Rootzone reality - A network of fluxmeters measuring nitrogen 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 nitrogen (N) losses in drainage water below the root zone. Results from this study will provide growers and regional authorities with measured N losses from cropping farms across a range of sites and seasons. The experimental design across the DFM network includes three sites each across four monitor regions, and uses 12 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 for the period between DFM installation and 30 September 2015 with N lost primarily in the Nitrate-N form. Most drainage (78–100%) occurred over the mid-autumn to early spring period (April to September). Variability in N losses between sites reflect the duration of the monitoring period (five to 13 months) as well as the wide range of climate, management and soil characteristics.

Key Words
Nitrogen losses in drainage, cropping systems, nutrient management

Introduction
Optimising nutrient supply is a key management consideration for all farmers 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) 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.

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 in drainage water below the root zone. The project will run initially for three years and provide growers and regional authorities with measurements of drainage losses from cropping farms across a range of sites and seasons. Here we summarise the N loss results across the 12 sites for the period between DFM installation (August 2014 to May 2015) to the end of September 2015, the first year following establishment of the network.

Methods
Tension fluxmeters: design and installation
Drainage water from below the root zone was captured using passive-wick drainage fluxmeters (DFMs). A detailed review of the design and functionality of DFM units is provided by Gee et al. (2009) and Meissner et al. (2010). In summary, drainage water enters the 120 cm long cylindrical units through a convergence zone 20 cm in diameter. In the convergence zone 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 ensures that water enters only when soil moisture is at or above field capacity. Attached to each DFM are polyethylene tubes to remove drainage water under suction during sampling events. The top of the DFM was installed to 1 m below the soil surface, a depth below which nutrient uptake by many field crops is likely to be minimal.

Experimental design
The experimental design across the fluxmeter network included four monitor regions, with three sites in each region and 12 DFMs at each site. The four monitor regions were Canterbury, Manawatu, Hawke's Bay and Waikato/Auckland. All sites were located on commercial properties, selected to provide a range of cropping systems, soil types, climatic conditions and management practices relevant to each region. DFMs at each site were arranged in three clusters of four units. DFMs in each cluster were equi-spaced at a distance of about 4 m from a central sump which accommodates tubes used to extract the drainage water. DFM clusters were spaced between 25 to 40 m apart. Fluxmeters were installed between August 2014 and May 2015 (Table 1) during the transition between crops.

Measurements
Drainage sampling
Drainage samples were routinely collected from the fluxmeter units using a suction pump. A water balance model was used to assist in predicting the timing of sampling. At each sampling event, the volume of drainage was recorded and subsamples retained for analyses of inorganic N (nitrate-N and ammonium-N). Analyses were performed by an IANZ-accredited laboratory following standard analytical procedures.

Weather
Weather data for each site (daily and long term) were collated using data from the nearest NIWA climate station. Observations included daily air temperature (minimum, mean and maximum), solar radiation, rainfall, vapour pressure, wind run and mean sea level (MSL) pressure.

Soil and crop sampling
Soil samples were collected at the start of each new crop sequence to quantify basic soil fertility (pH, Olsen P, exchangeable cations and CEC) and soil N characteristics (mineral N in the form of ammonium and nitrate, anaerobically mineralisable N (AMN), total N and total C). Crop samples were collected on two or three occasions during each crop sequence to quantify biomass productivity and N uptake. All soil and plant analyses were performed by an IANZ-accredited laboratory following standard analytical procedures. Soil fertility and crop data are not presented in this paper.

Statistical analyses
At each site and for each event, mean drainage volumes and N concentrations were weighted by the number of working fluxmeters within each cluster. To verify that measured drainage volumes were realistic, a water balance model was used that accounted for daily rainfall, irrigation, crop water use and soil hydraulic properties.

Results and discussion
Drainage volumes
There was a wide range in measured drainage (0.3 to 611 mm) across the 12 sites (Figure 1a). This reflected the different length of monitoring (five to 13 months) as well as the unique range of climate, management and soil characteristics at each site. In general, measured drainage was lower at the Canterbury (range was 8–101 mm) and Hawke's Bay sites (range was 0.3–71 mm) where rainfall totals were 3–18% below long-term averages for the respective sampling periods (Figure 1a). Measured drainage was higher at 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. At one site (Site 12, Waikato) measured drainage volumes appeared too high compared to the modelling, a finding that may be related to subsurface flooding of the fluxmeter units. No results have been reported for this site.

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 (Hawke's 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 1a).

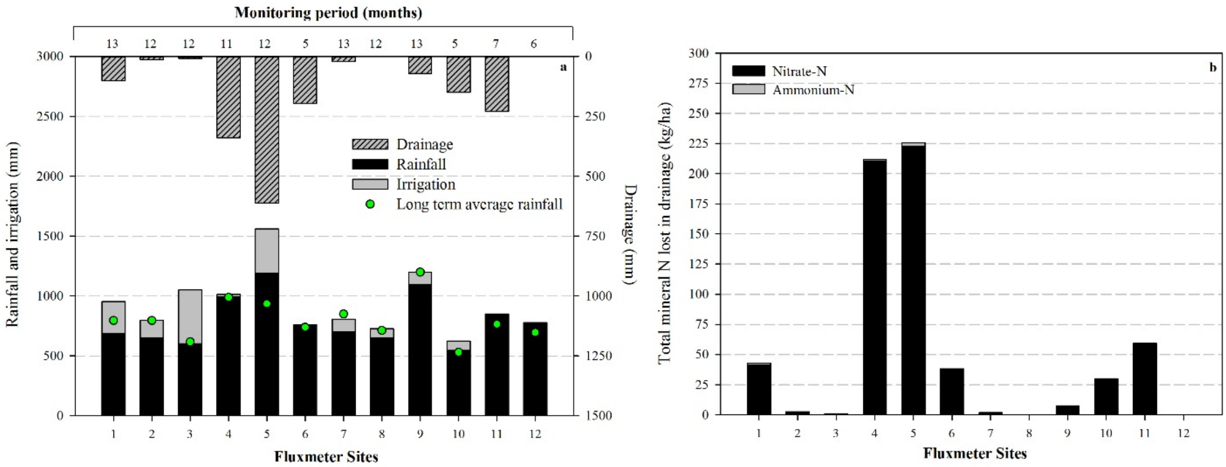

Figure 1. Rainfall (actual and long-term average), irrigation and measured drainage (a) and mineral N losses (b) at the 12 fluxmeter sites. The data cover the period between fluxmeter installation and 30 September 2015. Fluxmeters were installed between August 2014 and May 2015.

Nitrogen losses in drainage water

Calculated losses of mineral N (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 1b). Losses were less than 25 kg N/ha at five of the sites, between 25 and 50 kg N/ha at 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 1). 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. At Site 4, high losses (212 kg N/ha) were consistent with elevated soil mineral levels (data not presented) which reflected high N inputs. At Site 5, high losses (226 kg N/ha) reflected soil (sandy loam) and climate factors (above average rainfall).

Measured N losses observed under the fluxmeter network are comparable with those reported in previous studies. For example, losses 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 results from the fluxmeter network span different time frames at each site (some sites have been operating for less than 6 months). Once the datasets are compiled across multiple years, a more complete interpretation will be possible with respect to specific physical, climatic and management factors at each site.

Table 1. Background site information, number of sampling events and average concentrations of nitrate-N and ammonium-N in fluxmeter drainage samples collected in the period between fluxmeter installation and 30 September 2015. MC-LG = mixed cropping and livestock grazing, MC = mixed cropping, IVP = intensive vegetable production.

Site	Region	System	Soil texture	Installation date	Sampling events	Nitrate-N (mg/L)[1]	Ammonium-N (mg/L)[1]
1	Canterbury	MC-LG	Silt loam	26 Aug 2014	6	26.2 (5.9 – 36.6)	3.1 (1.0 – 6.1)
2	Canterbury	MC-LG	Silt loam	22 Sept 2014	3	22.3 (14.2 – 36.4)	9.3 (4.4 – 17.2)
3	Canterbury	MC-LG	Silt loam	24 Sept 2014	2	7.8 (5.7 – 9.9)	1.0 (0.6 – 1.3)
4	Manawatu	IVP	Silt loam	20 Oct 2014	8	49.9 (9.5 – 75.0)	1.7 (0.5 – 4.6)
5	Manawatu	MC-LG	Sandy loam	29 Sept 2014	7	33.7 (10.1 – 80.1)	1.0 (0.0 – 3.3)
6	Manawatu	MC	Silt loam	20 Apr 2015	3	17.5 (11.9 – 20.4)	0.7 (0.6 – 0.8)
7	Hawke's Bay	MC-LG	Silt loam	8 Sept 2014	4	8.0 (3.1 – 19.3)	0.9 (0.1 – 2.1)
8	Hawke's Bay	MC-LG	Silt loam	2 Oct 2014	1	21.5	3.1
9	Hawke's Bay	MC-LG	Silt loam	4 Sept 2014	8	9.5 (2.3 – 20.9)	1.7 (0.02 – 3.3)
10	Waikato	MC	Sandy loam	13 May 2015	4	17.2 (15.9 – 19.1)	0.4 (0.2 – 0.8)
11	Auckland	IVP	Clay loam	10 Mar 2015	4	29.0 (14.3 – 48.9)	0.3 (0.1 – 0.5)
12	Waikato[2]	IVP	Clay loam	7 Apr 2015	4	-	-

[1]The range of nutrient concentrations (average for each sampling event) is presented in parenthesis. [2]A reliable estimate of N concentrations could not be reported for Site 12 due to flooding of the fluxmeter units.

Conclusions

In the period between fluxmeter installation (August 2014 and May 2015) and 30 September 2015, measured N losses across the fluxmeter network have ranged from 0.2 to 226 kg N/ha. The observed range in N losses is consistent with the different duration of monitoring (five to 13 months), as well a wide range of climate, management and soil characteristics found at each site. These initial results indicate that the network is effectively capturing N drainage losses and will provide long-term patterns of N use efficiency. Collection of detailed soil, plant, climate and management information is ongoing and will inform future modelling and establishment of good management practices.

Acknowledgments

This work is funded by: the Ministry for Primary Industries Sustainable Farming Fund (SFF), the Foundation for Arable Research, Horticulture New Zealand, Environment Canterbury, Horizons Regional Council (Manawatu-Whanganui), Hawke's Bay Regional Council, Waikato Regional Council, Auckland Regional Council and Ravensdown. The Canterbury, Manawatu and Hawke's Bay sites are part of the SFF Root Zone Reality Project (SFF 401484) and the Waikato/Auckland sites are part of an extension project (Horticulture NZ RI 1009).

We thank our grower collaborators for their support and interest in the project, and for providing information about their farming systems and crop management practices.

We are grateful for the technical teams involved in the installation and ongoing maintenance of the network: Shane Maley, Mike George, Paulo Zuccarini, Nathan Arnold, Adrian Hunt and Christina Finlayson.

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