italian ryegrasses were used to increase pasture production; nitrogen fertiliser usage was limited to less than 30 kg N ha^{-1} yr^{-1} on pastures; the system produced whole crop cereal silage; cows were wintered on crop (9.2 ha); and system (3) was a ‘Restricted’ (RES) herd where 110 cows milked on 39.2 ha (SR 2.8 cows ha^{-1}) were wintered in the loose-housed barn for around 70 days over the winter months. An additional 8.8 ha was used to produce feed for the barn. The barn was also used in spring and autumn to house cows over night when there was a risk of treading damage to wet soils. The wintering barn was a Red Path Dairyshelter (www.redpath.co.nz; Figure 3.1A). It was a loose-housed barn with a clear roof and windbreak along 2 sides of the barn. The base of the barn was a compacted stone and clay layer that was designed to capture all urine excreted via either absorption in the bedding or via subsurface drains through to the effluent system. The bedding used in the barn for the duration of the monitoring was woodchip. Water troughs were located at the ends of the barn (Figure 3.1 A), although in 2014 these were relocated away from the bedded area and on to the unroofed feeding alley adjacent to the barn.

This Chapter focuses on the RES herd and the experiment conducted in relation to that system.

3.3 Identification and monitoring of effluent and manure streams

The loose-housed barn (Figure 3.1 A) had a purpose-built effluent collection pond (with a small weeping wall; Figure 3.1 B, C) designed to capture effluent generated from the barn: both the liquids draining through the bedding, and solids scraped from the feeding alley. FDE from the dairy shed and leachate from the silage pit also drained to this collection pond before being pumped to the main farm effluent ponds via large weeping walls.

Monitoring sites were established in late 2012 to measure the volumes of effluent generated and collect composite samples at 4 locations. A further three solid effluent streams were measured at specific times. Monitoring was conducted from February 2013 until August 2014. The streams monitored and methods of monitoring were:

1. Liquid effluent draining through the woodchip bedding was monitored by a 3 litre tipping bucket connected to a data logger. Composite samples were taken for nutrient analysis by a

syphoning system located at one side of the tipping bucket that captured 0.3% of each tip in a storage container that was then emptied weekly.

2. FDE from the dairy shed. A purpose-built sediment trap was established; however, issues with blocking of flow meters resulted in spot sampling for volumes and nutrient concentrations. Based on these spot samplings (4 samples over 4 weeks), a value of the volume of FDE produced per cow per milking was estimated.

3. Effluent from the silage pad was monitored by a 5 litre tipping bucket, connected to a data logger and installed in a purpose-built bunker. Composite samples were taken for nutrient analysis by a syphoning system located at one side of the tipping bucket that captured 0.3% of each tip in a storage container that was then emptied weekly.

4. The volume of liquid effluent pumped from the collecting pond to the main effluent ponds was calculated by an hour meter installed on the pump. Spot samples (6 samples, taken monthly) of the liquid effluent in the collecting pond were taken from behind the small weeping wall.

5. The volume of solids scraped from the feeding alley was measured on three occasions. Spot samples were taken for nutrient analysis.

6. The volume of solids removed from the small collecting pond were to be measured by Telford staff recording the numbers of slurry tanker loads (and the date) required to empty the solids from the pond over the monitoring time. This was not done, therefore there is no data for this effluent source.

7. The final effluent source is the barn bedding itself. The volume removed from the barn at the end of the winter (and during the winter if a partial removal was done) was recorded on two occasions. Spot samples were taken from the stacks of removed bedding on the day of removal. 20 grab samples along the length of the pile and at different depths and heights were taken and mixed together back in the lab.

The effluent sources coming from the wintering barn originate from the 110 RES herd cows. These streams are: (1) the effluent draining through the woodchip bedding, (2) the solid effluent scraped from the feeding alley and concrete cleaning strip, and (3) the barn bedding emptied from the barn. The other two streams were derived from all 750 cows on the farm. The first is the FDE from the dairy-shed, where the number of cows being milked were used to calculate volume generated per cow. The other stream entering the collecting pond was the effluent from the silage pad. This too can be calculated per-cow using records of the amount of silage fed to each mob. However, the nutrient contribution from the silage effluent was so small as to be irrelevant.

3.4 Methods of measuring liquid and solid effluent volumes, and obtaining samples for analysis.

3.4.1 Effluent system

A.

B.

C.

Figure 3.1. Telford barn and effluent system. A. Telford wintering barn and feeding alley, B. purpose-built collection pond and C. small weeping wall in collection pond with wider than normal slats.

The liquid effluent from the wintering barn, silage pad and dairy shed were gravity fed to a small purpose-built collecting pond of 50 m^3 storage capacity (Figure 3.1 B; Figure 3.2, point 6). The other source of effluent entering this pond was the solid and liquid effluent scraped from the feeding alley. Solids were scraped every one to two days during the times the barn was in use. The collection pond was designed with a weeping wall (with larger spacing than normal slats; Figure 3.1 C) to screen out the larger fraction of solids. However, there were issues with the weeping wall blocking and this was eventually removed. Liquid effluent was pumped from the collecting pond to the main FDE ponds (13,000 m^3 storage capacity) via two large weeping walls. The pump was able to pump 27.6 m^3 per hour. Effluent was applied to land during spring and summer using a combination of K-line sprinklers and travelling irrigator.

3.4.2 **Rainfall collection areas**

The wintering barn roof area was 767 m^2 (10.65 m x 72 m). The feeding alley was an additional 360 m^2 and there was a 72 m^2 area for feeding troughs. This is a total 1,199 m^2. Roof water from the barn was collected and stored in tanks for use in the dairyshed, rain water from the feeding alley and troughs enters the effluent system (Figure 3.2). During the milking season any rainwater collected on the milking shed yard also went to the collecting pond, along with the FDE. The rainwater collection area of the dairy shed yards was 1,732 m^2. When the shed is not in use over the winter period there was a diverter in place so that rainwater (no FDE) is directed to a nearby creek. The concrete silage pad (1,250 m^2) also drained to the collecting pond when the storm water diverters were off. The concrete cleaning strip was 196 m^2 and the pond a further 34 m^2. This was a total of 3,646 m^3 of concreted area capturing rainfall that could potentially enter the effluent system (Table 3.1).

Rainfall was recorded in the paddock neighbouring the wintering barn by a 0.2 mm increment Davis rain gauge that was logged hourly.

Table 3.1. Concreted areas of the Telford farm that contribute rainfall runoff to the effluent system

Area	Surface area (m^2)
Feeding alley and troughs	432
Dairy shed yards	1,732
Silage pad	1,250
Cleaning strip	198
Effluent pond	34
Total surface area contributing rainfall to the main effluent ponds	3,646

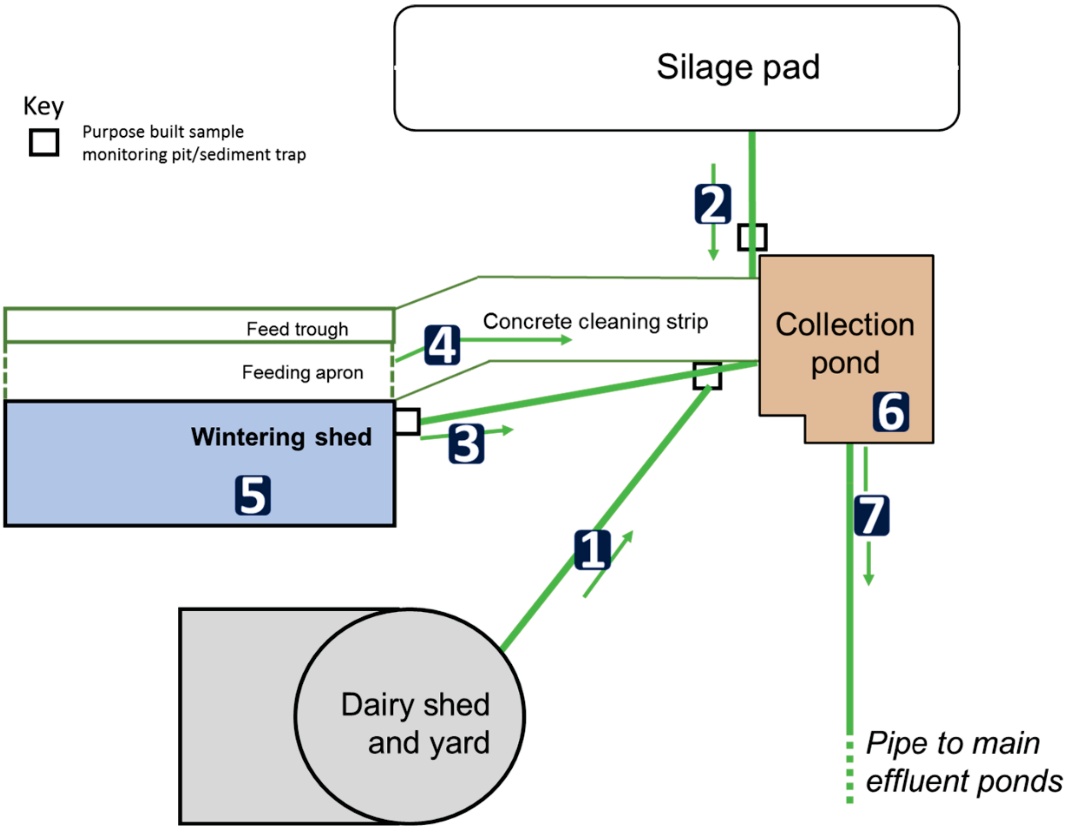


Figure 3.2 Diagram of the Telford farm effluent and manure measuring sites. These are: 1) FDE, 2) silage pad leachate, 3) effluent draining through the wintering barn bedding, 4) effluent scraped from the feed pad and concrete cleaning strip, 5) barn bedding, and 6) collection pond effluent. Effluent is then pumped via pipe '7' to a large weeping wall for storage in the main effluent ponds.

3.4.3 Monitoring sites (Figure 3.2)

Monitoring sites were established in 2012 to measure the volumes of each effluent stream and also to take samples of the effluent for nutrient analysis.

1. Monitoring of the FDE was via a sediment trap (spot 1 in Figure 3.2) located near the collecting pond where the pipe transporting FDE to the collecting pond was located. This sump was used for spot sampling of effluent volumes and collections of effluent samples. The initial plan was to install a flow meter in the pipe to record flow rates. However, there was no affordable flow meter available that could handle the solids and stones that were present in the FDE.
2. A sediment trap containing a 5 litre tipping bucket connected to a Campbell logger that measured the leachate from the silage pad (spot 2 on Figure 3.2). There was a collection container that collected a composite sample from all tips. This was analysed monthly.
3. To monitor the effluent draining through the barn bedding, a pit was located at the south end of the wintering barn (Figure 3.1 C). This housed a 3 litre tipping bucket that was connected to a Campbell logger that recorded the number of tips the bucket made. There was a

composite sample of effluent taken by syphoning a proportion of each tip into a storage container. The container was emptied and a sample was sent for nutrient analysis on a weekly basis during winter and a monthly basis the remainder of the year. The bucket was located at the base of the pipe that drained the wintering barn, which in turn drained to the collection pond (point 3 in Figure 3.2).

4. Effluent scraped from the feeding alley was monitored (spot 4 on Figure 3.2). This was done by three spot measurements carried out at different times during the winter. Here the material from the feeding alley was scraped to form a uniform pile at the end of the alley. The area of the pile was then calculated and a sample taken for analysis and estimate of bulk density.
5. Barn bedding was sampled for nutrient analysis when it was removed from the barn. Volume and number of loads removed were recorded for volumes produced (spot 5 on Figure 3.2).
6. Measurement of the volume of liquid effluent pumped from the collecting pond to the main effluent ponds was recorded by an hour meter installed on the pump (spot 7 on Figure 3.2). This was used to estimate the volume pumped. The hour meter reading was recorded weekly during the winter and less frequently during the milking season. Additionally, the volumes of solids removed by tanker from the pond were to be recorded as they occurred.

3.4.4 **Effluent analysis**

Composite samples were taken from the barn and silage streams and stored at 4 °C, for a maximum of 48 hours, before being sent to a commercial laboratory for chemical analysis of TKN. Spot samples were taken for the: FDE, solids scraped from the feeding alley, and the pond solids. These too were stored at 4°C for a maximum of 48 hours before being sent to a commercial laboratory for analysis of TKN. There were a number of different methods of analysis over the monitoring period. Some of this variation was down to the laboratory conducting the analysis (water analysis laboratory or fertiliser analysis laboratory; all Eurofins Ltd laboratories) and others were due to a change in the methods used over time. Methods used for TKN were: Kjeldahl digest, phenol hypochloride colorimetry (APHA (2005) 4500) or, Kjeldahl digestion, Steam distillation (Excl. NO_3-N). The objective of both methods is the same and that is digestion to remove the organic matrix.

Samples of the barn bedding material were taken at the end of the winter and were stored at 4°C for a maximum of 48 hours before analysis a commercial laboratory for; TN, NH_4^+-N, NO_3^-N. The methods of analysis are shown in the table below (Table 3.2).

Table 3.2. Tests and method of analysis conducted on barn bedding samples at a commercial laboratory.

Test	Test method	Reference
TN	Combustion elemental analyser: Thermal conductivity detection	(AOAC 1996)
NH_4^+-N	Water extraction, FIA determination	(Instruments 1998b; Wisconsin-Extension 2003)
NO_3^-N	Water extraction, FIA determination	(Instruments 1998a; Wisconsin-Extension 2003)

3.5 Results from the effluent monitoring and sample analysis

3.5.1 Rainfall

Total annual rainfall at the site was 686 mm and 726 mm during 2013 and 2014 respectively. The 30-year annual average rainfall for the region for the years 1981-2010 was 679 mm, with an average annual mean air temperature over the same period of 10.4°C (NIWA 2015a)(Station number 5867). Winter rainfall (1 June – 31 August) was 168 mm and 140 mm in 2013 and 2014 respectively.

3.5.2 Effluent volumes and nutrient characteristics

i. Rainfall collected in the measurement systems.

Based on the annual rainfall amounts above falling on the areas reported in Table 3.1 and assuming the dairyshed diverter is in place during June and July, the volume of rainfall contributing to the effluent system would be 1017 m^3 and 1075 m^3 in 2013 and 2014 respectively. This assumed that the silage pad diverter was not used.

ii. Effluent volumes, directly from the wintering barn, entering the effluent pond system

The total annual volume recorded from the three barn streams in 2013 was 365 $m^{3,}$ of which roughly 158 m^3 came from the barn drainage, 89 m^3 from the feeding apron and the remaining 118 m^3 from rainfall on the feeding apron and scraping alley. In 2014, monitoring stopped at the end of August; the annual total until this time was 374 m^3, of which 220 m^3 came from the barn leachate, 63 m^3 came from the feeding apron and 91 m^3 came from rainfall that fell on the apron and scraping alley. These volumes are shown on a monthly basis (Figure 3.3). Figure 3.4 shows the wintering barn effluent streams as well as the other wintering streams entering the effluent pond system. This shows that the contribution from the three wintering barn streams were small relative to the volumes of FDE that would be produced by 110 RES herd cows using the dairy shed.

The volumes of FDE produced by the whole herd were estimated to be an average of 32.5 m^2 per day for a herd of 650. This is based on;

- 16,000 litres afternoon yard wash
- 12,000 litres morning yard wash
- 2,400 litres plant wash per milking (x 2 a day)
- 2,400 litres for vat wash once a day.

Totalling 32,500 litres per day.

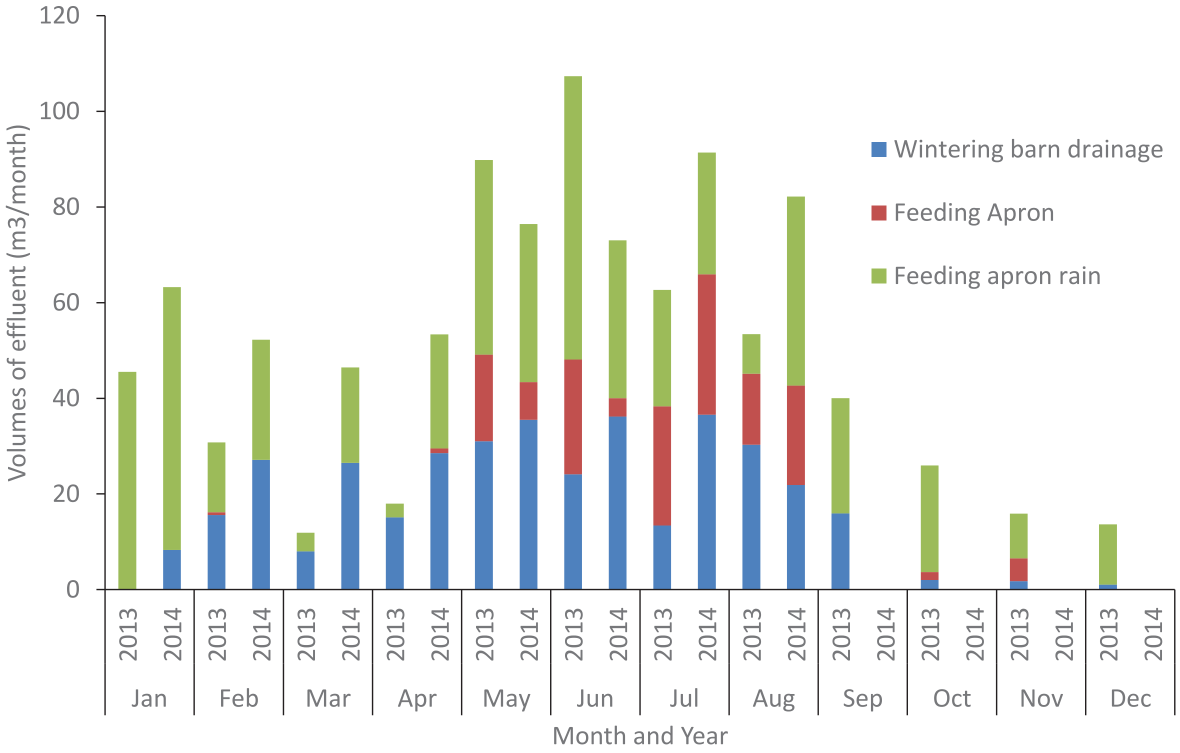


Figure 3.3. Total monthly volumes of the different effluent streams generated from the wintering barn over two complete winters of monitoring (2013 and 2014).

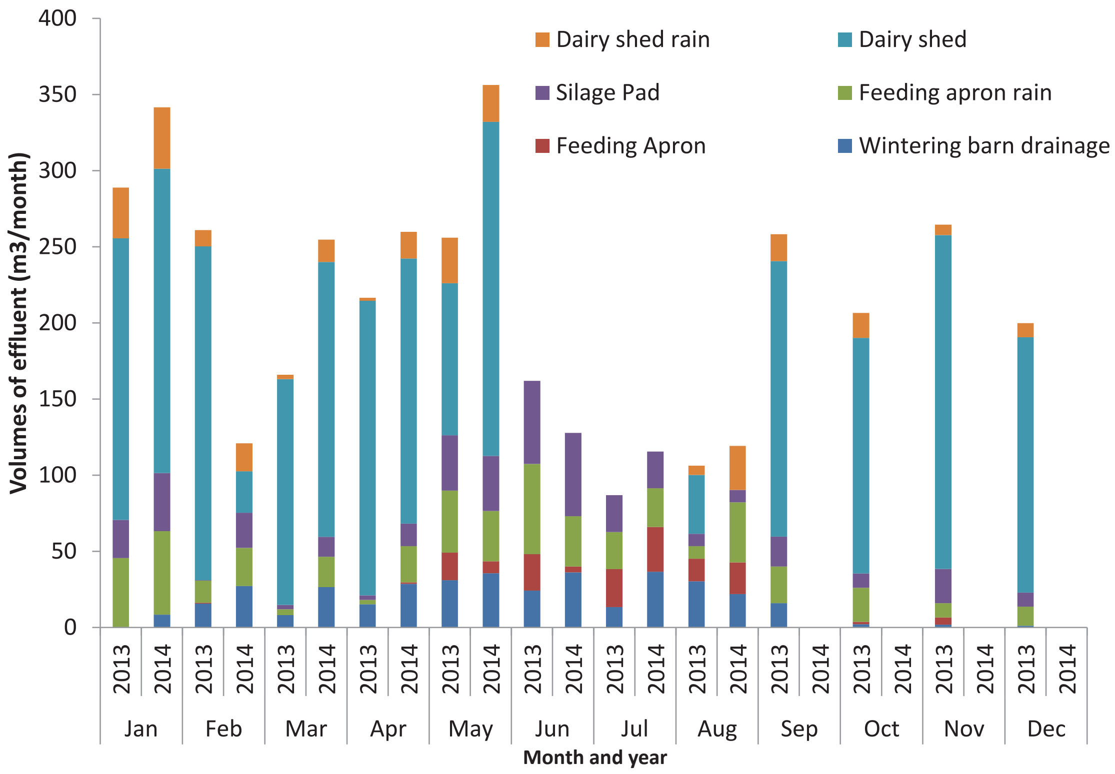
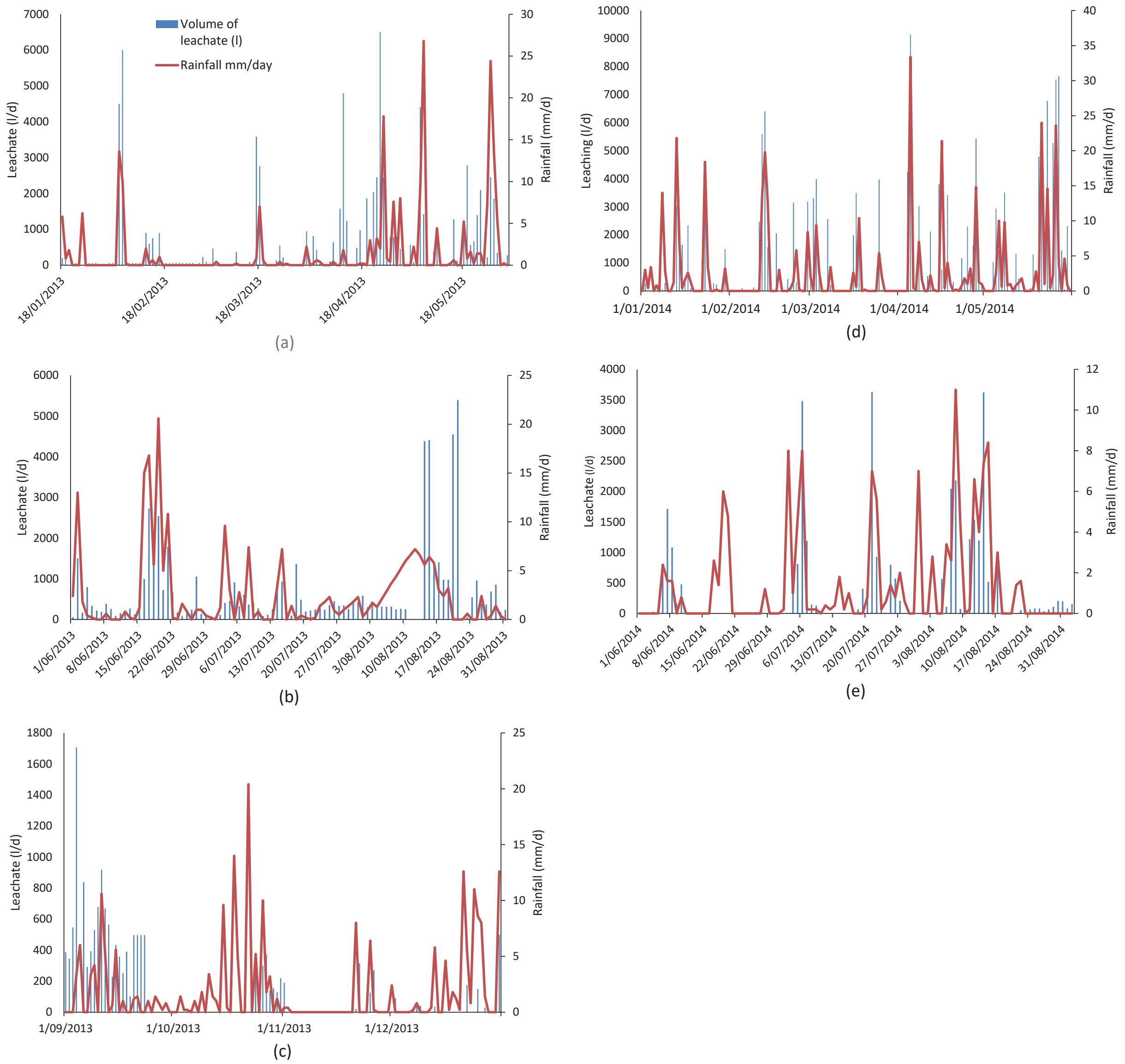


Figure 3.4. All effluent streams entering the Telford effluent collecting pond; scaled for the 110 cows of the RES herd.

The results in Figure 3.3 above highlighted a significant problem with the wintering barn drainage when compared to expected volumes of urine produced (calculated as 20 litres urine cow^{-1} day^{-1} X number cow days in the barn). The values recorded appear unrealistically high and there was drainage recorded when there were no cows in the barn. There were two possible reasons for this: firstly the monitoring equipment could have been faulty, or secondly, there could have been extra liquid entering the wintering barn system and thus the effluent system. Calibration of the monitoring equipment allowed us to rule out the first possibility. Analysis comparing daily rainfall the daily volumes drained from the wintering barn (Figure 3.5) showed a clear relationship between rainfall and leachate volume. The possibility that there was extra liquid entering the system was drawn to the attention of the farm management.



(a)

(d)

(b)

(e)

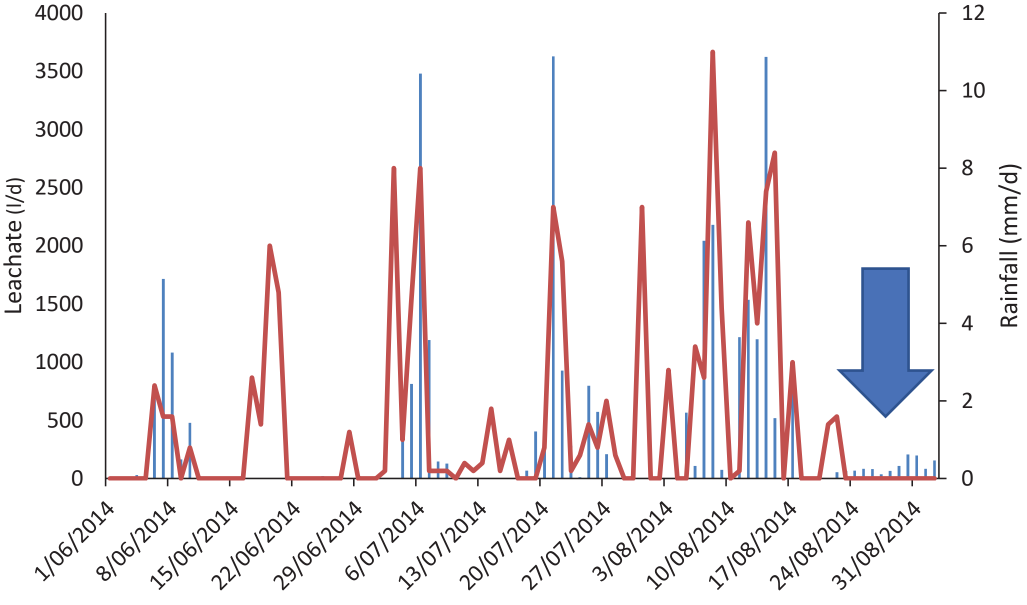
(c)

Figure 3.5. Comparison of rainfall (red lines, mm day^{-1}) and drainage (L day^{-1}) from the wintering barn (blue bars) during 2013 (a, b, c) and 2014 (d, e). The months when the cows were in the barn 24 hours a day are shown in graphs b and e.

Assuming the cows excreted 20 litres of urine per cow per day (Haynes & Williams 1993), and the maximum number of cows were in the barn (110 cows) then the maximum volume of urine produced in 24 hours would be 2,200 litres. The graphs in Figure 3.5 shows a large number of times when the daily leaching volume exceeds this maximum volume. Add to this the fact that it is highly unlikely that all urine would have been deposited on the bedding surface, or that the surface would have no absorbance capacity, it can safely be assumed that there is, in fact, an additional water source.

Assuming that this additional source is rainfall, then there is one period at the end of the two years of monitoring when there was a reasonable number of consecutive days where cows were housed for 24 hours a day and there was no rainfall. This period of ten days was from 23rd August until 1st

September 2014 (Figure 3.6). During this time the number of cows slowly reduced from 65 to 49 cows (as they left the barn to calf). Over this period 999 litres of drainage was collected, for the equivalent of 12696 cow.hours (number of cows in the barn x total hours day^{-1} in the barn x number of days in barn). Assuming a daily total urinary volume of 20 litres cow^{-1}, this calculates to an estimate of 9% of the daily urinary output drained through the barn bedding (an average of 1.8 litres cow^{-1} day^{-1}). As this period was the end of the winter, the bedding surface was very saturated; it could have been expected that this value could have been lower at the beginning of the season while the bedding was still dry and thus had significant absorption capacity.



(e)

Figure 3.6. Daily rainfall (red lines) and wintering barn drainage volumes (blue bars) for the period of June – August 2014 when cows were in the barn 24 hours a day. The blue arrow depicts a period of time when there was no rainfall and yet drainage was recorded.

The recovery of the equivalent of 1.8 L cow^{-1} day^{-1} indicates there was a significantly large additional volume of drainage captured. The total drainage from the wintering barn from 1st January 2014 until 2nd September 2014 was 195 m^3; during the time the cows were in the shed, the expected total volume of urination would be 154 m^2. Assuming only 9% of this should actually have drained this would represent a volume of 14 m^3. The additional volume collected (over and above the expected volume of 14 m^3) represents over five times the capacity of the collection pond (Table 3.3, 158 m^3 collected).

The silage pad produced 190 m^3 of effluent in 2013 and 212 m^3 from Jan until Aug 2014 (Table 3.3). The expected contribution from the 1,250 m^2 concrete pad based on rainfall totals of 686 mm in 2013 and 500 mm Jan-Aug 2014 would have produced an expected drainage volume of 858 m^3 in 2013 and

625 m^3 in 2014, suggesting that the silage pit divert was used for a large proportion of the year. Unfortunately there was no record kept of when the silage pit diverters were on.

The solids scraped from the feeding apron were calculated to represent an average of 0.79 m^3 day^{-1} for 110 cows using the barn 24 hrs day^{-1} (Equation 3.1). This is from a measured 7.18 litres cow^{-1} 24-hours^{-1}. Total solids from the feeding apron were 89 m^3 in 2013 and 63 m^3 from Jan-Aug 2014 (Table 3.3). These values included the winter use plus any spring and autumn use.

Equation 3.1. $(7.18\ l\ cow^{-1}\ 24\text{-}hrs^{-1}\ X\ 110\ cows)/1000 = 0.79\ m^3\ day^{-1}\ 110\ cows^{-1}$

Hourly effluent production: $7.18\ l\ cow^{-1}\ day^{-1} / 24 = 0.299\ l\ cow^{-1}\ hr^{-1}$

The liquid pumped from the collection pond to the main FDE ponds was estimated by calculating the volume pumped from the recorded hours of pumping multiplied by the pumping rate. The volume pumped per minute was measured on three separate occasions and the value of 0.46 m^3 $minute^{-1}$ was consistently recorded. Using this value of FDE volume pumped per minute and the number of hours pumped, the total volume pumped to the main pond in 2013 was over 41,000 m^3 and in 2014 Jan-Aug was over 16,000 m^3. This is significantly higher than the volumes calculated or measured going in to the collection pond (3,097 m^3 in 2013 and 2,233 m^3 in 2014; Table 3.3). This discrepancy was queried with farm staff and it seems that there were two factors contributing to the longer pump running times. These were: 1) there was some back flow in the pipe resulting in effluent being pumped twice after it flowed back into the collection pond once the pump stopped, and 2) the pipe taking the effluent from the collecting pond to the large FDE ponds often blocked and the pump was left running for hours at a time while nothing was being pumped through it. It was therefore concluded that the calculation using the hour meter was inaccurate and unreliable. Thus the volumes measured or estimated as going into the collection pond (Table 3.3) were used as the values going to the main effluent ponds minus and pond sludge removed from the collection pond.

The final effluent source is the barn bedding itself. This does not enter the effluent pond system but is a significant source of nutrient. In 2014 there was 550 m^3 spent bedding removed from the barn (the volume removed in 2013 was not recorded). Of this total, 215 m^3 was removed in mid-June, and the remaining 335 m^3 removed at the end of the winter; this is 5 m^3 cow^{-1}. This material had a bulk density of 0.675 (675 kg m^{3-1}) and a dry matter percentage of 35%, thus the total produced on a dry weight basis was 118 T or 1.07 T cow^{-1} yr^{-1} (based on an average of 110 cows day^{-1} in the barn over the period of use).

Table 3.3. Effluent streams and products entering and leaving the effluent collection pond in 2013 and Jan-Aug 2014 (m^3). Actual figures measured or calculated and also figures calculated per cow.

Effluent source	2013 (m^3)		2014 (Jan – Aug) (m^3)	
Effluent streams entering the pond system				
	Total volumes recorded	Per cow	Total volumes recorded	Per cow
Wintering barn drainage	158	1.44[1]	220	2.00[1]
FDE for 110 cows	*1398*[3]	*12.7*	*852*	*7.7*
Silage pad	190	1.2[2]	212	1.3[2]
Solids from feeding apron	89	0.81[1]	63	0.57[1]
Rainfall from feeding alley	*297*	*4.0*[1]	*215*	*2.9*[1]
Rainfall from dairy shed	*940*	*8.5*	*722*	*6.6*
Total	3,072	28.65	2,284	21.07
Effluent streams not entering pond system				
Barn bedding			550	5

[1] The average cow numbers in the barn was 110 per day over the 70 day winter. [2] 70% of the silage on-farm was fed to the RES herd. [3] Equation 3.2

Equation 3.2. Calculation of annual FDE production for 110 cows.

(32.5 m^3/650 cows)*110 = 5.5 m^3 per day per 110 cows multiplied by 226 days

This value of 226 days takes into account days were there were less than 110 cows milked. This is an estimate assuming only 50% of the cow.days in May were milked ((31 x 110)/2), and only 20% of the August cow.days were milked ((31 x 110)/5).

iii. Nitrogen loads and values

Due to the additional water in the wintering barn leachate, the concentration of the leachate was more dilute than would be expected. However, the total nutrient load remains the same.

For the farming system monitored, the total annual nitrogen nutrient load entering the effluent system in 2013 was 19.8 kg N cow^{-1} y^{-1}. The contributing volumes from different sources are shown in Table 3.4 below. The majority of the nutrient is contained in the solid fractions of the effluent (the feeding apron scrapings and the barn bedding). Minimal nutrient was captured in drainage from the silage pad or from the wintering barn. The silage stack produced almost no N. The amount generated in drainage from the wintering barn was 0.3 kg N cow^{-1} y^{-1} (Table 3.4).

Table 3.4. Annual quantities and nutrient concentrations of Nitrogen for the different effluent sources generated from a loose-housed wintering barn

	Nitrogen
Total annual nitrogen quantities measured from different sources (kg cow^{-1} yr^{-1})	
FDE	1.8
Silage pad	0.0
Wintering barn leachate	0.3
Feeding apron	5.3
Barn bedding	19.8
Nitrogen concentrations (wet weight)	
FDE	204 mg L^{-1}
Silage pad	12 mg L^{-1}
Wintering barn leachate*	234 mg L^{-1}
Feeding apron	4.17 kg T^{-1}
Barn bedding	5.86 kg T^{-1}

* Represents the measured concentration of sample from the barn leachate.

3.6 Discussion

3.6.1 Volumes and nutrient concentrations for different effluent streams

The volume and nutrient concentrations of nitrogen in FDE in our study were similar to those published elsewhere. The average concentration of N in FDE was 204 mg N L^{-1} (<1 – 400 mg N L^{-1}) was within the ranges of 81-506 mg N L^{-1}reported by Longhurst *et al* (2000). The volume of FDE per cow used was based on estimates of the volumes of water used for each activity (vat wash, plant wash and yard wash); these averaged 46.9 L per cow per day, were similar to the value of 50 litres per cow reported in a review of the literature of FDE (Houlbrooke *et al.* 2004b). There is, however, less published data on nutrient concentrations and volumes from the silage leachate and the different wintering barn effluent and manure streams.

Silage effluent production (rather than rainfall collected on the storage area) occurs soon after the silage has been cut, peaking at 10 days post ensiling. Ninety percent of the total effluent is produced by day 20-26 (Gebrehanna *et al.* 2014). Concentrations of TKN recorded in the tipping bucket ranged from 1.14 mg N L^{-1} to 21.6 mg N L^{-1} (average 12 mg L^{-1}). The highest values (21.6 and 20.4) occurred in April and May 2013 respectively; other values were less than 10 mg N L^{-1}.

Two of the three effluent and manure streams from the barn have similar nutrient concentrations to those reported in the literature, although the systems reported in the literature differ slightly to the loose-housed deep litter barn studied here.

Nitrogen concentration for the solids scraped from the feeding alley was 4.17 kg N T^{-1}. This result was similar to the findings of Houlbrooke *et al.* (2011a). They reported values for N concentrations in scrapings from two feed pads that were slightly higher than our findings (5.33 and 6.28 kg N T^{-1}). However their reported value of concentrations of N in solids scraped from a European style wintering barn was slightly lower than our values (3.19 kg N T^{-1}).

The volume of barn bedding measured here (1.07 m^3 cow^{-1} $year^{-1}$, dry material) is less than that estimated by van der Weerden *et al.* (2014) of 3.83 m^3 cow^{-1} over an 80 day winter. However, the figures in our study relate to a 70 day winter so the figure could increase to 1.22 m^3 cow^{-1} if they were in the barn for 80 days rather than 70. The percentage of dry material per wet tonne (35%) compares well to the 34% reported for a carbon-rich wintering pad and the 33% reported for a Herd Home bunker with wood shavings. It is also within the range of 20-50% quoted for Covered barns (Longhurst *et al.* 2012; Longhurst *et al.* 2006a).

It is not possible to compare concentrations of nitrogen in drainage from the wintering barn as this was highly diluted by an unknown water source in this work (234 mg N L^{-1}). There is very little data in the literature documenting liquid draining through a deep litter wintering barn. However, Houlbrooke *et al*. (2011) sampled liquid effluent draining from a HerdHomes® Shelter. The average value they reported was 920 mg N L^{-1}.

These findings highlight the need to conduct such monitoring over a wide range of dairy farming systems, as there is such a variety of systems used and the effluent contributed by the off-paddock wintering system contributes a significant proportion of the total volume of effluent captured. In this system, 20% of the total volume of effluent captured by the farm effluent system was attributable to the wintering barn. If the runoff from the silage pad is included in the calculation as a component of the wintering barn then this value increases to 29%.

Monitoring and measuring all manure and effluent streams on a dairy farm is a costly and complex exercise. This monitoring trial was conducted on a commercial dairy farm and there were many complications and challenges gathering data.

These included:

1. An obvious discrepancy with the volumes of drainage through the wintering barn recorded and those that were expected. An error in the monitoring equipment was ruled out and it was realised that there was an additional source of liquid entering the effluent system. This additional source was approximately 290 m^3 a year which was enough to fill the collection pond nearly 6 times. Rainfall was the likely contributor to this additional volume.

2. Because of this additional volume of water in the wintering barn effluent stream, the concentrations of nutrients recorded were not representative of the actual concentrations coming from the barn. However, assuming there was little nutrient in the rainfall that was collected, then the total load of nutrient produced is relevant.

3. The cost for a flow meter that was able to handle the stones and other solids in the FDE was prohibitively expensive; accurate recording of FDE volumes was thus not possible.

3.7 Conclusions

These findings show that there is relatively high nitrogen content in manures collected from a loose-housed deep litter wintering barn with a woodchip bedding. The main nitrogen sources were in the solids collected from the bedding and the feeding apron. For a dairy system incorporating a loose-housed deep litter wintering barn with a woodchip bedding, the total amount of nitrogen captured annually per cow was 19.8 kg N cow^{-1}. The volume of barn bedding was 1.07 m^3 cow^{-1} $year^{-1}$ dry matter (3.1 m^3 cow^{-1} $year^{-1}$ wet weight).

Due to the variable management of housing systems and the wide variety of systems available it is worthwhile that this survey is conducted over a wider range of systems. However, to help reduce some of the complexity and potential difficulties of monitoring, it would be beneficial to include an extra labour unit whose responsibility it is to obtain accurate data on the different effluent streams. It is time consuming and requires a strong desire to obtain accurate data by at least one person on-farm.

3.8 Acknowledgements

This experiment was funded by the Pastoral 21 programme, a collaborative venture between DairyNZ, Fonterra, Dairy Companies Association of New Zealand, Beef + Lamb NZ and the Ministry of Business, Innovation and Employment.

The Telford farm staff and Management are acknowledged for their assistance recording farming activities and also AgResearch technical staff Tom Orchiston, Wayne Worth and Stuart Lindsay for their assistance with trial establishment, sample collection and sample analysis.

4. Nitrogen losses from winter grazed crop on stony soils: the use of a channel lysimeter to measure N leaching under restricted (6 hr) and unrestricted (24 hr) grazing

4.1 Abstract

Nitrogen (N) leaching losses from a dairy-grazed winter brassica crop on an excessively well drained soil are poorly quantified. A field experiment measuring N leaching losses under a grazed brassica crop on a stony soil was conducted using hydrologically-isolated, in-paddock, channel lysimeters. The development of the field trench channel lysimeters and associated leachate sampling system are described. A dual soil water balance (SWB) was calculated and the captured leachate volumes were found to match very well with the SWB predicted drainage. Measured N leaching losses were significantly lower than those predicted by *OVERSEER* (14.4 kg N ha^{-1} measured for a mid-winter 24 hour grazing event compared with 154 kg N ha^{-1} yr^{-1} *OVERSEER* prediction for a winter grazed crop paddock). This low loss was due to insufficient rainfall to induce drainage greater than 1 pore volume resulting in a proportion of the urinary N applied remaining in the soil profile. The implications of this remaining N is that it could be taken up by subsequent crops or lost when the next drainage season begins. The number of channel lysimeters used in this experiment (8) was insufficient to detect a statistically significant difference in N leaching from different crop grazing durations (11.8 kg N ha^{-1} for the 6 hour grazing vs 14.4 kg N ha^{-1} for the 24 hour grazing).

4.2 Introduction

Common practice for wintering dairy cows in the lower South Island of New Zealand is grazing brassica crop *in situ*. The benefits of this system are that the brassica crop is a relatively low-cost feed that can be grazed at high stocking densities and provides a reliable winter feed source in a region where winter pasture growth rates are negligible. A wintering system that enables cows to be wintered on-paddock is favoured by farmers as it is a low-cost, low-labour input system that does not require the high capital costs of alternatives such as wintering barns or wintering pads. There are however, disadvantages to this system. The high stocking densities during winter when soils are wet can, depending on soil type, result in soil damage and pugging (Drewry & Paton, 2005). The deposition of urine onto bare soil, combined with high rainfall, results in the leaching of nitrogen (N) from urine patches to ground water (Monaghan *et al*, 2013). This leaching can be exaggerated when grazing occurs on stony soils (Smith *et al*, 2012). However, these stony soils are favoured by farmers for winter grazing because pugging does not occur, farmers can get vehicles on them during the winter, and cows are able to achieve targeted body condition score increases. Quantification of nitrogen leaching losses from winter grazed brassica crops on excessively freely draining soils are poorly understood.

The hypotheses for this work are:

1. Channel lysimeter methodology is suitable for measuring drainage volume and thus predicting losses to drainage under a grazed system, and
2. The introduction of a portable pad, where cows can stand when not grazing the crop, will collect excreta while cows are off paddock. Thus, the use of duration controlled grazing will result in reduced urinary N load on the grazing crop and reduce N loss to water.

A crop grazing experiment was conducted on a stony soil to investigate the impact on N leaching of on/off grazing of brassica crops during winter. This experiment was designed to complement the portable pad trial and provide further information on the total losses from the whole system. This enabled comparison between the N leached from the grazing of crop for 6 hours and then returning to the portable pad for the remaining 18 hours per day, and grazing crop 24 hours per day. This experiment represented the leaching associated with one mid-winter grazing event of either 6 or 24 hours. This experiment is henceforth referred to as the “Otama” experiment.

4.3 Methods

The trial site was located on a dairy support block near Otama in Southland, New Zealand (45.9289° S 168.8060°E; Figure 4.1). On this property young stock were reared, dairy cows were wintered on brassica crop, and silage was made to support the milking herd (Figure 4.1).

Figure 4.1. Location of trench plots for the Otama channel lysimeter experiment. The site sits adjacent to the Mataura River, north east of Gore Township

i. Soil type

The soil type at the site was a Riversdale stony sandy loam, a Recent soil (soil classification: Typic Fluvial Recent Soil;(Hewitt 1998)). This is a shallow sandy loam that is moderately stony and well drained. Topsoil P retention is low and this soil has a high N leaching vulnerability (Landcare_Research 2016a). The soil profile from 1 – 700 mm can be seen in Figure 4.2.

The description of the stone fraction of the soil of the 0-300 mm layer was:

22 % >12 mm diameter
46 % 12 – 2 mm
32 % < 2 mm

For the 300-600 mm layer the stone content of the soil was:

25 % > 12 mm
45 % 12 – 2 mm
30 % < 2 mm

Figure 4.2. Soil profile for a Riversdale soil at the site of the Otama experiment (0-700 mm depth

ii. Paddock history

Prior to the channel establishment in 2012 the site was in dairy-support pasture. From mid-September until the end of May it was grazed with dairy heifers at 7.9 stock units (SU) ha^{-1} (assuming 3.5 SU for a heifer). In November 2012 the paddock and the experiment plots were sown with kale. No fertiliser history was available.

4.3.1 **Channel lysimeter establishment**

Hydrologically isolated channel lysimeters were established in 2012 to capture sub-surface drainage and to enable the measurement of drainage flows and the collection of drainage samples. Seed bed preparation and crop establishment was conducted as part of the normal farming operation with plots sown along with the rest of the paddock. The experimental site was then fenced to exclude stock. Grazing occurred once each year, around July 1, to simulate a mid-winter grazing event. Plots were individually fenced and stocked at 4 cows per 4 x 20 m plot. Any plots yielding insufficient feed had the feed supply supplemented by the cut and carry of extra crop that was then fed to the cows on the plots. After either 6 or 24 hour grazing periods, cows were excluded from the plots for the remainder of the year. Grazing of the plots occurred over three consecutive years: 2013, 2014, and 2015.

The experimental site was established in Nov 2012. The individual channel lysimeter locations were pegged out and then the soil removed by a digger using a narrow trenching bucket (Figure 4.3, photos A, B & C). The 0-0.3 m layer of topsoil was removed initially, and kept to one side. The channels were then dug to a depth of at least 0.7 m. The channels were 1 m wide and 20 m long (Figure 4.3; Photos C & D), and were 4 m apart. The fall on the channels back towards the collection sump (located by the fence line) was measured to be 1% (Figure 4.3; Photo E).

The width of the channel was dictated by the width of the bucket on the loader (1 m) and the length of 20 m was selected assuming that there were potentially 10 urination events that would be captured in a 24 hour period.

The estimated number of urinations falling on the plot and channel lysimeter surfaces were based on the following:

Number of urinations cow^{-1} day^{-1} = 10 (Chapter 5, Table 5.8)

Number of cows plot^{-1} = 4

Plot area = 80 m^2 (4 x 20 m)

Channel capture area = 20 m^2 = ¼ of plot area

Potential total number of urinations = 4 cows x 10 events per cow = 40 events

Potential number captured by trench = 40 / 4 = 10 urination events

This figure would potentially be 2.5 urine patches (10 / 4) for the 6 hour grazing.

The channels were lined with a plastic sheet to hydraulically-isolate them and a slatted drainage pipe placed in the bottom of the channel and overlain with pea gravel (Figure 4.3; Photo F). The drainage pipe ran the length of the channel and then was fed through the wall of the hard plastic cylinder used to house the tipping bucket monitoring system (Figure 4.3; Photo G, Figure 4.4; Photos A, B & C). The channels were then backfilled with soil, ensuring the top 0.3 m was replaced at the surface (Figure 4.3; Photos H & I).


A


B


C


D


E

Figure 4.3. Photos of the establishment of the Otama channel lysimeters, November 2012. Photos are: A. Measurement of channel location, B & C. Excavation of channels, D. Lysimeter channel, E, Measuring fall in channel, F. Plastic liner with drainage pipe and pea gravel, G. Connecting drainage pipe to collection chamber, H. Filling in channel lysimeters, I. Site after completion with drainage chambers visible.

4.3.2 **Custom modification of drainage flow measurement system**

4.3.2.1 **Establishment of tipping buckets - 2013**

The initial plan for the sampling pits was to make use of the concept of a submersible pump. However, due to financial constraints it was decided to use tipping buckets. Unfortunately, this required the collection columns (Figure 4.4; Photo A), which were originally designed and sized for a submersible pump and already installed, to be re-configured for use with a tipping bucket. This required the removal of soil from the bottom of the cylinder to enable the tipping bucket to be housed (Figure 4.4; Photo B). A Campbell Scientific CR10 data logger recorded the number of tips and was downloaded during site visits. Due to the difficulty in altering the collection area because of the stony soil, and the small working space, there was very little space for any form of composite sample container as the tipping bucket required most of the space in the collection column (Figure 4.4; Photos C & D). A small, shallow collection tray was located under the tipping bucket and samples were taken using a syringe attached to a long tube.

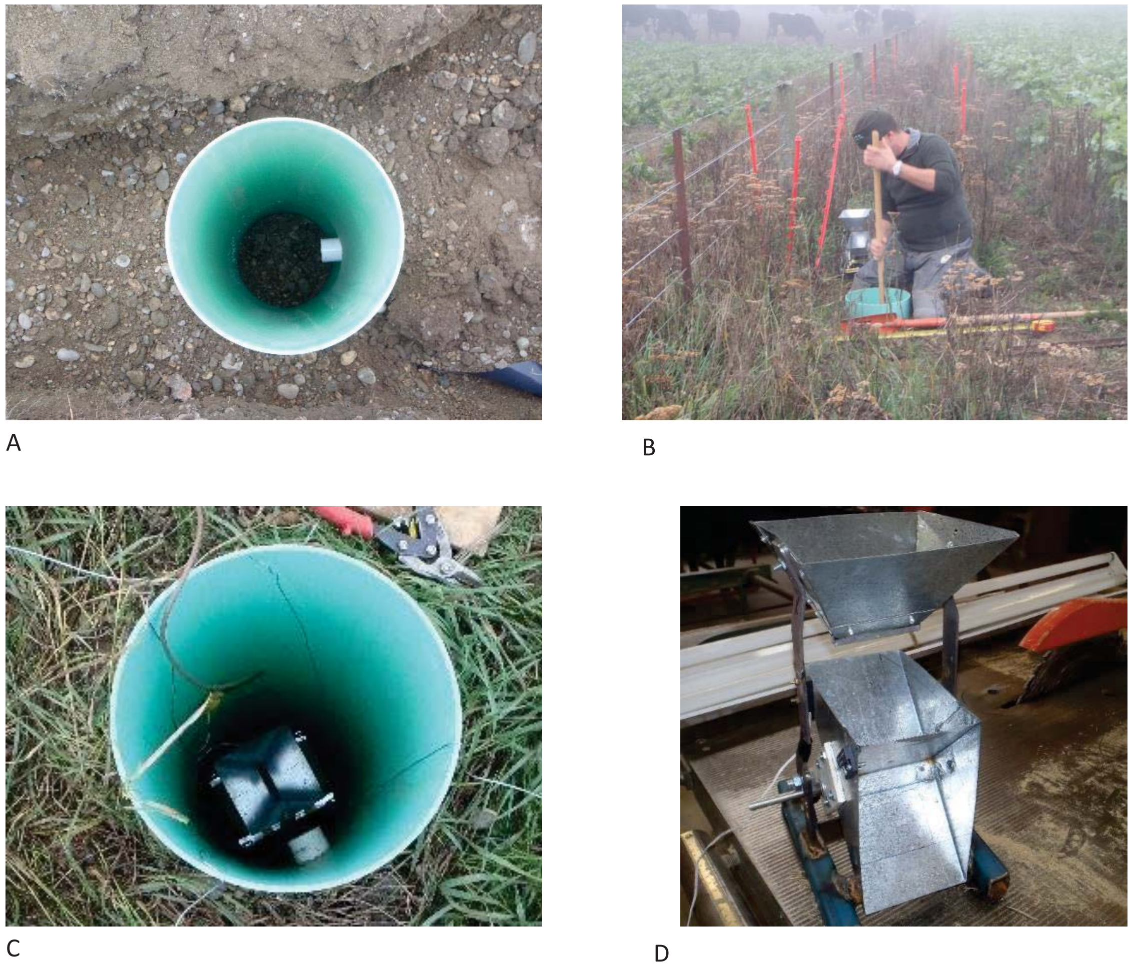


Figure 4.4. Photos of the sampling pits and tipping buckets in 2013. Photos are: A. sampling and drainage pit with drainage pipe connected, B. Altering the sampling pit to make it deeper, C. Tipping bucket in position in the sampling pit, D. Tipping bucket.

4.3.2.2 **Alterations to tipping buckets - 2014**

Due to issues with sample collection outlined above, and sample contamination (discussed below), the sampling pits were altered for the 2014 drainage season. A larger pit was dug next to the existing collection columns (Figure 4.5; Photo A). The drainage was directed into the new pit to fall into the re-located tipping buckets. A sampling container was housed in a smaller, deeper hole, to sit below the ground level of the pit (Figure 4.5; Photo B). This container captured flow-proportional samples of drainage by a siphoning device (Figure 4.5; Photo B) connected to one side of the tipping bucket which captured approximately 0.2% of each tip. It was necessary to secure the collection containers as they were prone to floating away if the pits flooded. A Campbell Scientific CR10 data logger recorded the number of tips and was downloaded during site visits (Figure 4.5; Photo C).

Although the collection pits were made larger in 2014, and it had been estimated that there would be enough surface area in the bottom of the pit for the trench drainage to drain away, there were still continuing issues with some of the pits flooding. It was likely that this flooding was actually the water table rising above the base level of the pits. This flooding contaminated the samples collected as the water table flooded over the buckets.

A

B

C

Figure 4.5. Photos of the enlarged sampling pits in 2014. Photos are: A. Pipe directing drainage into tipping bucket located in larger sampling pit, B. Composite sample container located below the base of the pit, C. View of the whole sampling pit.

4.3.2.3 **Customisation with submersible pump - 2015**

For the 2015 drainage season it was decided to use a submersible pump system that had been designed by Tom Orchiston, a member of the Nutrient Losses to Water and Atmosphere team at AgResearch, Invermay (Figure 4.6 and Figure 4.7). This system meant that samples were uncompromised if there was flooding of the pits from ground water.

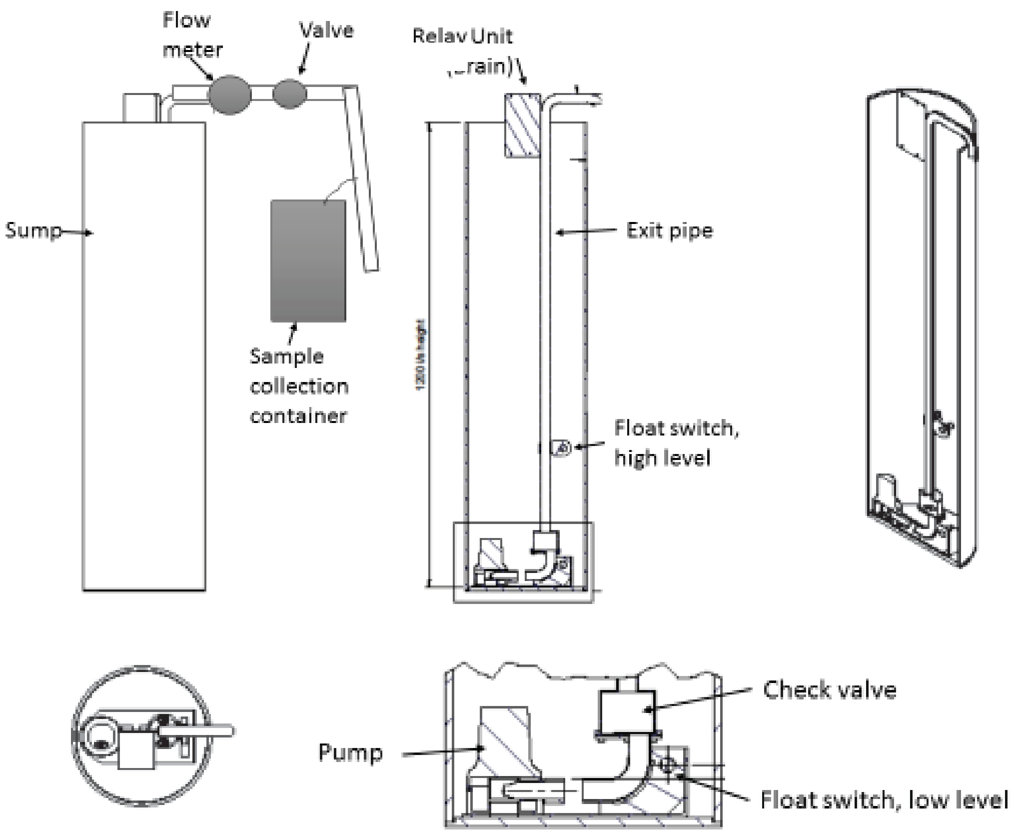


Figure 4.6. Diagram of the Submersible pump used at the Otama trench site. (Amended from Orchiston, T, 2015)

Figure 4.7. Submersible pump in use at the field site for the 2015 drainage season.

The submersible pump system consisted of a closed-bottomed cylinder housing a submersible pump, controlled by float switches and relays (Figure 4.6 and Figure 4.7). The drainage from the trench was directed into the top of the cylinder and when the water level reached a trigger height (approximately

30 litres) the pump was activated and the cylinder drained. The drainage was pumped through a pipe via a mechanical flow meter (RAF Multi jet water meter 20 mm with pulse output). A pulse was sent for every litre and this pulse was then recorded by an Odyssey rain gauge logger that gave a time and date stamp for every recorded litre. The drainage was then discharged into the bottom of a soak pit where it could not return to the monitoring system. A flow proportional sample (approximately 0.2%) was syphoned from each discharge. This was stored in a composite sample collection container which was emptied during site visits, at which time a sub-sample was taken for analysis.

4.3.3 **Grazing events**

Grazing occurred in 2013 (Kale), 2014 (Fodder Beet) and 2015 (Fodder Beet). However, due to the problems with the sampling techniques in 2013 and 2014 there were no reliable data collected for these years. For this reason reporting is restricted to the 2015 season. Grazing of the fodder beet crop occurred on June 30, 2015. Four plots were grazed for 24 hours and four were grazed for 6 hours. All plots had 4 mixed age (MA) cows per plot; 20 m^2 cow^{-1}. Plots were split into high and low flowing plots using drainage data from previous years. Treatments were then allocated to plots using blocked randomisation (Table 4.1).

Table 4.1. Channel lysimeter treatment (6 or 24 hour grazing), crop sown, and date of grazing for the Otama experiment.

		Trench number							
Grazing date	Crop	1	2	3	4	5	6	7	8
30/6/15	Fodder beet	6	6	24	6	24	6	24	24

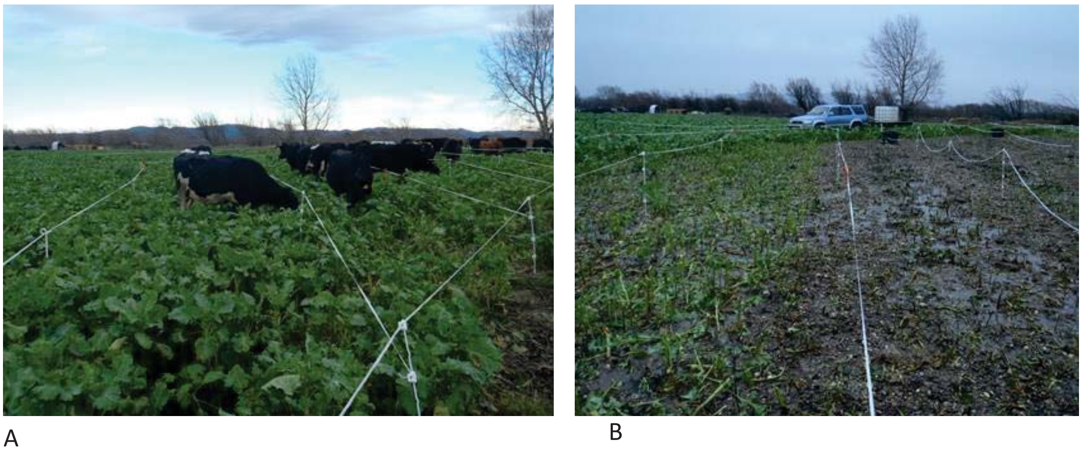


Figure 4.8. A, 2013 grazing of kale at Otama site; B, 2013 site post grazing. Plot on left was a 4 hour plot and plot on right was grazed for 24 hours.

A photo of the 2013 grazing event shows the visual difference between a 24 hour grazed plot (Figure 4.8 b; right-hand side) and a restricted grazing plot (Figure 4.8 b; left-hand side).

4.3.4 Sample collection and analysis

i. Rainfall

Rainfall was recorded at the pad site by a Raintrak telemetered rainfall system (Item ID: HS-RT-GSM; www.envcoglobal.com) connected to a Campbell Scientific CR 10 data logger.

ii. Site visits

Site visits were triggered by rainfall events that resulted in drainage. These were generally rainfall events of greater than 5 mm within a 24-hour period. Forty millilitre samples were taken for nitrate-N and ammonium-N analysis.

Table 4.2. Number of sample collected per month for each of the trial years.

	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
2013			3	5						8
2014	1	2	2	4	2					11
2015		3	3	5	4	3	3		1	22

iii. Sample analysis

Samples were collected within 24 hours of the predicted drainage and then stored frozen. At the end of each year the samples were sent in bulk to the AgResearch internal laboratory in Ruakura for nitrate-N (NO_3-N) and ammonium-N (NH_4-N) analysis using a Skalar SAN^{++} segmented flow analyser (Skalar Analytical B. V., Breda, Netherlands). The nitrate method involved cadmium reduction to nitrite followed by diazotisation with sulphanilamide and coupling with N-(1-naphthyl) ethylenediamine dihydrochloride to form an azo dye measured colorimetrically at 540 nm. The ammonium method is based on the modified Berthalot reaction. Ammonia is chlorinated to monochloramine which reacts with salicylate and is then oxidised to form a blue/green coloured complex which is measured colorimetrically at 660 nm (Mulvaney 1996).

iv. Drainage volumes

Due to the submersible pump system, drainage events were not recorded as soon as they drained out of the channel. Drainage from the channels collected in the cylinder until it reached the trigger height (30 litres) when the pump was then triggered and the cylinder was drained. When this occurred, the data logger recorded the volume of leachate pumped out and the date at which this occurred. Thus if 29 litres of drainage occurred on day 1 and then no further drainage occurred until day 7 and the pump was triggered on day 7, then the date recorded for that entire 30 litres drainage was day 7. This altered the dates of individual drainage events but not the total cumulative drainage volume.

4.3.5 Soil water balance

A soil water balance (SWB) based on the concept described by Scotter *et al.* (1979) and Woodward *et al.* (2001) was generated to determine the expected daily drainage at the site and soil water deficits. This method involved using daily rainfall and potential evapotranspiration measurements. The method uses the concept suggested by Scotter *et al*. (1979) that there are two soil water pools in the root zone: a rapidly depleted soil water layer (0 - 42 mm in this experiment) and a second layer where soil water is not as easily extracted.

Daily rainfall was recorded at the site by a 0.1 mm tipping bucket rain-gauge linked to a Campbell Scientific CR 10 data logger. Potential evapotranspiration data (Penman ET) were obtained from the NIWA Gore meteorological weather station located c. 22 km SSE of the trial site.
The soil water deficit was zeroed on the 29th April after a 13.1 mm rainfall event resulted in drainage in seven of the eight plots.

As the SWB was for a crop paddock grazed mid-winter and then remaining fallow until the end of the reporting period (bar some weed growth), the Dual SWB method (Allen *et al.* 1998) was used to generate crop ET values (ET_C). This takes into account the ET values from the crop area of the paddock and the bare ground area. It also allows for the proportions of ET from each of those areas to change as crop stage changes and when grazing occurs.

i. Evapotranspiration values used.

ET_C was calculated using the dual crop coefficient recommended by Allen *et al* (1998). This involves calculating the ET from the crop and also the ET from the bare ground. The proportion of crop and bare ground changes as the crop grows and also after grazing. The crop evapotranspiration ET_C was calculated using Equation 4.1. This requires a daily SWB for the soil surface layer (70 cm).

Equation 4.1 $ET_C = (K_{cb} + K_e)\ ET_0$

Where:

ET_C is the crop evapotranspiration
K_{cb} is the basal crop coefficient (Value used = 0.85)
K_e is the bare soil ET or evaporation coefficient
ET_0 is the reference crop ET (mm day^{-1})

Source: Allen *et al* (1998), equation 69, p157

As there were no reported values for the K_{cb} values for swedes, values were taken as mid-points between Turnip and Sugar beet as provided by Allen *et al* (1998). K_{cb} for the end of the season (last 20 days prior to grazing) was the value for infrequently wetted taken from Table 12 (p 110) (0.90 -0.05). Then the mid-season value from Table 12 of 1.15 was adjusted for ground cover less than 80% = 1.15-0.10.

Thus:

K_{cb} Mid = 1.05

K_{cb} End = 0.85

Calculation of K_e is required for Equation 4.1. This can be calculated using equation 4.2.

Equation 4.2 $K_e = K_r (K_{c\,max} - K_{cb}) \leq f_{ew} K_{c\,max}$

Where:

K_e is the soil evaporation coefficient, which is the smaller of the two values:

$K_r (K_{c\,max} - K_{cb})$ or $f_{ew} K_{c\,max}$

K_r is the evaporation reduction coefficient dependant on the cumulative depth of water evaporated from the topsoil

f_{ew} is the fraction of soil exposed and wetted

$K_{c\,max}$ maximum value of K_c following rain or irrigation

Source: Allen *et al* (1998), equation 71, p142

The equation to calculate $K_{c\,max}$ requires a measurement of crop height and daily wind speed at 2 m above ground level. Unfortunately these were not recorded for the experimental site. Thus, it was not possible to calculate $K_{C\,max}$. Allen *et al* (1998) recommend setting $K_{c\,max}$ at K_{cb} + 0.05 in the absence of measured crop height and wind speed data as $K_{c\,max}$ is always greater or equal to K_{cb} + 0.05.

f_{ew} was calculated as in equation 4.3 and substituted in equation 4.2 to calculate K_e which was then substituted in equation 4.4 to calculate K_r.

Equation 4.3 $f_{ew} = \min(1-f_c , f_w)$

Where:

$1-f_c$ is the average exposed soil fraction not covered or shaded by plants (0.01-1),

f_w is the average fraction of soil surface wetted by rain or irrigation (0.01-1).

Source: Allen *et al* (1998), equation 75, p147

$1-f_c$ was estimated to be 0.35 and f_w 0.35 thus f_{ew} was 0.35 in the mid stage of plant growth and 0.2 for $1-f_c$, f_w and thus f_{ew} in the end stage of plant growth. In the SWB, the values between the mature and mid stages of growth (the only two stages of plant growth in the experimental period) were extrapolated to represent the change over time from one value to the other as the plants grew.

ii. Soil evaporation coefficient (K_r)

The soil evaporation coefficient has a value between 1 and 0. When the soil surface is wet then K_r is 1. When the moisture in the topsoil becomes limiting K_r decreases from 1 to 0 when the water available in the topsoil is depleted. This coefficient can be calculated by equation 4.4 and occurs once the soil surface is visibly dry. Thus for the majority of winter $K_r = 1$.

Equation 4.4 $$K_r = \frac{TEW - D_e, i-1}{TEW - REW}$$

Where:

TEW is total evaporable water (mm). The value of 17.5 mm was used (Allen *et al* (1998), Table 19, page 144).

REW is readily evaporable water (mm). The value of 7.5 mm was used (Allen *et al* (1998), Table 19, page 144).

$D_{e,\, i-1}$ is the cumulative depth of evaporation from the soil surface layer at the end of the previous day.

Source: Allen *et al* (1998), equation 74, p146.

$D_{e,\, i-1}$ is calculated using equation 4.5.

Equation 4.5 $$D_{e,i} = D_{e,i-1} - (P_i - RO_i) - \frac{I_i}{f_w} + \frac{E_i}{f_{ew}} + T_{ew,i} + DP_{e,i}$$

Where:

$D_{e,i-1}$ is the cumulative depth of evaporation from the exposed and wetted fraction of Topsoil at the end of the previous day (i-1)

$D_{e,I}$ is the cumulative depth of evaporation at the end of the day

P_i is rainfall on day i (precipitation)

RO_i is precipitation runoff from the soil surface (assumed to be zero in this case)

I_i is irrigation (zero in this case)

E_i is evaporation on the day ($E_i = K_e\ ET_o$)

$T_{ew,I}$ Is the depth of transpiration from the exposed and wetted fraction of the soil surface on day i

$DP_{e,I}$ is deep percolation loss from the topsoil layer if soil water content exceeds field capacity

f_w fraction of soil surface wetted by irrigation

f_{ew} exposed and wetted soil fraction

Source: Allen *et al* (1998), equation 77, page 152.

$D_{e,i}$ must always be greater than, or equal to, zero and less than or equal to TEW (17.5 mm). To calculate $D_{e,i}$ it is necessary to calculate deep percolation loss from the topsoil layer ($DP_{e,i}$) which requires equation 4.6.

Equation 4.6 $$DP_{e,i} = (P_i - RO_i) + \frac{I_i}{f_w} - D_{e,i-1}$$

Where:

P_i is rainfall

RO_i is runoff (zero for us)

I_i is irrigation

f_w is the fraction of the soil surface wetted by irrigation

$D_{e,i-1}$ is previous day evaporation from topsoil layer. The SWB is started after a heavy Rainfall event where $D_{e,i-1}$ is zero.

Source: Allen *et al* (1998), equation 79, page 156.

As there was no irrigation and no runoff the equation became:

Equation 4.7 $$DP_{e,i} = P_i - D_{e,i-1}$$

Allen *et al* (1998) suggest setting the values of K_{cb} and $K_{c\ min}$ to zero in equation 4.2 as this will provide the most accurate estimates of ET_c during the non-growing and bare soil stages of crop rotation. Thus, the values used in the generation of ET_C in this SWB for under crop cover were:

Z_r	Rooting depth	0.7 m
p	Average fraction of TAW that can be removed from the root zone before a reduction in ET occurs (0-1)	0.5
TAW	Total available water in the root zone (mm)	84 mm
RAW	Readily available soil water in the root zone (mm)	42 mm
TEW	Total evaporable water	17.5 mm
REW	Readily evaporable water (mm).	7.5 mm
θ_{FC}	Water content at field capacity	0.23 $m^3\ m^{-3}$

θ_{WP}	Water content at wilting point	0.11 $m^3\ m^{-3}$
$K_{cb\ End}$	Basal crop coefficient end of crop growth season (last 20 days)	0.85
$K_{cb\ Mid}$	Basal crop coefficient mid-crop growth season	1.05
$K_{C\ max\ End}$	Maximum value of K_c following rain or irrigation	0.90
$K_{C\ max\ Mid}$	Maximum value of K_c following rain or irrigation	1.10
$f_{ew\ mid}$	The fraction of soil exposed and wetted mid growth	0.35
$f_{ew\ end}$	The fraction of soil exposed and wetted end of season	0.2
$f_{ew\ bare}$	The fraction of soil exposed and wetted during bare soil	1.0

ET_C was then calculated as described in equation 4.1.

Soil specific values for total available water (TAW) and total plus readily evaporable water (RAW) were calculated as in equations 4.8 and 4.9 and used to determine the soil specific daily SWB.

Equation 4.8 $TAW = 1000\ (\theta_{FC} - \theta_{WP})\ Z_r$

Where:

TAW	the total available water in the root zone (mm)
θ_{FC}	the water content at field capacity ($m^3\ m^{-3}$)
θ_{WP}	the water content at wilting point ($m^3\ m^{-3}$)
Z_r	the rooting depth (m)

Allen *et al.* (1998) equation 82, pg 162

Equation 4.9 $RAW = p\ TAW$

Where:

RAW	the readily available soil water in the root zone (mm)
p	the average fraction of TAW that can be removed from the root zone before a reduction in ET occurs (0-1).

Allen *et al* (1998) equation 83, page 162

Values given for rooting depth and p for turnips were 0.5 m - 1.0 and 0.5, respectively. Values for sugar beet were 0.7-1.2 m rooting depth and 0.55 for p (Allen *et al*, 1998; Table 22, page 163). Given the depth of the trenches and the crop was fodder beet, the values of 0.7 m rooting depth and p of 0.5 were used.

Riversdale soil is classed as a sandy loam (Landcare_Research 2016a) for which Allen *et al* (1998; Table 19, p 144) suggest values of 0.18 - 0.28 and 0.06 - 0.16 $m^3\ m^{-3}$ for θ_{FC} and θ_{WP}, respectively.

4.3.6 **Statistical analysis**

GenStat (17th Edition) was used to generate a statistical analysis of the drainage concentration data using Restricted Maximum Likelihood (REML) analysis. This method of analysis was used as it allows for missing data for the dates where not all plots were flowing. It also allows for repeated measurements. The Autoregressive one error term was fitted as the data were non-independent. Due to a large variation in the concentration data a log transformation plus one was used for the analysis.

4.4 **Results**

Due to the unreliability of the results from 2013 and 2014 only results from 2015 have been analysed and are presented. Samples from 2013 and 2014 were confounded by water table contamination.

i. Temperature and rainfall

Monthly air temperature for 2015 was lower than the 30 year average throughout the whole year (Figure 4.9). Average daily air temperatures did not exceed 6°C until mid-September. Total annual rainfall figures from the nearby (-46.115, 168.8873) Gore NIWA weather station for 2015 were higher than the 30-year-average (1032 mm and 945 mm, respectively). The annual rainfall for the trial site was 861 mm (site data available for the dates 10 April 2015 – 18 December 2015; Gore NIWA station data were used to fill the remainder of the year). This is less than the Gore site but it can be seen in Figure 4.10 that the Otama trial site had lower rainfall values than the Gore site in all months except May.

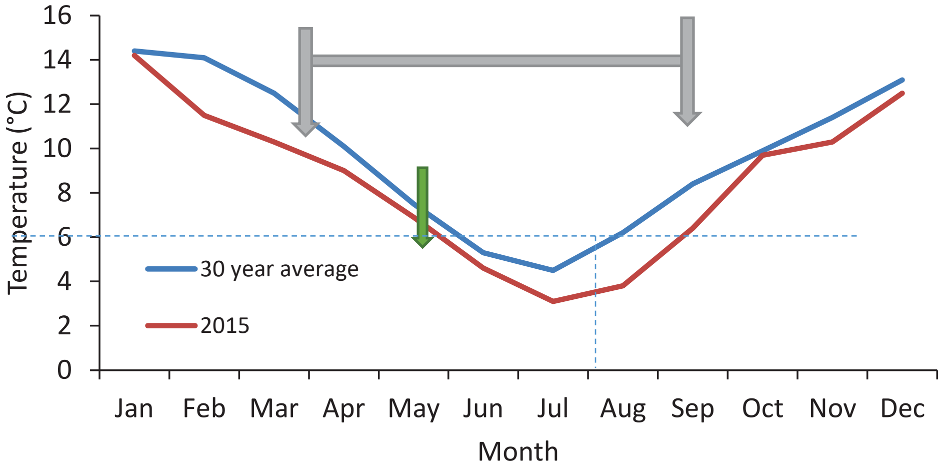


Figure 4.9. Monthly average air temperature (°C, 9 am) from the Gore weather station for 2015 (red line) and the 30-year-average from years 1980-2010. Grazing occurred on the 30th June (Green arrow) and the duration of the trial and drainage monitoring was 5th May until 23rd October (grey arrows and bar). Average air temperatures didn't exceed 6°C until mid-September (dashed blue lines).

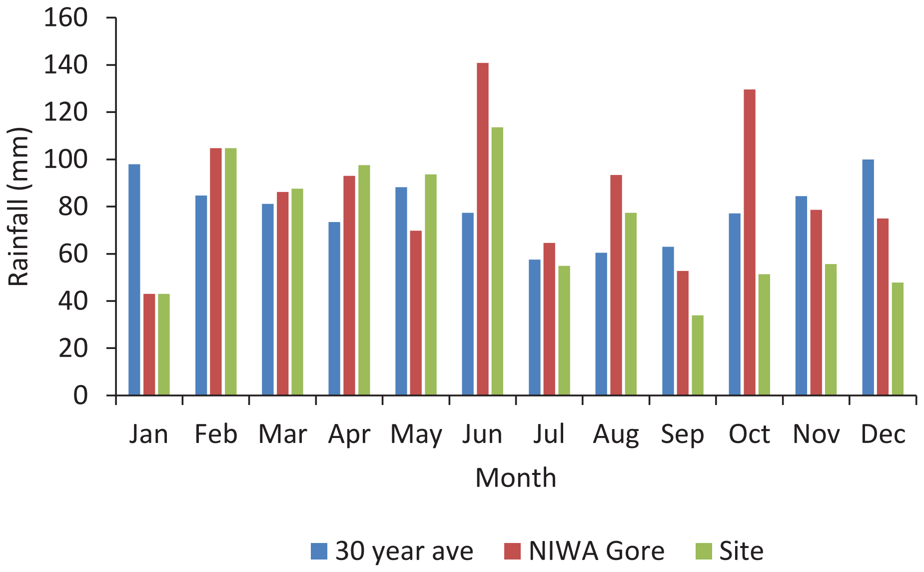


Figure 4.10. 2015 monthly rainfall figures for: the trial site (Site; measurements from 10 April to 18 Dec, missing data replaced with Gore NIWA data), NIWA Gore weather station number 5778, and 30-year-average data 1981-2010 for the Gore NIWA weather station number 5778.

ii. Drainage volumes – SWB predicted and measured

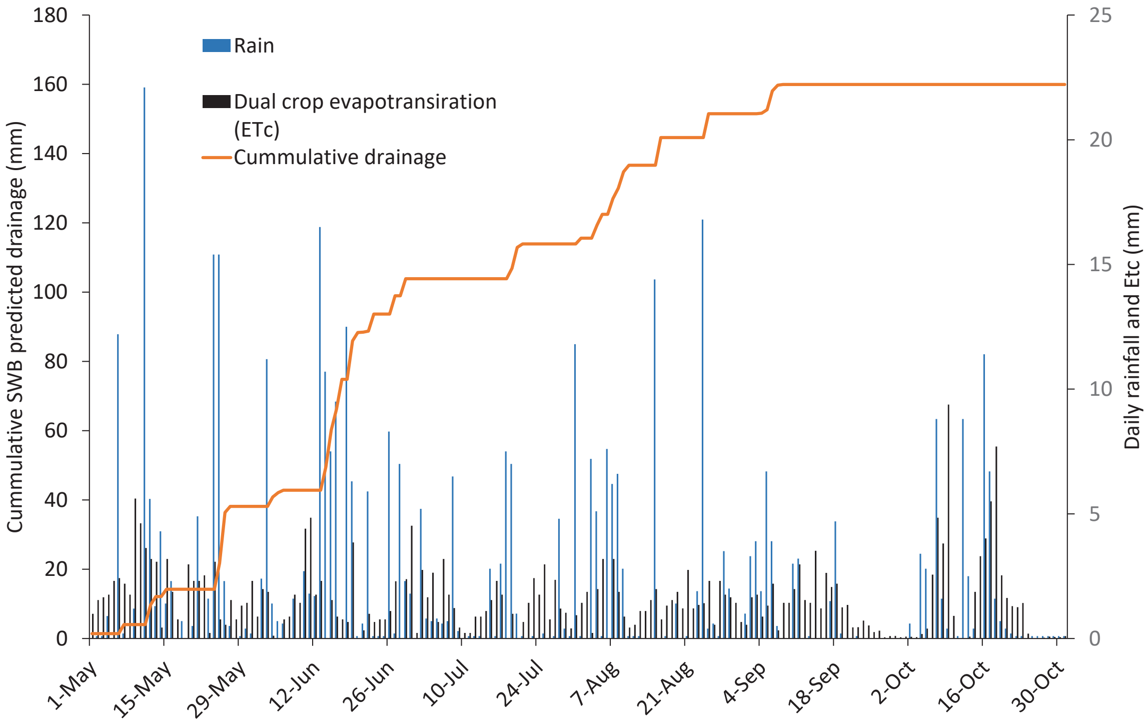


Figure 4.11. Drainage volumes and weather data for the Otama experimental site for the period of measurement in 2015. Daily rainfall and dual crop evapotranspiration (ET_C) are plotted along with SWB-predicted cumulative drainage (160 mm).

The SWB predicts a total drainage of 160 mm from the beginning of May until 31 October (the point drainage recording stopped; Figure 4.11). The total rainfall for this period was 425 mm. This calculated drainage represents 38% of measured rainfall. Evapotranspiration (ET) calculated using the dual crop coefficient method is shown by the black lines in Figure 4.11. By the end of September ET rates were high enough and rainfall events small and infrequent enough that no drainage events were predicted by the SWB. The predicted ET values from the regional met station (Gore AWS) and ET crop values as estimated using the dual crop coefficient are shown in Figure 4.12. This shows that ET_C values were slightly below ET values for the majority of the monitoring period. However, they differ more in October when there is no crop cover.

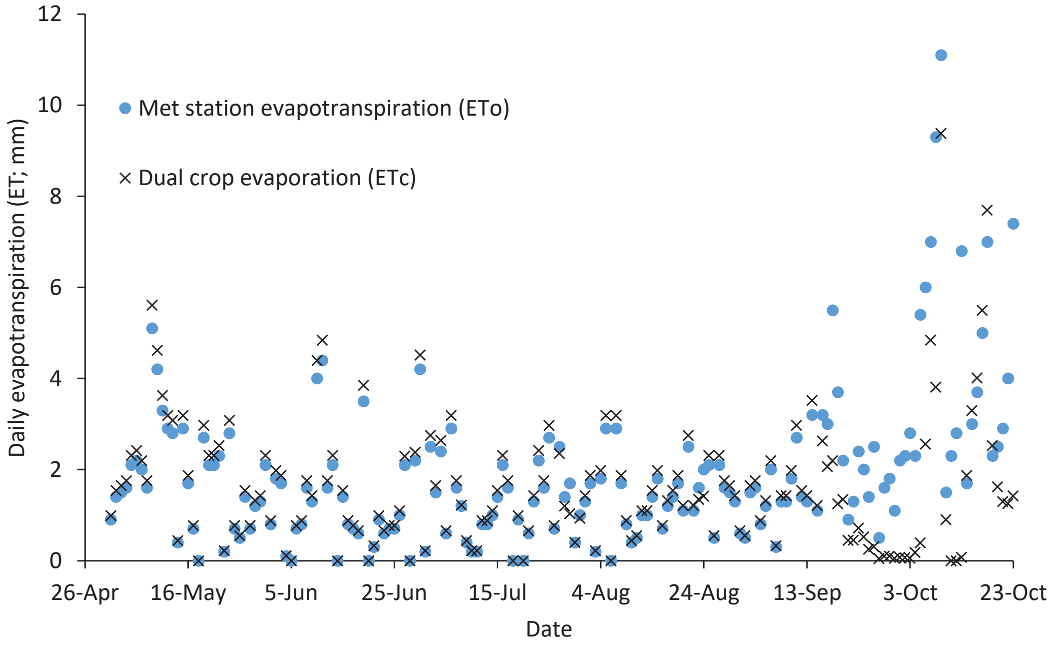


Figure 4.12. Daily evapotranspiration values from Gore met station data (ET_0; blue dots) and calculated using the dual crop coefficient (ET_C; crosses) method described by Allen *et al* (1998). Values reported are from the start of the recorded 2015 drainage period until the end of drainage measurements (May 1 – October 31)

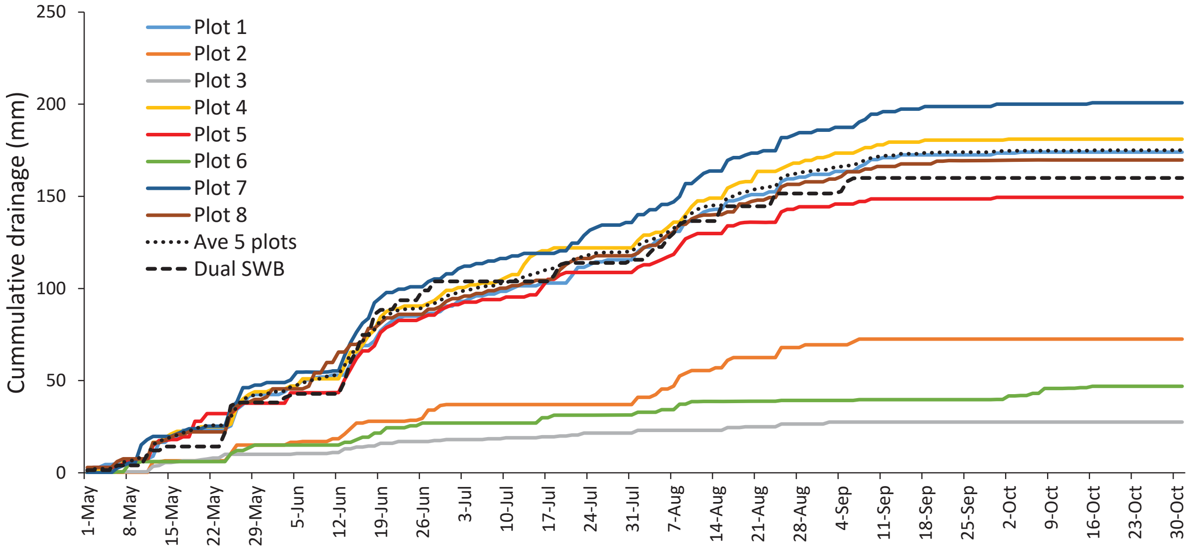


Figure 4.13. Cumulative drainage from the 8 field plots from the first recorded drainage event (1st May) until the 31st October 2015 when drainage recording stopped. The SWB prediction for drainage is shown by the black dashed line.

There was a very good agreement between the drainage predicted from the "dual" SWB model and 5 of the trial plots (Figure 4.13). The average value of the 5 trial plots is shown by the black dots and is 109% of the predicted drainage. Drainage values range from 17 to 126% for all 8 plots, or 93 – 126% for the 5 plots averaged, of the predicted drainage.

From the drainage data above it is obvious that three of the plots were not functioning as expected. These plots were assumed to have structural problems (e.g. pierced lining or blocked pipes) as the submersible pumps and data loggers were checked and found to be working accurately. Thus data for plots 2, 3 and 6 were withdrawn from drainage volume and nutrient load analysis. They were, however, included in drainage nitrogen concentration analysis as it was assumed that the concentrations measured were representative.

The drainage depth of 160 mm (SWB predicted) and 177 mm 173 mm (treatment average; measured) from May 1st to October 31st for the 6 and 24 hour plots, respectively, represents nearly 2 pore volumes of drainage (1 pore volume is the PAW water in the soil depth above the liner which is 84 mm and over 20 m^2 is a volume of 1.68 m^3). However, the grazing event (30th June) occurred halfway through the drainage season when 92 mm of drainage had already occurred, thus post-grazing there was only 1 pore volume drainage (0.081 m x 20 m^2 = 1.62 m^3; Figure 4.14) before the end of monitoring on 31st October.

iii. Drainage concentrations

There was no significant difference between treatments in concentrations of ammonium-N (P = 0.978). The average treatment nitrate-N drainage concentration for the 6 hour grazing treatment was 7.22 mg L^{-1} (range 1.79 – 22.09 mg L^{-1}) compared to an average of 10.05 mg L^{-1} (range 4.75 – 24.96 mg L^{-1}) in the 24 hour grazing treatment. This was a statistically significant treatment effect for nitrate-N (P = 0.090). There was a highly significant date effect on nitrate-N concentration ($P<0.001$) and a date by treatment effect ($P<0.001$). However, the possibility that this date by treatment effect was due to the grazing event on the 30th June was investigated by comparing the effect of the treatments before and after the grazing. The post grazing effect was found to be non-significant (SED 2.504). This shows that the difference between the treatments was not influenced by grazing treatment i.e. the difference was not evident solely after the grazing event. The difference in nitrate concentration in drainage from the 24 and 6 hour treatments was not a response to the treatments as the 24 hour average was significantly higher prior to the grazing. Thus, the significant difference in the treatments cannot be attributed to the grazing event.

If all the deposited urinary N was leached in one pore volume, the estimated nitrate concentration would be 52 and 13 mg N L^{-1} for the 24 and 6 hour grazing treatments, respectively (see section 4.5.2 for calculation). The average concentrations measured at around 1 pore volume were 26 mg L^{-1} and between 22 and 12.5 mg N L^{-1} for the 24 and 6 hour treatments, respectively (Figure 4.14). For 2 pore volumes, the expected concentrations would be 26 and 6.5 mg N L^{-1}, respectively.

iv. Nitrate-N and Ammonium-N losses per hectare

N leaching losses were calculated using equation 4.10.

Equation 4.10 Load (kg ha^{-1}) = event size (mm) x concentration (mg L^{-1}) / 100

The average total leaching loss of nitrate-N [1] from 6 May until 19 October 2015 for the 6 hour treatment was 11.8 kg nitrate-N ha^{-}. For the same period, the loss for the 24 hour treatment was 14.4 kg nitrate-N ha^{-1}. The range in total losses from the individual plots were 8.8 to 14.8 and 10.0 to 17.6 kg nitrate-N ha^{-1} for the 6 and 24 hour treatments, respectively (Figure 4.16). Average total ammonium-N losses were 0.246 and 0.278 kg ammonium-N ha^{-1} for the 6 and 24 hour treatments, respectively (the range for 6 hour treatment was 0.142 - 0.349 and for the 24 hour treatment the range was 0.228 - 0.379 kg ammonium-N ha^{-1}; Figure 4.17).

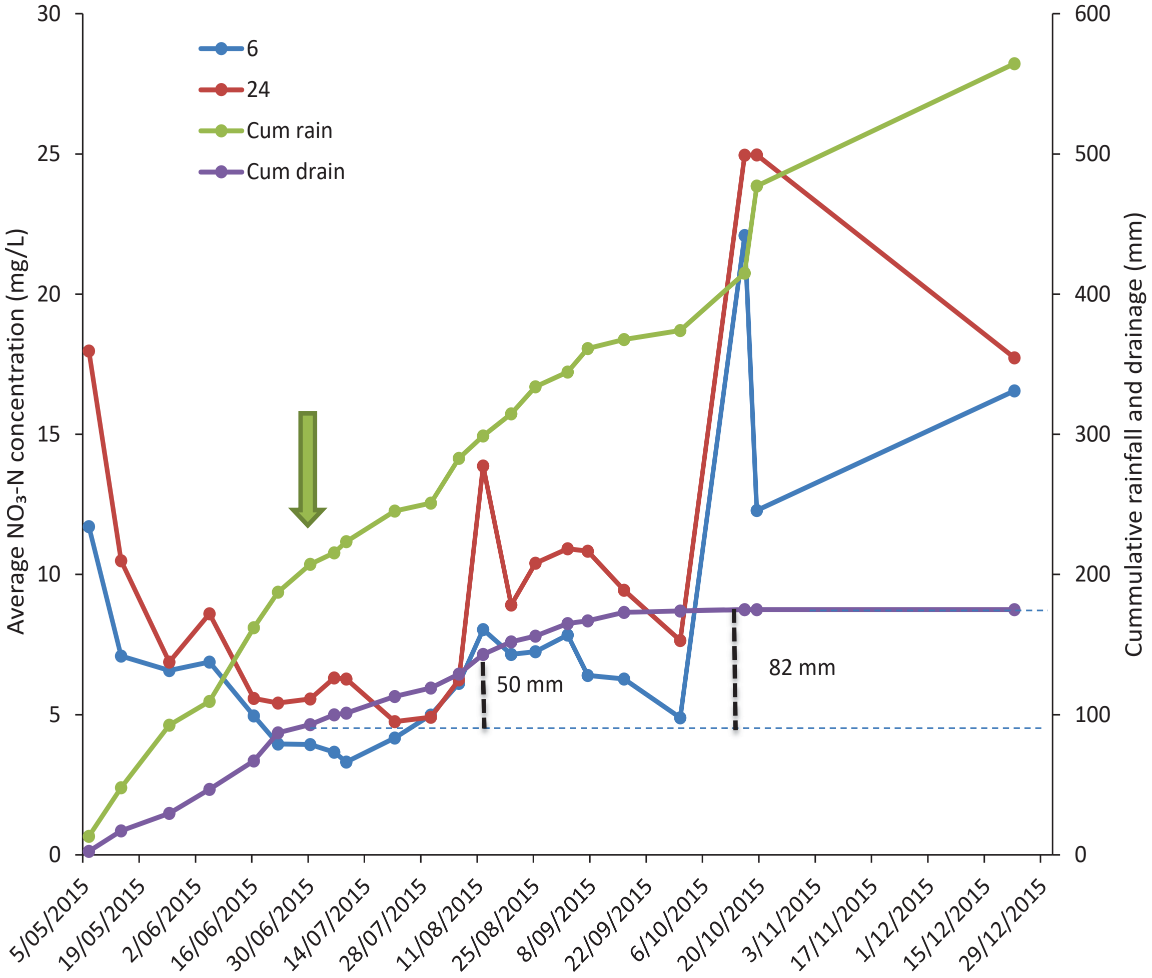


Figure 4.14. Average drainage nitrate-N (NO_3-N) concentrations: 24 hour (red line) and 6 hour grazing treatments (blue line). Cumulative rainfall is shown by the green line and cumulative drainage by the purple line. Grazing occurred on the 30th June (green arrow). The date of the first peak in concentration post-grazing is 12/8/16 and the second peak is 16/10/16. The cumulative drainage at the point of grazing was 92 mm and is shown by the bottom blue dashed line, the final drainage value was 174 mm, represented by the top blue dashed line.

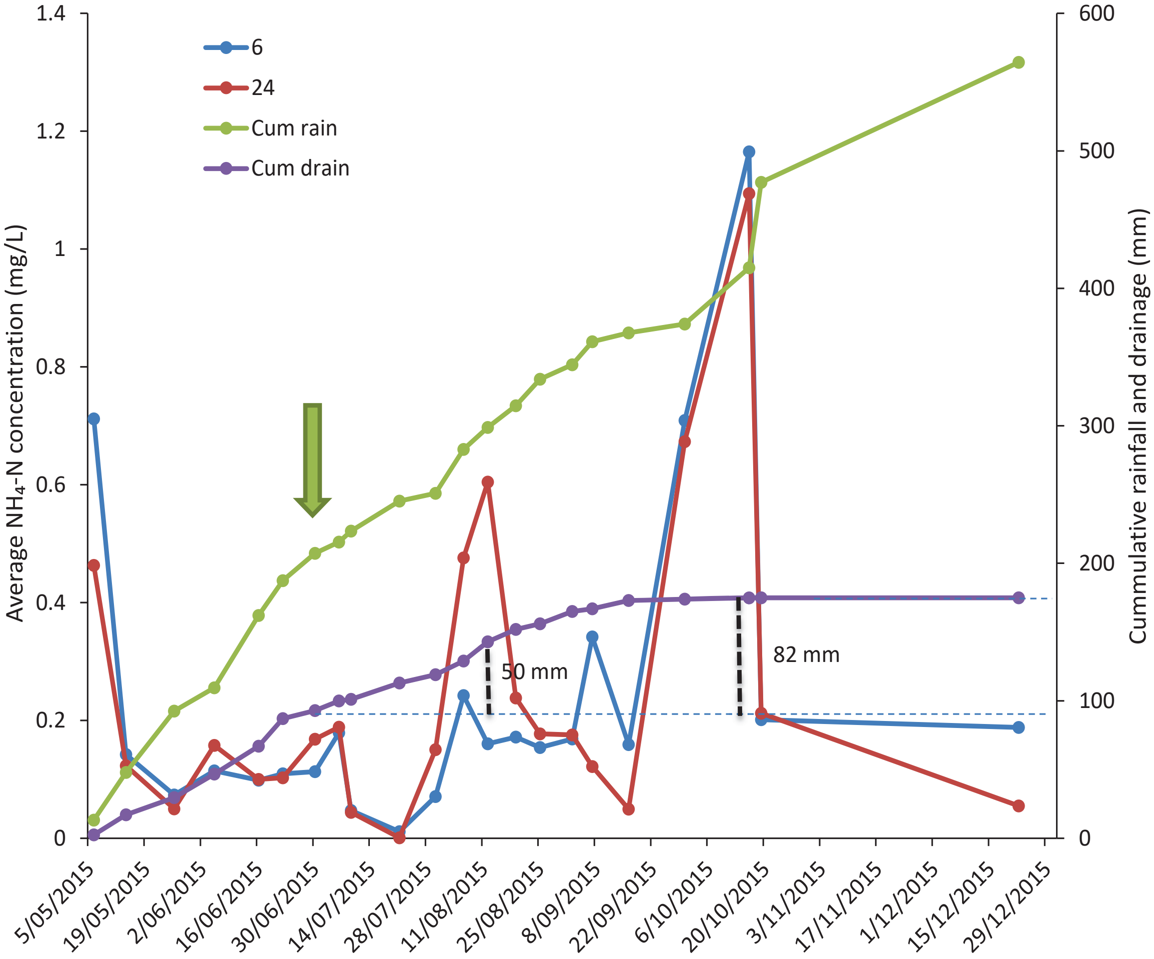


Figure 4.15. Average drainage Ammonium-N (NH_4-N) concentrations: 24 hour (red line) and 6 hour grazing treatments (blue line). Cumulative rainfall since the previous sampling is shown by the black bars. Grazing occurred on the 30th June (green arrow). The date of the first peak in concentration post-grazing is 12/8/16 and the second peak is 16/10/16. The cumulative drainage at the point of grazing was 92 mm and is shown by the bottom blue dashed line. The final drainage value was 174 mm, represented by the top blue dashed line.

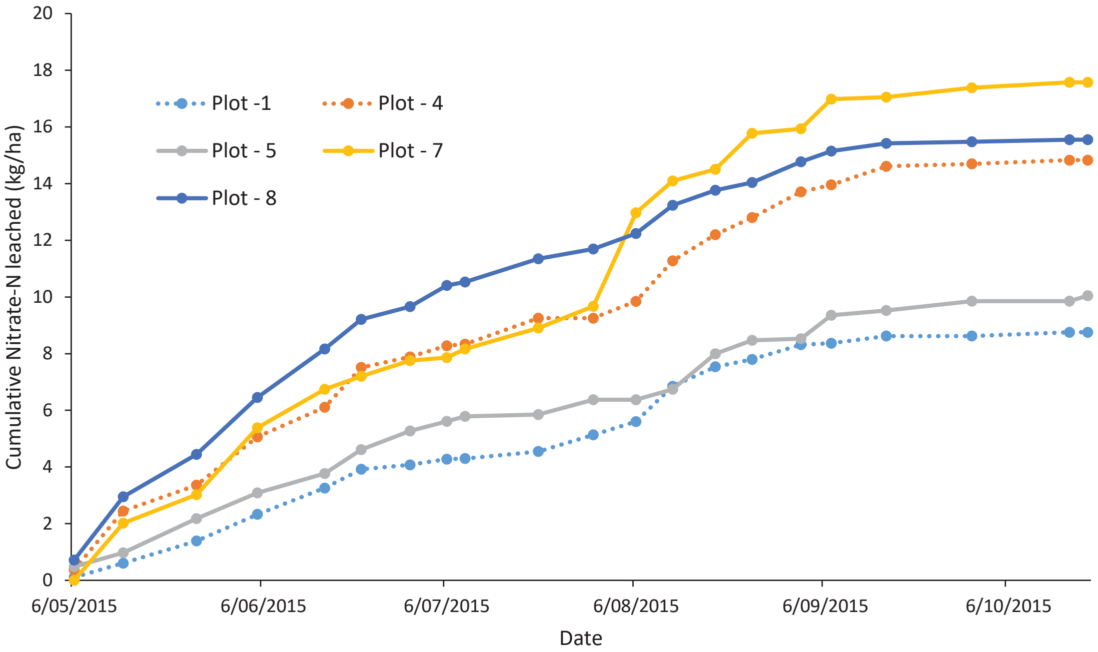


Figure 4.16. Cumulative nitrate-N leached (kg/ha) for each plot from the first leachate sampling (6st May 2015) until the last leachate sampling (19th October) before drainage recording stopped (31st October). Dashed lines represent the 6 hour grazing treatment and solid lines are the plots grazed for 24 hours. Values are generated from measured drainage volumes and measured concentrations. Three plots have not been included due to their low captured drainage volumes, suggesting a physical fault in the trench.

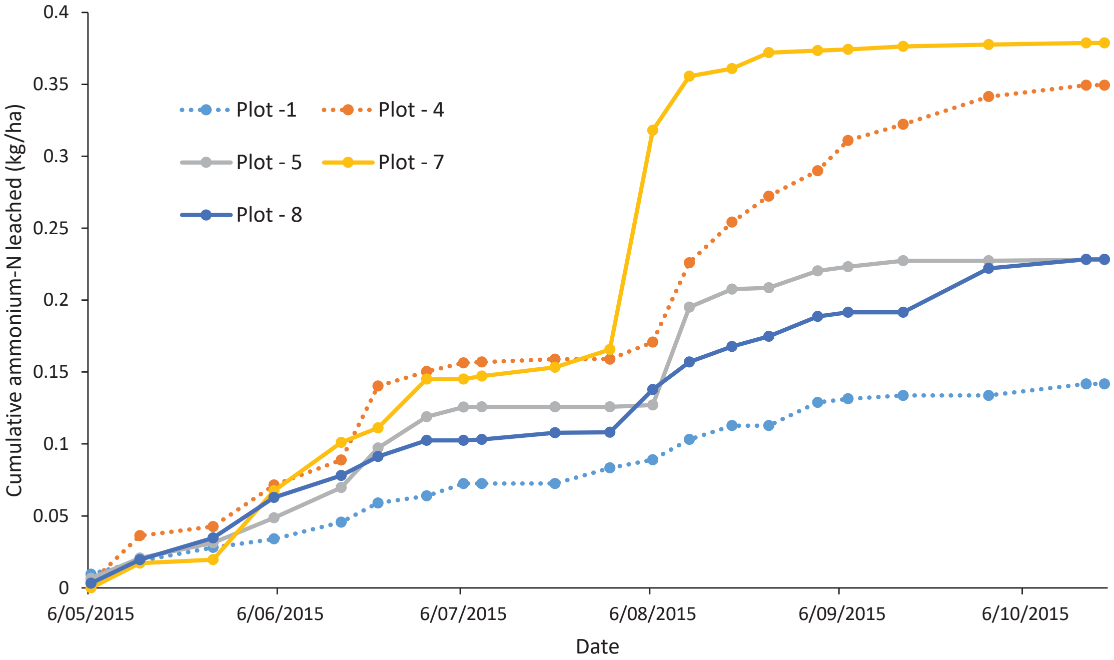


Figure 4.17. Cumulative ammonium-N leached (kg/ha) for each plot from the first leachate sampling (6st May 2015) until the last leachate sampling (19th October) before drainage recording stopped (31st October). Dashed lines represent the 6 hour grazing treatment and solid lines are the plots grazed for 24 hours. Values are generated from measured drainage volumes and measured concentrations. Three plots have not been included due to their low captured drainage volumes, suggesting a physical fault in the trench.

To test for significance, N leaching losses for each sampling date were compared using REML analysis. This analysis showed a highly significant date effect ($P<0.001$) and a treatment effect ($P = 0.039$) but no treatment by date effect ($P = 0.981$). This indicates that there was no treatment effect on N leaching losses caused by the grazing treatments imposed. The average for the plots grazed for 24 hours was higher than the 6 hour plot prior to the grazing treatment on the 30th June and this difference did not significantly change in response to grazing. The same results were seen for ammonium-N losses with a significant date effect ($P<0.001$) but no treatment ($P = 0.929$) or date by treatment ($P = 1.000$) effect.

4.5 Discussion

4.5.1 The use of lined trenches as channel lysimeters

The methodology of creating a channel lysimeter (using a lined trench) appeared suitable for measuring drainage volume and thus predicting nutrient losses to drainage under a grazed system. Close agreement between the measured drainage values and those predicted by a soil water balance model show that the use of lined trenches as channel lysimeters was successful at capturing drainage. However, it would appear that care needs to be taken in installing and maintaining these lysimeters. Three of the plots had to be removed from analysis due to low drainage flows suggesting that there were either holes in the liner or, perhaps more likely, blockages in the drainage pipe. Since conducting this experiment other work using pea gravel to cover a slatted drainage pipe has used a geotextile cloth over the pipe (and under the pea gravel) to reduce the risk of pipe blockages. This is something that would be recommended if this system was developed in the future. These geotextile fabrics are readily available from companies such as Geofabrics (www.geofabrics.co.nz).

While capturing drainage was successful, the measurement method for recording drainage volumes took a few attempts to resolve. Due to the depth required for the trenches and the height of the water table in winter, the tipping bucket and syphoning methods to measure drainage volumes and to collect a drainage sample did not work well. Use of the submersible pump system designed by Tom Orchiston at AgResearch was successful in both measuring drainage volumes and capturing drainage samples. However, due to the method of recording drainage, the system was unable to record individual drainage events less than 1.5 mm ($0.03m^3/20\ m^2$). This is because the drainage is stored in a sump until it reaches the trigger level at 30 litres. Then the pump is triggered and the sump emptied. It is at this point that the logger records the volume of drainage discharged from the pump. This means that drainage is measured in 30 litre increments, representing an equivalent drainage depth of

1.5 mm. Ideally, the system would be modified so that some form of recording of drainage volumes could occur as the drainage exited the trench pipe.

4.5.2 N leaching losses

The second hypothesis of this work was that the introduction of a portable pad, where cows can stand when not grazing crop, will collect excreta while cows are off paddock. Thus, the use of duration controlled grazing will result in reduced urinary N load on the grazed area and reduced N loss to water.

The results from this experiment showed no significant effect of the duration of grazing treatments on N concentration or total N leaching losses. It is possible that the channels did not capture the full effect of the treatments. Whilst plots were 4 m wide by 20 m long, the width of the capture channel was only 1 m in the middle of the plot. It is possible that the urine depositions did not always occur over the channel area. Assuming a urinary patch size in a fodder beet paddock of 0.18 m^2 (Cameron 2016) and 10 urination events per cow per day, then each trench, with 4 cows grazing, would have 7.2 m^2 of the area covered (assuming no overlapping urine patches). This is only 18% of the total surface area for a 24-hour grazing and potentially 1.8 m^2 or only 4.5 % of the area in the 6-hour grazing.

In Section 4.3.1 the number of urine patches predicted to be deposited on the lysimeter area was 10 and 2.5 for the 24 and 6 hour treatments, respectively. Assuming that a urine patch contained 4.4 g N L^{-1} (Stevens and Thompson, 2012) and the average urination was 2 L, then the 24 hour grazing would have 88 g N applied to the trench area (2 L/event x 10 events = 20 L at 4.4 g/L = 88 g N/20 m^2) and the 6 hour grazing would have 22 g N applied (2 L/event x 2.5 events = 5 L X 4.4 g/L = 22 g N/20 m^2). This application is equivalent to 44 kg N ha^{-1} and 11 kg N ha^{-1} for the 24 and 6 hour grazing treatments, respectively ((g N applied/20 m^2)*10,000 = g N ha^{-1}/ 1,000 = kg N ha^{-1}).

Only 82 mm of drainage (on average) occurred after the grazing treatment on the 30th June (Figure 4.14). Thus only one pore volume of drainage occurred following grazing. The second peak (22 and 26 mg N L^{-1} for the 6 and 24 hour grazing treatments, respectively) of nitrate-N seen in Figure 4.14 is located at the point when approximately one pore volume had drained through the profile. The initial, smaller peak (8 and 14 mg N L^{-1} for the 6 and 24 hour grazing treatments, respectively), was situated at half a pore volume (post-grazing). If solute movement in drainage through this stony soil obeyed classic matric flow, the peak in nitrate-N concentration would appear after 1 pore volume of drainage had occurred. One pore volume of accumulated drainage occurred 78 days after urine deposition, after the 1st October (Figure 4.18). If all deposited urine N was lost in one pore volume

(84 mm x 20 m^2 = 1.68 m^3) of drainage, then the expected drainage concentration would be 52 and 13 mg L^{-1} for the 24 and 6 hour treatments, respectively (88 g N/1.68 m^3 and 22 g N/1.68 m^3). Average measured drainage N concentrations for the period after displacement of one pore volume (after 1st October) were 22.6 and 17.0mg N L^{-1} for the 24 and 6 hour grazing treatments, respectively. However, although one pore volume had drained by October it would appear that the drainage season was cut short and much of the deposited urine N remained in the soil profile. The drainage N concentrations after 1st October were consistent with the concept that the solute front has only just emerged at the liner and drainage layer.

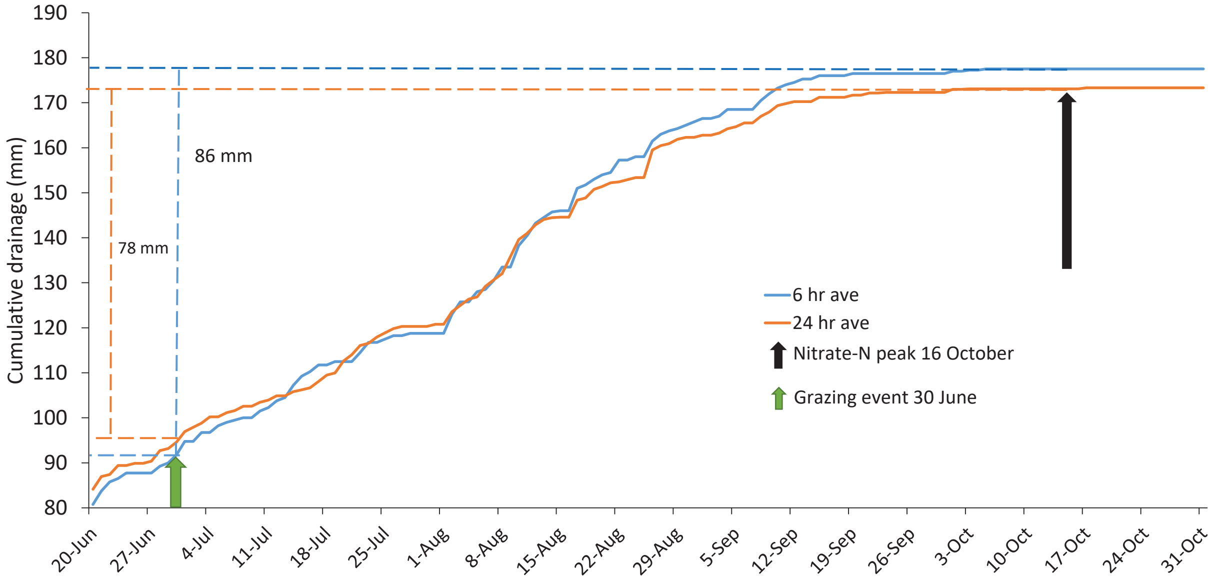


Figure 4.18. Average cumulative drainage for in-field channel lysimeters at Otama, grazed for either 6 or 24 hours. Grazing occurred on the 30th June (green arrow) and peak nitrate-N concentrations in drainage occurred on 16th October (black arrow) after 0.93 and 1.02 pore volumes of drainage occurred for the 6 and 24 hour treatments, respectively.

In Figure 4.14 it can be seen that there is a higher nitrate value in May prior to grazing. Plotting the SWB-predicted drainage and the grazing events shows that this initial peak could be the “tail” of the solute displacement from the previous year’s cultivation and crop establishment (October 2014) because it appears when just over 2 pore volumes of drainage had occurred since the June 2014 grazing event (Figure 4.19). It is possible however, that this is a result of the cultivation of the plots (October 2014) causing mobilisation of nutrients already in the system. The drainage between cultivation in 2014 (orange arrow; Figure 4.19) and May 2015 is approximately one pore volume.

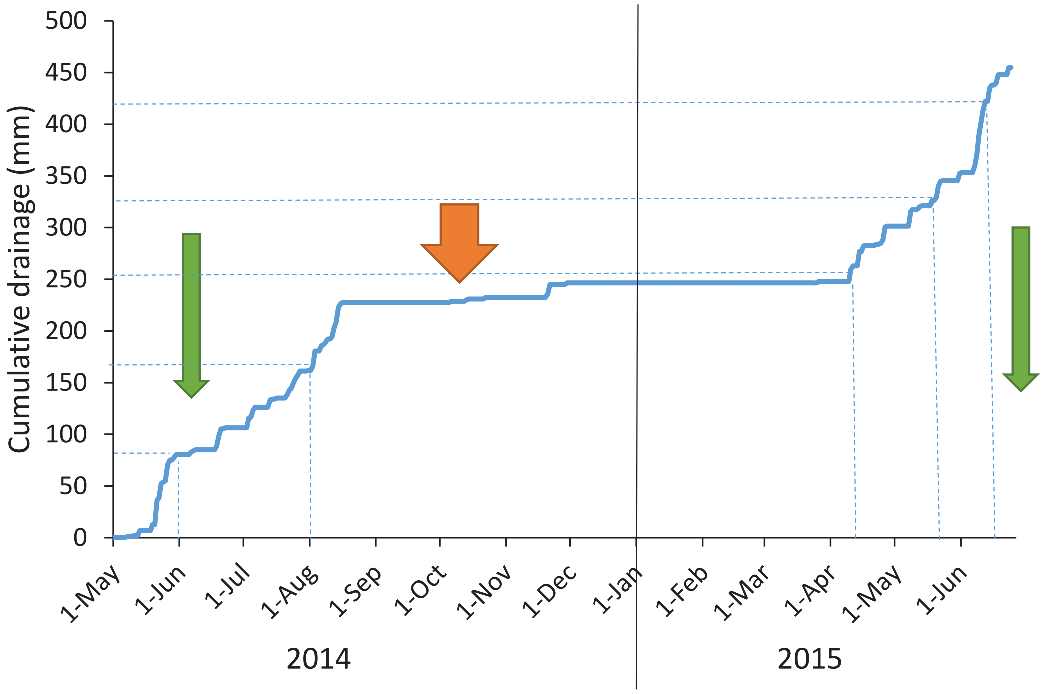


Figure 4.19. SWB predicted drainage for the Otama channel lysimeter site from 1 May 2014 until June 2015. Green arrows depict the grazing events and the orange arrow the timing of cultivation of the crop paddock. The dashed blue lines represent increments of one pore volume of drainage.

The nitrate-N drainage concentrations measured in this experiment compare well with those measured by Monaghan *et al.* (2013) (Figure 4.20). In their experiment they measured nitrate-N leaching under a single simulated grazing of a kale crop plus or minus a nitrification inhibitor treatment. The results from the current Otama experiment indicate values that range between the lower (0.3 mg N L^{-1} in 2007) and higher (32 mg N L^{-1} in 2008) drainage N concentration values recorded by Monaghan *et al* (2013). The measured total leaching losses in the current experiment were 11.8 and 14.4 kg nitrate-N ha^{-1} from April until Oct from the 6 and 24-hour treatments, respectively. This is considerably lower than the 44 kg nitrate-N $year^{-1}$ measured by Monaghan *et al* (2013) in 2008 when their drainage season went from May to November. However their total drainage measurements from the three years were 713, 400 and 351 mm yr^{-1} which are considerably greater than the 160 mm total drainage during this field experiment. In addition, calculations of the expected drainage concentrations if one pore volume contained the N applied were 52 and 13 mg N L^{-1} for the 24 and 6 hour treatments, respectively. The peak concentration of 22 mg N L^{-1} drainage for the 6 hour treatment is consistent with the expected solute front. However, the peak concentration of 26 mg N L^{-1} drainage for the 24 hour treatment was significantly less than the expected 52 mg N L^{-1}.

The low N recovery in drainage for the 24 hour treatment is surprising. This could be due to:

1). Insufficient drainage before the end of the experiment to displace the urinary N load allowing a following crop to take up N.

2). It is possible that a low proportion of urine patches was captured by the trench, or the fodder beet feed diet produced very low urinary N concentrations.

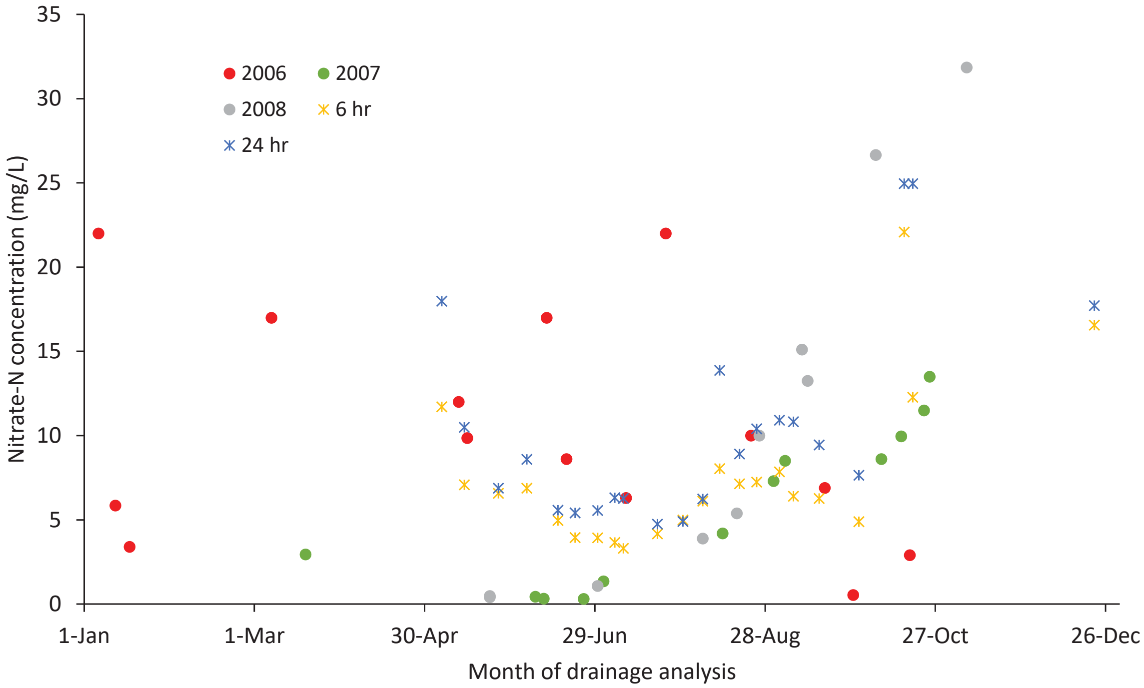


Figure 4.20. Experimental results for the Otama experiment: 6 hour (yellow crosses) and 24 hour (blue crosses) grazing treatments on a Fodder Beet crop. Results are compared to those by Monaghan *et al.* (2013) in the years: 2006 (red dot), 2007 (green dot) and, 2008 (grey dot). Compared data represents a one 24-hour grazing event on kale.

Comparing the concentration data from all plots shows that the 6 hour plots have 36 % of samples below 5 mg N L^{-1} compared to 9 % of the samples from the 24 hour plots. The percentage of samples between 5 and 11 mg N L^{-1} were 45 and 68% for the 6 and 24 hour plots, respectively. Water is deemed unsuitable for drinking at 11 mg N L^{-1} and 18 percent of the 6 hour measurements were above this level compared to 23 % of the 24 hour plot samples. The same number of samples were taken from each set of treatments.

The next step for this work would be to model the two grazing treatments using APSIM. This may help identify whether mineral nitrogen remained in the soil after the measurements stopped in October.

It would also enable the simulation of two contrasting total urinary N loads for the treatments, thus addressing the question of whether the urination events were captured by the trenches.

4.6 Conclusions

This trial did not determine a difference in N leaching from imposing a one-off grazing event of either 24 or 6 hours duration. It is quite possible that this was due to insufficient drainage before the end of the experiment to displace the urinary load. However, the drainage water nitrate-N concentrations compare well with data reported by Monaghan *et al* (2013). The average total losses of nitrate-N for the 6 hour treatment was 11.8 kg nitrate-N ha^{-1} from 6 May until 19 October 2015. For the same period, the loss from the 24 hour treatment was 14.4 kg nitrate-N ha^{-1}. These results are in direct contrast to the current thought that stony soils are excessively 'leaky' in terms of nitrate-N leaching as a result of winter grazing. The estimated loss of N from assuming all urinary N would be leached (44 to 11 kg N/ha) are lower than values currently estimated by *OVERSEER* for stony soils as a result of winter grazing. The timing of grazing with respect to late winter rainfall and drainage is a critical determinant of the amount of N leached and the amount remaining in the soil profile, which could be recovered by a later winter, early spring catch crop.

4.7 Acknowledgements

Thanks to Nathan and Debbie Erskine for the use of their property and stock for the location and grazing of the trenches. Thanks to the AgResearch technical team (Tom Orchiston, Wayne Worth, Chris Cowrie and Rachel Worth) for assistance in trial establishment; to Tom Orchiston and Chris Smith for assistance with sample and data collection; and Stuart Lindsey (AgResearch, Ruakura) for mineral N sample analysis. I also acknowledge Tom Orchiston's work in developing the submersible pump system. Thanks to Peter Johnstone for his assistance with statistical analysis.

5. Portable pad technology and trial

Stage one of this research has been summarised in a paper Chrystal, J., Monaghan, R., Hedley, M., & Horne, D. (2016). Design of a low cost winter stand-off pad for reducing nutrient losses from winter forage crops grazed by dairy cows. The paper was published in the Fertilizer and Lime Research Centre conference proceedings ((Chrystal *et al.* 2016a)

5.1 Abstract

A review of existing dairy wintering systems identified a need for a low-cost wintering system that utilised brassica crops but could reduce N leaching losses from crop paddocks. A new duration controlled grazing system involving a stand-off pad was developed and named the 'Portable Pad' system.

Arranged adjacent to the crop paddock the portable pad system consists of:

1. An impermeable liner to capture effluent, overlain by a suitable surface for cow comfort and durability;
2. An effluent capture system;
3. A low- rate, low depth (LRLD) effluent irrigation system for the safe return of liquid effluent to pasture.

This chapter investigates the portable pad concept while the LRLD effluent system is investigated in Chapters 6 and 7.

Investigation of the portable pad concept was conducted in a two-stage field experiment. The first stage in the evaluation of this system was a field experiment to determine if a portable pad could be constructed that captured the excreta and rainfall deposited on the pad surface and to find a readily-available commercial product suitable for the cow comfort layer. A geotextile carpet was identified as the cow comfort surface of choice and the experiment was successful in capturing the effluent deposited on the surface.

The second stage in the evaluation was a field experiment comparing traditional winter grazing of a brassica crop and the proposed portable pad on-off grazing system, in which cows grazed crop for 6 hours day^{-1} and returned to the portable pad for further supplementary feed for the remaining 18 hours day^{-1}. Urine event measurements showed that there was a daily pattern of urinary N

excretion evident. This showed reduced urinary N excretion during the period from 10 am until around 4 pm. By scheduling the 6 hour grazing period for animals utilising the portable pad system for this period of the day, the dairy urinary N deposited on paddock could be restricted to around 9% of daily output.

Investigation of cow lying times indicated that cows were, on average, able to meet the minimum recommended daily lying time of 8 hours day^{-1}. Cow body condition scores (BCS) indicated that BCS increases could be achieved over the winter period using the portable pad system if cow crop allocations were adequate (a 0.33 increase in BCS was measured over one month when crop allocation was increased from 4.5 to 11.5 kg DM cow^{-1} day^{-1}). The research suggests that the portable pad concept shows merit and is worthy of further research.

5.2 **Introduction**

Dairy cow wintering in southern New Zealand most commonly involves grazing brassica crops *in situ*. This system is relatively low-cost compared to alternative wintering systems, such as barns and wintering pads, due to: the low cost of the feed, low labour requirement, no structure needed, and no effluent storage required. However, grazing at high stocking densities during winter, combined with high winter rainfall and excessively free-draining soils or heavy soils and sloping land can result in high contaminant losses (N, P, *E. coli*, sediment) to water. This wintering practice is increasingly coming under scrutiny from those who are seeking alternatives to reduce these losses. Current alternatives are high cost and require feed to be brought to the animals at further cost. In the current economic climate with a low dairy pay-out, these high-cost solutions for reducing contaminant losses in winter are particularly unappealing to farmers. Therefore, a low-cost stand-off that reduces contaminant losses to water, whilst utilising the low cost brassica crop as a feed source, is urgently sought. This experiment investigated the feasibility of a portable pad system that consists of an impermeable liner to capture effluent, overlain by a suitable surface for cow comfort and durability. Cows graze the brassica crop *in situ* and return to the portable pad for a proportion of the day (18 hours). The portable pad has the ability to be moved around the farm in different years as the location of the forage crop paddock changes. Minimal effluent storage is required due to the application of the liquid effluent to a neighbouring pasture during winter using low rate and low depth application methods (this will be discussed in chapters 6 and 7).

This chapter describes a two-stage experiment designed to investigate the feasibility of the portable pad concept. The first stage in the evaluation of this system was a field experiment where the objectives were:

(i) to determine if a portable pad could be constructed that captured the excreta and rainfall deposited on the pad surface and

(ii) to find a readily-available commercial product suitable for the cow comfort layer.

Of the 3 surfaces trialled, a geotextile ‘carpet’ was selected as the surface of choice. The concept of effluent capture and the use of a low-cost plastic liner overlain with a cow comfort layer proved worthy of further investigation in stage two. This next stage was a comparison between the traditional grazing of a brassica crop during winter and the proposed system using a portable pad. Here cows grazed crop for 6 hours a day and returned to the portable pad for the remainder of the day.

The key requirements of the pad in stage two were:

1. An area of 8 m^2 per cow.
2. *Ad lib* supplementary feed (baleage and hay) available on the pad.
3. Stock water available on the pad.
4. A capture system for effluent; both solid and liquid.

The measurements taken during the trial were:

1. Cow lying times; as an indicator of animal welfare.
2. Urinary nitrogen (N) output (volume, timing & number of events, N concentration).
3. Cow body condition score (BCS); as an indicator of animal welfare.
4. Feed intake.
5. Crop paddock soil roughness; as an indicator of soil treading damage.
6. Effluent volumes and nutrient concentrations.

The objective of this chapter is to test the hypotheses:

(i) that it is possible to design a low-cost portable pad that consists of an impermeable liner, overlain by a cow comfort layer and that the effluent deposed on the pad can be captured, and

(ii) that it is possible for cows to winter graze brassica crops and return to the portable pad for 18 hours a day without negatively impacting animal welfare.

5.3 Methods

5.3.1 Trial site

The experiment was established in 2013 on AgResearch's Invermay deer unit near Mosgiel, Otago, New Zealand (45° 51′ S; 170° 24′ E). The farm is a 579 ha sheep, beef and deer property. Warepa deep silt loam is the predominant soil type on the experimental areas. This soil is imperfectly drained with a high structural vulnerability and a medium N leaching vulnerability (Landcare Research, 2016). The 30-year (1981-2010) average annual rainfall for Invermay is 817 mm (with an average of 58 in June and 71 in July) and the average annual air temperature is 10.2 °C (5.8 °C in June and 5.3 °C in July) (NIWA 2016). The swede crop (4 ha) grazed during the second stage of the trial was located on the deer farm (Paddocks Stag 2 and Valley Hay; Figure 5.1) and had previously been in a perennial ryegrass and white clover permanent pasture for over 20 years (Stag 2) and over 10 years (Valley Hay), both grazed predominantly by deer. The swede crop was established with conventional cultivation.

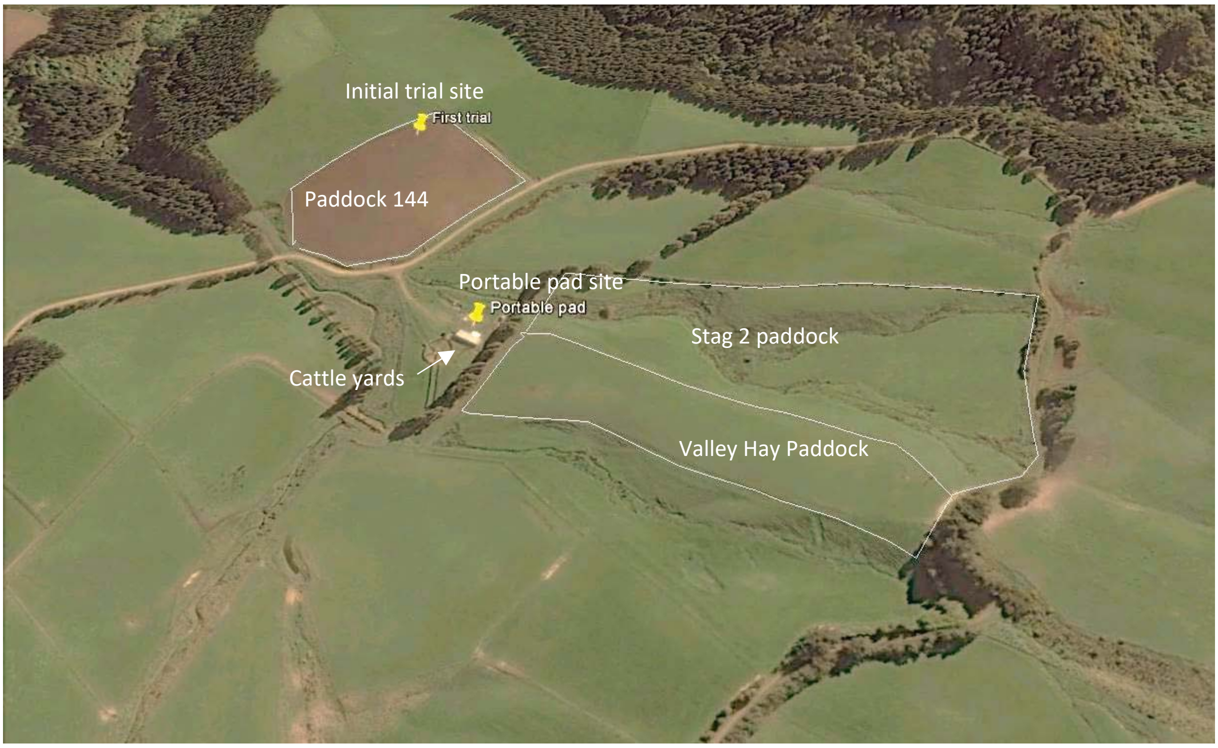


Figure 5.1. Trial locations for two stages of portable pad field experiments and paddocks on the Invermay deer farm grazed by cows during the second stage experimental period.

i. Experimental design

The experiment was established to compare two simulated dairy cow wintering systems. It was necessary to conduct the trial in two stages, the initial stage being proof of concept. The second stage was conducted to compare the two dairy systems. A 'Control' treatment had cows winter grazing a swede crop *in situ* with baleage or hay fed *ad lib*. The second, 'Pad', treatment had cows grazing the swede crop *in situ* but returning to a portable pad for 20 or 18 hours per day

5.3.2 **Animal Ethics**

Stage one of this experiment was conducted on the Invermay farm during March/April 2013 while stage two of this experiment was conducted on the Invermay farm during the winter of 2013. Both stages had the approval of the AgResearch Invermay Animal Ethics Committee (Initial trial # 12825, winter trial #12343).

5.3.3 **Stage 1 pad design and establishment**

An experiment was conducted to determine if:

1. a pad could be constructed that can capture the excreta and rainfall deposited on the pad surface,
2. there was an existing, commercially available, surface suitable for cow comfort and outdoor use as a surface on a portable pad.

A small portable pad was established on the 11th March 2013 on the Invermay farm (Paddock 144: latitude 45°51'16"S, longitude 170°24"16E; Figure 5.1) consisting of an impermeable plastic liner (Figure 5.2; Photo A) and the three pad surfaces. The pad drained into a collection sump and the three surfaces were fenced off so that cows remained in three groups. Cows were stocked at 4 square meters per cow. Animals were held on the pad during the day (8am until 5pm) and returned to a pasture paddock at night.

The three surfaces trialled (Figure 5.2) were:

1. Cowmax™ carpet (Figure 5.2, photo A), a geotextile carpet designed for dairy farm laneway stabilisation. Produced by Geofabrics, formally Maccaferri (www.geofabrics.co.nz).
2. Kura interlocking rubber mats (Figure 5.2, photo B) designed for bedding areas in dairy barns. (www.numat.co.nz)
3. A rolled rubber matting (Figure 5.2, photo C) designed for lining laneways within a dairy barn. (www.numat.co.nz)

The pad was established by topping and rolling the paddock to ensure nothing sharp could puncture the effluent liner from below. The liner was laid out in one piece (Figure 5.2, photo D). The cow comfort surfaces were then placed on the top of the liner (Figure 5.2, photos: A, B & C). To stop effluent flowing off the sides of the pad the liner was laid over a round deer fence post (Figure 5.2, photo E) and held down with another fence post. This bunded the edges of the pad. The pad and the three individual surfaces were then fenced off with hotwire. Electric 'gates' were placed at the top of each pad section (Figure 5.2, photos: F, G & H). Bale feeders were located at the top of the pad and water troughs at the bottom.

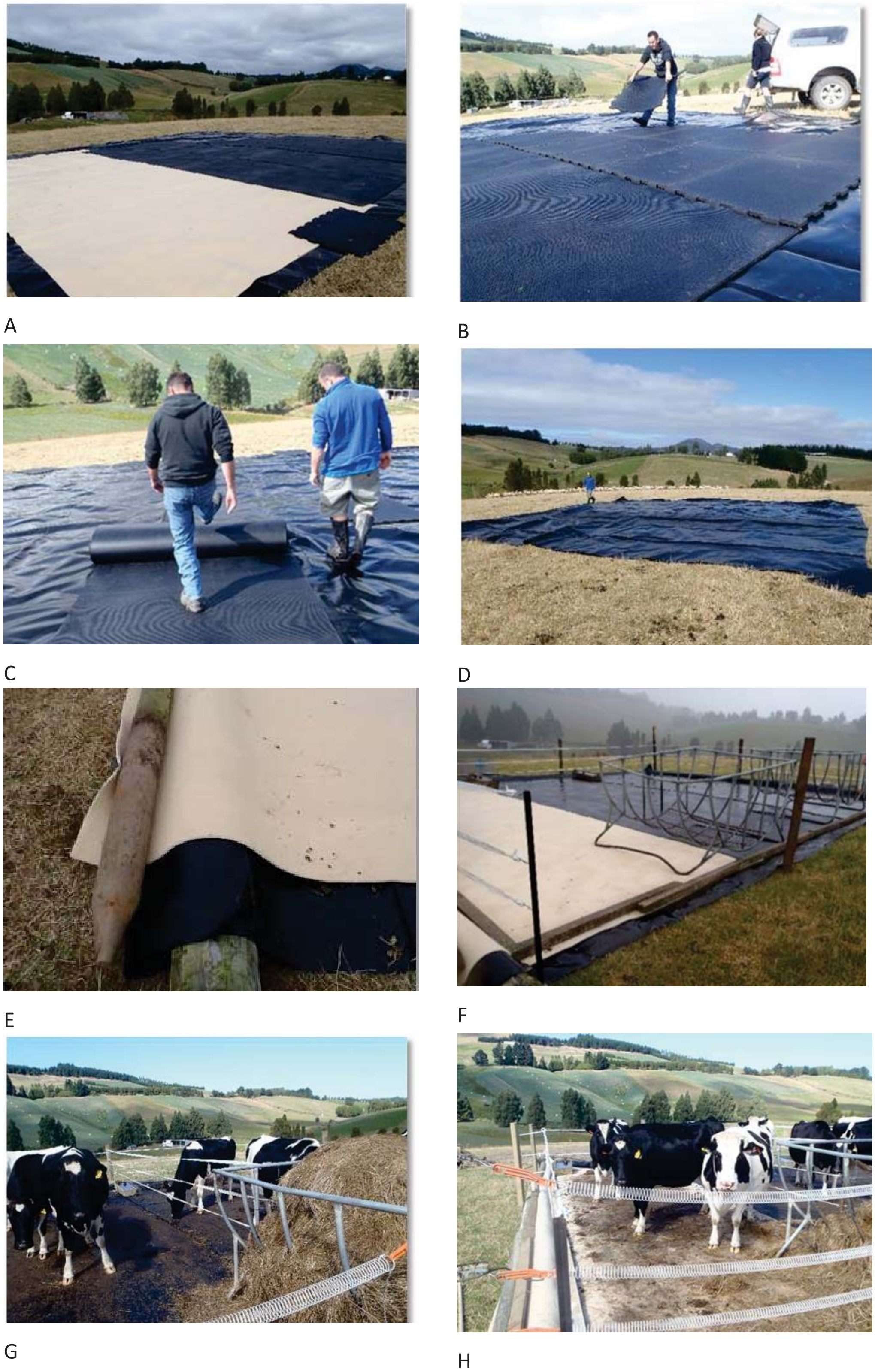


Figure 5.2. Photos of initial portable pad trial. A. pad layout with impermeable liner and 3 surfaces, B. Kura matting, C. rolled rubber, D. impermeable liner, E. bunding of sides, F. final pad, G. cows on matting, H. cows on Cowmax™

5.3.3.1 Animals

The animals used for stage 1 of the trial were non-pregnant dairy heifers that were research animals from the Invermay farm (2-years-old, Friesian, approximate liveweight (LW) 550 kg).

5.3.3.2 Stage 1 measurements

i. Lying time loggers

Lying time loggers were placed on the rear left leg of all cows for a period of 7 days. Onset Pendant G data loggers (http://www.onsetcomp.com/products/data-loggers/ua-004-64) were used to continuously measure the standing and lying times of the cows. The data were downloaded using HOBOware Pro software (http://www.onsetcomp.com/support/manuals/12730-MAN-BHW-UG) and converted to daily summaries of: lying and standing times, lying bouts and, lying duration information using SAS software (http://www.sas.com/en_us/software/analytics/stat.html). The SAS software code was designed for this purpose (Schütz *et al.* 2015).

5.3.4 Stage 2 pad and experimental design

The purpose of the second stage of this work was to conduct an experiment over the winter period using the cow comfort surface identified in stage 1. A portable pad was constructed using the geotextile carpet (Cowmax™). The pad was designed to house 20 cows with an area of 8 m² per cow. Cows grazed crop for a period of 4 or 6 hours per day (4 hours initially but it was then increased to 6 hours) before returning to the pad for the remainder of the 24 hour period. Effluent deposited on the pad was captured and stored (solids) or returned to pasture via a low rate, low depth sprinkler (liquids). A second 'Control' mob of 20 cows' grazed crop according to conventional wintering practice, remaining on the crop 24 hours a day. Measurements of: feed intake, cow lying times, urine N concentration, timing and number of urination events, and soil roughness were taken for both mobs.

5.3.4.1 Animals

Forty non-lactating, Kiwi-cross dairy cows (MA, average LW 524 kg) from a local commercial dairy farm were used for stage 2 of the experiment. They arrived on the property in late May and were grazed on pasture until the 31st May when they were weighed, body condition scored and split into two mobs. The two mobs then grazed crop 24 hours a day until the pad was established. At 2:30 pm on the 5th June the Pad mob was moved to the portable pad.

5.3.4.2 **Site establishment**

The site chosen for the location of the portable pad was on the Invermay deer farm (latitude 45°51’22”S, longitude 170°24”19E, slope 4°). The site (Figure 5.1 and Figure 5.3) was chosen for the following attributes:

- Close to cattle yards for animal handling (Figure 5.3, photo A; cattle yards were in the roofed structure behind the shed)
- Sheltered
- Near crop paddock for grazing (Figure 5.1)
- Easy access for earthworks and monitoring (Figure 5.3, photo B)
- Slight slope (4°)
- Pasture paddocks nearby to pump liquid effluent to
- Existing stone trap for effluent collection

Earthworks were undertaken to remove the pasture and generate a smooth surface of soil as a site for the pad. A pit was dug to house three 3,000 litre tanks to hold gravity-fed liquid effluent (Figure 5.3, photo C).


A.

B.

C

Figure 5.3. Photos of winter portable pad establishment. A. the site prior to pad establishment, B. creating a base for the pad, C. the pit dug to house storage for the liquid effluent.

5.3.4.3 Pad products and design

The pad consisted of:

1. An impermeable liner to capture effluent, overlain by a suitable surface for cow comfort and durability;
2. An effluent capture system;
3. A low- rate effluent irrigation system for the safe return of liquid effluent to pasture.

An effluent liner (from Polythene and P.V.C. Products Ltd, Gore; www.polythenepvc.co.nz) was used as the impermeable base. The liner measured 23 m x 12 m x 1 mm. The liner was overlain with a cow comfort geotextile 'carpet' product called Cowmax^{TM}, produced by Geofabrics (formerly Maccaferri; www.geofabrics.co.nz). Cowmax^{TM} was originally designed to stabilise dairy farm laneways and came in 4 m wide strips which were glued together on site using Ados F2, a high performance general purpose contact adhesive.

The plastic liner was laid in one piece and secured over wooden deer fence posts used to create a bund around the two longer sides of the pad and also creating a 'V' into the stone trap collection area (Figure 5.4). The plastic was nailed to the posts. The Cowmax™ was laid in three strips, vertically down the pad, with the overlapping sections glued together. The edges of the Cowmax™ were nailed over the deer posts used to bund the pad. A three strand electric fence was used around the pad to keep the cows on the carpet area (Figure 5.5). The top side of the pad had electric gate wires to allow cows to move on and off the pad. A section of Kura matting (www.numat.co.nz) was laid over the top of the pad where the entrance area was.

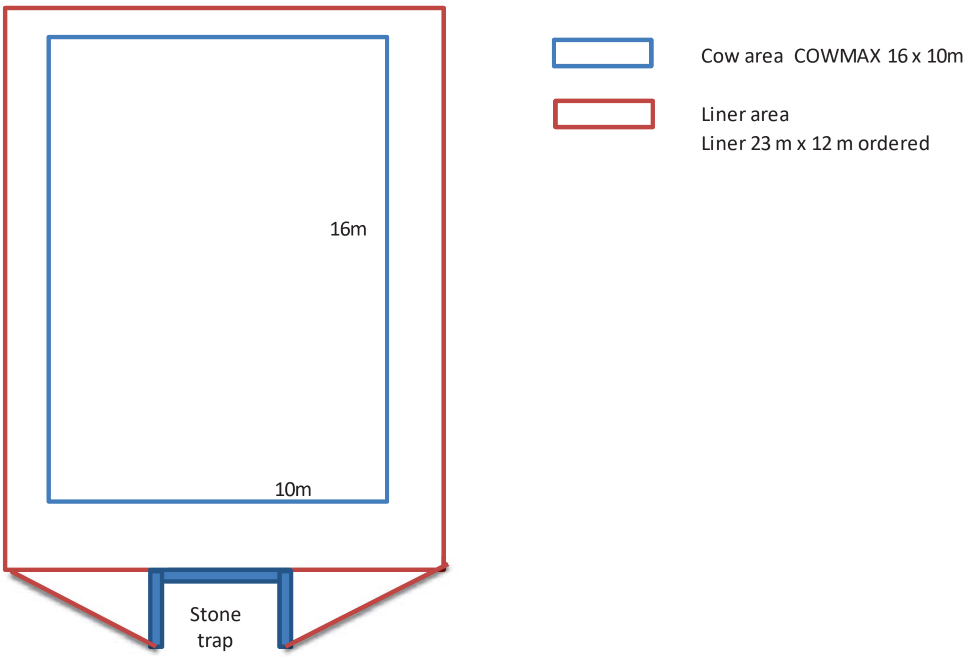


Figure 5.4. Schematic diagram of the portable pad design

Figure 5.5. Portable pad showing side bunding and electric fence (Kura matting is shown stacked on the left of the photo).

5.3.5 Stage 2 measurements

5.3.5.1 Weather

Rainfall was recorded at the pad site by a Raintrak telemetered rainfall system (Item ID: HS-RT-GSM; www.envcoglobal.com) connected to a data logger. Soil temperature was recorded by a nearby weather station located on the Invermay sheep farm.

5.3.5.2 Feed supply

Cows were fed swedes grazed *in situ* and were given a new break daily. Ad lib baleage, or hay, was fed in bale feeders located in the crop paddock for the Control mob or on the pad for the Pad mob.

During June, the Control animals grazed the Stag 2 paddock and Pad animals the adjacent Valley Hay paddock (Figure 5.1). Crop yields and allocations were taken weekly. However, the BCS measurements taken at the end of June indicated that animals in both mobs were not gaining the targeted increase in BCS. Thus, during July crop pre- and post-measurements were conducted three times a week. At the same time the Control animals were moved to the same paddock as the Pad animals (Valley Hay) and grazed side-by-side up the paddock with the mobs separated by a hot wire. At this time the mob allocations were calculated using the DairyNZ winter crop allocation calculator (http://www.dairynz.co.nz/feed/feed-management-tools/). Prior to this, the farm management staff had been calculating the daily crop allocations.

Crop allocation was recorded by weighing three 1m^2 quadrats per mob and a pre and post grazing measurement for each mob was conducted three times a week throughout July and weekly in June. Weekly swede bulb and leaf was weighed separately and a wet subsample taken back to the laboratory and dried in an oven at 100°C for 24 hours for DM analysis. This resulting DM figure was used for the calculations of the other two measurements taken during that week. After grazing, the residual forage mass was measured in the same way and the feed intake calculated on a mob basis and then averaged per cow. Supplementary feed intake was estimated by the number of bales of hay or baleage fed to each mob over a period of time with an estimated wastage of 20%. Prior to the trial beginning, a sample of: swede bulb, swede leaf, baleage and hay was sent to a commercial laboratory (Eurofins NZ) for: % dry matter (DM), total kjeldahl nitrogen (TKN) and metabolisable energy analysis (MJME kgDM^{-1}).

5.3.5.3 **Body condition and liveweight measurements**

Body condition scoring was undertaken three times during the trial by a qualified veterinarian: at the start of the trial (31 May 2013), mid trial (1st July), and at the end of the trial (31st July). The NZ 10 point scale was used (Roche *et al.* 2004).

On the three occasions the cows body condition score was assessed they were also weighed in a crate with attached load bars with a two kilogram degree of accuracy on the scales.

5.3.5.4 **Lying time logger methods**

Loggers (Onset Pendant G data loggers) were used to continuously measure the standing and lying times of twenty cows (10 Controls, 10 Pad). The loggers used and method of use are described in (Schütz *et al.* 2015). The loggers were set to record the x- and y-axis at 30 second intervals. The loggers were set and then placed in a fabric pouch and attached to the hind leg of the cows. An experienced Technician came down from AgResearch, Ruakura, to train animal handlers at Invermay and the loggers were attached by experienced animal handlers. The leg was prepared by clipping the hair at the site before gluing a velcro patch to the leg. The pouch was then secured using velcro and a strap that went around the leg of the animal (Figure 5.6). Leg loggers were not put on cows that had urine sensor measurements taken. The loggers were removed from the animals on three occasions, downloaded, reset, and put back on the cows (except 31st July when they were removed from the cows and not reattached; Table 5.1). The data were downloaded using HOBOware Pro software (Onset Corp., Pocasset, MA) and converted to daily summaries of: lying and standing times, lying bouts and, lying duration information using SAS software (SAS Institute Inc., Cary, NC). There was a period of time from the 10th until the 14th June when there were no data recorded and also for the 15th, 23rd and 31st July (Table 5.1). Other than these dates there were complete 24-hour periods of lying and standing times recorded. One cow (#12) was removed from the trial on 12th July as she slipped her calf 7 days earlier. Her logger was removed on the 12th and put on another cow on the 15th when all cows had loggers removed, downloaded and re-attached.

Table 5.1. Table of events for the period of time lying time loggers were used to monitor cow movements

Date	Action
31st May 2013	Loggers on cows
31st May – 5th June	Treatments not imposed – all cows on crop
10-14th June	Realised no data from 10th June
14th June 2013	Loggers downloaded and back on
4th July 2014	Loggers downloaded and back on
	Incomplete data set for 4th July
15th July	Incomplete data set
23rd July	Incomplete data set
31st July	Loggers downloaded
	Incomplete data set

Figure 5.6. Attachment site for Hobo logger used to record cow lying times. The logger is housed in a pouch which is then attached to the leg by a strap and velcro (shown above).

i. ***Urine sensor***

AgResearch Urine Sensors (Mark II) (Betteridge *et al.* 2013) were used on 14 animals (7 Pad and 7 Control) for two periods of 5 days. This was to record the: estimated urinary volume, urinary N concentration, and timing of urination events to estimate the proportion of urinary N captured by the pad system. The first period of 5 days was 17th -21st June 2013 and the second period was 15-19th July 2013. The 7 Pad animals that had the sensors on in June swapped treatments with the 7 Control animals at the start of July so that the same animals were monitored on both treatments. This was done so that each animal was its own control to be sure that any treatment effects noticed were actually due to the different treatments and not differences between animals. Unfortunately, during the July analysis, the sensors on the Pad animals recorded faulty reflective index (RI) values, which were used to estimate N concentrations, so there is no estimate of urinary N for those 7 animals for the July recording period.

The equation used to calculate the urinary N was,

Equation 5.1 $((87.073 * RI) - 116.23) / 100 = \%$ urinary N

ii. Method of attachment ***(Figure** *5.7***)***

Three days prior to the sensors being attached to the cows, the cows were fitted with a cow cover and given time to acclimatise to that before the sensors were fitted. The sensors were then fitted to each cow.

The vulva area of the cow had the hair clipped using an electric hair trimmer. The urine 'collector" was then glued to the vulva of the cow. This collector captured any urine and directed it down a rubber tube to the urine sensor. The weight of the urine sensor was supported by Velcro straps that were attached to the cow cover. The sensor was protected from dung, mud and urine by a plastic sleeve. The sensor measured an estimate of urine volume and nitrogen concentration as the urine passed through the sensor before being deposited on the ground. Data was stored in the sensor and was able to be downloaded by a ZigBee wireless network system (Betteridge *et al.* 2013).

The cows were able to carry out their natural behaviours of grazing, lying and walking with the urine sensors on. The sensors were checked daily to ensure they were working. This was done by the wireless download system which meant that the cows did not have to be brought into the yards unless it was necessary to re-attach sensors.

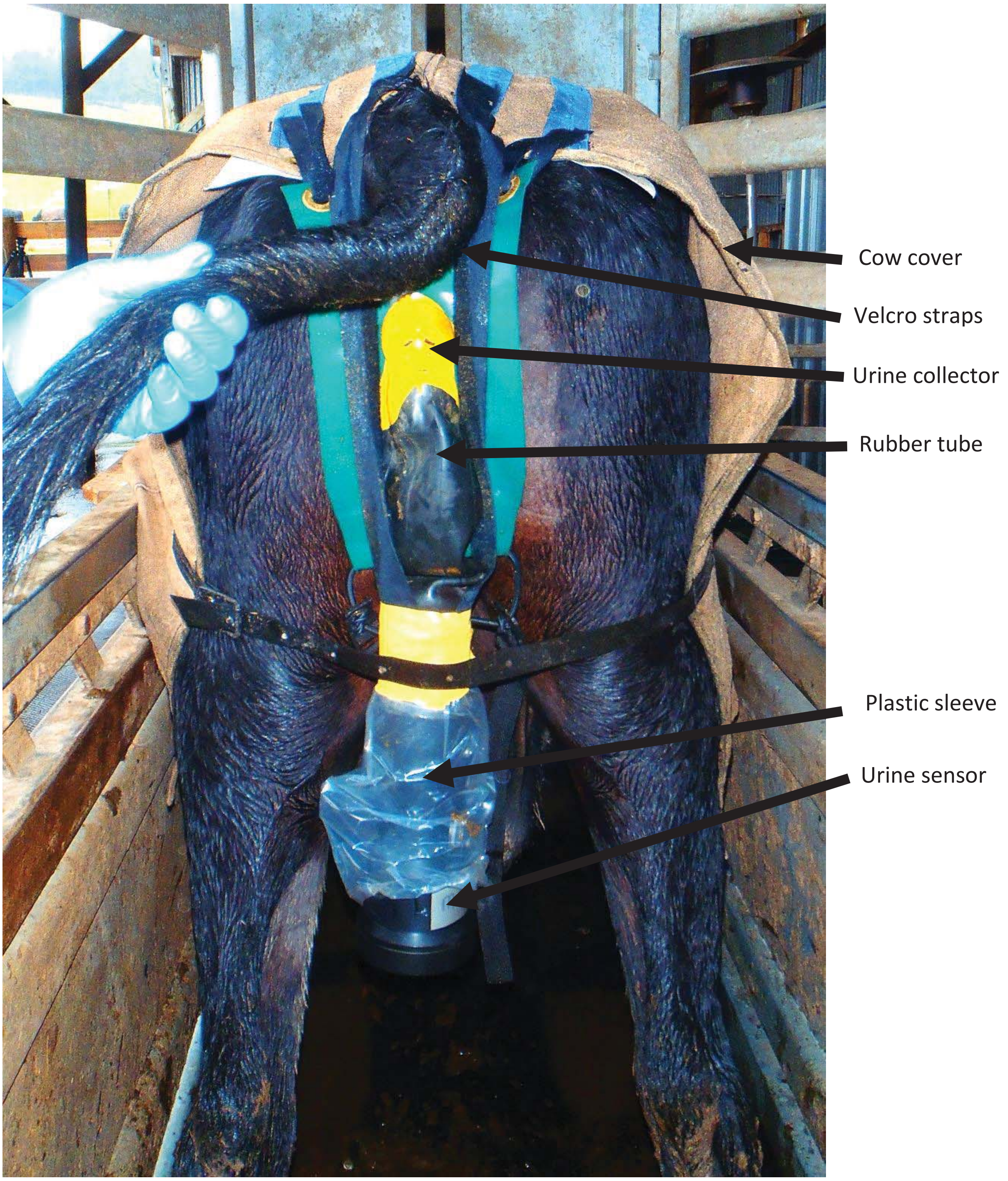


Figure 5.7. Urine sensor attached to a cow and cow cover for urine data collection

iii. Issues with the sensors

There were a number of problems with the urine sensors that resulted in missed data. Firstly, they were prone to falling off the cows either completely or partially. Secondly, the glue attaching the collector to the vulva came unstuck meaning that all or part of the urination event was missed. Thirdly, this also allowed for dung to enter the sensor and block it. When it was noticed (either visually or by looking at the downloaded data) that something was wrong with some of the sensors then all the sensor cows were brought into the yards and their sensors checked and re-attached if required. In both June and July this occurred on day 3 with the sensors removed on day 5. In addition, in July on day 2 two pad cows were brought into the yards and their sensors checked.

After downloading the data it was apparent that in July only one of the Pad sensors recorded RI that is necessary to estimate the N concentration. There was volume data for the 7 sensors but only an estimate of nitrogen concentration for one.

iv. Chain technique for measurement of surface roughness

It was hypothesised that restricting the time cows spent on the paddock, by removing them to the portable pad, would result in less soil damage than if they remained on the paddocks 24-hours a day. To estimate the degree of soil damage caused by grazing, the chain test was used to measure surface roughness.

A one meter long roller chain was placed on the ground in a straight line and moulded by hand to the surface contour. The length that the chain reached was then measured using a wooden ruler (Figure 5.8). The rougher the surface the greater the loss in chain length (Saleh 1993).

Three measurements were taken for the crop break for each mob immediately prior to a new break being offered to the cows. The measurement locations were chosen randomly by throwing the chain and straightening it out parallel to the crop face from wherever it landed. The chain was then pressed into the contour of the surface and the change in length (cm) compared to that on a flat surface was recorded. The resulting measurements were used to assign a roughness class and name (Table 5.2).

Figure 5.8. Chain measurement of determining a quantitative value for determining surface roughness for crop paddocks

Table 5.2. Chain test classification criteria adapted from the work of Saleh (1993) and used in an AgResearch SOP for a measurement of soil roughness using a chain test.

Loss in length (cm) of a 1 m chain	Roughness class	Roughness name	Indentation
0-5	1	Slightly rough	Flat ≤ 2 cm
5-10	2	Moderately rough	Pressing 2-3 cm
10-15	3	Distinctly rough	3-4 cm
15-20	4	Very rough	4-5 cm
>20	5	Extremely rough	≥ 5 cm

v. Effluent collection, application and nutrient analysis

Solid effluent was scraped from the pad daily when the cows were on their swede break. This was done (by farm staff) using a commercially available quad bike mounted scraper (Figure 5.9) (http://www.newmanengineering.co.nz/de-crap-itreg.html). The solids were scraped down to the concrete bunker at the edge of the pad and then removed by tractor. The daily volume of solids removed was weighed by built in scales on the tractor with a 10 kg degree of accuracy. Solids were then stored on a concrete pad. A sample of both the solid and liquid effluent was taken weekly and stored frozen until being sent to a commercial lab (Eurofins NZ) for nutrient analysis at the end of the trial. Volumes of liquid effluent were calculated by recording the pumping times used to pump the liquid effluent from the storage tanks to pasture via a low rate, low depth irrigation system. The volume of effluent pumped per minute was then measured.

The system used to apply the effluent was a k-line system (RX Plastics NZ; www.rxplastics.co.nz/k-line-std-effluent) comprising 6 pods each with a Nann 5022 sprinkler with a 4.0mm nozzle. This has an application area diameter of between 23.5 and 25 meters and pumped between 0.85 and 1.03 m^3 $hour^{-1}$. In this experiment the effluent was pumped uphill (to the top of paddock 144, Figure 5.1) to the sprinklers. However, the pump capacity was recorded without the head developed by the vertical high tot the top of the hill. So pump rates were initially over estimated. It was decided to use the mid-range of the manufactures pumping values for our calculations which was 0.94 m^3 $hour^{-1}$.

Figure 5.9. ‘De Crap It^{TM} scraper used to scrape solid effluent from the portable pad

5.3.6 Statistical analysis

ANOVA analysis was conducted using Genstat 17th Edition.

5.4 Results

5.4.1 Stage one results

The number of cows in each group were reduced from 5 to 3 or 4 as the area per cow was reduced due to a reluctance of the cows to be near the electric fences that separated the surfaces. Six days into the experiment the rolled rubber surface treatment was removed from the trial due to animal welfare concerns. The rolled rubber mat was deemed too slippery and there was a noticeable reluctance of the animals to lie down, potentially an indication of their insecurity of stable footing trying to stand up again.

The remaining two surfaces remained in the experiment for the duration of the 4 weeks. At this point the Cowmax^{TM} carpet was selected as the surface to construct the Stage two winter portable pad with.

The reasons for this were: that it had better grip when wet than the Kura interlocked mats, it seemed to draw moisture away from the surface and the cost was \$19 m^2 compared to \$85 m^2 for the Kura mats. Table 5.3 outlines the pros and cons for the three surfaces trialled.

Table 5.3. Pros and Cons of the different surfaces trialled for use as a portable pad surface

Surface	**Pros**	**Cons**
Cowmax 	• Non slippery • Easy to roll out • Takes moisture out of dung. • <\$20 m^2	• Needs to be secured in place • Questions about cow comfort – lying times may not reaching industry minimum target of 8 hours per day • May require a harder surface
Rolled rubber 	• Easy to unroll	• Too slippery for cows – animal welfare issue – not suitable as a surface for this purpose • \$59 m^2
Kura interlocking matting 	• Easy to lock together. • Locks become more secure with cow traffic. • Liquid flows through cracks to sublayer	• May require a flat surface • \$85 m^2 • Questions about slipperiness in heavy rain

Cow lying times on both the Cowmax^{TM} and Kura matting were above the minimum recommended value of 8 hours-per-day lying (Figure 5.10). Average lying times on Cowmax were 12.5 hours day^{-1} and for Kura 11.5 hours day^{-1}, these values were not statistically significantly different (25th – 29 April inclusive). However, it is important to note that cows were grazing on paddock during the night for this experiment and there may have been an element of cows compensating for reduced lying times when on the pad by increasing their lying times at night when on paddock.

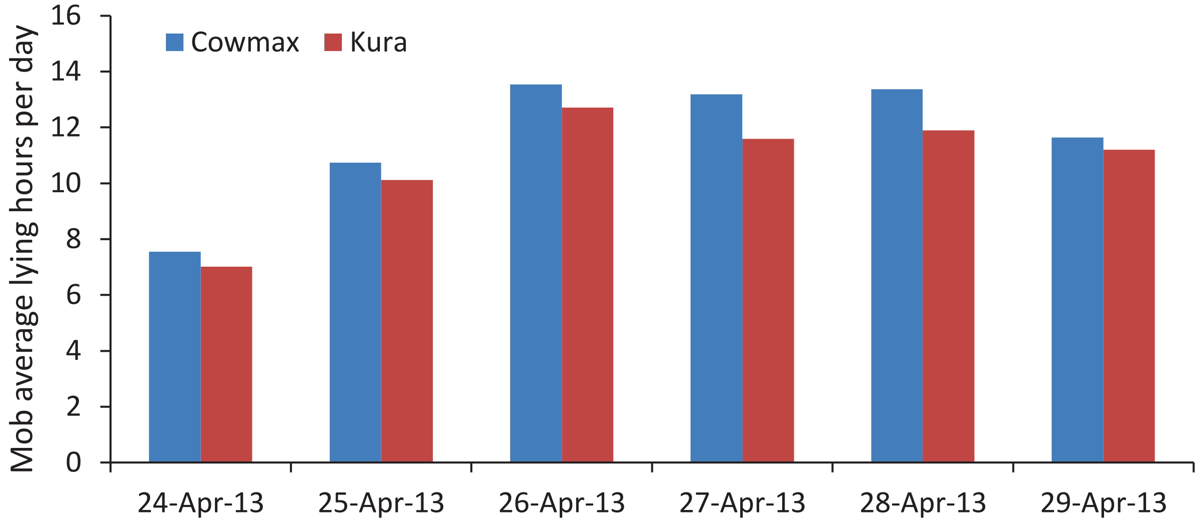


Figure 5.10. Mob average daily lying times for cows on the Stage 1 portable pad trial surfaces of Cowmax™ and Kura matting.

5.4.2 Stage two results

i. Weather

During the two month experimental period the site received 199 mm rain with 168 mm of this falling during June and 65% of the June rainfall occurring during the 4 day period the urine sensors were on the animals (Figure 5.11). In July the site received 31 mm rain; again, nearly half the month's rainfall (47%) was received during the 5 days the cows had the urine sensors on. This compared to the 30-year average values (1981-2010) of 58 mm for June and 71 mm for July (NIWA 2016).

Air temperature at 9 am averaged 4.3°C in June and 4.0°C in July (the temperatures during the urine sensor periods for June and July were 6.8°C and 5.7°C respectively). This compares to a 30-year average temperature (1981-2010) of 5.8 and 5.3 °C in June and July respectively (NIWA 2016).

ii. Feed intake

The average daily intake, of both crop and supplement, over the trial period for the Control mob was 15.3 kg DM cow^{-1} day^{-1} and for the Pad mob was 13.9 kg DM cow^{-1} day^{-1}. The range for the Control mob was 20.7-10.9 kg DM cow^{-1} day^{-1} and the Pad mob 18.3-8.7 kg DM cow^{-1} day^{-1} (Table 5.5).

Table 5.4. Laboratory results for ME, TKN and DM of feed components

	Swede bulb	Swede leaf	Baleage	Hay
Metabolisable energy (MJ kgDM^{-1})	10.3	12.6	9.9	7.9
TKN %	1.11	3.27	1.67	0.98
DM%	10%	13%	50.4%	87.3%

From July 4th onwards Pad cows were on the crop break for 6 hours per day (10:30am - 4:30pm) prior to that it was 4 hours per day.

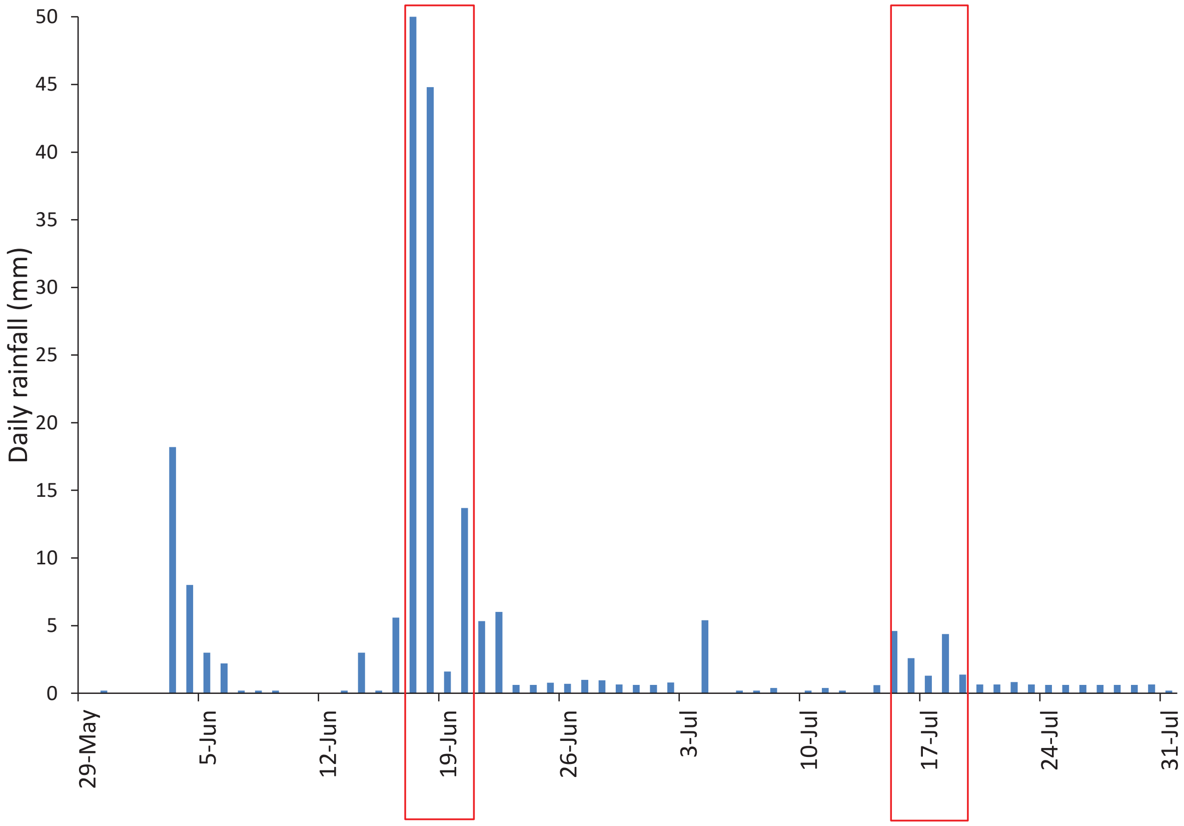


Figure 5.11. Rainfall during the main portable pad experimental period (2013). Red boxes denote the periods when the urine sensors were used.

Table 5.5. Feed intakes of swede and supplement of the Control and Pad mobs for the duration of the trial.

		Swede					Supplement		
Date	Mob	Offered	Residual	Eaten	Yield	Utilisation	Offered	Eaten	Total daily eaten
2013		kg DM/cow	kg DM/cow	kg DM/cow	t/ha	%	kg DM/cow	kg DM/cow	kg DM/cow
10 June	Pad	3.7	0.2	3.5	8.7	94%	11.5	9.2	12.7
	Control	4.6	0.1	4.5	9.1	98%	14.4	11.5	16.0
16 June	Pad	3.7	0.8	3.0	8.8	79%	11.5	9.2	12.2
	Control	3.4	2.6	0.9	8.2	25%	14.4	11.5	12.4
24 June	Pad	5.0	1.2	3.7	9.7	75%	6.2	5.0	8.7
	Control	6.4	2.0	4.4	11.5	69%	12.2	9.8	14.2
1 July	Pad	4.7	0.1	4.6	10.1	98%	12.0	9.6	13.5
	Control	4.4	0.2	4.2	9.4	95%	8.9	7.1	11.3
2 July	Pad	11.1	4.9	6.2	4.5	56%	12.0	9.6	15.8
	Control	11.3	1.9	9.4	1.6	83%	8.9	7.1	16.5
3 July	Pad	9.0	6.8	2.2	10.1	25%	12.0	9.6	11.8
	Control	8.4	4.6	3.8	9.4	45%	8.9	7.1	10.9
4 July	Pad	11.1	7.8	3.3	10.7	30%	12.0	9.6	12.9
	Control	10.7	6.7	3.9	10.3	37%	8.9	7.1	11.0
6 July	Pad	11.1	3.6	7.6	10.7	68%	12.0	9.6	17.1
	Control	10.7	3.2	7.5	10.3	70%	8.9	7.1	14.5
7 July	Pad	10.7	3.6	7.2	10.6	67%	12.0	9.6	17.0
	Control	10.0	3.3	6.7	9.9	67%	8.9	7.1	13.9
8 July	Pad	10.6	5.5	5.0	10.6	47%	8.6	6.9	12.3
	Control	9.9	5.1	4.8	9.9	48%	14.7	11.8	16.7
12 July	Pad	12.8	7.8	4.9	10.6	39%	8.6	6.9	11.8
	Control	11.9	5.2	6.7	9.9	56%	14.7	11.8	18.5
14 July	Pad	10.8	6.6	4.3	9.5	39%	8.6	6.9	11.2
	Control	12.7	6.1	6.6	10.6	52%	14.7	11.8	18.3
16 July	Pad	11.2	8.7	2.6	9.5	23%	14.4	11.5	14.1
	Control	13.2	8.3	4.8	10.6	37%	9.1	7.3	12.1
21 July	Pad	12.7	8.3	4.4	9.5	35%	14.4	11.5	15.9
	Control	14.8	3.9	10.9	10.6	73%	9.1	7.3	18.1
22 July	Pad	11.0	2.8	8.3	12.1	75%	8.6	6.9	15.2
	Control	10.1	3.5	6.6	10.5	65%	12.1	9.7	16.3
25 July	Pad	11.0	3.0	8.0	12.1	73%	8.6	6.9	15.0
	Control	10.1	1.6	8.5	10.5	85%	12.1	9.7	18.2
28 July	Pad	13.1	1.7	11.3	10.8	87%	8.6	6.9	18.3
	Control	13.0	2.0	11.0	10.2	85%	12.1	9.7	20.7

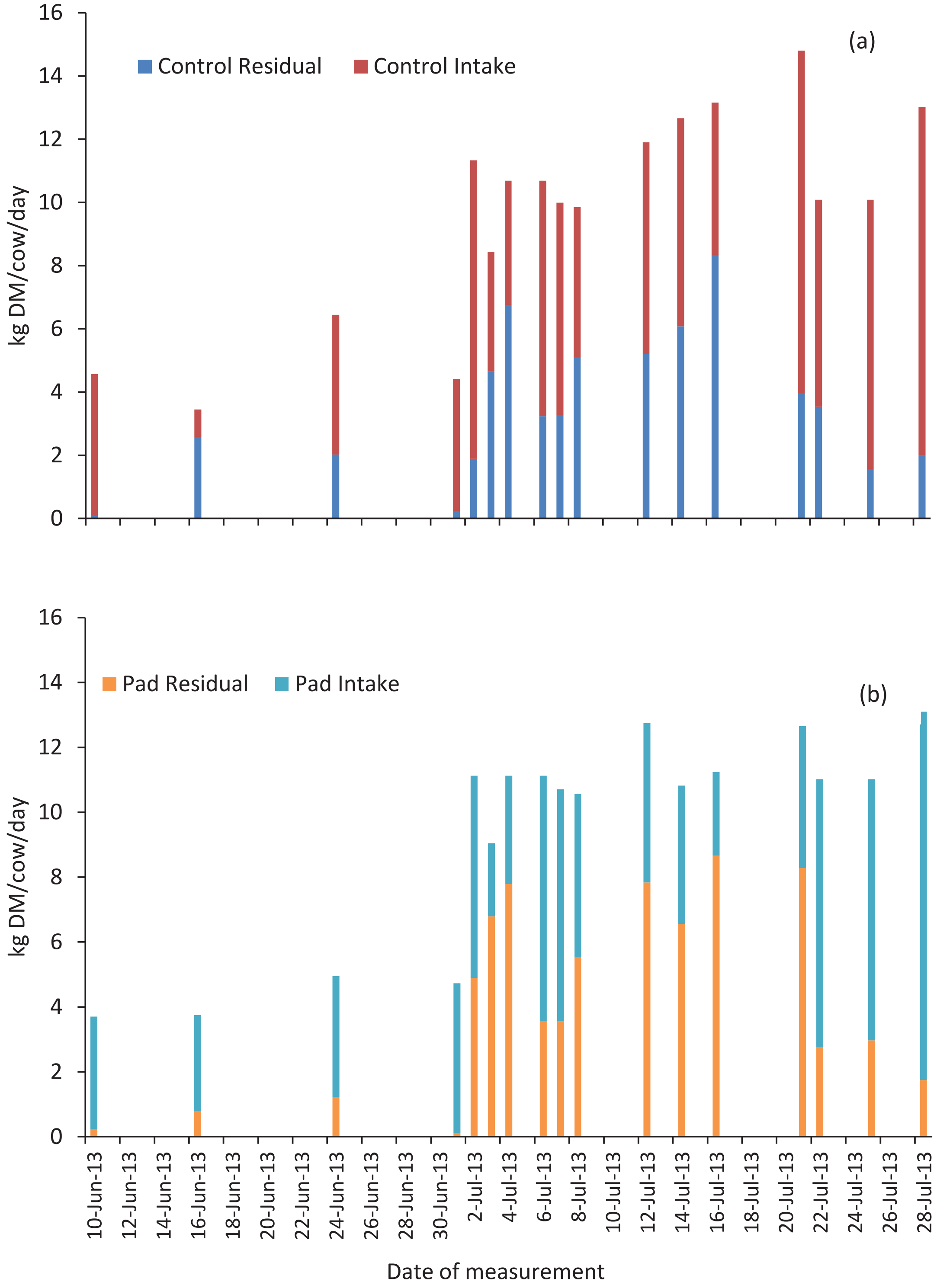


Figure 5.12. Daily swede intake and residual per cow averaged for the Control mob (a) and the Pad mob (b).

An analysis of variance was conducted using GenStat (v 17.1) and found that there was no treatment effect (pad vs control) on the amount of crop eaten (P = 0.479), however, there was a statistically significant effect of date on the amount eaten (p <0.001). There was no significant treatment by date interaction (P = 0.568). When dropping the grazing time per day out of the analysis there was no change to the sum of squares implying that there was no difference in feed intakes between the 4 and 6 hour grazing events that the pad mob experienced in June and July, respectively.

As there was a date effect a covariate regression analysis was conducted to investigate the amount eaten per cow with the covariate of the amount allocated per cow. This was highly statistically significant (P <0.001). Plotting swede allocation against swede intake (Figure 5.13) shows the positive relationship with an increase in swede allocation resulting in an increase in feed intake.

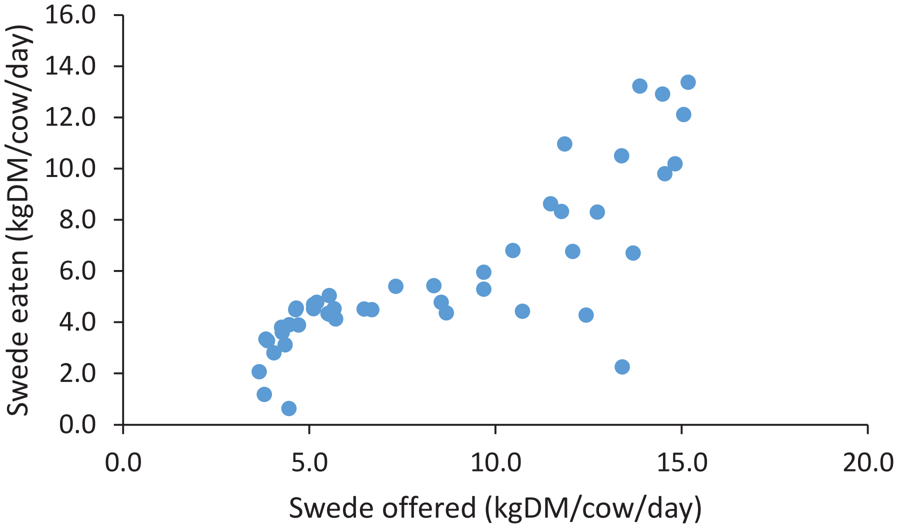


Figure 5.13. Relationship between swede allocation and swede intake of cows grazing swedes in winter. Both the 24-hour and 6-hour grazed results are presented. Intake is increased as allocation increases (P < 0.001)

iii. Body condition data

A 0.5 increase in BCS was the goal over the 2 month experimental period. Both mobs averaged a BCS of 4.58 at the beginning of the experiment and mid-trial BCS data (Figure 5.14) indicated both mobs were losing condition, although this loss was not statistically significant (-0.08 BCS Pad; P = 0.319, -0.12 BCS Control; P = 0.138). Thus, feed allocations were increased, as was the time on crop for the Pad animals (Figure 5.12 a & b). The pad cows increased from 4 to 6 hours day^{-1} on crop and crop feed allocations increased to levels required to achieve the goal BCS. Crop allocations from this point were calculated using the DairyNZ crop calculator (http://www.dairynz.co.nz/feed/feed-management-tools/). This change in crop allocation and grazing time (for Pad animals) resulted in increases in BCS of 0.33 for the Pad mob (P <0.001) and 0.45 for the Control mob (P <0.001) over the second month of the trial. The difference of 0.08 between the Pad and Control mobs for the 1st August is not significant

(P = 0.108). Similarly, the difference of 0.04 between the two mobs on 1st July I not significant (P = 0.664).

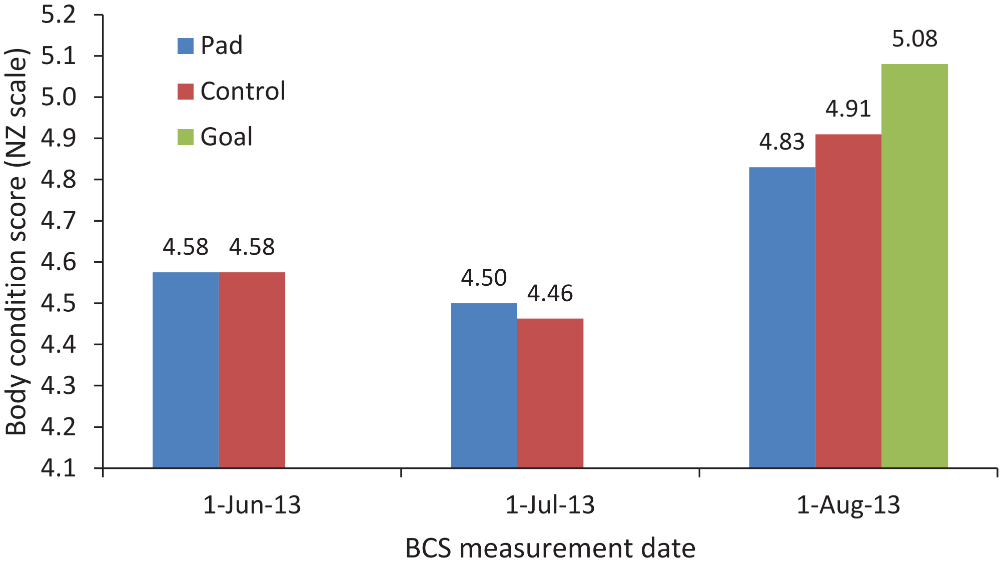


Figure 5.14. Body condition score of cows at start, mid and end-points of the portable pad trial for both the Control (n=20) and Pad cows (n=20). The goal of a 0.5 gain in BCS is shown by the green bar.

iv. Lying time logger results

Analysis of the lying time data indicates that animals in both mobs lay down less during poor weather, particularly in wet conditions (Figure 5.15). When paddock conditions were favourable (dry and sheltered) the Control animals lay down for longer periods per day than those on the Pad. In June the Control animals lay down on average 7.56 hours per day and Pad animals lay for 7.52 hours per day (ns; Table 5.6). However this average daily lying time was heavily influenced by the low lying times recorded between the 11th and 17th of June when there was a cold and wet spell of weather. In July, when weather conditions were drier, both mobs reached the Industry minimum target (MAF 2010) of 8 hours per day lying (Table 5.6: Controls 11.99 h, Pad 9.43 h; P<0.001) . However 95% of the Control animals reached the 8 hour target compared to only 57% in the Pad mob (Table 5.6). Pad animals, during the June period where they had 4 hours day^{-1} on the crop, lay down for 2% of their total lying time during the 4 hour period they were on crop. From the 5th July, when they had 6 hours per day on the crop paddock, they lay down for an average of 17% of their total lying time during the 6 hour period they were on crop (range 0 – 65%). This suggests that the Pad animals did not require the entire 6 hours to graze, but used some of this time to lie down.

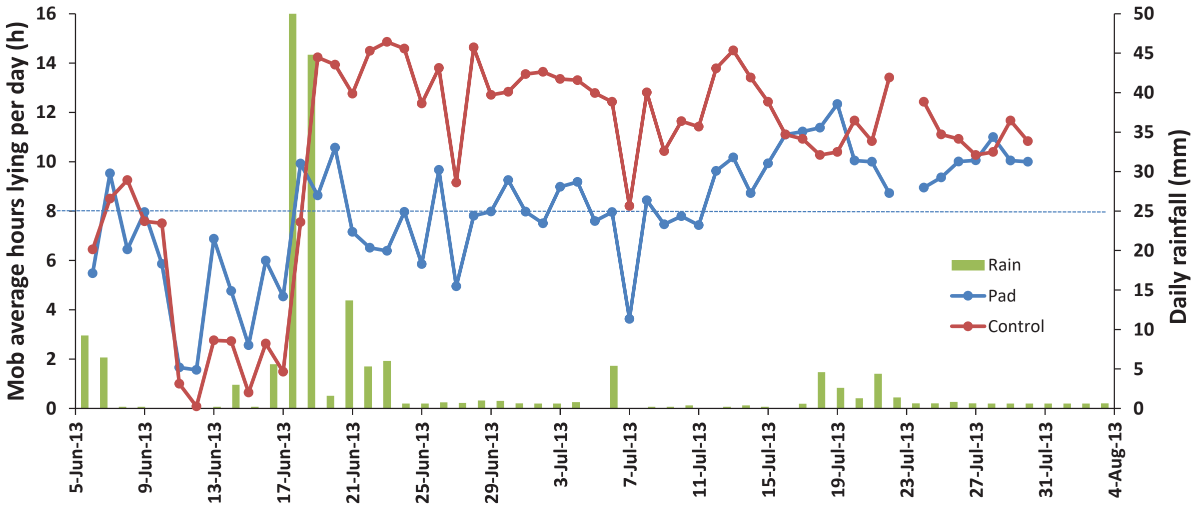


Figure 5.15. Average daily lying times of cows in two alternative winter management systems, traditional crop grazing and restricted crop grazing plus stand-off. Values are averaged over the animals in each mob with loggers (total 20 animals) and compared with daily rainfall (mm). Blue dotted line depicts the minimum recommended daily lying time.

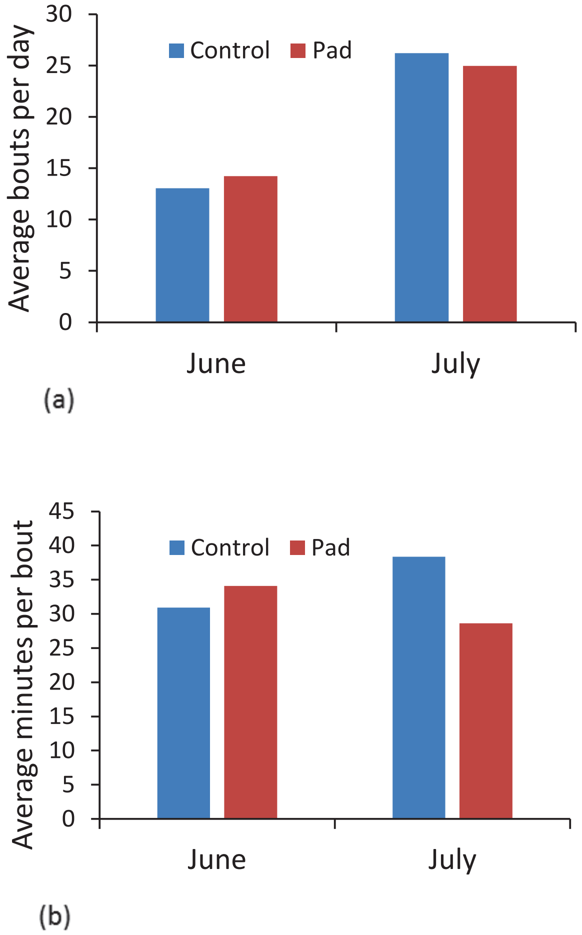
Table 5.6. Overall and monthly average mob lying times for cows either grazing swedes 24/7 (Control) or cows held on a portable pad for 20 (June) or 18 (July) hours per day and grazing swedes *in situ* the remainder of the time (Pad).

	Period 1		Period 2	
	Control	Pad	Control	Pad
Average lying time (h/cow/day)	7.56	7.52	11.99	9.43
s.e.d	1.041	1.041	0.199	0.199
# cows	20	20	19	20
P value	0.974	0.974	*<0.001*	*<0.001*
*Average lying during Pad mob crop grazing hours**	0.6	0.1	1.5	1.5
s.e.d	0.1281	0.1281	0.368	0.368
# cows	11	9	11	9
P value	*0.005*	*0.005*	0.987	0.987
Average lying remainder of day	8.4	6.5	10.49	7.93
s.e.d	0.865	0.865	0.550	0.550
# cows	11	9	11	9
P value	0.044	0.044	*<0.001*	*<0.001*
Percentage of cows achieving the minimum recommended lying period of 8 hours/day	49%	29%	95%	57%

* (taken from animals and days where there was a complete 24-hour period of measurements)

v. *Lying bouts*

Daily lying bout measurement is the number of times an animal lies down over a 24-hour period. This gives more information regarding the behaviour of the animal than lying times alone. A large number of lying bouts, or bouts of short duration, may indicate that an animal is uncomfortable or unsettled.



(a)

(b)

Figure 5.16. Measured bouts of lying down of cows either in a winter crop grazing system or the portable pad system; (a) average number of lying bouts per day and (b) the average number of minutes per bout.

The average number of lying bouts for each mob increased significantly from June to July (Figure 5.16, Table 5.7; p <0.001). This reflects the increase in the total lying time between June and July seen in Table 5.6. The Control animals increased from an average of 13 bouts per day to 26 bouts per day and the Pad mob increased from 14 bouts per day to 25 bouts. Interestingly the duration of each bout for the Control animals increased from 31 minutes in June to 38 minutes in July whereas the lying duration per bout for the Pad animals decreased from 34 minutes per bout in June to 29 minutes per bout in July. There was no significant difference in the number of bouts between mobs (p = 0.882) or between mobs and treatments (p = 0.395). There was also no significant difference between month for bout duration (p = 0.921) or treatment (p = 0.498) however the month by treatment interaction was significant for lying bout duration at the 10% level (p = 0.010).

Table 5.7. Mob average lying bout data. Average number of bouts per day and average bout duration (in minutes).

	Period 1		Period 2	
	Control	Pad	Control	Pad
Average number of bouts per day	13	14	26	25
P value - month	<0.001			
P value - Treatment	0.882			
P value month.treatment	0.395			
Average lying bout duration (minutes)	31	34	38	29
P value - month	0.921			
P value - Treatment	0.498			
P value month.treatment	0.010			

vi. Urine sensor results

Urine sensors were attached to 7 cows in each mob for two 5-day periods during the trial. However, due to problems with sensor recording and also incomplete data sets for some days, out of a possible 140 full cow-day data sets (14 animals x 10 days) only 30 full cow-day data sets were recorded. To calculate average urinary N concentration per hour, all data sets were analysed. For the daily (24 hours) figures, only the 30 cow-day data sets with a full 24-hour period of recording were used for analysis.

The Control animals, in June, excreted 86.9 g N cow^{-1} day^{-1} (n = 5) compared to 90.7 g N cow^{-1} day^{-1} from the Pad animals (n = 4) (Table 5.8). Measured daily volumes of urine were: 18.4 litres cow^{-1} day^{-1} in June and 19.0 litres cow^{-1} day^{-1} in July for the Control mob, and 21.4 litres cow^{-1} day^{-1} for the Pad mob in June. The average number of events per day per cow were 11.4, 9.5 and 10 for the Control mobs in June and July, and the Pad mob in June, respectively.

The average daily urinary nitrogen for Controls was 8.4 g N event^{-1} (Figure 5.17). Calculating daily urinary N by multiplying 8.4 g N by the average number of events (11.4; Table 5.7) results in the figure of 95.8 g N cow^{-1} day^{-1}. This compares to the recorded value of 86.9 g N cow^{-1} day^{-1} (Table 5.8).

For Pad animals there were only 2 days of complete data for one cow and the average daily N excretion was 90.7 g N cow^{-1} day^{-1} over 9.5 urinary events. Taking the average urinary event N values from Figure 5.18 of all the recorded urinary events (8.6 g N event^{-}) and multiplying by the number of events (10; Table 5.8) gives a daily N excretion of 81.7 g N cow^{-1} day^{-1} from the pad animals. This compares to the recorded value for the 4 cows of 90.7 g N day^{-1} (Table 5.8).

Table 5.8. Urinary measurement data for cows and days where there was a 24-hour period of data recorded

	June Control	June Pad	July Control
g urinary N cow^{-1} day^{-1} *			
Mean	86.9	90.7	135.9
s.e.m	9.0	18.8	63.3
s.d	20.2	37.5	89.6
Minimum	63.7	58.8	72.6
Maximum	109.9	133.1	199.2
No of cows	5	4	2
Volume day^{-1} (l)			
Mean	18.4	21.4	19.0
s.e.m	1.6	3.5	4.4
s.d	3.5	7.1	4.4
Minimum	13.7	14.9	14.6
Maximum	22.4	31.3	23.4
No of cows	5	4	2
Events day^{-1}			
Mean	11.4	10	9.5
s.e.m	0.9	0.9	1.5
s.d	2.1	1.8	2.1
Minimum	9	8.5	8
Maximum	14	12.5	11
No of cows	5	4	2
Urinary N concentration (g litre^{-1})			
Mean	4.8	4.2	7.1
s.e.m			
s.d			
Minimum	2.1	2.8	4.9
Maximum	9.3	8.1	8.5
No of cows	5	4	2
Proportion of daily urinary N excreted between the hours of 10 am and 4 pm (%)			
Mean	19%	9%	25%
s.e.m			
s.d			
Minimum	11%	4%	21%
Maximum	26%	16%	29%
No of cows	5	4	2

* See section 5.3.5, equation 5.1

The predicted average daily nitrogen intake of each mob is 218 g N day^{-1} for the Pad mob and 240 g N day^{-1} for the Control mob. This is calculated from the measured N content of feed (Table 5.4) and assuming that 15% of the crop intake was leaf and 85% bulb. Assuming somewhere between 70 and 90% of the consumed N is excreted then this equates to 153-196 g N day^{-1} from the Pad cows and 168 – 216 g/day from the Control cows. The values recorded by the sensors were considerably lower than these values suggesting that either the cow intake was lower during the period of urine sensor measurement (which is quite possible given the poor weather conditions) or the equation used was inaccurate, or the sensors underestimated volume or urinary N concentration. The sensor was not calibrated specifically for this experiment and a calibration provided by Des Costall was used to estimate N concentration in urine (pers. comm).

There was a daily pattern of urinary N excretion over a 24-hour period where, on average, less N was excreted per hour between 10 am and 4 pm compared to the period during the evening and night. This pattern is seen in both the Control and Pad mobs (Figure 5.17 and Figure 5.18). The volume of urine deposited between 10 am and 4 pm was between 33 and 42% (average of 3 animals over 5 days) of the total daily volume, although this represents only 25% of the day. Additionally, there is only 9% (range 4 – 16%) of urinary N deposited between the hours of 10 am and 4 pm (Table 5.8). Thus the cows were on the pad 75% of the time yet it has the potential to capture 91% (96 – 84%) of the daily urinary N deposited.

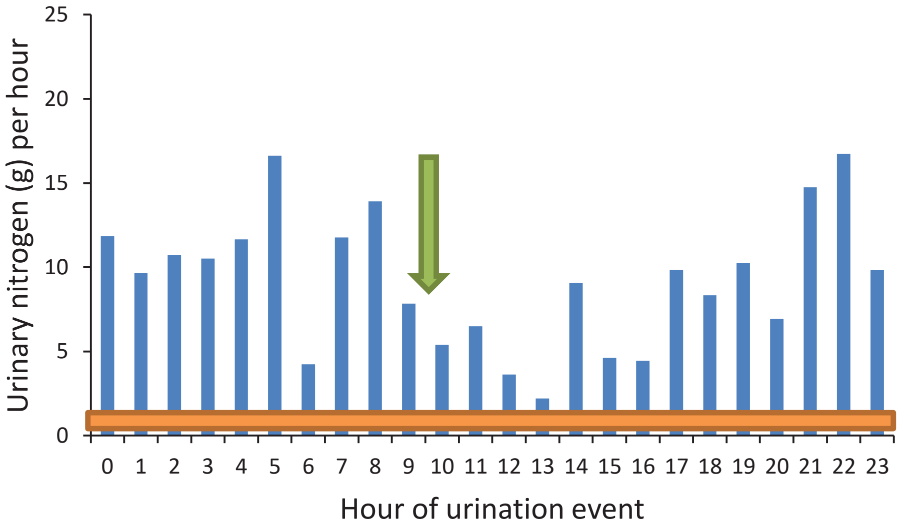


Figure 5.17. Average amount of nitrogen excreted at different times during a 24 hour period for Control animals (average of 393 events from 14 cows). An average urine concentration of 8.4 g N per urination event. The arrow depicts the time when cows were offered a new swede break. The orange bar is the period of time that *ad lib* baleage or hay was offered.

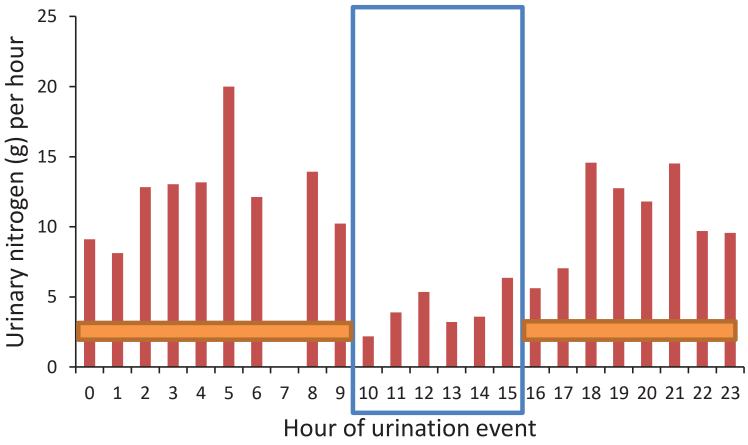


Figure 5.18. Average amount of nitrogen excreted at different times during a 24 hour period for Pad animals (average of 200 events from 14 cows). An average urine concentration of 8.6 g N per urination event. The blue box depicts the period of time cows were on the crop paddock and the orange bar the time *ad lib* baleage or hay was offered.

vii. Soil roughness – chain test method.

There appeared to be a difference in soil roughness between treatments. The measured soil roughness of the area grazed by the Control mob was generally higher than that of the Pad mob (Figure 5.19). This is particularly evident after the rainfall event on 15th July suggesting that in wetter conditions the benefit of reduced time of cows on soils was greater than when soils were drier (Figure 5.19). The range of roughness class for the Pad soils was 1 – 3.7 (average 2.4; moderately rough) and for the Control soils the range was 2-4.7 (average 3.0; distinctly rough); see Table 5.2 for definitions of roughness classes.

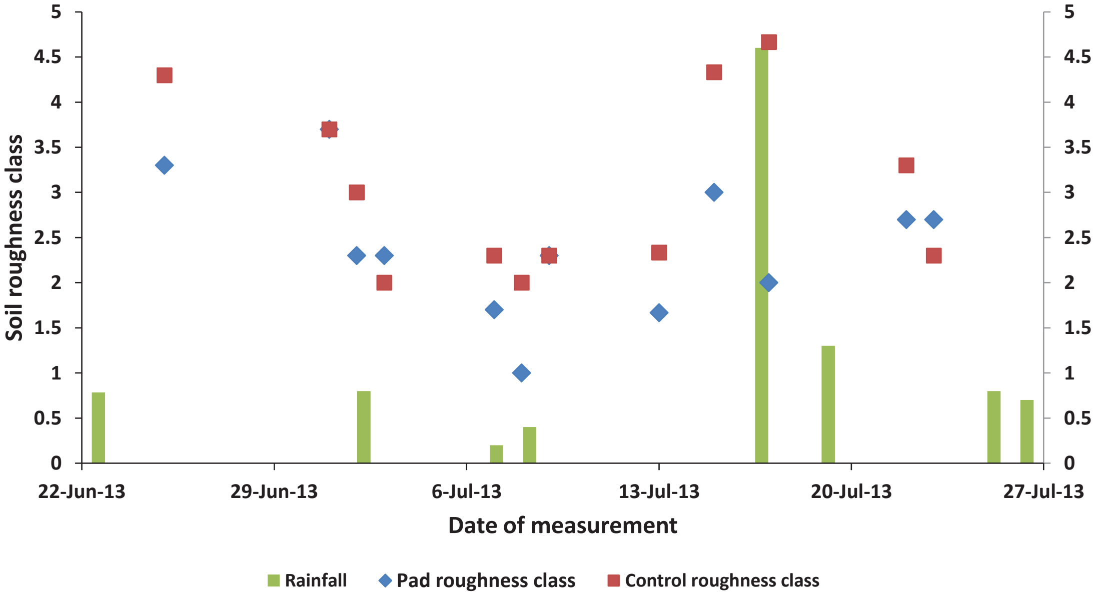


Figure 5.19. Surface roughness class for crop paddocks grazed by Control (24-hrs-a-day grazing) and Pad (6-hrs-a-day grazing) mobs and daily rainfall for the measurement period of 25th June until 23rd July 2013.

viii. Effluent collection data

Cows produced 25 kg solid effluent cow^{-1} day^{-1} (wet weight) when on the pad for 18 hours day^{-1} and 30 kg solid effluent cow^{-1} day^{-1} when on the pad for 20 hours day^{-1}. As baleage or hay was fed on the pad, this solid effluent fraction contained a component of the supplementary feed wastage. The average total N concentration of the solid effluent (Table 5.9) was 23.6 g N kgDM^{-1} which is equivalent to 8.7 kg TN daily from 100 cows (one cow produces 25 kg solid effluent at 14.8% DM which is 3.7 kg DM cow-^{1} day^{-1} multiplied by 23.6 g N kgDM^{-1} is 87 g N cow^{-1} day^{-1}). Of this 8.7 kilograms, 1.7 kilograms is in the form of ammonium-N (NH_4^+-N). One hundred cows also produce daily: 2.3 kg's phosphorus, 7.1 kg's potassium, 5.7 kg's calcium, 1.4 kg's Magnesium and 1.5 kg's sulphur (Table 5.9). The dry matter concentration of the solids averaged 14.8% and the range was 8.6 - 21.1% DM.

Table 5.9. Nutrient concentrations of solid effluent scraped from the pad and sampled from the scraped pile weekly. Values reported on a day matter basis (samples n = 9)

	Average	Minimum	Maximum	Per 100 cows/day (8.5 m^2 pad collection area/cow) (kg)
TN (g/kg DM)	23.6	14.3	34.1	8.7 kg
NH_4-N (g/kg DM)	4.7	0.5	9.5	1.7 kg
NO_3^--N (mg/kg DM)	0.02	0	0.04	0.007 kg
P (g/kg DM)	6.3	4.7	7.9	2.3 kg
K (g/kg DM)	19.2	6.7	30.1	7.1 kg
Ca (g/kg DM)	15.5	8.4	24.6	5.7 kg
Mg (g/kg DM)	3.7	2.1	4.8	1.4 kg
S (g/kg DM)	4.0	1.9	5.5	1.5 kg
DM %	14.8	8.6	21.1	
pH	7.2	6.9	7.6	

An estimated 33,830 litres of rainfall was captured by the pad during the 65 day trial period (0.199 m rainfall multiplied by the collection area of the pad (170 m^2) was 33.83 m^3 or 33,830 litres of rainfall). This is an average of 515 litres rainfall per day. Assuming a cow urinates, on average, 21.4 litres per day (Table 5.8; Pad June) and 71% (assuming upper end of the range of 4 – 29% deposited on crop) of this volume is captured by the pad then an additional 15 litres cow^{-1} day^{-1} is captured. Multiply this by 20 cows, an additional 300 litres per day. Therefore the estimated total average daily volume of effluent captured on the pad is 815 litres day^{-1} or 41 litres cow^{-1} day^{-1} (515 litres rainfall plus 300 litres urine per 20 cows).

Unfortunately flow rate of the effluent sprinkler system was not accurately recorded. However, the website for the sprinkler supplier gives specifications for the model used. Flow rates for the Naan 5022 Sprinkler using a black 4 mm nozzle at a pressure or 2.5 or 3.0 bar are of 0.9 or 1.03 m^3 $hour^{-1}$ respectively (RX Plastics NZ; www.rxplastics.co.nz/k-line-std-effluent). Using the hours recorded that the pump was on results in an estimated 356 or 390 litres per day. This is less than the calculated value above. Possible reasons for this are: (1) inaccurate recording of pumping time, (2) the fact that flow rate was not accurately recorded, (3) some liquid was being lost from the pad. It is possible that this third scenario occurred during high rainfall events.

The average concentration of effluent captured by the pad was 484 mg $litre^{-1}$ TN which equates to 2.0 kg N day^{-1} per 100 cows (assuming 41 litres effluent cow^{-1} day^{-1}). The majority of this nitrogen, 62%, is in the form of NH_4^+-N, compared to only 20% of the TN in the solid effluent being NH_4^+-N.

Table 5.10. Nutrient concentrations of liquid effluent collected from the pad and sampled from the storage tanks weekly. (samples n = 9)

	Average	Minimum	Maximum	Per 100 cows day^{-1} (8.5 m^2 pad collection area cow^{-1}; 42 litres cow^{-1}) (kg)
TN (mg/litre)	484	92	1134	2.0
NH_4^+-N (mg/litre)	301	47	793	1.3
NO_3^--N (mg/litre)	1.1	0.6	1.6	0.005
P (mg/litre)	48	11	84	0.2
K (mg/litre)	1153	253	2384	4.8
Ca (mg/litre)	166	45	367	0.7
Mg (mg/litre)	55	14	128	0.2
S (mg/litre)	182	32	426	0.8
DM %	0.75	0.18	1.68	
pH	7.7	7.4	7.9	

5.4.3 Costing of portable pad technology

Initial estimates of the cost per cow of the Portable Pad technology using the Cowmax™ carpet were \$270 cow^{-1} establishment costs and annualised costs of \$37 cow^{-1} $year^{-1}$. Revised costs took into account an increase in area per cow from 6 to 8 square meters and the inclusion of a lined pit for solids storage. Revised costs were \$334 cow^{-1} or \$72 cow^{-1} $year^{-1}$ when annualised (Table 5.11). This included the cost to empty the solids pit annually.

This compares to a covered shelter costing around \$3500 cow^{-1}, or an annualised cost of \$175 cow^{-1} year^{-1}.

Table 5.11. Cost of portable cow wintering pad technology (assume 9 m^2 cow^{-1} including bunding)

	Cost per cow (\$)	Life Expectancy (years)	Annualised cost (\$ cow^{-1} year^{-1})
Plastic liner	54	3	18
Cowmax carpet	177	8	22.13
Solids pit liner	12	3	4
K-line	7	15	0.47
Water trough	30	15	2
Earthworks	20	5	4
Solids pit effluent removal	20	1	20
Pad surface scraper	14	10	1.39
TOTAL	\$334		\$72

5.5 Discussion

Key research objectives for this work in relation to the concept of the pad were, (i) that it is possible to design a low-cost portable pad that consists of an impermeable liner, overlain by a cow comfort layer and that the effluent deposited on the pad can be captured, and (ii) that in winter it is possible for cows to graze brassica crops and return to the portable pad for 18 hours day^{-1} while maintaining animal welfare standards.

5.5.1 Portable pad as a concept to capture the effluent deposited

Key to the success of the concept of the portable pad is the ability of the impermeable layer plus cow comfort layer to successfully capture effluent deposited on the surface. In both stages of the trial solid effluent was scraped from the surface (by hand scrapers on the initial pad and a bike mounted scraper in the second stage). This requires a collection and storage area for the scraped solids. In the first stage solids were scraped down the pad to a storage area on the liner only. In the second stage solids were scraped to a concrete bunker area already in place and then they were removed and stored on a concrete pad.

The amounts of solid effluent collected were 30 kg cow^{-1} day^{-1} when the cows were on the pad for 20 hours and 25 kg cow^{-1} day^{-1} when they were on the pad for 18 hours per day. This solid material had a component of the baleage in it as the cows were fed baleage on the pad.

Estimated volumes of liquid effluent captured using pumping hours recorded (390 litres per day) were lower than calculated volumes using rainfall, pad area and measured urine volume (802 litres per day). This discrepancy of an average of over 400 litres per day was perhaps due to the pad not capturing all rainfall at high rainfall events. It is likely that during high intensity rainfall events such as those experienced between the 16th and 22nd June (Figure 5.11) the pad system was unable to cope with the volumes of rainfall deposited on the surface and there was runoff generated. This runoff risk must be avoided in future pad design and choice of location.

Additionally, nitrogen captured in the liquid effluent (using the calculated volume of 802 litres day^{-1} = 40 litres cow^{-1}) amounted to 20 g N cow^{-1} day^{-1} whereas the expected amount captured by the pad is around 82 g N cow^{-1} day^{-1} (Figure 5.20). This could be due to some of the urinary N being removed with the solid effluent. The volume of N removed in solids was 87 g cow^{-1} day^{-1} totalling 107 g N cow^{-1} day^{-1}.

Average daily nitrogen intake in feed was 218 g N cow^{-1} day^{-1} and assuming 80 percent of this is excreted in dung and urine (Haynes & Williams 1993) then it would be calculated to have an average of 174 g N cow^{-1} day^{-1} excreted. The average daily N volume captured by the system is between 107 g N cow^{-1} day^{-1} (adding the volumes captured in solid and liquid effluent) and 169 g N cow^{-1} day^{-1} which is between 49 and 78% of the N intake and between 61 and 97% of the expected daily N excretion. This value will include a proportion of N in the feed that was present in the solids removed from the pad and it excludes any N excreted as dung during the time on paddock.

i. Pattern of urinary N excretion

The daily pattern of urinary N excretion appears to be unaffected by restricting the grazing to 6 hours. Both mobs show urinary N patterns of lower N excretion during daytime hours (around 10 am until 4pm). This can be used to the advantage of the farmer in that if the animals grazing period is timed to coincide with the low urination period then the amount of N excreted on the paddock can be minimised.

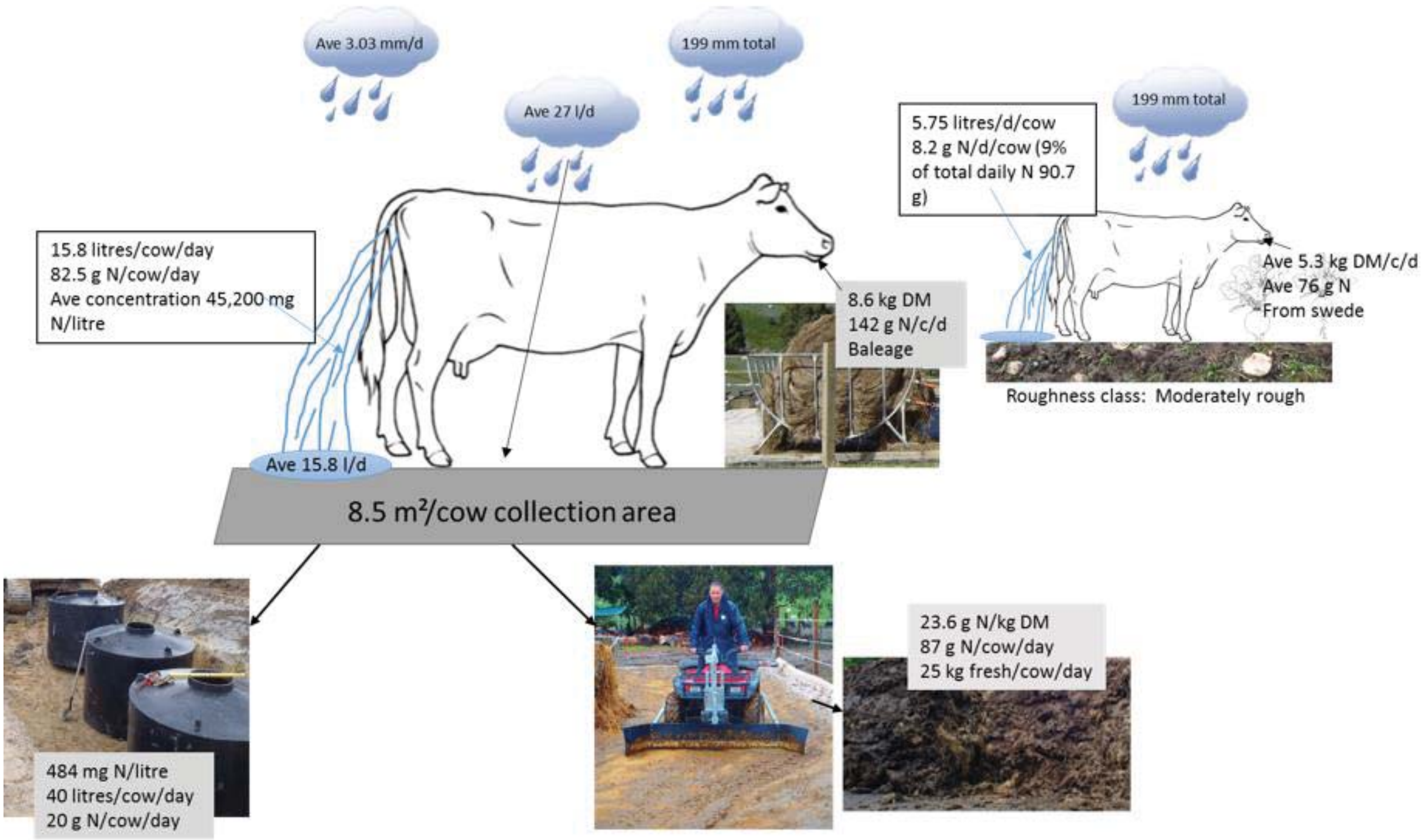


Figure 5.20. Diagram depicting nitrogen cycling in the portable pad system. Inputs (feed and rainfall) and outputs resulting in effluent, urine and dung deposited either on the pad or the paddock over the two month field experimental period.

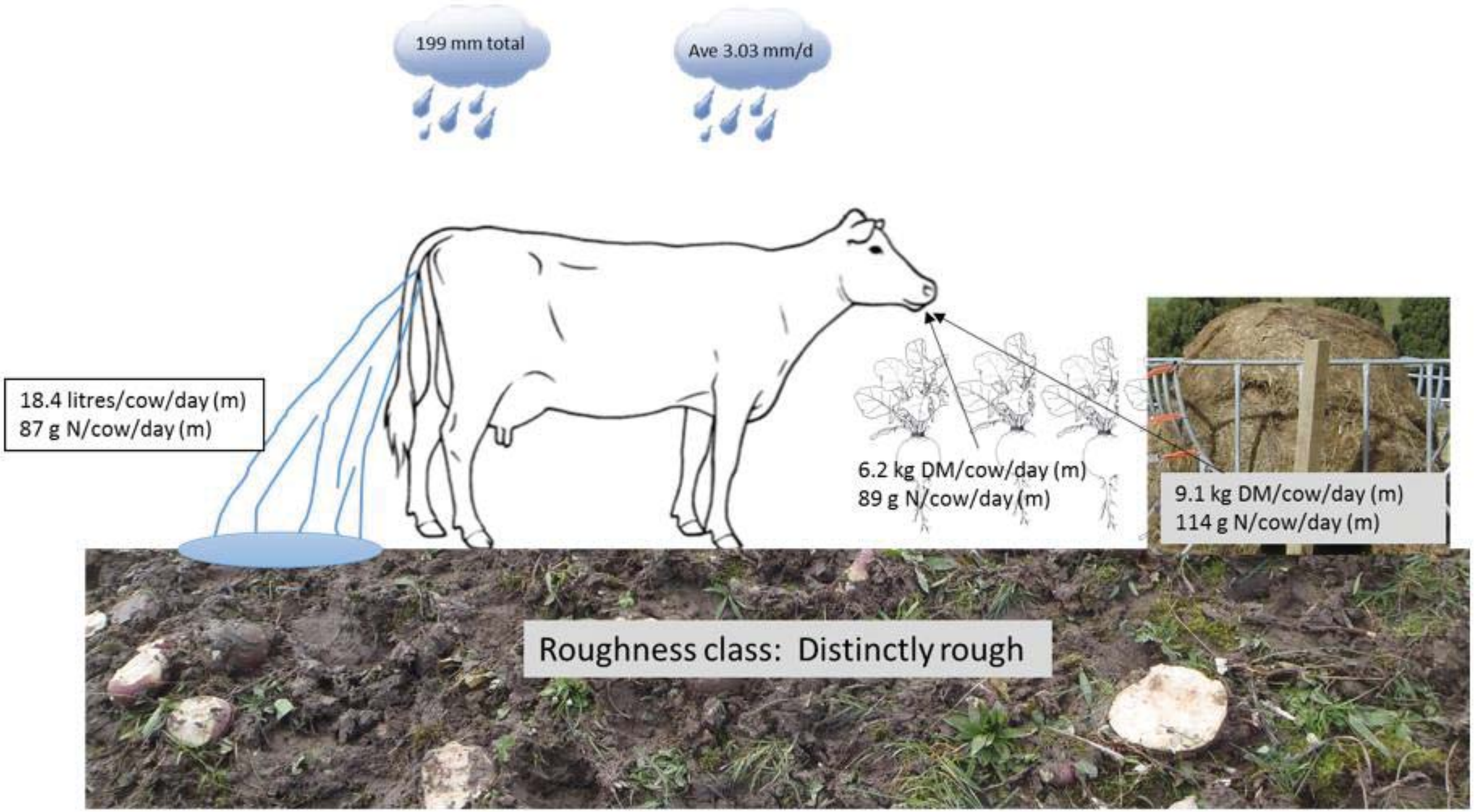


Figure 5.21. Diagram depicting nitrogen cycling in the traditional crop wintering system. Inputs (feed and rainfall) and outputs resulting in urine and dung deposited on the paddock over the two month field experimental period.

5.5.2 Portable pad use and the ability to maintain animal welfare.

Feed intake from swedes during June was too low by industry standards and this was obvious from the lack of BCS increase in the cows. Cows were offered an average allocation of 4.5 kg DM cow^{-1} day^{-1} in June compared to a recommendation of around 9 kg DM cow^{-1} day^{-1} calculated by the DairyNZ 'Winter Crop Calculator' (www.dairynz.co.nz). However, the crop allocation in the second month of 11.5 kg DM cow^{-1} day^{-1} was similar to those offered in an experiment conducted at Lincoln University comparing intakes of cows offered 11 or 14 kg DM cow^{-1} day^{-1} kale plus 3 kg DM cow^{-1} day^{-1} supplement to cows offered 11 kg DM cow^{-1} day^{-1} grass plus the supplement (Rugoho *et al.* 2014). The utilisation they found with the 11 kg DM kale group was 95% which is much higher than our 70% for swedes in July when the cows had 6 hours on crop. In their experiment cows were offered their allocation of supplement one hour prior to crop allocation. They found that within 6 hours of the forage allocation the cows had consumed more than 86% of their daily DM intake. To achieve a 0.5 BCS increase DairyNZ suggests offering 11.4 kg DM cow^{-1} day^{-1} of swedes in June and 14.1 in July to achieve actual intakes of 9.3 and 11.5 kg DM cow^{-1} day^{-1} in June and July respectively assuming a 70/30 swede/supplement split (DairyNZ 2013b). The intakes recorded of 7.1 and 6.1 kg DM cow^{-1} day^{-1} from swedes when grazing for 6 hours were considerably less than the DairyNZ figures. The only reason our cows were able to increase their body condition during July was because of the high intakes of supplementary feed. In this trial control cows consumed 9.1 kg DM cow^{-1} day^{-1} from supplement for both June and July and the pad cows consumed 9.7 and 8.5 kg DM cow^{-1} day^{-1} in June and July respectively. This is unrealistic for a practical farming situation as farmers were unlikely to feed supplements *ad lib* and were more likely to offer a daily allowance. Rugoho *et al* (2014) offered an allowance of 3 kg DM cow^{-1} day^{-1} of barley straw and the recommendation for feeding swedes is no less than 30% of the diet a high fibre supplement such as cereal silage. The silage in our trial made up 67 and 69% of the diet in June and 56 and 58% in July for the control and pad animals respectively.

5.6 Conclusion

Conclusions with respect to our research hypotheses:

Hypothesis 1 a – that it possible to construct and operate a portable pad

A pad was constructed using an effluent liner that captured the effluent deposited on the pad. Through the stage 1 experiment it was determined that the best surface for a cow comfort layer (of the three trialled) was a geotextile fabric; in this case Cowmax™ carpet.

Successful use of the pad requires daily scraping of solid effluent and also either storage or a low rate, low depth application of liquid effluent to land. This winter-applied effluent may also require resource consent. There were also concerns about the welfare of the animals from a 'lying-time' perspective.

Suggested improvements:

1. Tensioning the cow comfort layer to reduce bunching of the fabric
2. Feeding the supplementary feed on the paddock and not the pad.
3. Finding or developing a cow comfort surface that results in increased cow lying times, while remaining low cost and practical.

Areas for further research are:

1. Developing a tensioning system to keep tension on the pad cover
2. Farm scale implementation of the portable pad concept.

Hypothesis 1 b – that the pad will capture the excreta and rainfall

There is a daily pattern of urinary N excretion evident that shows reduced urinary N excretion during the period from 9am until around 3 pm. By scheduling the 6 hour grazing period for animals utilising the portable pad system to coincide with this period of lower N excretion, the dairy urinary N deposited on paddock can be restricted to around 9%.

Hypothesis 2 – the pad will not negatively impact animal welfare

Over an extended period of time where there was a range of weather conditions the pad was able to achieve animal welfare lying time minimum recommended requirements (8 hours day^{-1}). However there were issues that were not restricted to the pad, where in adverse weather conditions (low temperatures, wind, rain and wet ground conditions) neither the paddock nor the pad meet animal welfare minimum lying time recommendations.

5.7 Acknowledgements

Thanks to Karl White (Invermay Farm Manager) and Lachie Ashton for their valuable advice and assistance with the design and establishment of both pads. Also to Karl and Lachie and the Invermay farm staff for day-to-day monitoring of the cows. Thanks to the AgResearch technical team (Tom Orchiston, Wayne Worth, Tash Styles, Karren O'Neill and Gemma Worth) for assistance in trial establishment and animal handling. Thanks to Des Costall for his assistance with the urine sensors and for training me in their use. Thanks also to Stuart Lindsey (AgResearch, Ruakura) for mineral N sample analysis.

6. Low depth winter applied effluent application

6.1 Abstract

In southern New Zealand housing dairy cows over the winter provides an alternative to wintering cows on crop, however, the cost of storing the effluent produced is potentially prohibitive to many farmers. Current methods of applying liquid effluent to land are seen to be too risky during the wet winter months as there is the risk of high nitrogen (N) losses to water.

This led to an investigation of the possibility of applying liquid effluent to land during the winter months using a low depth sprinkler system. A small plot experiment was conducted to measure nitrogen leaching losses under treatments of different depths of effluent applied daily during the winter using a sprinkler system. It was found that applying farm dairy effluent at a depth of 2 mm day^{-1} (each day over winter except if rainfall had exceeded 4 mm in the preceding 24-hours) resulted in losses of only 7% of the applied mineral-N. The cost of implementing this system could be as low as \$2,000 ha^{-1} and only around 6% of the capital cost that would be spent building an effluent pond to hold the liquid effluent generated by an uncovered wintering pad.

It is hypothesised that the losses measured in this trial were higher than they would be if a low rate application was used, for example 4 mm hr^{-1} instead of the 34 mm hr^{-1} used in this trial. Therefore, it is recommended that further research is conducted to investigate the concept of low rate and low depth winter applied liquid effluent under the following criteria:

1. Use of an effluent source that better represents effluent captured by a wintering system. This is likely to have higher nutrient concentrations than FDE.
2. Use of a low rate of application rather than the 35 mm hr^{-1} used in this work. Use of a k-line type system applying at a rate of 4 mm hr^{-1}.
3. Limit the daily depth to 2 mm day^{-1} either in one application or two 1 mm applications.
4. Limit the total N load to a figure such as 80 kg N ha^{-1} winter^{-1}.

6.2 Introduction

On New Zealand's pastoral-based dairy farms winter is an important part of the system. This represents the period of late pregnancy when cows are 'dry' (not milking and with lower energy requirements) that coincides with the winter period of slower pasture growth. The southern most regions in New Zealand have a cooler climate and soil type conditions that result in a need to manage the wintering component of the system somewhat differently to the rest of the country. In the Southern South Island 'Wintering' usually occurs in a 10-week period from late May until calving in early August. Due to the regions low pasture growth rates over winter (Table 6.1) farms in the southern South Island are unable to grow sufficient pasture to feed dairy cows over winter and reach targeted pasture covers for spring. Another reason that cows need to be wintered off the milking platform pastures is that winter rainfall (Table 6.2), combined with imperfectly and poorly-drained (heavy) soils, results in water-logged paddocks. These are susceptible to treading damage and can result in reduced future pasture production. An estimated 47% of Southland's dairy soils are classed as having very poor, poor, or imperfect drainage (drainage classes 1-3) (Beautrais 2014). Therefore, dairy farms must graze cows elsewhere (or have an off-paddock facility) because of the issue of wet paddocks and to ensure pasture covers are adequate for the start of spring while ensuring cows are at targeted body condition scores (BCSs) for calving and early lactation.

Table 6.1. Winter growth rates and milk production in different regions of New Zealand (DairyNZ 2011).

	Southland	Otago	Canterbury	Manawatu	Waikato	Northland
Pasture growth (kg DM ha^{-1} day^{-1})						
June	11	-	10	19	25	25
July	6	-	7	19	25	25
Percentage of national herd						
	11%	5%	17.3%	4.5%	24%	6%
Milk production per cow (National average 2012/13 season = 346 kg MS cow^{-1} $season^{-1}$)						
	384	366	391 (north) 382 (south)	360	330	282
Per hectare production (National average 2012/13 season = 988 kg MS ha^{-1} yr^{-1})						
	1,051	1,127	1,363 (north) 1,317 (south)	996	970	645

Figure 6.1. Map of the lower South Island of New Zealand depicting the locations of the Southland and South Otago regions whose climate data is presented in Table 6.2. (Source: Topomap)

Table 6.2. 30-year average climate data for Southland (1-8) and South Otago (9, 10) sites, 1970-2000. The map location reference numbers can be seen on the map in Figure 6.1 (NIWA 2015a)

Map location reference number *	Location	Annual Rainfall (mm)	Mean air temp (°C)	Mean Daily Maximum Air Temperature (°C)	Mean Daily Minimum Air Temperature	Total Sunshine hours
1	Moa Flat	-	9	13.9	4.1	-
2	Balfour	863	-	-	-	-
3	Otama	814	-	-	-	-
4	Gore	-	-	-	-	1602
5	Waimumu	1280	-	-	-	-
6	Otautau	1195	9.8	14.9	4.7	1445
7	Winton	938	10.1	15	5.2	1652
8	Woodlands	1106	10	14.7	5.3	-
9	Hillend	840	-	-	-	-
10	Balclutha	685	10.4	15.2	5.6	1625

*** relates to Figure 6.1**

Sixteen percent of the national herd is farmed in Southland and South Otago (Table 6.1). Both regions have relatively high production compared to other regions in the country (Table 6.1). This 16% of cows represents around 780,000 cows to be wintered in the region.

Traditionally, in Southland and South Otago, cows have been wintered on brassica crops. Grazing winter brassica crops results in the excreta deposited onto paddocks contributing to losses of nutrients (nitrogen (N) and phosphorus (P)) and faecal micro-organisms (*E. coli*) to waterways (McDowell & Houlbrooke 2008; Orchiston *et al.* 2013; Smith *et al.* 2012). Brassica crops are grazed at a high stocking density and, due to the strip grazing method of consuming the crop, the excreta is deposited onto bare soil where there is no opportunity for plant uptake of the nutrients. Intensive grazing on paddocks during winter also results in soil physical damage and reduced subsequent plant yields. In recent years there has been an increase in the use of off-paddock dairy wintering systems in Southland as farmers try to resolve the environmental problems associated with brassica grazing. Many of these systems generate winter captured effluent that then requires storage until soil conditions are favourable for land application. The cost and/or practicality of extra effluent storage is potentially restricting increased farmer uptake of off-paddock wintering systems. In some cases, farms with existing off-paddock wintering systems are applying liquid effluent to land during the risky winter months.

The focus of this work was to determine whether it was possible to apply liquid effluent to pasture during winter without significantly increasing losses of nutrients and faecal micro-organisms to ground water. This was an attempt to provide farmers with an alternative solution to costly winter storage systems that require capacity to store all winter generated liquid effluent.

Recent modelling work, representing a Southland scenario, by Monaghan *et al* (2010) has indicated that low rate irrigation systems have the potential to significantly reduce contaminant losses in mole-tile drainage compared to the use of a travelling irrigator (Monaghan *et al.* 2010). Houlbrooke *et al.* (2004a), found that the mole and pipe discharge that resulted from a 25 mm FDE application to a Pallic soil, near field capacity, contained less than 50% of the FDE-N. Additionally, lysimeter studies by McLeod *et al* (1998) on a similar Pallic soil has shown that maintaining the application rate of farm dairy effluent (FDE) at less than 10 mm hr^{-1} minimises movement of solutes into the subsoil. Thus, even if drainage is generated from FDE application to wet soils, some removal of nutrients will occur. Further field investigation was warranted to examine if application of low FDE depths to pasture during winter will increase the removal rate of nitrogen, phosphorus and *E. coli*.

The first step was to conduct an analysis of the storage volumes required to winter dairy cows in different rainfall areas of Southland and South Otago. This was done using the Massey Dairy Effluent Storage Pond Calculator (DairyNZ 2013a). A comparison was done between (1) the storage requirements if all winter-generated effluent was required to be stored between mid-May and mid-August and (2) the storage required if it was possible to irrigate liquid effluent during the winter. The assumptions for the model were:

- The effluent system was for the wintering barn alone; dairy shed effluent system was not considered.
- The cows were housed in a deep litter barn with an adjacent uncovered feeding alley.
- The feeding alley size was 360 m^2/100 cows.
- Rainwater from the barn was diverted.
- Solids were scraped uphill and stored elsewhere.
- 30% of the total daily excreta (urine and dung) represented the volume of the urine component captured by the effluent system. The remainder were stored in the deep litter of the barn.

Table 6.3. Comparison of effluent storage requirements for winter-generated effluent with and without the use of a low depth effluent application to pasture over winter

Cow numbers	Location	Rainfall (mm)	Storage requirement without winter effluent applications (m^3)	Storage with winter application* (m^3)
100	Balclutha	686	378	82
300	Balcultha	686	983	217
100	Riversdale	797	346	82
300	Riversdale	797	1010	154
100	Winton	958	410	99
300	Winton	958	1210	295
100	Woodlands	1031	427	104
300	Woodlands	1031	1243	272

* Assuming an application depth of 2 mm day^{-1}, an application area of 2 ha per 100 cows, a 0 mm soil moisture deficit for application to occur, and a 150 kg N ha^{-1} $winter^{-1}$ nitrogen limit.

This modelling exercise showed an average 76-78% reduction in required storage capacity (Riversdale 300 cows achieved an 85% reduction in storage capacity required) is achievable if the concept of applying effluent during winter is viable (Table 6.3).

The hypothesis was that it is possible to apply low depths of liquid effluent to land during winter using a sprinkler system without significantly increasing the total amount of contaminant losses from a portable pad system (restricted crop grazing plus LRLD liquid effluent application) above the amounts lost from a traditional winter crop grazing scenario. The losses of nutrients and faecal micro-organisms in pipe drainage induced by daily sprinkler irrigation of contrasting effluent application depths were compared. The measured nitrogen losses are presented in this Chapter. These are core data required to model the total N loss generated by the portable pad system. Phosphorus, suspended sediment and *E. coli* data were not core data required for modelling N loss from the barn system but are of significant interest to the dairy industry so are presented in Appendix 11.3.

6.3 Methods and Materials

6.3.1 Field site selection

The field site was located at Telford Rural Polytechnic Dairy Farm in south Otago and had originally been used for a DCD experiment conducted from April 2009 until March 2012, as described by de Klein *et al* (2014). This site was chosen as it presented the appropriate physical challenges for the application of winter-applied effluent. The site was imperfectly drained and had cold and wet winters resulting in low winter pasture growth rates. The soil was a Tokomairiro deep silt loam (Fragic Perch-gley Pallic soil, NZ Soil Classification (Hewitt 1998)). The main characteristics of this soil are that it is imperfectly drained, has moderate fertility and high water availability. Assuming pasture plant tissue nitrogen ranges from 1-5% on a dry weight basis (Whitehead 1995) then the potential uptakes of N for growth through winter periods are minimal: an average daily pasture growth rate in June of 10 kg DM ha^{-1} would result in a nitrogen requirement of only 0.1-0.5 kg N ha^{-1} for that month. Thus, winter-applied N would be vulnerable to leaching.

Table 6.4. Site climate and pasture growth rate data during the experimental period (2012

	Average daily pasture growth rates kgDM ha^{-1} 2008^{A}	**Monthly rainfall 2012^{B}**	**Lowest daily mean temp 2012^{B}**	**Highest daily mean temp 2012^{B}**	**Mean of 9 am soil temp 2012^{B}**
May	23	41 mm	3.2	11.9	5.5
June	10	64 mm	0.2	8.0	3.2
July	3	34 mm	-0.7	11.1	2.3
August	12	24 mm	4.9	10	5.1

^{A} Dalley & Geddes, 2012, ^{B} NIWA, 2015

The experimental site was cultivated and sown with a perennial ryegrass/white clover pasture mix in February 2009. Stock had been excluded from this site since its establishment in 2009. Pasture height was maintained by a ride-on mower and grass removed prior to the start of the experiment in May 2012. During the experiment pasture around the sprinkler nozzles in the higher rate treatments was trimmed using electric shears to keep the nozzles free from obstruction, however, the height of the grass was not sufficient to warrant mowing of the whole plots due to the low pasture growth rates over winter (Table 6.4).

6.3.2 Field site establishment

The establishment of the leaching experiment plots is explained in detail in de Klein *et al* (2014). Briefly, the site consisted of 20 hydrologically isolated plots that were 2 x 10 m, with a drain in the middle of each plot at 0.7 m depth. This drain was placed at the bottom of a narrow trench and backfilled with c. 40 cm of pea gravel and c. 30 cm of topsoil (Figure 6.2). Drainage pipes captured subsurface drainage water from each plot and this was collected in one of two collection pits (Figure 6.3 A) located at the base of the plots. Drainage from each plot was captured by a tipping bucket system (Figure 6.3 B) similar to that described by Monaghan *et al* (2009). Each tipping bucket had a capacity of 3 litres and the number of tips was recorded using a Campbell Scientific CR10 data logger. The one difference to the method described by Monaghan *et al* was that the stilling well that had been installed above each tipping bucket was removed and replaced with a PVC pipe system that directed the flow into the buckets. The proportion of each tip captured was increased to c. 0.5% to enable a large enough subsample to be collected for analysis.

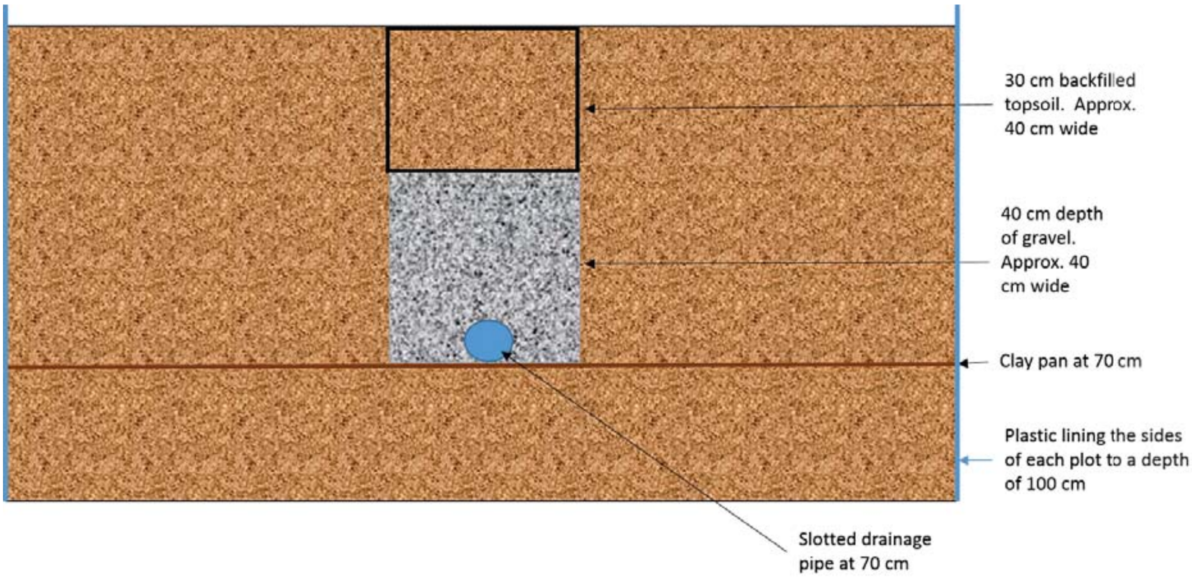


Figure 6.2. Cross-sectional diagram of the drainage plot structure at the Telford trial site. A drainage pipe is located at 70 cm depth lain on a clay pan. 40 cm of pea gravel sits above the drainage pipe with 30 cm topsoil above that. The sides of the plot were lined with plastic.

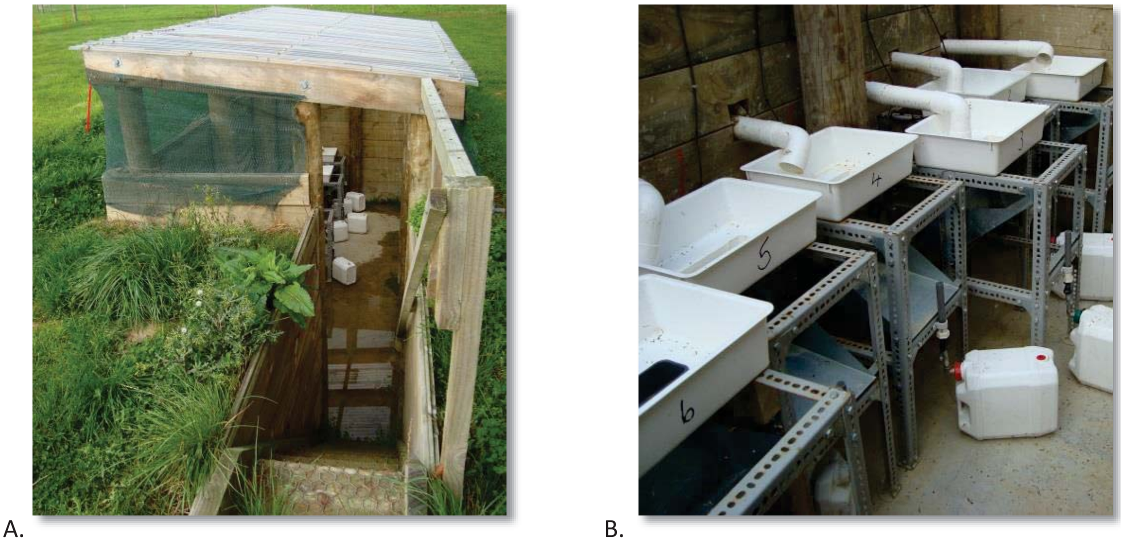


Figure 6.3. Photos of (A) the collection pit (A) and (B) tipping buckets and sample collection containers. Note that the stilling wells in the photo were removed prior to the trial commencing.

6.3.3 Installation of the low depth sprinkler system

An off-the-shelf garden irrigation system (Pope Micro Full Circle Jet Spray model Number 1010817) was purchased to simulate a sprinkler irrigation system at a small scale suitable for the size of the experiment plots. Each plot had a 10 meter pipe along the centre with seven 2 mm nozzles per plot located 1.25 m apart (Figure 6.5). As plots were 2 m wide, and the diameter of the nozzle application area was 1.25 m, a buffer area of at least 37.5 cm was created between neighbouring plots.

i. Irrigated area

Concerns regarding the possibility of effluent being blown from the destination plot into a neighbouring plot resulted in the effluent application area (irrigated area; Figure 6.4) not being the same size as the plot area. This created a 'buffer' area between the plots to help reduce the risk of effluent being blown into neighbouring plots. The 'irrigated area' was only 48% of the whole plot. Irrigation depth (mm) was calculated from irrigated volume, where:

Equation 6.1. Litres irrigated /irrigated area (A) x 7 nozzles per plot = irrigation depth (mm) per plot

$A = \pi r^2$ (where r is 0.625) = 1.23 m^2

Leachates therefore represent drainage from the area that had effluent applied plus the 'non-irrigated' areas, which received no irrigation (same as control plots). Drainage volumes and nutrient concentration from the control plots were used to determine the contribution to drainage and nutrient loss from the area of the plot receiving FDE applications (see Section 6.3.8 for calculations).

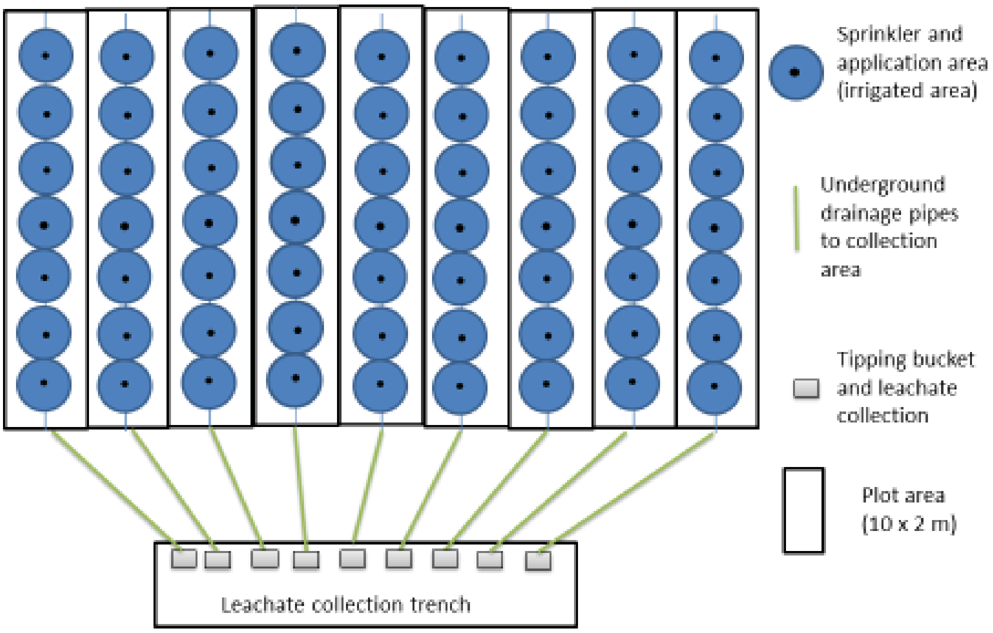


Figure 6.4. Schematic diagram of half the low depth experimental site depicting the irrigated and non-irrigated areas of each plot.

ii. Irrigation system

Effluent was pumped from the main farm storage ponds via the existing effluent system and then stored at the experimental site in three 3,000 litre plastic tanks (Figure 6.5 A). Effluent was pumped from the storage tanks via an 80 mm pipe to a board containing 6 timers (Figure 6.5 B; one for each effluent application treatment and one to collect a composite effluent sample, Figure 6.5 C). These timers were set to apply each treatment one after the other. Flow meters were located in the pipes just after the timers and these were used to check that the actual application volumes corresponded with the application events scheduled (Figure 6.5 D). Hoses from each treatment timer were connected (after the flow meters) to the three 10 mm diameter hoses leading to the individual plots for each treatment. Effluent was then applied via 2 mm diameter nozzles (Figure 6.5 E).

The system of pumping the effluent from the storage tanks to the sprinkler applicator was powered by a diesel generator housed in a shed on the site. The generator was connected to a remote start up switch that was also connected to the automatic rain-gauge.

On 16 June 2012 a composite sampler was installed to collect a sample of the FDE (post tank and pre plots) applied to the plots each day after the applications to the plots had occurred (Figure 6.5 C)

Effluent application rates were the same across all plots. Depths were controlled using timer switches for each treatment (Figure 6.5 B). There was a tap at the start of each plot to manually turn off the effluent flow into that plot if necessary.

Figure 6.5. Photos of the effluent irrigation system including the storage tanks and shed to house the generator (A), the timers used to control application depths to each plot (B), collection of a composite FDE sample (C), flow meter (D) and irrigation nozzle (E).

6.3.4 Frost control

Issues with pipes freezing in hard frosts resulted in a change in application time, from 11 am to 3 pm from 1st July 2012 until 6th August 2012. From the 4th July no irrigation occurred if the temperature of the pipes was less than 1°C. Insulation (12 mm thick) was used to encase the 10 mm diameter pipe, located down the centre of each plot, leaving gaps near the nozzles so as not to interfere with the effluent application. This was done as a protection against frost and frozen pipes after frozen pipes interrupted application timings and risked damaging the pump and generator system.

6.3.5 Treatments

There were 6 different treatments and 3 reps of each treatment. Treatments were allocated to plots using blocked randomisation (Table 6.5). Drainage data from historic usage of the plots indicated a number of high and low yielding plots; these were separated into blocks to ensure that each had a mixture of high, low and average yielding plots. The blocks were then randomly allocated a treatment.

Table 6.5. Block randomisation of the 18 experimental plots.

Trt. Code	**Block 1**	**Block 2**	**Block 3**	**Irrigation Treatment (irrigated area).**
A	8	9	11	Control (nil effluent)
B	7	18	19	2 mm per application
C	5	12	17	7 mm per application
D	2	6	16	5 mm per application
E	4	10	14	2 mm daily
F	3	13	15	12 mm per application

Four of the treatments were subject to a rainfall rule. The rule was that effluent application only occurred on days where there was less than 4 mm rainfall in the preceding 24 hours. These treatments were 2 mm, 5 mm, 7 mm and 12 mm effluent day^{-1} (irrigated area). The other two treatments were Control (nil effluent) and 2 mm effluent daily regardless of rainfall. Treatment depths were controlled by a timer knowing that the application rate of the system was 35 mm hr^{-1} or 4 minutes for every 2.33 mm depth (Table 6.6). Over the 92 day experiment period total nitrogen applications ranged from the equivalent of 150 kg N ha^{-1} in the 2 mm treatment to 753 kg N ha^{-1} in the 12 mm treatment (Table 6.6).

Table 6.6. Volumes and loads of nitrogen applied to treatments. Values represent cumulative loads per hectare applied over the 92 day season (and average load applied per application in brackets) and were derived from eight composite effluent samples taken during the season.

	Control	**2 mm daily (irrigation area)**	**2 mm (irrigation area)**	**5 mm (irrigation area)**	**7 mm (irrigation area)**	**12 mm (irrigation area)**
Volume of effluent applied/plot/application (litres)	0	20	20	40	60	100
Time taken to apply the allocated volume of effluent/application (minutes)	0	4	4	8	12	20
Actual depth (mm) of effluent/application on irrigated area (8.59 m^2 of each 20 m^2 plot)	0	2.33	2.33	4.66	6.98	11.64
Volume applied over the 92 day season in litres (mm applied to irrigated area)	0	1,740 l (203 mm)	1,480 l (172 mm)	2,960 l (345 mm)	4,440 l (517 mm)	7,400 l (862 mm)
N applied (kg/ha) *	0	176 (2.02)	150 (2.02)	301 (4.06)	452 (6.11)	753 (10.18)

* number in brackets are daily application values (kg/ha)

i. Rainfall rule

Applications occurred from 13th June 2012 until 12th September 2013 (92 days). The rainfall rule (effluent applied daily unless 4 mm rainfall had occurred in the preceding 24 hours) applied to 13 out of 92 days. There were a further 5 days when effluent was not applied to any plot due to technical faults (1 day) and frost (4 days). The daily and total amounts of effluent applied to each plot under the different treatments is shown in Table 6.6.

6.3.6 Soil sampling

Sampling for soil mineral N and soil moisture contents to a depth of 60 cm at four depth ranges (0-7.5 cm, 7.5-15 cm, 15-30 cm and 30-60 cm) was carried out on the 31st May 2012 prior to the start of the effluent applications. The last date of treatment application was 10th September 2012 and 7 days later 5 soil cores per plot were taken for analysis. Samples were taken from only the 0-7.5 cm depth as the soil was too wet to get samples from greater depths. Samples were sent to NZ Labs for: a basic soil test, cation exchange capacity (CEC), total base saturation (TBS) and exchangeable bases (EB). Final soil samples were taken at four depth ranges: 0-7.5 cm, 7.5-15 cm, 15-30 cm and 30-60 cm on 27th November 2012, 78 days after the last effluent application. However, only three plots (1, 2, & 3) were able to be sampled due to equipment failure. Soil rings were also taken for PAW calculations for use in calibrating a soil water balance.

6.3.7 Drainage and effluent sample analysis

Sample analysis was carried out on the composite drainage samples collected during the drainage period. There were 14 collection dates of drainage for the duration of the experiment and 8 composite samples of the effluent applied taken (Table 6.7).

Drainage samples were analysed for ammonium-N (NH_4-N), nitrate-N (NO_3-N) and dissolved organic nitrogen (DON). Nitrate-N and ammonium-N methods of analysis have already been outlined in Chapter 4 (Section 4.3.4). Samples were analysed for total dissolved N (TDN) using a Skalar SAN^{++} segmented flow analyser (Skalar Analytical B. V., Breda, Netherlands) (Jones & Willett 2006). DON was then a simple calculation of TDN minus ammonium-N and nitrate-N

Effluent samples were analysed by NZLabs for a number of analytes. Ammonium-N (NH_4-N) and nitrate-N + nitrite-N (NO_2-N + NO_3-N) were analysed using standard colorimetric procedures (APHA, 2005, 4500_NH3 H, 4500_NO2 B, 4100 B). Total Kjeldahl nitrogen (TKN) was analysed by Kjeldahl digest and phenol hypochlorite colorimetry (APHA 4500_orgN D). Total nitrogen (TN) was a calculation of TKN plus NO_2-N plus NO_3-N

Table 6.7. Dates that drainage and effluent samples were taken and the number of days in each sampling period for the low depth effluent application experiment

	Drainage sample taken	Days in sampling period	Effluent sample	Days in sampling period
18/6/12	X	6	X	6
25/6/12	X	7	X	7
28/6/12	X	3		
9/7/12	X	11		
16/7/12	X	7		
23/7/12	X	7	X	28
30/7/12	X	7	X	7
31/7/12	X	1		
6/8/12	X	6	X	7
13/8/12			X	7
15/8/12	X	7		
20/8/12	X	2	X	7
27/8/12	X	12		
7/9/12	X	11		
12/9/12			X	23
29/9/12	X	5		
Totals	14	92	8	92

6.3.8 Data analysis

The value presented for the concentration of nutrient in the effluent applied is a weighted average taking in to account the concentration of each composite sample taken and the number of days that sample represented.

Data for the volume of drainage from each plot were corrected for the irrigated area component of each plot using equation 6.1.

Equation 6.1 $V_W = V_T – \text{Þ}_N.V_N/\text{Þ}_W$

Calculating the concentration of each analyte in the drainage from the irrigated area of the plot was done using the total seasonal weighted average concentration (C_T) using equation 6.2.

Equation 6.2 $C_W = (V_T.C_T – \text{Þ}_N.V_N.C_N) / (V_W – \text{Þ}_W)$

Where:

V_T = the total volume of drainage measured over the 92 day experiment (measured).

V_W = volume of drainage from the irrigated area of each plot (calculated).

V_N = the volume from the Control plot in the corresponding block for each treatment block. This calculation was done on the total seasonal value for each plot (measured).

C_T = the weighted average concentration of the analyte in the plot over the 92 day experiment (measured).

C_W = the average concentration from the irrigated area of the block (calculated).

C_N = the weighted average concentration of the analyte from the Control plot in the corresponding block (measured).

$Þ_W$ = the proportion of the plot that was irrigated i.e. the irrigated area (0.4295).

$Þ_N$ =the proportion of the plot that was not irrigated (0.5705)

6.3.9 Soil water balance

A soil water balance was generated in the method described in Chapter 4 (Section 4.3.5) except there was no requirement to adjust the met station evapotranspiration value as this was a pasture with full coverage of the ground and not a crop with bare ground to take into consideration. Rainfall was measured at the site by a 10 mm tipping bucket rain-gauge linked to a Campbell Scientific CR 10 data logger. There was also a manual rain-gauge that was emptied each time the site was visited. This was used to check against the automatic rain-gauge. Potential evapotranspiration data (Penman ET) were obtained from the NIWA Balclutha meteorological weather station located c. 2 km NE of the experiment site.

6.4 Results

6.4.1 Climatic results and soil data

Monthly rainfall at the experiment site was similar to 30-year average monthly data (NIWA Meteorological Site No. 5867) for the area (Table 6.8).

Table 6.8. Monthly rainfall for June, July and August from a range of sources: data recorded at the experiment site in 2012, local NIWA met station (No. 5867) data for 2012 and, 30-year average rainfall data from the same met station for four 30-year periods.

	June	July	Aug
Experiment site 2012	64	57	32
NIWA site 2012	76	44	30
1951-1980	62	47	38
1961-1990	59	51	39
1971-2000	62	54	44
1981-2010	58	59	42

Soil temperatures slowly increased during the experiment, from an average of approximately 4°C in July to approximately 8°C by the end of August (Figure 6.6). There was a period of 4 days at the start of July when soil temperatures were less than 2°C. Pipes had been insulated prior to this period but irrigation did not occur when soil temperatures were this low due to freezing pipes.

Soil moisture contents in the control plots were near field capacity (approximately 60%) for most of the experimental period, although they dipped to 55% for a period in early September (Figure 6.7).

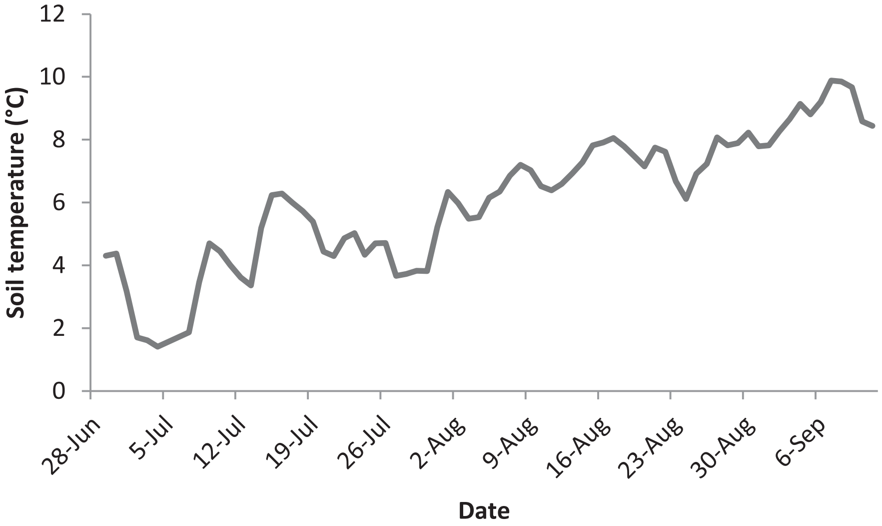


Figure 6.6. Daily average soil temperature (0-10 cm depth) for the experimental site.

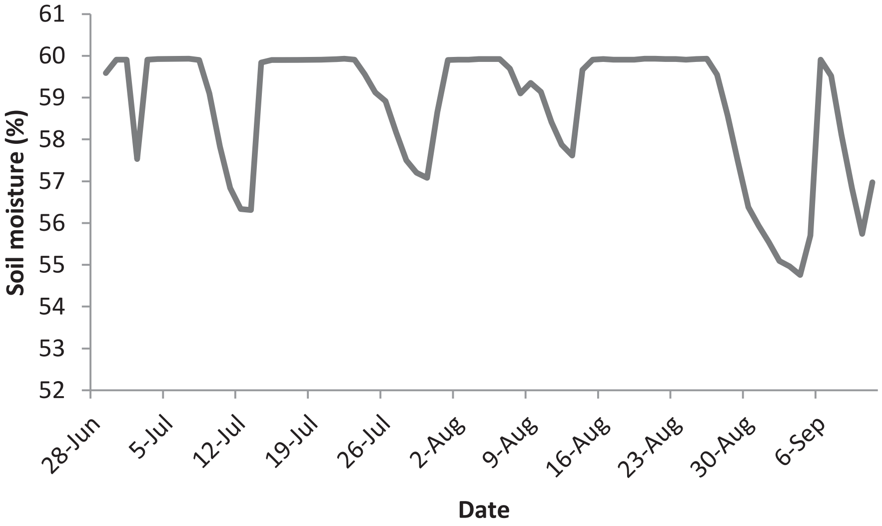


Figure 6.7. Average daily soil moisture for the experimental site.

Cumulative rainfall during the experiment was 110 mm. The resulting drainage from the Control plots (without added water from irrigation) was 39 mm (Table 6.9). The 39 mm of rain-induced drainage from the non-irrigated areas of the treatment plots was subtracted (weighted by area) from the total drainage values to give a value for effluent induced drainage from the irrigated area. The drainage depth, expressed as a percentage of effluent depth applied (effluent induced drainage), ranged from 51% in the 2 mm treatment to 12% in the 5 mm treatment.

Table 6.9. Volumes of FDE applied and drainage from the plots during the experimental period

	Control	**2 mm daily**	**2 mm**	**5 mm**	**7 mm**	**12 mm**
Rainfall (mm)	110	110	110	110	110	110
Effluent (mm)	0	80	69	138	207	350
Total liquid applied (mm)	**110**	**190**	**179**	**248**	**317**	**536**
Drainage (mm)	39	64	74	56	121	181
Percentage of applied liquid leached	35%	34%	41%	23%	38%	34%
Effluent induced drainage* (mm)	0	25	35	17	82	142
% of effluent	0	31%	51%	12%	40%	41%

* Calculated by subtracting the 39 mm rain induced drainage from the total drainage

6.4.2 Drainage compared with computed soil water balance (SWB)

Soil water balance figures for the whole plot predict cumulative drainage values for the period from 21 June until 8 September of 66 mm, 77 mm, 67 mm, 116 mm, 180 mm and 323 mm for the Control, 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments, respectively. Captured drainage ranged from 48% (5 mm) to 110% (2 mm) of the predicted drainage (Table 6.10)

Table 6.10. Comparison of measured verses SWB predicted drainage totals for effluent applications to land of a range in treatment application depths

Effluent application depth	Control 0 mm	2 mm daily	2 mm	5 mm	7 mm	12 mm
Measured drainage (mm)	39	64	74	56	121	181
SWB predicted drainage (mm)	66	77	67	116	180	323
% of predicted	59%	83%	110%	48%	67%	56%

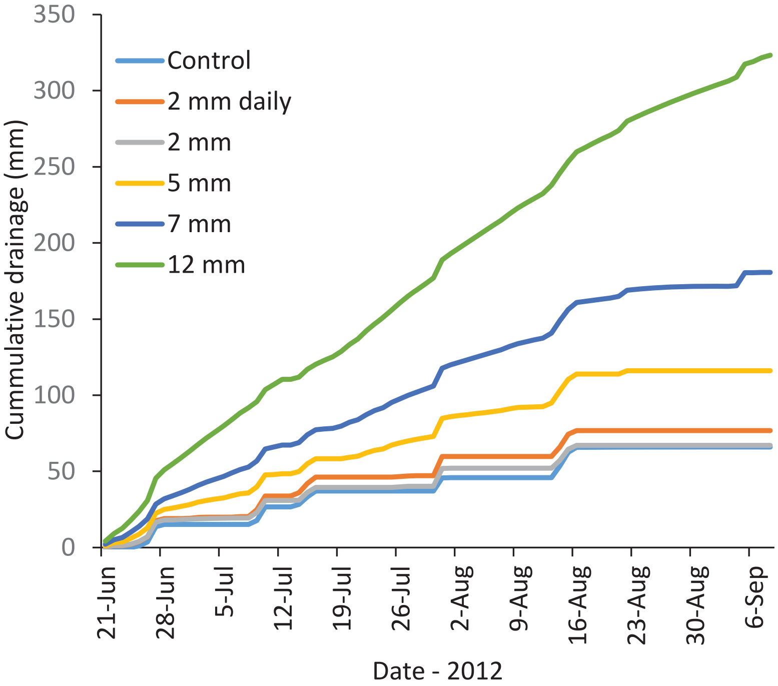


Figure 6.8. Soil water balance results from the whole plot area. Application depths were modelled as the average application over the whole plot. Thus, application depths of effluent were 1, 2, 2, 3 and 5 mm for the 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments, respectively. Modelled using corrected Met data (see Table 6.11)

The treatment average cumulative drainage volumes (and the individual plot cumulative drainage volumes) measured at the experiment site were all lower than the volumes predicted by the soil water balance (

Figure 6.9 6.9 (a) to (f)). Within each treatment there was variability between individual plots. This was most pronounced in the 2 mm daily treatment where plot 4 (Figure 6.9 b) appeared to stop flowing towards the end of July and prior to that recorded comparatively low flows.

During the period 13th to 15th July, the rainfall logger recorded 46 mm of rain over that period. When this rainfall was used in the SWB the effect of this on predicted drainage was seen in the SWB graph lines and was noted most significantly in the Control graph (Figure 6.10 a). The predicted drainage (10 mm) from this period of high rainfall is not reflected in the measured drainage from any of the plots. Possible reasons for this were that the high rainfall caused runoff from the site, or alternatively that the recorded rainfall was, in fact, an error. Upon checking the local met station data (Table 6.11) these four days of rainfall were deemed to be a possible logger error so the data from the met station was used instead. The corrected values were used in

Figure 6.9 6.9 whereas Figure 6.10 shows the resulting graphs using the uncorrected rainfall data.

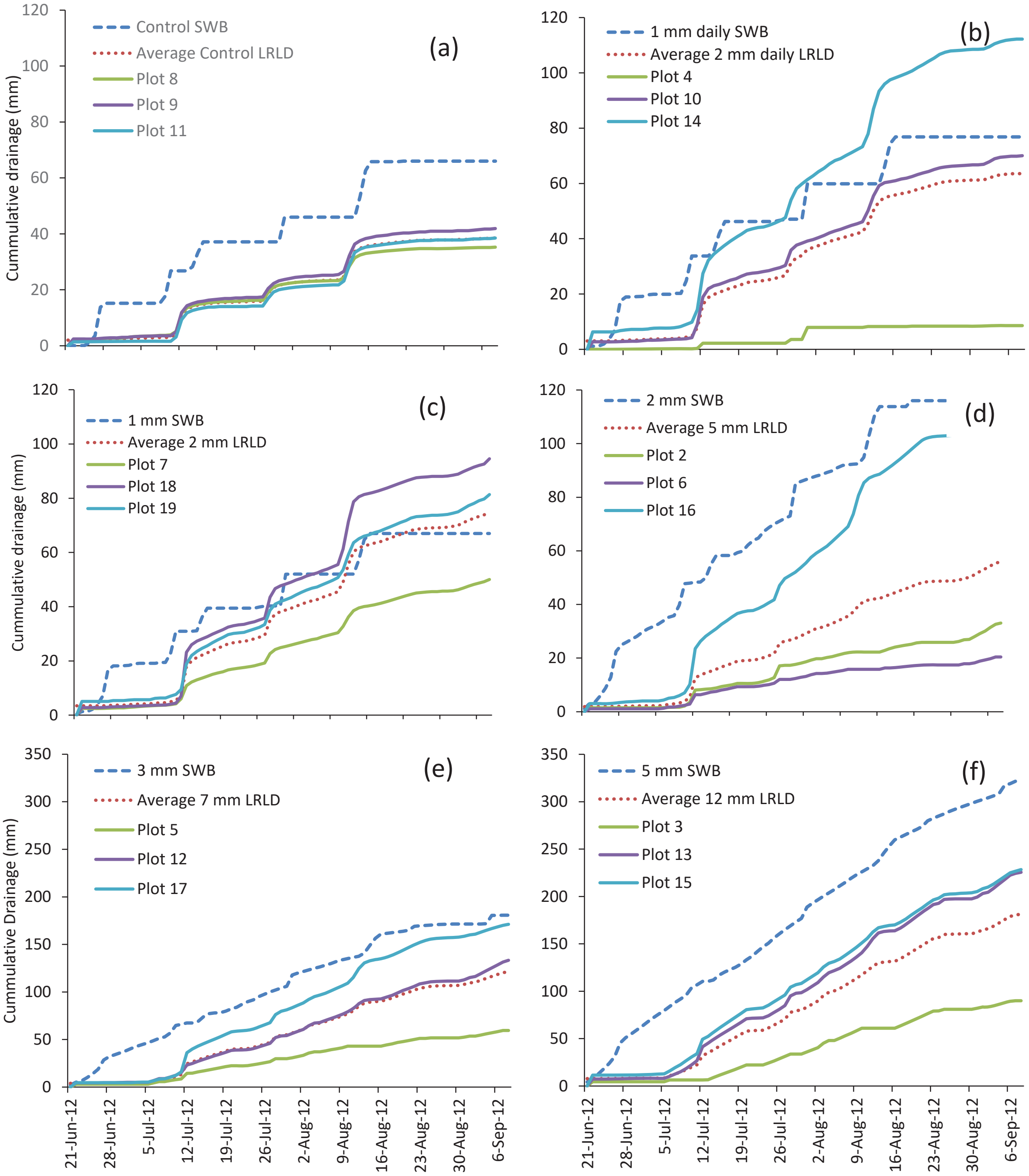


Figure 6.9. Average whole plot treatment drainage results and individual whole plot results compared with whole plot SWB modelled results for the period of 21 June 2012 until 8 September 2012. Each treatment is plotted separately: (a) Control, (b) 2 mm daily, (c) 2 mm, (d) 5 mm, (e) 7 mm, and (f) 12 mm effluent applied to the irrigated area daily unless rainfall exceeded 4 mm in the preceding 24-hours.

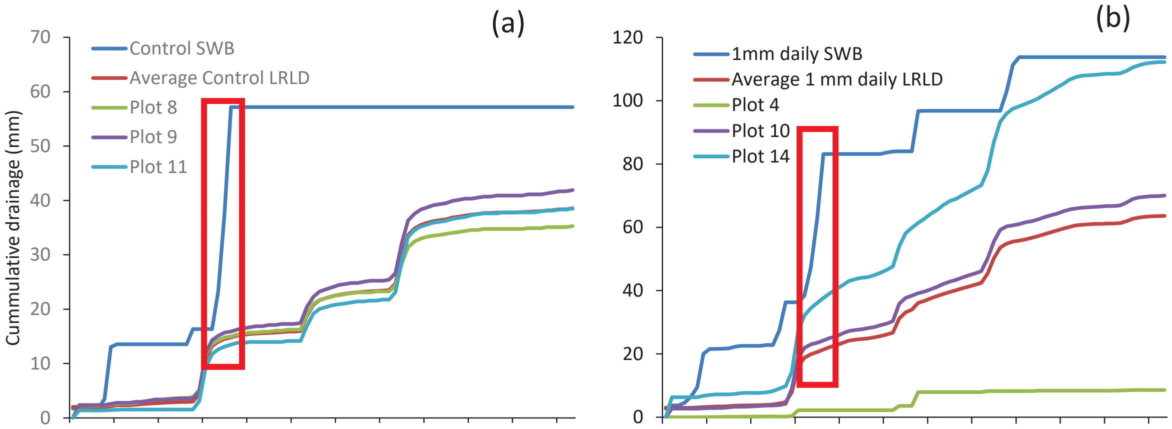


Figure 6.10. Modelled (SWB) and measured drainage for Control (a) and 1 mm daily (b) treatments using the experiment site rainfall data for the period 13-16 July 2012, the time period is indicated by the red boxes.

Table 6.11. Rainfall values recorded at the field site for the dates 13 July until 16 July and the met station data used to replace the questionable field site values.

Date	Site rainfall logger (mm/day)	Local met station rainfall (mm/day)
13 July 2012	4.6	0
14 July 2012	7.9	3.2
15 July 2102	14.5	5
16 July 2102	20.3	4.2

6.4.3 Drainage results

The application of effluent to pasture during winter resulted in increased losses of nitrogen in drainage compared to plots that did not receive effluent. However, the calculated concentrations (C_W; see data analysis Section 6.3.8) of ammonium and mineral-N in the drainage from the irrigated areas of the plots was considerably less than that of the effluent applied (22-58%; Figure 6.11 c). The lower the depth of daily application the lower the concentration of nitrogen in the drainage. The 2 mm daily and 2 mm with rainfall rule treatments resulted in considerably less nitrogen concentration in the drainage than the 5 mm, 7 mm and 12 mm treatments. There was no significant difference in the concentration of nitrogen in drainage between the 2 mm daily application (regardless of rainfall) and the application of 2 mm effluent daily (with rainfall rule). Ammonium-N concentrations in the applied effluent were high (49-64 mg/L), whereas nitrite-N and nitrate-N concentrations were low (0.04 - 1.4 mg/L). The concentrations of nitrite-N and nitrate-N in the drainage were higher than in the effluent applied. This was likely due to nitrification of the ammonium-N to nitrite-N and then to nitrate-N.

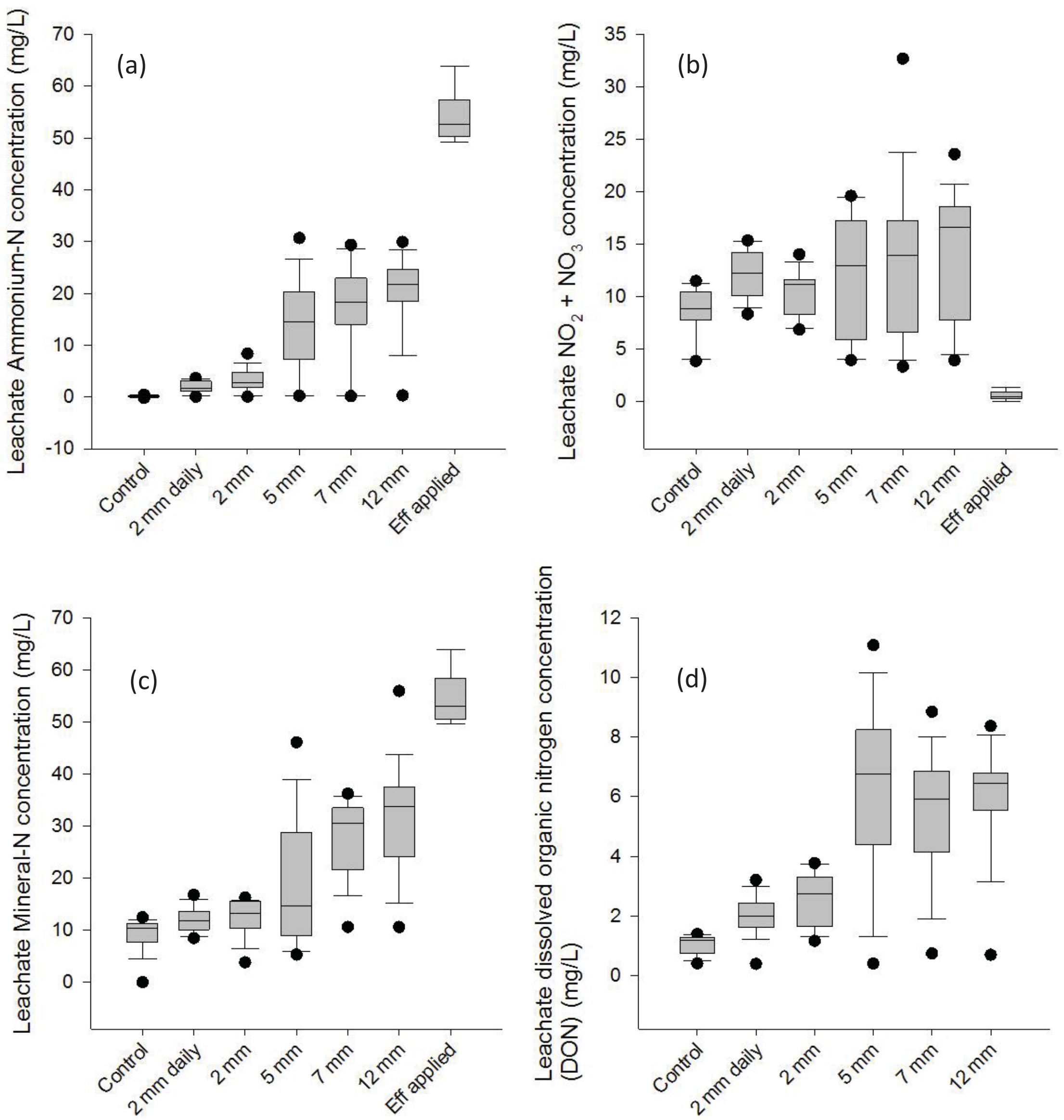


Figure 6.11. Analyte concentrations in drainage and effluent from the irrigated area of the treatment plots. Drainage concentrations were calculated based on measured values that were corrected for background drainage from untreated plot areas: (a) ammonium-N, (b) NO2 + NO3 , (c) Mineral-N (ammonium-N plus NO3 + NO2-N), (d) Dissolved organic nitrogen (DON). DON was not measured in the effluent applied.

Table 6.12. Average nitrogen concentrations of the applied effluent and drainage from the control, 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments. NO_3-N, nitrate-N; NH_4^+-N, ammonium-N, DON and dissolved organic N

	Average flow-weighted concentration (mg litre^{-1})						
Nutrient form	Applied effluent	Control	2 mm daily	2 mm	5 mm	7 mm	12 mm
NO_3-N	0.53	8.70	12.10	10.51	12.10	13.51	14.09
NH_4^+-N	49.16	0.15	1.91	3.18	14.18	17.30	20.13
DON	Not measured	1.05	2.02	2.62	6.40	5.56	6.06

Concentrations of effluent constituents in drainage increased as application depth increased (Table 6.12). Loads of effluent constituents in drainage increase as the depth and total volume of effluent applied increased. In addition, the percentage of constituent applied in effluent that was lost in drainage increased significantly in the 7 mm and 12 mm treatments compared to the 2 mm and 5 mm treatments (Table 6.13).

The 5 mm treatment appears not to fit the pattern of increased drainage and increased losses with increased application depths; whilst the concentrations were greater than the 2 mm treatment, this wasn't reflected in load losses. This was due to the low average drainage volumes of the three treatment plots. Most of the treatments have a range of losses from the individual plots with most having a high, medium and low draining plot. However, the 5 mm treatment is skewed by two very low draining plots (
Figure 6.9 d). Mineral N losses in the form of nitrate-N were found in drainage from the control plots which received no effluent (Table 6.13, Figure 6.12). Losses of 3.7 kg mineral-N ha^{-1} were measured in the control plots. Values in the treated plots ranged from 16.3 kg ha^{-1} mineral-N in the 2 mm daily treatment to 118.7 kg ha^{-1} mineral-N in the 12 mm treatment. Losses of nitrogen increased greatly in the 7 and 12 mm treatments. Below these application depths mineral N, (expressed as a percentage of the mineral N applied as effluent) were: 10, 7 and 7% for the 2 mm daily, 2 mm and 5 mm treatments, respectively. After this, losses increased significantly to 41% for the 7 mm application depth and 51% for the 12 mm application depth.

Table 6.13. Mineral-N, TP, DRP, SS and *E. coli* yields in drainage from the plots and total amounts applied for the period 18 June until 12 September 2012.

Kg/ha	Control	2 mm daily	2 mm	5 mm	7 mm	12 mm
Total losses per treatment (kg ha^{-1})						
Mineral N	3.7	16.3	23.9	23.3	60.6	118.7
Total amounts applied (kg ha$^{-1)}$						
Total N	0	176	150	301	452	753
Drainage corrected for background (Control) losses. The values in brackets are the percentage of the effluent applied yielded in corrected drainage.						
Mineral N		12.6 (10%)	20.2 (7%)	19.6 (7%)	56.9 (41%)	115 (51%)

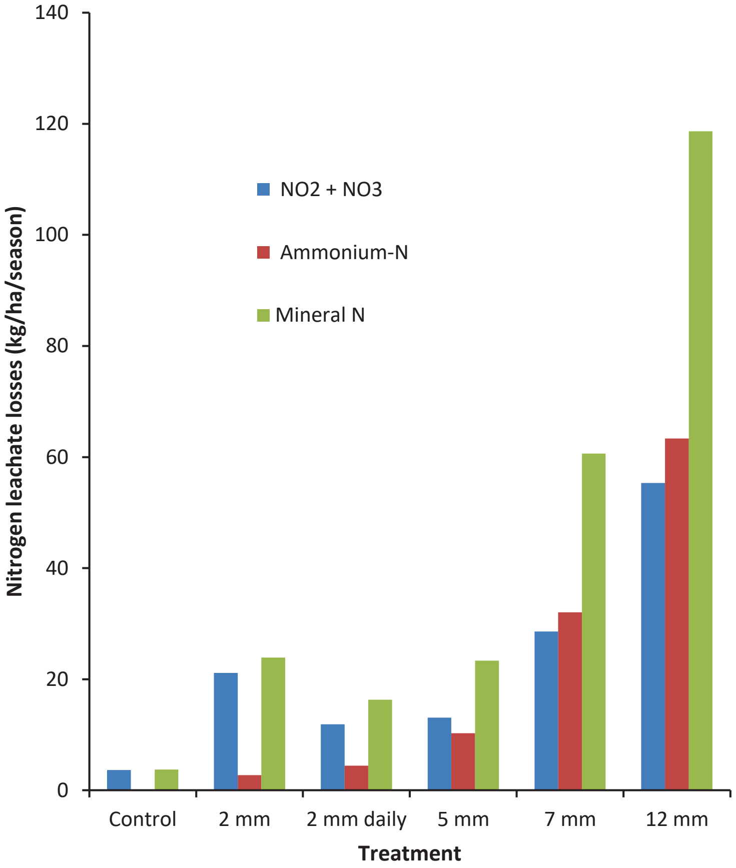


Figure 6.12. Nitrogen losses in drainage over 92 winter days in response to varying effluent application depths.

6.4.4 Cost of irrigation infrastructure required to implement the low rate, low depth concept

This section provides a rough comparison of the costs between building an effluent storage system to contain all winter-generated effluent and using a k-line system applying effluent daily. The wintering system generating effluent is assumed to be an outdoor, unroofed, wintering pad with a surface that does not absorb urine and water. The area per cow is 8.5 m^2 and the rainfall is 199 mm over the winter period. Cows contribute 15.8 litres urine and 83 g N per cow per day (Figure 5.20).

For 100 cows over a 70 day winter period, this generates 58 kg N 100 $cows^{-1}$ $winter^{-1}$. It is also assumed that a k-line system is required and the effluent is applied at a maximum load of 80 kg N ha^{-1} for the winter period. For an 80kg N ha^{-1} limit it would require 58 kg/80 kg = 73% of a hectare, or 7,300 m^2 100 $cows^{-1}$. The capital cost of a k-line system is \$2,000 ha^{-1} (Lincoln University, 2014). For pond storage to contain all winter generated effluent, 280 m^3 would be required for 100 cows. This is assuming a rainfall of 199 mm over the 70 days and 15.8 litres urine captured cow^{-1} day^{-1}. The capital cost could be around \$33,000-\$65,000 and \$4,000 annual running costs for 100 cows (Lincoln University Financial Budget Manual quotes \$105,500 capital cost and \$14,200 annual running for 300 cows; L. Bowler, DairyNZ pers comms. suggests \$90,000-\$95,000 for a larger pond but liner and earthworks are the only non-fixed costs).

Table 6.14. Figures adapted from estimates provided by Logan Bowler (DairyNZ) for the cost to build a pond of 1189 m^3. Fixed costs are marked with an asterix, a non-liner relationship between cost and pond size was assumed following L Bowler's advice

Item	Cost
Earthworks	\$10,000
Synthetic liner (\$18/m^2) (180 m^2)	\$ 3,240
Power to site plus control boards	\$20,000*
Pump and agitation	\$ 7,000
Fencing	\$ 2,000
Effluent mainline (\$15/m assumed 1000m)	\$10,000*
Drag hose plus travelling irrigator	\$10,000*
Total	\$65,250

Thus the capital cost of a low rate, low depth system could be as low as 3-6% of the capital cost of building a storage pond to capture the effluent generated from an uncovered wintering pad. There would, however, be labour costs associated with the low rate, low depth system or costs to automate it.

6.5 Discussion

The data suggest that it is possible to apply liquid effluent to land during the winter months using a low daily application depth without resulting in contaminant losses significantly higher than those found in the current winter crop grazing system. The losses of mineral N + DON in drainage of the

2 mm plots is 33% less than figures measured by Smith *et al* (20 mg L^{-1} in the current experiment compared with 30 mg L^{-1} in Smith *et al*) in drainage from a winter grazed crop in Northern Southland on stony soils (Smith *et al.* 2012). Concentrations of nitrate-N immediately post grazing and during the winter months in an experiment at Woodlands (Southland) showed drainage concentrations of 6-10 mg L^{-1} (Monaghan *et al.* 2013). These results of 11 mg L^{-1} for 2 mm day^{-1} and 12 mg L^{-1} nitrate-N in drainage for 2 mm daily were similar to those on the heavier soil at Woodlands. Thus the losses of nitrate-N from the winter low depth application of the two 2 mm treatments appear to be similar to losses from winter grazing of crop. If concentrations are similar then the application area and drainage volumes are required to determine if there is a true difference in total losses or not.

In a field experiment measuring subsurface drainage under normal farming practice, in Southland, during the lactation season (although not during winter) Monaghan *et al.* (2016) had an average drainage NO_3-N measurement of 16.8 mg L^{-1} which is below the concentration measured for all the treatments in this work. However, their NH_4^+-N figure was 0.9 mg L^{-1} and only the control plot was below this (0.15 mg L^-) with other values reaching as high as 20 mg L^{-1} in the 12 mm treatment.

It is difficult to compare the results from this experiment and those in the literature as they need to be expressed as a common metric such as kg N lost/cow wintered. The experiment conducted here used an FDE that has a very low N concentration. The 2 mm daily treatment applied 176 kg N ha^{-1} over the 92 day period. This equates to 1.93 kg N day^{-1} (175 kg/ 92 days). If a portable pad system captures 82 g N cow^{-1} day^{-1} (Figure 5.20) then this daily application of 1.93 kg N is from 2.4 cows (1.93 kg / 0.82 kg). Thus the loss of 16 kg N ha^{-1} from the 2 mm treatment and 24 kg N ha^{-1} from the 2 mm daily treatment equate to 6.7 and 10 kg N cow^{-1} 92-day-$winter^{-1}$. This would be from the land that received effluent, there would also be the crop area that the cows grazed for 6 hours per day. These calculations are carried out in full in Chapter 8.

Evidence in the literature would suggest that using a low depth combined with a low rate of application would reduce the losses further. This experiment had an application rate of 34 mm hr^{-1} which is far greater than would be ideal for an effluent application. Ideally, this winter FDE application concept would be conducted with a sprinkler system with application rates of around 4 mm hr^{-1}. Findings by McLeod *et al* (1998) support the hypothesis that low rate applications could reduce the contaminant losses further than these results show. They found that applications of effluent at a rate $\leq$ 10 mm hr^{-1} minimised drainage movement to the subsoil. They also found that pulsed applications at application rates above this did not result in the effluent being retained in the topsoil. Thus, application rate is potentially an important factor as well as application depth. In this experiment ammonium-N was high in the effluent applied and if it had been retained in the soil for a period of time it would denitrified to NO_3-N. The high NH_4^+-N values in the drainage suggest that there was some preferential flow of the effluent straight through the soil into the drainage. This could possibly have been exasperated by the high application rate.

Another factor that could possibly result in lower losses would be limiting the total rate of N application. This experiment continued to apply effluent to the plots for the duration of the experiment regardless of total applied N. In a practical situation the sprinklers would be moved once a target rate of N had been applied. The impacts of this and the use of a low application rate will be investigated further in Chapter 7.

6.6 Conclusions

The concept of applying low depths of liquid effluent to pasture during winter shows merit. Applying liquid effluent to land during winter at a low daily application depth of 2 mm can reduce the requirement for effluent storage and results in significantly less N leaching losses than if higher depths are applied. However, the system losses could potentially be lower than those presented here and further research should be conducted

Further research on adaptations to the land application system should focus on the following research objectives:

1. Determine whether land application of an effluent source with higher nutrient concentrations than FDE, one that better represents effluent captured by a wintering system, is likely to cause large N loss to water.
2. Determine whether a low rate of application of 4 mm hr^{-1}using a K-line type system leads to lower N leaching losses than the spray application that delivered 35 mm hr^{-1} that was used in this work.
3. Determine whether limiting the daily depth to 2 mm day^{-1} either in one application or two 1 mm applications results in significantly lower N leaching losses than those measured.
4. Determine whether setting a maximum N load to any one area of land will reduce N leaching losses compared with continuous applications throughout winter to the same area of land.

Further work to analyse the annual losses as a whole-system analysis would help put this work into a systems context.

6.7 Acknowledgments

This research was funded by the Pastoral 21 programme, a collaborative venture between DairyNZ, Fonterra, Dairy Companies Association of New Zealand, Beef + Lamb NZ and the Ministry of Business, Innovation and Employment. I would like to thank AgResearch technicians for their help with experiment set-up, sample collection and sample analysis. Also Neil Cox for his assistance with statistical analysis and the best way to account for the irrigated and non-irrigated plot area effect.

7. Simulation modelling of low rate and low depth winter applied effluent application

The APSIM modelling described in this chapter has been summarised and presented as a conference paper; Describing nitrogen leaching from farm dairy effluent irrigated on artificially drained soils (Cichota *et al.* 2016) published in the FLRC conference proceedings 2016. Integrated nutrient and water management for sustainable farming, Massey University, Palmerston North, New Zealand.

7.1 Abstract

When farm dairy effluent was irrigated at a low depth (LD) to the Tokomairiro soils on the Telford farm in winter, only 7% of the applied mineral nitrogen leached in the drainage (Chapter 6). An application rate of 1 mm day^{-1} was most effective. It is expected that as climate and soil properties change, the effectiveness of low depth (LD) effluent irrigation will vary. It is also expected that combining low depth with a low application rate will further reduce the losses. However, repeat studies of a low rate low depth (LRLD) effluent application system in a wide range of soils and climates is not practical. Therefore, the APSIM computer simulation model was used to (i) accurately simulate the drainage and nitrogen loss from the Telford farm LD experiment and (ii) to predict drainage and N loss outcomes in other climates and soils when low rate and low depth application is used.

APSIM was used to simulate LRLD to pasture on seven soil types and three different rainfall regimes (high 1082 mm, medium 908 mm and low 701 mm annual rainfall) over 11 years. Results showed that soil type has the greatest effect on the amount of N leached. Stony soils leach significantly more N than finer textured soils. The rainfall regime also had a significant effect on the nitrate drainage values with higher rainfall resulting in higher N leaching across all soil types. However, the impact of high rainfall was much greater on the two stony soils than the other soils modelled.

7.2 Introduction

One of the main challenges facing the development of a cost effective alternative to wintering cows on brassica crop, grazed *in situ*, (i.e. duration controlled grazing) is the management of captured effluent, particularly the cost of storing effluent. If it was possible to capture effluent and apply it to land daily during winter, the cost of storage would be greatly reduced. Chapter 6 investigated the concept of daily application of low depths of liquid effluent to pasture during the winter months. The hypothesis tested here was that different soil types and climates (specifically rainfall over winter) would impact the magnitude of N leaching losses resulting from the daily application of effluent to pasture, during winter, using a LRLD irrigation system.

The regular application of effluent to land during winter is an important component of the proposed portable pad stand-off system that is a potential low cost alternative to wintering on brassica crop. For many farmers the cost of an expensive barn or off-paddock systems with associated effluent storage is prohibitive. However, the current practice of wintering on crop results in high N leaching losses (Monaghan *et al.* 2013) making it a 'hot-spot' for N leaching. Under Environment Southland's (Environment 2016) proposed Southland Water and Land Plan there will potentially be restrictions placed on traditional wintering practices in an attempt to limit N leaching. Thus, a low-cost alternative to the current method of grazing winter crop is urgently sought. The use of a LRLD effluent application method during winter could potentially allow farmers to adopt low cost stand-off systems (such as the Portable Pad, Chapter 5) without having to build high cost effluent storage systems.

In this chapter the **A**gricultural **P**roduction **S**ystem S**IM**ulator (APSIM; Holzworth *et al.* (2014)) version 7.7 r3615 was used to model N leaching losses under LRLD. Initially, the model was calibrated using the results of the field experiment on the Tokomariro silt loam outlined in Chapter 6. The calibrated model was then used to investigate potential N losses under daily effluent applications to a range of soil types, climates, and effluent concentrations. A depth of 2 mm day^{-1} was irrigated at an application rate of 4 mm hr^{-1}.

A range of soil types and locations were selected for the modelling exercise. The soils and their properties were selected using the following criteria: (1) similar (topsoil texture, subsoil drainage) to important Southland soils used for dairying (Hunter 2015), and either (2) had previously been modelled in APSIM (Cichota *et al.* 2013a; Cichota *et al.* 2013b; Vogeler *et al.* 2010), or (3) there were field-derived data available to build the soil parameter table required by APSIM.

Initially, the field experiment site (described in Chapter 6, Section 6.3) was modelled using the special characteristics of Tokomairiro_LRLD drainage plots in addition to a soil on the same site without the artificial drainage plot characteristics (Tokomairiro silt loam). Then effluent application by LRLD to a range of different soil types and climates was simulated: Waikoikoi silt loam, Pukemutu silt loam over clay, Lismore stony silt loam and the Gore stony silt loam. The Waikoikoi and Pukemutu were two of the soils suggested by Hunter (2015). The Lismore (found in Canterbury) and the Gore soils were selected as free-draining stony soils that represent the free draining Oreti (stony silt loam) and Riversdale (stony sandy loam) soils found in Southland. Soil details are given later in Table 7.2 and Table 7.3.

The objectives of this work were:

1. To evaluate the ability of APSIM to simulate LD and LRLD. To achieve this objective, APSIM's predictions of the field situation descried in Chapter 6 were compared with the measured data.
2. To use APSIM to extrapolate the results of Chapter 6 and explore the potential leaching of N under LRLD irrigation of effluents with different N concentrations to contrasting soil types and for a range of rainfalls. The N concentration of the effluent was varied in the following manner.
    a. Use of a farm dairy effluent (FDE) with a low N concentration. Named FDE scenario.
    b. Use of an effluent that contains over 6 times more Nitrogen than the FDE scenario. Named Increased effluent concentration scenario.

    These scenarios were explored under three different rainfall regimes: low (701 mm at Telford), medium (908 mm at Winton) and high rainfall (1082 mm at Woodlands).
3. To use APSIM to investigate the potential benefits of combining LRLD effluent irrigation with a Portable pad. The use of the portable pad – LRLD combination was investigated for 6 contrasting soil types and associated climates. Named Portable pad scenario.

7.3 APSIM modelling methods

7.3.1 The APSIM model

APSIM was used to simulate the application of effluent to pasture using the low rate, low depth system. This model is a farm systems model with modules simulating: soil functions, crop and pasture growth and nutrient uptake, and the impacts of livestock production systems on soil N cycling. It enables users to assess the impacts of a range of systems and scenarios on a number of variables including N leaching (Holzworth *et al.* 2014). APSIM soil modules simulate the processes occurring in the soil profile, including: water infiltration and movement, runoff and drainage, evaporation, nitrogen transformations and cycling, and soil organic matter decomposition (Holzworth *et al.* 2014). The field experiment results obtained in the low depth experiment (Chapter 6) were used to calibrate APSIM before using the model to test the LRLD system in other climate-soil scenarios with appropriate management decisions such as applying a maximum N load to any one area of land.

APSIM consists of modules and manager scripts. Modules are set by the developers of the programme and simulate the growth, development and yields of pastures and crops and their interactions with the soil environment (Keating *et al.* 2003). Manager scripts are developed by users and contain rules for adapting the model to their particular scenarios; they must be present in all APSIM simulations. The manager scripts interact with other modules according to set timing criteria and send them commands and/or parameters by which a simulation is controlled.

7.3.1.1 Modules used to simulate the experiment

For simulating the experimental conditions in the Tokomairiro soil at Telford, an APSIM simulation was set up. The main modules used included: AgPasture for simulating plant growth, and 'SoilN', 'SurfaceOM',' SoilTemp2', and 'Swim2' to describe the soil processes. In addition, a manager script called 'Fertigation Continuous' was developed for controlling the application of effluent in the validation simulations. For the scenarios another manager script was used which controlled the grazing of 'AgPasture'. Brief explanations of the main modules used and the manager script developed, are given below. Detailed documentation can be found at www.apsim.info. 'Swim2' is explained in the drainage section 7.3.2.

i. SoilN

The 'SoilN' module contains a pool for fresh organic matter (FOM) and divides the remaining soil OM into two further pools, BIOM and HUM (Figure 7.1). 'BIOM' represents, approximately, the soil microbial biomass and microbial products and has a fast turnover rate, 'HUM' turnover is very slow representing the rest of the soil OM. This separation acknowledges that not all the soil OM is equally susceptible to mineralisation. The rate of decomposition of fresh organic matter (FOM) depends on the C:N ratio and its value depends on the source of the organic material; a constant C:N is assumed for both BIOM and HUM. The C:N ratio for BIOM is set at 8, whereas the C:N ratio for HUM is derived from the soil C:N ratio entered by the user

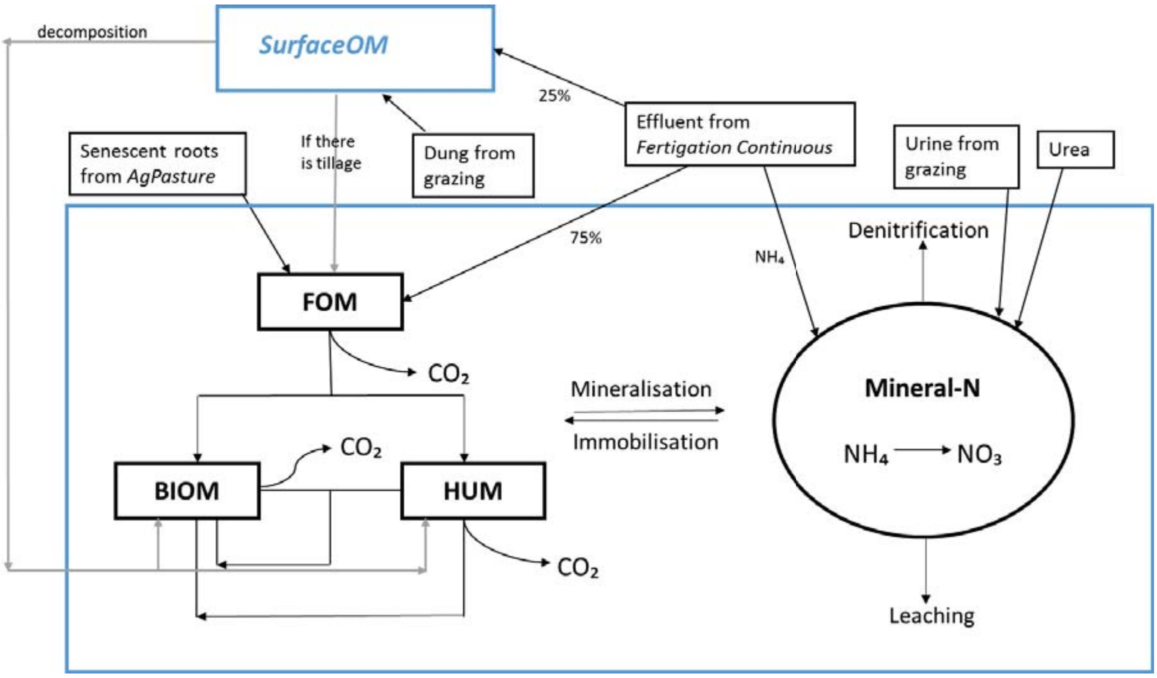


Figure 7.1. Schematic representation of the nitrogen cycling processes within the *SoilN* module (within the large blue box) and interactions with other modules (*AgPasture* and *Surface OM)* and manager scripts (*Fertigation Continuous)*. Adapted from, Probert *et al.* (1998), page 7.

ii. AgPasture

The 'AgPasture' module for APSIM was developed to simulate the growth of multi species of pasture, including water and nutrient uptake and dry matter turnover (Li *et al.* 2010). The grazing of pastures and return of N in dung and urine to the soil system is handled by a manager script. In this case the manager script 'Cut rotation' for 'AgPasture' was used. In this simulation 'AgPasture' was employed to simulate the ryegrass/white clover sward receiving the effluent applications. 'AgPasture' interacts with other modules in APSIM. Senescent roots transfer to FOM (Figure 7.1) within 'SoilN', and plant litter is returned to the soil surface through the 'SurfaceOM' module. Dung is also transferred to 'SurfaceOM' while urinary N is returned to the mineral-N pool within the 'SoilN' module. This module also interacts with the weather module (Met) and plant N uptake is a function of interactions with the soil modules ('SoilN' and 'SWIM2'). The aspects of 'AgPasture' that differ from other crop modules in APSIM are the pasture-specific parameters. The parameters can be set in the module itself or defined via manager scripts.

The pastures specific parameters are:

Module parameters:

- Pasture species
- Initial above ground dry matter (DM) weight
- Initial root DM weight
- Initial rooting depth

Manager script user-defined parameters:

- Fraction of nitrogen returned as excreta
- Fraction of returned nitrogen in urine
- Urine deposit depth (mm)
- Pasture dry matter at which grazing will occur.

iii. SurfaceOM

'SurfaceOM' contains the information about plant, dung and effluent residues on the soil surface and computes their decomposition and eventual incorporation into the soil. At initialisation the user stipulates the organic matter type (in this case it was grass) and the initial surface residue (kg ha^{-1}). The C:N ratio of the initial residue is entered as the fraction of residue standing.

iv. SoilTemp2

This module simulates variations in soil temperature, using basic daily climate data and soil moisture values. The only user-defined parameter needed to be set for soil temperature when using 'SWIM2' is the clay content (%) of each soil layer.

v. Manager script: Fertigation Continuous

To enable comparison with measured data when modelling the field experiment, and to enable a range of scenarios to be tested, a manager script was developed (named 'Fertigation Continuous') to apply effluent to soils on a daily basis (Table 7.1). The inputs for the manager script include: effluent start and stop dates; defining an 'irrigation season', the amount of irrigation to apply each time (mm), the application rate of irrigation (mm h^{-1}), concentrations of NH_4^+, NO_3^- and organic-N, C:N ratio of the effluent, and the fraction of organic N retained in the surface organic matter pool. A rainfall rule was used to stop application using the following criteria: amount of rainfall that causes the application to stop (mm), the number of days to consider summing rainfall and the number of days to wait after application is stopped. A termination rule was used to cut short the irrigation season on one individual 'paddock'. This was done by the user defining the maximum cumulative load of N to apply to any one area ('paddock') in the season (kg N ha^{-1}).

7.3.2 **Drainage in SWIM2**

There are two modules available for simulating water and solute transport in APSIM (‘SoilWat’ and ‘SWIM’). For this work ‘SWIM2’ was used. ‘SWIM’2 (Verburg *et al.* 1996) simulates soil water dynamics numerically based on the Richards’ equation (equation 7.1).

Equation 7.1 Richards’ Equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K\frac{\partial H}{\partial x}\right] + S$$

Where

K is the hydraulic conductivity (cm^3 water/cm^2 soil/h),

H is the hydraulic head (cm water),

x is the distance into the soil (cm soil),

θ is the volumetric water content (cm^3/cm^3),

t is time, and

S is source strength (cm^3 water/cm^{3}soil/h)

The basic assumption of the module is that the soil is horizontally uniform and can be split into layers down the depth of the soil. One value for water content and solute concentration in a layer represents the whole layer; there is no graduation within a layer. However, layers can be of varying thickness.

‘SWIM2’ was chosen instead of the more recent ‘SWIM3’ as ‘SWIM3’ was not sensitive to the parameters in the bottom soil layer in relation to artificial drainage and was ignoring the effect of reduced drainage between soil layers in the presence of artificial drainage or low conductivity. This is probably due to this boundary condition not being implemented in ‘SWIM’3, as it is a trimmed down version of the original ‘SWIM2’ model. ‘SWIM2’ enabled the simulation of subsurface drainage from mole-tile systems by using the steady-state Hooghoudt equation (equation 7.2) (Malone *et al.* 2007). The Hooghoudt equation computes drainage from parallel subsurface drains based on relationships between depth and spacing of drains, hydraulic conductivity of the soil and the water table position. The water table height (m) is given by the solution of Richards’ equation which identifies where and how much water there is. If it is at saturation then the layer is in the water table and thus artificial drainage can occur. The user must also know the depth of a restricting layer (this can simply be found by digging a trench), and the depth at which the drainage system is situated.

Equation 7.2 Hooghoudt Equation

$$S_d = 4.0 * \mathrm{L}K_{sat} * m * (2.0d_e + m)/L^2$$

Where

S_d is drainage flux (mm hr^{-1})

LK_{sat} is lateral saturated hydraulic conductivity (mm h^{-1}) (model input)

m is the water table height above the drain (mm)

d_e is equivalent depth from the drain to the bottom of the restricting layer (mm)

L is the distance between the drains (mm) (model input).

The basic relationship between these two equations is that Richards equation defines (and calculates) where the water is and does this for the whole soil at once. The Hooghoudt equation checks where the water table is each day; it then calculates the potential drainage flux (S_d). The S_d value then feeds in to the S value in Richards equation, along with other values such as plant uptake, for example, (although S_d relates to the drain layer only, whereas plant uptake is distributed to all layers with plant roots). The Richards' equation is then solved for the whole soil and new values of water content are computed. The value of S_d may have to be adjusted if there isn't enough water (or there is more than before) and these calculations happen in parallel several times during the day until a balance is found.

APSIM partitions water into Evapotranspiration, surface runoff, drainage through artificial drains (if present; called 'subsurface drain' by APSIM), downward drainage not collected by the drains (called 'drain' in APSIM), and total drainage (the sum of 'subsurface drain' and 'drain'). Figure 7.2 illustrates the components of water and solute balances addressed by 'SWIM2' for a soil without subsurface drainage (Verburg *et al.* 1996). Each of the drainage types can cause N leaching, which can be split further into the various forms: NO_3-N, NH_4^+-N, and urea-N in the drainage.

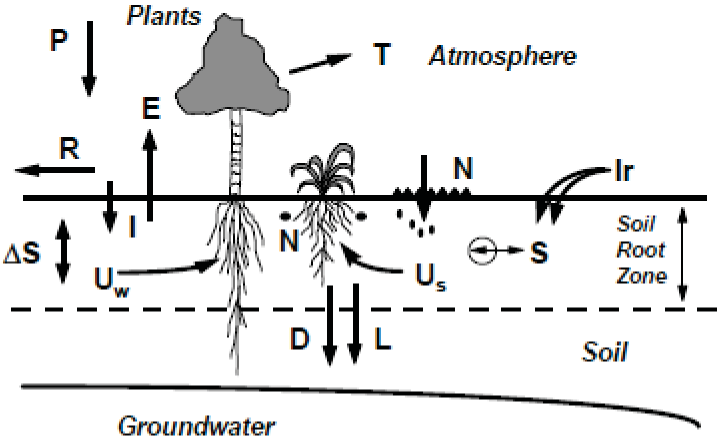


Figure 7.2. Source Verburg *et al.* (1996) page 3. Components of the soil water and solute balances addressed by SWIM2; P = precipitation, R = runoff, I = infiltration, U_w = water uptake, U_S = solute uptake, T = transpiration, E = evaporation, D = drainage, L = solute leaching, Ir = irrigation/fertigation, N = nutrients/fertiliser, ΔS = storage, S = solute source/sink

7.3.3 *Validation file* - modelling the field experiment

A base validation file was set up to model the field experimental results from Chapter 6.

Values used for the base low depth model were:

- Soil type: Tokomairiro silt loam (Tokomairiro_LRLD in Table 7.2)
- Rainfall and soil moisture values for the base file were collected on site (Section 6.4.1). For the model this data was complemented with weather data from the nearby Telford weather station (NIWA 2015b).
- Year: 2012
- Daily effluent application depths (6 treatments): (1) 0 mm (control), (2) 1 mm daily, (3) 1 mm, (4) 2 mm, (5) 3 mm, (6) 5 mm. The treatments (3 to 6) with the 1, 2, 3 and 5 mm application depths were subjected to the rainfall rule i.e. that irrigation only occurred if there had been less than 4 mm rainfall in the preceding 24 hours.
- Effluent application rate: 34 mm hr^{-1}
- Effluent N concentration: 54 mg NH_4^+ L^{-1}, 0.39 mg NO_3^- L^{-1}, 40 mg organic-N L^{-1}
- Applications occurred from the 13th June until the 12th September 2012
- Pasture height at 13 June was 1200 kg DM ha^{-1} and no harvests occurred during the simulation period
- There was no threshold for maximum cumulative N load.

The drainage system in the Validation file was set up to mimic the Telford field experiment plots (Figure 6.2). This consisted of a drainage pipe at 70 cm overlain by 40 cm of pea gravel and then 30 cm of backfilled topsoil. The soil was parameterised following procedures described by Cichota *et al.* (2013a). The soils hydraulic properties were obtained from unpublished data collected during the previous experiment conducted on the site (De Klein & Letica 2009), supplemented with data from the New Zealand Soils Database (Landcare_Research 2016a).

7.3.4 **Modelling LRLD irrigation of effluents**

The scenarios modelled here were for dairy cows wintered in an off-paddock system where effluent was captured and returned to land during winter via a LRLD irrigation system. Therefore, there was minimal requirement for storage of effluent because it was mostly returned to land as it was produced. Nutrient concentrations of effluent captured will vary depending on the off-paddock system used, thus a range of concentrations were simulated (Table 7.4). The areas of land required for the LRLD system to operate was an important output of the APSIM model.

i. Criteria for simulation scenarios

The simulations were designed to model the application of liquid effluent to land during the winter months using a LRLD system. The following rules were used when pastures were grazed: (1) once the sward biomass reached 2000 kg DM ha^{-1} it was grazed to a residual biomass of 1500 kg DM ha^{-1}, and (2) of the N in the pasture, 75% was returned as dung and urine (Figure 7.1). Dung DM was defined as a function of pasture digestibility (varying between 30-40%). The simulations started on 1st June of each year with a pasture biomass of 1200 kg DM ha^{-1} and there was minimal pasture growth over the winter period. Effluent irrigation applications began on 1st June and continued until 10th August with no pasture harvests during this period. Drainage was modelled until December 31st for each simulation to capture any lag effect of the effluent irrigation.

An effluent irrigation rule was used to limit the application of effluent to any area to a cumulative rate of 80 kg N ha^{-1}. This value was chosen as it allowed a reasonable amount of effluent to be applied to land in winter but left scope to add fertiliser N at other times of the year without pushing the farm over a rate of 200 kg N ha yr^{-1}. This varied slightly as the model completed the daily application event even if this pushed it over the 80 kg ha^{-1} limit. Thus, if the cumulative application was 79 kg ha^{-1} prior to irrigation and each daily application applied 5 kg N ha^{-1}, then the total cumulative N load to that area would be 84 kg N ha^{-1}. To limit the load of N per hectare, while still enabling irrigation to occur for the duration of the winter, a number of paddocks were used. Once a paddock's cumulative N load exceeded the 80 kg N ha^{-1} threshold, irrigation ceased on that paddock and began on the next, moving on to a third paddock once the N applied exceeded 80 kg N ha^{-1} on that paddock, etc. In this fashion movements of the effluent irrigator around the farm were simulated.

Initial modelling runs comparing N losses with and without the rainfall rule invoked resulted in very little difference to the total N leached. Thus the results presented are those without the rainfall rule as it was deemed that LRLD system would be easier to manage if farmers did not have to take the volume of rainfall into consideration and if the only constraint was maximum N load. Effluent applications were 2 mm depth day^{-1}, applied at a rate of 4 mm hr^{-1}. Applications occurred daily regardless of rainfall. No additional fertiliser was added in the simulations and all simulations were run on a flat landscape.

ii. Input data for scenario testing

Climate data from three lower South Island locations were used to represent a range of rainfall patterns (Table 7.1). Long-term average data were used and sourced from NIWA's Virtual Climate Stations (VCS; NIWA, 2016, Tait *et al*, 2012). Total annual rainfalls used for each location were: Telford 701 mm y^{-1}, Winton 908 mm y^{-1}, and Woodlands 1082 mm y^{-1}. The monthly variations in rainfall are shown in Figure 7.3. The annual average daily temperatures did not differ much between locations and were: 10.2°C at Telford, 10.2°C at Winton and 10.1°C at Woodlands.

Table 7.1. Climate data from three lower South Island locations of differing annual rainfall patterns. Sites were selected to represent a low. Medium and high rainfall region within Southland. Annual rainfall, site co-ordinates and average daily temperature are given.

Rainfall region	Location	Co-ordinates	Annual rainfall (mm yr$^{-1)}$	Average daily air temperature (°C)
Low rain	Telford *	Latitude 46.275°S, longitude 169.725°E	701	10.2
Ave rain	Winton	Latitude 46.125°S, longitude 168.325°E	908	10.2
High rain	Woodlands	Latitude 46.375°S, longitude 168.575°E	1082	10.1

* site of LRLD trial; Ch 6

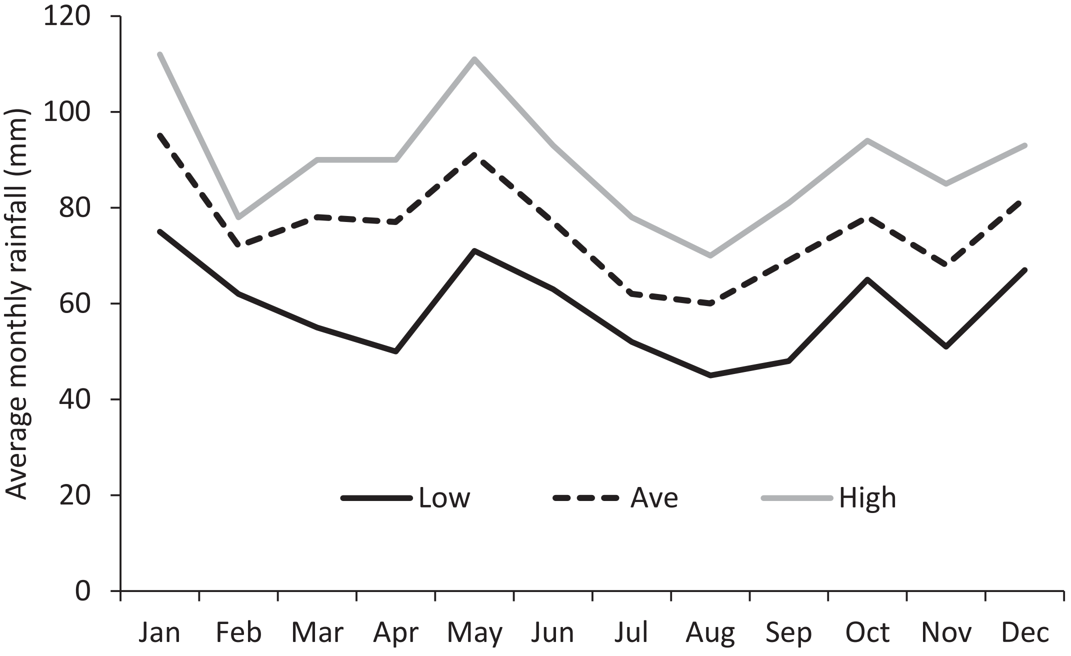


Figure 7.3. Monthly long-term average rainfall data for the three South Island locations used in the APSIM simulation of LRLD irrigation of effluent.

The soils used for the simulation were chosen to represent a range of soil types used for wintering dairy cows on brassica crops in Southland (pers. Comm. Hunter, M, 2015) and also the Tokomairiro (Mottled Fragic Pallic; Hewitt (1998) p 94) from the field experiment site at Telford. These Southland soils were:

1. Waikoikoi (Fragic Perch-gley Pallic; Hewitt (1998) p 92),
2. Pukemutu (Argillic-fragic Perch-gley Pallic; Hewitt (1998) p 92), and
3. Gore/Balmoral (Acidic Orthic Brown; Hewitt (1998 p 61).
4. A Canterbury Lismore soil (Pallic firm brown; Hewitt (1998) p 60) was also modelled to represent a variation of a stony soil as adequate data for a Southland stony soil of similar properties could not be found.

The physical characteristics of these soils, as described on the Landcare Research Smap soil datasheets, are outlined in Table 7.2. The Tokomairiro is an imperfectly drained silty loam prone to water logging. This soil type is artificially drained with mole and tile drainage. To simulate common farming practice, mole drains were included in the simulation model at a depth of 45 cm and a spacing of 2 meters. A second Tokomairairo soil profile was simulated with a pipe drain at 70 cm with 40 cm pea gravel and 30 cm topsoil above. This simulated the soil profile in the drainage plots used for the

LD effluent irrigation experiment described in Chapter 6, Section 6.3.2, Figure 6.2. Two variations of the Waikoikoi soil were modelled, with and without mole and tile drains as described above (45 cm depth and 2 m spacing). The Waikoikoi is a moderately deep silty loam that is naturally poorly drained. It too has a high water logging vulnerability. The Pukemutu soil is a deep silty loam that is poorly drained and has high water logging vulnerability. This soil was modelled with mole and tile drains at a depth of 45 cm and a 2 m spacing. Both the Gore and Lismore soils are shallow, silty loam, stony soils that are well drained with a very low risk of water logging. The Gore is stonier than the Lismore, with 43% stones in the top 30 cm plus 77% in the 30-50 cm zone, compared to 17% in the top 10 cm, 26% in the 10-30 cm and 54 % in the 30-50 cm depth in the Lismore.

The farm dairy effluent (FDE) risk category (Houlbrooke & Monaghan 2010) for the Tokomairiro, Waikoikoi and Pukemutu is B for flat land (if the slope is > 7° then it becomes risk category C), which is 'high risk' and can only be irrigated with effluent when a soil water deficit (SWD) exists. The application depth of effluent must be less than the SWD.

The Gore and Lismore soils are FDE risk category D which is 'low risk'. Application of effluent must be less than 50% of plant available water (PAW) (which is 66 mm PAW in the Gore and 134 mm PAW in the Lismore).

The soils used for the simulation and basic properties by soil horizon are outlined in Table 7.3.

iii. Effluent applications and factors

To generate an effluent application event three factors had to be selected within APSIM. These were: the N concentration of the effluent, the depth of application, and the irrigation interval (i.e. daily, every 72 hours). There was one other factor that controlled whether or not the application occurred, this was the limit on the cumulative N applied to any area i.e. 80 kg N ha^{-1}. Once this limit was reached irrigation stopped on this area (after that days scheduled application) and began on another paddock. The rainfall rule was not imposed as the use of the rule made little difference to the total N leaching and it was deemed an additional complication for the farmer with limited effect. In addition, it was assumed that the system would have sufficient pond storage capacity to buffer variation in the daily effluent volumes generated.

The different factors able to be changed and the values simulated are shown in Table 7.4. The total number of scenario combinations was 14,784.

Table 7.2. Physical characteristics of the 6 soils (7 scenarios including 2 versions of Waikoikoi soil; with and without drains) taken from Smap datasheets prepared by Landcare Research www://smap.landcareresearch.co.nz/home. FDE, farm dairy effluent

	Soil physical characteristics from Smap datasheets
Tokomairiro_LRLD	Imperfectly drained – artificial drainage at 70 cm Silty loam High water logging vulnerability Medium N leaching vulnerability FDE risk category B – high risk impeded drainage or low infiltration rate
Tokomairiro	Moderately deep (40 – 60 cm) Imperfectly drained – artificial drainage at 45 cm Silty loam High water logging vulnerability Medium N leaching vulnerability FDE risk category B – high risk impeded drainage or low infiltration rate
Waikoikoi	Moderately deep (50 – 70 cm) Poorly drained Silty loam High water logging vulnerability Medium N leaching vulnerability FDE risk category B – high risk impeded drainage or low infiltration rate
Waikoikoi Drains	Moderately deep (50 – 70 cm) Poorly drained - artificial drainage at 45 cm Silty loam High water logging vulnerability Medium N leaching vulnerability FDE risk category B – high risk impeded drainage or low infiltration rate
Pukemutu	Deep soil depth (> 1 m) Poorly drained Silty loam over clay High water logging vulnerability Medium N leaching vulnerability FDE risk category B – high risk impeded drainage or low infiltration rate
Lismore	Shallow (15 – 30 cm) Well drained Silty loam, stony Very low water logging vulnerability Very high N leaching vulnerability FDE risk category D – low risk
Gore (Balmoral)	Shallow (20 – 30 cm) Well drained Silty loam, extremely gravelly Very low water logging vulnerability Very high N leaching vulnerability FDE risk category D – low risk

Table 7.3. Attributes of the soils used for simulations of effluent irrigation. Hydraulic properties for the Tokomairiro_LRLD soils were taken from field measurements conducted on-site (see text above). Values for the other soils were based on data from the New Zealand national soils database (NZ NSD), complemented with pedotransfer functions (PTFs) (Cichota *et al.* 2013b; Vogeler *et al.* 2011) . K_{SAT}, saturated hydraulic conductivity; PAW, plant available water.

Soil type	Depth (cm)	Texture			Bulk density (kg/m^3)	Carbon (%)	CEC (cmol(+) /kg)	K_{SAT} (mm/h)	PAW (mm)
		Sand (%)	Clay (%)	Stones (%)					
Tokomairiro_LRLD	0-10	15	25	0	1056	4.0	16.90	638	18.3
Root zone PAW	10-30	15	25	0	1188	2.0	10.70	634	39.7
	30-45	10	30	25	1313	0.2	5.75	1854	19.8
	45-60	95	1	70	1300	0.1	2.00	4156	3.4
	60-150	15	35	0	1407	0.1	10.40	0	131.2
Tokomairiro	0-10	35	25	0	1096	4.0	16.90	109	18.2
Root zone PAW	10-20	35	25	0	1159	2.2	10.70	41	19.5
	20-32.5	30	30	0	1244	0.8	9.50	13	27.6
	32.5-50	25	30	0	1309	0.5	9.80	2	43.3
	50-65	25	35	0	1385	0.2	10.40	1	27.9
	65-150	20	35	0	1407	0.1	11.00	0	115.7
Waikoikoi	0-15	6	23	0	1200	4.1	15.70	2	44.1
&	15-25	6	16	0	1220	2.6	12.50	1	36.5
Waikoikoi_Drains	25-48	6	21	0	1250	1.6	9.80	1	66.9
Root zone PAW	48-76	5	23	0	1250	0.3	7.10	0	79.5
	76-120	7	10	20	1260	0.1	8.60	0	100.9
	120-150	10	17	50	1300	0.2	9.50	0	39.6
Pukemutu	0-10	4	23	0	1097	3.47	14.20	7	26.6
Root zone PAW	10-20	5	19	0	1208	2.16	11.15	5	28.1
	20-35	4	26	0	1316	1.15	8.80	1	37.9
	35-50	4	25	0	1443	0.55	9.80	0	33.5
	50-80	5	26	0	1520	0.3	11.05	0	59.8
	80-150	5	26	0	1502	0.3	11.05	0	144.6
Gore	0-30	25	21	42	1110	4.28	14.70	152	36.2
Root zone PAW	30-50	63	11	77	1120	1.60	7.40	559	8.1
	50-90	89	1	72	1370	0.42	2.50	1498	12.6
	90-150	94	1	79	1400	0.26	1.50	2104	8.8
Lismore	0-10	27	28	17	944	3.58	15.38	603	18.2
Root zone PAW	10-30	25	27	26	1186	2.34	12.26	181	32.4
	30-50	33	25	54	1100	1.11	11.00	115	21.8
	50-70	67	13	64	1069	0.92	7.18	357	15.6
	80-120	76	8	71	1083	0.76	5.88	487	22.6
	120-150	82	6	74	1096	0.75	5.74	508	13.2

Table 7.4. List of factors used to generate base and simulation runs, using APSIM, for low rate, low depth application of effluent to land (LRLD). Underlined figures are the factors used for extrapolation of the base simulation to the wider range of soils and climates.

Factor	Variation (number) and description
Soil type	(7) see **Table 7.2** for description
Climate location, relative rainfall	(3) Telford, Low (701 mm); Winton, Ave (908 mm); Woodlands, High (1082 mm)
Year	(11) 2000-2010
Effluent application depth	(2) 2 mm, 1 mm
Effluent application rate	(4) 4 mm h^{-1}, 11 mm h^{-1}, 23 mm h^{-1}, 34 mm h^{-1},
Ratio of N concentrations	(4) 'Base' – 54 mg L^{-1} NH_4^+, 0.39 mg L^{-1} NO_3^-, 40 mg L^{-1} organic-N 'Low' 100 mg L^{-1} NH_4^+, 0.42 mg L^{-1} NO_3^-, 40 mg L^{-1} organic-N 'Med' 200 mg L^{-1} NH_4^+, 0.60 mg L^{-1} NO_3^-, 400 mg L^{-1} organic-N 'High' 301 mg L^{-1} NH_4^+,1.1 mg L^{-1} NO_3^-, 848 mg L^{-1} organic-N.
Rainfall rule	(2) On (no irrigation if > 4mm rainfall in preceding 24 hours) or off

iv. FDE scenario

For the purposes of generating simulations that reflect the use of LRLD systems, the parameter options outlined above were used. The first simulation was termed the FDE Scenario. The input parameters from the validation file were altered, using the options outlined in Table 7.4, to simulate a farming scenario assuming that a k-line system was used to apply effluent to land over winter and applications on any one area could not exceed approximately 80 kg N ha^{-1} in total. The following criteria were used to set the model parameters and scenarios were run for the seven soil types and three rainfall regions outlined in section 7.3.4 (Table 7.2 and Table 7.3).

- Effluent application occurred from 1st June until 10th August. Effluent remaining in the pond after this point was stored.
- Effluent applications did not exceed a total cumulative load of 80 kg N ha^{-1}. If a treatment reached this limit within the application period then effluent was applied to another area thus simulating moving the irrigator/k-line to another part of the farm.
- Applications were 2 mm depth applied at 4 mm hr^{-1} representing a standard k-line irrigator.
- Effluent was applied daily. The effluent applications were not constrained by the rainfall rule.
- Effluent applied was 'base' effluent concentration: 54 mg L^{-1} NH_4^+-N, 0.39 mg L^{-1} NO_3-N, 40 mg L^{-1} organic N (Table 7.4).

v. Increased effluent concentration scenario

The scenario of increased effluent concentration used the same input parameter criteria as the FDE scenario, outlined above, with one difference; the effluent N concentration was over 6 times greater than the FDE scenario. This scenario used the 'Med' effluent concentration in Table 7.4; 200 mg L^{-1} NH_4^+, 0.60 mg L^{-1} NO_3^-, 400 mg L^{-1} organic-N.

7.3.5 **Portable Pad Scenario methods**

The results of the Validation file were based on an effluent containing 54 mg L^{-1} NH_4-N, 0.39 mg L^{-1} NO_3-N and 40 mg L^{-1} organic N totalling 94 mg N L^{-1} effluent. This is representative of an FDE that is heavily diluted by wash water or rainfall. The second scenario (Increased effluent concentration) increased the N concentration of effluent to six times that of the FDE, although this too was relatively dilute compared to barn effluents and slurries.

This simulation of the Portable pad scenario uses the concentration of effluent that would be representative of the effluent produced if the portable pad system (Chapter 5) was to be employed in any one of three different climate locations. Taking the values reported in Chapter 5 of dairy cow urination volumes and N concentrations during the 18 hours they were on the portable pad, then there is potentially 82 g N cow^{-1} day^{-1} from urine, and 15.8 L day^{-1} cow^{-1} urine, captured on the pad (Figure 5.20). It is possible to estimate the concentration of liquid effluent captured on a portable pad using the average rainfall of the region and the pad area per cow. Assuming a pad area of 8.5 m^2 cow^{-1} capturing rainfall and an average daily rainfall from 1 June until 10 August of 1.9 mm, 2.3 mm and 2.8 mm day^{-1}, for the low, medium and high rainfall regions, respectively. The average volumes of effluent captured per cow per day can be calculated using equation 7.3, these were 32, 35 and 40 L day^{-1} for the low, medium and high rainfall regions, respectively.

Equation 7.3:

[Average daily rainfall (mm)/1000 (mm/m) x pad area per cow (m^2)] x 1000 (L/m^2) + 15.8 L urine cow^{-1} day^{-1}

= average L effluent cow^{-1} day^{-1}

Low rain: [1.9 x 8.5] + 15.8 = 32 L effluent day per cow

Medium rain: [2.3 x 8.5] + 15.8 = 35 L effluent day per cow

High rain: [2.8 x 8.5] + 15.8= 40 L effluent day per cow

The average effluent concentration can then be calculated using equation 7.4.

Equation 7.4:

Daily effluent conc (mg N L^{-1}) = daily urinary N captured (mg) / ave daily volume of liquid (L)

Where:

Daily urinary N captured = No. cows x 82 g N = no. cows x 82,000 mg

Average effluent concentration in the different rainfall regions would be:

Low rain:	2567 mg N L^{-1}
Med rain:	2320 mg N L^{-1}
High rain:	2071 mg N L^{-1}

The N fractions in the 'High effluent' concentration effluent from the original scenarios (Table 7.4) were used to partition the overall N concentration values given by equation 7.4 into the three fractions so that the concentrations of effluents from the pads were:

Low rain	680 mg NH_4^+-N L^{-1}, 2 mg NO_3^-N L^{-1}, 1916 mg organic-N L^{-1}
Med rain	608 mg NH_4^+-N L^{-1}, 2 mg NO_3^-N L^{-1}, 1713 mg organic-N L^{-1}
High rain	545 mg NH_4^+-N L^{-1}, 2 mg NO_3^-N L^{-1}, 1535 mg organic-N L^{-1}

By way of an example, the land area required to apply the effluent captured by 100 cows in the low rainfall region was calculated as follows:

Daily application volume for an application depth of 2 mm = 2 L/m^2

Average daily volume generated for 100 cows = 3195 L applied at 2 L/m^2 = 1597.5 m^2

So each daily area is 0.16 ha and 24 irrigator shifts to a new area were required to keep the N load under the 80 kg N ha^{-1} limit; thus the total area required was 3.8 ha for the low rainfall region.

7.4 APSIM modelling results

7.4.1 Drainage volume results

The APSIM simulated drainage depths compared well with the field results but over predicted drainage at the higher irrigation depths (Figure 7.4). The modelled values explained 93% of the measured drainage depths.

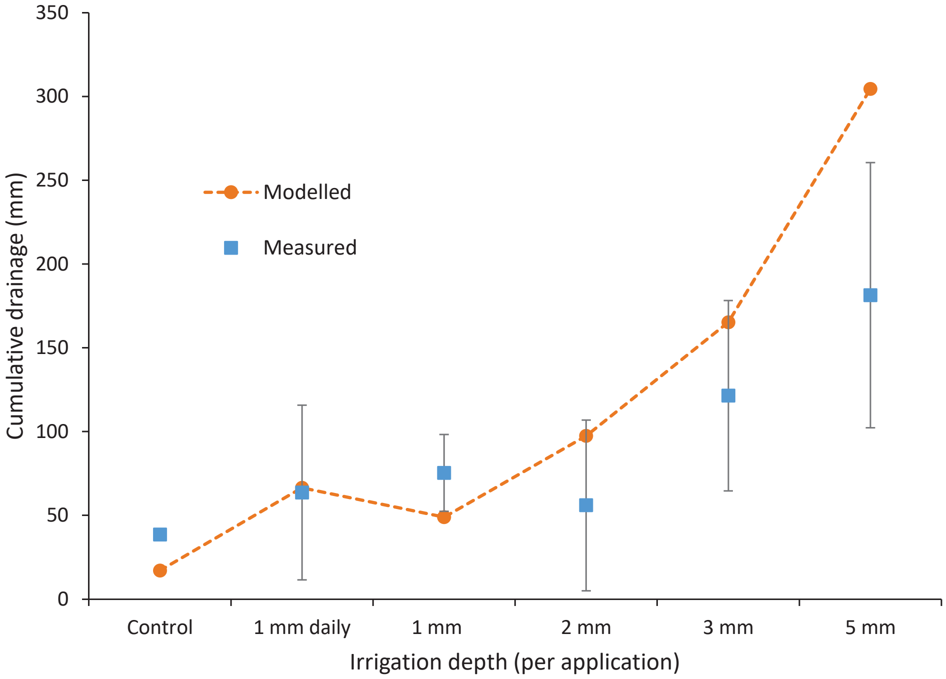


Figure 7.4. Measured and modelled cumulative drainage from the artificial drains of the LRLD experiment site for the different treatment application depths. Error bars represent one standard deviation. (Unadjusted R^2 = 0.93 for model's explanation of measured values).

7.4.2 Simulation pipe drainage discharge concentrations

i. Ammonium-N results

For both the field measurements and APSIM simulations, the concentrations of ammonium-N in the drainage increased with increasing application depth. However, the trend over time predicted by APSIM for the higher application depths, was not seen in the measured data (e and f in Figure 7.5). The model was also unable to predict the high ammonium-N concentrations (almost as high as nitrate-N) measured in drainage from the outset of the irrigation period, which must result from preferential flow from the surface soil to drains. APSIM-SWIM does not have the ability to model preferential flow, and because it was suspected that this soil exhibited preferential flow a “work around” was developed in which the soil ammonium adsorption parameter in the model was decreased so as to generate predicted ammonium-N in drainage that agreed with measured results (Figure 7.6). The parameter decreased was the distribution coefficient (called ‘exco’ in APSIM) which was reduced from 40.0 L kg^{-1} to 0.5 L kg^{-1}. Lowering ammonium-N adsorption has a similar effect on ammonium leaching as preferential flow, in that, it speeds up the flow of solute through the soil. Therefore, the model predicts ammonium losses more similar to measured values but without simulating preferential flow.

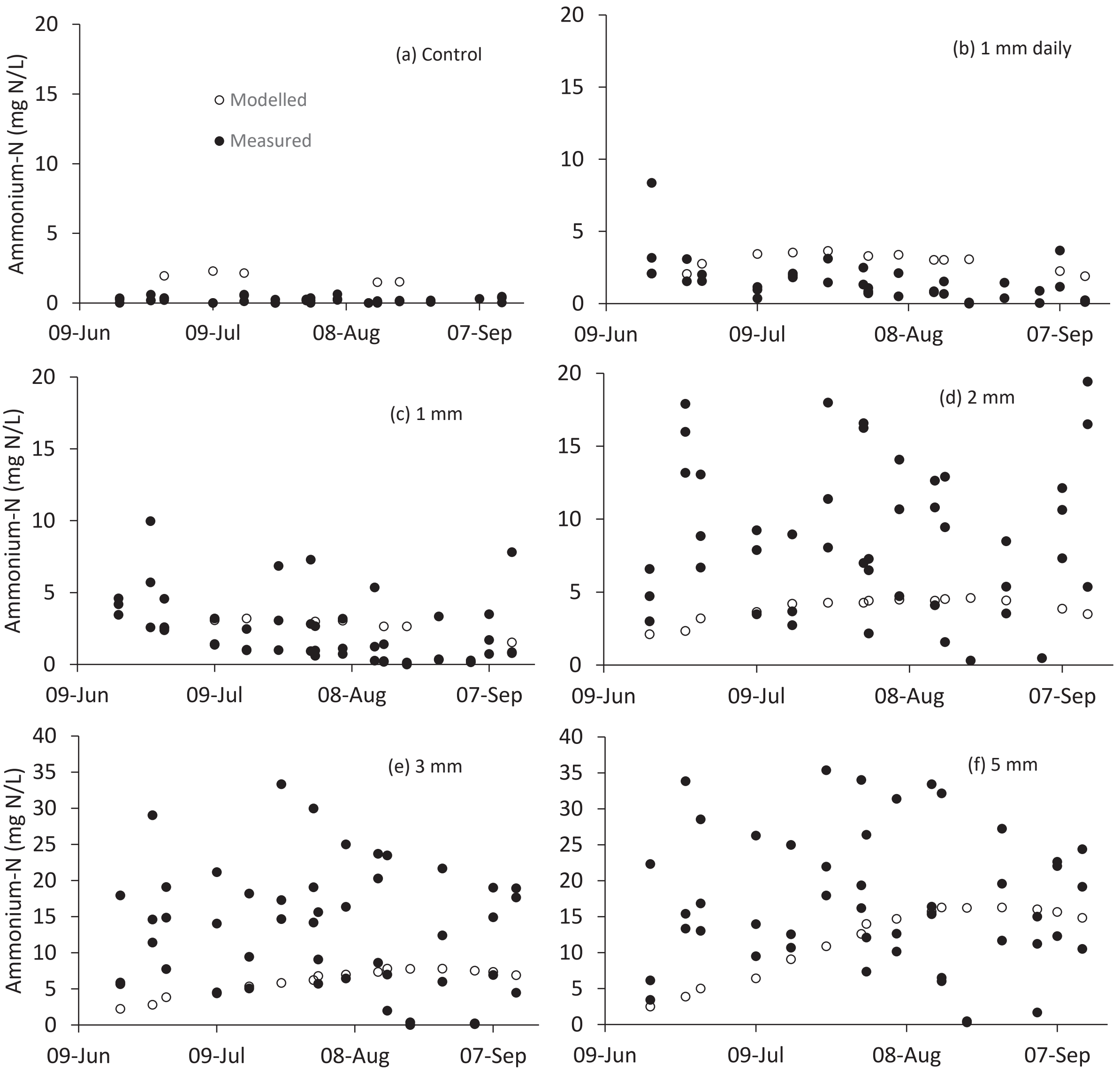


Figure 7.5. Measured and modelled ammonium-N (NH_4-N) concentrations in the captured drainage from artificial drains under different effluent irrigation depths. Treatments were: (a) Control (nil effluent), (b) 1 mm daily irrespective of rainfall rule, (c) 1 mm, (d) 2 mm, (e) 3 mm, and (f) 5 mm. Treatments c, d, e & f were subject to a rainfall rule where no application of effluent occurred if there had been ≥ 4 mm rainfall in the preceding 24 hours.

APSIM predicted 42, 9, 22, 8, 7 and 2 % of the measured drainage ammonium-N concentration values for the Control, 1 mm daily, 1 mm, 2 mm, 3 mm and 5 mm treatments respectively. Thus the model explained less than 2 – 42 % of the measured drainage ammonium-N concentrations.

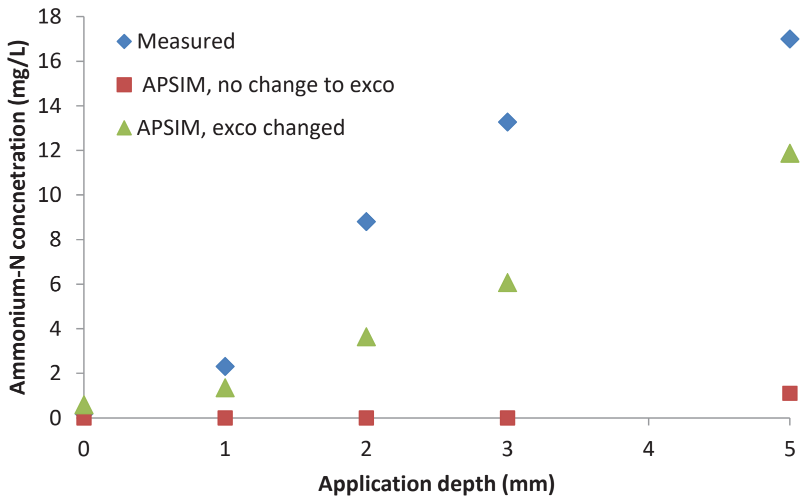


Figure 7.6. Average concentrations of ammonium-N measured in drainage (◆) and APSIM-modelled results prior to (■), and following (▲), lowering *exco* in APSIM to better account for ammonium-N losses via preferential flow pathways.

ii. Nitrate-N results

Modelled nitrate-N concentrations in drain discharge agreed well with measured data. The model explains between 29 and 75% of the measured values (40, 65, 29, 72, 75 and 70 % for the Control, 1 mm daily, 1 mm, 2 mm, 3 mm and 5 mm treatments respectively). The results shown in Figure 7.7 were for simulations conducted after the adjustment was made to the ‘exco’ parameter to better model ammonium-N losses via preferential flow. This adjustment to ‘exco’ improved the accuracy of the APSIM predictions for nitrate-N as well as ammonium-N. This is because the movement of ammonium-N and nitrate-N are linked; by speeding up the flow of ammonium-N through the soil there was less nitrogen remaining in the topsoil where it could be denitrified or taken up by plants. The temporal pattern of predictions for nitrate-N was a better match with measured data than was the case for ammonium-N. Total nitrate-N leaching values were higher when ‘exco’ was decreased, even at high irrigation rates. Reducing ‘exco’ caused ammonium-N to move down the profile quicker where it was subsequently nitrified and then leached as nitrate-N. The rate of flow through the profile was not fast enough, even at the highest application depth, to remove ammonium-N via leaching before it was reduced to nitrate-N via nitrification in the soil profile. Measured nitrate-N concentrations increased with time after initiation of effluent irrigation. This trend was also predicted by APSIM. This trend is particularly evident in the 2, 3, and 5 mm treatments. Predicted nitrate-N concentrations were at the lower end of the range of concentrations measured for all treatments, except for the 5 mm treatment where APSIM predictions sit near the average measured concentrations.

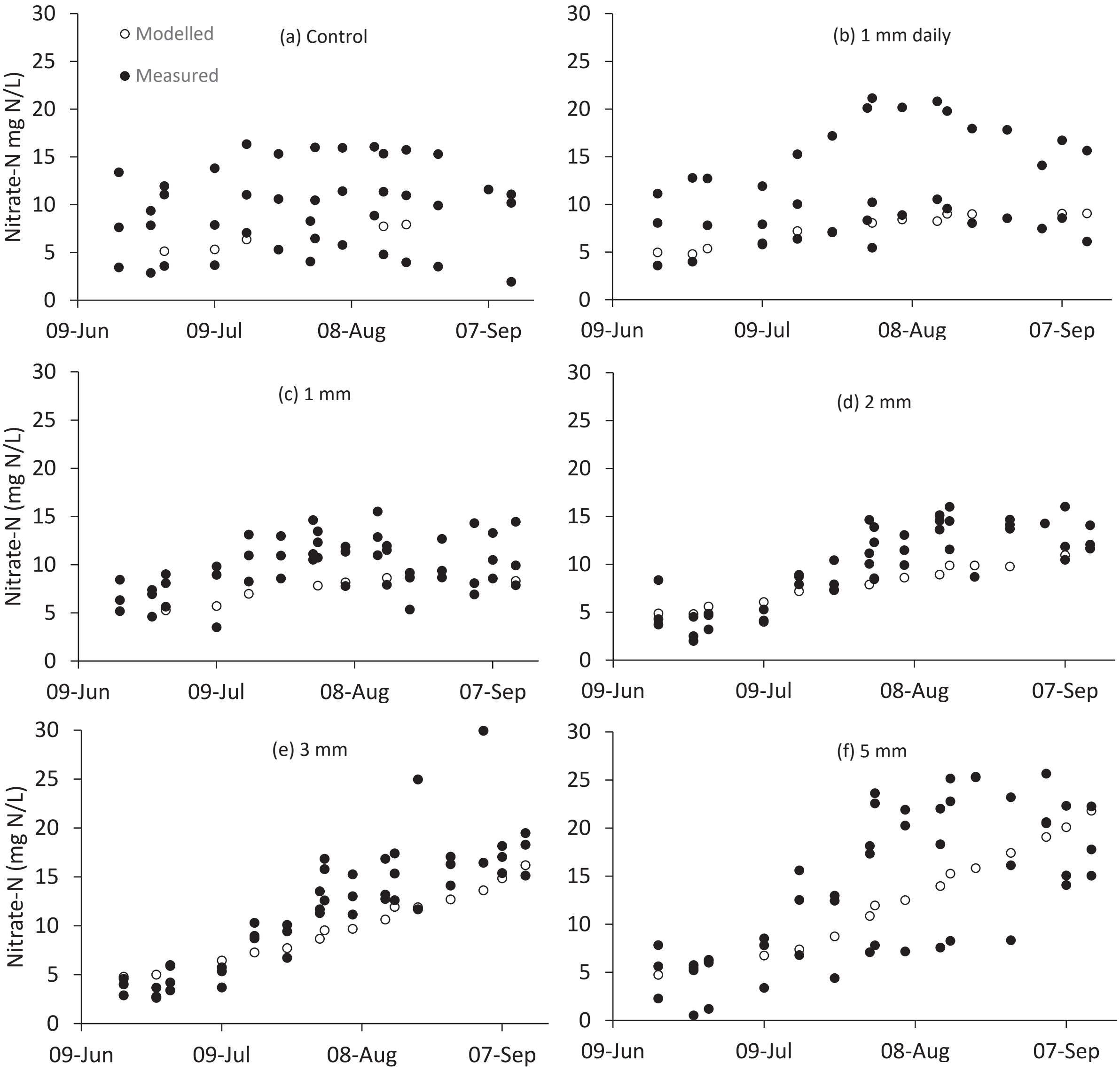


Figure 7.7. Measured and modelled nitrate-N (N0$_3$-N) concentrations in the captured drainage from artificial drains under different depths of low depth effluent irrigation. Treatments were: (a) Control (nil effluent), (b) 1 mm daily, (c) 1 mm, (d) 2 mm, (e) 3 mm, and (f) 5 mm. Treatments c, d, e & f were subject to a rainfall rule where no application of effluent occurred if there had been ≥ 4 mm rainfall in the preceding 24 hours.

7.5 Discussion of modelling *validation file* of LRLD trial data

APSIM did a reasonable job of predicting drainage volumes captured by the drains, particularly at the lower application depths. APSIM predictions of the percentage of total drainage (deep plus artificial) captured by the drains ranged from 29 – 75% (Control, 29%; 1 mm daily, 45%; 1 mm 39%; 2 mm, 50%; 3 mm, 62%; 5 mm 75%). The predicted percentage captured by the artificial drains increased with increasing effluent application depth. The remainder of the water was in deep drainage as there was no runoff predicted by the model. In comparison, percentages of measured drainage captured by the artificial drains of total predicted (SWB) drainage ranged from 48 – 110% (Table 6.10). No runoff was observed during the field experiment.

The modelled predictions for ammonium-N concentration were not in good agreement with measured results in the first instance with only 2 – 42 % of the variation in ammonium-N concentrations predicted by the model. Predictions were particularly bad at the higher application depths (8, 7 and 2 % predictions of the 2, 3 and 5 mm treatment concentrations, respectively). This was because APSIM does not have the ability to model preferential flow and it was suspected that this was occurring in the experiment. As discussed earlier (Section 7.4.2) it was necessary to adjust the adsorption parameters to produce a better agreement between measured and modelled results. However, even with this adjustment, the model predicted an increasing trend in ammonium-N concentrations over time that was not seen in the measured data. This inability of APSIM to model preferential flow is something that needs to be addressed in future versions of APSIM.

Modelled predictions of nitrate-N concentrations were in better agreement than the ammonium-N. Although APSIM tended to under estimate the losses of the Control (40 %) and lower application depths (29 % at 1 mm and 65 % at 1 mm daily). At the higher application depths the model was able to predict between 70 and 75 % of the variation in measured nitrate-N concentrations. The model predicted 72% of the N concentration at the 2 mm application depth, 75 % at 3 mm, 70 % and at 5 mm.

7.6 Results of *FDE Scenario*: Applying FDE to land over winter using a low rate, low depth system

The constraining factors for this scenario were: (1) the application season (1 June until 10 August), and (2) the maximum cumulative total N load for any one area (81.25 kg N ha^{-1}).

For the APSIM model outputs (Table 7.5) the following points of clarification relate to the presentation of the results:

- The total N applied to each area was averaged to get the average total N applied.
- The cumulative N leached from each area was averaged to give an average N leached per hectare.

- The results presented are the sum of the leaching losses from 1st June until 31st December.
- Drainage values are total drainage (deep drain plus artificial drain).

Table 7.5. APSIM model outputs of N leaching losses and percentage losses of N applied for daily applications of farm dairy effluent (FDE) to land over winter (FDE scenario) Average values are over 10 years, min and max values are the lowest and highest annual losses from the 10 years modelled.

Soil	Climate	Average N leaching (kg N ha^{-1})	Max N leaching (kg N ha^{-1})	Min N leaching (kg N ha^{-1})	Average % of N applied lost in drainage	Max % of N applied lost in drainage	Min % of N applied lost in drainage
Tokomairiro	Dry	**0.5**	1.2	0.1	**1.0**	2.3	0.3
	Ave	**1.1**	2.5	0.5	**1.5**	2.6	0.6
	Wet	**3.3**	9.9	1.0	**3.3**	7.1	1.0
Tokomairiro _LRLD	Dry	**0.7**	1.7	0.2	**1.5**	3.3	0.4
	Ave	**1.6**	3.8	0.9	**2.3**	3.8	1.0
	Wet	**4.5**	12.9	1.5	**4.6**	9.3	1.5
Waikoikoi	Dry	**0.3**	0.6	0.1	**0.6**	1.2	0.1
	Ave	**0.7**	1.8	0.3	**1.0**	1.7	0.4
	Wet	**2.1**	6.6	0.7	**2.2**	4.8	0.5
Waikoikoi_ Drains	Dry	**0.3**	0.7	0.1	**0.6**	1.4	0.2
	Ave	**0.7**	1.8	0.4	**1.1**	1.9	0.4
	Wet	**2.3**	7.0	0.7	**2.3**	5.0	0.7
Pukemutu	Dry	**0.5**	1.2	0.1	**0.9**	2.4	0.2
	Ave	**1.0**	2.5	0.5	**1.4**	2.5	0.6
	Wet	**3.0**	9.0	0.9	**3.0**	6.5	0.9
Lismore	Dry	**2.2**	4.0	0.8	**4.5**	8.6	1.7
	Ave	**3.9**	8.9	2.4	**5.6**	9.1	2.8
	Wet	**8.5**	20.7	3.8	**8.9**	14.9	3.6
Gore	Dry	**3.5**	6.4	1.5	**7.3**	13.7	3.1
	Ave	**5.9**	12.8	3.5	**8.4**	13.1	4.7
	Wet	**11.8**	26.0	5.9	**12.3**	18.6	5.6

Only two irrigation areas were required. The total area required will depend on the volumes of effluent requiring land treatment during the winter period. A total of 81.2 kg N ha^{-1} was applied to the first area between 1 June and 14 July. The irrigator then moved to the next area, applying 49 kg

N ha^{-1} until August 10. Total leaching losses ranged from 0.1 kg N ha^{-1} (imperfectly and poorly drained soils) to 26 kg N ha^{-1} in the free draining Gore soil.

Results also show that leaching losses are higher in a wet climate than a drier climate and there is greater variation within years than between rainfall climates for each particular soil type (Table 7.5). The higher the annual rainfall, the greater the between-year variation on each soil type.

7.7 Discussion of simulated *FDE application*

As winter rainfall increased there was a pattern of greater drainage and increasing N leaching for the 11 year average for each rainfall region (low, med, high). Although, results showed a greater range in drainage between years, within a single climate, highlighting the between-year variation within a region. The results also showed a clear difference in N leaching losses for different soil types. For example on a Pukemutu soil the average N losses ranged from 0.5 to 3.0 kg N ha^{-1} in a dry and wet rainfall region, respectively. Within the wet rainfall region (on a Pukemutu soil) the between year variation (of the 10 years simulated) ranged from 0.9 to 9 kg N ha^{-1}. Stonier soils showed greater leaching losses than finer textured soils (higher PAW in the top soil layers) with the average leaching loss under a high rainfall region resulting in 11.8 kg N ha^{-1} lost from a stony Gore soil, compared to 3.3, 2.1 and 3 kg N ha^{-1} losses from the Tokomairiro, Waikoikoi and Pukemutu soils, respectively.

The concentration of the effluent applied in these simulations is similar to that of FDE and as such is unlikely to be something that is generated from a wintering system. The effluent concentrations modelled in this section are likely to represent a scenario where effluent was being applied from the FDE pond during winter. However, this is not ‘best practice’ as having sufficient effluent storage, and ensuring that ponds are emptied during more suitable times of the year are the recommended practices. However, the data presented in Table 7.5 suggests that LRLD of FDE may be a reasonable emergency solution in periods when ponds are full during the winter on properties with finer textured soil types and where an existing k-line effluent application system is present.

7.8 Results from simulating the higher effluent N concentrations of barn effluents

The objective of this scenario was to investigate the use of the LRLD system using an effluent with a higher N concentration than in the FDE scenarios. This simulation was run using the same criteria set out in the FDE scenario above. The main change was that the concentration of the effluent was increased to 200 mg L^{-1} NH_4^+-N, 0.60 mg L^{-1} NO_3^-N, 400 mg L^{-1} organic-N to simulate barn or standoff pad effluents and the maximum total load per hectare was 84.1 kg N (due to the greater N concentration).

In this simulation, 7 effluent applications per area occurred before the irrigator was required to move to a different area. These 7 applications resulted in a total load to that area of 84.1 kg ha^{-1}. Applying effluent until 10 August required in 9 application areas being required; 8 having a load of 84.1 kg N ha^{-1} and the ninth having a load of 72.1 kg N ha^{-1} (Figure 7.8).

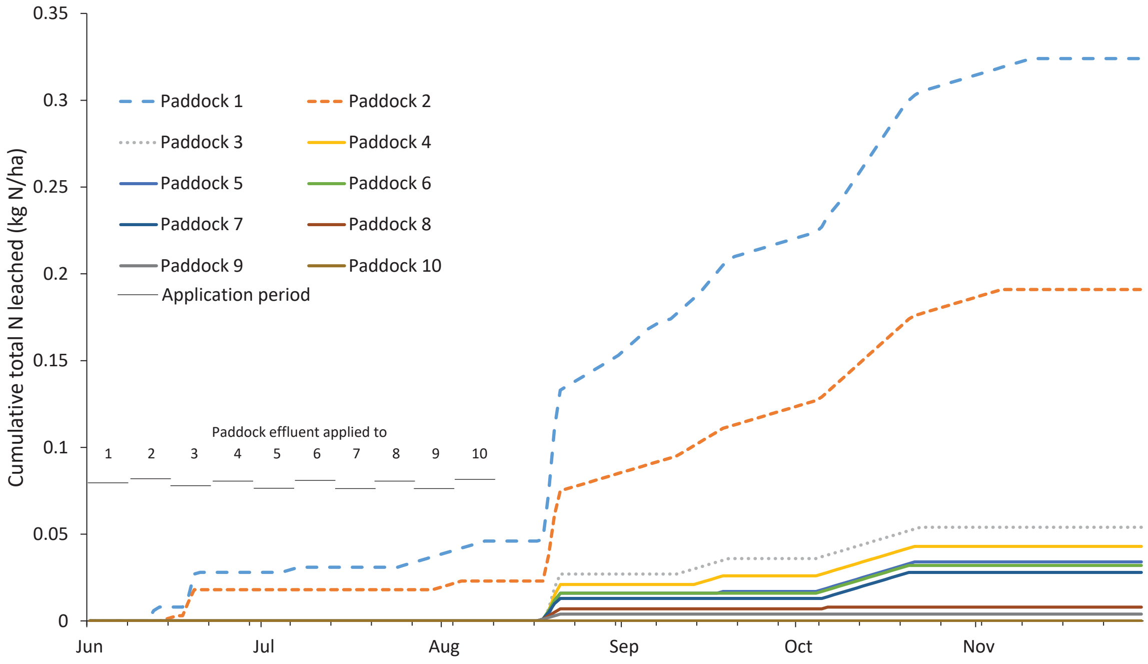


Figure 7.8. APSIM simulated Nitrogen leaching losses from daily effluent applications of 2 mm day $^{-1}$. Effluent concentration was 200 mg L^{-1} NH_4^+-N, 0.60 mg L^{-1} NO_3^-N, 400 mg L^{-1} organic-N and the maximum total load per hectare was 84.1 kg N. Once the maximum load was reached applications moved to another paddock. Application periods (7 days) for each paddock (1-10) are indicated by the horizontal bars. The soil used in this simulation scenario was a Tokomairiro silt loam and the climate data was NIWA climate data for Telford, New Zealand for the year 2000. Annual rainfall was 751 mm in 2000.

Simulation results of total cumulative N leaching until the end of the calendar year show that even though paddocks received the same load of N, there was considerable variation in total N leaching, with paddocks receiving N in the first 14 days of the simulation (1-7 June for paddock 1, 8-14 June for paddock 2) leaching considerably more than paddocks receiving N later in the season (Figure 7.8). Further analysis shows that these losses (for any soil, but shown here for a Tokomairiro) were exaggerated in a wet climate (Figure 7.9). In both dry and wet climates (early June effluent application and comparing 5 soil types) shows that stony soils have the greatest N leaching losses; these were even greater in a wet climate (Figure 7.10).

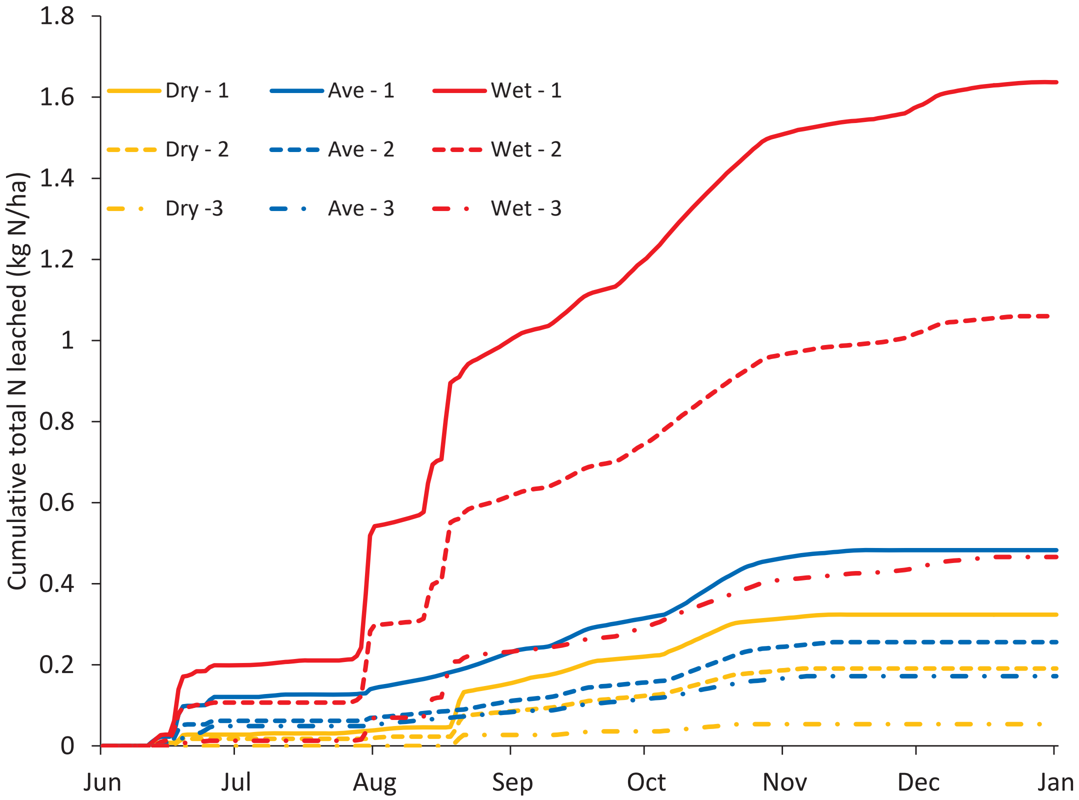


Figure 7.9. Cumulative total N leaching from the first 3 paddocks, of a Tokomairiro soil, to receive effluent. Comparison is made between a dry climate (yellow lines), an average climate (blue lines), and a wet climate (red lines). Paddock 1 (solid lines) received effluent 1-7 June 2000, paddock 2 (dashed lines) received effluent 8-14 June 2000, and paddock 3 (dash, dot lines) received effluent 15 – 21 June 2000.

7.9 Discussion of simulating higher effluent N concentrations equivalent to barn effluents

Use of a more concentrated effluent and a maximum N load of 80 kg N ha^{-1} rule means that the number of days that effluent is applied to any one area is less than was observed for the FDE scenario. This results in less water applied per area and an overall reduction in N loss ha^{-1}. The timing of effluent applications had a large impact on the total N losses from June 1 through to December 31 for each application area. Early applications, in the first two weeks of June, resulted in significantly greater losses than later applications (Figure 7.8). This was caused by subsequent higher rainfall generating greater total drainage (from those application areas following their first day of effluent application).

Figure 7.11 shows the volume of rainfall occurring on each application area following effluent application. In 2000, the year used to produce Figure 7.8, Figure 7.9 and Figure 7.10, the annual rainfall was 751 mm. There was 38 mm rainfall in the first week of June that coincided with the initial effluent application period to an already wet soil, thus for paddock 1 much of the 38 mm of rain moved the N through the soil profile. However, there was no effluent N on the non-irrigated paddock areas (areas planned to receive subsequent effluent applications) for that rainfall to transport through the soil profile. There was little variation in rainfall volume occurring after effluent application for the last 4 paddocks as there was little rainfall over those weeks. Thus, their N losses did not vary greatly from each other (Figure 7.8). Altering the scenario to investigate the N losses under different rainfall climates (Figure 7.9) showed that these early losses were exaggerated in wetter climates. This is due to surplus rainfall generating drainage that transports nitrogen through the soil profile below the root zone. As with the FDE scenario, losses were greater for stonier soils. The implications of this are that losses can be reduced when: a higher concentration effluent is applied if irrigation occurs later in the winter (thus requiring a period of storage), and when applications occur on a finer textured soil type.

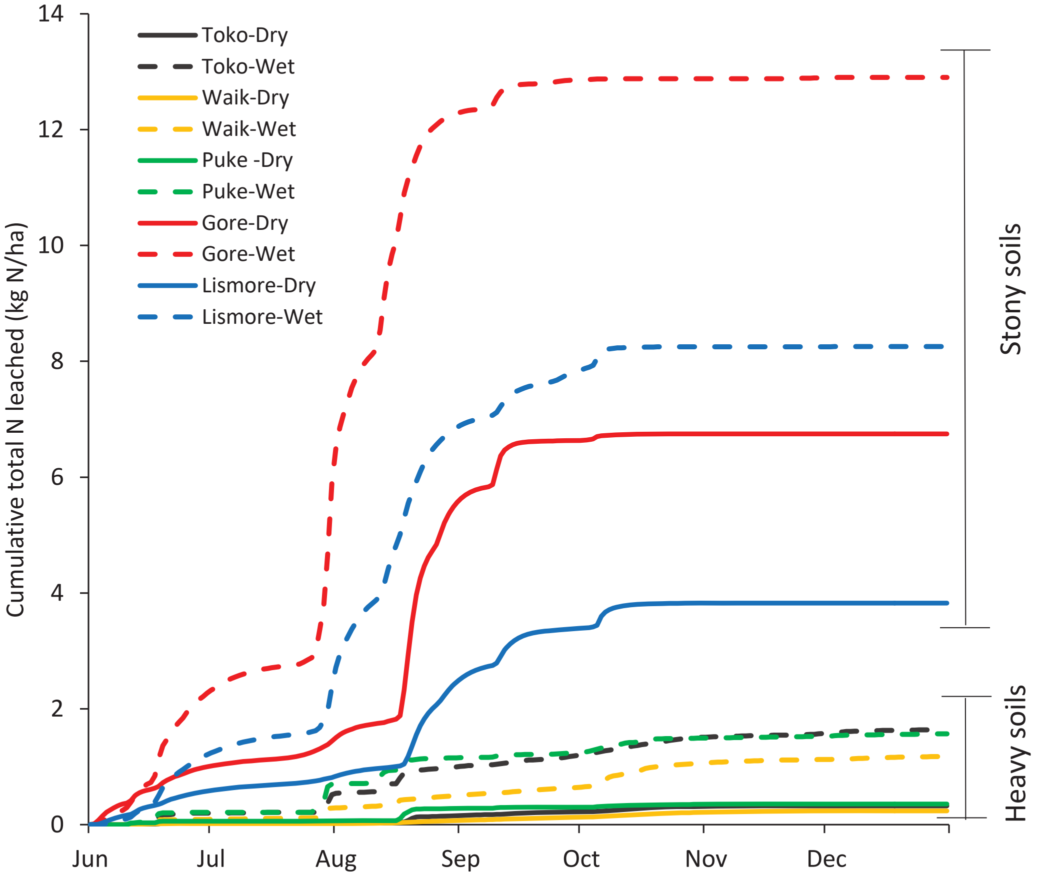


Figure 7.10. Cumulative total N leached from paddock 1 for two different climates (dry – solid line; wet – dashed line) and 5 different soil types; the heavy soils: Tokomairiro (grey), Waikoikoi (yellow), Pukemutu (green) and the stony soils: Gore (red) and Lismore (blue) soils. Simulation year was 2000.

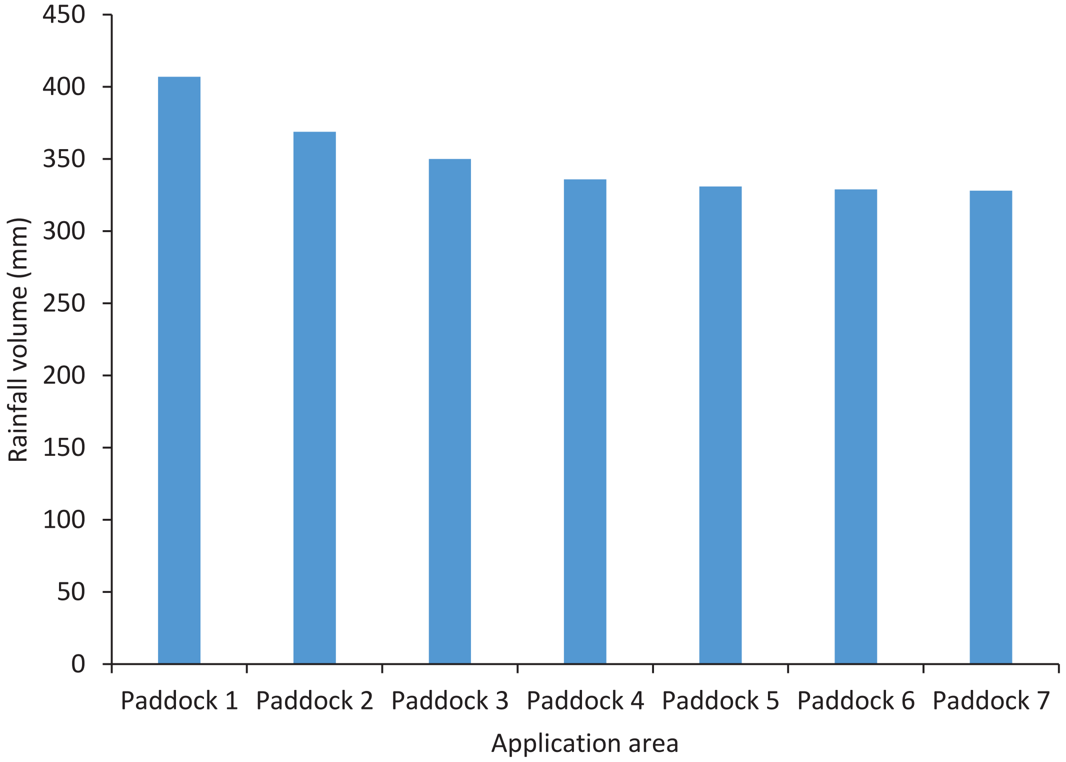


Figure 7.11. Depth of rain falling on each effluent application area following the first day of effluent application for that area. Year was 2000 and the rainfall region was Telford.

7.10 Results of simulating a *Portable pad scenario*

The objective of this scenario was to investigate the N leaching losses from areas receiving winter applied effluent when using the LRLD system as a component of the portable pad system (described in Chapter 5, Section 5.3.4). Section 7.3.5 described how the effluent concentrations for each of the rainfall regions were calculated. These concentrations (Table 7.6) were then modelled for three soil types: Tokomairiro, Lismore and Gore. These soils were selected as there is little difference in key soil physical properties between the finer textured soils; thus only one (Tokomairiro) was modelled to represent them all. In addition, the two stony soils (Lismore and Gore) were modelled to represent the free draining soils with low PAW. The 80 kg N ha^{-1} maximum load rule (Section 7.3.4) was applied and the rainfall rule was ignored. Therefore, in a practical situation, minimal effluent storage would be required. This gives nine scenarios: three climate locations (with their different effluent concentrations) and three soil types. Due to the high concentration of N in the effluent this meant that applying the maximum N load rule, and ceasing effluent irrigation (only) on the day that 80 kg N ha^{-1} was achieved, resulted in N loads per hectare that were 102, 93, and 83 kg N ha^{-1} for the low, medium and high rainfall regions respectively (Table 7.6). A fourth scenario (called 'reduN') was run for the low rainfall region where it was assumed that an N load exceeding 100 kg N ha^{-1} was unacceptable. Thus the transfer to a new location occurred a day earlier and the total N application rate was 52 kg N ha^{-1}.

This increased the area of land required to apply the effluent generated by 100 cows from 3.8 ha to 5.6 ha, while reducing the average (Figure 7.12) and per cow N losses.

Table 7.6. Simulation of effluent concentrations generated by a portable pad under different rainfall inputs. Calculated concentrations of effluent N for three rainfall regions: Low 701 mm yr^{-1}, Med 908 mm yr^{-1}, and High 1082 mm yr^{-1} and the resulting N load (kg N ha^{-1}). The land area required for 100 cows if applications occur from June 1 until August 10 are presented. Scenario names are used in the headings for Figure 7.12 and Figure 7.13.

Rainfall region	Effluent concentration	Total N load (kg ha^{-1})	Area required for 100 cows (ha)	Scenario name
Low	680 ppm NH_4^+-N, 2.49 ppm NO_3^-N, 1916 ppm organic-N	102	3.8	L-rain_H- eff
Low	680 ppm NH_4^+-N, 2.49 ppm NO_3^-N, 1916 ppm organic-N	52	5.6	L-rain_H-eff_reduN
Med	608 ppm NH_4^+-N, 2.22 ppm NO_3^-N, 1713 ppm organic-N	93	4.2	M-rain_M-eff
High	545 ppm NH_4^+-N, 1.99 ppm NO_3^-N, 1535 ppm organic-N	83	4.8	H-rain_L-eff

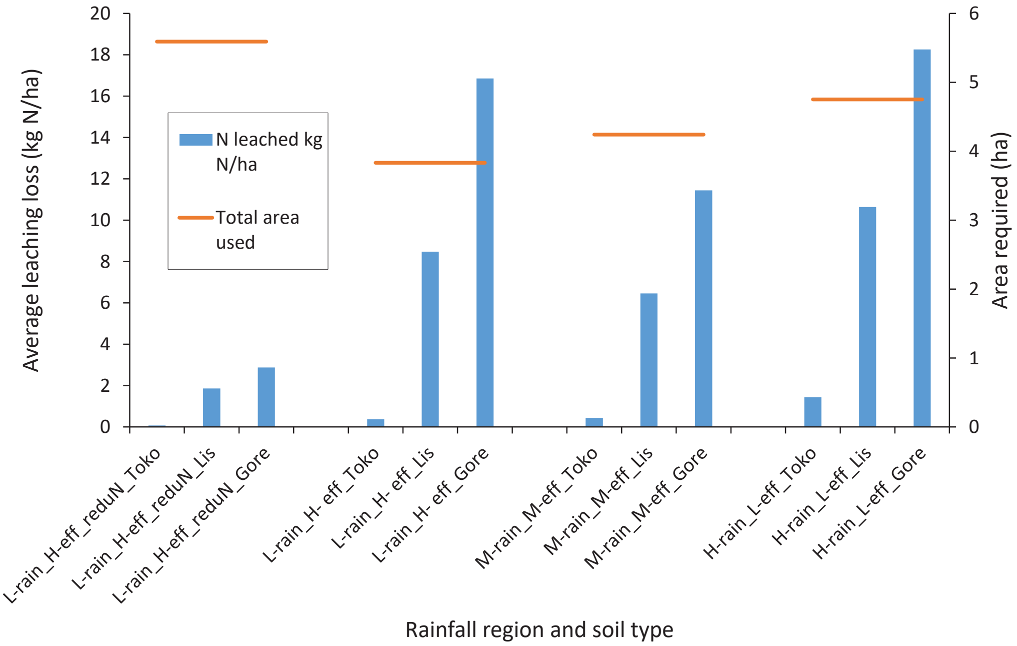


Figure 7.12. Simulation of average N leaching losses and total land areas required when the effluent collected from a portable pad system (100 cows wintered) is directly irrigated to adjacent pasture using a low rate, low depth effluent irrigation system. Results compare three soil types (Tokomairiro – 'Toko', Lismore – 'Lis', Gore), three rainfall regions (L-rain, M-rain, H-rain) and three effluent concentrations (L-eff, M-eff, H-eff). A further scenario (reduN) of a lower total N load ha^{-1} was simulated for the low rainfall region.

Table 7.7. APSIM model outputs of N leaching losses per 100-cows and effluent applied (kg N 100-cows^{-1}). The percentage of N applied N lost in drainage are given. Results are presented for three rainfall regions (low, med, high), three soil types (Tokomairiro, Lismore, Gore) and for four scenarios (Low, med and high effluent concentration with 80 kg N ha^{-1} max load and a reduced N max load).

	kg N lost/100-cows wintered	N applied kg N 100-cows^{-1}	% of N applied lost as drainage
L-rain_H-eff_reduN_Toko	0.4	290	0.1%
L-rain_H-eff_reduN_Lis	10.4	290	3.6%
L-rain_H-eff_reduN_Gore	16.1	290	5.5%
L-rain_H- eff_Toko	1.4	390	0.4%
L-rain_H- eff_Lis	32.5	390	8.3%
L-rain_H- eff_Gore	64.5	390	16.6%
M-rain_M-eff_Toko	1.9	390	0.5%
M-rain_M-eff_Lis	27.4	390	7.1%
M-rain_M-eff_Gore	48.6	390	12.6%
H-rain_L-eff_Toko	6.8	390	1.8%
H-rain_L-eff_Lis	50.5	390	13.0%
H-rain_L-eff_Gore	86.8	390	22.4%

Total N losses per cow wintered range from 0.004 kg in the reduced N scenario (low rainfall region) on a Tokomairiro soil, to 0.868 kg in a high rainfall region on a Gore soil (Table 7.7). Percentage of applied effluent N lost in drainage ranges from 0.1 % in the L-rain_H-eff_reduN_Toko scenario to 22.4% in the H-rain_L-eff_Gore scenario.

7.11 Discussion of Portable pad scenario

The modelling analysis conducted here suggests that N losses resulting from applying the effluent generated from the portable pad on a finer textured soil type (e.g. Tokomairiro) were under 2 kg N ha^{-1} even in a high rainfall region (Figure 7.12). The maximum area required to apply the effluent captured from 100 cows would be less than 5 ha if the 80 kg N ha^{-1} rule was in place (Table 7.6) Further calculations are required to be carried out to compare the total losses from the whole wintering system utilising the portable pad with those from a traditional cropping scenario. As well as the losses from the LRLD applied effluent, there would be the losses from the cows grazing the brassica crop, *in situ*, for 6 hours a day. These calculations and a comparison with 24-hour crop grazing, and a wintering barn, are carried out in Chapter 8.

While the losses from the stony soils were significantly higher than those from the finer textured soils, they were less than losses from current winter grazing on stony soils. Smith *et al.* (2012) report average losses of 81 kg N ha^{-1} year^{-1} under a grazed winter crop on a stony Southland soil. Even on a finer textured soil, reported losses under a grazed winter crop were considerably higher than the losses under LRLD reported here; 52 kg N ha^{-1} yr^{-1} under grazed kale on a Pukemutu soil (Monaghan *et al.* 2013).

7.12 Summary of all scenarios

Low rate, low depth applications of effluent during winter result in N losses to surface and ground waters. However, these losses were relatively small compared to other winter farming practices such as grazing brassica crops *in situ*. The simulated amount of effluent N leached per cow wintered ranged from 0.4 to 6.8 kg N 100-cows^{-1} for poor/imperfectly drained soils, to 16.1 to 86.8 kg N 100-cows^{-1} for free draining, stony Gore soils (Table 7.7). The magnitude of the losses from this system are dependent on a number of factors: soil type, winter rainfall, effluent concentration, maximum N load, and timing of application.

Losses were reduced by decreasing the amount of water captured by a standoff system. This occurs in low rainfall regions, or by applying a more concentrated effluent (similar to that captured on a wintering pad or from a roofed shelter). Additionally, applications after mid-June resulted in significantly lower total N losses (cumulative June-December) than applications that occurred during the first two weeks of June. Losses from stony soils were, on average, significantly higher than those from the finer textured soils and these were higher again in wetter climates and using a lower concentration effluent similar to an FDE. The relative risks of N leaching losses associated with the LRLD system are shown in Figure 7.13.

7.12.1 Rule of thumb for estimating N losses from use of the LRLD system

Farmers wishing to estimate the losses that could occur if they were to adopt the LRLD system currently have the models *OVERSEER* and APSIM available to predict losses. However, APSIM requires a level of user expertise that the general public would not have. It is also time consuming both to gather data and to generate an accurate simulation. *OVERSEER*, on the other hand, is less time consuming and more user friendly. However, *OVERSEER* does not currently have the ability to accurately predict N losses from the LRLD system. It will be shown in Chapter 8 that *OVERSEER* significantly over-predicts leaching losses of nitrogen when the LRLD system is modelled.

The ability of a simple relationship between the PAW value of the soil, the drainage volumes, and the N leaching losses predicted by APSIM was used to rank the risk of N losses from LRLD irrigation system under a particular soil type and rainfall/drainage climate. The number of PAW pore volumes replaced by drainage was calculated by dividing the total drainage (easily found using a simple SWB) by the PAW to 45 cm (source SMap Online; Landcare Research, 2016). Forty five centimetres represents the plant rooting depth in APSIM and common pipe drain depth. When the number of pore volumes replaced was calculated for all soil types and plotted against the APSIM estimate of N leached (kg N ha^{-1}) a simple linear relationship (Figure 7.14 a) was found that explained 62% of the variation in N leached for all soils, 94% when only considering fine textured soils and a poor 30% (Figure 7.14 b) when considering only stony soils; suggesting that this simple ranking method will not be suitable for free draining, stony soils. This suggests that the N leaching risk of winter applied effluent can be predicted in poor or imperfectly drained soils, if the PAW to 45 cm of a soil plus the expected drainage from a simple SWB are known. Thus modelling each soil type and location using APSIM may not be necessary to generate an approximate idea of the N loss risk from implementing this scenario for imperfectly drained soils.

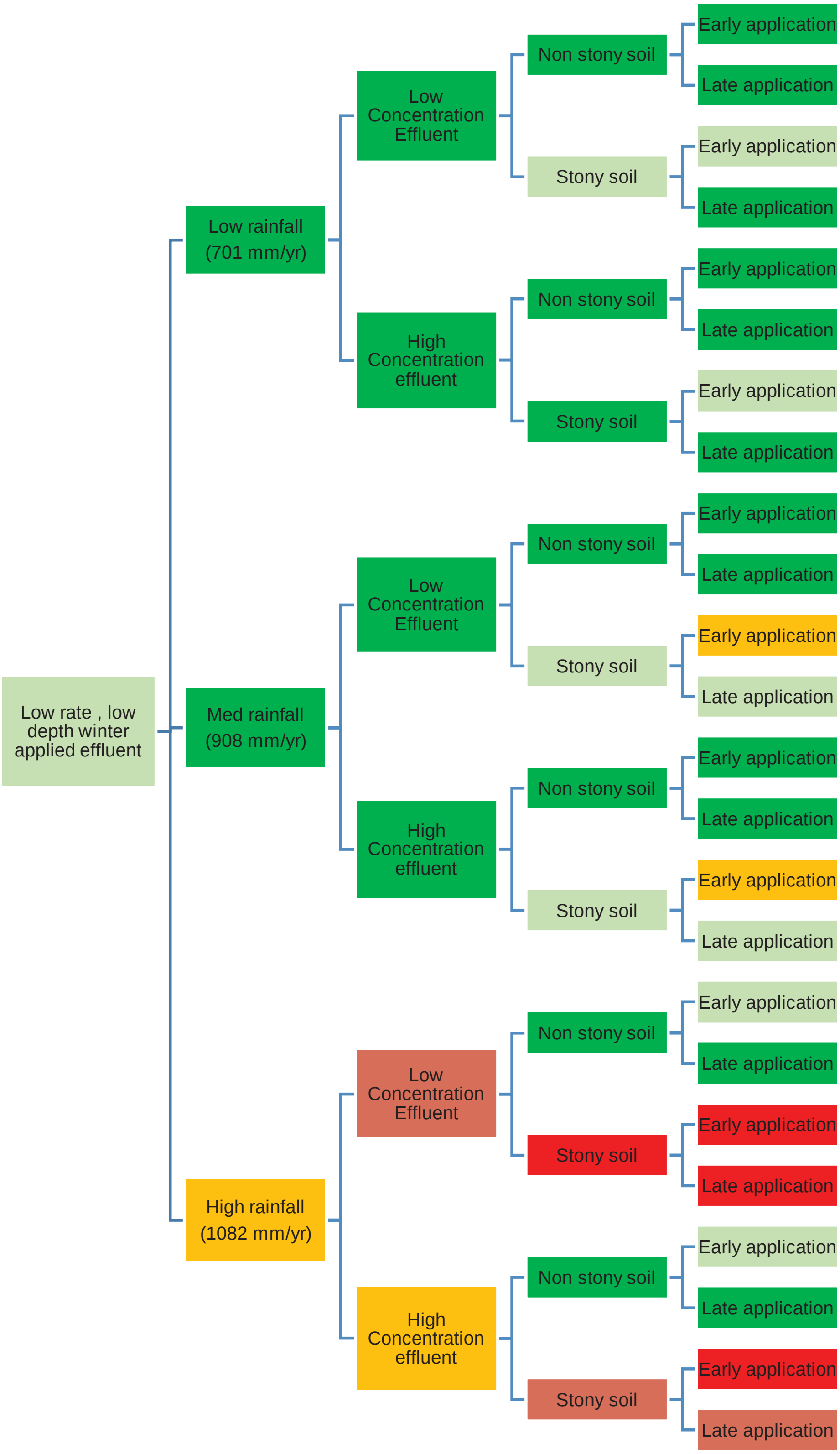


Figure 7.13. Decision tree of the relative risks of N leaching losses associated with applying the low rate low depth irrigation system under different scenarios. Red is high risk, Amber some risk, Green low risk. Low concentration effluent (Total N around 100 mg N L^{-1}) would be similar to FDE, high concentration similar to effluent obtained from a portable pad (around 2000 mg N L^{-1}). Early application in the first 2 weeks of June and late application from 15 June onwards. This assumes a constant maximum N load over the scenarios.

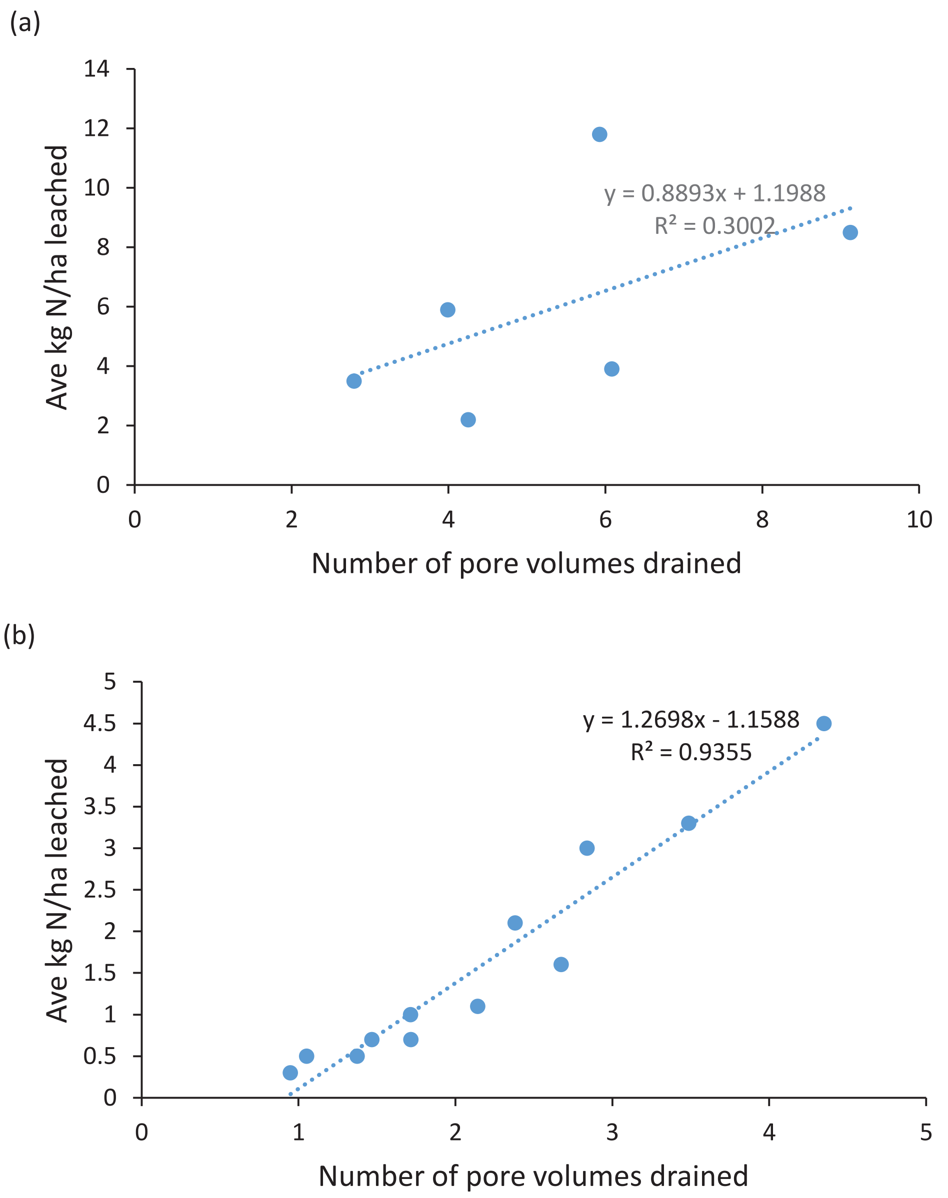


Figure 7.14. (a) The relationship between number of pore volumes (to 45 cm) drained and total N lost in drainage (averaged over 10 years) in poor/imperfectly drained soils, $R^2 = 0.9355$, and (b) the relationship between the number of pore volumes drained and the total N lost in drainage in stony, freely drained soils, $R^2 = 0.3002$

If this LRLD system was to be recommended for use by farmers then the following criteria would be suggested:

- Applications of 2 mm day^{-1} and a rate of 4 mm hr^{-1}
- Daily applications regardless of rainfall.
- Maximum N load of around 80 kg N ha^{-1}. However, this should be tailored to the effluent N concentration to avoid over application of N.
- Lower N load for stony soils
- No use of low concentration effluents (similar to FDE) on stony soils in high rainfall regions.

7.13 Conclusions

The use of the LRLD system results in modelled N leaching losses that were lower than the losses under winter crop grazing, although whole system losses need to be calculated (Chapter 8), and if a strict set of irrigation and N loading rules were adhered to then the losses could be relatively small. Losses of N are particularly small on fine textured soils. In contrast, N leaching losses under LRLD to stony soils may cause concern. However, the LRLD system can be adapted for use on stony soils: higher concentration effluents and later application dates are likely to reduce N leaching from these soils. It follows, that this version of the LRLD system has the potential to be used in almost any situation.

7.14 Acknowledgments

Thanks to Rogerio Cichota for his help with setting up the base model including creating the soils (soil parameterisation), fertigation manager and met files. Also his help explaining how the model works. Thanks to Peter Johnstone for help with the stats.

8. Simulation modelling and comparison of the N leaching losses from three different wintering systems

8.1 Abstract

OVERSEER Nutrient Budget software is regularly used as a tool to predict N leaching losses from farming systems. In this Chapter the N leaching losses, over a range of climates and soil types, from a dairy farm incorporating traditional brassica crop wintering is modelled using *OVERSEER* and compared with N leaching loss from a dairy farm using a crop wintering system incorporating a portable standoff pad and also a dairy farm system with a deep-litter wintering barn. The hypothesis was that the portable pad system could reduce N losses, compared to a traditional grazed winter brassica crop, to values similar to those achieved by the use of a deep-litter wintering barn. If modelled N leaching loss results contrasted with measured data (where available) then estimates based on measured data were incorporated into the systems N loss model. *OVERSEER* does not currently have the capacity to model N leaching loss from low rate, low depth winter applied liquid effluent. In addition, *OVERSEER* values of N leaching losses from winter grazed brassica crops were significantly higher than measured figures. In all 3 scenarios, when compared to the combined loss results (*OVERSEER* supplemented with measured and APSIM modelled data), *OVERSEER* predicted between 34 and 63% increased losses from the whole farm system (milking platform, winter crop blocks, and support block areas for young stock) which was attributable solely to a possible over estimation of N losses from crop paddocks. A combination of *OVERSEER* predictions of N losses plus measured and modelled (APSIM) N losses indicated that the portable pad system could reduce whole farm system losses by 5 to 26 % (1 to 6 kg N ha^{-1} yr^{-1}) compared with traditional brassica crop wintering. The use of a barn resulted in 13 to 26 % (2 to 6 kg N ha^{-1} yr^{-1}) reduction in N leaching losses.

8.2 Introduction

Grazing brassica crops *in situ* is the traditional dairy wintering practice in the lower South Island of New Zealand. This practice has been under increasing scrutiny from local Regional Councils due to the relatively high nitrogen (N) leaching losses from this component of the whole farm system (Environment 2016). Alternative wintering options that are currently available to farmers to reduce N leaching losses are high cost and involve a large capital investment. The use of structures such as barns and permanent wintering pads, to keep cows off paddocks during the winter while capturing the effluent produced, are examples of existing alternatives to grazing brassica crop *in situ*. However, there is the risk that farmers will intensify their farming system (particularly with roofed structures) to cover the capital cost of such structures (Beukes *et al.* 2011; Lee 2015). While intensification can result in a lower environmental cost per unit of production (kg N leached/ kg MS produced), it may have a nil or negative effect on the total losses per hectare.

In Chapter 5 winter crop grazing incorporating a standoff to reduce urinary load on the paddock was investigated using a portable pad system. This is a lower cost alternative that stands cows' off-paddock for a significant proportion of the day, whilst still enabling the low-cost brassica crop to be grazed *in situ*.

A field experiment was conducted to investigate the nutrient losses under the proposed low depth application of effluent to pasture (Chapter 6). This concept was explored further using the Agricultural Production System SIMulator (APSIM; Holzworth *et al.* (2014)) version 7.7 r3615 to model low rate and low depth (LRLD) application to a range of soils and under a number of winter rainfalls (Chapter 7). Also N leaching losses under a winter grazed crop were measured for one year (Chapter 4): the effect of different grazing times (6 or 24 hours day^{-1}) on N leaching was compared in this experiment.

In this Chapter the results and understanding developed from the different component experiments described above are used to inform *OVERSEER* nutrient budgeting software (described below) in order to simulate the N losses from the portable pad system. These were then compared with the *OVERSEER* simulated losses from the traditional brassica crop wintering system and a wintering system utilising a deep litter wintering barn.

The aims of this chapter are to:

1. Model (using *OVERSEER* and *Farmax*) a traditional wintering system (base farm), a portable pad system and a system with a deep litter wintering barn.
2. To compare the predicted N leaching losses from these three systems.
3. Compare the predicted losses from different components of the system (LRLD applications of effluent, crop paddocks) with measured losses and APSIM modelled losses.
4. Identify any areas of disparity between measured and modelled data.

8.3 **Methods**

For the purposes of this modelling exercise a theoretical farm, loosely based on the Telford farm (the basis of the barn work in Chapter 3), was modelled using *Farmax* DairyPro (v 7.0.0.97; hereafter called *Farmax*) and *OVERSEER*® Nutrient Budgets (v 6.2.2; hereafter called *OVERSEER*).

8.3.1 Models used

i. OVERSEER® Nutrient Budgeting model (OVERSEER) (v 6.2.2) (Wheeler et al. 2003).

The *OVERSEER* model is a New Zealand-based farm specific tool to examine the impact of farming practices on nutrient use and flows. It is used extensively in the dairy industry as all dairy farms are required to complete a nutrient budget. It is most often used by a fertiliser representative or a farm consultant. Users are required to obtain a Post Graduate qualification in the use of *OVERSEER* and in the development of nutrient management plans.

ii. Farmax DairyPro model (v 7.0.0.97) (Farmax) (Bryant et al. 2010; White et al. 2010)

Farmax is a whole-farm system model that has the ability to simulate the physical attributes, feeding and performance of dairy cows in grazed pasture systems.

The model requires farm specific data to be collected and entered accurately by an expert user.

Use of the *OVERSEER* and *Farmax* models together allows various farm system scenarios and their associated nutrient losses to the environment to be simulated.

8.3.2 System scenarios tested

The same base farm was used to model three different scenarios:

1. "Base" with crop wintering (swedes),
2. "Portable Pad" the base farm utilising the portable pad for wintering cows, and
3. "Barn" the base farm with a woodchip deep litter barn for wintering cows.

The farms were initially modelled in *Farmax* to check for feasibility and to gain production data that could then be used in *OVERSEER*. For the *Farmax* modelling it was only necessary to model the base farm, with the cropping component, and the barn scenario. For the purposes of the *Farmax* model inputs and outputs for the base and portable pad scenarios were the same. When modelling in *OVERSEER* it was necessary to model all three scenarios.

8.3.3 *Farmax* modelling file generation

For the purposes of this exercise the Base farm grazed and wintered all stock including the young stock. The farm stocking rate (SR) was 1.9 cows ha^{-1} and milked 400 Kiwi cross cows with an average liveweight (LW) of 460 kg. The replacement rate was 23 %. Total days in milk was 266 days. The property was a total of 212 ha comprising: a 102 ha Main block (permanent pastures not receiving effluent), 30 ha Effluent block, and an 80 ha Young Stock and crop block. Pasture growth rates were taken from those recorded at Telford over the 2012/2013 season (Table 8.1). For all scenarios the potential pasture growth was 12.7 t DM ha^{-1} yr^{-1}. Urea was applied to the 'Main' and 'Young Stock' blocks in three applications of 35 kg N ha^{-1} yr^{-1} and to the Effluent block in two applications of 35 kg N ha^{-1} yr^{-1}. Pasture growth rates were increased slightly on the 'Effluent' block for the months October-February to account for the Nitrogen in the effluent. Silage was made on all blocks and yielded 1.6 t DM ha^{-1} yr^{-1}. Areas of silage were different for the barn scenario compared to the two crop scenarios (105 ha for crop and pad scenarios and 125 ha for barn scenario; Table 8.2). The Barn scenario required an additional 275 tonnes of silage to be purchased for winter feed to be fed in the barn. This was necessary to ensure cows reached the targeted 0.5 increase in body condition score (BCS) over the winter. The winter crop of swedes yielded 12 t DM ha^{-1} following the application of 300 kg ha^{-1} DAP at sowing and 75 kg ha^{-1} urea 6 weeks later (DairyNZ 2010). For all scenarios mixed age (MA) cows and in-calf rising 2-year-old (R2) heifers were wintered, either on crop or in the barn, for 70 days. The basic production figures and areas where data varied between scenarios is shown in Table 8.2. The data for modelling the Base and Portable scenarios in both *Farmax* and *OVERSEER* were the same.

Table 8.1. Monthly pasture growth rates used for *Farmax* modelling (kg DM/ha/day)(Dalley & Geddes 2013)

Block	J	J	A	S	O	N	D	J	F	M	A	M
Main (non-effluent area)*	6	10	20	40	50	56	50	56	52	41	19	17
Effluent	6	10	20	40	53	57	53	58	54	41	19	17

*Pasture growth rates were also used for pasture phase of crop blocks and young stock block.

8.3.4 *OVERSEER* modelling file generation

The systems were 'located' at Telford near Balclutha in South Otago, 60 km from the coast with flat topography. The soil on the base farms was assumed to be a Pukemutu (Argillic-fragic Perch-gley Pallic, Hewitt 1998). This soil has a silty loam over clay that is poorly drained and, for the purpose of the simulation, mole and tile drainage was present across the whole property. Top soil texture selected in *OVERSEER* was 'silt loam' and the natural soil drainage and run-off characteristics selected in *OVERSEER* were 'imperfect soil drainage' and 'susceptibility to pugging or treading damage in winter or with rain'. Soil test data was the same for all scenarios and the 'typical values' given by *OVERSEER* were used. These were: Olsen P 30 (mg P L^{-1}), Quick Test (QT) K 7, QT Ca 9, QT Mg 21, QT Na 8, and Organic S 9 (mg S kg^{-1}). Other general management operations were: no in-shed feeding, no once-a-day milking, and silage is stored in a stack with the effluent contained. The individual block management operations for the base farm are shown in Table 8.3. Management related to the portable pad or barn scenarios are marked with an asterix.

Table 8.2. Outputs from *Farmax*. Those used as inputs for *OVERSEER* are marked with an asterix.

	Scenario	
	Base and Portable pad	Barn
Total Milk Solids (to Factory)*	153,720 kg	153,720 kg
Milk Solids per ha	725 kg/ha	725 kg/ha
Milk Solids per cow	386 kg/cow	386 kg/cow
Total Silage Produced*	168 t DM	200 t DM
Total ha used for silage (and block used)*	105 ha (75 ha Main, 10 ha Eff, 20 ha Young)	125 ha (75 ha Main, 10 ha Eff, 40 ha Young)
Pasture silage purchased*	0 t DM	275 t DM
Total ha Swede crops*	23 ha	0 ha
Winter feed offered	8 kg DM hd^{-1} day^{-1} swedes + 2 kg DM hd^{-1} day^{-1} silage	11.5 kg DM hd^{-1} day^{-1} silage
Winter change in body condition score (BCS)	+0.7 = 4.5 (start June) to 5.2 (start Aug)	+0.5 = 4.5 (start June) to 5.0 (start Aug)

8.3.4.1 *OVERSEER* input parameters for the portable pad and barn scenarios

i. Portable pad scenario

The portable pad system involved the cows grazing brassica crop *in situ* for 6 hours a day and returning to the pad for the remaining 18 hours a day. Effluent is captured and applied to land.

Portable pad scenario parameters for *OVERSEER*:

- The pad was located on the crop block.
- The pad was uncovered with an inert surface, fully lined, effluent captured, surface scraped regularly, solids stored open to the rain, liquid removed from the block.
- Solids were applied to the 'Main' block paddocks in February, requiring 6 months storage. Liquid effluent was sprayed from sump using a low application method and applications were actively managed. Applications were to 23 and 33 % of the young stock block for Telford and Woodlands climates (Table 8.3), respectively.

ii. Barn scenario

The barn has a woodchip bedding area and a concrete feeding alley. Cows were wintered for 70 days and fed silage. Effluent was captured and stored until conditions were optimal for land application.

Additional barn scenario parameters for *OVERSEER* (Table 8.2)

- Good quality pasture silage purchased, 275 t DM. Stored in 'average' storage conditions. 100 t DM is fed in the wintering barn and utilisation was set at 'very good'. The remaining 175 t DM is fed to young stock.
- Milk production taken from the *Farmax* model was 153,720 kg MS yr^{-1}.
- The wintering barn was set with the following conditions within *OVERSEER*:
    - Covered wintering pad or animal shelter
    - Carbon rich bunker material
    - 4 months between animals first entering the barn and removal of bedding material.
    - Liquids were drained away and added to the FDE system.
    - A concrete feeding apron is present and used.
    - Feeding apron is scraped (no water) and the scraped material is stored in a stack.
    - Solids were spread on young stock paddocks (February) and were stored open to the rain for 6 months prior to this.
- Feeding regime is wintering pad only. The 'Most of the farm is grazed out before moving animals onto the pad' option was NOT ticked as this scenario includes the Young Stock block as well.
- Cows spend 4 hours a day on the feeding apron and the percentage of milking cows using the barn were 100% in June and July and 25% in August to represent a 70 day wintering period.
- Silage made on the Main Block is fed in the wintering barn.
- An additional 32 t DM silage is made on the Young Stock block and fed in the barn.

Table 8.3. Farm block managements for base farm, those that change in portable pad or barn scenarios are marked with an asterix

Main Block 102 ha • Silage 75 ha • 3 x Urea applications of 35 kg N/ha on 19 Aug, 12 Oct, 2 Dec • Grazed by dairy cows • Effluent pond solids removed every 3 years and spread evenly on Main block. • Barn located on this block*	**Effluent Block 30 ha** • Silage 10 ha • 2 x Urea applications of 35 kg N ha^{-1} on 28 Aug and 28 Feb • Grazed by dairy cows • Effluent system is a low rate application system sprayed regularly and is actively managed.
Young stock block 57 ha (* 80 ha in barn scenario) • Silage 20 ha (crop scenario has 40 ha silage)* • 3 x Urea applications of 35 kg N/ha on 22 Aug, 12 Oct, 2 Dec • Pasture grazed by young stock. Crop grazed by dairy cows (18 ha) and in calf R2-yr heifers (5 ha)* • Portable pad located on this block* • Has liquid effluent applied, using low rate system, during winter in portable pad scenario*	**MA cow winter crop 7 ha first yr crop, 11 ha second yr crop (within the young stock block)** • In portable pad scenario solids from pad were spread on the crop paddocks in December* • First year follows 8 years as pasture. Modelled as a separate cropping block, not as a fodder crop rotated through a pasture block. • First year crop is Swedes sown in November grazed June – August. Then sown in November into second year Kale crop. • Second year crop is swedes following kale. • Fertiliser 300 kg/ha DAP at sowing and 75 kg/ha Urea in January. • First year crop was conventional cultivation and second year crop was minimal till.
Replacement heifers winter crop 5 ha (within the young stock block) • Sown from pasture in November. Modelled as a separate cropping block, not as a fodder crop rotated through a pasture block. • First year crop (conventional cultivation) is Swedes sown in November grazed June – August. Then 4 ha is sown in November (minimal till) into second year Kale crop for the MA cows. • Fertiliser 300 kg ha^{-1} DAP at sowing and 75 kg ha^{-1} Urea in January.	**General** • Silage is stored in a stack with effluent contained. • No once-a-day milking. • No supplementary feed fed in the milking shed. • Top soil texture = silt loam. • Imperfect soil drainage with susceptibility to pugging or treading damage in winter or with rain.* • Mole and tile drainage over 100% of the farm. • Soil test data: Olsen P 30, Quick Test (QT) K 7, QT Ca 9, QT Mg 21, QT Na 8, Organic S 9 mg kg^{-1}

iii. Silage volume issues within OVERSEER

Farmax modelling calculated a figure of 475t DM silage to be fed to young and MA cows in the barn scenario. This was made up of 200 t made on the farm and 275 t purchased. Cows and replacements in the barn were offered 11.5 kg DM cow^{-1} day^{-1} of which 9.8 kg DM cow^{-1} day^{-1} was eaten (85 % utilisation) over the 70 day wintering period (totalling 395 t DM). This was 120 t DM of the pasture silage made on the farm plus 275 t DM purchased pasture silage fed to dry cows in the wintering barn. In early modelling runs using *OVERSEER* v 6.2.1 the model generated a nutrient budget. However, in later modelling runs the *OVERSEER* version had changed to 6.2.2 and feeding that amount of silage resulted in an error message stating that animals in the Wintering Barn were being fed 89% too much. Interestingly, attempting to duplicate the feed error message in a new file failed as the programme generated a silage stack error that was unable to be corrected. In order to generate an *OVERSEER* nutrient budget it was necessary to reduce the amount of silage fed to the MA cows in the wintering barn to 100 t DM and feed the remaining 175 t to young stock (using the file with the 89% feed error message). Feeding an extra 175 t DM to young stock kept the quantities of silage fed within the farming systems the same. In order to confirm that the error in feed quantity was in the *OVERSEER* programme and not in *Farmax* the amount of feed utilised within *Farmax* was decreased to be 7.6 kg DM cow^{-1} day^{-1} (the quantity of feed utilised by cows in *OVERSEER* assuming an 85% utilisation of the 9 kg DM cow^{-1} day^{-1} offered; Table 8.4) which resulted in a decrease in BCS from 4.5 at the start of winter to 4.2 at the start of lactation (Table 8.4). Thus, it was concluded that *OVERSEER* was underfeeding cows in the wintering barn.

Table 8.4. Simulated values for silage fed and utilised by dairy cows in a wintering barn. Values differ between the predicted values in *Farmax* and the allowed value in *OVERSEER*. The resulting change in cow BCS over the winter period as predicted by *Farmax* in response to the different feed levels is presented. The target change in BCS was +0.5.

	Farmax	*OVERSEER*
Silage offered	11.5 kg DM cow^{-1} day^{-1}	9 kg DM cow^{-1} day^{-1}
Silage utilised	9.8 kg DM cow^{-1} day^{-1} (this is a 85% utilisation)	7.6 kg DM cow^{-1} day^{-1} (assuming 85% utilisation)
Farmax predicted change in BCS over winter under different feeding regimes	+0.5	-0.3

8.3.5 Scenario variations

After the initial scenarios for the base farm, the portable pad and barn systems were run for the Pukemutu soil at Telford, additional scenarios were conducted in *OVERSEER* to look at the impacts of different soil types and climates on N leaching.

8.3.5.1 Climate

Two different climates were modelled in *OVERSEER*. The inputs for these were generated by *OVERSEER* using the climate station tool in the 'Climate' tab for each farm block. This tool generates rainfall, total PET and average temperature data from latitude and longitude data inputs. The co-ordinates used were those for Telford (latitude 46.275°S, longitude 169.725°E) and Woodlands (latitude 46.375°S, longitude 168.575°E) which are the examples of a low and high rainfall region used in Chapter 7. The values predicted by *OVERSEER* are shown in Table 8.5.

Table 8.5. Regional climate data predicted by *OVERSEER* using the 'climate station tool'

	Telford (low rainfall)	Woodlands (high rainfall)
Total rainfall (mm yr^{-1})	717	1156
Total PET (mm yr^{-1})	796	766
Average temperature (°C)	10.4	10.0
OVERSEER predicted drainage – Pukemutu soil (mm yr^{-1})	31	95
OVERSEER predicted drainage – Gore soil (mm yr^{-1})	159	473

8.3.5.2 Soil type

Four of the soil types that were modelled in APSIM (Chapter 7) were used for comparative purposes in this exercise. The soils modelled, and soil parameters selected for *OVERSEER*, were:

1. Pukemutu silt loam (Argillic-fragic Perch-gley Pallic; Hewitt (1998) p 92), 'medium' soil texture group in the lower profile, susceptibility to pugging is 'winter or rain', 100% of the area mole and tile drained. PAW to 70 cm is 149 mm (Table 7.3).
2. Waikoikoi silt loam (Fragic Perch-gley Pallic; Hewitt (1998) p 92), 'medium' soil texture group in the lower profile, susceptibility to pugging is 'winter or rain', 100% of the area mole and tile drained. PAW to 70 cm is 210 mm (Table 7.3).

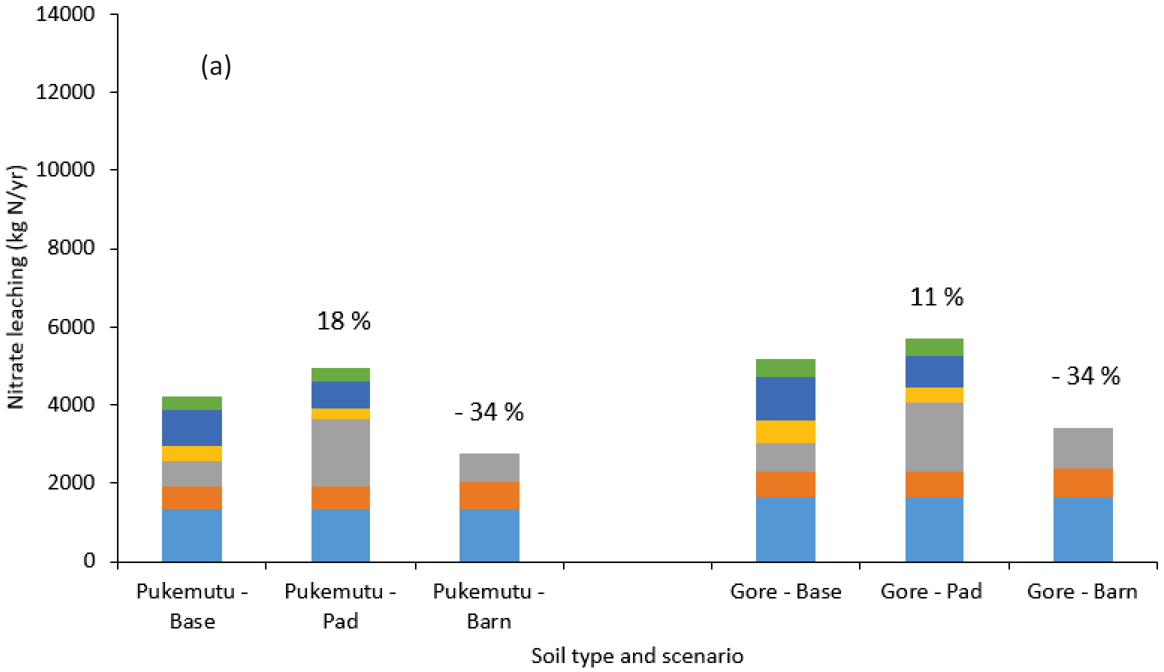
3. Lismore stony silt loam (Pallic firm brown; Hewitt (1998) p 60), topsoil texture is 'stony', 'medium' soil texture group in the lower profile, pugging is 'rare' and there is no artificial drainage. PAW to 70 cm is 158 mm (Table 7.3).
4. Gore stony silt loam (Acidic Orthic Brown; Hewitt (1998 p 61), topsoil texture 'stony', 'medium' soil texture group in the lower profile, pugging is 'rare' and no artificial drainage. PAW to 70 cm is 53.8 mm (Table 7.3).

Soil test values for all were populated with typical values generated by *OVERSEER*. These were: Olsen P 30 (mg P kg^{-1}), Quick Test (QT) K 7, QT Ca 9, QT Mg 21, QT Na 8, Organic S 9 (mg kg^{-1}).

8.4 *OVERSEER* Results

The results for the poorly drained Pukemutu and stony Gore soils, representing the two extremes of the soils simulated, are presented and discussed here.

OVERSEER nitrogen leaching loss predictions of the barn scenario resulted in a considerable reduction in N leaching compared to the base scenario (average 34% and 47% reduction over the two soil types under Telford and Woodlands climates, respectively). The use of the whole portable pad system, including the LRLD winter irrigation to pasture, increased N losses of the base scenario by 18% in the Telford rainfall region (717 mm yr^{-1})and an average of 15 % in the Woodlands region (1156 mm yr^{-1}; Figure 8.1).



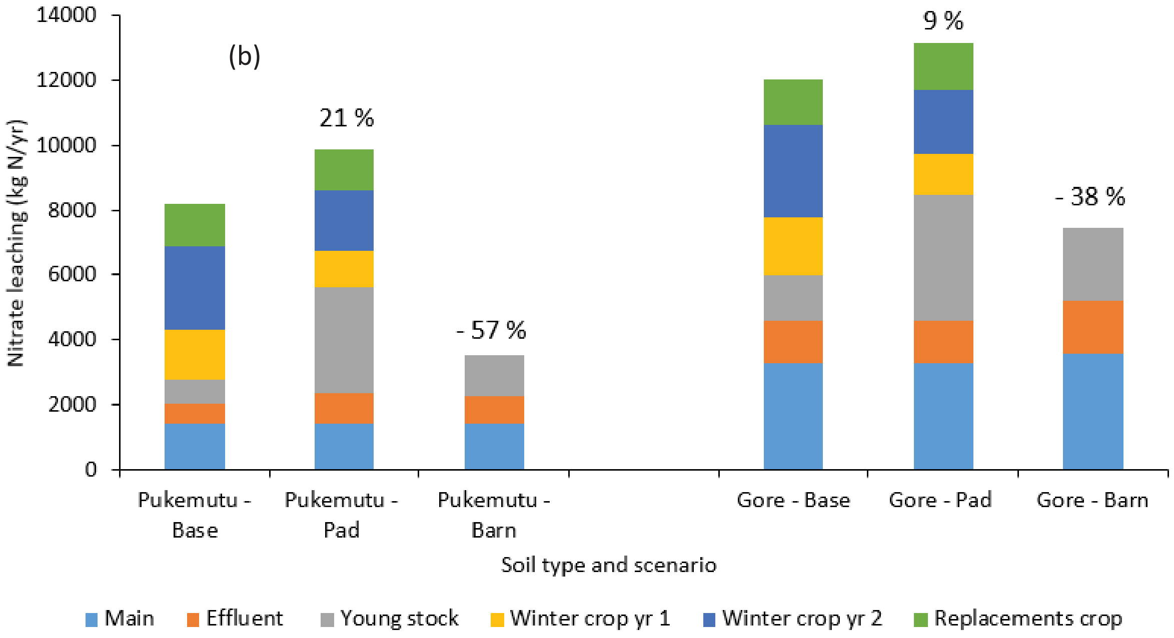


Figure 8.1. *OVERSEER* predictions of whole farm N leaching losses for the 4 farm wintering system scenarios modelled over four soil types (two shown in the figure; poorly drained Pukemutu and stony Gore soils) and for two climates, Telford rainfall region with 717 mm annual rainfall (a) and Woodlands rainfall region with 1156 mm annual rainfall (b).

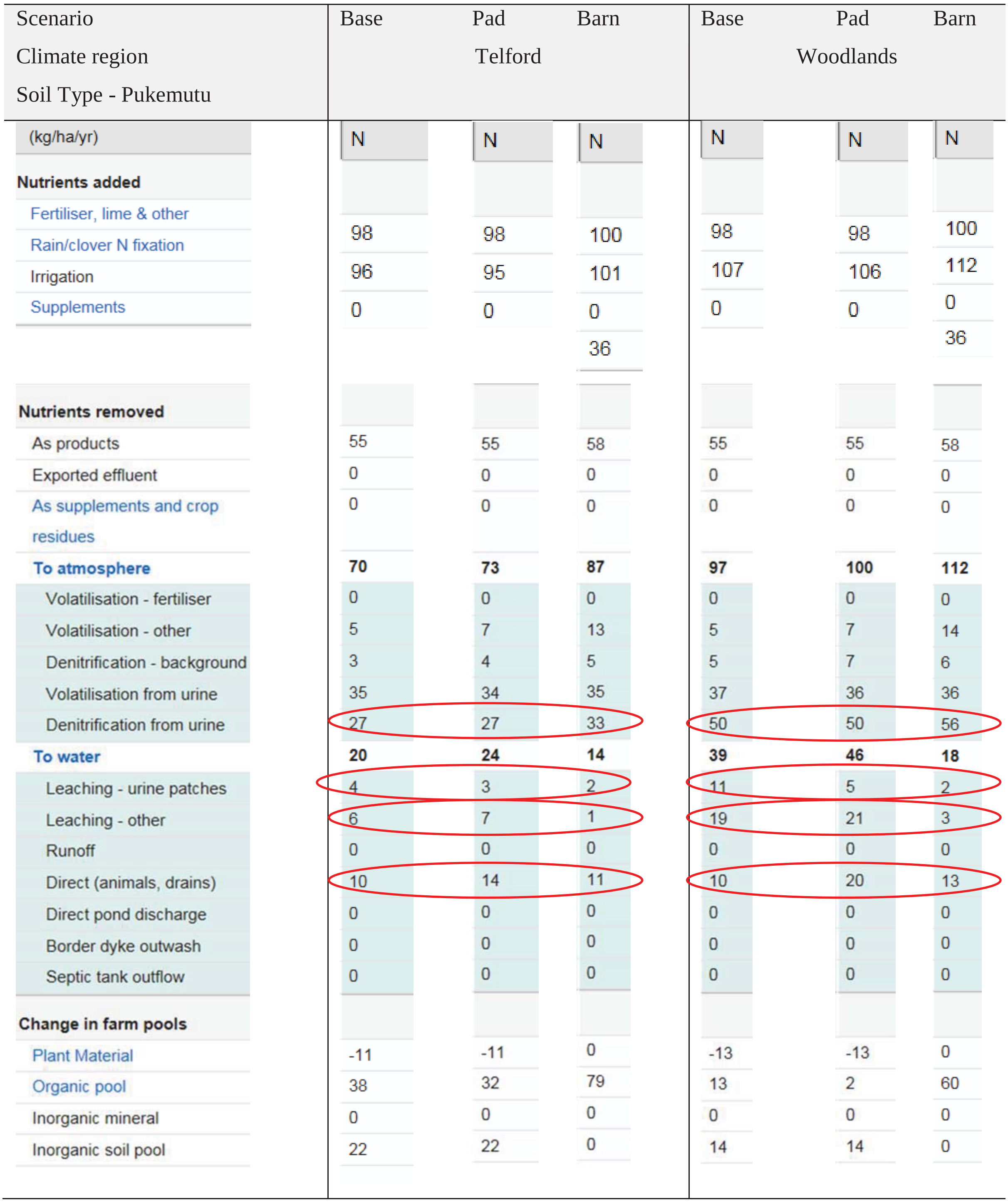
A breakdown of the leaching losses of nitrogen (predicted by *OVERSEER*) from the different scenarios (base, pad and barn), under the two climates (Telford 717 mm yr^{-1} and Woodlands 1156 mm yr^{-1}) and for two contrasting soil types (poorly drained Pukemutu (a) and stony Gore (b)) are shown in Table 8.6. In the mole and tile drained Pukemutu soil a significant proportion of the N leaching losses were from 'Direct (animal, drains)' which will be the leaching losses from the tile drain network (Table 8.6a). This particular loss pathway is not present in the stony undrained Gore soil (Table 8.6b). In all the base and pad scenarios, the losses from the crop paddocks as 'Leaching – other' is a large source of N leaching (after tile drainage losses). This loss pathway is investigated further in section 8.5.2.

While the focus of this work is on the N leaching losses it is interesting to note that the barn scenario, with the lowest N leaching losses, has the highest N losses to the atmosphere (Table 8.6). The gaseous N losses were greater in the Pukemutu soil than the Gore and larger under the higher rainfall climate. This is a result of significantly more 'Denitrification from urine' in the fine textured soils (33 and 56 kg N ha^{-1} yr^{-1} for Telford and Woodlands barn on a Pukemutu soil, respectively), compared to stony soils 1 and 2 kg N ha^{-1} yr^{-1} for Telford and Woodlands barn on a Gore soil, respectively).

The results show that losses of N to water were strongly influenced by rainfall and therefore the quantity of drainage. Losses were higher, for the same system, in a higher rainfall region than in the lower rainfall region (Table 8.6). As an example, the N leaching losses from the base farm on a Pukemutu soil under the Telford rainfall (717 mm yr^{-1}) was 20 kg N y^{-1}, losses were approximately twice as large (39 kg N y^{-1}) under the Woodlands climate (1156 mm yr^{-1}). The losses on the Gore soil from the base farm under the Telford climate were 24 kg N y^{-1} and under the Woodlands climate they were 141 % greater (58 kg N yr^{-1}). This effect is greater than the effect seen under the same climate but different soil types. Losses from the base farm under a Telford climate were 20 kg N y^{-1} from a Pukemutu soil and 24 kg N y^{-1} (20 % higher) from a Gore soil than a Pukemutu. The difference between soil types is greater under the Woodlands climate, where 39 and 58 kg N y^{-1} was leached from the Pukemutu and Gore soils, respectively, representing a 49 % increase.

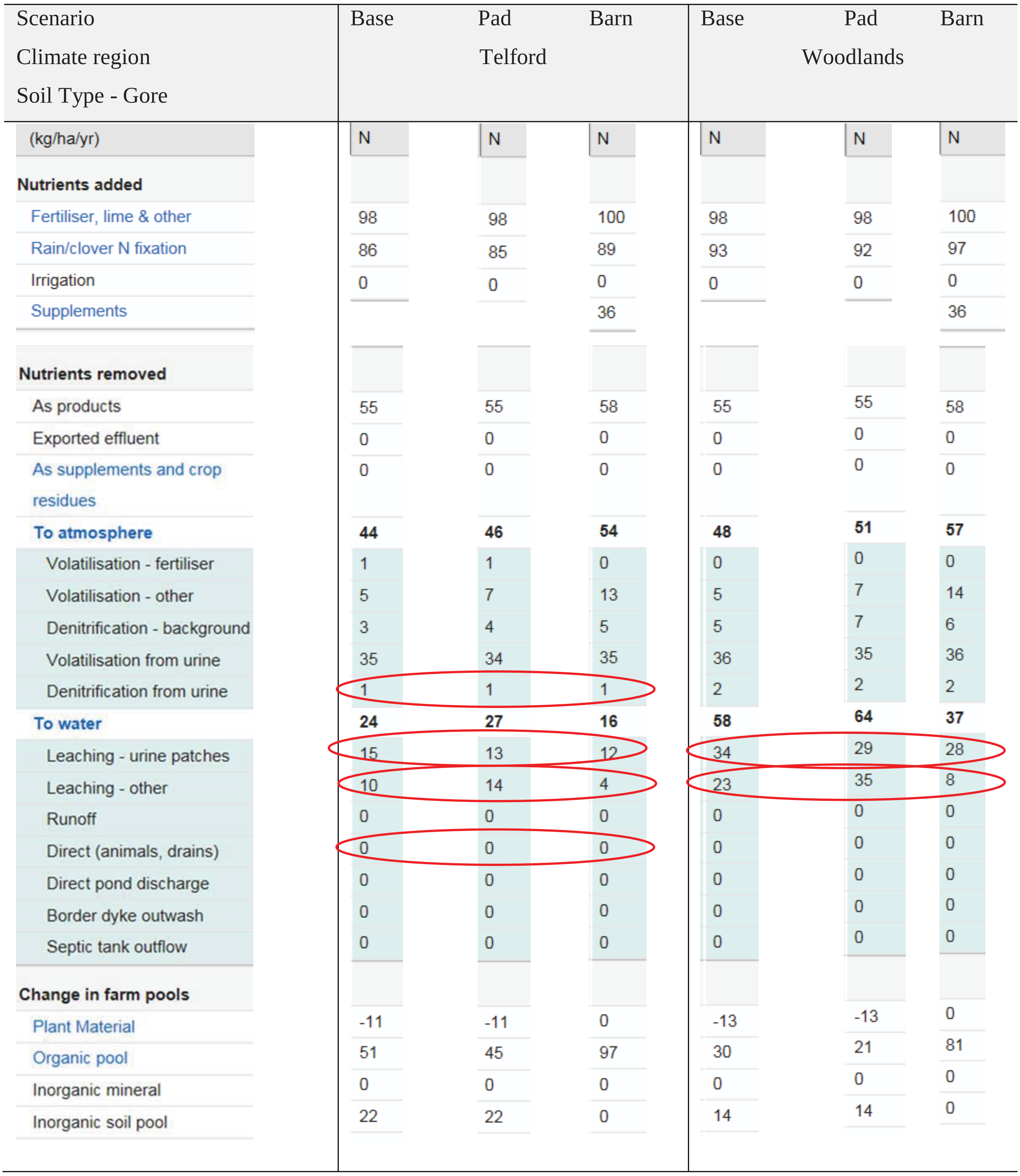
Table 8.6. Screen prints of *OVERSEER* nutrient budget scenario reports for Nitrogen. Nitrogen added to and lost from the system for the base, pad and barn scenarios for both the Telford (717 mm rainfall yr^{-1}) and Woodlands (1156 mm rainfall yr^{-1}) climates are presented for (a) the Pukemutu soil and (b) the Gore soil.

(a)



Scenario	Base	Pad	Barn	Base	Pad	Barn
Climate region		Telford			Woodlands	
Soil Type - Pukemutu						
(kg/ha/yr)	N	N	N	N	N	N
Nutrients added						
Fertiliser, lime & other	98	98	100	98	98	100
Rain/clover N fixation	96	95	101	107	106	112
Irrigation	0	0	0	0	0	0
Supplements			36			36
Nutrients removed						
As products	55	55	58	55	55	58
Exported effluent	0	0	0	0	0	0
As supplements and crop residues	0	0	0	0	0	0
To atmosphere	**70**	**73**	**87**	**97**	**100**	**112**
Volatilisation - fertiliser	0	0	0	0	0	0
Volatilisation - other	5	7	13	5	7	14
Denitrification - background	3	4	5	5	7	6
Volatilisation from urine	35	34	35	37	36	36
Denitrification from urine	27	27	33	50	50	56
To water	**20**	**24**	**14**	**39**	**46**	**18**
Leaching - urine patches	4	3	2	11	5	2
Leaching - other	6	7	1	19	21	3
Runoff	0	0	0	0	0	0
Direct (animals, drains)	10	14	11	10	20	13
Direct pond discharge	0	0	0	0	0	0
Border dyke outwash	0	0	0	0	0	0
Septic tank outflow	0	0	0	0	0	0
Change in farm pools						
Plant Material	-11	-11	0	-13	-13	0
Organic pool	38	32	79	13	2	60
Inorganic mineral	0	0	0	0	0	0
Inorganic soil pool	22	22	0	14	14	0

(b)



Scenario Climate region Soil Type - Gore	Base	Pad Telford	Barn	Base	Pad Woodlands	Barn
(kg/ha/yr)	N	N	N	N	N	N
Nutrients added						
Fertiliser, lime & other	98	98	100	98	98	100
Rain/clover N fixation	86	85	89	93	92	97
Irrigation	0	0	0	0	0	0
Supplements			36			36
Nutrients removed						
As products	55	55	58	55	55	58
Exported effluent	0	0	0	0	0	0
As supplements and crop residues	0	0	0	0	0	0
To atmosphere	**44**	**46**	**54**	**48**	**51**	**57**
Volatilisation - fertiliser	1	1	0	0	0	0
Volatilisation - other	5	7	13	5	7	14
Denitrification - background	3	4	5	5	7	6
Volatilisation from urine	35	34	35	36	35	36
Denitrification from urine	1	1	1	2	2	2
To water	**24**	**27**	**16**	**58**	**64**	**37**
Leaching - urine patches	15	13	12	34	29	28
Leaching - other	10	14	4	23	35	8
Runoff	0	0	0	0	0	0
Direct (animals, drains)	0	0	0	0	0	0
Direct pond discharge	0	0	0	0	0	0
Border dyke outwash	0	0	0	0	0	0
Septic tank outflow	0	0	0	0	0	0
Change in farm pools						
Plant Material	-11	-11	0	-13	-13	0
Organic pool	51	45	97	30	21	81
Inorganic mineral	0	0	0	0	0	0
Inorganic soil pool	22	22	0	14	14	0

In summary, *OVERSEER* predicted losses from the three different scenarios were:

Base farm, Pukemutu soil, Telford climate	20 kg N ha^{-1} yr^{-1}
Portable pad, Pukemutu soil, Telford climate	24 kg N ha^{-1} yr^{-1}
Barn, Pukemutu soil, Telford climate	14 kg N ha^{-1} yr^{-1}
Base farm, Pukemutu soil, Woodlands climate	39 kg N ha^{-1} yr^{-1}
Portable pad, Pukemutu soil, Woodlands climate	46 kg N ha^{-1} yr^{-1}
Barn, Pukemutu soil, Woodlands climate	18 kg N ha^{-1} yr^{-1}
Base farm, Gore soil, Telford climate	24 kg N ha^{-1} yr^{-1}
Portable pad, Gore soil, Telford climate	27 kg N ha^{-1} yr^{-1}
Barn, Gore soil, Telford climate	16 kg N ha^{-1} yr^{-1}
Base farm, Gore soil, Woodlands climate	58 kg N ha^{-1} yr^{-1}
Portable pad, Gore soil, Woodlands climate	64 kg N ha^{-1} yr^{-1}
Barn, Gore soil, Woodlands climate	37 kg N ha^{-1} yr^{-1}

The influence on N leaching losses, in order of a decreasing degree of influence, are: rainfall, soil type and farm system.

8.4.1 **Portable pad results**

OVERSEER predicted increased N leaching losses under a portable pad system compared to the traditional brassica crop wintering system (Table 8.6). However, a field experiment (Chapter 6) and modelling investigations (using APSIM) into the likely predicted losses from LRLD winter applied effluent suggest that the losses from this component of the system are minimal (Chapter 7; Table 7.7). In addition, logic and the results from an experiment investigating the temporal pattern of urination events (Chapter 5) suggest that the use of a portable pad for 18 hours a day should result in reduced N leaching losses from the winter crop component of the portable pad system compared with the base system where the crop is grazed 24 hr day^{-1}. While there was some reduction in N leaching losses from urine patches predicted by *OVERSEER* for the Gore soil in response to the pad, these reductions were not as large as would be expected. This appears to be due to the high contribution to total N leaching from non-urine patch losses in the crop paddock. This is contradictory to the thought of some researchers that the majority of N leaching losses from a winter crop are urine derived (Lilburne *et al.* 2012). Although other researchers acknowledge the contribution to N leaching losses of large amounts of mineral N that may remain in the soil after grazing and the cultivation process

(Monaghan *et al.* 2013). Examples of measured N leaching from urine and non-urine patches are available in the literature. In a lysimeter trial measuring N leaching losses under winter grazed kale with and without urine added, it was found that losses under the urine treatments were as high as 475 kg mineral-N ha^{-1} while the non-urine treatment losses were 33 kg mineral-N ha^{-1} (Malcolm *et al.* 2015). A similar experiment, investigating N leaching under grazed fodder beet, measured losses of 53 and 79 kg mineral-N ha^{-1} in two separate drainage seasons from urine patches and only 10 kg mineral-N ha^{-1} from the non-urine patch areas (Malcolm *et al*, 2016).

In section 8.5 this disparity between modelled results and the expected results (given current knowledge, as described in the literature, and measured data from chapters 5 and 7) is investigated. Alternative values for N leaching losses from the young stock block incorporating the area of land receiving LRLD winter applied effluent, and the winter crop paddocks are presented.

8.5 Identifying disparity between measured, APSIM-modelled, and *OVERSEER* N leaching losses

8.5.1 N leaching losses from winter-applied effluent using the low rate, low depth technology

In the *OVERSEER* simulation of the portable pad scenario, modelled effluent captured on the pad was applied to pasture (15.3 and 19.2 ha under a Telford and Woodlands climate, respectively; Table 8.7) on the Young Stock Block. Compared with the simulation of the base crop the simulation of the portable pad system, including the LRLD application of effluent to pasture, created greater N leaching losses to water. The 'Young Stock' block was the source of the whole farm increase in N leaching (Figure 8.1). In part, this is expected as *OVERSEER* is not able to simulate the recently developed LRLD system. The low depth effluent experiment presented in chapter 6 resulted in actual losses in drainage water from the 2 mm application depth of an average of 23.9 kg N ha^{-1} (Chapter 6; Table 6.13). This was with a total application load of 150 kg N ha^{-1}. This values is smaller than the range predicted by *OVERSEER* of, 31 to 68 kg N ha^{-1}. In addition, simulations of the LRLD effluent application in APSIM predicted even smaller N leaching losses (range 0.1 to 18 kg N ha^{-1}). (Section 7.10 , Figure 7.12).
Thus, the next stage of the analysis was to explore the portable pad scenario results using APSIM predictions rather than the *OVERSEER* prediction, of N losses to water from the 'Young Stock' block.

The pasture areas required to accommodate the recommended N load (80 kg ha^{-1}; Chapter 7, Section 7.3.4) of the liquid effluent generated by the portable pad were 3.83 ha and 4.8 ha per 100 cows for

Telford and Woodlands regions, respectively (total areas required were 15.3 and 19.2 ha for the simulated 400 cows). Values of N losses to water per hectare generated by APSIM modelling (Chapter 7; Figure 7.12) are shown in Table 8.7. Over-estimation of N leaching losses from the portable pad system by *OVERSEER* appears to result from the effluent application using LRLD to the Young Stock pasture block. The impact of effluent application in addition to stock grazing the pasture block was estimated as follows. The N losses to water caused by grazing-only was estimated using *OVERSEER*. The additional N loss created by effluent application was simulated using APSIM and then added to the N lost from grazing. The average block losses predicted by *OVERSEER* plus the values for the LRLD effluent applications predicted by APSIM are shown in Table 8.7. The percentage over-prediction of the full grazing plus LRLD effluent application by *OVERSEER* were higher in the high rainfall region and also on the finer textured soils (Table 8.7). Over-prediction for the Young Stock Block ranges from 7 % on the Gore soil in the lower rainfall region, to 74 % on the Pukemutu soil in the higher rainfall region. Over-predictions were a lot higher in the imperfectly drained soil than the stony Gore soil.

Table 8.7. Values for N loss to water derived from APSIM modelling (Chapter 7; Figure 7.12) to improve predictions of N leaching losses from LRLD effluent application to land in winter at a low (Telford; 717 mm) and a high (Woodlands; 1156 mm) rainfall. Applications of effluent to a poorly drained Pukemutu soil and a freely drained Gore soil occurred for 70 days, from 1 June until 10 August. *OVERSEER*-predicted N losses for the young stock block (with the addition of winter applied effluent using LRLD) and predicted values accounting for the APSIM modelled results for LRLD are given.

Soils	Pukemutu		Gore	
Region/rainfall	Telford	Woodlands	Telford	Woodlands
LRLD application area and losses				
Land area required for 400 cows (ha)	15.32	19.2	15.32	19.2
N losses (Kg N ha^{-1}) due to effluent application (APSIM predicted)	0.4	1.4	16.9	18.3
OVERSEER Young Stock Block grazing only losses (taken from Base farm)	11	13	13	25
Whole block losses (kg N ha^{-1})				
OVERSEER-predicted Young Stock Block N losses to water (kg N ha^{-1} yr^{-1})	30	57	31	68
Predicted Young Stock Block losses using *OVERSEER* plus APSIM (kg N ha^{-1} yr^{-1})	11.4	14.5	28.9	43.3
% reduction	62 %	74 %	7 %	36 %

8.5.2 Altering crop losses to represent urine data from Chapter 5 and data from the literature

OVERSEER simulates and reports the total block N leaching losses separated into 'leaching – urine' and 'leaching – other'. Thus, for the crop paddocks it was possible to determine the extent that *OVERSEER* reduced the leaching losses in response to the restricted grazing in the portable pad scenario. The losses predicted by *OVERSEER* for the portable pad and base scenarios can be seen in Table 8.9. This shows that *OVERSEER* reduced the quantity of N leaching under urine patches from the crop paddock in the pad system to approximately 25% of the corresponding base farm value: this equates to the relative percentage of the day that the cows were on-paddock.

However, if only 9% of the daily urinary N was deposited on the paddock during the 6 hour grazing period (Chapter 5; Table 5.8) it could be expected that the crop losses for the portable pad scenarios on the different soil types would be lower than those predicted by *OVERSEER*. Calculated losses from crop paddocks, assuming 9% of urine events occur on paddock and are shown in Table 8.9.

It can be seen in Table 8.9 that the 'leaching – urine patch' losses predicted by *OVERSEER* for crop blocks are smaller than the 'leaching - other' losses. The large values of N predicted as leaching from non-urine patches (i.e. the remainder of the paddock) are questionably high (range 35 – 157 kg N ha^{-1} yr^{-1}). These were likely derived from soil organic matter (OM) and uneaten crop residue mineralisation. The graph of N pools for a first year swede crop produced by *OVERSEER* can be seen in Figure 8.2. This shows that residue root N (blue line) increases from 90 to 290 kg N ha^{-1} over the month (December) immediately following cultivation. This N is then mineralised over the next 12 months, the resulting soil mineral N pool is in excess of 120 kg N ha^{-1} for most of the drainage season. This results in *OVERSEER* calculating large N leaching losses from the paddock and attributing a large loss to the non-urine patch area.

This high plant residue can also be seen in the *OVERSEER* generated graphs of the change in N pools for the first and second year winter crop blocks (shown here for a Gore soil with Woodlands climate; Figure 8.3). The graphs are for both the pad scenario (grazing restricted to 6 hours day^{-1}; bottom row, Figure 8.3) and also the base scenario where cows graze the crop 24 hours day^{-1} (top row, Figure 8.3). The value in the graphs of annual OM mineralisation (156 kg N ha^{-1} yr^{-1}) is the value given in the *OVERSEER* prediction of non-urine N leaching losses in Table 8.8. This is the annual value but it can be seen in the graphs (Figure 8.2) that the N leaching losses (kg N ha^{-1}) peak over Nov-Jan each year. This OM response follows the curve of the 'residue' line suggesting a relationship between plant residue and OM mineralisation. In contrast, work by Malcolm *et al.* (2016) found losses from a grazed fodder beet crop, on a stony Balmoral soil, receiving no urine were 10 – 11 kg NO_3^- - N ha^{-1} which is significantly lower than the 156 kg N ha^{-1} yr^{-1} predicted by *OVERSEER* (Table 8.8). The Malcolm *et al.* (2016) experiment was conducted using lysimeters with water inputs (rain plus irrigation) of 1172 and 1017 mm yr^{-1}, for each year of the two-year experiment and drainage values of 425 and 350 mm for each year of the two-year experiment. The water input used by Malcolm *et al* (2016) is not dissimilar to the 1156 mm yr^{-1} for the Woodlands scenarios and the drainage value only slightly lower than the 569 mm predicted by *OVERSEER* for the Woodlands scenario on a Gore soil. Values reported here are for 12 months compared to 9 – 10 months for Malcolm *et al.* (2016). These authors conducted a similar lysimeter experiment investigating N leaching losses from a kale crop (Malcolm *et al.* 2015). Here the losses from non-urine patches were 33 kg N ha^{-1} yr^{-1}, in this experiment the rainfall was 1160 mm and drainage was 535 mm (similar to the *OVERSEER* predicted drainage of 569 mm; Table 8.8).

In Malcolm *et al.* (2015), kale was harvested to a residual height of 10 cm when grazing was simulated and the lysimeters remained fallow until mid-spring when they were resown in pasture. In the fodder beet trial the fodder beet plants were pulled and removed from the lysimeters to simulate grazing. Lysimeters remained fallow until spring when they were resown in pasture. Both trials were mechanically 'trampled' at the time of simulated grazing. There was very little plant residual remaining after the simulated grazing in either of the trials, but particularly the fodder beet trial (Malcolm, pers comms 2016). This would appear to support the theory that the mineralisation of the crop residue N as predicted by *OVERSEER* is causing the large modelled non-urine leaching losses. This is an interesting point as, in *OVERSEER*, the user is unable to select a crop utilisation value whereas when feeding supplementary feed, such as baleage, there is the ability for the user to rank the utilisation as 'very good', or 'good'. It is suggested that the development of a 'crop utilisation' or 'crop residual' function within *OVERSEER* would enable better predictions of N leaching losses from non-urine areas of a grazed winter brassica crop.

Table 8.8. Description of non-urine patch losses from winter grazed brassica crops. A comparison between *OVERSEER* modelled results and measured results in the literature of; crop type, non-urine patch N leaching losses, rainfall input, drainage volume, and reporting period.

Measured or Modelled	Measured[1]	Measured[2]	Measured[2]	*OVERSEER* modelled
Crop	Kale	Fodder Beet	Fodder Beet	Swedes
Non-urine N losses kg N ha^{-1}	33	10	11	156
Rainfall input (mm)	1160	1172	1017	1156
Drainage (mm)	535	425	350	569
Reporting period	June – May (11 months)	June – April (10 months)	June – May (9 months)	Jan – Dec (1st yr crop) Nov – Oct (2nd yr crop)

[1]Malcolm *et al.* (2015); [2]Malcolm *et al.* (2016)

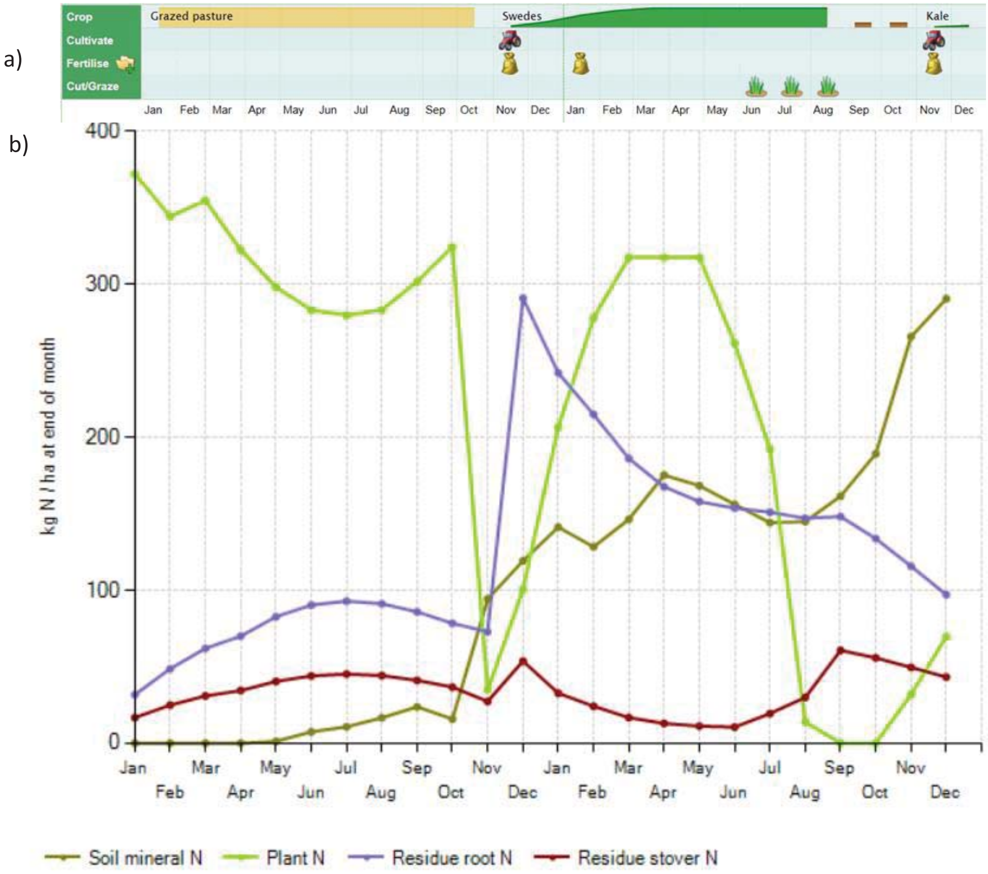


Figure 8.2. Screen print of *OVERSEER* crop rotation table (a) and N pools graph (b) for first year cow crop block from the base farm scenario of a stony Gore soil and a Woodlands rainfall climate (1156 mm yr^{-1}). The first 12 months the paddock is in pasture, conventional cultivation and crop sowing occurs in November of the first year, grazing occurs during June-Aug of the second year, it remains fallow for September and October, then cultivated using minimum till in the second November for a second-year winter crop.

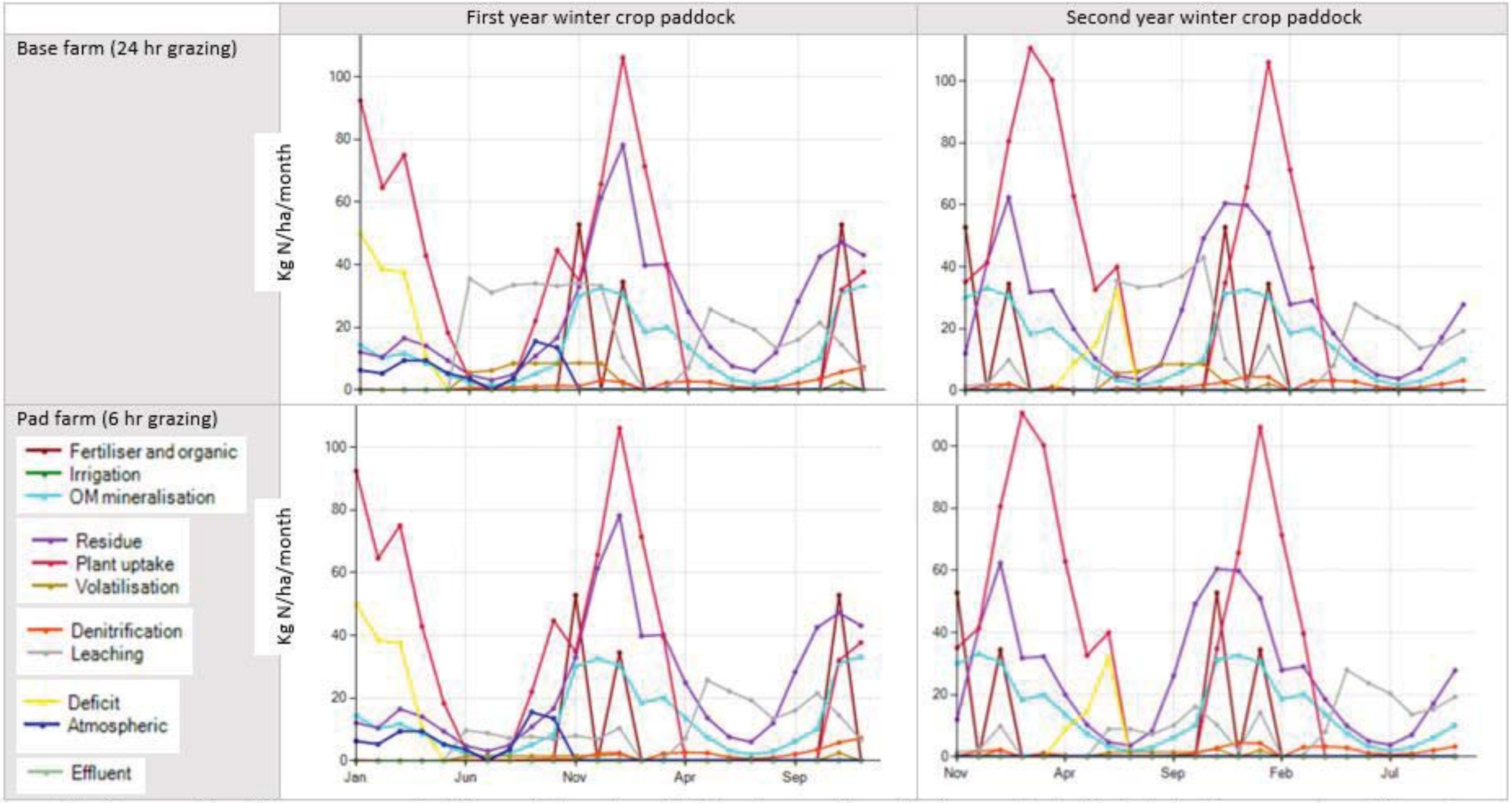


Figure 8.3. Screen prints of *Overseer* generated 'Change in N pool graphs'. Graphs are of the wintering crop blocks for both the base scenario and the pad scenario under a Woodlands climate and on a Gore soil type. Both first and second year cropped paddocks are shown. The pad scenario depicts a restricted grazing scenario where cows graze 6-hours-a-day compared to the base farm scenario where they graze 24-hours-a-day. Note the graphs on the left have a Jan-Dec scale whereas the graphs on the right have a Nov-Oct scale.

In other work, total N leaching losses (urine patch plus non-urine patch areas) measured under grazing of a winter brassica crop (on a free draining soil in Northern Southland) averaged 81 kg N ha^{-1} yr^{-1} but were as small as 8.5 kg N ha^{-1} yr^{-1} (Smith *et al.* 2012). This along with Malcolm *et al* (2015, 2016) research, supports the suggestion that *OVERSEER* values of 'leaching – other' are larger than they should be.

In order to generate alternative values to the unrealistic *OVERSEER* estimates for 'leaching-other', the following process was derived. The first step was to correct the values for N leaching from the non-urine patch in the Gore soil under a Woodlands climate. This site was chosen first as there was published data for two lysimeter experiments measuring leaching losses from grazed winter brassica crops under both urine and non-urine patches (Malcolm *et al.* 2015; Malcolm *et al.* 2016). These lysimeter experiments were conducted on a Balmoral stony soil, similar to the Gore soil, and rainfall inputs were similar to the rainfall at Woodlands. Nitrogen loss values for urine and non-urine patch areas were extrapolated to paddock scale (step 2) by estimating the area of the paddock covered by urine patches and then the difference in total area was the non-urine patch area. The area of the paddock covered by urine patches (per cow, per day) was calculated by multiplying the surface area covered by a urine patch deposited on a swede crop paddock (0.2 m^2 Cameron (2016)), the number of urination events per cow per day and the average paddock area per cow per day. The third step was to extrapolate this value to generate estimated values for the other soil type and climate (Step 3). The resulting figures are presented in Table 8.9.

The default values in *OVERSEER* were used to predict urine patch losses because there is a lack of data in the literature to allow the development of alternative values. Initially, a method was developed to estimate the contribution of urine patches from cows grazing a swede diet (step 4). However, this method required an accurate estimate of urine patch N concentration and load. Due to a lack of data in the literature and unreliable measurements (Chapter 5) there was little confidence in the values generated using this method so finally the default values for *OVERSEER* were used.

This represents an area where further research is required. Especially in the development of a standardised method for scaling lysimeter data up to represent losses under a grazed winter crop. Also, quantifying daily urinary N excretion values from cows fed a swede based diet and development of a method to estimate N loss from a known urinary N load.

i. *Steps taken to generate alternative N leaching loss values alternative to those predicted by OVERSEER*

Step 1 Estimate a value for non-urine patch N leaching under Gore soil and Woodlands climate

1. Non-urine patch losses from kale are reported at 33 kg N ha^{-1} (Malcolm *et al.* 2015) and 10 – 11 kg N ha^{-1} under fodder beet (Malcolm *et al.* 2016). Both experiments had a similar soil type to the Gore soil (Balmoral) and a similar rainfall + irrigation input to that of the Woodlands climate. Thus, a mid-point value (21 kg N ha^{-1}) is used as an estimate as there is no reported data pertaining to non-urine patch losses from a grazed swede crop.

To scale the value of 21 kg N ha^{-1} to paddock level, an estimate of the area of the grazed paddock that receives urine and the area that does not is required. No guidance was found in the literature on the proportions of these areas. Therefore Step 2 was used to calculate the area of the paddock receiving urine.

Step 2 Calculation of the area of the winter grazed forage crop paddock receiving urine and the area not receiving urine

1. Calculation of the average paddock area grazed per day per cow
   = (16 ha x 10,000) / (70 days x 400 cows) = 5.7 m^2 cow^{-1} day^{-1}
   It is acknowledged that as the winter progresses cows will have a larger area to move around (especially if the crop is not back-fenced).

2. Calculation of the percentage of the area receiving urine patches
   = 10 urinations cow^{-1} day^{-1} (Chapter 5, Table 5.8) x 0.2 m^2 urine $patch^{-1}$ (Cameron 2016) = 2 m^2 of the 5.7 m^2 covered by urine = 35%, assuming no overlap of patches. Thus non-urine patch areas are 65 % of the paddock.

Step 3 Non-urine patch N loss values adjusted for paddock area not receiving urine

1. To calculate the N loss load per hectare the urine and non-urine patch values must then be estimated on a weighted area of the grazed paddock. Thus the non-urine patch area losses were calculated as 21 kg N ha^{-1} (Step 1) multiplied by 65 % (Step 2) which is 14 kg N ha^{-1} for the Gore soil under a Woodlands climate.

2. In order to estimate losses on the Gore soil under the drier Telford climate, the values from Malcolm *et al*, 2016 of 10 kg N ha^{-1} yr^{-1} in drainage were adjusted down by 38 % as the rainfall was 38 % lower than Woodlands. Thus the non-urine losses for the Gore soil under a Telford climate became 6 kg N kg N ha^{-1}.

3. Due to a lack of data for non-urine patch losses on a Pukemutu (or similar) soil, the lower values of Malcom *et al* (2016) data were selected to represent the losses from non-urine areas on Pukemutu soil plus Woodlands climate loss as this was the lowest reported value and there was no further information available to suggest an alternative value. Thus the value of 10 kg N ha^{-1} was used. Again this was reduced by 38 % to give a value of 6 kg N ha^{-1} for Pukemutu soil and Telford climate.

Step 4 A method for predicting N leaching losses from urine patches using a relationship between N load and % N lost in drainage.

1. Calculation of the urine patch N loading rate (Selbie *et al.* 2015)

$$\text{Urine N rate (kg N ha}^{-1}) = \text{Conc (g N L}^{-1}) \times \frac{\text{Vol (L)}}{\text{Surface area (m}^2)} \times 10$$

Where:

Conc = 4.4 g N L^{-1} (Stevens & Thompson 2012).

Volume = 19.6 L urine cow-1 day^{-1}/10.5 urination events cow^{-1} day^{-1} = 1.9 L urination $event^{-1}$ (Chapter 5, Table 5.8)

Surface area = 0.2 m^2 (Cameron 2016)

Resulting Urine N rate = 418 kg N ha^{-1}

The urine concentration value of Stevens and Thompson (2012) was taken from 20 cows on two sampling occasions. The cows were fed a diet of swede and baleage. There were two treatments, a high allowance and a standard allowance. The urinary N concentration did not differ significantly between the treatment groups. The cows were offered either: 11 kg DM swedes plus 4 kg DM baleage cow^{-1} day^{-1} or 9 kg DM swedes and 4 kg DM baleage cow^{-1} day^{-1}. Crude protein values of the swede leaf, swede bulb and baleage were 24.7, 8.2 and 16.7 % CP, respectively. Dry matter values were 13.3, 11.4 and 27 % DM for the leaf, swede bulb and baleage, respectively. The proportions of leaf and bulb offered were not measured.

2. The percentage of N applied, which is lost from a swede-fed cow urine patch on a Gore soil = 36 %. This value was generated by plotting literature values reported by Malcolm (2015, 2016) for the N load applied in a urine patch against the percentage of applied N that is lost in drainage. The resulting relationship is shown in Figure 8.4. The blue points represent the N losses in drainage a urine patch deposited by cows grazing fodder beet: the load in the urine patch was 250 & 300 kg N ha^{-1} (Malcolm *et al.* 2016). The red point represents the percentage loss of N in drainage of kale-fed cow urine at a load of 500 kg N ha^{-1} and the green point a kale-fed cow urine patch at 700 kg N ha^{-1} (Malcolm *et al.* 2015). The green dashed line represents the point a swede crop applying 418 kg N ha^{-1} would lie. Figure 8.4 suggests that approximately 36 % of the N applied in urine by cows grazing swedes is lost in drainage i.e. 154 kg N ha^{-1}. Due to the limited data available the best fit in Figure 8.4 is a linear extrapolation which was then used to estimate the percentage urinary N lost in drainage.

The values for rainfall and drainage in the two lysimeter experiments graphed below (Figure 8.4) are similar to the *OVERSEER* predicted values of 1156 mm rainfall and 555 mm drainage for the crop paddock of the Gore soil type and Woodlands rainfall. In addition, the drainage values measured by Malcolm *et al.* (2015, 2015; Figure 8.4) are similar to the 569 mm predicted by *OVERSEER*.

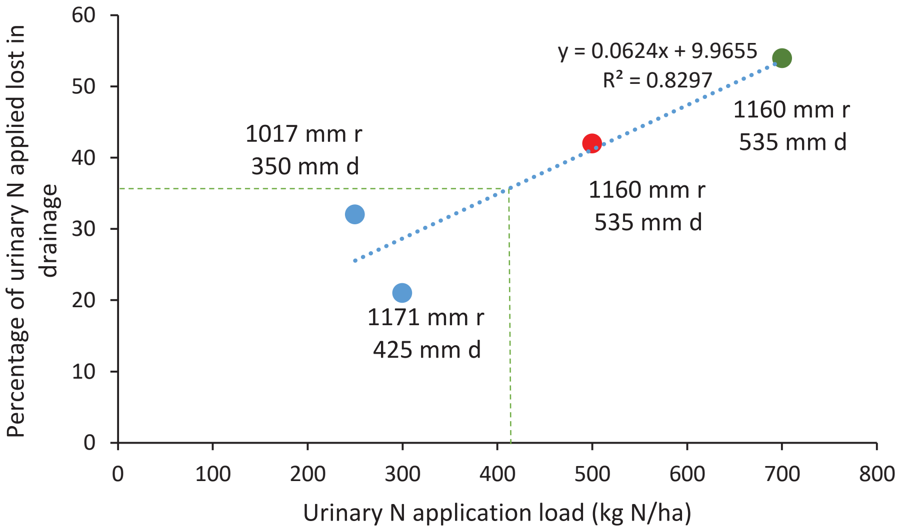


Figure 8.4. Plotted values of percentage N leached against N application load in urine deposited by cows grazing forage crops. Values are from fodder beet (red and green points; 11 months of measurements) and kale (blue points; 9-10 months of measurements) lysimeter experiments conducted on a Balmoral stony soil (Malcolm *et al.* 2015; Malcolm *et al.* 2016). Rainfall (r) and drainage (d) values for the individual trials are depicted on the graph. The dashed green line represents the percentage loss from an applied N load of 418 kg N ha^{-1}.

3. Thus urine patch losses would be 150 kg N ha^{-1} (36 % of 418 kg N ha^{-1}).

4. The contribution of urine patch losses to the whole paddock losses is 150 kg N ha^{-1} multiplied by 35% of the paddock receiving urine which equates to 53 kg N ha^{-1} from urine patches. This compares to 96 kg N ha^{-1} predicted by *OVERSEER* (Table 8.9; Woodlands/Gore/Base).

5. The whole paddock loss therefore, becomes 53 + 14 = 67 kg N ha^{-1} from a winter grazed swede crop on a Gore soil with the Woodlands climate. Compared to 253 kg N ha^{-1} yr^{-1} predicted by *OVERSEER* (Table 8.9) and 110 kg N ha^{-1} yr^{-1} calculated using the 'Combined Source Method' (Table 8.9).

However, as mentioned above, the calculated value for urine patch N losses is not used in the 'Combined Source' analysis due to a lack of urinary N data. Although the urine values predicted using the method outlined in Step 4 were lower than those predicted by *OVERSEER*. This highlights an area where further research is required as the N leaching losses under urine patches (and non-urine patches) for a range of winter brassica crops, soil types and rainfall inputs are poorly understood.

The 'Combined Source Method' is a combination of *OVERSEER* predictions of farm N losses for pastoral blocks on the farm combined with N losses from winter applied effluent using the LRLD application system extrapolated from field measurements and APSIM modelled results. In addition, crop block N loss predictions were a combination of *OVERSEER* predictions for the urine patch area leaching losses and N leaching losses calculated from literature values for the non-urine patch areas. The resulting values are presented as an alternative representation of the actual farm system losses compared to the values predicted by *OVERSEER* alone.

Table 8.9. *OVERSEER* predicted N leaching losses (kg N ha^{-1} yr^{-1}) from winter crop paddocks split into 'leaching - urine patches' and 'leaching – other' losses. Values for the portable pad and base farm scenarios are presented.

Soil type – crop year	Telford			Woodlands		
	Leaching – urine patches	Leaching - other	Total	Leaching – urine patches	Leaching - other	Total
OVERSEER predicted results for winter crop blocks (kg N ha^{-1})						
Pukemutu base	23	35	57	78	146	224
Pukemutu pad	5	35	40	18	146	164
Gore base	34	45	79	96	157	253
Gore pad	8	45	53	22	157	179
Corrected results for winter crop blocks– using the methods outlined section 8.5.1 and in Steps 1-3 in section 8.5.2						
Pukemutu base	23	6*	29	78	10	88[1]
Pukemutu pad	2.1	6*	8.1	7.0	10	17
Gore base	34	8*	42.8[2]	96	14	110
Gore pad	3.1	8*	19.2	9	14	22.9

* Value is 38 % lower than the Woodlands value as explained in Step 3, point 2.

[1] Value is higher than the value of 40 kg N ha^{-1} yr^{-1} reported by Monaghan *et al.* (2013) under a grazed swede crop on a Pukemutu soil and a Woodlands climate.

[2] Value is within the range of 8.1 - 122 kg N ha^{-1} yr^{-1} reported by Smith *et al.* (2012) on a stony soil under a climate similar to Telford.

8.6 Combined Source Method

The suggestion that the leaching values predicted by *OVERSEER* from a crop paddock were incorrect relates, not only to the portable pad scenario, but to the base farm scenario as well. This incorporates the three cropping areas on the farm: cow winter crop year 1, cow winter crop year 2, and replacement crop. Figure 8.5 shows the original *OVERSEER* values for the base and portable pad scenarios, compared with the values generated using the 'Combined Source' method. The crop paddock losses were significantly reduced in the 'Combined Source' calculations (Table 8.9). As an example, crop paddock losses from the base farm on a Pukemutu soil under the higher Woodlands rainfall, were reduced from 224 kg N ha^{-1} as predicted by *OVERSEER* to the re-calculated value of 88 kg N ha^{-1}. Losses on the same soil and climate conditions from the crop paddock on the farm utilising the portable pad were reduced from 164 kg N ha^{-1} (*OVERSEER* predicted) to 17 kg N ha^{-1} ('Combined Source' predicted).

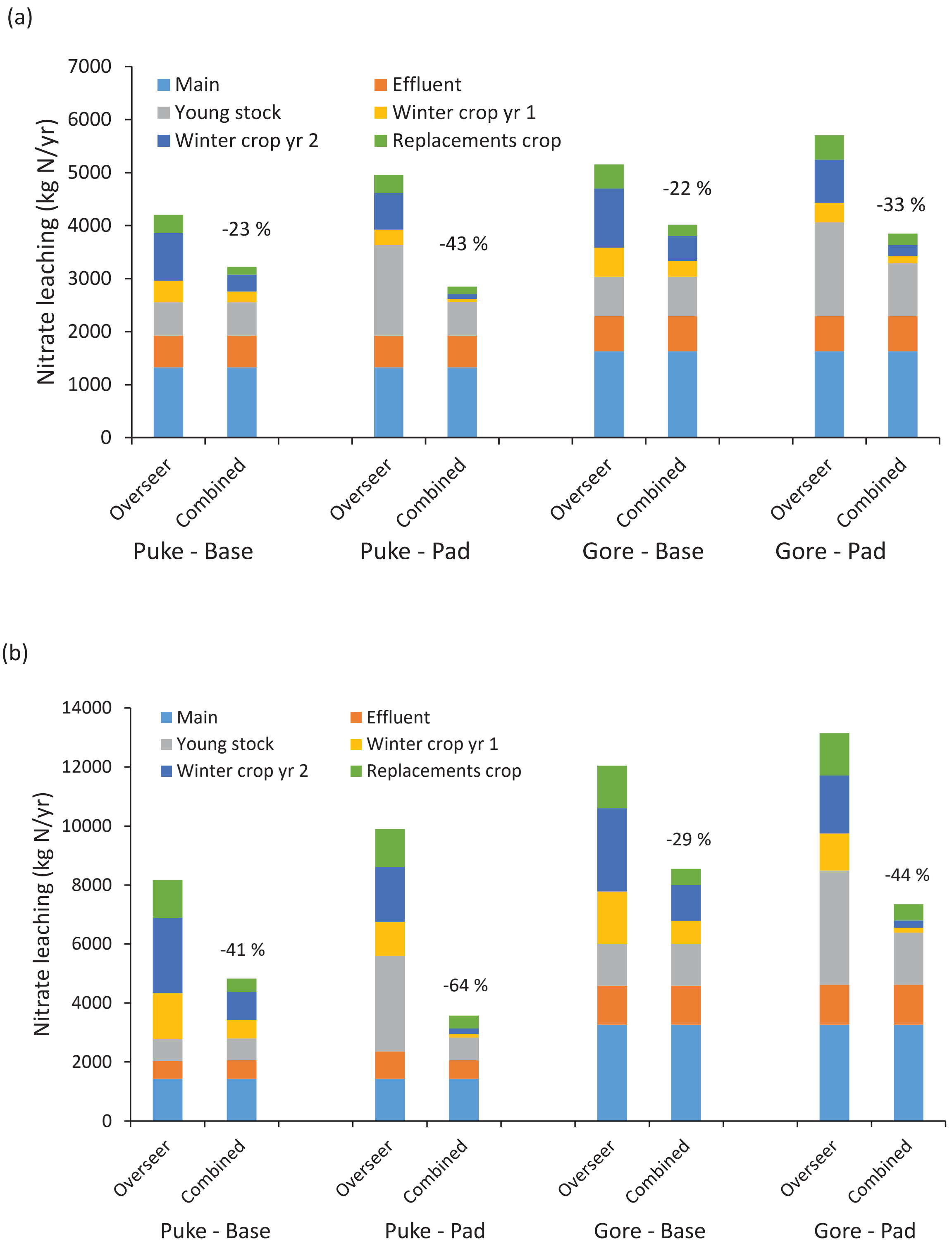


Figure 8.5. Comparison of *OVERSEER* predicted and 'Combined Source' values for the base and portable pad scenarios. Results are presented for the Pukemutu and Gore soil types and under a Telford (a; 717 mm rainfall yr^{-1}) and Woodlands (b; 1156 mm rainfall yr^{-1}) climate.

The combined potential over-estimation by *OVERSEER* of the N leaching losses under grazed crop and also from under LRLD effluent irrigation in winter results in between 22 to 43% over-prediction under a Telford climate and 29 to 64% over-prediction under a Woodlands climate (Figure 8.5).

The re-worked comparison of the 3 different farming systems is shown in Figure 8.6 where all scenarios contain 'Combined Source' crop and LRLD losses, where applicable.

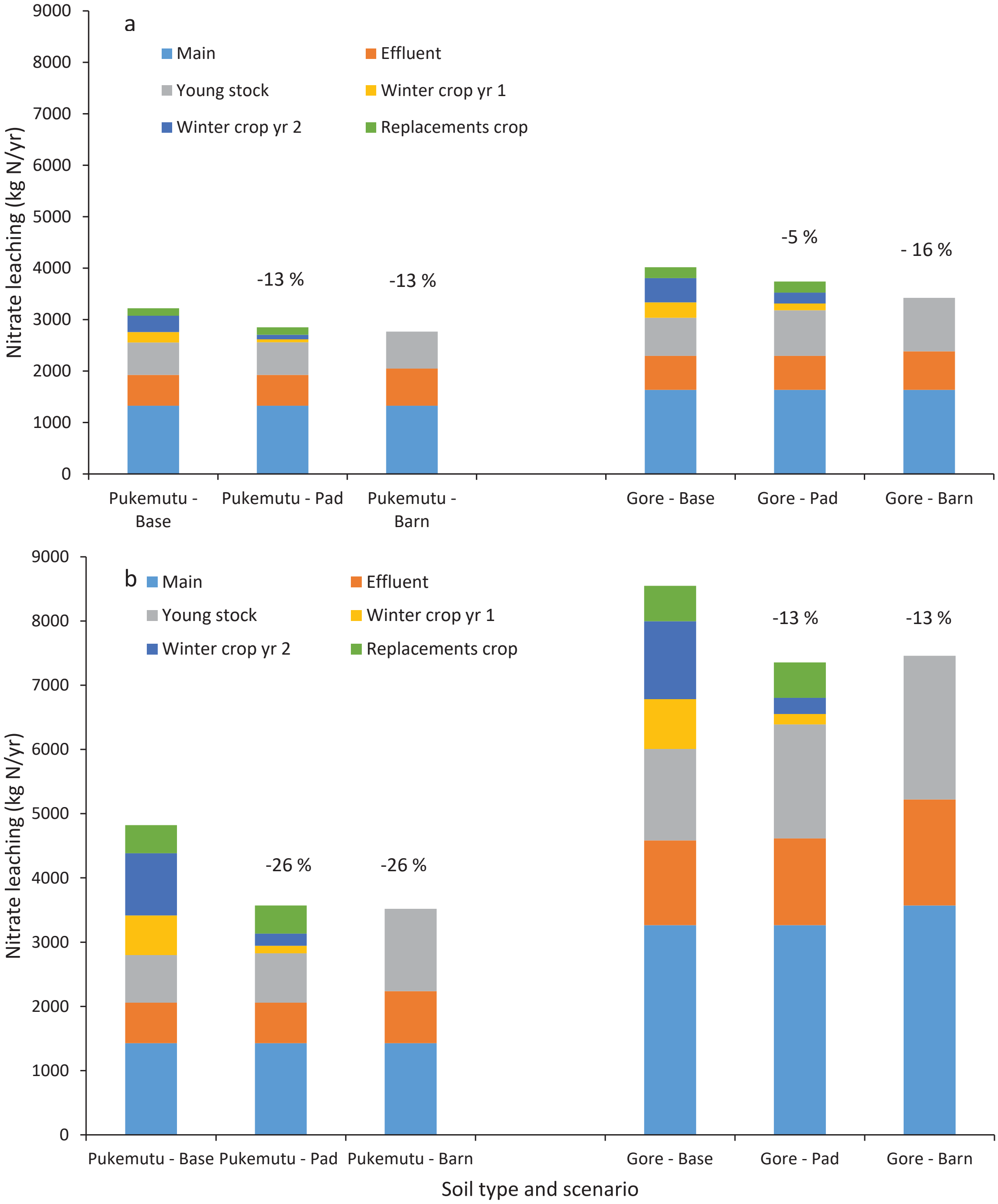


Figure 8.6. Whole farm system losses for the base, portable pad and barn scenarios. *OVERSEER* values are replaced with 'Combined Source' predicted losses for crop blocks and blocks receiving LRLD effluent. Results are presented for the Pukemutu and Gore soil types and under a Telford (a) and Woodlands (b) climate.

The 'Combined Source' method estimates that under the Telford and Woodlands climates the average farm leaching losses are 1-2 kg N ha^{-1} yr^{-1} and by 5-6 kg N ha^{-1} yr^{-1} less from the portable pad system than from the base system, respectively. In contrast, *OVERSEER* predicted a 3 kg N ha^{-1} yr^{-1} increase in leaching on the adoption of the pad system. Relative to the base system, the combined source method estimates reductions in leaching losses of 2-3 kg N ha^{-1} yr^{-1} and 5-6 kg N ha^{-1} yr^{-1} for the barn scenario under the Telford and Woodlands climates, respectively (Table 8.10).

Table 8.10. *OVERSEER* and 'Combined Source' predictions for nitrate losses (kg N ha^{-1} yr^{-1}) for the whole farm. Results are for 3 farm wintering system scenarios (Base, Pad and Barn). Also 2 soil scenario variations (Pukemutu and Gore) and 2 climate scenario variations; a low rainfall region (Telford; 717 mm rainfall) and a high rainfall region (Woodlands; 1156 mm rainfall).

	Whole farm losses Original		Whole Farm losses 'Combined Source'	
Pukemutu	Telford	Woodlands	Telford	Woodlands
Base	20	39	15	23
Pad	23	47	13	17
Barn	13	17	13	17
Gore				
Base	24	57	19	40
Pad	27	62	18	35
Barn	16	35	16	35

8.7 Discussion

8.7.1 Discussion of the predicted N leaching losses from the three contrasting wintering systems

Modelling of the three systems in *Farmax* required only two scenarios to be simulated (crop and barn) as the assumption was that the portable pad data would be similar to the base system within *Farmax*. Thus the *Farmax* models of the farm production figures were the same for both base and portable pad scenarios. The generation of the *Farmax* model for the barn scenario was conducted ensuring that the same per cow production was produced. This ensured that the scenarios were comparing 'like with like'.

Comparison of the *OVERSEER* predicted losses from the different components of the portable pad system with measured and APSIM-modelled losses highlighted three areas of disparity. These were: (1) the use of a LRLD effluent system to apply liquid to land on a daily basis over winter, (2) the 'urine patch leaching' under restricted grazing, and (3) the prediction of non-urine patch N leaching losses under a grazed winter crop. In these areas *OVERSEER* over-predicted losses compared to measured and APSIM-modelled results. Thus, N leaching results from *OVERSEER* were amended using measured and APSIM-modelled results resulting in the 'Combined Source' method of estimating N leaching losses from the three systems.

The 'Combined Source' results predict that the portable pad system, incorporating LRLD winter applied effluent results in lower N leaching losses than traditional crop wintering. When compared to traditional brassica crop wintering total farm system losses were reduced by 5-13 % and 13–26 % under a Telford and wetter Woodlands climate, respectively. Barn losses were slightly lower than portable pad losses for only one scenario. The Gore soil under the Telford climate results in a 16 % reduction in N leaching losses compared to the crop whereas the Pad scenario only produces a 5 % reduction. This was due to the LRLD component of the system. The leaching losses were higher on the stony soil and with the lower rainfall the effluent was more concentrated which also increased N leaching losses. However, in this scenario there was no change to cow numbers or total farm production with the introduction of a barn. An increase in farm system intensification, post barn, is something that Newman and Mashlan (2015) found occurred on all of the 35 farms that they surveyed. If this occurs then the reduction in N leaching losses are likely to be less.

8.7.2 Discussion of the financial cost of the portable pad and barn systems

In addition to reduced nitrogen leaching losses (compared to the base crop scenario), the portable pad appears to have a significantly lower capital (Table 8.11) cost than the barn scenario (around \$1,300 cow^{-1} less) and lower working expenses (\$194 cow^{-1} less). While a detailed financial analysis of the different wintering farm systems is beyond the scope of this study, a comparison of the approximate costs involved in the different systems is instructive. Firstly, there are the capital costs associated with both the portable pad and the barn structures. The portable pad costs have been estimated in an earlier Chapter (5.3.3) and estimates of different barn systems were available in the literature. The estimate of the capital cost of the portable pad system is \$314 cow^{-1}. A review of the literature shows there is a large range in the cost of barns. Newman and Mashlan (2015) interviewed 35 farmers with barns of varying types and locations and derived estimates of cost. The range in capital costs of barn and associated machinery was \$952 - \$5,788 cow^{-1}. The barns most similar to the deep litter barn considered here were three Redpath barns costing \$2,480, \$952 and \$1,475; these three barns were located in the Waikato. Also a Compost barn, located in the Bay of Plenty, costing \$1,966. The average of these four barn costs was used to compare with the capital cost of the portable pad. Thus, the cost of \$1,718 cow^{-1} for a barn is contrasted with the cost of \$314 cow^{-1} for the portable pad.

An approximate calculation of the working expenses of the systems show an additional cost of around \$194 cow^{-1} for the barn system. This analysis takes into account; the cost of crop establishment and regrassing for the pad scenario, the cost of purchasing silage for the barn scenario, the cost of making an additional 40 ha silage for the barn scenario, and the cost of the barn bedding and management (Table 8.11). It is recognised that there are other costs associated with each system but these are the main costs that differ between the two systems. It is assumed that the labour requirements for the systems are the same (although perhaps slightly higher than the base farm). Power costs would likely exist for the barn but these are assumed to balance out with costs of running the effluent systems for the portable pad.

Table 8.11. Partial budget of estimated costs (per cow) related to working expenses differ between the two systems. Where costs are similar they have not been included (e.g. labour).

	Portable Pad	Barn
Cropping[1]	\$103.46 cow^{-1} (\$2,299 ha^{-1} and 18 ha)	
Purchased silage[2]		\$ 104.80 cow^{-1} based on \$0.16 c kgDM^{-1}
Made silage[3]	\$26.78 cow^{-1}	\$42.50 cow^{-1} \$425 ha^{-1} x 40 ha
Barn bedding and management, including the cost of bedding removal[5]		\$92.86 cow^{-1}
Regrassing[4]	\$28 cow^{-1}	
8% capital cost depreciation	\$25.12	\$137.44
Cost – 33 year life expectancy	\$52 (**Table 5.11**– solids removal)	\$52
Total	\$235.36 cow^{-1}	\$429.76 cow^{-1}
	\$444 ha^{-1}	\$811 ha^{-1}
Difference		\$194 cow^{-1} \$367 ha^{-1}

References: Askin & Askin (2014): C57[1], B41[2], B61[3], C44[4]; (Laurenson 2016)[5]

A more detailed analysis of the costs associated with the different scenarios requires further investigation.

8.7.3 **Practical implications of the portable pad**

Analysis of both the reduction in N leaching losses and financial cost associated with the portable pad in comparison to traditional winter crop grazing and a wintering barn suggest that the portable pad has potential as a low-cost wintering system. There are practical implications related to the use of the portable pad that need to be acknowledged if the system is to be adopted.

Due to the materials used for the pad (see Chapter 5), and need to re-locate the pad around the farm as the crop paddocks move, there is a limit to the size the pad can realistically be. Experience suggests that the pad should be limited to 100 cow capacity. This results in a pad with 850 m^2 cow lying area plus any associated solids storage area (alternatively solids can be removed regularly to an off-site storage facility).

In the scenario modelled here each pad (100 cows) would require 4.5 ha of crop nearby and either 3.8 or 4.8 ha (Telford and Woodlands climates, respectively) of pasture to apply the liquid effluent to over the 70 day winter. The pad will require a power supply for both the electric fencing of the pad and the pumping of the liquid effluent. A lane way (permanent or temporary) to guide the cows to and from the crop each day and a water supply to the pad are also necessary. Labour requirements are related to cow and effluent management. Cows need to be shifted out to the crop paddock and then back to the pad again 6 hours later. It is recommended that grazing is timed to take advantage of the diurnal pattern of urinary N excretion identified in Chapter 5 (Figure 5.18). Avoiding the early morning urination events when N concentration is high, and grazing during the day, can reduce the total daily N excreted on the paddock to as low as 9%. Thus grazing from 9 am until 3 pm is recommended. Also the pad needs to have the solids scraped (ideally daily) and the pump for irrigation must be started and then stopped again once the sump is empty (this could potentially be automated). Experience showed that the scraping of the pad could be done while the sump was emptying and the use of an ATV mounted pad scraper was an efficient method of cleaning the pad surface.

8.7.4 **Discussion of the *OVERSEER* model**

When using models, the user must be cautious regarding the results and the weight of influence they have on any decision. The generation of the *OVERSEER* files for the portable pad and barn scenarios highlighted four issues with the *OVERSEER* model. These were:

1. Differences between *OVERSEER* versions regarding the quantities of silage able to be fed to cows in the wintering barn.
2. The inability of *OVERSEER* to correctly model the nitrogen losses under the LRLD winter applied effluent system.

3. The questionably high non-urine leaching losses under the grazed winter swede crop.
4. Insufficient reduction in urine-leaching losses under duration controlled grazing of brassica crops.

In addition, the need to use both the *Farmax* and *OVERSEER* models to comprehensively model the scenarios highlighted a fifth point that could be seen as a future enhancement to *OVERSEER*,

5. An integration between *OVERSEER* and *Farmax*.

1). In this work the scenarios were initially run using *OVERSEER* version 6.2.1. In that version the input of 275 t DM silage was fed to the MA cows in the barn over winter. This value was generated from modelling the system in *Farmax* and was the quantity of feed required to achieve cow BCS targets at the end of winter. Common farm practice indicates this level of feeding to be practicable. In the initial modelling, *OVERSEER* generated a nutrient budget for this scenario. However, when the files were opened four months later in version 6.2.2 the model would no longer generate a nutrient budget and had the error message that the system was 'feeding 89% too much intake to the MA cows over the winter'. It was necessary to reduce the amount of purchased feed given to the MA cows from 275 t DM to 100 t DM and then feed the remaining 175 t DM to the young stock.

2). *OVERSEER* is not equipped to accurately model the N leaching losses under the use of the LRLD application of effluent to land. In Chapter 7 the APSIM model suggests that the losses from the use of the LRLD system under certain management guidelines (e.g. max N load, 2 mm ha day^{-1}, 4 mm ha^{-1} hr^{-1}) were very low. Thus, the incorporation of the LRLD system as described in Chapters 7 and 8 could be considered for inclusion in a future version of *OVERSEER*.

3). The N leaching losses under a grazed swede crop predicted by *OVERSEER* were higher than expected. They do not match lysimeter data by Malcolm *et al.* (2016) who predict 10-11 kg N ha^{-1} yr^{-1} from non-urine spots and 64 - 79 kg N ha^{-1} yr^{-1} under urine patches. These results were on a stony Balmoral soil, similar to the Gore soil. However, *OVERSEER* predicted 96-101 kg N ha^{-1} yr^{-1} loss from urine patches and 157-156 kg N ha^{-1} yr^{-1} from non-urine patches (Gore soil, Woodlands climate, year 1 and year 2 crop, respectively). It appears that *OVERSEER* over-predicts N losses from the non-urine patch in particular. The *OVERSEER* values for urine and non-urine patch N leaching losses from the crop in the scenarios modelled here seems to be in direct contradiction to comments made regarding the revised leaching model for *OVERSEER*. Wheeler *et al.* (2011) state that splitting leaching losses into urine and non-urine recognises "that the between-urine patch area of the paddock" is similar to "a cut and carry paddock where N is used very efficiently". It thus recognises that the "N leaching is driven by the urine patch", which implies that the major proportion of the N losses should come from the urine patch losses. In the *OVERSEER* results for our simulation, it was very evident that the losses were N driven by mineralisation of previous pasture or crop residues and not driven by the urine-patch losses in the winter brassica crop blocks.

4). OVERSEER seems to reduce the leaching losses from urine deposition in in a pro-rata fashion. Reducing the grazing period to 25% of the day reduced the N leaching losses from urine patches to around 25% of the losses from 24 hour grazing. However, our research (Chapter 5) suggests that only 9% of the daily urinary N was excreted during the 6 hour period that cows were grazing crop. Urinary N concentration is lower during the day and highest in the early morning. Thus the timing of the grazing can impact the percentage reduction in N leaching afforded by duration controlled grazing and this is something that *OVERSEER* does not take into account.

5). Dairy farm scenario modelling is required to test farm management changes designed to reduce N loss to water. For this purpose combined modelling using *OVERSEER* and *Farmax* is an advantage. A potential evolution of the *OVERSEER* tool that would be of use is the integration of *OVERSEER* and *Farmax* so that the two models work together and 'share' data. This would reduce both the risk of user data input error and reduce the time spent duplicating data entry in the two models.

OVERSEER is a continually developing tool where the existing model components are improved as new field data is available for model calibration. In addition, as farm systems change or new farm systems become more common then there is new capability added to *OVERSEER*. Researchers should be considering the possibility of future experimental work which adds to the dataset used by *OVERSEER*. Thus, it would be beneficial for researchers to contact the *OVERSEER* developers at the trial design stage to determine if their work has the potential to improve *OVERSEER*, and if so, then to ensure that the data required by *OVERSEER* was generated by the experiment. It may be necessary for *OVERSEER* to have a budget available to extend, or add to, proposed experiments if the required data was outside the original scope of the experiment. For example funding the extension of a field experiment to 12 months of data collection from an original budget and experimental design for only 10 months of data collection.

8.8 Conclusions from 'Combined Source'

A 'Combined Source Method' was developed to estimate N leaching associated with a range of wintering scenarios. This method is a combination of *OVERSEER* predictions of N leaching from pastoral blocks supplemented with, (1) values for N leaching from winter applied effluent to pasture predicted by field trial and APSIM modelled results, and (2) winter crop block non-urine patch losses extrapolated from values in the literature. This combined modelling technique predicted that:

1. The portable pad significantly reduces losses from the whole farm system compared to traditional brassica crop grazing. A reduction in N leaching of 2-7 kg N ha^{-1} yr^{-1} representing a 5 – 26 % reduction in losses. These reductions are achieved due to the decrease in N losses from the crop paddocks.
2. Barn losses were slightly lower than portable pad losses in the lower rainfall scenario on the Gore soil (16 % lower compared to 5 %) and the same for the higher rainfall scenarios and the Pukemutu soil. However, it is possible that in an actual farming situation the farming intensity and production would increase in order to offset the capital cost of the barn and thus this may reduce the benefits in N loss reduction in the barn scenario.
3. Rainfall has a large impact on N leaching losses, as does soil type. The degree of the reduction in N leaching as a consequence of using the portable pad (or a barn) is greater in a wetter climate on a fine textured soil.

8.8.1 Scenarios that were poorly modelled by *OVERSEER*

The measured values for LRLD and literature values for winter crops identified N leaching values that were not well modelled by *OVERSEER*. These are:

1. Winter applied liquid effluent using a LRLD system. *OVERSEER* does not currently have the capability to accurately model winter applied effluent using the LRLD system. If this was to become common practice on farms then *OVERSEER* would need to include this in the model.
2. Winter brassica crop N leaching losses. *OVERSEER* over-predicts N leaching losses from winter grazed swede crops. This seems to be influenced most mostly by unaccountably high non-urine patch losses generated by a large residual N which is left after cultivation that is available for mineralisation and results in soil mineral N values in excess of 120 kg N ha^{-1} for the entirety of the drainage period (Figure 8.2).
3. OVERSEER reduces the N leaching losses from the animals as a direct reflection of the percentage of time they are on the paddocks. For example if the cows graze only 25 % of the day then the losses are reduced to 25 % of the full day's losses. However, measured results suggest that, due to a daily pattern of urinary N excretion, it is possible that although cows are on-paddock for 25 % of the day they will excrete less than 25 % of their daily urinary N (Chapter 5; Table 5.8).

9. Conclusions and future research priorities

9.1 Summary of research focus and the overarching hypotheses

Dairy cow wintering systems used in southern New Zealand can be split into two broad categories, 1). On-paddock systems (of which the most common is wintering on brassica crop *in situ*), and 2). Off-paddock systems (of which there are many different housed and un-housed systems; all, however, require effluent capture and storage systems). Research in this thesis focused on one example of each category and the development of a hybrid system (termed the portable pad system). This system utilised the brassica crop *in situ* and also stood cows off-paddock for a significant portion of the day, captured effluent and returned the liquid fraction to pasture using a low rate, low depth effluent spray system (LRLD).

The overarching hypotheses for this research were:

1. A knowledge framework can be developed that outlines key components of, and the interactions within, different types of dairy wintering systems in the southern South Island.

A knowledge framework (Section 2.6; Figure 2.7) was successfully developed following a comprehensive review of the relevant literature relating to dairy cow wintering systems in the southern South Island of New Zealand. This identified two broad categories of wintering system: (1) on-paddock (crop or pasture grazed), and (2) off-paddock. The focus for this work was then narrowed to one example from each category (crop grazing and a deep-litter barn).

2. This framework can be utilised to develop management strategies that deliver reduced environmental and improved economic outcomes.

A new hybrid system was developed for the crop system that utilised grazing of the crop combined with a daily confinement period (up to 18 hours) on a novel wintering pad with an associated effluent management system: the “portable pad system” (Chapters 4, 5, 6, 7 & 8).

The main findings of the research from each wintering system investigated are outlined below.

9.2 Main findings of this research

The main findings have been split into the three systems investigated: portable pad, deep litter barn and crop. Reference is made in the text to the 9 objectives outlined in Chapter 1.

9.2.1 Portable Pad

9.2.1.1 Development of a novel low-cost portable pad system.

A low-cost stand-off system, termed the portable pad, was designed (Chapter 5) that utilised the low cost brassica crop as an *in situ* feed source. The portable pad system investigated involved a low-cost stand-off area that reduced contaminant losses to water, whilst utilising the low cost brassica crop as a feed source. The feasibility of the portable pad system was investigated. In this system cows grazed the brassica crop *in situ* and returned to the portable pad for a proportion of the day (up to 18 hours). The portable pad has the ability to be moved around the farm in different years as the location of the forage crop paddock changes. Minimal effluent storage is required due to the application of the liquid effluent to neighbouring pasture during winter using low rate and low depth (LRLD) application methods

A pad was constructed that utilised an effluent liner that captured the effluent deposited on the pad surface. Through the stage 1 trial it was determined that the best surface for a cow comfort layer (of the three trialled) was a geotextile fabric; in this case Cowmax™ carpet. Urine event measurements showed that there is a daily pattern of urinary N excretion evident. This showed reduced urinary N excretion during the period from 10 am until around 4 pm. By scheduling the 6 hour grazing period for animals utilising the portable pad system for this period of the day, the dairy urinary N deposited on paddock can be restricted to around 9%.

Investigation of cow lying times indicated that cows were, on average, able to meet the minimum recommended daily lying time of 8 hours day^{-1}. Cow body condition scores (BCS; Chapter 5, Section 5.4.2 iii) indicated that BCS increases could be achieved over the winter period using the portable pad system if cow crop allocations were adequate (a 0.33 increase in BCS was measured over one month when crop allocation was increased from 4.5 to 11.5 kg DM cow^{-1} day^{-1}; Chapter 5, Section 5.4.2).

9.2.1.2 Investigation of a low rate, low depth effluent system for winter applications of liquid effluent.

In order for the portable pad system to require only minimal liquid effluent storage (only one days worth or enough for a storm event), a system allowing daily applications of liquid effluent to land was investigated. A field experiment was conducted nitrogen (N) leaching losses when liquid effluent was applied to pasture, during winter, at a range of application depths (2, 5, 7, 12 mm; Chapter 6; Chapter 1, Objective 3). Application depths of < 2 mm day^{-1} resulted in a loss (over the application period) of 16 kg N ha^{-1} compared to 119 kg N ha^{-1} for the 12 mm application depth (nil effluent treatment losses were 4 kg N ha^{-1} for the same period; Chapter 6, Section 6.4.3, Table 6.13). The field results were used to calibrate the APSIM model which was then used to investigate the effects of the low rate, low depth effluent application strategy across a range of soil types and climates (Chapter 7; Chapter 1, Objective 4). The results showed N leaching losses were relatively low, particularly on heavy soils, with stony soils the main soil type that may cause concern. However, the system is able to be adapted to situations with stony soils to make the most of advantages created by higher concentration effluents and later application dates. This system has the potential to be used in almost any situation, and if a strict set of irrigation and N loading rules were adhered to, then N leaching losses could be relatively small (0.1 to 0.9 kg N cow^{-1} winter^{-1} in a portable pad scenario; Chapter 7, Table 7.7). These rules are:

- Applications of 2 mm day^{-1} and a rate of 4 mm hr^{-1}.
- Daily applications regardless of rainfall.
- Maximum N load of around 80 kg N ha^{-1}. However, this should be tailored to the effluent N concentration to avoid over-application of N (Chapter 7, Section 7.10).
- Lower N load for stony soils
- No use of low concentration effluents (similar to FDE) on stony soils in high rainfall regions.

9.2.1.3 Volumes of effluent produced by the portable pad system

The volumes of solid effluent collected on the portable pad were 30 kg cow^{-1} day^{-1} when the cows were on the pad for 20 hours and 25 kg cow^{-1} day^{-1} when they were on the pad for 18 hours per day (Chapter 5, Section 5.4.2 viii; Chapter 1, Objective 2). This solid material had a component of baleage in it, as the cows were fed baleage on the pad.

Estimated volumes of liquid effluent captured using pumping hour's recorded (390 litres per day for 20 cows) were lower than calculated volumes using rainfall, pad area and measured urine volume outputs (802 litres per day for 20 cows). Average daily nitrogen intake in feed was 218 g N cow^{-1} day^{-1} and, assuming 80 percent of this was excreted in dung and urine (Haynes & Williams 1993), the resulting excreta would be an average of 174 g N cow^{-1} day^{-1}. The average daily N load captured by the system was between 107 g N cow^{-1} day^{-1} (adding the volumes captured in solid and liquid effluent) and 169 g N cow^{-1} day^{-1}, which is between 49 and 78% of N intake and between 61 and 97% of expected daily N excretion. This value will include a proportion of N in the feed that was present in the solids removed from the pad; it excludes any N excreted as dung during the time on paddock.

9.2.1.4 Nitrogen losses from winter grazed crop on stony soils: the use of a channel lysimeter to measure N leaching under restricted (6 hr) and unrestricted (24 hr) grazing

A “trench lysimeter” system was used to collect drainage for analysis from areas of winter brassica that had been grazed by cows for 6 (representing the portable pad system) or 24 h (representing the traditional system; Chapter 4; Chapter 1, Objective 1). The average total loss of nitrate-N for the 6 hour treatment was 11.8 kg nitrate-N ha^{-1} from 6 May until 19 October 2015. For the same period, losses for the 24 hour treatment were 14.4 kg nitrate-N ha^{-1}. There was no significant difference between the N leaching loads for a one-off grazing event of either 24 or 6 hours. It is quite possible that this was due to insufficient drainage before the end of the experiment to displace the urinary load. However, the nitrate-N concentrations in the collected drainage compared well with data reported by Monaghan *et al* (2013). These N leaching loads were much smaller than that the N loss to water for fodder crops on stony soils predicted by *OVERSEER* (loads ranging between 40 - 253 kg N ha^{-1}; Chapter 8, Section 8.5.3, Table 8.9) as a result of winter grazing. The timing of grazing with respect to later winter rainfall and drainage is a critical determinant of the amount of N leached and the amount remaining in the soil profile, which could potentially be recovered by a later winter-early spring catch crop.

9.2.2 Deep litter barn (as an example of an existing off-paddock system) effluent and bedding.

A deep litter barn was investigated as an example of an existing off-paddock system. The key knowledge gap identified in the literature review were related to the effluent products generated by the system (Chapter 3).

For a dairy system incorporating a loose-housed deep litter wintering barn, the main nutrient sources were in the solids collected from the bedding and the feeding apron. The total amounts of nutrient captured annually per cow were 38.4 kg N, 9.6 kg P, and 56.1 kg K (Chapter 3, Section 3.3; Chapter 1, Objective 2). This amounted to a fertiliser value of \$136 cow^{-1} year^{-1}. The total volume of effluent captured by the effluent system was 28 m^{3} cow^{-1} year^{-1}, including 2.7 m^{3} cow^{-1} year^{-1} and 4.5 m^{3} cow^{-1} year^{-1} from the barn drainage and feeding apron (plus apron rain), respectively.

9.2.3 Traditional crop system – cow lying times

Lying time results found that cows wintered on crop with no off-paddock area reached, on average, the minimum recommended daily lying time of 8 hours. However, during the first month of measurements only 49 % of cows reached this minimum target compared to 95 % in the second month of measurements. During the first period there was a week of extreme weather (cold, windy, wet and snow) and the cows on crop did not lie for more than 3 hours a day (on average) for a period of 7 days (Chapter 5, Section 5.4.2, Figure 5.15).

9.2.4 Whole system comparison

Whole system comparisons were conducted (Chapter 8) to provide modelled N leaching loss estimates for three contrasting wintering systems: crop, wintering barn and portable pad (Chapter 1, Objective 9). The N leaching losses of the different systems were simulated by using a combination of *OVERSEER* simulation plus measured and/or APSIM-generated values. This comparison found:

1. A wintering system that included the portable pad had significantly lower N leaching losses from the whole farm system compared to traditional brassica crop grazing. A reduction in N leaching of 2-7 kg N ha^{-1} yr^{-1} could potentially be achieved, representing an 8 – 25% reduction in N loss. The modelled farm system N loss reductions were achieved by reducing the N leached from the grazed forage crop paddocks.

2. The scenario of a deep-litter wintering barn resulted in N losses lower than the grazed crop system employing a portable pad in the lower rainfall scenario on a stony Gore soil type.

3. Rainfall has a large impact on modelled N leaching losses, as does soil type. The percentage reduction in N leaching as a consequence of using the portable pad (or a barn) is greater in a wetter climate on a heavier soil compared to an excessively drained stony soil.

9.3 Priorities for future research (in no particular order)

This study has presented an opportunity to study a wide range of system interactions that are relevant to minimising the impact of wintering dairy cows in Southland. Recommendations for future research will be restricted to some key observations that were made during the experimental and modelling studies.

9.3.1 Portable pad

Further research is required in relation to the management of the surface fabric and also the feeding of supplements on the pad. Specifically, these are:

1. Developing a tensioning system to keep tension on the pad cover. This is a key area requiring further investigation in order for the system to be successful in a commercial sense.

2. Positioning of supplementary feed to avoid adding solids to the scraped effluent and also to reduce high traffic areas as these cause problems with tensioning of the carpet. The issue that has to be solved is how cows are fed supplements in association with the pad (possibly fed down the side of the pad, with solids scraped up slope and liquids drained down to a collection sump). Additionally, studies on animal welfare need to evaluate the implications of standing cows off-paddock for up to 18 hours a day with water only, and whether this is acceptable or not.
3. This initial portable pad housed only 20 cows. It is important that a farm scale field experiment including the use of the LRLD effluent application system is conducted to test viability at a commercial scale.
4. A partial budget suggests that the cost of the portable pad is significantly lower than the deep litter barn. However a comprehensive financial analysis is required to complete a robust comparison of all systems
5. It is possible that this geotextile fabric can be used as a bedding surface for other off-paddock systems. This concept has been incorporated in wintering pad research on the Ashley Dene Research Farm (Lincoln University, Canterbury) as part of the P21 research programme. This experiment compares five different surfaces on a permanent wintering pad designed to house 100 cows surface^{-1}. Initial results from 2 weeks of cows on the geotextile look promising, as cow lying times compare well with both paddock and woodchip values.

9.3.2 **N leaching from grazing winter crops**

The channel lysimeter experiment (Chapter 4) on the stony soil did not show a statistically significant difference in N leaching between treatments (Chapter 4, Section 4.4). The drainage volume was similar between treatments (average 177.5 and 173.3 mm for the 6 and 24 hour treatments, respectively). It is quite possible that there was insufficient drainage before the end of the experiment to displace the urinary load. Ideally the drainage measurements would have continued until just prior to the next year's grazing event in order to capture another pore volume of drainage through the profile. It is also possible that not all the urine patches were captured along the trench. The weather conditions on the day of grazing were an air temperature of 9.6 °C and rainfall of 1.8 mm (wind speed was not recorded) (Chapter 4, Section 4.3.4) which would suggest that the behaviour of the animals did not influence their position in the plots (perhaps if it had been driving rain they might have stood facing away from the wind and rain). The trench width was 1 meter wide and fenced 4 meters wide to allow adequate room for the cows during grazing. The trench length was calculated to account for this grazing width; however, it is possible that not enough of the urine depositions were located over the trench capture area. Therefore, it is recommended that future research using this method of in-field channel lysimeter incorporates a channel design capture area where the whole of the grazing area in the plots is covered.

Possible solutions for this existing infrastructure, if these channel lysimeters were to be used again, could be to (1) manually apply urine down the centre of the trenches and then remove plants to simulate grazing, and (2) to observe the cows during the grazing period and record the location and number of urine depositions. It is important that this type of in-field research delivers measured information because the simulation models are not accurately predicting N leaching losses from grazed crops. Measured data is required to calibrate the models.

In addition, on these sites the height of ground water and direction of flow needs to be recorded and this study would be well linked to denitrification studies looking at ground water attenuation of nitrogen.

In Chapter 8 (Section 8.6) other studies on the grazing of winter fodder crops (e.g. Malcolm *et al* 2015, 2016), using barrel lysimeters, were used as data sources to identify paddock scale losses. High yielding fodder crops lead to high grazing intensities. The high grazing density of grazing dairy cows on winter crops delivers repeated overlap of urine patches. The consequences of this on N loss from the root zone can be addressed using urine patches (multiple) placed on barrel lysimeters. It is important that future research into urine patch overlap is undertaken on high yielding winter crops or areas where cows are held and fed supplements.

Another research priority is the development of a method to scale up lysimeter results to field scale. This method will need to account for double and triple urine patch overlapping. Questions that need to be answered are: What percentage of double and triple urine patches are there during strip grazing of crops? Is there an effect of lag time between the deposition of second and the third patch on N leaching?

There is insufficient information on the urinary N content of cows fed a range of winter crops, including swede, fodder beet, kale, and oats. In order for simulation models to work accurately, this information needs to be acquired.

9.3.3 **Wintering barn**

This study characterised and quantified the nutrient contents of different effluent products generated by a deep litter barn (Chapter 3). Characterisation and quantification of the different effluents generated for a range of different wintering barn types is required to fill that knowledge gap.

When deep litter barns are used in cool wet climates the bedding does not have the opportunity to dry out when the barn is in use. Further research needs to be undertaken to investigate the ideal type, size and shape of bedding material, and management and drainage solutions that speed the drying of bedding. Further research, possibly through focus farms or case study farms, needs to be conducted to identify the different ways that farmers are preparing their beds to minimise moisture levels and waterlogging.

A range of bedding materials are being proposed for both inside and outside use. Examples are: sawdust and lignite mix, stones, and woodchip; however, these need to be carefully researched before they are used.

9.3.4 **OVERSEER model**

Currently there are a number of concerns with *OVERSEER* and its ability to model the scenarios necessary to cover the range of wintering systems.

1. The existing function within *OVERSEER* for feeding supplement to cows in a wintering barn does not allow the level of feeding that is traditionally used for feeding dry cows in Southland. This limitation needs to be corrected urgently.
2. The current version of the *OVERSEER* winter crop model needs improvement. The *OVERSEER* model predicts N losses from the winter grazed crop that are unrealistically high. N leaching values are currently higher than expected, particularly from the non-urine patch areas of the paddock. Future model developments need to be aligned with further field research in this area to provide measured values for model validation.
3. It is also important to acknowledge that at the early stages of designing research into the impact of cattle systems on the environment there would be a major benefit of prior discussions with *OVERSEER* developers about the design and measurements in the experiment such that inputs, outputs and outcomes are relevant to further development of *OVERSEER*.

9.3.5 **Urine sensors**

The urine sensors were bulky and heavy, requiring the use of a cow cover to take the weight of the sensor (Chapter 5, Section 5.3.4, Figure 5.7). In addition, the sensors were prone to falling off as cows lay in the paddocks and on the pad. It is important that future research is undertaken to improve these sensors for use on lactating cows and in wet, muddy climates. A lighter, smaller sensor is required with an improved method of attachment to the cow.

10. References

Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome 300*: D05109.

Anon. 2000. National water quality management strategy. p. 17. In: Australian and New Zealand guidelines for fresh and marine water quality. Ed. Zealand, A. a. N. Z. E. a. C. C. A. a. R. M. C. o. A. a. N. Environment Australia, Australia.

Anon. 2010. Regional Water Plan for Southland (amended in accordance with Council and Environment Court decisions). p. 3. In: Rule 50. Ed. Southland, E. Invercargill.

Anon. 2014. Farm and Orchard Expenses. pp. B-180. In: Financial Budget Manual 2014. Eds. Askin, D.; Askin, V. Lincoln University.

AOAC 1996. Official methods of Analysis of AOAC International In: Nitrogen (Total) in Fertilizers: Combustion Method. (993.13). Ed. Cunnif, P. 993.13: AOAC International, Washington, DC.

AOAC 2005. Official methods of analysis of AOAC International. In: Arsenic, Cadmium, Nickel and Selenium in Fertilizers, Microwave Digestion and Inductively Coupled Plasma-Optical Emission Spectrometry Eds. Horwitz, W.; Latimer, G. AOAC International, Gaithersburh, MD.

APHA 2005. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C., USA.

Askin, D.; Askin, V. Eds. 2014. Financial Budget Manual 2014 Lincoln University, Christchurch.

Beare, M.; White, S.; Wilson, D. 2006. Managing winter forage crops sustainably. In: SIDE conference proceedings.

Beare, M.H.; Tabley, F.; Gillespie, R.; Maley, S.; Harrison-Kirk, T.; Ruiter, J.d. 2010. Nitrate leaching from high production forage crop sequences. *Proceedings of the New Zealand Grassland Association 72*: 23-28.

Beautrais, J. 2014. Southland dairy soil drainage. Personal Communication.

Betteridge, K.; Costall, D.A.; Li, F.Y.; Luo, D.; Ganesh, S. 2013. Why we need to know what and where cows are urinating - a urine sensor to improve nitrogen models. *Proceedings of the New Zealand Grassland Association 75*: 119-124.

Beukes, P.C.; Gregorini, P.; Romera, A.J.; Dalley, D.E. 2010. The profitability and risk of dairy cow wintering strategies in the Southland region of New Zealand. pp. 174-178. In: Australasian Dairy Science Symposium 2010. Eds. Edwards, G. R.; Bryant, R. H. Lincoln University.

Beukes, P.C.; Gregorini, P.; Romera, A.J.; Dalley, D.E. 2011. The profitability and risk of dairy cow wintering strategies in the Southland region of New Zealand. *Agricultural Systems 104*: 541-550.

Bowler, D.G. 1980. The drainage of wet soils. Department of Soil Science, Massey University, New Zealand.

Bryant, J.R.; Ogle, G.I.; Marshall, P.R.; Glassey, C.B.; Lancaster, J.A.S.; Garcia, S.C.; Holmes, C.W. 2010. Description and evaluation of the Farmax Dairy Pro decision support model. *New Zealand Journal of Agricultural Research 53*: 13-28.

Cameron, K. 2016. Spatial area of urine patch in swede, fodder beet and kale crops. Personal communication.

Cameron, K.C.; Di, H.J. 2004. Nitrogen leaching losses from different forms and rates of farm effluent applied to a Templeton soil in Canterbury, New Zealand. (Special Issue: Land application of farm wastes). *New Zealand Journal of Agricultural Research 47*: 429-437.

Carter, M.R. 1988. Temporal variability of soil macroporosity in a fine sandy loam under mouldboard ploughing and direct drilling. *Soil and Tillage Research 12*: 37-51.

Carter, M.R. 1990. Relative measures of soil bulk density to characterize compaction in tillage studies on fine sandy loams. *Canadian Journal of Soil Science 70*: 425-433.

Chadwick, D.R.; John, F.; Pain, B.F.; Chambers, B.J.; Williams, J. 2000. Plant uptake of nitrogen from the organic nitrogen fraction of animal manures: A laboratory experiment. *Journal of Agricultural Science 134*: 159-168.

Chatfield, K.; Mora, H.; Longhurst, B. 2011. "Its raining effluent", effect of herd home slurry on growth of maize and sorghum in Waikato. p. 9. In: Adding to the knowledge base for the nutrient manager. Eds. Currie, L. D.; Christensen, C. L. Occasional Report No. 24: Fertilizer and Lime Research Centre, Palmerston North.

Christensen, C.L.; Hanly, J.A.; Hedley, M.J.; Horne, D.J. 2010. Reducing nitrate leaching losses by using duration-controlled grazing of dairy cows. pp. 153-156. In: 19th World Congress of Soil Science. Eds. Gilkes, R. J.; Prakongkep, N. International Union of Soil Science, Brisbane, Australia.

Chrystal, J.; Monaghan, R.; Hedley, M.; Horne, D. 2016a. Design of a low cost winter stand-off pad for reducing nutrient losses to water from winter forage crops grazed by dairy cows. p. 9. In: Integrated nutrient and water management for sustainable farming. Eds. Currie, L. D.; Singh, J. Fertilizer and Lime Research Centre, Massey University, Palmerston North.

Chrystal, J.; Monaghan, R.; Hedley, M.; Horne, D. 2016b. Volumes and nutrient concentrations of effluent products generated from a loose-housed wintering barn with woodchip bedding. p. 12 pages. In: Integrated nutrient and water management for sustainable farming. Eds. Currie, L. D.; Singh, J. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Chrystal, J.; Smith, C.; Monaghan, R.; Hedley, M.; Horne, D. 2016c. Effects of applying dairy wintering barn manure of differing C:N ratios directly to pasture on N mineralisation and forage growth. *New Zealand Journal of Agricultural Research*

Chrystal, J.M.; Monaghan, R.; Dalley, D.E.; Styles, T. 2012. Assessments of N leaching losses from six case study dairy farms using contrasting approaches to cow wintering. In: New Zealand Grassland Association. 74: Gore.

Cichota, R.; Chrystal, J.; Laurenson, S. 2016. Describing nitrogen leaching from farm diary effluent irriaged on artificially drained soils. p. 10. In: Integrated nutrient and water management for sustainable farming. Eds. Currie, L. D.; Singh, J. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zeland.

Cichota, R.; Snow, V.O.; Vogeler, I. 2013a. Modelling nitrogen leaching from overlapping urine patches. *Environmental Modelling & Software 41*: 15-26.

Cichota, R.; Vogeler, I.; Snow, V.O.; Webb, T.H. 2013b. Ensemble pedotransfer functions to derive hydraulic properties for New Zealand soils. *Soil Research 51*: 94-111.

Clark, D.A.; Caradus, J.R.; Monaghan, R.M.; Sharp, P.; Thorrold, B.S. 2007. Issues and options for future dairy farming in New Zealand. *New Zealand Journal of Agricultural Research 50*: 203-221.

DairyNZ 2009. Animal Welfare and the New Zealand Dairy Industry. p. 32. In: A Guide for Veterinarians and Rural Professionals. DairyNZ, Hamilton.

DairyNZ 2010. Swedes - growing a high yielding crop (1-76). In: DairyNZ Farmfact. 2016: DairyNZ,

DairyNZ 2011. Dairy Farm Pasture Growth Rates. pp. C-84 - C-87. In: Farm Technical Manual. Eds. Trafford, G.; Trafford, S. Caxton Press, Christchurch.

DairyNZ 2013a. Farm Dairy Effluent - How to use the Dairy Effluent Storage Calculator (DESC). p. 42. New Zealand.

DairyNZ 2013b. Winter brassica crops-feeding to dairy cows (1-75). In: DairyNZ farmfact. DairyNZ, New Zealand.

DairyNZ 2014. Stand-off pads. Your essential guide to planning, design and management. p. 49. Ed. DairyNZ 1: New Zealand.

Dalley, D.; Geddes, T. 2012. Pasture growth and quality on Southland and Otago dairy farms. pp. 237-241. In: Proceedings of the New Zealand Grassland Association. Ed. Swain, D. 74: Wickliffe Solutions, Gore, NZ.

Dalley, D.; Geddes, T. 2013. Pasture growth rates Telford 2012/2013. Telford dairy farm, Unpublished Data.

Dalley, D.; Pinxterhuis, I.; Geddes, T.; Hunter, M.; Kyte, R. 2014. Which wintering system is right for you? In: SIDE. Ed. Doig, K. The Caxton Press, Invercargill.

Dalley, D.E.; Verkerk, G.A.; Geddes, T.; Irwin, A.; Garnett, E. 2012. Impact of wintering system in the southern South Island of New Zealand on the lying behaviour of dairy cows. Melbourne, Australia.

De Klein, C.A.M.; Letica, S. 2009. NOMR site soil physical data. Unpublished data.

de Klein, C.A.M.; Letica, S.A.; Macfie, P.I. 2014. Evaluating the effects of dicyandiamide (DCD) on nitrogen cycling and dry matter production in a 3-year trial on a dairy pasture in South Otago, New Zealand. *New Zealand Journal of Agricultural Research 57*: 316-331.

de Klein, C.A.M.; Monaghan, R.M.; Ledgard, S.; Shepherd, M. 2010. A system's perspective on the effectiveness of measures to mitigate the environmental impacts of nitrogen losses from pastoral dairy farming. pp. 14-28. In: Australasian Dairy Science Symposium. Eds. Edwards, G. R.; Bryant, R. H. Lincoln University, Lincoln University.

Di, H.J.; Cameron, K.C. 2002. The use of a nitrification inhibitor, dicyandiamide (DCD), to decrease nitrate leaching and nitrous oxide emissions in a simulated grazed and irrigated grassland. *Soil Use and Management 18*: 395-403.

Di, H.J.; Cameron, K.C. 2003. Mitigation of nitrous oxide emissions in spray-irrigated grazed grassland by treating the soil with dicyandiamide, a nitrification inhibitor. *Soil Use and Management 19*: 284-290.

Di, H.J.; Cameron, K.C. 2004. Treating grazed pasture soil with a nitrification inhibitor, eco-n™, to decrease nitrate leaching in a deep sandy soil under spray irrigation - A lysimeter study. *New Zealand Journal of Agricultural Research 47*: 351-361.

Di, H.J.; Cameron, K.C.; Shen, J.P.; He, J.Z.; Winefield, C.S. 2009. A lysimeter study of nitrate leaching from grazed grassland as affected by a nitrification inhibitor, dicyandiamide, and relationships with ammonia oxidizing bacteria and archaea. *Soil Use and Management 25*: 454-461.

Drewry, J.J.; Cameron, K.C.; Buchan, G.D. 2008. Pasture yield and soil physical property responses to soil compaction from treading and grazing — a review. *Soil Research 46*: 237-256.

Drewry, J.J.; Littlejohn, R.P.; Paton, R.J.; Singleton, P.L.; Monaghan, R.M.; Smith, L.C. 2004. Dairy pasture responses to soil physical properties. *Soil Research 42*: 99-105.

Drewry, J.J.; Paton, R.J. 2005. Soil physical quality under cattle grazing of a winter-fed brassica crop. *Soil Research 43*: 525-531.

Eghball, B.; Power, J.F. 1999. Composted and noncomposted manure application to conventional and no-tillage systems: Corn yield and nitrogen uptake. *Agronomy Journal 91*: 819-825.

Environment, S. 2016. Evaluation Report: Proposed Southland Water and Land Plan. p. 92. Ed. Council, E. S. R. Environment Southland, Invercargill, NZ.

Environment Southland, 2016a. Propopsed Southland Water and Land Plan, Part A. p 205 Environment Southland, Invercargill, NZ.

Favero, S.; Portilho, F.V.R.; Oliveira, A.C.R.; Langoni, H.; Pantoja, J.C.F. 2015. Factors associated with mastitis epidemiologic indexes, animal hygiene, and bulk milk bacterial concentrations in dairy herds housed on compost bedding. *Livestock Science 181*: 220-230.

Fisher, A.D.; Stewart, M.; Verkerk, G.A.; Morrow, C.J.; Matthews, L.R. 2003. The effects of surface type on lying behaviour and stress responses of dairy cows during periodic weather-induced removal from pasture. *Applied Animal Behaviour Science 81*: 1-11.

Fisher, A.D.; Verkerk, G.A.; Morrow, C.J.; Matthews, L.R. 2002. The effects of feed restriction and lying deprivation on pituitary–adrenal axis regulation in lactating cows. *Livestock Production Science 73*: 255-263.

FMRA Analytical Methods for Fertiliser Materials. 11.1: Fertiliser Manufacturers Research Association, New Zealand.

Fregonesi, J.A.; Veira, D.M.; von Keyserlingk, M.A.G.; Weary, D.M. 2007. Effects of Bedding Quality on Lying Behavior of Dairy Cows. *Journal of Dairy Science 90*: 5468-5472.

Galanos, E.; Gray, K.R.; Biddlestone, A.J.; Thayanithy, K. 1995. The Aerobic Treatment of Silage Effluent: Effluent Characterization and Fermentation. *Journal of Agricultural Engineering Research 62*: 271-279.

Gebrehanna, M.M.; Gordon, R.J.; Madani, A.; VanderZaag, A.C.; Wood, J.D. 2014. Silage effluent management: A review. *Journal of Environmental Management 143*: 113-122.

Gonyou, H.W.; Christopherson, R.J.; Young, B.A. 1979. Effects of cold temperature and winter conditions on some aspects of behaviour of feedlot cattle. *Applied Animal Ethology 5*: 113-124.

Goulter, C. 2010. Dairy Shelter on the Canterbury Plains. In: SIDE. Eds. Gow, N.; Doig, K.

Griffin, T.S.; Hutchinson, M. 2007. Compost maturity effects on nitrogen and carbon mineralization and plant growth. *Compost Science & Utilization 15*: 228-236.

Gutser, R.; Ebertseder, T.; Weber, A.; Schraml, M.; Schmidhalter, U. 2005. Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. *Journal of Plant Nutrition and Soil Science 168*: 439-446.

Haynes, R.J.; Williams, P.H. 1993. Nutrient Cycling and Soil Fertility in the Grazed Pasture Ecosystem. pp. 119-199. In: Advances in Agronomy. Ed. Donald, L. S. Academic Press,

Helmke, P.A.; Sparks, D.L. 1996. Lithium, Soidum, Potassium, Rubidium and Cesium. pp. 551-574. In: Methods of Soil Analysis. Part 3 - Chemical Methods. Ed. Bartels, J. M. Soil Science Society of America Inc., Madison, Wisconsin, USA.

Hewitt, A.E. 1998. New Zealand soil classification. Manaaki Whenua - Landcare Research New Zealand, Lincoln, New Zealand. 133 pp.

Holzworth, D.P.; Huth, N.I.; deVoil, P.G.; Zurcher, E.J.; Herrmann, N.I.; McLean, G.; Chenu, K.; van Oosterom, E.J.; Snow, V.; Murphy, C.; Moore, A.D.; Brown, H.; Whish, J.P.M.; Verrall, S.; Fainges, J.; Bell, L.W.; Peake, A.S.; Poulton, P.L.; Hochman, Z.; Thorburn, P.J.; Gaydon, D.S.; Dalgliesh, N.P.; Rodriguez, D.; Cox, H.; Chapman, S.; Doherty, A.; Teixeira, E.; Sharp, J.; Cichota, R.; Vogeler, I.; Li, F.Y.; Wang, E.; Hammer, G.L.; Robertson, M.J.; Dimes, J.P.; Whitbread, A.M.;

Hunt, J.; van Rees, H.; McClelland, T.; Carberry, P.S.; Hargreaves, J.N.G.; MacLeod, N.; McDonald, C.; Harsdorf, J.; Wedgwood, S.; Keating, B.A. 2014. APSIM – Evolution towards a new generation of agricultural systems simulation. *Environmental Modelling & Software 62*: 327-350.

Horan, B.; Mee, J.F.; Rath, M.; O'Connor, P.; Dillon, P. 2004. The effect of strain of Holstein-Friesian cow and feeding system on reproductive performance in seasonal-calving milk production systems. *Animal Science 79*: 453-467.

Houlbrooke, D.; Longhurst, B.; Orchiston, T.; Muirhead, R. 2012. Land applying dairy manures and slurries: Evaluating current practice. p. 8. In: Advanced Nutrient Management: Gains from the Past - Goals for the Future. Eds. Currie, L. D.; Christensen, C. L. Occasional Report No. 25: Fertilizer and Lime Research Centre, Palmerston North.

Houlbrooke, D.; Longhurst, B.; Orchiston, T.; Muirhead, R.W. 2011a. Characterising dairy manures and slurries. Report No. AGRX0901. AgResearch Ltd.

Houlbrooke, D.; Monaghan, R. 2010. Land application of farm dairy effluent: development of decision framework for matching management practice to soil and landscape risk. pp. 35-45. In: Farming's future: minimising footprints and matching margins. Eds. Currie, L. D.; Christensen, C. L. Occasional Report No. 23: Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Houlbrooke, D.J.; Drewry, J.J.; Monaghan, R.M.; Paton, R.J.; Smith, L.C.; Littlejohn, R.P. 2009a. Grazing strategies to protect soil physical properties and maximise pasture yield on a Southland dairy farm. *New Zealand Journal of Agricultural Research 52*: 323-336.

Houlbrooke, D.J.; Horne, D.J.; Hedley, M.J.; Hanly, J.A.; Scotter, D.R.; Snow, V.O. 2004a. Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils. I. An evaluation of the deferred irrigation system for sustainable land treatment in the Manawatu. *New Zealand Journal of Agricultural Research 47*: 405-415.

Houlbrooke, D.J.; Horne, D.J.; Hedley, M.J.; Hanly, J.A.; Snow, V.O. 2004b. A review of literature on the land treatment of farm-dairy effluent in New Zealand and its impact on water quality. *New Zealand Journal of Agricultural Research 47*: 499-511.

Houlbrooke, D.J.; Horne, D.J.; Hedley, M.J.; Snow, V.O.; Hanly, J.A. 2008. Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. *Soil Research 46*: 45-52.

Houlbrooke, D.J.; Paton, R.J.; Littlejohn, R.P.; Morton, J.D. 2011b. Land-use intensification in New Zealand: effects on soil properties and pasture production. *Journal of Agricultural Science 149*: 337-349.

Houlbrooke, D.J.; Paton, R.J.; Morton, J.D.; Littlejohn, R.P. 2009b. Soil quality and plant yield under dryland and irrigated winter forage crops grazed by sheep or cattle. *Soil Research 47*: 470-477.

Hunter, M. 2015. Southland Soils, dairy wintering soil types. Ed. Chrystal, J. Roslin Consultancy, Instruments, L. 1998a. Quik Chem Method. Method 12-107-04-1-B: Lachet Instruments, Milwaukee, WI, USA.

Instruments, L. 1998b. Quik Chem Method. Method 12-107-06-3-A: Lachet Instruments, Milwaukee, WI, USA.

Jarvis, S.C.; Ledgard, S. 2002. Ammonia emissions from intensive dairying: A comparison of contrasting systems in the United Kingdom and New Zealand. *Agriculture, Ecosystems and Environment 92*: 83-92.

Jones, D.L.; Willett, V.B. 2006. Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. *Soil Biology and Biochemistry 38*: 991-999.

Journeaux, P.; Newman, M. 2015. Economic & Environmental Analysis of Dairy Farms with Barns. Cost Benefit Analysis of 14 NZ Dairy Farms with Barns. Report AgFirst and DairyNZ.

Keating, B.A.; Carberry, P.S.; Hammer, G.L.; Probert, M.E.; Robertson, M.J.; Holzworth, D.; Huth, N.I.; Hargreaves, J.N.G.; Meinke, H.; Hochman, Z.; McLean, G.; Verburg, K.; Snow, V.; Dimes, J.P.; Silburn, M.; Wang, E.; Brown, S.; Bristow, K.L.; Asseng, S.; Chapman, S.; McCown, R.L.; Freebairn, D.M.; Smith, C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy 18*: 267-288.

Landcare_Research 2016a. S-map Online. Fast, simple access to New Zealand soils data. In: Soil Factsheets.

Landcare_Research 2016b. Soil Report: Warepa deep silt loam, hilly. 2016: Landcare Research, S-map Online.

Laurenson, S. 2016. Telford barn bedding financial analysis. In: Unpublished data. AgResearch, Lincoln

Laurenson, S.; Houlbrooke, D.J. 2014. Assessing the agronomic benefit of noninversion tillage for improving soil structure following winter grazing of cattle and sheep. *Soil Use and Management 30*: 595-602.

Laurenson, S.; Houlbrooke, D.J.; Beukes, P.C. 2016. Assessing the production and economic benefits from preventing cows grazing on wet soils in New Zealand. *Journal of the Science of Food and Agriculture* 4584-4593.

Lee, A. 2015 (February). Barns come with pros and cons. *New Zealand Dairy Exporter* 88-89.

Li, F.Y.; Snow, V.; Holzworth, D.; Johnson, I.R. 2010. Integration of a pasture model into APSIM. p. 6. In: Food Security from Sustainable Agriculture: Proceedings of the 15th Australian Agronomy Conference. Eds. Dove, H.; Culvenor, R. A. The Regional Institute Ltd, Lincoln, New Zealand.

Lilburne, L.; Carrick, S.; Webb, T.; Moir, J. 2012. Computer-based evaluation of methods to sample nitrate leached from grazed pasture. *Soil Use and Management 28*: 19-26.

Lindsay, S. 2016. Nitrate-N and Ammonium-N analysis method.

Longhurst, B.; Houlbrooke, D.; Orchiston, T.; Muirhead, R. 2012. Characterising dairy manures and slurries. p. 6. In: Advanced Nutrient Management: Gains from the Past - Goals for the Future. Eds. Currie, L. D.; Christensen, C. L. Occasional Report No. 25: Fertilizer and Lime Research Centre, Massey University, Palmerston North.

Longhurst, R.D.; Luo, J.; O'Connor, M.B.; Pow, T. 2006a. Herd Homes: nutrient management and farmer perceptions of performance. pp. 309-313. In: New Zealand Grassland Association. 68: Dunedin.

Longhurst, R.D.; Miller, D.; Williams, I.; Lambourne, A. 2006b. On-farm wintering systems - issues to consider. *Proceedings of the New Zealand Grassland Association 68*: 289-292.

Longhurst, R.D.; Roberts, A.H.C.; O'Connor, M.B. 2000. Farm dairy effluent: a review of published data on chemical and physical characteristics in New Zealand. *New Zealand Journal of Agricultural Research 43*: 7-14.

Luo, J.; Donnison, A.; Ross, C.; Bolan, N.; Ledgard, S.; Clark, D.; Qiu, W. 2008a. Sawdust and bark to treat nitrogen and faecal bacteria in winter stand-off pads on a diary farm. *New Zealand Journal of Agricultural Research 51*: 331-340.

Luo, J.; Ledgard, S.F.; Lindsey, S.B. 2008b. A test of a winter farm management option for mitigating nitrous oxie emissions from a dairy farm. *Soil Use and Management 24*: 121-130.

Luo, J.; Lindsey, S.; Ledgard, S. 2008c. Nitrous oxide emissions from animal urine application on a New Zealand pasture. *Biology and Fertility of Soils 44*: 463-470.

Macdonald, K.; Roche, J. 2008. Condition Scoring Made Easy: Condition scoring for dairy herds. p. 36. DairyNZ, New Zealand.

Macdonald, T.; Scrimgeour, F.; Rowarth, J.S. 2014. Cow housing systems - An economic analysis. p. 6. In: Nutrient management for the farm, catchment and community. Eds. Currie, L. D.; Christensen, C. L. Occasional Report No. 27: Fertilizer and Lime Research Centre, Massey Univeristy, Palmerston North.

MAF 2010. Animal Welfare (Dairy Cattle) Code of Welfare 2010: A code of welfare issued under the Animal Welfare Act 1999. Ed. Committee, N. A. W. A. MAF Biosecurity New Zealand, Wellington, New Zealand.

Malcolm, B.J.; Cameron, K.C.; Edwards, G.R.; Di, H.J. 2015. Nitrogen leaching losses from lysimeters containing winter kale: the effects of urinary N rate and DCD application. *New Zealand Journal of Agricultural Research 58*: 13-25.

Malcolm, B.J.; Cameron, K.C.; Edwards, G.R.; Di, H.J.; de Ruiter, J.M.; Dalley, D.E. 2016. Nitrate leaching losses from lysimeters simulating winter grazing of fodder beet by dairy cows. *New Zealand Journal of Agricultural Research* 1-10.

Malone, R.W.; Huth, N.; Carberry, P.S.; Ma, L.; Kaspar, T.C.; Karlen, D.L.; Meade, T.; Kanwar, R.S.; Heilman, P. 2007. Evaluating and predicting agricultural management effects under tile drainage using modified APSIM. *Geoderma 140*: 310-322.

March, M.D.; Shalloo, L.; Roberts, D.J.; Ryan, W. 2017. Financial evaluation of Holstein Friesian strains within composite and housed UK dairy systems. *Livestock Science 200*: 14-22.

McDowell, R.W. 2006. Phosphorus and Sediment Loss in a Catchment with Winter Forage Grazing of Cropland by Dairy Cattle. *J. Environ. Qual. 35*: 575-583.

McDowell, R.W. 2012. Minimising phosphorus losses from the soil matrix. *Current Opinion in Biotechnology 23*: 860-865.

McDowell, R.W.; Dils, R.M.; Collins, A.L.; Flahive, K.A.; Sharpley, A.N.; Quinn, J. 2016a. A review of the policies and implementation of practices to decrease water quality impairment by phosphorus in New Zealand, the UK, and the US. *Nutrient Cycling in Agroecosystems 104*: 289-305.

McDowell, R.W.; Drewry, J.J.; Muirhead, R.W.; Paton, R.J. 2003a. Cattle treading and phosphorus and sediment loss in overland flow from grazed cropland. *Soil Research 41*: 1521-1532.

McDowell, R.W.; Drewry, J.J.; Paton, R.J.; Carey, P.L.; Monaghan, R.M.; Condron, L.M. 2003b. Influence of soil treading on sediment and phosphorus losses in overland flow. *Soil Research 41*: 949-961.

McDowell, R.W.; Houlbrooke, D.J. 2008. Phosphorus, nitrogen and sediment losses from irrigated cropland and pasture grazed by cattle and sheep. *Proceedings of the New Zealand Grassland Association 70*: 77-83.

McDowell, R.W.; Monaghan, R.M.; Close, M.E.; Tanner, C.C. 2016. Agricultural Catchment Restoration. p. 29. Unpublished.

McDowell, R.W.; van der Weerden, T.J.; Campbell, J. 2011. Nutrient losses associated with irrigation, intensification and management of land use: A study of large scale irrigation in North Otago, New Zealand. *Agricultural Water Management 98*: 877-885.

McLaren, R.G.; Cameron, K.C. 1994. Soil Science: an introduction to the properties and management of New Zealand soils. Oxford University Press, Auckland, New Zealand. 294 pp.

McLeod, M.; Aislabie, J.; Ryburn, J.; McGill, A.; Taylor, M. 2003. Microbial and chemical tracer movement through two Southland soils, New Zealand. *Australian Journal of Soil Research 41*: 1163-1169.

McLeod, M.; Schipper, L.A.; Taylor, M.D. 1998. Preferential flow in a well drained and a poorly drained soil under different overhead irrigation regimes. *Soil Use and Management 14*: 96-100.

Menneer, J.C.; Ledgard, S.; Sprosen, M. 2008. Soil N process inhibitors alter nitrogen leaching dynamics in a pumice soil. *Australian Journal of Soil Research 46*: 323-331.

Miller, J.J.; Beasley, B.W.; Drury, C.F.; Zebarth, B.J. 2009. Barley Yield and Nutrient Uptake for Soil Amended with Fresh and Composted Cattle Manure. *Agronomy Journal 101*: 1047-1059.

Monaghan, R.; Dalley, D.; Davison, L.; Laurenson, S.; Wall, A.; Stevens, D.; Chrystal, J.; A, G. 2014. Key physical production and water quality indicators for the Telford farmlet systems: 2012/13 and 2013/14 lactation seasons. Report No. RE500/2014/084. AgResearch Ltd.

Monaghan, R.M.; Hedley, M.J.; Di, H.J.; McDowell, R.W.; Cameron, K.C.; Ledgard, S.F. 2007a. Nutrient management in New Zealand pastures: recent developments and future issues. (Special issue: New Zealand agricultural research in the twenty-first century. Celebrating 50 years of publication.). *New Zealand Journal of Agricultural Research 50*: 181-201.

Monaghan, R.M.; Houlbrooke, D.J.; Smith, L.C. 2010. The use of low-rate sprinkler application systems for applying farm dairy effluent to land to reduce contaminant transfers. *New Zealand Journal of Agricultural Research 53*: 389-402.

Monaghan, R.M.; Paton, R.J.; Drewry, J.J. 2002. Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. *New Zealand Journal of Agricultural Research 45*: 197-205.

Monaghan, R.M.; Paton, R.J.; Smith, L.C.; Drewry, J.J.; Littlejohn, R.P. 2005. The impacts of nitrogen fertilisation and increased stocking rate on pasture yield, soil physical condition and nutrient losses in drainage from a cattle-grazed pasture. *New Zealand Journal of Agricultural Research 48*: 227-240.

Monaghan, R.M.; Smith, L.C. 2004. Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils. II. The contribution of preferential flow of effluent to whole-farm pollutant losses in subsurface drainage from a West Otago dairy farm. *New Zealand Journal of Agricultural Research 47*: 417-428.

Monaghan, R.M.; Smith, L.C.; de Klein, C.A.M. 2013. The effectiveness of the nitrification inhibitor dicyandiamide (DCD) in reducing nitrate leaching and nitrous oxide emissions from a grazed winter forage crop in southern New Zealand. *Agriculture, Ecosystems & Environment 175*: 29-38.

Monaghan, R.M.; Smith, L.C.; Ledgard, S.F. 2009. The effectiveness of a granular formulation of dicyandiamide (DCD) in limiting nitrate leaching from a grazed dairy pasture. *New Zealand Journal of Agricultural Research 52*: 145-159.

Monaghan, R.M.; Smith, L.C.; Muirhead, R.W. 2016. Pathways of contaminant transfers to water from an artificially-drained soil under intensive grazing by dairy cows. *Agriculture, Ecosystems & Environment 220*: 76-88.

Monaghan, R.M.; Wilcock, R.J.; Smith, L.C.; Tikkisetty, B.; Thorrold, B.S.; Costall, D. 2007b. Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand. *Agriculture, Ecosystems & Environment 118*: 211-222.

Moore, A.D.; Alva, A.K.; Collins, H.P.; Boydston, R.A. 2010. Mineralization of nitrogen from biofuel by-products and animal manures amended to a sandy soil. *Communications in Soil Science and Plant Analysis 41*: 1315-1326.

Muirhead, R.W.; Littlejohn, R.P.; Bremer, P.J. 2004. Evaluation of the effectiveness of a commercially available defined substrate medium and enumeration system for measuring Escherichia coli numbers in faeces and soil samples. *Letters in Applied Microbiology 39*: 383-387.

Mulvaney, R.L. 1996. Nitrogen - inorganic forms. pp. 1123-1184. In: Methods of soil analysis: Part 3. Ed. Sparks, D. L. SSSA, Madison, WI.

Newman, M.; Journeaux, P. 2015. The economic and nutrient loss impacts of constructing and running cow housing facilities - a case-study of five South Island freestall barns. p. 13. In: 59th AARES Annual Conference. 59: Australian Agricultural & Resource Economics Society, Rotorua.

Newman, M.; Mashlan, K. 2015. To barn or not to barn, that is the question. pp. 299-314. In: SIDE - South Island Dairy Event. SIDE, Lincoln University, Christchurch.

NIWA 2015a. The National Climate Database. In: 30-year average climate data South Otago and Southland sites. 2015: www.cliflo.niwa.co.nz

NIWA 2015b. The National Climate Database. In: Telford weather station (26163) climate data. 2015: www.cliflo.niwa.co.nz

NIWA 2016. The National Climate Database. In: 30-year annual average climate data for Invermay (Station 5365). 2016: www.cliflo.niwa.co.nz

O'Brien, D.; Shalloo, L.; Patton, J.; Buckley, F.; Grainger, C.; Wallace, M. 2012. A life cycle assessment of seasonal grass-based and confinement dairy farms. *Agricultural Systems 107*: 33-46.

O'Driscoll, K.K.M.; Hanlon, A.; French, P.; Boyle, L.A. 2009. The effects of two out-wintering pad systems compared with free-stalls on dairy cow hoof and limb health. *Journal of Dairy Research 76*: 59-65.

Olsen, S.R.; Cole, C.V.; Watanabe, F.S.; et al. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *Circular. United States Department of Agriculture 939*:

Orchiston, T.; Monaghan, R.; Laurenson, S. 2013. Reducing overland flow and sediment losses from winter forage crop paddocks grazd by dairy cows. p. 7. In: Accurate and efficient use of nutrients on farms. Eds. Currie, L. D.; Christensen, C. L. Occasional report No. 26: Palmerston North.

ORC. 2014. A guide to water quality rules. Plan change 6A - Otago water plan. Managing contaminant discharge and sediment from runoffs, drains, leaching and earthworks, Otago Regional Council, Dunedin, NZ.

Probert, M.E.; Dimes, J.P.; Keating, B.A.; Dalal, R.C.; Strong, W.M. 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems 56*: 1-28.

Qian, P.; Schoenau, J.J. 2002. Availability of nitrogen in solid manure amendments with different C:N ratios. *Canadian Journal of Soil Science 82*: 219-225.

Rayment, G.E.; Lyons, D.L. 2011. Soil Chemical Methods - Australasia. CSIRO Publishing, Victoria, Australia.

Redbo, I.; Ehrlemark, A.; Redbo-Torstensson, P. 2001. Behavioural responses to climatic demands of dairy heifers housed outdoors. *Canadian Journal of Animal Science 81*: 9-15.

Reich, L.J.; Weary, D.M.; Veira, D.M.; von Keyserlingk, M.A.G. 2010. Effects of sawdust bedding dry matter on lying behavior of dairy cows: A dose-dependent response. *Journal of Dairy Science 93*: 1561-1565.

Roche, J.R.; Dillon, P.G.; Stockdale, C.R.; Baumgard, L.H.; VanBaale, M.J. 2004. Relationships Among International Body Condition Scoring Systems. *Journal of Dairy Science 87*: 3076-3079.

Rugoho, I.; Gibbs, S.J.; Edwards, G.R. 2014. Dry matter intake and body condition score gain of dairy cows offered kale and grass. *New Zealand Journal of Agricultural Research 57*: 110-121.

Saleh, A. 1993. Soil roughness measurement: chain method. *Journal of Soil & Water Conservation 48*: 527-529.

Schütz, K.E.; Clark, K.V.; Cox, N.R.; Matthews, L.R.; Tucker, C.B. 2010. Responses to short-term exposure to simulated rain and wind by dairy cattle: Time budgets, shelter use, body temperature and feed intake. *Animal Welfare 19*: 375-383.

Schütz, K.E.; Cox, N.R. 2014. Effects of short-term repeated exposure to different flooring surfaces on the behavior and physiology of dairy cattle. *Journal of Dairy Science 97*: 2753-2762.

Schütz, K.E.; Huddart, F.J.; Sutherland, M.A.; Stewart, M.; Cox, N.R. 2015. Effects of space allowance on the behavior and physiology of cattle temporarily managed on rubber mats. *Journal of Dairy Science 98*: 6226-6235.

Scott, C.A.; Geohring, L.D.; Walter, M.F. 1998. Water quality impacts of tile drains in shallow, sloping, structured soils as affected by manure application. *Applied Engineering in Agriculture 14*: 599-603.

Scotter, D.; Clothier, B.; Turner, M. 1979. The soil water balance in a Fragiaqualf and its effect on pasture growth in central New Zealand. *Soil Research 17*: 455-465.

Selbie, D.R.; Buckthought, L.E.; Shepherd, M.A. 2015. Chapter Four - The Challenge of the Urine Patch for Managing Nitrogen in Grazed Pasture Systems. pp. 229-292. In: Advances in Agronomy. Ed. Donald L, S. Academic Press,

Shepherd, M.; Stafford, A.; Smeaton, D. 2012. The use of a nitrification inhibitor (DCn^{TM}) to reduce nitrate leaching under a winter-grazed forage crop in the Central Plateau. pp. 103-107. In: Proceedings of the New Zealand Grassland Association.

Singleton, P.L.; Addison, B. 1999. Effects of cattle treading on physical properties of three soils used for dairy farming in the Waikato, North Island, New Zealand. *Soil Research 37*: 891-902.

Smith, L.C.; Monaghan, R.M. 2003. Nitrogen and phosphorus losses in overland flow from a cattle-grazed pasture in Southland. *New Zealand Journal of Agricultural Research 46*: 225-237.

Smith, L.C.; Orchiston, T.; Monaghan, R. 2012. The effectiveness of the nitrification inhibitor dicyandiamide (DCD) for mitigating nitrogen leaching losses from a winter grazed forage crop on a free draining soil in northern Southland. pp. 39-44. In: Proceedings of the New Zealand Grassland Association.

Smith, S.M.; Vale, W.W. 2006. The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. *Dialogues in Clinical Neuroscience 8*: 383-395.

Sprosen, M.S.; Ledgard, S.F.; Lindsey, S.B. 2009. Effect of rate and form of dicyandiamide application on nitrate leaching and pasture production from a volcanic ash soil in the Waikato. *New Zealand Journal of Agricultural Research 52*: 47-55.

Stevens, D.; Wall, A.; Thompson, B. 2011. Impact of dairy wintering systems on the environment, cow condition score and subsequent milk production: Winter feeding summary. Report AgResearch.

Stevens, D.R.; Thompson, B.R. 2012. Intake, crop utilisation and nitrogen output of cows wintetring on swedes at two different allowances in Southern New Zealand. In: Proceedings of the 5th Australiasian Dairy Science Symposium Ed. Jacobs, J. Melbourne, Australia.

Stewart, M.; Fisher, A.D.; Verkerk, G.A.; Matthews, L.R. 2002. Winter dairy grazing systems: management practices and cow comfort. *Proceedings of the New Zealand Society of Animal Production 62*: 44-48.

Suarez, D.L. 1996. Beryllium, Magnesium, Calcium, Strontium and Barium. pp. 575-602. In: Methods of Soil Analysis. Part 3 - Chemical Analysis. Ed. Bartels, J. M. Soil Science Society of America Inc., Madison, Wisconsin, USA.

Tabatabai, M.A.; Frankenberger, W.T. 1996. Liquid Chromatography. pp. 225-246. In: Methods of Aoil Analysis. Part 3 - Chemical Methods. Ed. Bartels, J. M. Soil Science Society of America Inc., Madison, Wisconsin, USA.

Tait, A.; Sturman, J.; Clark, M. 2012. An assessment of the accuracy of interpolated daily rainfall for New Zealand. *Journal of Hydrology New Zealand 51*: 25-44.

Thomas, G.W. 1996. Soil pH and Soil Acidity. pp. 475-490. In: Methods of Soil Analysis. Part 3 - Chemical Methods. Ed. Bartels, J. M. Soil Science Society of America Inc., Madison, Wisconsin, USA.

Thomas, S.M.; Beare, M.H.; Francis, G.S.; Barlow, H.E.; Hedderley, D.I. 2008. Effects of tillage, simulated cattle grazing and soil moisture on N2O emissions from a winter forage crop. *Plant and Soil 309*: 131-145.

Thomas, S.M.; Francis, G.S.; Barlow, H.E.; Beare, M.H.; Trimmer, L.A.; Gillespie, R.N.; Tabley, F.J. 2004. Winter grazing of forages - soil moisture and tillage effects impact nitrous oxide emissions and dry matter production. pp. 135-140. In: Proceedings of the New Zealand Grassland Association.

Thomsen, I.K.; Kjellerup, V. 1997. Yields and N uptake of barley and ryegrass from soils with added animal manure differing in straw and urine content. *European Journal of Agronomy 7*: 285-292.

Tucker, C.B.; Rogers, A.R.; Schütz, K.E. 2008. Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system. *Applied Animal Behaviour Science 109*: 141-154.

Tucker, C.B.; Rogers, A.R.; Verkerk, G.A.; Kendall, P.E.; Webster, J.R.; Matthews, L.R. 2007. Effects of shelter and body condition on the behaviour and physiology of dairy cattle in winter. *Applied Animal Behaviour Science 105*: 1-13.

Van der Weerden, T. 2014. Manure material weight in cubic meters. Personal communication.

van der Weerden, T.J.; Luo, J.; Dexter, M.; Rutherford, A.J. 2014. Nitrous oxide, ammonia and methane emissions from dairy cow manure during storage and after application to pasture. *New Zealand Journal of Agricultural Research* 1-16.

Verburg, K.; Ross, P.J.; Bristow, K.L. 1996. SWIMv2.1 user manual. Report CSIRO Division of Soils.

Vogeler, I.; Cichota, R.; Snow, V.; Jolly, B.; Bryant, J.R. 2010. Determining risk indicators for N leaching using APSIM modelling. Report AgResearch.

Vogeler, I.; Cichota, R.; Snow, V.O.; Dutton, T.; Daly, B. 2011. Pedotransfer Functions for Estimating Ammonium Adsorption in Soils *Soil Science Society of America Journal 75*: 324-331.

Watanabe, F.S.; Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. *Soil Science Society of America Journal 29*: 677-678.

Webster, J.R.; Stewart, M.; Rogers, A.R.; Verkerk, G.A. 2008. Assessment of welfare from physiological and behavioural responses of New Zealand dairy cows exposed to cold and wet conditions. *Animal Welfare 17*: 19-26.

Wheeler, D.M.; Cichota, R.; Snow, V.; Shepherd, M. 2011. A revised leaching model for OVERSEER Nutrient Budgets. p. 6. In: Adding to the knowledge base for the nutrient manager. Eds. Currie, L. D.; Christensen, C. L. Fertilizer and Lime Research Centre, Massey University, Plamerston North, New Zealand.

Wheeler, D.M.; Ledgard, S.F.; deKlein, C.A.M.; Monaghan, R., M; Carey, P.L.; McDowell, R.W.; Johns, K.L. 2003. OVERSEER® nutrient budgets – moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association 65*: 191-194.

White, T.A.; Snow, V.O.; King, W.M. 2010. Intensification of New Zealand beef farming systems. *Agricultural Systems 103*: 21-35.

Whitehead, D.C. 1995. Grasses: Uptake of Nitrogen and Effects on Morphology and Physiology. In: Grassland Nitrogen. Biddles Ltd, Guildford, UK.

Wisconsin-Extension, U.o. 2003. Recommended Methods of Manure Analysis. A3769: US Department of Agriculture and Wisconsin Counties Cooperating Wisconsin, USA.

Woodward, S.J.R.; Barker, D.J.; Zyskowski, R.F. 2001. A practical model for predicting soil water deficit in New Zealand pastures. *New Zealand Journal of Agricultural Research 44*: 91-109.

Yeomans, J.C.; Bremner, J.M. 1991. Carbon and nitrogen analysis of soils by automated combustion techniques. *Communications in Soil Science and Plant Analysis 22*: 843-850.

11. Appendices

11.1 Trial 2: Barn bedding moisture

11.1.1 Introduction to the barn bedding moisture trial

During the use of the Telford barn in winter 2012, farm and research staff identified a problem with high moisture levels in the barn bedding resulting in severe pugging within the barn. Increased moisture of the bedding in loafing areas can reduce cow lying times; an indication of a negative effect to animal welfare. High moisture levels also increase the risk of mastitis (Favero *et al.* 2015), particularly if lactating cows are housed in the barn, and lameness if cows' hooves are constantly wet (O'Driscoll *et al.* 2009). This experiment was designed to measure the bedding moisture level throughout winter. Moisture contents were measured at two different depths to get values of the moisture content at, and below, the bedding surface. Photos were taken regularly to investigate whether visual assessment of the bedding moisture levels was possible.

The goal was to generate data to help design a fact sheet that could be made available, via DairyNZ, to farmers with advice and information relating to the management of a barn utilising a woodchip bedding. The context of this work was that the moisture content of the barn bedding is important both in terms of cost and also animal welfare. Reducing the frequency and volumes of replacement bedding required reduces the overall cost to the farmer.

11.1.2 Methods of monitoring and measuring moisture content in a wintering barn woodchip bedding

The design of the barn is outlined in section 3.2. Briefly, the barn structure was a roofed area over the bark bedding with an adjacent concrete feeding strip and feeding troughs both of which were uncovered. Water troughs were located at the north and south ends of the barn in the bedding area. The north and south ends of the barn were open to the elements while the west wall and east wall (between entranceways) were covered with a shade cloth.

During winter 2014, samples were taken weekly to quantify the moisture of the bedding at 9 sampling points covering three location types within the barn: Entranceway (Figure 11.1; points 1-3), Middle of barn (Figure 11.1; points 4-6), West wall (Figure 11.1; points 7-9). These sampling points were chosen as they represented a range in traffic volume. The Entranceways were high traffic areas, the West Wall was low traffic and the Middle of the barn was a medium traffic area. Samples were also taken at two depths at each of these sampling points, 0-150 mm and 150-300 mm, and the values for the three samples for each location type (High, Medium and Low traffic) were averaged for each sampling depth. Eighteen samples in total were taken at each sampling occasion and these were labelled at the sampling site and stored for a maximum of 24 hours in an air tight bag at 4°C until oven drying. Each sample was weighed and then dried for at least 24-hours at 104°C before being re-weighed. Samples were not allowed to cool before being re-weighed.

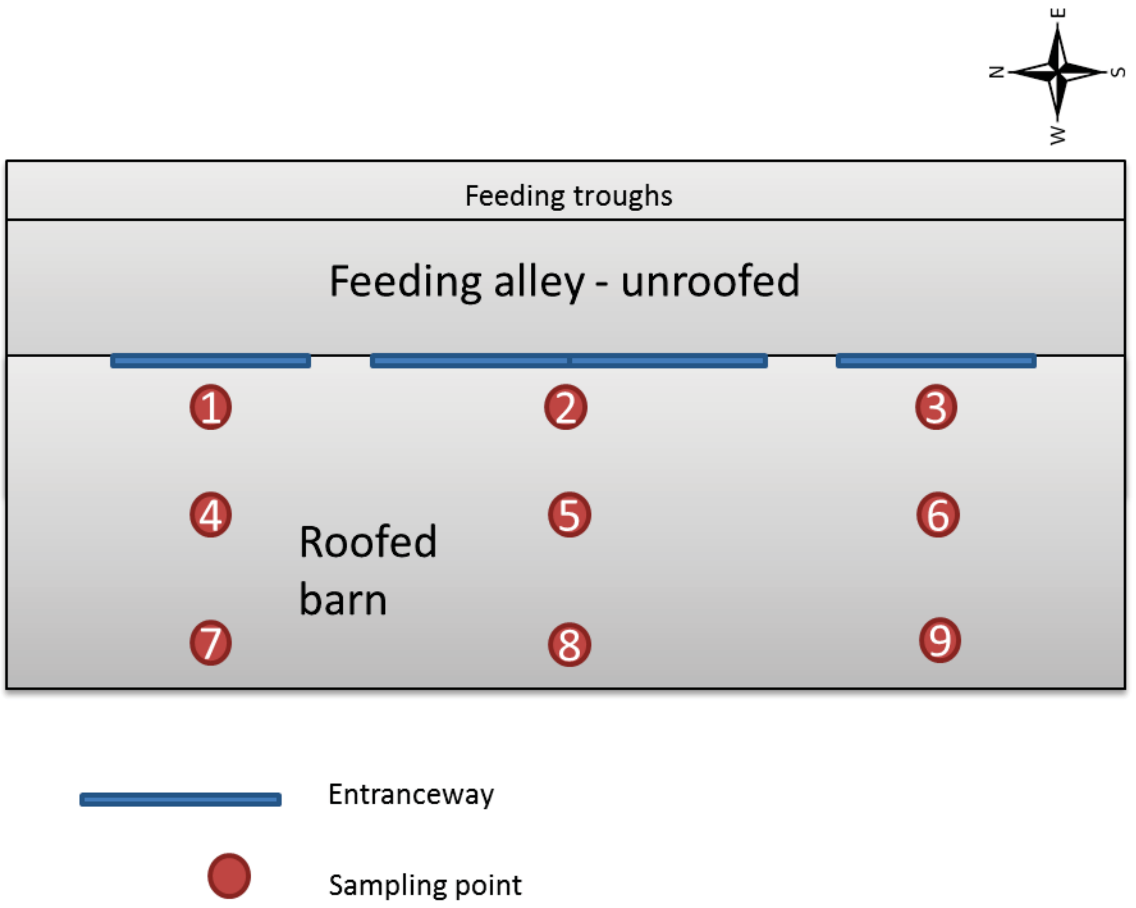


Figure 11.1. Diagram of wintering barn and sampling location points. 1-3 represent high traffic areas, 4-6 are medium traffic areas and 7-9 are low traffic areas.

Dry matter analysis was conducted weekly on the barn bedding between 9th June 2014 and 29th August 2014. Additionally, weekly photos of barn bedding surface were taken so that comparison between bedding moisture values and a visual image of the bedding surface could be done. The cows were taken out of the barn on the 1st September signalling the end of the wintering period in the barn. During the 2014 winter a fresh layer of bedding was added on 15th July after removing the top 215 m^3 of bedding. This was the only addition of fresh bedding during the winter. Management of the barn included daily ripping of the barn surface.

11.1.3 Results of barn bedding moisture monitoring

Overall the moisture content of the barn bedding increased over time and the high traffic areas were constantly wetter than low traffic areas (Figure 11.2).

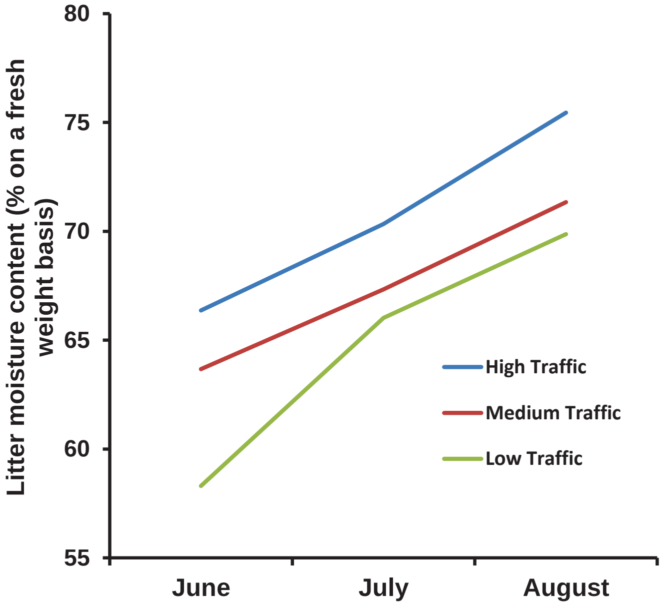


Figure 11.2. Average bedding moisture content of night, medium and low traffic areas within the Telford wintering barn in winter 2014.

The results showed that the moisture content of the bedding increased over time with the top 15 cm having a higher moisture content than the 15-30 cm layer at all locations. The high traffic areas were noticeably wetter than the rest of the barn (Figure 11.2)

When the top layer was removed on the 15th July (215 m^3) there was a noticeable reduction in the moisture content of the top layer at all locations. However, within a week the moisture content was back to levels similar to those prior to the addition of the new woodchip (Figure 11.3). Comparison of the weekly photos with the moisture results indicated that a visual assessment was sufficient to gauge moisture levels. It was visually obvious when the moisture levels in the bedding were high (Figure 11.4).

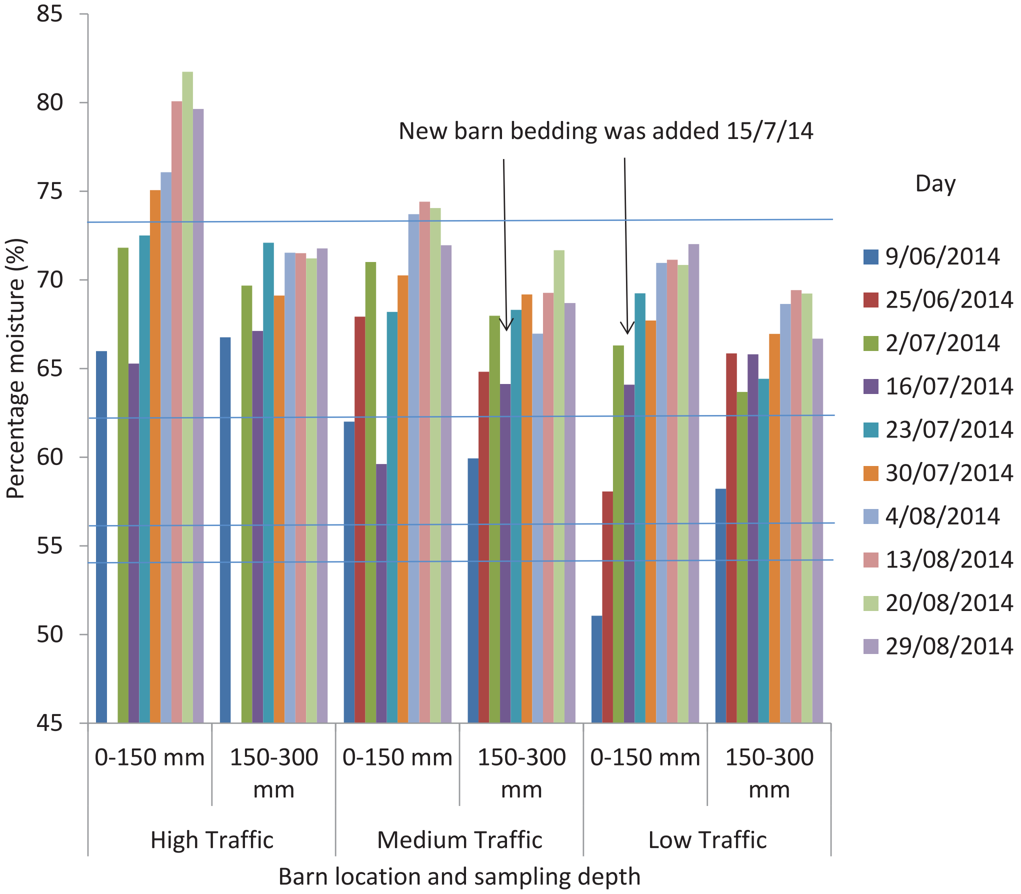


Figure 11.3. Barn bedding moistures, over time, at different locations throughout the barn and at two depths at each location. A top layer of the bedding was removed on 15/7/14 and replaced with a layer of fresh bedding. The moisture of the bedding removed was 73% and the bedding added was 62% (top two blue lines). The bottom blue lines show the moisture % (54% and 56% of the bedding stored to go in to the barn for the next season.

Figure 11.4. Loose-housed barn with bark and sawdust bedding on (a) the first day of winter (mid-May) and (b) mid-July.

11.1.4 **Discussion on barn bedding moisture**

These results suggest the following:

- High traffic areas have higher moisture levels than other areas of the barn.
- The drier (lower the moisture %) the fresh barn bedding used the better as there is greater absorbance capacity.
- The surface of the bedding is wetter than deeper layers probably due to an accumulation on the surface of dung.
- Refreshing the surface layers of the barn at intervals during the winter will help reduce the moisture levels in the top layer for a short period. Visual assessment of the bedding surface is sufficient to determine when this is required (Figure 11.5).
- Barn management to reduce moisture in the bedding area will increase the longevity of the bedding material. Minimising rain getting into the barn, maximising air flow to help dry bedding, having feeding and water trough areas away from the bedded area, holding cows in another area to minimise the number of cow/hours in the barn.

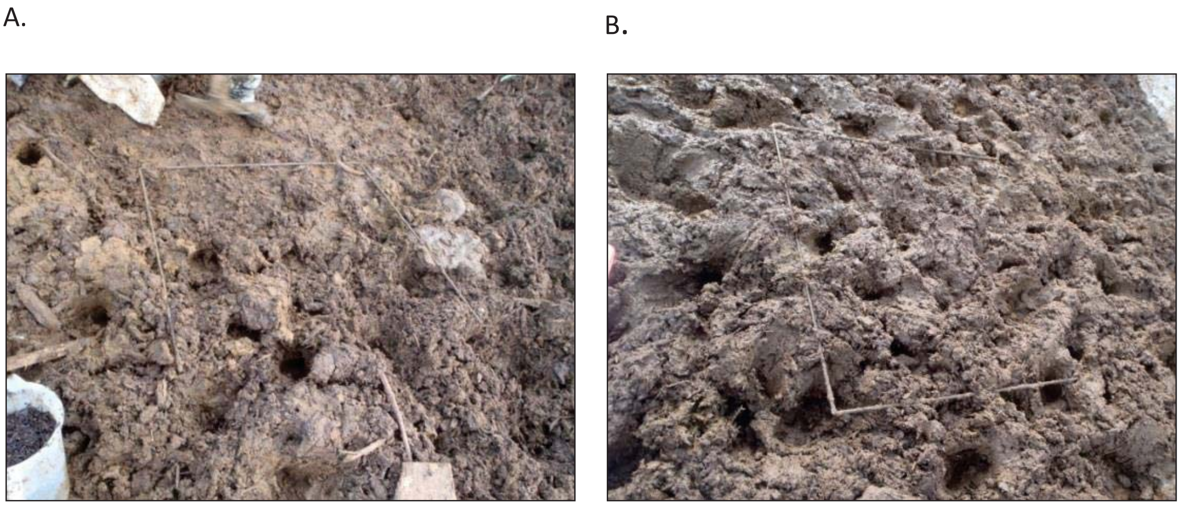


Figure 11.5. Barn surface condition at the end of winter (Aug) for A) low and B) highly trafficked areas

11.1.5 **Recommendations for farmers**

There were a number of management strategies applied to the barn surface during the time the research team was involved on the farm. The information below was the resulting experience and information for farmers considering adopting a woodchip bedding (Table 11.1).

Table 11.1. Woodchip bedding surface management strategies adopted during 2012-2014 period on Telford farm and their effectiveness at minimising barn bedding moisture and longevity.

Approach	**Effectiveness in managing barn**	**Why?**
Leaving the barn surface i.e. doing nothing to maintain it and only replacing when required	*Low*	The dung remained on the surface of the bedding creating a wet, sloppy surface that quickly became mucky.
Daily ripping of barn; with large and un-regular woodchip material sourced from farms own trees	*Low*	The ripper was not able to slice and turn the bedding due to the large chunks of wood material in the bedding.
Daily ripping of barn; with small and uniform woodchips (purchased commercially)	***High***	Allowed incorporation of dung through the bedding thus redistributing the material with a high moisture content throughout the bedding profile. Help dry out the surface
Chipping the off cuts from our own trees	*Low*	The chips were too large, non-uniform, stringy and wet. Figure 11.6 shows farm made material on left and purchased material on the right). The material used was the outside branches and slash material so it did not chip evenly.

Figure 11.6. Fresh barn bedding from two different sources. Wetter and larger woodchips on the left; drier and smaller, more uniform chips on the right.

11.2 Trial 3: Effects of applying dairy wintering barn manure of differing C:N ratios directly to pasture on N mineralisation and forage growth

This work has been summarised in a research article published in the New Zealand Journal of Agricultural Research. Chrystal, J., Smith, C., Monaghan, R., Hedley, M., Horne, D. (2016). Effects of applying dairy wintering barn manure of differing C:N ratios directly to pasture on N mineralisation and forage growth (Chrystal *et al.* 2016c).

11.2.1 Abstract

Two experiments were conducted to examine the effect of applying spent dairy wintering barn bedding (termed 'manure' for the rest of this paper) to a pasture soil. This chapter outlines one of these. An incubation study compared rates of Nitrogen (N) mineralisation of manures of differing storage durations (fresh, 2.5 months and 12 months storage) and C:N ratios (26:1, 22:1, 17:1 and 12:1), added to soil at a rate of 289 mg N kg^{-1} soil. Incubation results indicated the addition of Urea as an N source to the manure product at a rate to reduce the C:N ratio to approximately 12:1 resulted in a large increase in apparent net mineralisation. Knowledge of the C:N ratio of a manure product may help guide farmers in determining the best time to apply manure to soil to both maximise pasture growth and minimise potential nutrient losses to the environment.

Keywords: C:N ratio, mineralisation, manure, wintering, incubation, nitrogen, immobilisation

11.2.2 Introduction to the Incubation study

In southern New Zealand non-lactating, in-calf dairy cows have traditionally been wintered off pasture on brassica crops. Grazing of these crops are a significant source of nutrient losses to waterways (Monaghan *et al.* 2013; Orchiston *et al.* 2013; Smith *et al.* 2012). Wintering barns and standoff pads are increasingly being seen as alternative approaches to wintering dairy cows. However, wintering barns and standoff facilities generate large volumes of manure products that must, at some point, be returned to land (Houlbrooke *et al.* 2012). The characteristics of the manure and its immediate nutrient value (nitrogen, phosphorus, potassium; N, P, K) differs between, and within, systems (Longhurst *et al.* 2012). The potential fertiliser value of the manure can partially offset the financial cost associated with handling and storing the material (Macdonald *et al.* 2014). In southern New Zealand farmers have been incorporating loose-housed wintering barn manure directly into the soil during seedbed preparation, without a full appreciation of its agronomic value.

Research on the agronomic effectiveness of organic manures in New Zealand and overseas has largely concentrated on application of such manures to crop paddocks, as a means of adding organic matter, as well as applying nutrients (Chatfield *et al.* 2011; Eghball & Power 1999; Gutser *et al.* 2005; Miller *et al.* 2009; Qian & Schoenau 2002; Thomsen & Kjellerup 1997). Research has shown that the short term effect of applying such manures with a high carbon to nitrogen (C:N) ratio was reduced crop production, particularly where existing soil mineral N levels were low and/or the C:N ratio of the manure was high (Qian & Schoenau 2002; Thomsen & Kjellerup 1997). There are conflicting data in the literature regarding N mineralisation rates from manure-amended soil with one incubation study observing a poor correlation between C:N ratio and the rate of N mineralisation (Griffin & Hutchinson 2007), while other studies show higher rates of N mineralisation from materials that have lower C:N ratios (Chadwick *et al.* 2000; Moore *et al.* 2010; Qian & Schoenau 2002). None of these studies evaluated manures with a C:N ratio above 20.

To fully capture the value of manures generated from animal wintering facilities farmers require information on whether these materials are agronomically effective when directly applied to pastures, or whether additional treatment (e.g. composting) is required prior to application. This section reports on a soil incubation experiment conducted to measure N mineralisation from manure amended soil. The aim of this experiment was to evaluate the characteristics and fertiliser value of the manure generated by a loose-housed, wintering barn that used woodchip bedding material. The hypotheses tested were (i) the C:N ratio of the bedding material would influence the rate of mineralisation, and (ii) that adding a N source to material to reduce the C:N ratio would increase the rate of net N mineralisation.

11.2.3 **Methods for Incubation study**

The incubation experiment used soil taken from the 0-10 cm layer of the Tokomairiro deep silt loam (Fragic Perch-gley Pallic soil, NZ Soil Classification (Hewitt 1998)) from South Otago, which was air-dried and sieved (4 mm) prior to use. The field soil is imperfectly drained, has moderate fertility and high plant available water storage capacity. Some chemical characteristics of this soil were as follows: pH 6.1, Quicktest (QT) Ca 12, Olsen P 24 µg mL^{-1}, QT K 7, SO_4-S 17 ppm, total N 0.40 g 100 g^{-1}, total C 4.2 g 100 g^{-1}, these were analysed using standard protocols and methods (Helmke & Sparks 1996; Olsen *et al.* 1954; Rayment & Lyons 2011; Suarez 1996; Tabatabai & Frankenberger 1996; Thomas 1996; Yeomans & Bremner 1991).

Representative samples of manure were taken from three stacks that differed in storage length (Table 11.2) and chemical composition (Table 11.3). A representative sample of each original manure mix was taken and ground to < 4 mm prior to mixing with soil. Samples were incubated in the dark at 22°C in sealed plastic boxes of 2.7 L capacity. The lids of the boxes remained on for the duration of the trial other than for sample collections, water additions and regular venting intervals of 15 minutes at two to three day intervals. Each box contained 500 g of wet soil that was maintained at a moisture content of 24% v/v. Manure was added at a rate of 289 mg N kg^{-1} soil (total N). There were 5 treatments (Table 11.2**Error! Reference source not found.**) with 6 replicates. Urea in the +N treatment was added at a rate of 329 mg N kg^{-1} soil to reduce the C:N ratio from 26:1 to 12:1.

Sub-samples of approximately 45 g were removed 1, 3, 7, 14, 21, 28, 42, 56, 69 and 100 days after manure addition and analysed for mineral N and moisture contents. Fifteen grams of moist soil was mixed in a jar with 100 mL of 2 M KCl. This was shaken for one hour and the extract filtered and analysed for ammonium-N (NH_4^+-N) and nitrate-N (NO_3-N) concentrations using a Skalar SAN^{++} segmented flow analyser (Skalar Analytical B.V., Breda, Netherlands). The remaining sub-sample was used for moisture content analysis. KCl-extractable N values were expressed on a per hectare basis assuming a depth of 10 cm and a soil bulk density of 1040 kg m^{-3}. Apparent net N mineralisation was calculated as the difference between the amount of mineral N (ammonium-N + nitrate-N) extracted from manure treated soils and the soil alone (control) minus any fertiliser N added e.g. fresh manure + urea, and expressed as a percentage of the total manure N added.

Table 11.2. Details of experimental treatments imposed in the laboratory Incubation (soil amended with cow barn manure) using carbon-based wintering barn manure.

Abbreviation	Treatments	Period of manure storage (months)	Manure C:N ratio	Manure N addition kg N ha^{-1}	Fertiliser N addition kg N ha^{-1}
Incubation Experiment[1]					
Control	1. Soil only			0	0
Fresh	2. Soil + Fresh bedding	0	26:1	300	0
Short	3. Soil + Bedding stored for 2.5 months	2.5	22:1	300	0
Long	4. Soil + Bedding stored for 12 months	12	17:1	300	0
+N	5. Soil + Fresh bedding plus urea	0	12:1	300	342

[1] Soil Total N 0.40%, Total Carbon 4.2%.

Table 11.3. Chemical attributes of the three barn bedding manures (stored for different periods of time) used in a laboratory Incubation experiment designed to measure net rates of N mineralisation in soil amended with cow barn bedding material.

	Fresh manure	Short stored manure (2.5 months)	Long stored manure (12 months)
TN%	0.50	0.45	0.51
NH4_N %	0.002	0.004	0.001
NO3_N %	0.008	0.002	0.014
TP %	0.11	0.13	0.13
K %	0.78	0.53	0.455
TC %	12.8	10.0	8.6
DM %	35.3	29.2	35.3
pH	8.5	8.7	^
C:N ratio	25.6	22.3	16.8

^ analysis not conducted

Analysis conducted at Eurofins Ltd (NZ)

11.2.4 Results and Discussion of the Incubation Study

Fresh manure applied directly to soil resulted in net N immobilisation for the duration of the 100 day trial, which was not significantly different from the Control (ns; Figure 11.7). Manure that had undergone a short storage period prior to application to soil caused an initial period of N immobilisation over the first 14 days of the trial, then a period of mineralisation until day 28; apparent N mineralisation stopped at around 8% of the total N added as manure (ns, P=0.721Figure 11.7). The manure that was stored for 12 months prior to application mineralised about 10% of the N applied. This N appeared to be immediately available. Adding urea to the manure to deliver a C:N ratio of 12:1 increased the apparent mineralisation of manure N to nearly 60% by day 70 (P<0.001) (Figure 11.7).

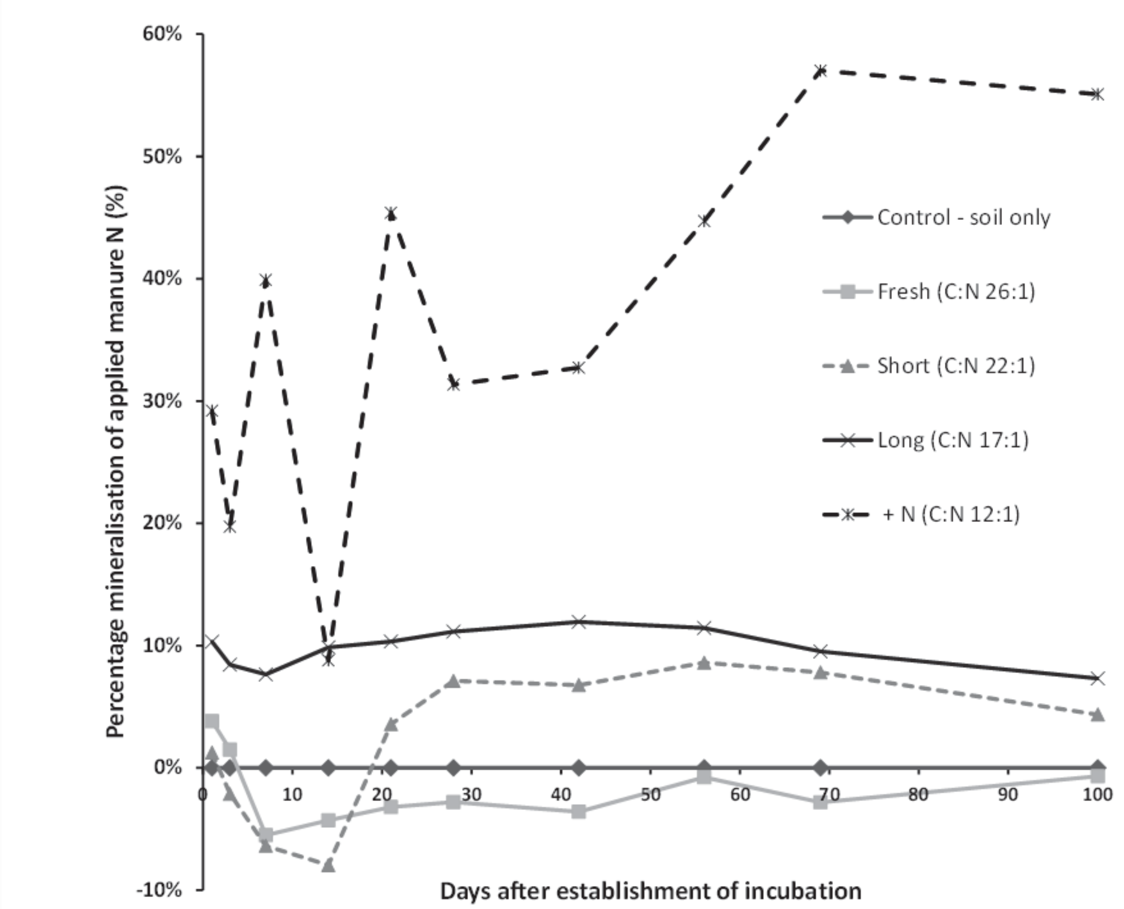


Figure 11.7. Percentage net mineralisation of applied manure N during laboratory incubation of soil amended with manure that had been applied fresh or stored for periods of 2.5 months (short), 12 months (long) or fresh amended with urea (+N) during trial establishment. Results were adjusted to account for the net mineralisation in the control treatment and for the N added as urea to the +N treatment. Variation in s.e.m was high over days 1-14 (average 21%) but lower for the remainder of the trial (average s.e.m was 6% for days 21-100).

11.2.5 **Conclusion of the Incubation Study**

Manure C:N ratio had an important effect on N release from manures that had been stored for different lengths of time. The C:N ratio decreased during manure storage. Applications of fresh manure resulted in an initial period of N immobilisation. This was attributed to the high C:N ratio (26:1). This immobilisation effect appeared to disappear as C:N ratio decreased. In contrast to the fresh manure treatment, application of manure that had a C:N ratio of 17:1 and had been stored for 12 months, resulted in a net mineralisation of approximately 8% of the applied manure N. This research indicates that spent bedding material (with a high C:N ratio) can be applied directly to pastures although additional fertiliser N may be required to overcome short-term N immobilisation processes. Knowledge of the C:N ratio of a manure product will assist decisions made about the supply of N that may become available for plant uptake.

11.2.6 **Summary**

Use of a loose housed barn with a woodchip bedding results in considerable volumes of used bedding material (7.4 m^3 cow^{-1} $winter^{-1}$). The volumes of bedding can be influenced by management decisions and practices. Management to reduce the moisture entering the barn and utilisation of the driest woodchip material available help increase the longevity of the bedding. Daily management of the bedding surface by ripping helps turnover the bedding and drain the liquid. However, for his to be successful a small and uniform woodchip is required.

At the end of winter the used bedding product has a high C:N ratio (as high as 27:1). If this is applied directly to plants it will result in net N immobilisation and potential restriction in plant growth. This immobilisation can be overcome by reducing the C:N ratio. This can be done by storing the used bedding for a period of time (12 months +). Alternatively, this can be done by adding a source of available N (such as Urea) to reduce the C:N ratio to something closer to 12:1.

11.2.7 **Acknowledgements**

These research trials were funded by the Pastoral 21 programme, a collaborative venture between DairyNZ, Fonterra, Dairy Companies Association of New Zealand, Beef + Lamb NZ and the Ministry of Business, Innovation and Employment.

Trial 2: Wayne Worth is acknowledged for his assistance in the collection on field samples.

Trial 3: Chris Smith and Ross Monaghan are acknowledged for their assistance with the manuscript for the published paper. Stuart Lindsay is acknowledged for his assistance with mineral N sample analysis for the Incubation trial.

11.3 Low depth winter applied effluent application - P, SS and *E. coli* results

Volumes and loads of nutrients and *E. coli* applied to treatments. Values represent cumulative loads per hectare applied over the 92 day season (and average load applied per application in brackets) and were derived from eight composite effluent samples taken during the season.

	Control	**2 mm daily (irrigation area)**	**2 mm (irrigation area)**	**5 mm (irrigation area)**	**7 mm (irrigation area)**	**12 mm (irrigation area)**
Volume of effluent applied/plot/application (litres)	0	20	20	40	60	100
Time taken to apply the allocated volume of effluent/application (minutes)	0	4	4	8	12	20
Actual depth (mm) of effluent/application on irrigated area (8.59 m^2 of each 20 m^2 plot)	0	2.33	2.33	4.66	6.98	11.64
Volume applied over the 92 day season in litres (mm applied to irrigated area)	0	1,740 l (203 mm)	1,480 l (172 mm)	2,960 l (345 mm)	4,440 l (517 mm)	7,400 l (862 mm)
N applied (kg/ha) *	0	176 (2.02)	150 (2.02)	301 (4.06)	452 (6.11)	753 (10.18)
P applied (kg/ha) *	0	48 (0.55)	41 (0.55)	82 (1.11)	122 (1.65)	204 (2.76)
E.coli applied (MPN/ha)	0	9.88×10^{10}	6.41×10^{10}	1.28×10^{11}	1.92×10^{11}	3.21×10^{11}

(MPN = most probable number, * number in brackets are daily application values (kg/ha))

The graphs below (Figure 11.8) show results for calculated concentrations (C_W) of DRP, TP, SS and *E. coli* in drainage from the irrigated area and measured concentrations in the effluent applied.

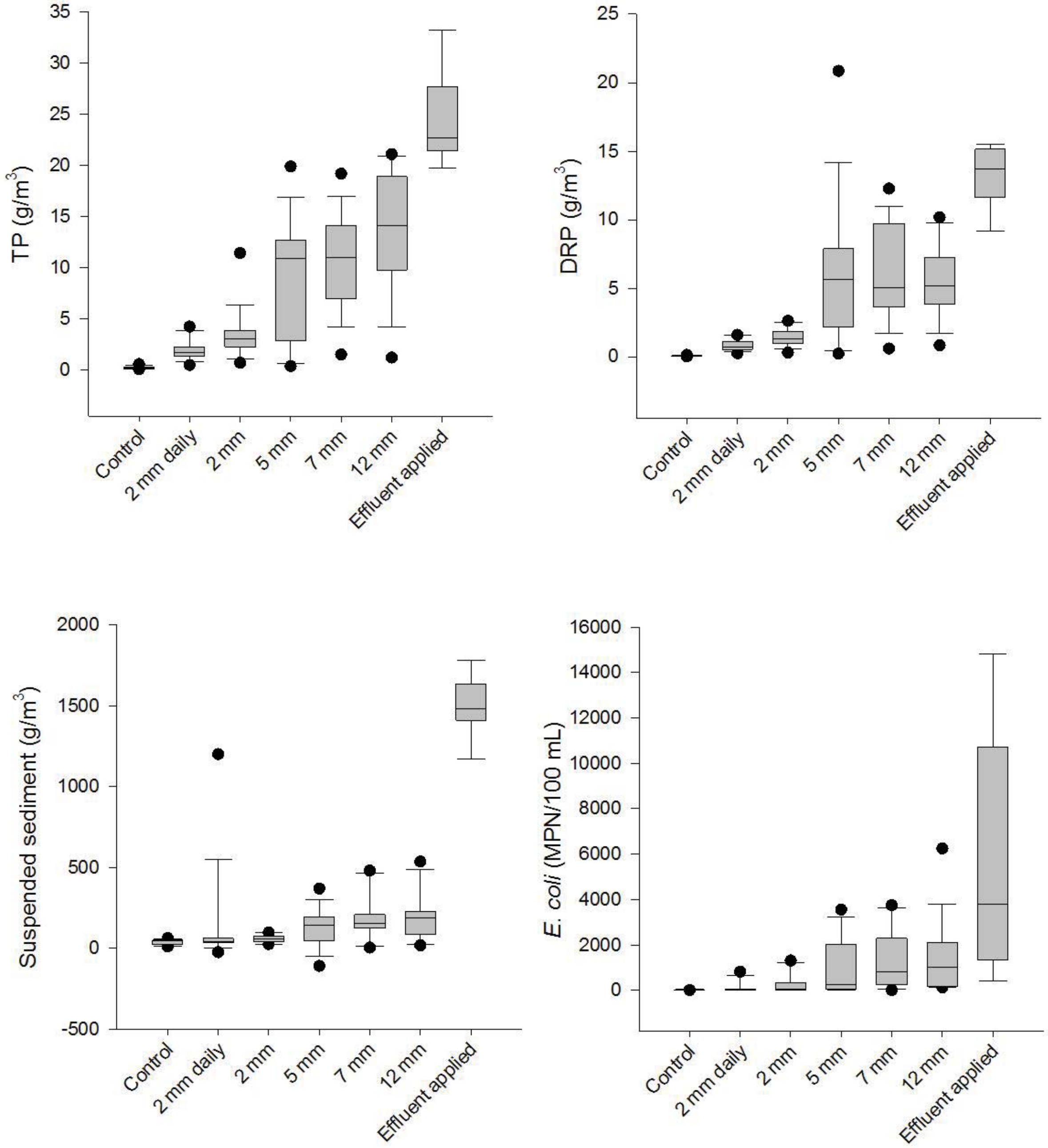


Figure 11.8. Calculated concentrations of TP, DRP, SS and *E. coli* in leachate and effluent. Leachate concentrations were calculated based on measured values that were corrected for background drainage from untreated plot areas.

Table 11.4. Average nutrient concentrations of the applied effluent and drainage from the control, 2 mm daily, 2 mm, 5 mm, 7 mm and 12 mm treatments. NO_3-N, nitrate-N; NH_4^+-N, ammonium-N, DON, dissolved organic N; TP, total phosphorus; DRP, dissolved reactive phosphorus; SS suspended sediments; counts of *E.coli*, Escherichia coli.

	Average flow-weighted concentration (mg litre^{-1})						
Nutrient form	Applied effluent	Control	2 mm daily	2 mm	5 mm	7 mm	12 mm
NO_3-N	0.53	8.70	12.10	10.51	12.10	13.51	14.09
NH_4^+-N	49.16	0.15	1.91	3.18	14.18	17.30	20.13
DON	Not measured	1.05	2.02	2.62	6.40	5.56	6.06
TP	24.60	0.23	1.98	3.37	9.08	10.65	13.69
DRP	13.17	0.06	0.79	1.45	5.92	6.06	5.65
SS	1508	40	122	58	128	181	192
E. coli (MPN*/100mL)	5827	14	114	266	946	1269	1373

* MPN – most probable number

Total phosphorus lost in drainage followed a similar pattern to nitrogen, with an increase in losses for the 7 and 12 mm application depths (Figure 11.9). However, the percentage losses of applied TP in effluent were lower than N in the higher treatments: 16% for TP compared to 41 % for mineral N in the 7 mm treatment; and 20% loss of TP compared to 51% loss of mineral N in the 12 mm treatment. Percentage losses for the 2 mm daily, 2 mm and 5 mm treatments were similar for both TP and mineral N. Total phosphorus losses ranged from 3.0 to 40.9 kg ha^{-1} in the treatment plots, compared to 0.1 kg ha^{-1} in the control plots (Table 6.13).

Losses of *E. coli* were relatively low compared to the total counts applied in effluent (Figure 11.10). Losses range from 1.77 x 10^9 to 3.57 x 10^{10} MPN, which is a range of 3 to 11% of the *E. coli* counts measured in the applied effluent (Table 6.13).

Table 11.5. Mineral-N, TP, DRP, SS and *E. coli* yields in drainage from the plots and total amounts applied for the period 18 June until 12 September 2012.

Kg/ha	Control	2 mm daily	2 mm	5 mm	7 mm	12 mm
Total losses per treatment (kg ha^{-1})						
Mineral N	3.7	16.3	23.9	23.3	60.6	118.7
TP	0.1	4.7	3.0	6.8	20.3	40.9
DRP	0.0	1.9	1.1	3.5	10.8	17.3
SS	19	86	152	119	335	631
E. coli	6.40×10^{7}	3.58×10^{9}	1.77×10^{9}	8.03×10^{9}	1.82×10^{10}	3.57×10^{10}
Total amounts applied (kg ha$^{-1)}$						
Total N	0	176	150	301	452	753
TP	0	48	41	82	122	204
DRP	0	27	22	45	67	112
SS	0	2955	2485	4970	7455	12425
E. coli	0	9.88×10^{10}	6.41×10^{10}	31.28×10^{11}	1.92×10^{11}	3.21×10^{11}
Drainage corrected for background (Control) losses. The values in brackets are the percentage of the effluent applied yielded in corrected drainage.						
Mineral N		12.6 (10%)	20.2 (7%)	19.6 (7%)	56.9 (41%)	115 (51%)
TP		4.6 (10%)	2.9 (7%)	6.7 (8%)	20.1 (16%)	40.8 (20%)
DRP		1.9 (7%)	1.0 (5%)	3.5 (8%)	10.8 (16%)	17.3 (15%)
SS		67 (2%)	134 (5%)	100 (2%)	316 (4%)	612 (5%)
E.coli		3.52×10^{9} (4%)	1.70×10^{9} (3%)	7.97×10^{9} (6%)	1.18×10^{10} (9%)	3.57×10^{10} (11%)

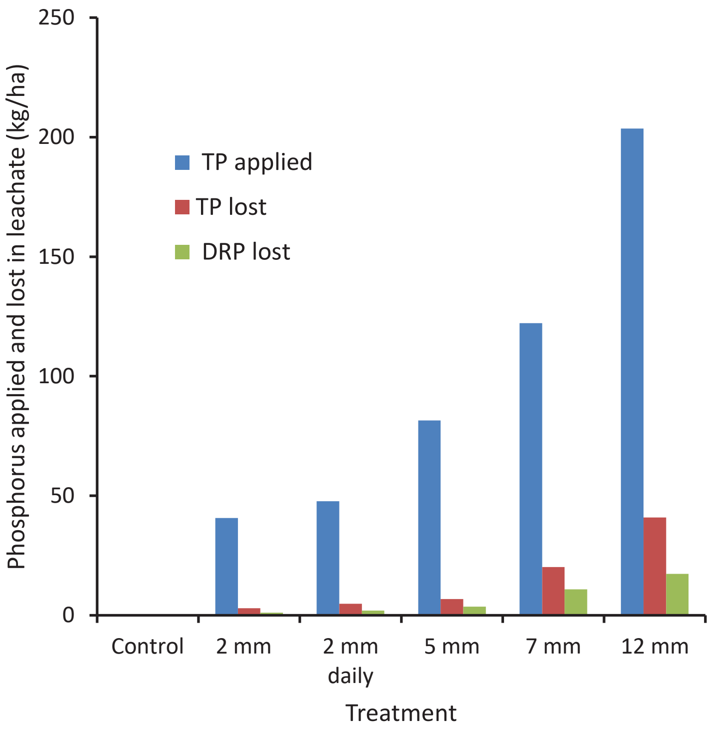


Figure 11.9. Phosphorus losses in leachate over 92 winter days in response to varying effluent application depths.

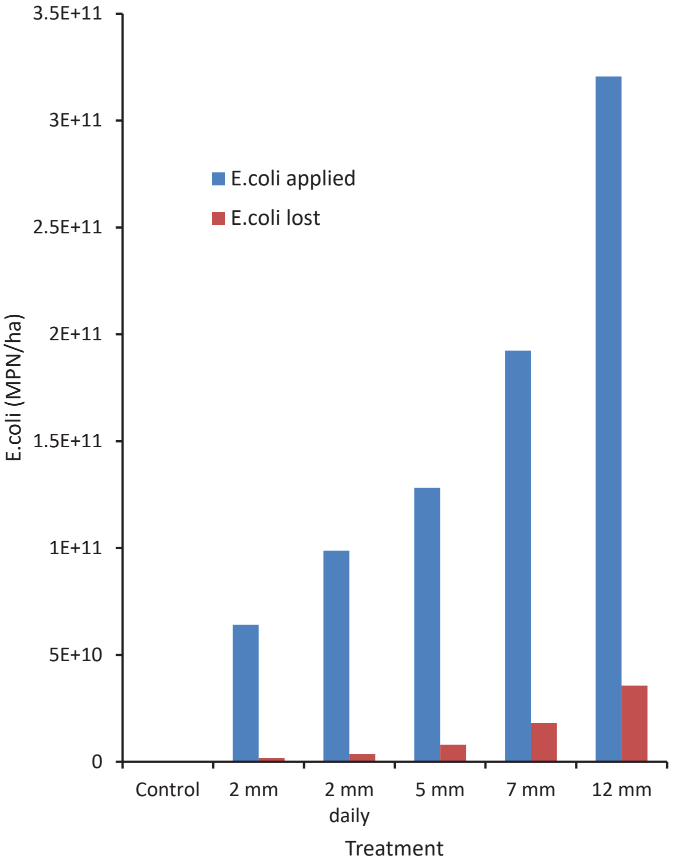


Figure 11.10. Total measured *E. coli* loss in leachate over 92 days of winter in response to daily effluent applications of varying depths (2012).