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ROOTZONE REALITY – A NETWORK OF FLUXMETERS MEASURING NUTRIENT LOSSES UNDER CROPPING ROTATIONS

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Abstract

Nutrient losses are an important economic and environmental consideration across the New Zealand cropping sector. Between August 2014 and May 2015 we established a network of passive-wick drainage fluxmeters (DFMs) on commercial cropping farms in the Canterbury, Manawatu, Hawke's Bay and Waikato/Auckland regions to measure loads and concentrations of nitrogen (N) and phosphorus (P) in drainage water below the root zone. Results from this study will provide growers and regional authorities with measured nutrient losses from cropping farms across a range of sites and seasons. The data will help inform our extension work to ensure good management practices are communicated, widely endorsed and adopted by growers and regional councils.

The experimental design across the DFM network includes the three sites across four monitor regions, and uses twelve fluxmeters per site. Individual sites were chosen to provide a range of cropping systems, soil types, climatic conditions and management practices relevant to each region.

Across the DFM network, measured losses have ranged from 0.2 kg N/ha to 226 kg N/ha and from 0.01 to 0.56 kg P/ha respectively for the period between DFM installation and 30 September 2015. Nitrate-N was the dominant form of N loss while most P was lost as dissolved reactive phosphate. Drainage occurred predominantly (78–100%) over the mid-autumn to early spring period (April to September). The variability in N and P losses among different sites reflect the duration of the monitoring period as well as the wide range of climate, management and soil characteristics. Efforts are ongoing with growers to identify how to reduce nutrient losses.

Introduction

Optimising nutrient supply is a key management consideration for all farms across New Zealand. Too little supply and crop productivity can be constrained; too much supply and grower profitability decreases and there is a concomitant increase in environmental risks associated with leaching losses. Despite the significance of this issue in New Zealand, there is limited information regarding measured inter-annual nitrogen (N) and phosphorus (P) losses from the root zone of commercial cropping fields. Such information is crucial to informing policy decisions around nutrient losses and supporting the development and implementation of good management practice (GMP) to reduce risks.

Losses of N and P in drainage water from cropping systems depend on a range of factors including the temporal and spatial distribution of surface-applied N and P, soil physical and chemical properties, site attributes (e.g. slope and surface hydrologic conditions), grower management practices (e.g. fertiliser use, irrigation, cover crops, cultivation techniques, crop sequences), crop uptake demands and climatic conditions (especially rainfall). In previous studies under arable systems, measured N leaching losses have been ranged from 35 to 110 kg N/ha/year (Adams & Pattinson 1985; Francis et al. 1994, 1995) and under vegetable production systems the measured losses have ranged from 63 to 292 kg/ha/year (Francis et al. 2003; Williams et al. 2003). In contrast with N losses, there is very little information on measured P leaching from these systems, the magnitude of which are likely to be closely linked to soil Olsen P levels and anion storage capacity (McDowell & Condron 2004).

In July 2014 work began to establish a network of drainage fluxmeters (DFMs) on commercial cropping farms in Canterbury, Manawatu, Hawke's Bay, Waikato and Auckland, to measure losses of N and P in drainage water below the root zone. Results from this work will provide growers and regional authorities with measurements of drainage losses from cropping farms across a range of sites and seasons. Data from this study will help to inform our extension work to ensure good management practices are communicated, widely endorsed and adopted. The data will also be available for future efforts to improve predictive models that can either be used to manage crops or inform policy development. Here we summarise the N and P loss results across the twelve sites for the period between DFM installation (August 2014 to May 2015) to the end of September 2015.

Materials and Methods

Tension fluxmeters

In this project drainage water from below the root zone is being captured using passive-wick tension fluxmeters (DFMs). The cylindrical units are 120 cm long and the top of the DFM is 20 cm wide. In the convergence zone at the top of the device, fine silica sand is packed on top of diatomaceous earth to filter out sediment-bound nutrients before water enters the storage reservoir. A passive wick is in contact with the sand. This wick ensures that water only enters the device when soil moisture is at or above field capacity, preventing preferential flow into or around the device. Attached to each DFM are 8 mm PE tubes to remove drainage water under suction during sampling events. Once installed, the units are designed to remain in the soil for an extended period. A detailed review of the design and functionality of DFM units is provided by Gee et al. (2009) and Meissner et al. (2010).

Experimental design

The basic experimental design across the fluxmeter network includes four monitor regions, with three sites in each region and 12 DFM devices at each site. The four monitor regions are Canterbury, Manawatu, Hawke's Bay and Waikato/Auckland. These regions vary in rainfall, soil type and crop management. The DFMs at each site have been arranged in clusters of four units, to accommodate local changes in soil and crop characteristics. DFMs in each cluster are equi-spaced at a distance of about 4 m from a central sump which accommodates all of the access tubes. The three clusters of DFMs at each site have been placed in a line, at a spacing of between 25 to 40 m between each cluster.

Site information

All sites are located on commercial properties that were selected to provide a range of cropping systems, soil types, climatic conditions and management practices relevant to each region (Table 1). Sites with high water tables or artificial drainage above 1 m were avoided. A summary of the crop rotations at each site from August 2014 to September 2015 is provided in Figure 2.

Installation process

Fluxmeters were installed between August 2014 and May 2015 (Table 1) during the transition between crop rotations. Soil moisture conditions were carefully considered before installation to minimise potential repacking effects associated with excessively wet or excessively dry soils.

The fluxmeters were located in comparatively uniform areas of each site to minimise potential variability in results. The intent was to record an average site value under GMP, rather than extreme values that might occur (e.g. under the humps and hollows of each field). The location was assessed by topography, test holes, grower knowledge of site history and where available we also used site-specific soil maps (e.g. S-map, EM profiles).

The top of the DFM was installed 1 m below the soil surface, a depth below which nutrient uptake by field crops is likely to be minimal. Each device was installed according to the following established procedure: holes (diameter 200 mm) were augered to a depth of 2.2 m. All soil was carefully removed and placed into numbered buckets in 10 cm increments for subsequent repacking. Soil from below 1 m (the top of the DFM) was discarded. DFMs were carefully lowered into the holes and the soil was the repacked back to a similar density as stratified soil layer. Soil was firmly repacked to best mimic conditions prior to disturbance. At most sites cultivation by the farmer, to a depth of 30-50 cm, occurred soon after the fluxmeters were installed.

Measurements

Drainage sampling

Drainage samples are routinely collected from the fluxmeter units. The timing of sampling varies by site and season, reflecting irrigation practices, rainfall and key soil physical and hydraulic properties that influence drainage. A simple water balance model is being used to assist in predicting the timing and volumes of drainage. Sampling involves using a suction pump to remove drainage water from each of the buried fluxmeters. The volume of drainage is then recorded and subsamples are retained for subsequent analyses of inorganic N (nitrate N and ammonium N), dissolved reactive phosphorus (DRP) and total P. Samples for inorganic N and DRP analysis are pre-filtered in the field using syringe filters (0.45 micron). Following collection the samples are taken back to the laboratory and then frozen until further analyses. Analyses are performed by an IANZ-accredited laboratory following standard analytical procedures.

Soil and crop sampling

Soil samples are being collected at the start of each new crop sequence to quantify indicators of basic soil fertility (pH, Olsen P, exchangeable cations and CEC) and soil N characteristics (mineral nitrogen in the form of ammonium and nitrate, anaerobically mineralisable N (AMN), total N and total C). Crop samples are being collected on two or three occasions during each crop sequence to quantify biomass productivity and N uptake. Final yields and nitrogen contents of each crop are being measured to quantify nutrient off-take from the farm. All plant analyses are performed by an IANZ-accredited laboratory following standard analytical procedures.

Table 1. Summary of key farm and site characteristics for the twelve fluxmeter sites.

Site	Region	Soil type	Farm system	Irrigation system	Fluxmeter installation date
1	Canterbury	Mayfield silt loam	Mixed cropping, winter livestock grazing	Centre pivot	26 August 2014
2	Canterbury	Barhill silt loam	Mixed cropping, livestock grazing	Gun	22 September 2014
3	Canterbury	Templeton silt loam	Mixed cropping, livestock grazing	Roto-rainer	24 September 2014
4	Manawatu	Shannon silt loam	Intensive vegetable production	Lateral	20 October 2014
5	Manawatu	Pukepuke sandy loam	Mixed cropping, livestock grazing	Centre pivot	29 September 2014
6	Manawatu	Ohakune brown loam	Mixed cropping	Travelling irrigator	20 April 2015
7	Hawke’s Bay	Waimakariri silt loam	Mixed cropping, livestock grazing	Centre pivot	8 September 2014
8	Hawke’s Bay	Waimakariri silt loam	Mixed cropping, livestock grazing	Gun	2 October 2014
9	Hawke’s Bay	Takapau silt loam	Mixed cropping, livestock grazing	Centre pivot	4 September 2014
10	Waikato	Waihou silt loam	Mixed cropping, livestock grazing	Centre pivot	13 May 2015
11	Auckland	Patumahoe clay loam	Intensive vegetable production	Gun/lateral	10 March 2015
12	Waikato	Patumahoe clay loam	Mixed cropping, livestock grazing	Gun	7 April 2015

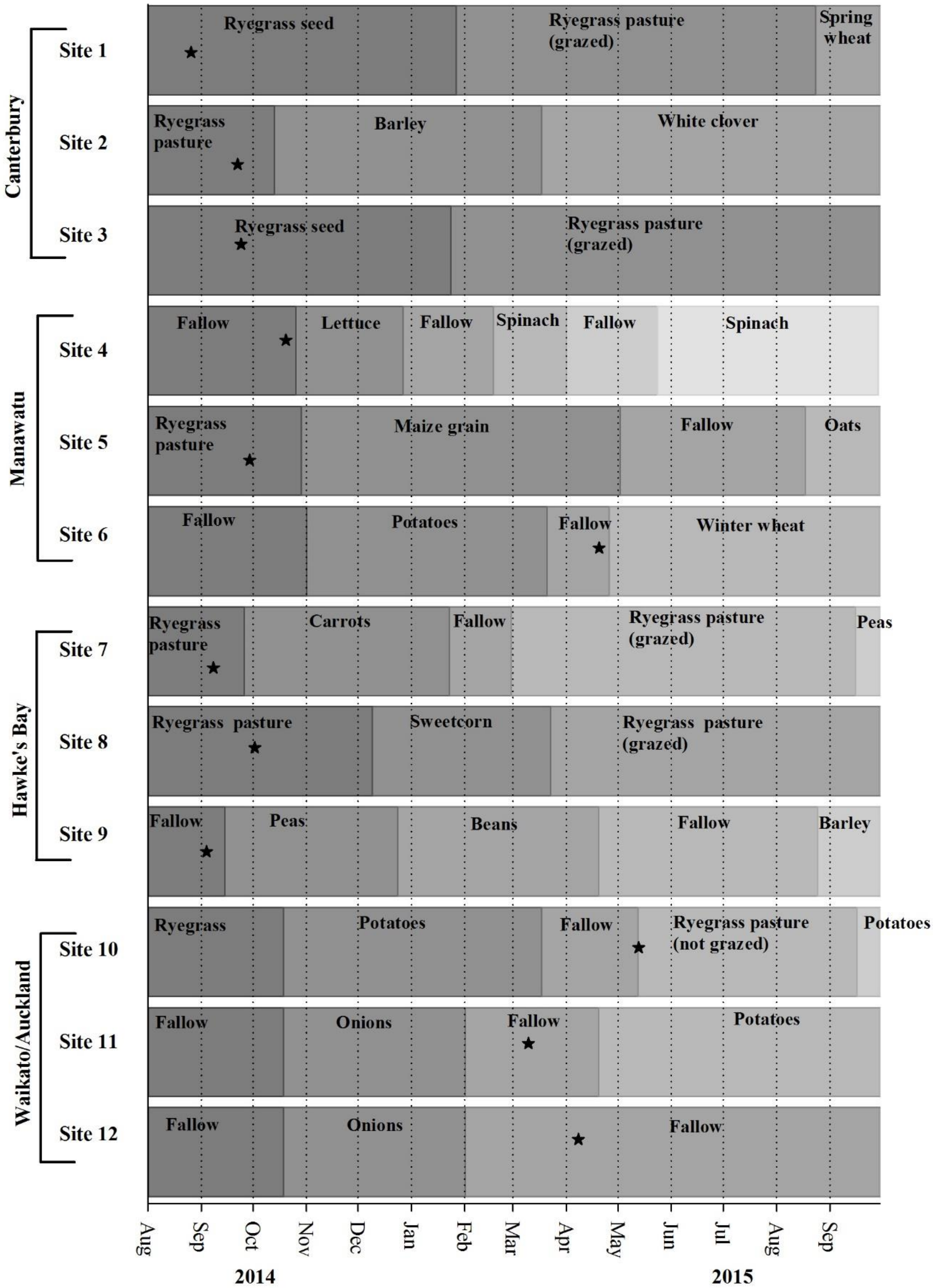

Figure 2. Crop sequences at the twelve experimental sites for the period 1 August 2014 to 30 September 2015. Fluxmeter installation dates (★) are shown for reference.

Weather
Weather data for each site (daily and long term) is collated using data from the nearest NIWA climate station. For some sites, a combination of stations is needed to provide the requisite data. Observations include daily air temperature (minimum, mean and maximum), solar radiation, rainfall, vapour pressure, wind run and mean sea level (MSL) pressure. These variables are currently used for the water-balance calculations, to estimate crop water use and drainage losses. The climate data will also be used in subsequent modelling of crop growth, nutrient uptake and the nutrient budget of each site.

Statistical analyses
A statistical summary (i.e. means, standard deviations of concentrations and fluxes) has been carried out for all measurements of drainage volume and nutrient concentrations. Some corrections have been applied to the data, to balance for the cluster arrangement of the fluxmeters. Cross-checks have also been made to verify measured drainage volumes using a water balance model that accounts for daily rainfall, irrigation, crop water use and soil hydraulic properties. One site within each region has also been instrumented with time-domain reflectometry (TDR) to monitor changes in soil water content (0-90 cm).

Results and discussion

Drainage volumes
Across the twelve sites there was a wide range in measured drainage (0.3 to 611 mm) (Figure 3a). This reflected the different length of monitoring (five to thirteen months) as well as the unique range of climate, management and soil characteristics at each site. In general, the measured drainage was lower in the Canterbury (range was 8–101 mm) and Hawke’s Bay sites (range was 0.3–71 mm) where rainfall totals were 3 to 18% below long-term averages for the respective sampling periods (Figure 3a). Measured drainage was higher in the Manawatu (range was 196–611 mm) and Waikato/Auckland sites (range was 150–229 mm) where rainfall totals were 0.3–28% above long-term averages for the respective sampling periods. Drainage data are being cross-checked against a soil water balance model to ensure the volumes are reasonable. At one site (Site 12, Auckland) measured drainage volumes appear to be too high, compared to the modelling, and we suspect this is due to subsurface flooding of the fluxmeter units.

Most drainage (78–100%) occurred between the mid-autumn to early spring period (April to September) in response to increased soil moisture levels and more rainfall. The exception was Site 7 (Hawkes Bay), where all drainage occurred in late spring (November to December). In general there was negligible drainage over the irrigation season (October to March). Irrigation application volumes were provided by the collaborating growers and ranged from 22 mm to 450 mm (Figure 3a).

Losses of N via drainage
Calculated losses of mineral nitrogen (nitrate-N + ammonium-N) in the drainage water ranged from 0.2 kg N/ha to 226 kg N/ha and occurred almost entirely as nitrate-N (Figure 3b). Losses were less than 25 kg N/ha at five of the sites, between 25 and 50 kg N/ha and three sites and greater than 50 kg N/ha at the remaining three sites. Losses of less than 25 kg N/ha were associated with a combination of low drainage volumes and low nitrate-N concentrations (Table 2). Losses of more than 25 kg N/ha were associated with a combination of increased drainage volumes and elevated nitrate-N concentrations in the drainage water. This was clearly evident at Sites 4 and 5 (Manawatu), where a combination of high drainage volumes

and high nitrate-N concentrations in drainage resulted in mineral N losses of 212 kg N/ha and 226 kg N/ha respectively (Figure 3b).

At this stage, measured N losses captured by the fluxmeter network are comparable with those observed in previous studies, which have ranged from 35 to 110 kg N/ha/year in arable systems (Adams & Pattinson 1985; Francis et al. 1994, 1995) and from 63 to 292 kg/ha/year in intensive vegetable production systems (Francis et al. 2003; Williams et al. 2003). It is important to note that our results span different time frames at each site (some sites have been operating for less than 6 months). Once the data sets are compiled across multiple crop sequences then we will be able to more fully interpret the results with respect to specific physical, climatic and management factors at each site.

At eight of the sites, the average nitrate-N concentrations in drainage over the sampling period were above the New Zealand Drinking Water Standard of 11.3 mg/L of nitrate-nitrogen (Ministry of Health 2008) (Table 2). Caution is needed when comparing measured concentrations to defined limits as in some cases (e.g. sites 2 and 8) drainage volumes were very low. Furthermore, nutrient concentrations captured at 1 m do not directly equate to nutrient concentrations that enter into fresh water bodies due to processes such as attenuation and dilution. Nevertheless, elevated nitrate-N concentrations in drainage are a sign of potential environmental degradation and these losses do need to be addressed.

Losses of P via drainage

Calculated losses of total P in the drainage water ranged from 0.01 to 0.56 kg P/ha and at most sites P was lost predominantly as DRP (Figure 3c). Total P losses were less than 0.10 kg P/ha at six sites, between 0.10 and 0.30 kg P/ha at three sites and greater than 0.30 kg P/ha at two sites. P losses tended to be greatest where drainage volumes and P concentrations were both elevated.

Overall total P losses as captured by the fluxmeter network appear to be minimal. The values are similar to those reported under grassland systems (< 2 kg/ha/year; Condron 2004; Houlbrooke et al. 2003; Toor et al. 2004). This reflects in part the retention of P by the soil matrix. Additionally, management practices such as cultivation may reduce P leaching losses by disrupting preferential flow pathways and increasing P sorption as water moves via matrix flow (Dodd et al. 2014). Cultivation is likely to increase run-off losses of P, which have not be monitored in this study. Nevertheless, although the net losses of P were low, the average total P concentrations in drainage water from nine of the sites were above the minimum concentration (0.10 mg/L) considered to stimulate aquatic weed growth (Ministry for the Enviroment 2014) (Table 2).

Elevated P concentrations could be an artefact of a soil settling process in the months following DFM installation. Across sites, P concentrations were observed to decrease over the respective collection periods, as did the concentration difference between total P and DRP (data not presented). Disturbance of the soil profile may have increased the transfer of soluble P forms. We note that the fluxmeter units are designed to mitigate the transfer of sediment bound P and consequently the difference between total P and DRP (Figure 3c) is most likely comprised primarily of dissolved organic P forms.

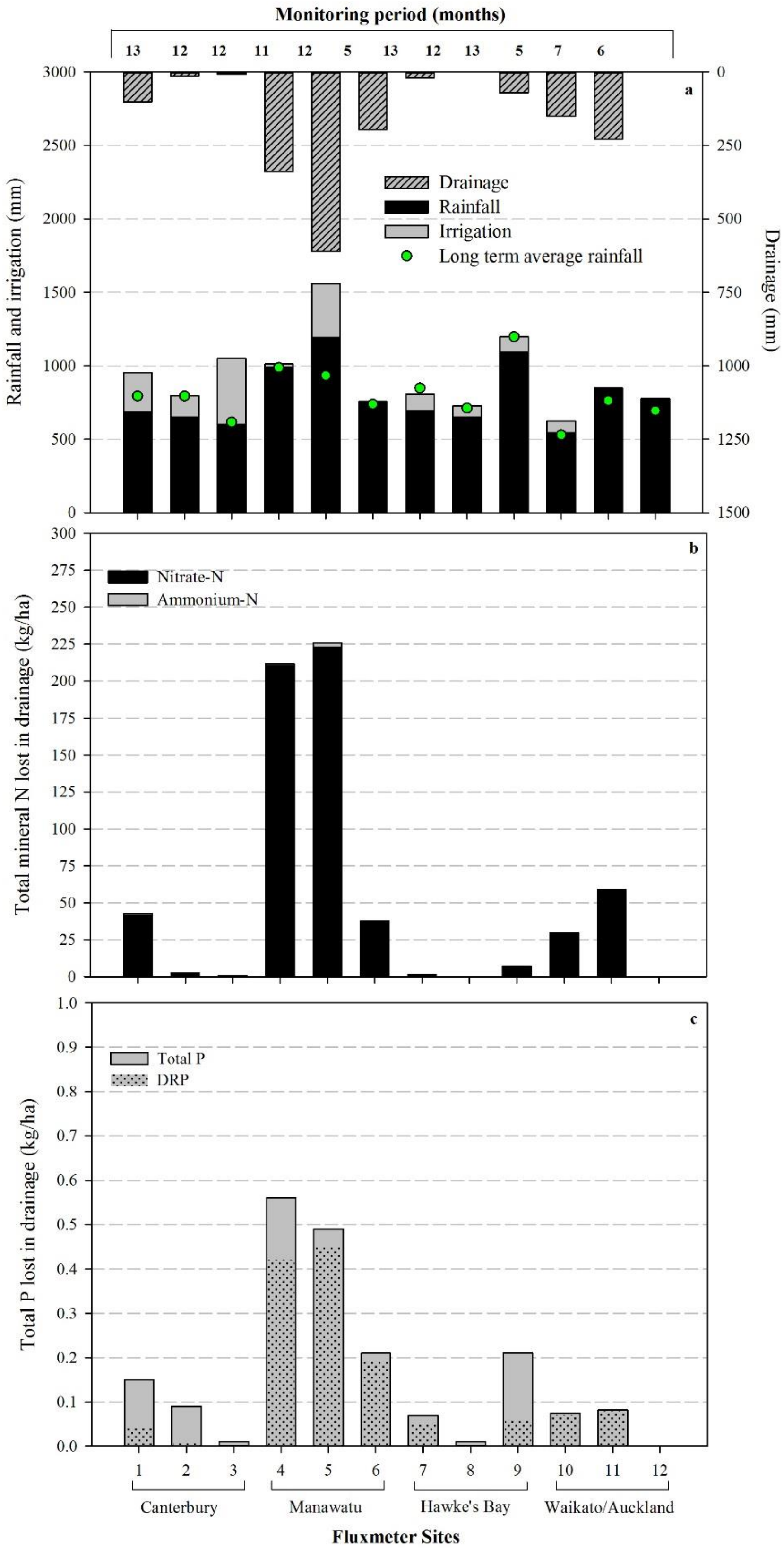

Figure 3. Rainfall (actual and long term average), irrigation and measured drainage (a), mineral N losses (b) and total P and DRP losses (c) at the twelve fluxmeter sites. The data covers the period between fluxmeter installation and 30 September 2015. Fluxmeters were installed between August 2014 and May 2015.

Table 2. Number of sampling events and average concentrations of nitrate-N, ammonium-N, total P and dissolved reactive phosphorus (DRP) in fluxmeter drainage samples collected in the period between fluxmeter installation and 30 September 2015. Fluxmeters were installed between August 2014 and May 2015.

Site	Region	Number of sampling events	Average Nitrate-N mg/L [1]	Average Ammonium-N mg/L [1]	Average DRP mg/L [1]	Average total P mg/L [1]
1	Canterbury	6	26.2 (5.9 – 36.6)	3.1 (1.0 – 6.1)	0.25 (0.07 – 0.47)	0.40 (0.09 – 0.58)
2	Canterbury	3	22.3 (14.2 – 36.4)	9.3 (4.4 – 17.2)	0.69 (0.62 – 0.72)	0.96 (0.73 – 1.18)
3	Canterbury	2	7.8 (5.7 – 9.9)	1.0 (0.6 – 1.3)	0.15 (0.01 – 0.29)	0.22 (0.02 – 0.41)
4	Manawatu	8	49.9 (9.5 – 75.0)	1.7 (0.5 – 4.6)	0.21 (0.11 – 0.42)	0.29 (0.13 – 0.62)
5	Manawatu	7	33.7 (10.1 – 80.1)	1.0 (0.0 – 3.3)	0.12 (0.04 – 0.30)	0.14 (0.06 – 0.49)
6	Manawatu	3	17.5 (11.9 – 20.4)	0.7 (0.6 – 0.8)	0.09 (0.01 – 0.24)	0.11 (0.02 – 0.28)
7	Hawke's Bay	4	8.0 (3.1 – 19.3)	0.9 (0.1 – 2.1)	0.24 (0.04 – 0.51)	0.32 (0.08 – 0.65)
8	Hawke's Bay	1	21.5	3.1	0.23	0.38
9	Hawke's Bay	8	9.5 (2.3 – 20.9)	1.7 (0.02 – 3.3)	0.16 (0.06 – 0.46)	0.43 (0.17 – 0.64)
10	Waikato	4	17.2 (15.9 – 19.1)	0.4 (0.2 – 0.8)	0.07 (0.03 – 0.18)	0.08 (0.02 – 0.20)
11	Auckland	4	29.0 (14.3 – 48.9)	0.3 (0.1 – 0.5)	0.03 (0.00 – 0.07)	0.03 (0.01 – 0.05)
12	Waikato[2]	4	-	-	-	-

[1]The range of nutrient concentrations is presented in parenthesis. [2]A reliable estimate of sample volumes of N and P concentrations could not be obtained at Site 12 due to flooding of the fluxmeter units.

Conclusions

Measured nutrient losses across the fluxmeter network ranged between 0.2 to 226 kg N/ha for nitrogen and between 0.01 to 0.56 kg P/ha for phosphorous. The observed ranges in nutrient losses partly reflects the different duration of monitoring (five to thirteen months), as well a wide range of climate, management and soil characteristics found at each site. Importantly, a more complete assessment of losses will be possible once the DFMs have settled and once more data is included across multiple crop rotations. Collection of detailed soil, plant, climate and management information is ongoing and vital to assist with interpretation of the data sets and with future modelling efforts. The value of this study lies in the long-term patterns of N and P losses that will be measured over at least three years of cropping. The insights into the interactions between the physical environment and crop management practices will inform strategies to communicate and promote good management practices.

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References

Adams JA, Pattinson JM 1985. Nitrate leaching losses under a legume-based crop rotation in Central Canterbury, New Zealand. New Zealand Journal of Agricultural Research 28: 101-107.

Condron LM 2004. Phosphorus surplus and deficiency. Wallingford, UK, CAB International.

Dodd RJ, McDowell RW, Condron LM 2014. Is tillage an effective method to decrease phosphorus loss from phosphorus enriched pastoral soils? Soil & Tillage Research 135: 1-8.

Francis GS, Haynes RJ, Williams PH 1994. Nitrogen mineralisation, nitrate leaching and crop growth after ploughing in leguminous and non-leguminous grain crop resiudes. Journal of Agricultural Science, Cambridge 123: 81-87.

Francis GS, Haynes RJ, Williams PH 1995. Effects of the timing of ploughing-in temporary leguminous pastures and two winter cover crops on nitrogen mineralization, nitrate leaching and spring wheat growth. Journal of Agricultural Science, Cambridge 124: 1-9.

Francis GS, Trimmer LA, Tregurtha CS, Williams PH, Butler RC 2003. Winter nitrate leaching losses from three land uses in the Pukekohe area of New Zealand. New Zealand Journal of Agricultural Research 46: 215-224.

Gee GW, Newman BD, Green SR, Meissner R, Rupp H, Zhang ZF, Keller JM, Waugh WJ, van der Velde M, Salazar J 2009. Passive wick fluxmeters: Design considerations and field applications. Water Resources Research 45(4): W04420.

Houlbrooke DJ, Horne DJ, Hedley MJ, Hanly JA, Snow VO 2003. The impact of intensive dairy farming on the leaching losses of nitrogen and phosphorus from a mole and pipe drained soil. Proceedings of the New Zealand Grasslands Association 65: 179-184.

McDowell RW, Condron LM 2004. Estimating phosphorus loss from New Zealand grassland soils. New Zealand Journal of Agricultural Research 47(2): 137-145.

Meissner R, Rupp H, Seeger J, Ollesch G, Gee GW 2010. A comparison of water flux measurements: passive wick-samplers versus drainage lysimeters. European Journal of Soil Science 61(4): 609-621.

Ministry for the Enviroment 2014. National policy statement for fresh water managment 2014.

Ministry of Health 2008. Drinking-water Standards for New Zealand 2005 (Revised 2008).

Toor GS, Condron LM, Di HJ, Cameron KC, Sims JT 2004. Assessment of phosphorus leaching losses from a free draining grassland soil. Nutrient Cycling in Agroecosystems 69(2): 167-184.

Williams PH, Tregurtha RJ, Francis GS 2003. Fate of urea applied to winter spinach in New Zealand. Nutrient Cycling in Agroecosystems 67: 245-254.