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Measuring real time nitrate leaching from a tile-drained Hawke's Bay onion field

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Abstract

Loss of nitrogen (N) from soils to freshwater has important implications for maintaining water quality. Data on N leaching losses in vegetable production systems is relatively scarce, and outputs from leaching models are likely to be viewed with varying degrees of confidence. Being able to measure N leaching losses in real time, relative to rainfall and drainage events, and then relate these losses to management practices, is important to both problem recognition and development of improvements in good agricultural practices.

A number of nitrate sensors are used internationally to measure nitrate-N concentrations in wells and sumps, but these have been largely untested under vegetable production in New Zealand. The purpose of this research was to compare data from a nitrate sensor installed in a sump measuring nitrate-N concentrations *in situ*, with data from grab samples that were taken immediately to a laboratory for analysis.

The data showed a strong linear relationship between the N concentration measured by the sensor and in the grab sample (sensor N concentration = 1.09 × grab sample N concentration + 0.14, R^2 of 97%). This indicates that the sensor can provide a good indication of sump nitrate-N concentrations, and that with calibration the accuracy can be improved further. The ability to measure real time nitrate concentrations in the drainage water provided data that showed clear links between management practices, rainfall events and N leaching.

Keywords: photometric nitrate sensor, *in situ* monitoring

Background

Nutrient (nitrogen and phosphorus) loss to freshwater is a large problem and particularly relevant for intensive export and process vegetable growing regions such as the Heretaunga Plains in Hawke's Bay where around 5800 hectares of vegetables are planted annually. Under the Hawkes Bay Regional Council's (HBRC) proposed Plan Change 9 (TANK), hundreds of horticultural growers will be required to develop a Farm Environmental Management Plan (FEMP), including a freshwater module with a 'schedule of actions' to manage identified risks such as nutrient loss.

Data on nitrogen (N) leaching losses in vegetable production systems is relatively scarce, and outputs from leaching models is likely to be viewed with varying degrees of confidence. Being able to measure N leaching losses in real time relative to rainfall and drainage events and then relate these to management practices is the key to both problem recognition and development of improvements to good agricultural practices (GAP). Appropriate practice change is essential for reducing nutrient losses to waterways. The majority of N is leached as nitrate, with only a small percentage being lost as ammonium (e.g. Martin et al. 2001). Therefore, measurement of nitrate-N leaching losses provides a good indication of N losses from cropping system. Nitrate sensors are used internationally to measure nitrate-N concentrations in wells and sumps, but these have been largely untested under vegetable production in New Zealand. The purpose of this research was to compare data from a nitrate sensor installed in a tile-drain sump measuring nitrate-N concentrations *in situ*, with data from weekly grab samples analysed at a commercial laboratory. OverseerFM was then used to predict the effect of management practices a farmer could use to reduce N leaching.

Materials and Methods

Site description

The field was located near Clive on the Heretaunga Plains of Hawke's Bay, New Zealand. The soil type is a Waitohi silt loam (previously Mangateretere silt loam). The soil is naturally poorly drained, with a dense clay-rich subsoil (36–45% clay, S-map 2021) from 30–60 cm below the soil surface. A high water table in winter also adds to the need for drainage. The field was tile and mole drained, with all drains leading to a single sump. At the sump, the tile drains entered at a depth of approximately 2 metres. The sump was pumped out automatically, when the water level rose above a minimum level. The amount of water that remained in the sump after pumping (i.e. below the float switch) was 2.2 m^3.

Field management

The field was managed by a commercial grower. The field was previously in onions, left fallow over winter, then sprayed out using herbicide on 7 August 2020. On 8 August 2020 the field was cultivated and planted in onions (*Allium cepa* L.). The paddock is 16.1 ha, with a planted area of 15.4 ha. Fertiliser was applied four times (Table 1). This gave a total of 153 kg N/ha applied. Weeds, pests and diseases were controlled using agrichemicals. Two irrigations, of 35 mm each, were applied by a big gun over the weeks of 7–14 December 2020 and 22–29 December 2020. Onions were lifted on 13 January 2021 and removed from the field on 25 January 2021. The yield was 92 t fresh weight/ha, with a N concentration of 1.26% N when dried to 13.7% DM.

The entire block remained fallow until 24 March 2021 when it was planted in winter oats. No fertiliser was applied. The oats were mulched on 6 July 2021 and the residue incorporated on 28 July 2021 when the paddock was ploughed.

Table 1. Nutrients applied as fertiliser to the onion field.

Application Date	N applied (kg/ha)	P applied (kg/ha)	K applied (kg/ha)	S applied (kg/ha)
2 September 2020	32	38	0	2
7 October 2020	47	0	0	0
6 November 2020	38	18	32	8
15 December 2020	37	16	45	24
TOTAL	154	72	77	34

Sampling and monitoring

Soil samples were collected at the start and finish of the onion crop at depths of 0–15, 15–30, 30–60 and 60–90 cm. Samples were analysed at Analytical Research Laboratories (ARL) for pH, Olsen P, exchangeable cations, mineral N and anaerobically mineralisable N (AMN) (Table 2). Soil moisture was measured at two-hourly intervals by 10HS decagon soil moisture sensors (Decagon Devices, Inc), which were installed horizontally at 15, 30 and 60 cm depth at the front and back of the field. Rainfall was measured daily using a rain gauge installed at the field. Weekly drainage was recorded by two flow meters located at the sump. The nitrate concentration of the water in the sump was measured at 60 to70 minute intervals by a TriOS Nico nitrate sensor (TriOS Optical Sensors, Denmark) supplied by Ravensdown. This is a UV photometric sensor with capability to compensate for turbidity. The sensor also has a mechanical brush (ZebraTech) optical lens cleaning system to minimise inaccuracies from the build-up of dirt or microbial growth. Samples of the sump water were collected weekly and submitted to ARL within 1 hour of collection for determination of nitrate-N concentration. Nitrogen leaching per hectare was calculated as the volume of water in the sump multiplied by the N concentration collected divided by 16.13 ha. Yields were measured by the grower. Onion N content was determined from a grab sample of 20 onions collected at harvest that was sent to ARL for analysis. Nitrogen leaching at 60 cm, phosphorus losses in drainage and greenhouse gas emissions were also estimated using OverseerFM. Two scenarios were modelled, one including the oat catch crop, and one with the land left fallow instead of being planted in oats.

Results

Soil test results

The soil contained adequate amounts of phosphate and exchangeable cations for onion production (Reid & Morton 2019) and moderate amounts of mineral N (Table 2). Soil tests at the end of the onion crop showed that 86 kg/ha of mineral N remained in the soil to a depth of 90 cm, with approximately 80% of this located in the top 30 cm (Table 2).

Table 2. Soil test results from the onions field. Data are from a sample taken on 28 July 2020, except for mineral N at the end of the trial, which was taken on 26 January 2021. Mineral N data assume a bulk density of 1.22 kg/dm^3 above 30 cm, and 1.42 below 30 cm (S-map). QT = Quick Test, AMN = anaerobically mineralisable N.

Depth (cm)	pH	Olsen P (µg/mL)	QT K	QT Mg	QT Ca	QT Na	AMN (kg N/ha)	Mineral N (kg N/ha)	
								Start	End
0-15	6.1	75	20	65	17	9	36	15	41
15-30	6.2	39	15	72	17	13	35	40	29
30-60	6.6	46	11	111	21	19	10	39	7
60-90	6.9	48	11	133	21	23	10	19	9

Rainfall, drainage and irrigation

There was a total of 274 mm of rainfall over the onion cropping period, with one-third of this falling over a three-day period in mid-November (Figure 1). Two irrigations of 35 mm were applied towards the end of the cropping period. For the majority of the onion cropping period, there was reasonably consistent drainage of approximately 7 mm every week (Figure 1), reflecting the slow-draining nature of the soil. A notable exception to this was the large amount of drainage that occurred in mid–late November as a result of a week of heavy rain. This accounted for 40% of the drainage for the onion cropping period. The amount of drainage slowed towards the end of the onion cropping period.

There was a further 281 mm of rainfall after the onion crop, with 115 mm falling in June (Figure 1). There was minimal drainage from the end of the onion crop until late June.

The soil moisture data (Figure 2) showed that the clayey subsoil at 60 cm depth had a consistently higher soil moisture content than the silt loam topsoil. The soil moisture content at 60 cm depth decreased from the start of December, hence the amount of measured drainage declined.

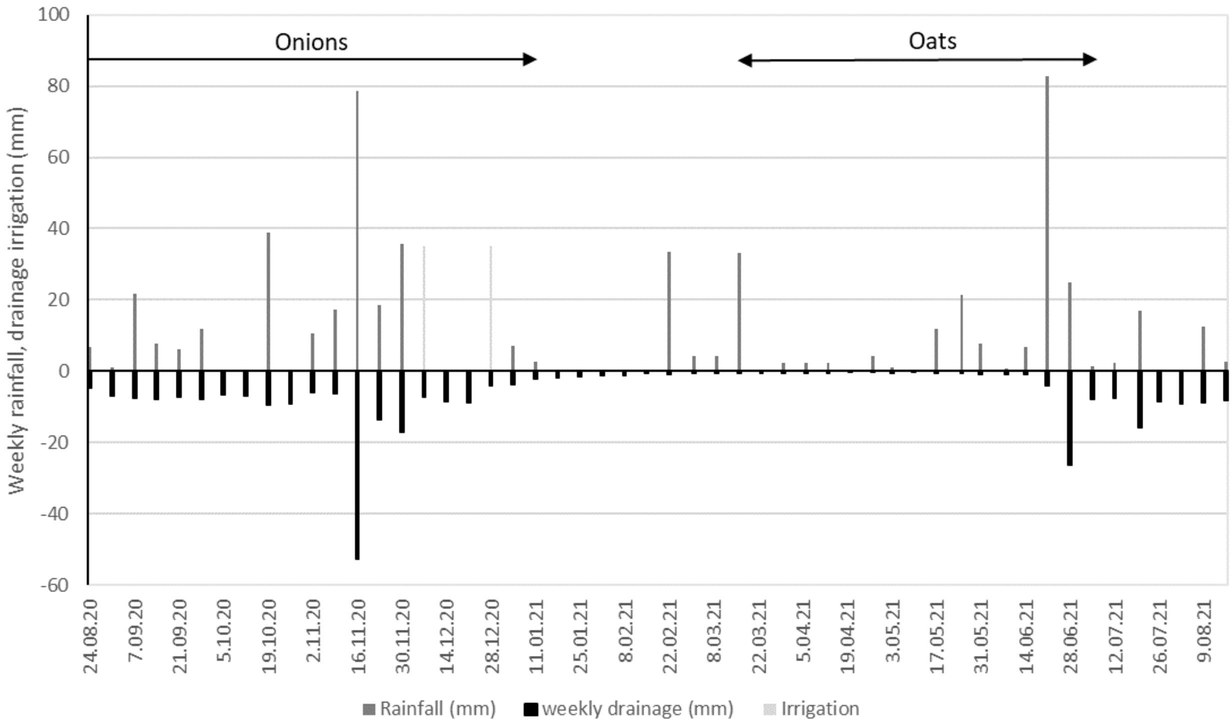

Figure 1. Weekly rainfall, drainage and irrigation over the cropping year. Rainfall over the onion cropping period was 274 mm and 555 mm for the year.

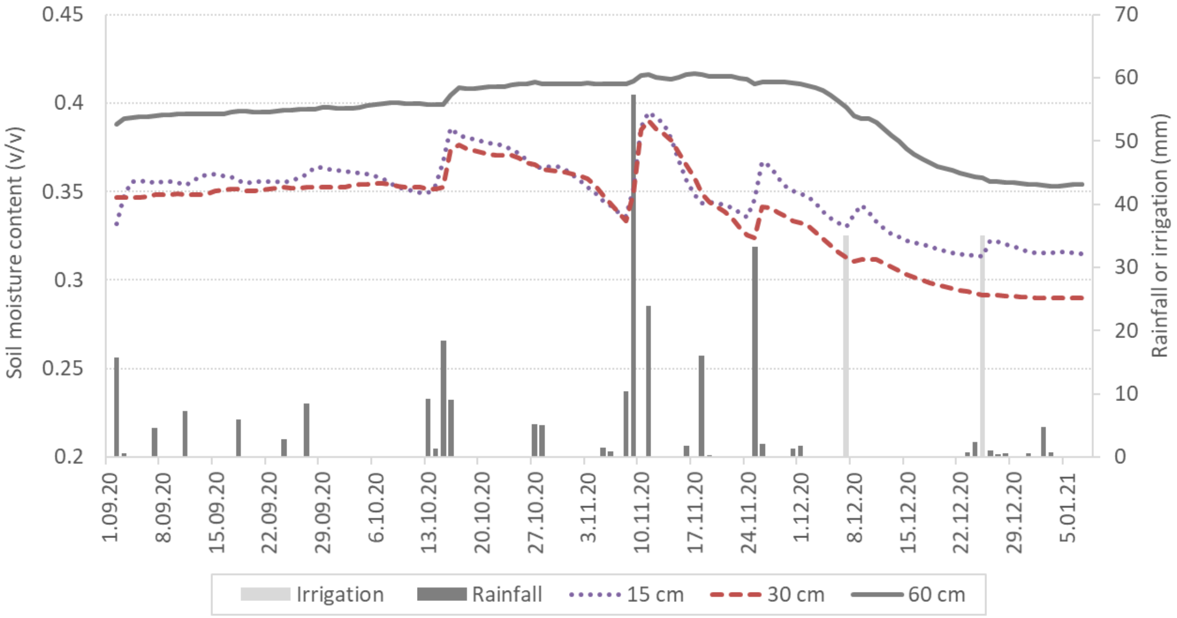

Figure 2. Volumetric soil moisture content at three depths as measured by decagon soil moisture sensors over the period of the onion crop. Rainfall and irrigation are also shown.

Nitrogen leaching

Nitrate-N concentrations in drainage water collected from the sump ranged from 1.6 to 8.7 mg/L over the cropping period (Figure 3), with an average of 3.4 mg/L. These concentrations are considered to be low for drainage captured under cropping systems, noting that the limit for potable drinking water set by the Ministry of Health (2008) is 11.3 mg-N/L. The four peaks in nitrate-N concentration followed heavy rain or irrigation events, and three of the four peaks occurred during or within two weeks of fertiliser application (Figure 3). The largest increase in sump nitrate-N concentration occurred in November 2020 when 93 mm of rain fell over a four-day period, within a week of a fertiliser application.

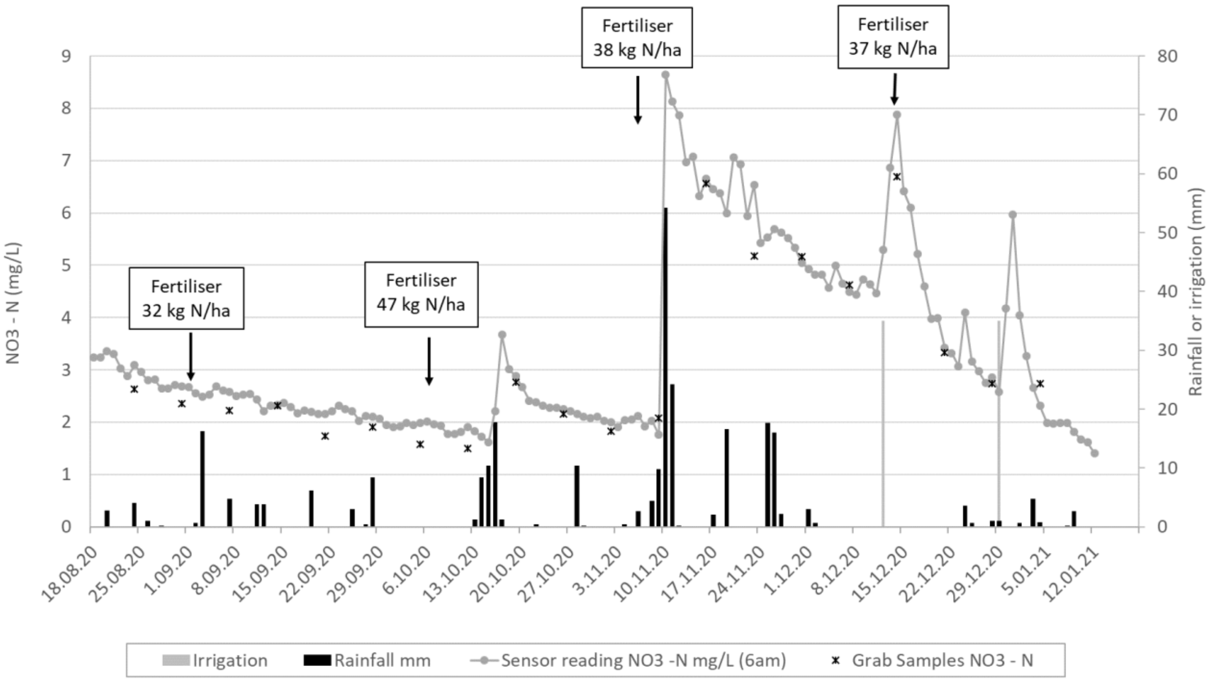

Figure 3. Changes in sump nitrate-N concentration over the onion cropping period. Both sensor and grab sample nitrate-N concentrations are shown. Rainfall, irrigation and fertiliser applications are also shown.

Nitrate leaching losses largely followed the pattern shown by the amount of drainage water lost (Figure 4) and totalled 8.4 kg N/ha during the onion crop and 10.6 kg N/ha over the whole year (Figure 4). Prior to the large rainfall event in mid-November, sump nitrate-N concentrations and the amounts of weekly drainage were relatively consistent, giving rise to nitrate leaching losses of approximately 0.16 kg N/ha/week (Figure 4). The large rainfall event within a week of a fertiliser application gave a large rise in drainage and sump nitrate-N concentration, causing a N loss of 3.7 kg/ha in one week. After the spike in nitrate leaching in November, nitrate leaching losses gradually declined to 0.04 kg N/ha/week by harvest time. The gradual decline in drainage from November to January (crop harvest) reflects the slow-draining nature of the soil after being saturated.

After onion harvest, N leaching losses had dropped to <0.02 kg N/ha/week (Figure 4). This very low rate of leaching continued until sizeable quantities of drainage occurred from late June. Leaching losses were then approximately 0.15 kg N/ha/week, except for two larger drainage events, which produced more leaching (Figure 4).

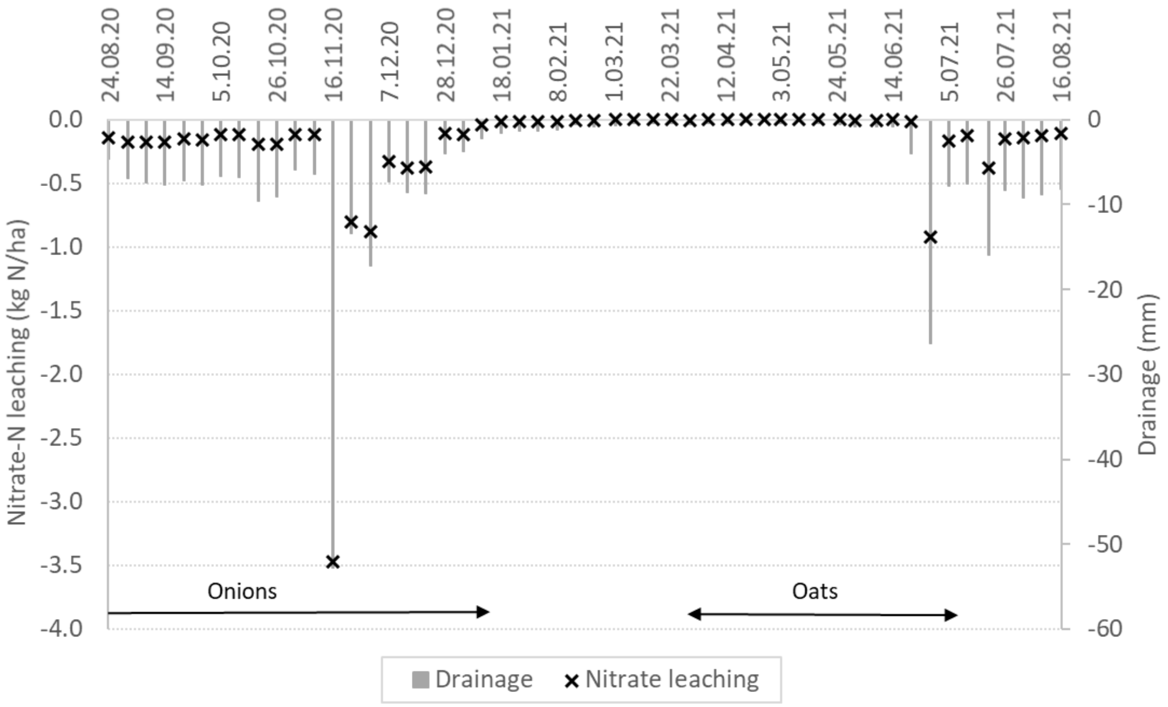

Figure 4. Drainage and nitrate-N leaching losses over the cropping year. These have been plotted as negative numbers to represent system losses. Total drainage and nitrate-N leaching losses were 204 mm and 8.4 kg N/ha over the duration of the onion crop, and 314 mm and 10.6 kg N/ha for the year.

Performance of the TriOS Nico N sensor

There was a strong linear relationship between nitrate-N measured by the sensor and that measured in the grab sample by the laboratory (Figure 5). The fitted linear regression line (Figure 5) indicates that the sensor nitrate-N values were approximately 9% higher than those determined in the laboratory from the grab samples.

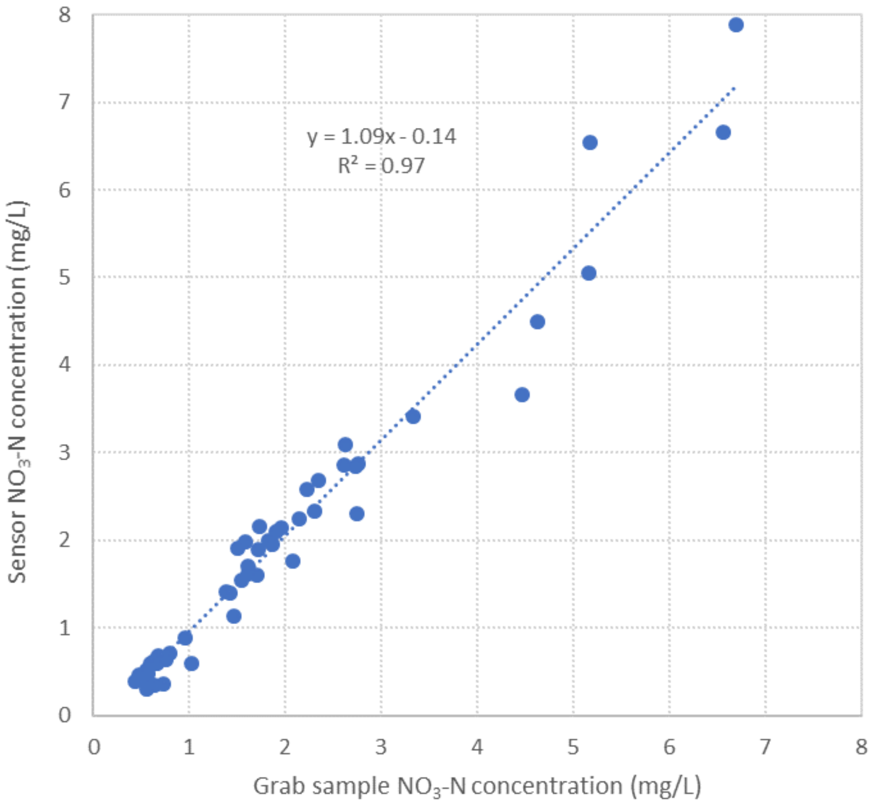

Figure 5. Plot of sensor nitrate-N concentrations against grab sample nitrate-N concentrations over the cropping period.

Overseer

Modelling losses from the field over the year using OverseerFM reports a total of 385 kg N leached from the root zone, or 23 kg/ha/y. Total modelled phosphorus loss in drainage was 16 kg or approximately 1 kg/ha/y. Modelled greenhouse gas losses were 43.8 eCO_2/t/y if the land was left fallow until a second onion crop was sown. Scenario modelling showed that the greatest reduction in modelled N leaching could occur through use of a catch crop to take up N from the soil over winter, as opposed to leaving the land fallow. For example, the planting of an oat crop in March for the winter period predicted N losses of 5 kg/ha/y – a reduction of 18 kg/ha/y. This modelled result helped the grower decide to plant the field in oats after the onion harvest. The figure of 5 kg/ha was half the amount of N leaching observed over the cropping year. Caution must be observed, however, when comparing the measured data with the modelled data, because the Overseer predictions use long term weather data, which will generate a different drainage pattern and soil temperatures to that experienced by the crop in the 2020–21 growing season.

In the oat catch crop Overseer scenario, phosphorus loss changed little. However, total greenhouse gas emissions were estimated to increase by 25% to 54.7 eCO_2/t/y, mainly as a result of increased nitrous oxide emissions arising from ploughing in the crop of oats into a soil that is periodically water-logged over winter, with some also arising from diesel consumption from the extra cultivation passes required to plant the catch crop. Growers will need to consider carefully the effects of trade-offs in pollution, planting the catch crop reduces N leaching, but increases greenhouse gas emissions.

Other scenarios modelled (such as reducing irrigation depth to 25 mm and increasing irrigation frequency to 10 days) showed no significant reduction in modelled N loss, as did changing from conventional cultivation practices to minimum tillage.

Discussion

The close agreement between the TriOS Nico sensor readings and the laboratory analysis of the grab samples indicates that the sensor can provide a good indication of sump nitrate-N concentrations. The strong linear relationship (sensor concentration = 1.09 × grab sample + 0.14, R^2 of 97%) indicates that with calibration, this accuracy could be improved even further. Sensor results can therefore be used to estimate nitrate-N leaching (kg/ha) when drainage volumes are measured. The TriOS Nico sensor used a mechanical brush (ZebraTech) optical lens cleaning system which was designed for industrial sewage and drinking water plants and proved to be suitable for deployment into the drainage sump used in this trial. Other optical cleaning systems such as water pump (water jet) have previously proved unsuccessful in sump situations where variable water turbidity levels, microbiological growth and organic carbon compounds can disrupt the measurements.

Results from this study suggest that, when paired with drainage volumes, the TriOS sensor can provide growers with a real time indication of N leaching from their cropping fields. The sensor results gave a much clearer picture of how nitrate leaching related to management practices than the weekly grab samples. For example, the spike in sump nitrate concentration immediately after the second irrigation was applied was completely missed by the weekly grab sample data (Figure 3).

In this study there was a clear link between farmer management practices such as fertiliser application or irrigation, and nitrate-N concentration in the drainage water. Reducing the amount or intensity of irrigation may be one factor to consider to lessen irrigation-induced drainage and leaching. Nothing can be done to avoid drainage from heavy rainfall events, such as that which occurred in mid-November, but reducing the amount of N in the soil can reduce the risk of leaching from a single heavy rainfall event. Hence splitting of N fertiliser into several applications throughout the season, as practiced here, is recognised as best practice (Reid and Morton 2019). The grower would have to consider whether a greater number of small applications was economic, especially when considering the potential for increased CO_2 emissions. The use of controlled-release fertilser products is another management strategy to reduce the risk surplus soil N relative to plant N demand (e.g. Azeem et al. 2014).

The nitrate-N concentrations in the sump drainage water of 1.6 to 8.7 mg/L (average of 3.4 mg/L) over the onion cropping period (Figure 3), were below the limit for potable drinking water set by the Ministry of Health (2008) of 11.3 mg-N/L. A loss of 8.4 kg N/ha during an onion crop is low compared with that found for onion crops in the Auckland or Waikato regions (Trolove et al. 2021). This may be because there was less drainage or a lower soil mineral N content than the fields in the study reported by Trolove et al (2021). There may also be a significant loss of N from this field by denitrification, given the wet, slow-draining properties of the subsoil (Figures 1 and 2). Low leaching losses in the period following the onion crop (2.2 kg N/ha; February – mid-August 2021) were consistent with negligible drainage over autumn, during which time the unfertilised oat crop could establish and take up remaining residual N before drainage resumed in mid-winter

The combined use of measuring and modelling is a good strategy to help growers reduce N leaching from crops. Modelling scenarios will help growers compare proposed strategies to select the option with the lowest N leaching risk, and real time measurements will help growers see the effects of the management decisions made on N leaching

Conclusions

The data showed a strong linear relationship between the N concentration measured by the sensor and in the grab sample (sensor N concentration = 1.09 × grab sample N concentration + 0.14, R^2 of 97%). This indicates that the sensor can provide a good indication of sump nitrate-N concentrations, and that with calibration the accuracy can be improved further. The ability to measure real time nitrate concentrations in the drainage water provided data that showed clear links between management practices, rainfall events and N leaching.

References

Azeem B, KuShaari KZ, Man ZB, Basit A, Thanh, T. H. 2014 Review on materials & methods to produce controlled release coated urea fertilizer. Journal of Controlled Release 181: 11-21 .

Martin RJ, Craighead MD, Williams PH, Tregurtha CS. 2001. Effect of fertiliser rate and type on the yield and N balance of a Pukekohe potato crop. Agronomy New Zealand 31: 71-80.

Ministry of Health. 2008. Drinking-water Standards for New Zealand 2005 (Revised 2008). Wellington: Ministry of Health. https://www.esdat.net/Environmental%20Standards/NZ/dwsnz-2005-revised-mar2019.pdf

Reid JB, Morton JD. 2019. Nutrient management for vegetable crops in New Zealand. Horticulture New Zealand Incorporated.

S-map 2021. The digital soil map for New Zealand. Manaaki Whenua. Version 3.1.224 https://smap.landcareresearch.co.nz/ Accessed 22/4/2021

Trolove S, Wallace D, Johnstone P, Sorensen I, Arnold N, van der Weyden J, van den Dijssel C, Dellow S, Wright P, Clark G, Cummins M, Green S. 2021. Protecting our groundwater: Fluxmeter network summary report. Plant & Food Research Report No. 20648