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Nitrogen and phosphorus leaching losses from pasture, winter forage crop and native bush sites in the West Matukituki Valley

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Report prepared for Otago Regional Council

March 2016

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1. Executive Summary

Measurements of nitrogen (N) and phosphorus (P) losses in leachate are reported for pasture, forage crop and native bush sites in the West Matukituki Valley, located west of Lake Wanaka. These measurements were made throughout 2015 and have been acquired to improve our knowledge of nutrient cycling and losses from sheep-beef farms within high rainfall environments. Given the high rainfall (c. 2400 mm pa) of the Matukituki Valley, nutrient losses from the crop and pasture sites during 2015 were expectedly large relative to those determined at other sites with lower rainfall inputs. Total fluxes of inorganic N (nitrate- plus ammonium-N) from the crop and pastures sites during 2015 were 62 and 19 kg N/ha, respectively. The pattern of N leaching from the crop site indicates that N deposited at the time of winter grazing is still eluting from the soil profile, and it is thus too early to estimate the total flux of N in drainage for this site. Fluxes of dissolved reactive P (DRP) from the crop and pastures sites during 2015 were 0.51 and 0.52 kg P/ha, respectively. Dissolved organic forms of both N and P made unexpectedly large contributions to total fluxes, accounting for 27 and 62% of the total flux of dissolved N in drainage from the crop and pasture sites, respectively, and approximately half of total dissolved P fluxes. Fluxes of nitrate-N measured in drainage at the bush site were relatively low, representing <3% of the nitrate-N fluxes measured at the pasture site; fluxes of DRP represented 40% of the DRP measured in drainage from the pasture site. Some implications from the study are (i) it would be desirable to continue measuring drainage fluxes of N from the crop site until all of the N deposited at the time of grazing in 2015 has eluted the soil profile, and (ii) gaining a better understanding of the bioavailability of dissolved forms of organic N and P in leachate would help determine the risks that these forms of nutrients pose to water quality.

2. Background

Otago Regional Council (ORC) requested a programme of experimentation that would deliver quantitative measurements of N and P losses (hereafter collectively referred to as "nutrient" losses) in leachate from selected sites within the high rainfall environment (c. 2400 mm pa) of the West Matukituki Valley, located west of Lake Wanaka. This information is needed to improve our knowledge of nutrient losses from:

- sheep-beef farming systems (there are relatively few datasets available),
- located in high rainfall environments, and
- often located on soils with low soil water holding capacities.

The information obtained from the programme of work proposed below will be used to reduce the uncertainty of nutrient loss risk predictions by the OVERSEER ® Nutrient Budgets (*Overseer*) model and to support community processes now underway that seek to gain a better understanding of existing and future steps in environmental management for farming activities in the sensitive Southern Lakes region.

This report describes the experimental approach and documents the results obtained during 2015.

3. Methods

3.1 Trial details

Three locations with contrasting land use were selected: (i) a sheep-cattle grazed pasture, (ii) a cattle-grazed winter forage crop, and (iii) a native bush site. Each was located in the West Matukituki Valley (Plate 1). One hundred porous ceramic cups and 50 porous teflon cups were installed at both the pasture and crop sites in late November 2014. The ceramic cups were placed in 2 rows of 5 within each block (10 m x 10 m in size). The teflon cups were placed alongside the ceramic cups where soil structure (i.e. stone content) allowed. Hence, for the pasture site, nine blocks contained between 1 and 8 teflon cups, while for the crop site seven blocks contained between 3 and 10 teflon cups each. There were 10 blocks per site. The cups were installed at a depth of between 45 and 55 cm. An additional 10 teflon cups were installed at the bush site on the same date.

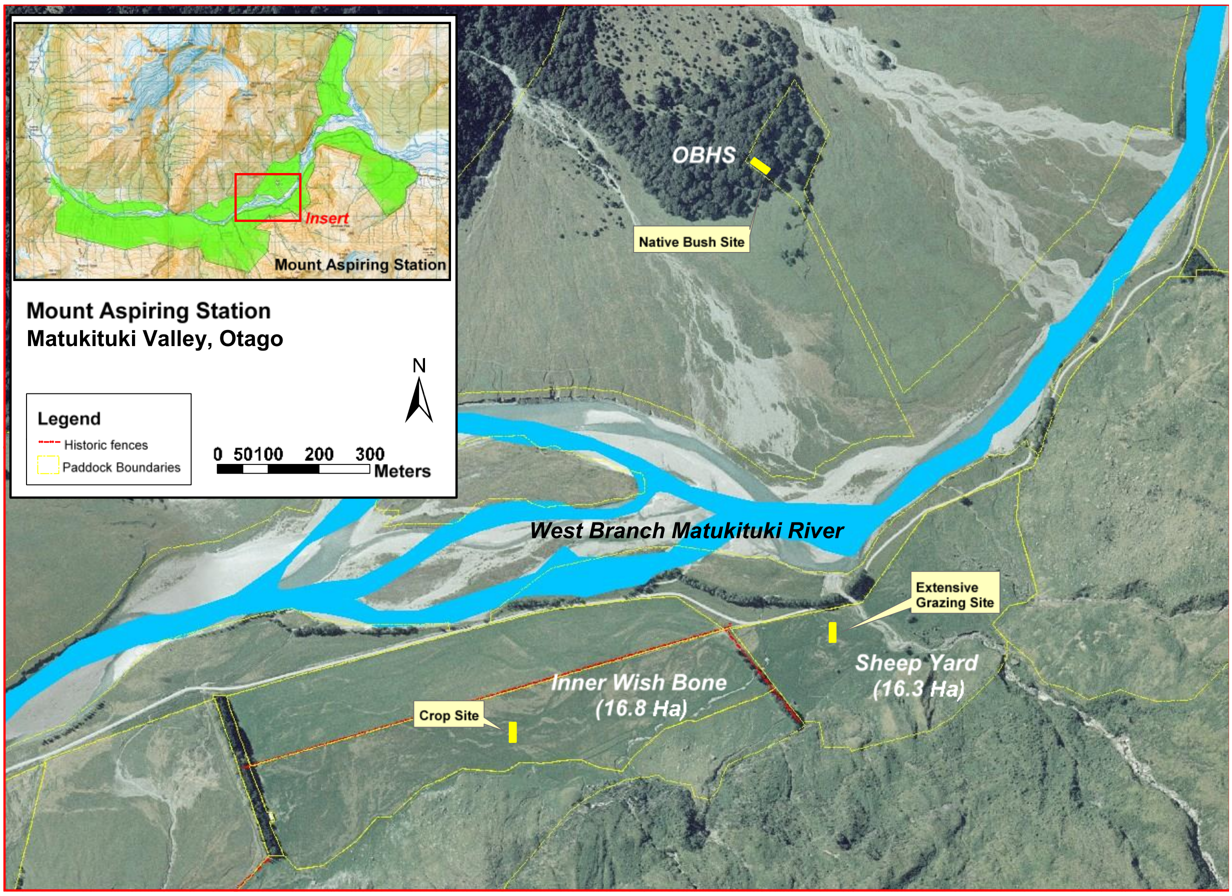


Plate 1. Location of the 3 sampling sites within the West Matukituki Valley.

The crop paddock had been cultivated out of pasture since early October 2014. A winter crop, consisting of a mix of swedes and kale, was sown in early November, approximately two weeks before installation of the porous samplers. Lime (1000 kg/ha) was applied to the crop site in October 2015. Other nutrient inputs to the crop site, as well as the pasture site, are shown in Table 1. The crop was grazed by cattle (211 calves, 30 R2 cattle and 4 R3 heifers) in late June 2015, then left fallow until early December, at which time it was cultivated and another winter forage crop (kale) sown. The high crop yield meant that the cattle took six days to graze the experimental area of 385 m^2. Three bales of hay each containing 294 kg DM were also fed on the experimental area over this period

The pasture paddock site was situated in a 16 ha grass paddock and grazed as part of the normal farm rotation by either sheep or cattle with stock being present most months of the year (see Appendix 1)

Table 1: Nutrients applied to the crop and pasture sites (kg/ha).

Date	N	P	K	S
Crop site				
November 2014	54	71	16	8
January 2015	47	30	50	14
February 2015	46			
December 2015	35	41	25	8
Pasture site				
September 2015	9	12	0	40

3.2 Soil Characterisation

The soil at each site was classified and characterised in January 2015 by first using 20 – 30 augers holes to assess variability (Appendix 2), then at, representative auger locations, by digging six pits to 60 cm depth (see Appendix 3 for photos). Samples were collected from four depths at each pit (0-75, 75-150, 150-300, and 300-600 mm). From these samples soil water holding capacity, gravel content and soil chemistry measurements were determined. Soil samples (10 x 25 mm cores, 60 cm deep) were also collected in November 2014 and extracted with 1M KCl before being analysed colorimetrically for NO_3-N and NH_4-N. Further profile soil samples (0-75, 75-150 and 150-500 mm) were collected in July 2015, immediately post grazing of the crop, by taking cores at six places randomly across the trial sites and analysed for anion storage capacity (ASC), Olsen P and water soluble P (WSP). A summary of these determinations are presented in Table 2, while the profile chemical data is shown in Appendix 4. Soil attributes in Table 2 are average values of the individual sampled depth increments that are specified above.

Table 2: Key soil features of the Matukituki leaching sites.

	Crop site		Pasture site		Bush site	
Soil classification	Recent		Recent		Brown	
	Young deposits from river		Young fan deposits		Fan deposits with thin loess cover	
Texture	Silt to fine sand		Fine to coarse sand		Loamy silt	
Depth to gravels	400 mm (range 0 - >600 mm)		220 mm (range 100 - >600 mm)		400 mm (range 260 -500 mm)	
Soil water holding capacity to 60 cm depth[1]	163 mm (range 96 - 221 mm)		117 mm (range 84 165 mm)		135 mm (range 112 - 161 mm)	
	Jan 15	July 15	Jan 15	July 15	Jan 15	July 15
ASC[2]						
0-75 mm	16%	14%	13%	15%	42%	40%
0-600 mm[3]	11%	11%	9%	9%	47%	43%
Olsen P[4] (µg/mL)						
0-75 mm	20	30	16	13	15	25
0-600 mm	10	14	7	6	21	22
WSP[4] (µg/mL)						
0-75 mm	0.018	0.042	0.022	0.032	0.033	0.043
0-600 mm	0.011	0.026	0.016	0.016	0.022	0.022
Soil N (kg/ha to 50 cm)						
NO_3-N	90		15			
NH_4-N	7		10			
Mineral N	97		25			

[1]water holding capacity is expressed as a whole soil value, corrected for stone content
[2]anion storage capacity
[3]The July sample depth was between 500 and 600mm
[4]These values are for the fine earth fraction of the soil.

3.3 Herbage and leachate measurements and estimates of drainage depths

Herbage measurements

Measurements of pasture production were obtained by means of 10 exclusion cages (each 1 m^2) that were placed around the edge of the experimental area. Pasture growth in these cages was measured monthly before they were moved to a new pre-trimmed area. Herbage subsamples from the cages were bulked before being analysed for dry matter (DM) content, species composition, chemical and feed values.

Yield of the crop was determined by measuring 4 x 1 m^2 quadrats within the experimental area immediately prior to the grazing that occurred in late June 2015. The crop from each quadrat was weighed, separated into kale or swedes, then dried (60°C) to determine dry matter content. Samples of both forages were then analysed for chemical contents and feed values.

Drainage estimates

A daily soil water balance was used to determine total daily surplus water volumes and soil water deficit values at each site. The conceptual structure of this balance was essentially that described by Scotter et al. (1979) and Woodward et al. (2001), with one important difference as described by Monaghan and Smith (2004). The ratio of actual evapotranspiration to potential evapotranspiration was assessed to have a value of 1.0 when soil moisture contents were between field capacity and a limiting soil water deficit of 50% of plant-available water. Thereafter, this ratio decreased linearly to become zero at the permanent wilting point. Potential evapotranspiration data were obtained from the Queenstown meteorological station c. 50 km south of the study site. Rainfall data was obtained from the ORC weather station via telemetry from the site. The soil water holding capacity used for this model was taken from the data shown for each site in Table 2 and adjusted for the depth to the porous cups (45 cm).

N and P leaching

Leachate collection occurred when the water balance model indicated that 100 mm of surplus rainfall had been received. Leachate samples were collected by putting suction on the porous cups and collecting the extracted water the next day. All samples were sent to a commercial lab (Eurofins ELS limited) for chemical analysis by flow injection analysis (APHA 2012). The analytes measured on the samples from the ceramic cups were nitrate- and nitrite-N (hereafter referred to as NO_3-N; determined using APHA method 4500 NO_3 or NH_4); ammonium-N (NH_4-N); and total dissolved N (TDN). Inorganic N was calculated as the sum of NO_3-N and NH_4-N, while dissolved organic N (DON) was computed as the difference between TDN and inorganic N concentrations. Samples from the teflon cups were analysed for dissolved reactive P (DRP, determined using APHA method 4500 P) and total dissolved P (TDP, determined following persulphate digestion and as per the DRP method noted above); dissolved organic P (DOP) was calculated as the difference between TDP and DRP concentrations.

4. Results and Discussion

4.1 Rainfall and drainage volumes

There was 2350 mm of rainfall received at the site between when the measurements commenced (November 2014) and the end of 2015. For the 2015 calendar year, there was 2240 mm of rainfall and between 1293 and 1335 mm of modelled drainage. There were 16 leachate collections over this period, with an average of 80 mm drainage between each sample collection, although this ranged from 30 to 140 mm due to rainfall patterns (Figure 1). There was 784 mm of drainage resulting in nine leachate collections before the cows grazed the crop site in late June, and 509 mm resulting in seven leachate collections after the crop grazing.

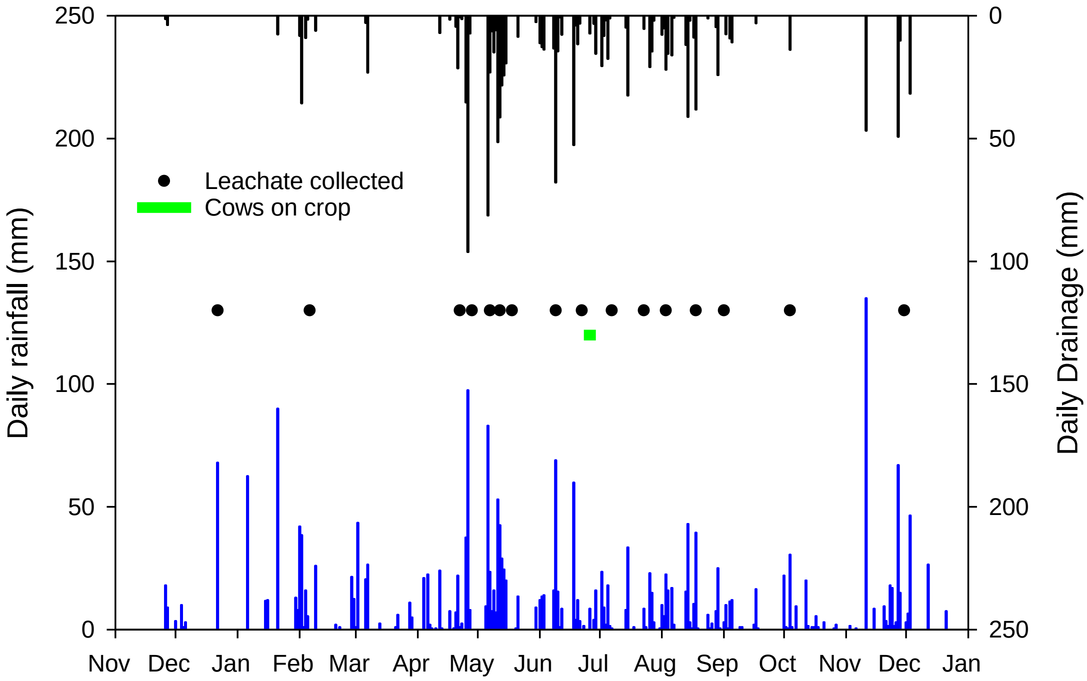


Figure 1: Measured daily rainfall and estimated surplus water at the Matukituki pasture site. The blue bars indicate rainfall and black indicate estimated drainage.

Despite drainage occurring during most months, events were more concentrated over the winter months and particularly in May and June.

4.2 Pasture and crop production

Pasture production was characterised by peaks in November and March and a low point in January, probably as a result of dry conditions at that time (Figure 2). Production for the 2015 year was 8,251 kg DM/ha. Analysis of botanical composition showed that, on average, the pasture consisted of 71% grass, 8% clover 7% weeds and 14% dead material. The clover content peaked at 13% in February and early December, while the amount of dead material peaked in late autumn and over the winter months.

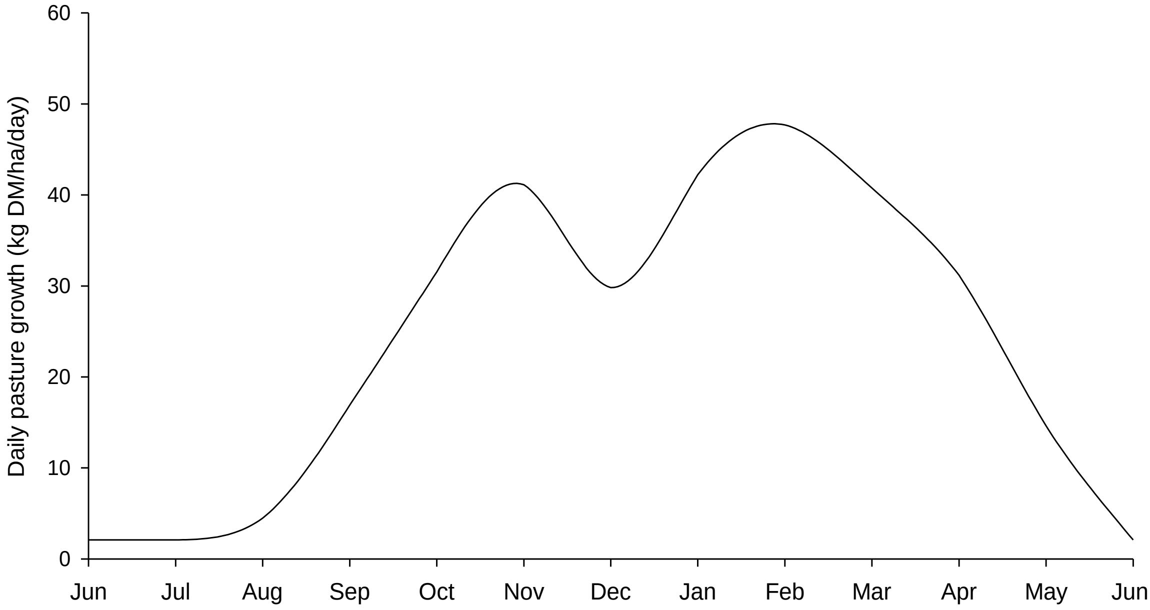


Figure 2. Annual pattern of pasture growth at the Matukituki Valley site in 2015.

Chemical analyses indicated that the pasture was consistently deficient in N and deficient in P, K and S over the late autumn to winter period. In terms of feed value, pasture metabolisable energy (ME) levels ranged from 8.3 in winter to 10.8 MJ/kg DM in December (normal range = 10 - 11). Crude protein (CP) levels ranged from 15 to 23% (normal range = 10 – 25).

The swede and kale crop produced 19.1 t DM/ha, with average N and P contents of 1.6%, and 0.278%, respectively. This meant that the crop contained c. 300 kg N/ha and 50 kg P/ha before grazing. A large proportion of these nutrients would be returned to the soil after grazing, thereby creating risk of nutrient loss. Crop ME and CP contents averaged 10.6 MJ/kg DM and 13.2%, respectively.

4.3 Leachate collection rates

There were 16 leachate collections in total, although the number of samples at each collection varied (Table 3). Of the 150 leachate collectors (ceramic plus teflon) installed in the pasture and crop paddock, on average 71% of those had sufficient sample volumes for NO_3-N analysis. Of the 50 teflon cups installed at the pasture and crop sites, 66% of those in the crop paddock and 60% in the pasture paddock gave sufficient sample volumes for DRP analysis The 10 teflon cups in the bush area averaged 6 samples for both NO_3-N and DRP analysis.

There was damage to a considerable number of the suction cups in the pasture paddock in late October 2015. The cause of this damage is unknown but is likely to be caused by animals dislodging the covers and chewing on the tubes. The damage was not fully rectified before the last sample collection in early December, at which time the collection rates were 41% for NO_3-N and 32% for DRP. There did not appear to be any effect of this smaller sample size on the pattern or variability of results, however, as indicated by:

- N and P concentrations at the pasture site tended to follow the patterns that were observed for preceding events, and
- the variability calculated for the mean NO_3-N concentration measured at the pasture site for that sampling was 84%, which compares favourably with the average Coefficient of Variation (CV) for the preceding samplings of 126%. The corresponding CV for DRP concentrations was 214% compared to the average of 134%, although it must be noted that the previous sampling (October) had a CV of 204%.

Table 3. Average (across all events), maximum and minimum numbers of leachate samples collected at the Matukituki sampling locations. Total potential number of suction cup samples for N analysis at the pasture and crop sites = 150; total number for P = 50. Total potential number of suction cup sample for N and P analysis at the bush site = 10

Analyte	Crop			Pasture			Bush		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
NO_3-N	106	129	60	106	132	61	6	9	4
NH_4-N	75	124	26	30	70	13			
Mineral N	75	124	26	30	70	13			
DON	54	87	21	24	54	11			
TDN	54	87	21	24	54	11			
DRP	33	40	21	30	42	16	6	9	4
DOP	19	36	4	6	31	2			
TDP	19	37	5	6	31	2			

4.4 Leachate N and P concentrations

4.4.1 Nitrogen concentrations

Nitrate-N concentrations in the crop paddock were initially high, presumably as a result of the mineralisation of soil N following cultivation of the paddock (Figure 3). They then dropped to reach equilibrium at 0.20 - 0.25 mg N/L following 150 mm of drainage, remaining at that level until the winter grazing event. Following grazing of the crop, concentrations then increased steadily to 24 mg/L after 1300 mm of drainage. The peak post-grazing nitrate-N concentration in the crop paddock had still not been reached at the time of writing this report; it would therefore appear likely that some of the urinary N deposited at the time of grazing of the crop in June 2015 will elute from the soil profile in drainage that will occur during 2016, unless recovered by the next crop before drainage starts again next season. Averaged across all events, the flow-adjusted NO_3-N concentration was 4.50 mg N/L; for the pre grazing and post grazing periods, these concentrations were equivalent to 0.54 and 10.64 mg N/L, respectively (Table 4).

There were no distinct peaks in NO_3-N concentrations in the leachate from the pasture site (Figure 3). Averaged over all events, the flow-adjusted mean NO_3-N concentration for the pasture site was 0.89 mg N/L (Table 4). This contrasts with the bush location, which averaged 0.03 mg N/L.

Ammonium–N concentrations fluctuated at the pasture site, and tended to align with grazing pressure. Average NH_4-N concentrations increased at the crop site immediately following grazing. Mean flow-weighted NH_4-N concentrations were 0.28 mg N/L for the crop paddock and 0.55 mg N/L for the pasture paddock.

Concentrations of DON were surprisingly high and greater than measured concentrations of ammonium-N at both the crop and pasture sites (bush site not measured). There was little difference in DON concentrations between the crop and pasture sites, with the exception of the last sampling when there was a considerable increase at the pasture site. Average flow-weighted DON concentrations for the pasture and crop areas were 2.50 mg N/L and 1.80 mg N/L, respectively. The patterns of DON elution (Figure 3) and comparison of the frequency distributions of DON, NO_3-N and NH_4-N concentrations (Appendices 5 & 6) suggest that there was a steady background elution of DON from the crop and pastoral soils, rather than clear pulsed outputs that coincided with excreta deposition.

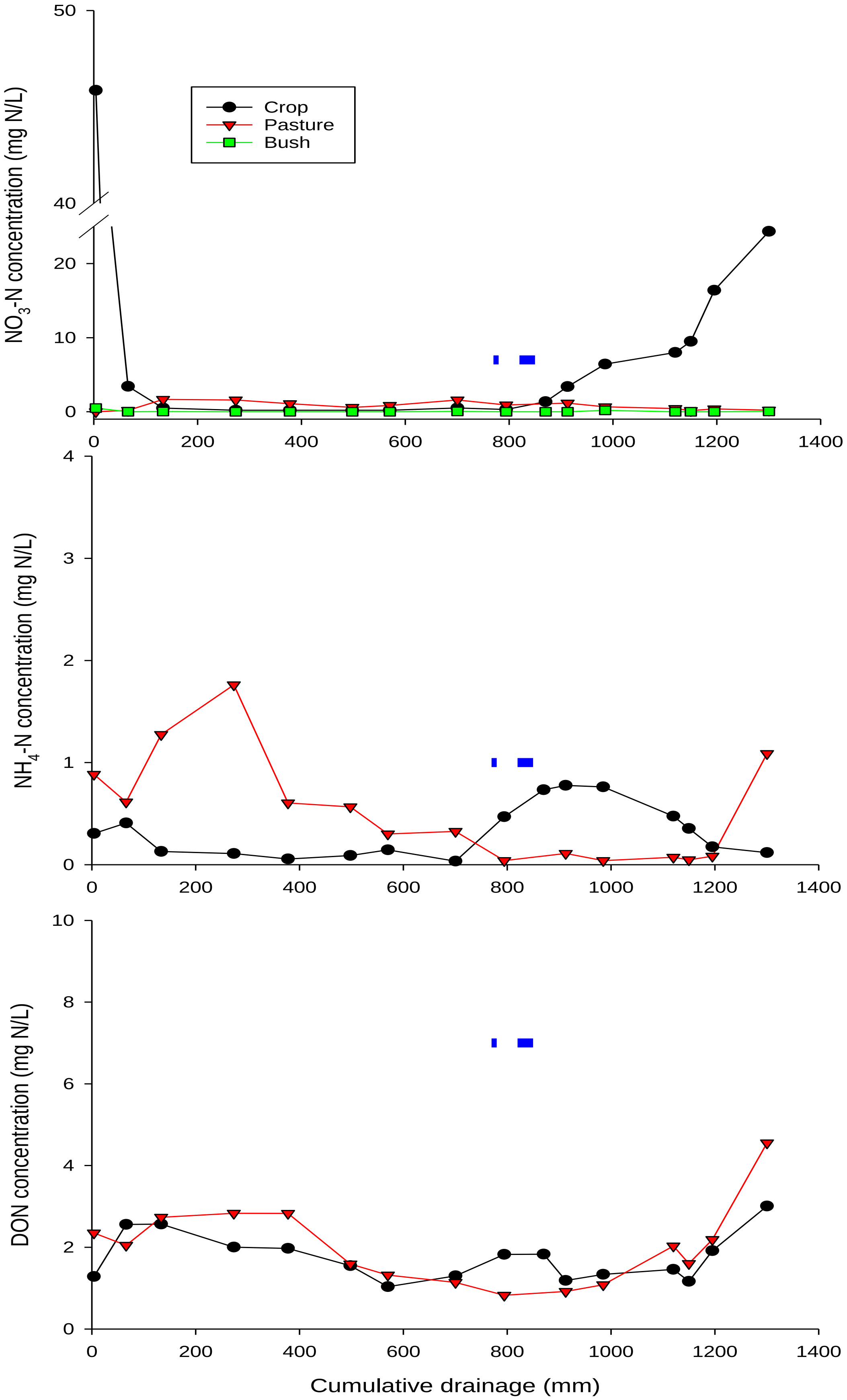


Figure 3: Concentrations of NO_3-N, NH_4-N and DON in leachate collected from the Matukituki sampling sites. The blue dots denote when stock grazed the crop paddock.

4.4.2 Phosphorus concentrations

Concentrations of DRP in leachate from the crop site averaged 0.020 mg P/L for the period before the crop was grazed and 0.070 mg P/L after the crop was grazed (Figure 4 and Table 4). A brief break-in of lambs to the crop site occurred in May and probably contributed to the rise in DRP concentrations observed at about 800 mm of drainage. DRP concentrations at the crop site fluctuated after the cows grazed the crop in June, but tended to increase, reaching 0.15 mg P/L in early December 2015. The mean flow-adjusted DRP concentration in drainage from the crop site was 0.040 mg P/L (Table 4).

The flow-weighted mean DRP concentration at the pasture site was 0.039 mg P/L, but fluctuated considerably, reaching peaks of 0.15, 0.10 and 0.23 mg P/L. These peaks were presumably due to the effects of stock grazing and dung deposition. Winter grazing pressure at the pasture site was significantly increased due to the feeding of silage to stock in close proximity to the sampling area. DRP concentrations at the bush site averaged 0.016 mg P/L (Table 4).

DOP concentrations at the crop site averaged 0.019 mg P/L over the growing season. These increased briefly to 0.083 mg P/L immediately following lambs breaking into the crop in May. Following grazing by cows in June, concentrations increased to 0.195 mg P/L before dropping to 0.034 mg P/L by December 2015. Averaged over all events, the flow-adjusted DOP concentration at the crop site was 0.040 mg P/L.

DOP concentrations at the pasture site averaged 0.061 mg P/L. However, this was influenced by one very high data point measured following about 400 mm of drainage (reached in early May). This high value (0.57 mg P/L) was likely the result of an excreta patch being directly above one of the six sampling cups that gave sufficient sample for DOP analysis at this sampling occasion. This one sample had a DOP concentration of 2.84 mg P/L, whereas the remaining 5 samples were all below 0.02 mg P/L. It was noticeable that both DRP and NH_4-N concentrations were also extremely high for this sample, confirming the likelihood of excreta being the cause of the elevated concentrations.

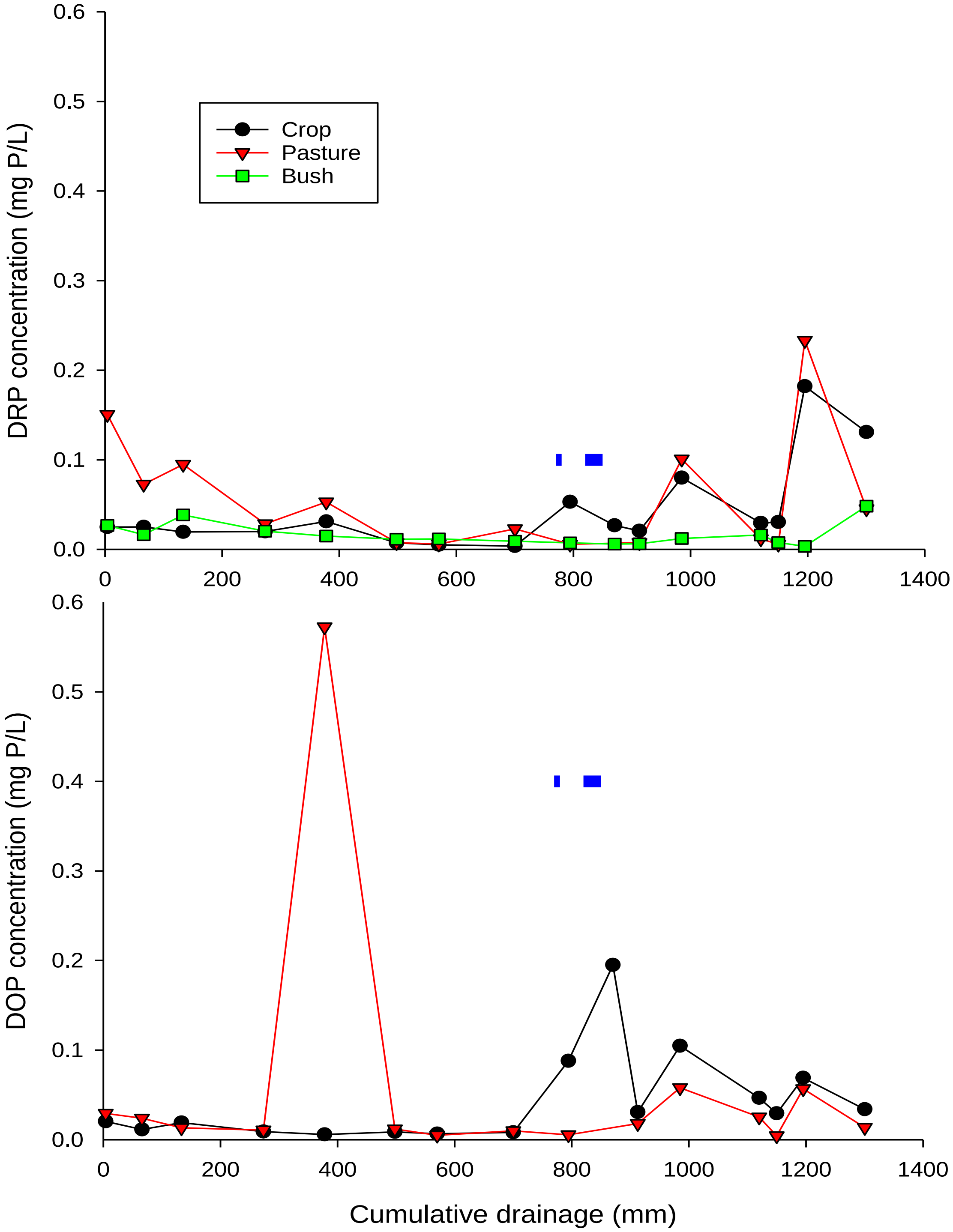


Figure 4: Concentrations of DRP and DOP in leachate collected from the Matukituki sampling sites. The blue dots denote when stock grazed the crop paddock.

4.5 Nutrient leaching loads

Table 4 summarises the estimated N and P leaching loads and flow-weighted mean concentrations for each site. As observed in previous studies (e.g. Smith et al. 2012; Shepherd et al. 2012; Monaghan et al. 2013; Malcolm et al. 2014), grazing of the winter forage crop resulted in a clear increase in nitrate-N concentrations in drainage. Because the N from this grazing event is still eluting from the soil profile, it is still too early to estimate the total flux of N in drainage resulting from this grazing event. We can however conclude that this total will at least equal (and most likely exceed) the 54 kg N/ha that was estimated to have been lost between the time of crop grazing and the end of 2015.

The total fluxes of dissolved N from the crop and pastures sites during 2015 were 85 and 53 kg N/ha, respectively. DON made an unexpectedly large contribution to these fluxes, accounting for 27 and 62% of the total flux of dissolved N in drainage from the crop and pasture sites, respectively. Drainage fluxes of dissolved inorganic N for the crop and pasture sites (which *Overseer* considers) were 62 and 19 kg N/ha, respectively.

The total fluxes of dissolved P in drainage from the crop and pasture sites during 2015 were 1.03 and 1.33 kg P/ha, respectively. As observed for N, dissolved organic forms made an unexpectedly large contribution to these P losses, accounting for approximately half of the total flux of dissolved P in drainage from the crop and pasture sites. Enhanced losses of DOP in drainage were observed following grazing of the crop. DRP fluxes were also lower in the crop paddock prior to grazing of the crop. This was likely attributable to the more uniform distribution of P within the cultivated layer, and perhaps a reduction in the abundance of preferential flow pathways capable of conducting P to below plant rooting depth. As noted for the other N and P fractions, DRP concentrations and fluxes did however increase following grazing of the crop; it will be interesting to see if this increase is sustained.

Due to the complexities involved in constructing a soil water balance for bush sites, the loads of nitrate-N and DRP documented in Table 4 need to be treated with caution. Our estimates are most likely an upper estimate of fluxes given (i) the deeper roots of trees and shrubs could intercept N transported in drainage below the depth of our suction cup samplers, and (ii) the forest canopy likely intercepted and re-distributed a significant proportion of incident rainfall that our soil water balance otherwise suggested landed directly on the soil surface. Another factor that confounds estimates of N and P fluxes in drainage from this site is that analysis of dissolved organic forms of N and P in drainage was not possible due to the limited volumes of leachate sample collected at this location.

Table 4. Estimated drainage volumes, nutrient loads (kg/ha) and mean flow-adjusted N and P concentrations (mg/L) at the crop, pasture and bush sites in the Matukituki Valley in 2015.

	Crop paddock			Pasture paddock	Bush area
	Total	Pre-grazing	Post-grazing		
Drainage, mm:	1293	784	509	1331	1314
Loads					
NO_3-N	58.1	4.2	53.9	11.9	0.3
NH_4-N	3.6	1.2	2.4	7.3	
DON	23.3	14.0	9.3	33.3	
Total dissolved N flux	85.0	19.4	65.6	52.5	
DRP	0.51	0.15	0.36	0.52	0.21
DOP	0.52	0.15	0.38	0.81	
Total dissolved P flux	1.03	0.30	0.74	1.33	
Flow-weighted mean concentrations					
NO_3-N	4.50	0.54	10.64	0.89	0.03
NH_4-N	0.28	0.16	0.47	0.55	
DON	1.80	1.79	1.82	2.50	
DRP	0.040	0.020	0.070	0.039	0.016
DOP	0.040	0.019	0.074	0.061	

4.6 Comparisons of measured losses with those estimated from *Overseer*

Single year comparisons with estimates obtained from models such as *Overseer* have to be made with caution. One reason for this is because *Overseer* is a long-term model calibrated against sites that have results for at least two seasons, and generally more than 4 seasons. A particular issue is matching rainfall amount and distribution for a single year with the long-term average distribution pattern embedded in *Overseer* (Wheeler et al., 2014). However, based on the single year of measured losses we can make the following preliminary comparisons and inferences:

- The measured value of dissolved inorganic N leaching for the pasture site (19.4 kg N/ha) compared reasonably well with the 24 kg N/ha/yr that was estimated by the *Overseer* model.
- The *Overseer* model estimated a N leaching loss of 229 kg N/ha/yr for the crop site, which is considerably higher than the measured loss of 62 kg N/ha. This may be partly attributable to the fact that *Overseer* calculates a value for all of the N that will be leached after grazing the crop, including N that is likely to be leached in the second and subsequent years. Based on the elution of nitrate-N evident in Figure 3, it is likely that there is still some N in the profile that could leach in 2016.
- Measured losses of dissolved P in drainage from the pasture site (1.33 kg P/ha/yr) compare reasonably well with *Overseer* -modelled estimates of P loss risk of 1.6 P/ha/yr. Poor agreement was however evident for the crop site, where modelled loss estimates of 4.4 kg P/ha/yr were much greater than measured leaching losses of 1.03 kg P/ha/yr.
- Drainage volumes calculated for the pasture site by the soil water balance method used in this study (1331 mm) compared well *Overseer*'s modelled estimate of 1319 mm. There was poorer agreement for the crop site, however, where the soil water balance estimate of 1293 mm was considerably less than *Overseer*'s estimate of 1568 mm. This discrepancy is likely to have also contributed to the greater estimate of N leaching at the crop site compared to what was measured.

A surprising feature of the results is the large amount of DON leached at both sites. *Overseer* has been calibrated against mineral N leaching data and therefore does not capture this organic form of N loss. The flow-weighted mean concentration of 2.50 mg DON/L measured in drainage from the pasture site was at the upper end of concentration ranges reported for a small number of studies reported in the literature where DON concentrations have been measured under grazed grasslands (0.9 to 2.4 mg DON/L: Hawkins et al. 2006; Monaghan et al. 2016; Necpalova et al. 2012; Watson et al. 2000). Combined with a relatively large drainage volume estimated for the Matukituki site, this DON represents a relatively large drainage flux of N compared to those reported for grazed grassland elsewhere (1.1 to 4.8 kg DON/ha/yr: Monaghan et al. 2016; Watson et al. 2000). The DON flux calculated for the crop site was, however, very similar to the mean DON flux of 22 kg N/ha/yr reported by Smith et al. (2012). The ecological significance of the large DON fluxes measured in drainage from the pasture and crops is uncertain. Based on a preliminary study by Ghani et al. (2012), much of the DON in subsurface drainage appears to be readily decomposable and thus potentially bioavailable.

5. Implications and next steps

- It would be desirable to continue sampling leachate from the forage crop site until nitrate-N deposited during 2015 has completely eluted the soil's rooting depth.
- Continuation of leachate sampling to capture a second year of measurement would add confidence to the results through (i) potentially encompassing a wider range of climate patterns that could affect drainage volumes and soil N processes, and (ii) capturing a second year of measurement for a 2-year cropping rotation which seems to be more typical of winter forage cropping sequences in the Valley.
- The relatively large drainage fluxes of dissolved N and P require further investigation to (i) allow comparison with a more detailed review of the scientific literature, and (ii) consider whether it is possible and appropriate to factor these forms into models of nutrient flows and losses.

6. References

APHA 2012. Standard methods for the examination of water and wastewater. 22nd Ed. American Public Health Association, Washington DC, USA.

Ghani, A., U. Sarathchandra, S. Ledgard, M. Dexter and S. Lindsey. 2012. Microbial decomposition of leached or extracted dissolved organic carbon and nitrogen from pasture soils. Biology and Fertility of Soils: 1-9. doi:10.1007/s00374-012-0764-4.

Hawkins, J.M.B., D. Scholefield and J. Braven. 2006. Dissolved free and combined amino acids in surface runoff and drainage waters from drained and undrained grassland under different fertilizer management. Environmental Science and Technology 40, 4887-4893.

Malcolm, B.J., Cameron, K.C., Edwards, G.R., Di, H.J., 2014. 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.

Monaghan RM, Smith LC. 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 and Environment 175, 29-38.

Monaghan, R.M., L.C. Smith and R.W. Muirhead. 2016. Pathways of contaminant transfers to water from an artificially-drained soil under intensive grazing by dairy cows. Agriculture, Ecosystems & Environment 220, 76-88.

Necpalova, M., O. Fenton, I. Casey and J. Humphreys. 2012. N leaching to groundwater from dairy production involving grazing over the winter on a clay-loam soil. Science of the Total Environment 432, 159-172.

Scotter DR, Clothier BE, Turner MA, 1979. The soil water balance in a Fragiaqualf and its effect on pasture growth in central New Zealand. Australian Journal of Soil Research.17: 455-465.

Shepherd, M.A., Stafford, A., Smeaton, D., 2012. The use of a nitrification inhibitor (DCn™) to reduce nitrate leaching from a winter-grazed forage crop in the Central Plateau. Proceedings of the New Zealand Grassland Association 74, 103-108.

Smith, L.C., Orchiston, T., Monaghan, R.M., 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. Proceedings of the New Zealand Grassland Association 74, 39-44.

Watson, C.J., C. Jordan, S.D. Lennox, R.V. Smith and R.W.J. Steen. 2000. Organic nitrogen in drainage water from grassland in Northern Ireland. Journal of Environmental Quality 29, 1233-1238.

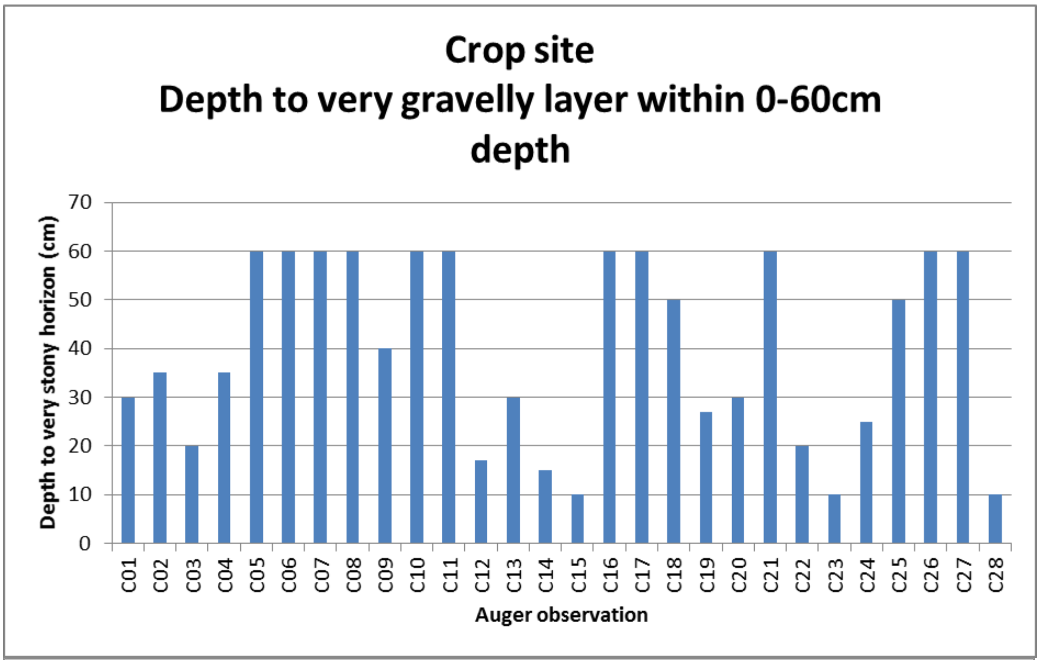
Wheeler. D., Shepherd, M., Freeman, M. and Selbie, D. (2014). OVERSEER® Nutrient budgets: Selecting appropriate timescales for inputting farm management and climate information. In: Nutrient management for the farm, catchment and community. (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 5 pages.

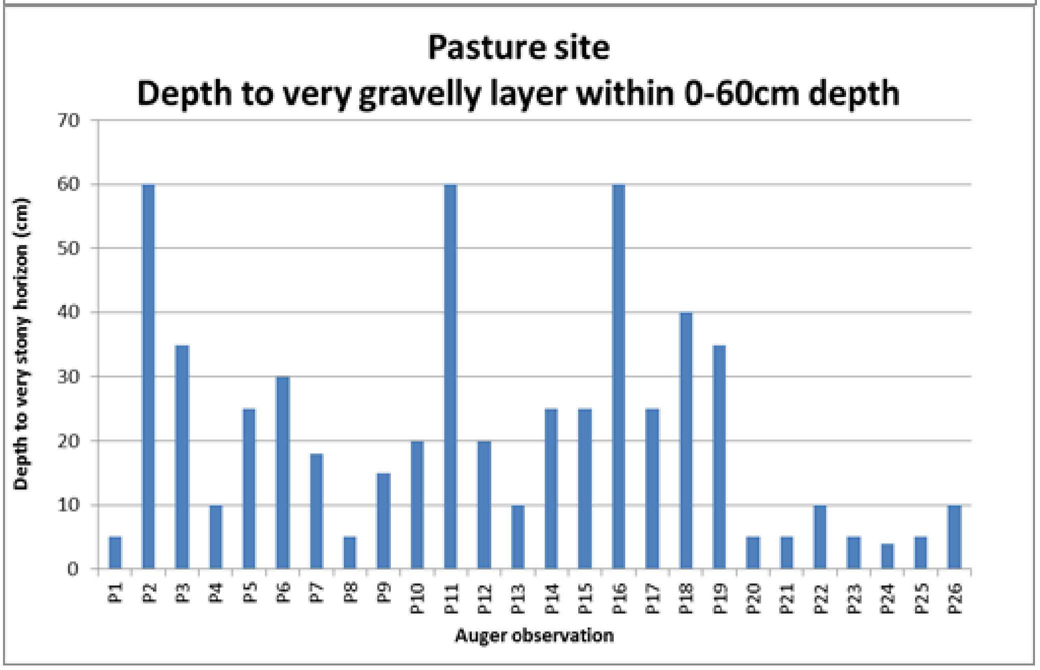
Woodward SJR, Barker DJ, Zyskowski RF, 2001. A practical model for predicting soil water deficit in New Zealand pastures. New Zealand Journal of Agricultural Research 44: 91-109.

7. Appendix 1: Details of stock numbers and grazing for the pasture site

Stock Class	Number	Date In	Date Out
Ewes (with lambs)	150	25/11/2014	12/11/2014
Ewes (with lambs)	20	12/11/2014	2/02/2015
Ewes (with lambs)	30	10/01/2015	2/02/2015
MA Steers	15	25/11/2014	21/12/2014
MA Steers	10	5/01/2015	24/02/2015
Two-tooths	600	22/02/2015	24/02/2015
R3 Heifers	77	22/03/2015	7/04/2015
Two-tooths	970	19/03/2015	2/04/2015
Two-tooths	1004	21/04/2015	22/04/2015
Light Ewes	661	12/05/2015	17/05/2015
Light Ewes	661	19/05/2015	22/05/2015
Small Calves	50	21/05/2015	22/05/2015
Calves	173	22/05/2015	23/05/2015
Hoggets	1014	6/06/2015	8/06/2015
R3 Heifers	82	29/06/2015	14/07/2015
Ewes	300	20/08/2015	21/08/2015
Single Ewes	1316	13/09/2015	15/09/2015
Ewes	83	11/10/2015	14/11/2015
Yearling Steers	44	27/10/2015	2/11/2015
Ewes & Lambs	230	15/11/2015	17/11/2015
Ewes & Lambs	100	18/11/2015	19/11/2015
Ewes & Lambs	30	20/11/2015	30/12/2015
Cows & Calves	91	20/11/2015	4/12/2015
Ewes & Lambs	70	31/12/2015	26/01/2016
Cows & Calves	45	11/12/2015	30/12/2015

8. Appendix 2: Graphs showing soil depth variability





9. Appendix 3: Photos of the soil profiles from the Matukituki Valley

9.1 Crop paddock

		
Crop pit 1 AWC = 215 mm Depth to gravels = >60cm	Crop pit 2 AWC = 144 mm Depth to gravels = 34 cm	Crop pit 3 AWC = 152 mm Depth to gravels = 31 cm
		
Crop pit 4 AWC = 221 mm Depth to gravels = > 60 cm	Crop pit 5 AWC = 96 mm Depth to gravels = at surface	Crop pit 6 AWC = 148 mm Depth to gravels = 20 cm

9.2 Pasture paddock

Pasture pit 1
AWC = 84 mm
Depth to gravels = 12 cm

Pasture pit 2
AWC = 113 mm
Depth to gravels = 58 cm

Pasture pit 3
AWC = 121 mm
Depth to gravels = 47 cm

Pasture pit 4
AWC = 165 mm
Depth to gravels = 32 cm

Pasture pit 5
AWC = 95 mm
Depth to gravels = 16 cm

Pasture pit 6
AWC = 123 mm
Depth to gravels = 20 cm

9.3 Bush area

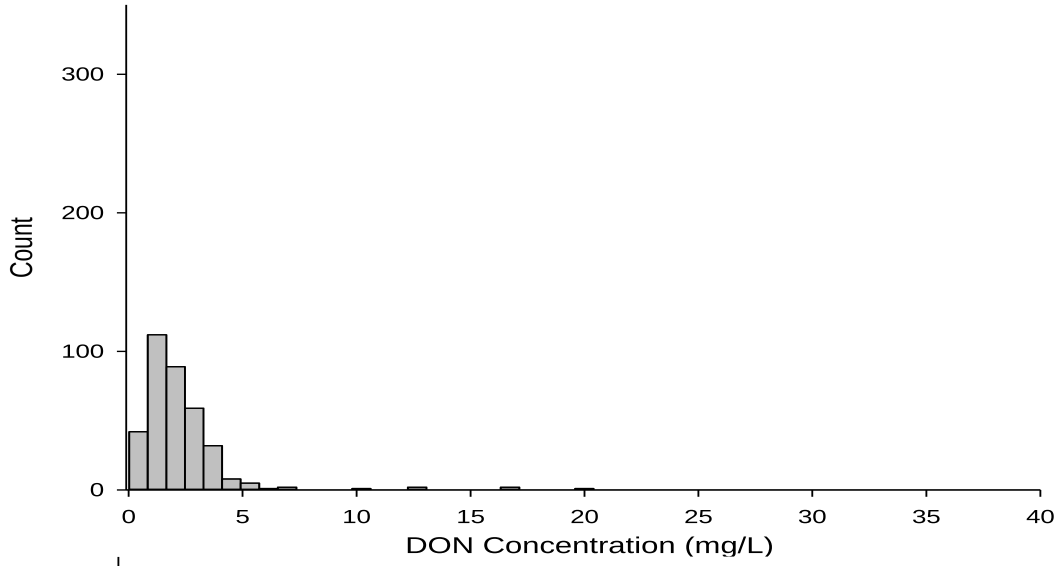
		
Forest pit 1 AWC = 148 mm Depth to gravels = 50 cm	Forest pit 2 AWC = 161 mm Depth to gravels = 44 cm	Forest pit 3 AWC = 117 mm Depth to gravels = 26 cm
		
Forest pit 4 AWC = 112 mm Depth to gravels = 36 cm		

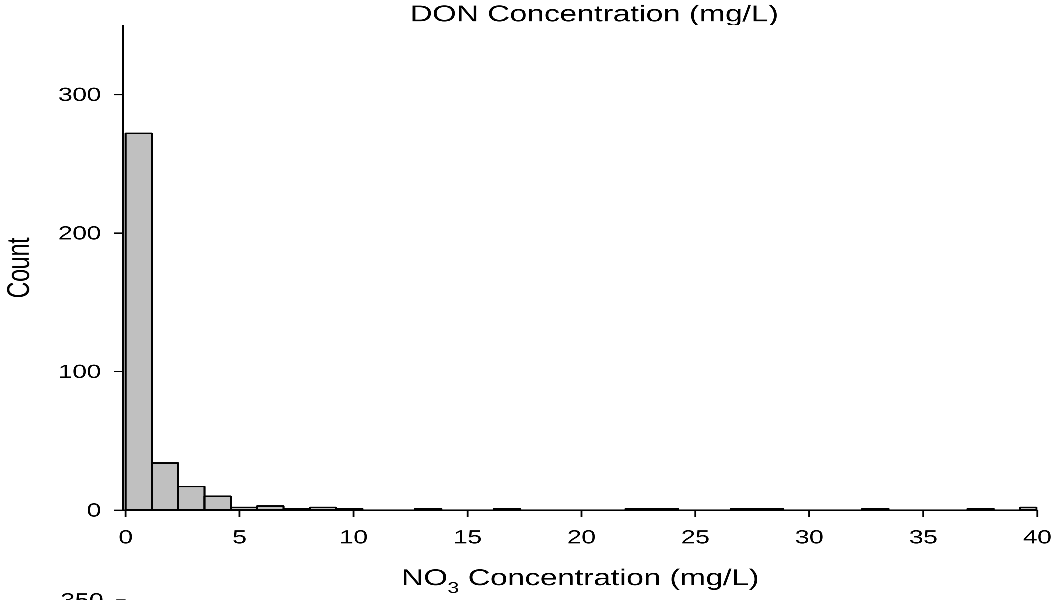
10. Appendix 4: Profile soil chemical results

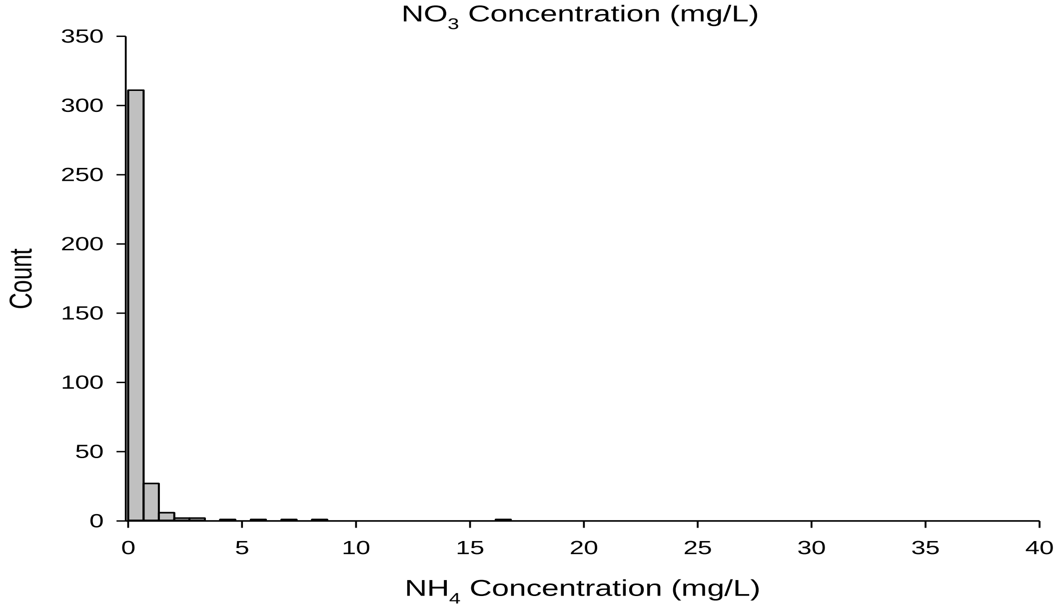
Site	Depth (mm)	ASC (%)	Olsen P (µg/mL)	WSP (µg/mL)
January 2015				
Crop site	0-75	16	20	0.022
	75-150	15	31	0.028
	150-300	8	10	0.013
	300-600	6	2	0.010
Pasture site	0-75	13	16	0.018
	75-150	11	10	0.012
	150-300	9	9	0.025
	300-600	5	3	0.008
Bush site	0-75	42	15	0.033
	75-150	43	22	0.020
	150-300	47	37	0.030
	300-600	56	14	0.010
July 2015 (post crop grazing)				
Crop site	0-75	14	30	0.042
	75-150	16	17	0.021
	150-500+	9	10	0.016
Pasture site	0-75	15	13	0.032
	75-150	12	6	0.014
	150-500+	7	5	0.014
Bush site	0-75	40	25	0.043
	75-150	42	20	0.028
	150-500+	43	22	0.016

11. Appendix 5: Frequency distributions of DON, NO_3-N and NH_4-N concentrations for the pasture site.

(Note the NO3-N graph omits the 1% of samples with concentrations >40 mg N/L).







12. Appendix 6: Frequency distributions of DON, NO_3-N and NH_4-N concentrations for the crop site.

(Note the NO3-N graph omits the 5% of samples with concentrations >30 mg N/L).