# MEASURING THE GREY-WATER FOOTPRINT OF POTATO PRODUCTION

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**Abstract**
As the dominant land use in New Zealand, agriculture has widespread impact on freshwater quality and quantity. The grey-water footprint has been proposed as an indicator of the impacts of land use on the quality of freshwater resources. It is expressed as the volume of freshwater that is required to assimilate the load of pollutant and it is based on the natural background concentrations and an appropriate water-quality standard. Previous studies have shown that among the agrichemicals used in crop production systems, the grey-water footprint is dominated by nitrate leaching. Due to the complexity in assessing nitrate leaching and the contamination of water resources, most of the grey-water footprint calculations of crop production systems are currently based on the single assumption that, on average, 10% of the applied nitrogen fertilizer is lost through leaching. However, measurements and modeling are needed to ecoverify the grey-water footprint. We monitored nitrate leaching in two potato fields using 12 tension fluxmeters. At one site (Site-2), which was planted in early October there was significant spring rainfall and, on average, about 68% of total rainfall (370 mm) drained during the nine weeks after planting. At the other site (Site-1), about 31% of the total rainfall (290 mm) drained and this crop was planted later in October. At Site-1 a loss of 13.5 kg/ha nitrate nitrogen was observed for the period of 38 days after planting. This is equivalent to 87% of nitrogen fertilizer applied to that site at the time of planting. This emphasizes the importance of validation of the grey- water footprint with measurements, as the nitrate leaching is simply not 10% of the applied fertilizer. This season has been very wet and the local weather needs to be put in context. To this end, the second step of our analysis will be to model nitrate leaching losses by considering a 40-year period of annual weather data to calculate the average grey-water footprint and assess its inter-annual variability.

**Key words:** grey-water footprint, nitrate leaching, fluxmeters

## Introduction

In recent times, there has been a major increase in the intensity of agricultural production in New Zealand, while at the same the time there is increasing evidence that the country's freshwater resources are becoming nutrient enriched and degraded as a result of pollution from non-point sources (Parkyn et al., 2002). The challenge for farmers is to maintain the benefits of irrigation and agrichemical use, whilst minimising the adverse effects on the receiving water resources. The grey-water footprint is proposed as an indicator of the impacts of land use on the quality of fresh water resources. It is calculated as the volume of freshwater that is required to assimilate the load of pollutants so that they are within guideline values based on natural background concentrations and the appropriate water quality standards (Hoekstra et al., 2011).

Previous studies of leaching of agrichemicals under crop production have identified nitrate – nitrogen ($NO_3$-N) as the major pollutant (Deurer et al., 2011, Green et al. 2010). Some of these studies indicate that the concentrations and loads of other pollutants, such as pesticides, are negligibly small, and in many cases their concentrations are below the detection limit of currently available analytical methods (Deurer et al., 2011). Furthermore, in many water footprinting assessments, nitrate-nitrogen is considered to be the primary pollutant of freshwater under cropping systems (Hoekstra et al., 2011, Hoekstra and Chapagain., 2008).

Due to the difficulty of measuring nitrate leaching and the contamination of water resources, most of the grey-water footprint calculations have been based on the simple assumption that on average about 10% of the nitrogen applied in fertilizer is lost through leaching (Chapagain et al., 2006). This is a very approximate estimation which obviously excludes factors such as; soil types, agricultural practices, local soil hydrology and the interaction between different chemicals in the soil. Therefore, we seek to calculate the grey-water footprint following accurate measurements and modelling of nitrate leaching. More detailed and reliable values for the grey- water footprint are imperative if water footprinting is to be taken seriously. We present preliminary results of measurements of nitrate leaching under potato cultivation in the Manawatu region.

**Methods**

Nitrate leaching was monitored in two potato fields on Manawatu sandy loam soil. At Site 1, a 'late-season' crop was planted on 31 October 2011: this site was planted with taewa, traditional Maori potatoes (cv. Moemoe). It was managed with low inputs to mimic a community-garden style of production. Site 2, a commercial-scale enterprise, was planted with the cultivar Fianna on 3 October 2011 i.e. approximately a month before Site 1. Neither of the potato fields was irrigated. Fertiliser was applied at the time of planting and application rate of nitrogen fertiliser in Site 1 was 15.4 N kg/ha.

As most potatoes are grown in free draining soils on flat to undulating terrain, contamination of surface waters by runoff of agrichemicals is minimal. Therefore, we only considered the pollution of groundwater by nitrate leaching through the root zone following the definition for the grey-water footprint given by Hoekstra et al., 2011(Eq. 1).

$$WF_{grey} = \frac{Effl\,(c_{effl} - c_{nat})}{(c_{max} - c_{nat})}, \qquad \text{(Eq. 1)}$$

Where, E*ffl* is the volume discharge of effluent (L of drainage) at concentration $c_{effl}$ (mg/L). Here, $c_{max}$ (mg /L) is the maximum concentration allowed according to the appropriate guideline values in the water quality standards, and $C_{nat}$ (mg /L) is the naturally occurring concentration of the receiving water.

Twelve tension fluxmeters, six at each site, were installed below the root zone of potatoes. At each site, three fluxmeters were placed beneath the row or ridge and three were placed in the inter-row. Fluxmeters were 85cm below the top of the row, and 60 cm below the surface in the inter-row (Fig.1). Drainage was collected after every significant (>10 mm) rainfall event. This was done by connecting the water outlet tube to a pump (Fig. 2). The leachate was analyzed for nitrate and ammonium in the laboratory using a segmented flow analyser RFA-300 (Raymond et al., 1987).

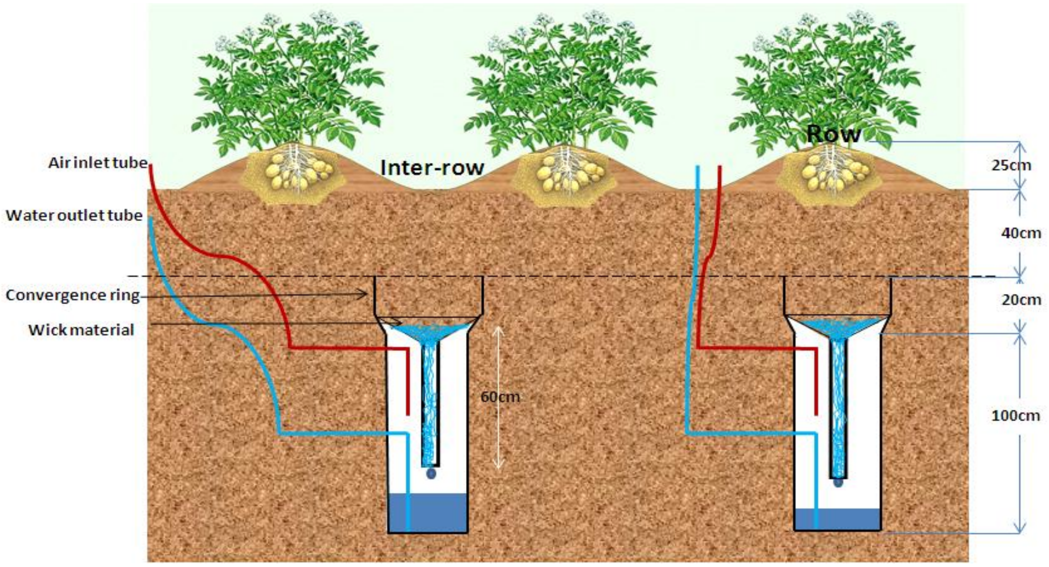


Figure 1. A schematic diagram showing fluxmeters installed under the row (right) and inter-row (left) in the potato field

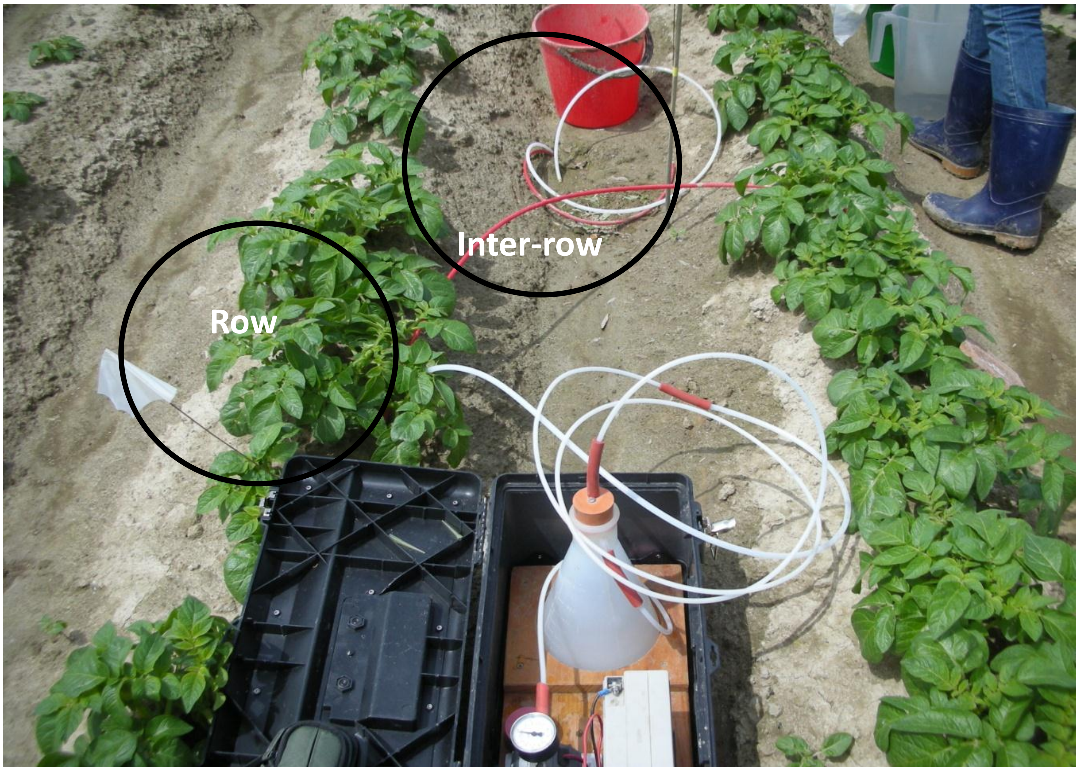


Figure 2 Extraction of drainage by connecting the tube to a pump. Each fluxmeter has two tubes to the surface, the white one to collect the water and the red for air entry and escape.

In our future modelling analyses, we will use 'Soil-Plant-Water-Atmosphere Model' (SPASMO) to assess the plant water use, drainage and nitrate leaching under a range of climate conditions (Green et al., 1999). We will assess inter-annual variability and explore options to reduce the water footprint. To verify the model we also measured rainfall at each site, green leaf area, plant height and density, and at Site-1, we also monitored soil moisture and temperature and the nitrogen content of different plant parts.

## Results and discussion

### *Drainage volume*

At both sites, about 90% of the rainfall during the first two weeks after planting left the soil has drainage. This is mainly because there has been a lot of rain at the beginning of the season plus plant water use is minimal during this period as it takes about 2-3 weeks for plants to emerge and develop leaf and root systems. This season was very wet, and so it would be interesting to compare the drainage measured here with a range of other years. This will be done via modelling in the next phase of our analyses.

When cumulative rainfall and drainage is considered, at Site-2 on average about 68% of total rainfall (370 mm) had drained during the first nine weeks after planting. At the other site, drainage was about 31% of the total rainfall (290 mm) during this period.

### *Nitrogen loss*

The loss of nitrogen (N) was determined following analysis of the leachate for ammonium and nitrate. Nitrogen loss in the form of ammonium was very low. At Site 1, some 38 days after planting of the Maori potatoes, nitrate-nitrogen loss was 13.5 kg ha$^{-1}$ (Fig.3). This is equivalent to 87% of the nitrogen fertiliser that was applied at the rate of 15.4 kg N/ha at the time of planting. It is important to note that this fertiliser application rate is low compared to the commercial operations. Some of this lost nitrogen could be derived from the mineralization of organic matter. Nitrogen loss for the Site 2 is still being processed.

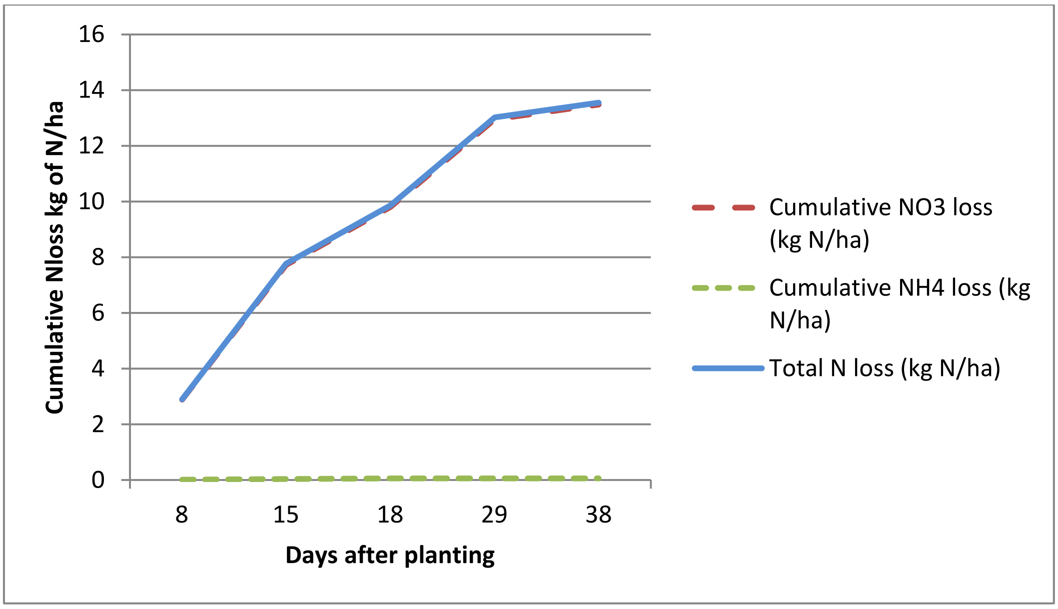


Figure 3. Cumulative nitrogen loss at Site-1, the Maori potatoes

***Assessment of plant nitrogen uptake to minimize the losses***

The total nitrogen content of the plant parts sampled at different stages of growth at Site-2 indicates that plant nitrogen demand is very low at the beginning of the season, right up to about four weeks after planting (Figure 3). This low N demand, coupled with the low plant evaporative water demand will have contributed to the N leaching during this period. Therefore, applied nitrogen would be prone to leaching at the beginning of growth cycle. Both nitrogen demand and water utilization by the plants rapidly increases as plant growth increases. The total nitrogen content of the plant's biomass, both above ground and below ground at Site-2 was 295kg N/ha at 94 days after planting (Figure 4). Synchronizing this nitrogen demand of the potato plant with soil nitrogen availability through fertilizer application is vital so as to minimise total N loss. Conventionally, fertilizer is applied at the time of planting. However, a later dressing of fertilizer, say at mounding, should reduce the grey-water footprint of production. We will model this management option.

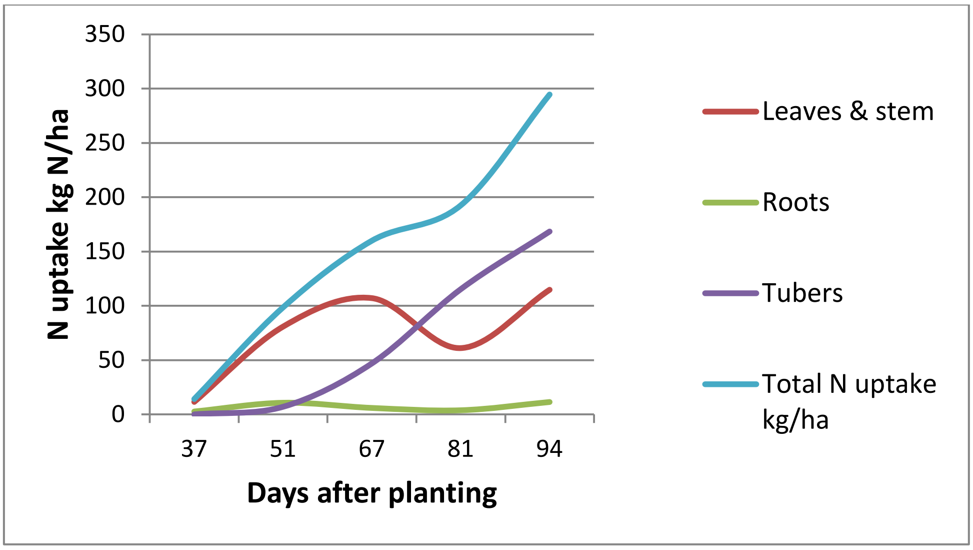


Figure 4 Cumulative nitrogen uptake by the potato plants at Site-2, cultivar: Fianna.

**Conclusions**

The grey water footprint has been proposed as an indicator of the impacts of land use on the quality of fresh water resources. Our results indicate that the commonly used assumption of 10% of applied nitrogen is lost through leaching in grey water footprint calculations for a crop production system is inadequate. Validation of the grey water footprint through accurate measurements is imperative if it is to be taken seriously.

When nitrogen fertilizer is applied at the time of the planting, a large fraction of the applied nitrogen is prone to leaching due to large quantities of N in soil sourced both from fertilizer and soil N mineralization plus low plant-nitrogen demand and the water use at beginning of the season. Synchronization between N uptake by the potato root and availability in the soil is needed to minimize N loss.

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