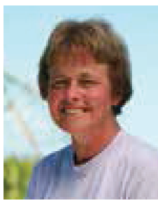
Best irrigation practice saves water and grows more

Big advances are being made in irrigation systems and management tools. Precision irrigation is important to avoid waste of water, loss of nutrients to the environment and loss of production. Mapping the soils and the use and management of farm blocks/paddocks, measuring soil moisture and drainage, and utilising weather forecasts are proven methods to increase irrigation efficiency. However, technical solutions are not the only answer. Regulatory and irrigation scheme infrastructural factors also influence decision making and have to be aligned to achieve efficient irrigation.



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Background

Major advances in the New Zealand irrigation industry over the last 30 years, supported by substantial investment in upgrading irrigation systems, has seen irrigation efficiency improve by 50%, as reported by Irrigation New Zealand **(irrigationnz.co.nz)**. Newer irrigation equipment may have real-time water metering and soil moisture sensors, and some also have precision application ability. New Zealand's irrigated area has grown from 460,000 ha in 2002 to approximately 720,000 ha in 2015. More irrigation schemes are planned which have the potential to significantly grow the irrigated area in New Zealand.

Pastoral based activities make up approximately 75% of our irrigated area (dairy 50%; sheep & beef finishing 25%), and the other 25% supports predominantly vegetable and arable crops alongside fruit and viticulture (e.g. wine grapes). In 2012 it was estimated that irrigated farms provided $2.7 billion to New Zealand's economy, and more than double this in terms of the benefits to the wider community.

When irrigation is introduced, productivity gains are significant, e.g. conversion of dryland to irrigated pasture in Canterbury can typically increase dry matter production by 50-100% (~8-10 t DM/ha to ~14-16 t DM/ha[1]).

Methods to best manage the increased input of water and nutrients into the system that accompany these productivity gains are a focus of our research. Water quality is declining in many water bodies[2] and irrigation poses a risk of over-applying water and increasing drainage of nutrients to water bodies, which can contribute to declining water quality.

Irrigation design

New irrigation systems need to be designed so that they can deliver the correct amount of water at an appropriate intensity **(www.dairynz.co.nz/environment/water-use/irrigation/).** If a system cannot do this then the operator will find it difficult to perform efficient irrigation. Also the need for precision or variable rate application should be assessed at the design stage, although variable rate can be retrofitted to older machines. Precision sprinkler systems can be installed to vary sprinkler by sprinkler the amount of water applied. Some of these machines are software-controlled so that 'prescription maps' (zone maps) can be uploaded to control the irrigation pattern.

Precision irrigation systems have many uses, providing greater flexibility for management.

They can vary irrigation to:

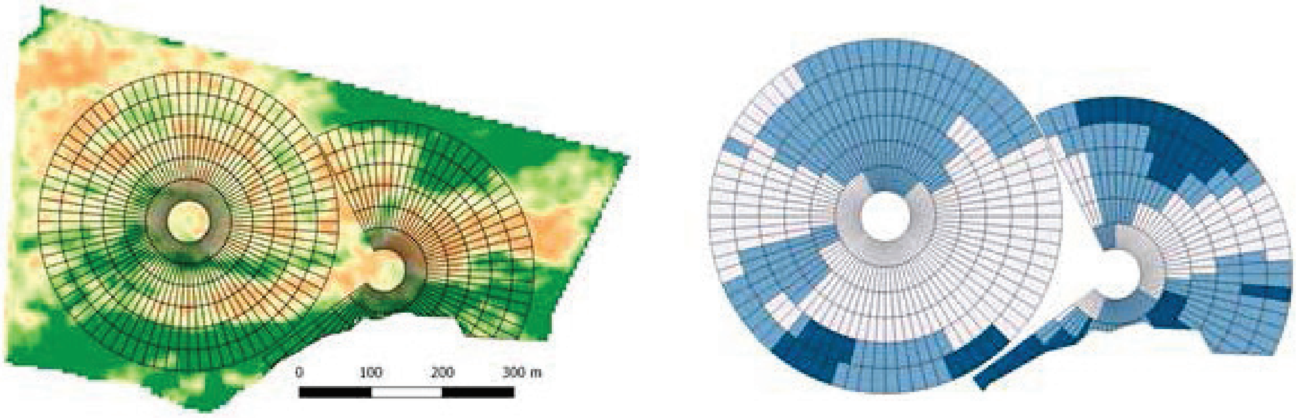
- Variable soils
- Variable topography
- Different crops and pasture planted side by side
- Renovated pastures
- Areas sprayed for weeds
- Areas where fertiliser has been applied.

Dairy farmers are also using precision irrigation systems to avoid irrigating races/laneways (reducing lameness in cows), wet boggy areas (e.g. around water troughs), and to give better control where systems move close to waterways and roads.

Optimum or Deficit?

In the Forages for Reduced Nitrate Leaching programme, Carlton et al[5] examined the effect of optimum and deficit irrigation regimes (based on soil moisture holding capacity) on herbage N uptake and dry matter yield from a spring-applied simulated urine patch on diverse and standard pasture grown on a Paparua fine sandy loam, and the effect this had on nitrate leaching. On this soil type, optimum irrigation was 18 mm and deficit irrigation was 9 mm every three days. Yield was the same for standard (perennial ryegrass and white clover) and diverse pasture (perennial ryegrass, white clover, red clover, chicory, plantain and prairie grass); N yield and N uptake were higher for optimum irrigation. Nitrate leaching from the spring applied urine patch was relatively low, but significantly lower when optimum irrigation was applied (Carlton et al., unpublished results).

Figure 1. Proximal soil sensor surveys are used to investigate soil differences (a), and for producing management zones (b).



a) EC (electrical conductivity) map derived from an EM (electromagnetic) sensor survey.

b) Management zones derived from the EC map, used to guide monitoring positions, e.g. for soil moisture.

Maps for Irrigation

The prescription or zone map is a map that identifies zones likely to require different irrigation schedules, and then it prescribes appropriate amounts of irrigation.

The map can simply be drawn up using the farmer's knowledge. Google Earth images can be used to draw around different paddocks, raceways and e.g. wet boggy areas; and paddock-scale soil maps can be used to identify soils that require different irrigation.

Research being undertaken in the MBIE "Maximising the Value of Irrigation" Programme is developing methods to produce these maps, which include the use of proximal soil sensor survey data (e.g. data derived from gamma radiometric or electrical conductivity sensors).

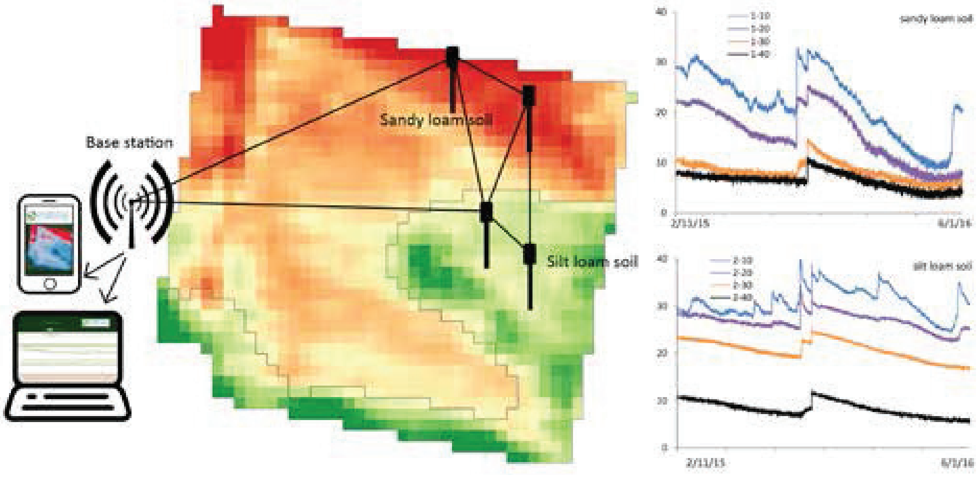
The sensor data are used to identify different irrigation management zones and after checking the soils visibly on the farm, this information is used to select the location of soil moisture sensors (Figure 1).

These methods are being trialled at seven focus farms in Canterbury (Winchester, Rakaia, Dorie), Hawkes Bay (Takapau, Waipawa, Otane) and Horowhenua (Levin); and at a research site at Massey University, Palmerston North. Soil moisture monitoring has occurred at each site over the last two or three seasons, with sensor positions guided by the zone maps.

At three sites, customised wireless soil moisture sensor networks are being used to provide soil moisture data in near real-time to the farmers via cell phone apps and webpages (Figure 2); and farmers provided positive feedback that this timely soil moisture data assists their irrigation scheduling decision making.

Figure 2. Wireless soil moisture sensor networks (WSNs) have been developed and are being tested at three sites. This figure shows a graphic representation of the smart phone apps and web pages receiving near-real-time soil moisture data from soil management zones at one site (left). The map is of the Massey University experimental plot, soil moisture data is being collected from four depths in two soil zones (see graphs on the right)

Note that the sandy zone drains faster than the silty zone, and is drier at depth.



In collaboration with Plant & Food Research and Lincoln AgriTech, crop sensors are also being trialled to see how well they can track plant stress factors. For example, near-infrared (NIR) sensing methods are being developed to monitor plant water stress (Figure 3a). NIR sensors use light as an indication of plant health as it is reflected strongly from healthy plants; this property makes healthy plants easy to identify on NIR images even at large scales such as on satellite images. Internationally, research has shown that an index based on NIR can be used to detect plant stress caused by insufficient irrigation.

Thermal cameras are also being trialled to monitor water stress indirectly by monitoring leaf surface temperature (Figure 3b). Evaporation of water through the stomata cools the plant leaf, but when water is limited, this tends to restrict evaporation from the leaf surface which in turn increases the temperature of the plant. So a small increase in plant leaf temperature is an indication of the initiation of water stress. The resolution of the image in Figure 3b is 640×480 pixels with an accuracy of about 0.05 °C. A chassis was built to hold the camera vertically to look at plants from above at a height of 1.9 meter from the ground. A Crop Water Stress Index (CWSI) expresses the difference between ''well-watered'' and ''total stress'' on a scale of 0 to 1, and we are conducting research to see if it can be used as an indicator for irrigation scheduling.

Soil moisture monitoring

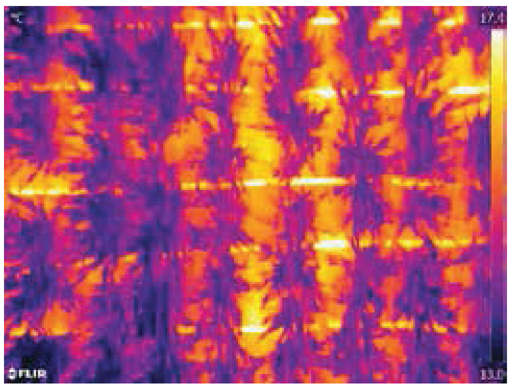
Dairy pastures need to be irrigated when the plant available water (PAW) stored in the soil starts to limit growth. The soil moisture content at which this occurs varies from soil to soil; and ideally site specific information is used to characterise this soil characteristic.

For example, a clay soil at a volumetric soil moisture content of 25% (i.e. 250 mm in 1 metre soil depth) may require irrigation, whereas a stony soil that contains this amount of water is likely to be very wet and will not require irrigation. The PAW range for NZ soils varies between very low for very stony soils (<30 mm) to very high for deep finer textured soils (>250 mm) **(smap.landcareresearch.co.nz).**

Very stony, coarse textured soils can only store small amounts of plant available water (PAW), whereas sandy loam textured soils can store more than 200 mm of water for plant water

Figure 3. Sensors are being trialled to directly monitor plant water stress. Source: Lincoln Agritech[3].

a) Sensors mounted onto the Plant & Food Research Lincoln rain shelter.



b) Thermal image of barley at an early growth stage. Scale inserted in the right part of the image represents temperature in °C (yellow indicates the warmer bare soil and purple indicates cooler plant leaves).

use. A depletion factor (typically 30 - 60%) of this PAW is used as a trigger point for irrigation, and this is calculated for the rooting depth of the plant, which in the case of established dairy pastures is typically set at 0.6 - 0.7m.

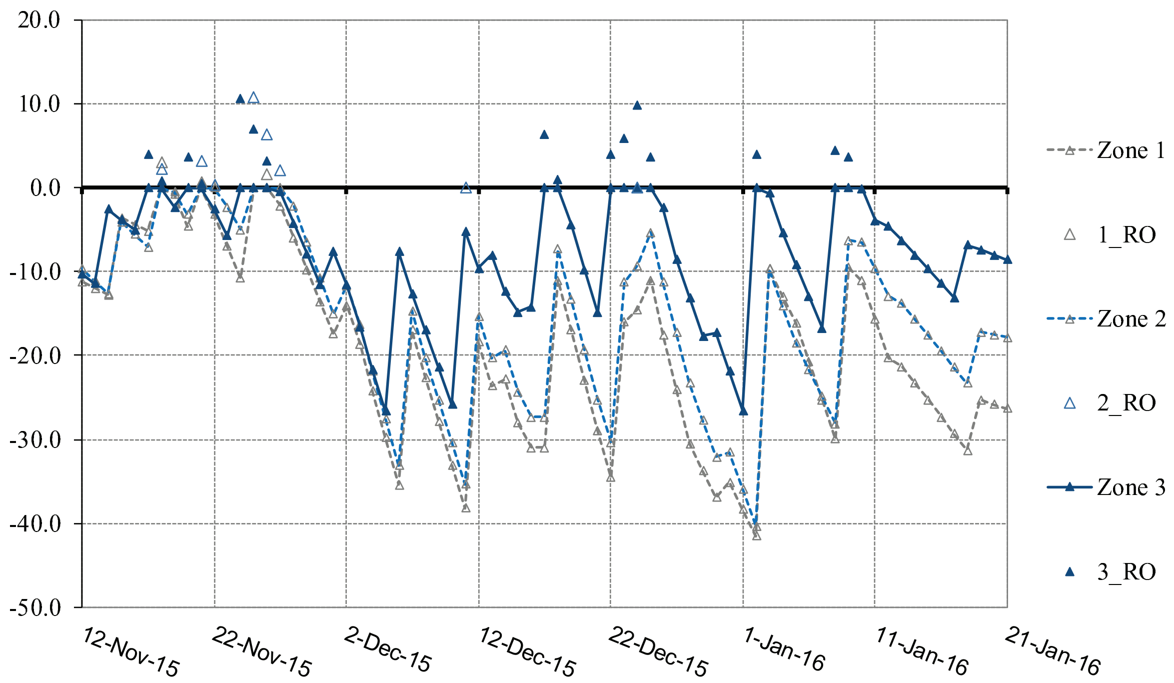
For example, Figure 4 reports soil moisture monitoring results for three soil zones over an irrigation season for the paddock and pivot represented shown in Figure 1. Here irrigation was applied uniformly to maintain adequate water in the soil for plant growth (soil moisture deficit < 40mm). However, the Zone 3 soil is an imperfectly draining soil and it remained wetter than the other two zones. This meant that for the last half of the irrigation season, the soil was wetter than field capacity, at which point there is a high risk of drainage and nutrient leaching. Ideally irrigation should have been withheld from Zone 3 while continuing to irrigate Zones 1 and 2.

This suggests that of the 150 mm of irrigation applied to these soils, approximately 40 mm could have been withheld from Zone 3 while maintaining adequate soil moisture, during the irrigation season. This equates to eight days of unnecessary irrigation assuming an evapotranspiration rate of 5 mm per day. This typifies results which are obtained from other trial sites where defining the zones to guide soil moisture monitoring are effective strategies to maintain water productivity and minimise drainage and nutrient leaching losses.

Drainage Costs

The NIWA-led Waimakariri Water Use Efficiency project ran from 2012 to 2017 and aimed to enable informed decision-making by irrigators in the Waimakariri Irrigation Scheme. Water was not always available in this irrigation scheme, so irrigators tended to apply water when it was available without taking soil moisture or weather forecast into account. NIWA supplied farmers with data on soil water demand (measured on farm using soil moisture meters) and 2- to 15-day rainfall forecasts via daily emails. Several meetings were held to discuss how farmers could integrate the updates into their irrigation practices. It was estimated that drainage due to over-irrigation costed these farms $2 per ha for every mm of drainage below the root zone due to loss of nutrients, reduction in pasture growth, costs of pumping and cost of water. The project identified that on-farm irrigation decisions are influenced by on-farm and off-farm factors: hydrological, climatic, infrastructural, and regulatory. Thus for successful uptake of more precise irrigation management, it is important to understand the external stimuli that, directly and indirectly, conflict or align with proposed practice changes[4].

Figure 4. Soil moisture graphs for three management zones, showing that Zone 3 soils are at field capacity or wetter for several periods during the last half of the irrigation season, while Zone 1 and 2 soils are being maintained at optimum soil moisture for plant growth. The solid triangles above the Field Capacity line are a 'risk indication' of drainage and nutrient leaching losses for these soils. RO = run-off/drainage ; SMD = soil moisture deficit (mm)



Conclusions

To achieve efficient use of water and nutrients and protect New Zealand's water quality, irrigation systems and management need to precisely apply water. Current research is focussing on the implementation of technology that can assist achieving this goal.

- Zone maps guide positioning of soil moisture sensors for monitoring irrigation requirement
- Soil moisture monitoring has multiple uses:
  - tracking soil moisture and predicting the number of days before irrigation is required
  - tracking soil moisture to avoid irrigation-related drainage events
- Crop sensors can be used to monitor water stress in plants, but no crop sensor method has been found to date that predicts irrigation timing before stress occurs.

Acknowledgement

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