Variable Rate Irrigation for improved water use efficiency

Final Report

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Landcare Research
Manaaki Whenua

Variable Rate Irrigation for improved water use efficiency

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Summary

Project and Client

- The Precision Irrigation Consortium, comprising Foundation for Arable Research, Dairy New Zealand, Precision Irrigation NZ-Lindsay International (ANZ) Pty Ltd, three case study farms, Massey University, and Landcare Research, conducted farm-scale trials of variable rate irrigation systems as part of an MPI funded Sustainable Farming Fund project.

Objectives

- Assess the performance of the new variable rate irrigation (VRI) technology, which has individual sprinkler control so that irrigation depth can be varied sprinkler by sprinkler along each span.
- Establish crop and pasture trials under variable rate irrigation systems to measure water savings
- Establish any yield impacts when variable rate scheduling is adopted
- Demonstrate the benefits of careful irrigation scheduling taking into account soil, topographic and crop differences
- Deliver field demonstrations, rural communications and scientific articles on variable rate irrigation and methods to improve irrigation water use efficiency

Methods

- Three farms were selected where farmers had recently invested in VRI. The soil variability under the irrigation system was assessed using electromagnetic (EM) sensor surveys, and the resulting EM maps were ground-truthed to assign management zones. Soil samples were collected from each zone to characterise their available water-holding capacity (AWC), and to investigate any relationship between EM and AWC. Soil moisture monitoring in each zone informed the irrigation prescription plans that tailored irrigation to suit the soil moisture requirements in each zone, using the individual sprinkler control of the VRI systems. Trials were conducted over two seasons to compare VRI with a uniform rate of irrigation (URI) and to assess impacts on irrigation water use, drainage, and yield.

Results

- The evaluations showed that the performance of the VRI equipment was comparable in URI and VRI modes.
- The trials to compare VRI with URI showed that VRI saved between 8 and 36% irrigation water at the three case study sites, over 2 years of trials.
- The trials demonstrated that VRI reduced drainage events related to irrigation which also mitigates against nutrient leaching.

- At two farms this water was diverted to otherwise water-stressed pasture or crops to increase overall farm productivity.
- At the dairy farm, the calculated increased productivity paid back in 1 year the cost of installing VRI onto the 750-m centre pivot.
- The trials showed that there was no negative impact on yield by withholding up to 36% water.
- Real-time soil moisture monitoring informed the precision irrigation scheduling and was also used to track when drainage occurred.

Conclusions

- Variable rate irrigation technologies enable improved use of freshwaters for irrigation, by increasing water-use efficiency and reducing the risk of nutrient loss with drainage events.
- Variable rate irrigation technologies allow irrigation application depths to be tailored to site-specific plant water demands on variable soils, with the precision of individual sprinkler footprints.
- Variable rate irrigation systems allow mixed cropping under one irrigator, the elimination of irrigation to exclusion areas (e.g. drains, tracks, overlaps on lateral move turning semi-circles), and unrivalled automated flexibility for precision irrigation placement under sprinkler irrigation systems.

Recommendations

- Refine methods to evaluate the mechanical performance of variable rate irrigation systems.
- Further refinement of methods to assign irrigation management zones using EM data by inclusion of terrain attributes (e.g. slope position, wetness index) derived from the elevation data.
- Further development of web-enabled real-time soil moisture monitoring, by putting in place improved data management and automated processing systems, with feedback control of the irrigation systems.
- Further refinement of the irrigation-scheduling tool, by accounting for crop type and crop stage, because some crops are especially vulnerable to moisture stress at different times of development, e.g. maize silking stage, potato early tuber development stage.
- Include predictive climate forecasting in the precision irrigation-scheduling tool.
- Further work is required to develop customised equipment and software for automation of VRI systems, e.g. smart phone applications.
- Scope the application of VRI concepts to all other forms of irrigation, e.g. drip, fixed hose, irripods.
- Scope the opportunities for using remote sensing imagery to assist in the delineation of soil management zones, and real-time tracking of soil moisture changes.

- Further research to refine our understanding of water retention for plant use by different types of soils, e.g. stony soils.
- Further research to relate the magnitude of water savings to degree of soil variability, and use this to inform new irrigation installations, e.g. in new irrigation scheme areas.

1 Introduction

The Ministry for Primary Industries (MPI) uses the Sustainable Farming Fund (SFF) to invest in farmer, grower, and forester-led projects that deliver economic, environmental, and social benefits to New Zealand's primary industries. The purpose of the SFF is to support Communities of Interest to undertake applied research and extension projects to tackle a shared problem or to develop a new opportunity. SFF projects are led by rural landowners and managers, often with the support of industry organisations, agribusiness, researchers or consultants (www.mpi.govt.nz/agriculture/funding-programmes/sustainable-farming-fund).

The Community of Interest for this project was the Precision Irrigation Consortium, comprising industry supporters, the Foundation for Arable Research (FAR), Dairy New Zealand (DairyNZ), Precision Irrigation NZ-Lindsay International (ANZ) Pty Ltd, three case-study farms, Massey University, and Landcare Research. The three case-study farms were selected where willing and entrepreneurial landowners and managers had recently invested in variable rate modification of sprinkler irrigation systems on their respective farms in the Manawatu, Canterbury and Otago regions.

The issue addressed was how best to manage this new equipment and capitalise on the new opportunities provided by it to improve irrigation water use efficiency. The project worked alongside the farmers to help develop good management practices for this new equipment. The project also aimed to assess the actual water savings achieved by these systems, by conducting controlled trials to compare a uniform rate of irrigation (URI), as delivered by a conventional sprinkler irrigation system, with a variable rate of irrigation (VRI), where irrigation can be varied, sprinkler by sprinkler, along the length of each span, to suit differences in soil, landscape and crop requirements.

2 Background

2.1 The Issue

An unprecedented demand by agriculture on global freshwater supplies is seen as the main cause of increasing global freshwater scarcity (Jury & Vaux 2007). This is shown in New Zealand where the area of irrigated land has roughly doubled every decade since the 1960s (Parliamentary Commissioner for the Environment 2004; Aqualinc Research Limited 2010). Land-use intensification and complementary developments such as plant breeding have maintained global food production for a growing global population since the 1960s, a period commonly referred to as the Green Revolution (Swaminathan 2007).

However, land-use intensification has increasingly relied on irrigation, and 70% of global freshwater extractions are now used for irrigation purposes (UN/WWAP 2003; Mu et al. 2009). In New Zealand irrigation demands closer to 80% of consumptive allocated freshwaters (Aqualinc Research Ltd 2010). Therefore in New Zealand and globally it is timely to research and implement, as appropriate, new technologies to improve water use efficiency (Mu et al. 2009; Lal 2009).

Water has traditionally been a readily available resource for all users, but as we move into the 21st Century, concepts of water metering, water trading, and water footprints (Chapagain & Hoekstra 2004) are becoming a reality. The improved efficiency of irrigation water use would therefore impact favourably on both local and global water scarcity issues, and also potentially reduce nutrient.leaching to groundwaters.

A project aim was to develop practical methods to map and monitor soil water status, allowing more precise irrigation scheduling using innovative technologies that include (i) electromagnetic (EM) soil surveys to delineate and quantify soil variability, supported by field investigation of the soil profile, (ii) web-enabled real-time soil moisture monitoring, and (iii) a variable rate modification of sprinkler irrigation systems. These three components of our research "tool-kit" are briefly introduced below.

2.2 EM mapping

The recent advent of mobile geo-referenced sensor mapping systems using, for example, electromagnetic (EM) sensors and accurate Global Positioning System (GPS) logging provides a new method to map and quantify contrasting and variable soil zones (Doolittle et al. 1994; Hedley et al. 2004, Bramley & Panten 2007). These zones may require different management, for example, when cultivating or planning irrigation schedules.

The Geonics EM38 (Geonics Ltd®) is one of several ground-based sensors available for soil sensor surveying (Fig. 1). This sensor measures the apparent electrical conductivity (EC in mS/m) of the soil, and provides one mean weighted value for a volume of soil approximately 1 m × 1 m × 1.5 m depth. The sensor was developed in the 1980s to investigate salinity issues in the Canadian Prairies and US, saline soils having characteristically high soil electrical conductivity (EC). However, the sensor was subsequently found to be useful in non-saline soils to investigate soil texture and moisture differences and support soil survey (Doolittle et al. 1994). Finer textured soils have higher EC values than coarse textured soils, due to better conducting pathways. Similarly wetter soils have higher EC values than drier soils. It is this interaction of soil EC, soil texture, and soil moisture that sometimes enables relationships to be developed between soil EC and soil available water-holding capacity.

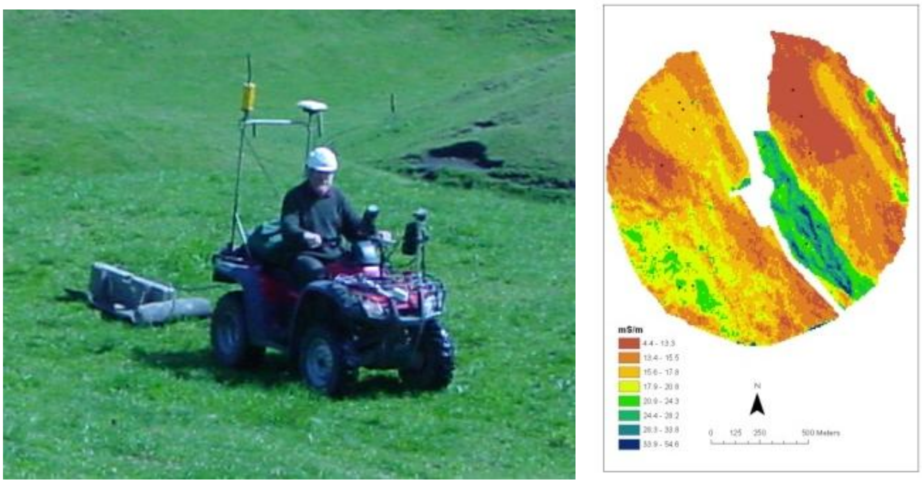

Figure 1 On-the-go electromagnetic soil mapping system, consisting of a vehicle with on-board RTK-GPS, datalogger, and field computer pulling an electromagnetic sensor to collect georeferenced sensor data. These

data are processed with GIS software to produce a digital map that reflects soil textural and moisture differences.

EM surveys provide paddock-scale digital soil mapping technology, which can be used to delineate soil management zones, which are then converted into irrigation prescription maps.

2.3 Soil moisture monitoring

Efficient water management plays an important role in irrigated agricultural systems (Kim & Evans 2009). In many cases, parts of irrigated paddocks are effectively over or under irrigated because of spatial variability in soil water storage. Under-irrigated areas are subject to water stress, resulting in production loss, while over-irrigated areas suffer from poor plant health and nutrient leaching.

Regular soil moisture monitoring is necessary to improve the timing, quantity, and placement of irrigation. Soil moisture may be monitored in one position using a variety of methods (e.g. neutron moderation by hydrogen atoms, or dielectric constant by time domain reflectometry, capacitance or standing wave instruments) or in a number of selected positions to monitor the range of conditions in that paddock.

Web-enabled wireless soil moisture sensors are now available, and can be networked to monitor different positions simultaneously (Kim et al. 2008). These systems have the advantage of sending real-time soil moisture information to assist the irrigator (Hedley et al. 2013). A number of soil moisture monitoring methods were used in this project, including weekly measurements by a neutron probe inserted into an access hole to assess the soil moisture profile, existing Aquaflex soil moisture sensors at the dairy farm, and prototype wireless soil moisture sensor networks (WSNs) installed under the VRI systems at Tahuna and Rangitata Holdings. Delta-T Devices SM300 sensors were used with the WSN system, which measure permittivity as a voltage (Fig. 2).

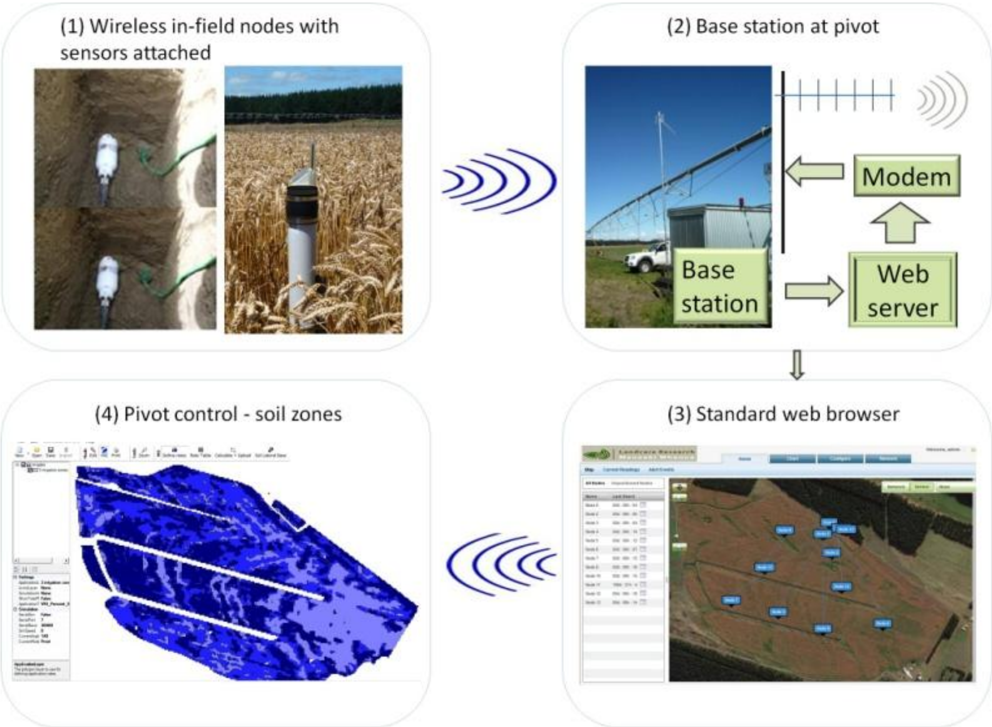

Figure 2 Soil moisture sensing was conducted in each soil zone using wireless telemetry with soil moisture sensors installed into the ground at optimum positions.

The prototype wireless sensor network (WSN) consists of a number of nodes, each consisting of a microcontroller, internal antenna self-powered by a solar panel, and the ability to transceive using radio frequencies. Nodes are attached to soil moisture sensors in the ground and wirelessly transmit data to a base station. The networks self-assemble into a mesh network, i.e. microcontrollers pass messages from one node to any other node in the network, extending the effective communication range without using high power radios. Soil moisture data are transmitted to a remote webpage, with graphical user interface (GUI). The WSN is therefore a low-energy, effective method of site-specific soil moisture monitoring.

2.4 Variable rate irrigation systems

The variable rate irrigation (VRI) system tested in this project was developed by Precision Irrigation NZ, and released commercially in 2010. The system provides precision control of all sprinklers on a centre-pivot or lateral-move irrigator. This is achieved by individually pulsing sprinklers on and off, while also controlling the irrigator speed to modify the application depth along the length of the irrigator (Fig. 3). Control of the irrigator speed and individual valves allows the amount of water applied to each area to be carefully regulated, optimising water application. Application depths can be set for individual zones or crops (Bradbury, 2013).

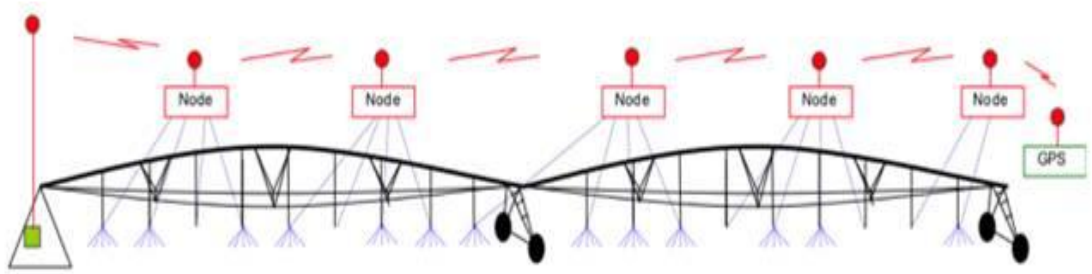

Figure 3 Variable rate irrigation hardware, showing the wireless node repeaters along the spans that transceive information from the central controller (at the pivot end) and the GPS (at the other end).

Irrigation planning is made easy with customised software, and water application can be optimised for both the area irrigated and the water source. Water source information can include min/max water pressure and flow rate provided by the pump as well as water quota information, i.e., maximum consented water volume or water flow rate. Paddock information relating to the irrigated area can include aerial photographs, EM survey maps, crop parameters, infra-red image maps and any user-defined information.

User-defined information may include avoidance areas such as races/tracks, ponds, troughs, specific paddocks or un-productive areas. Their location is mapped using a handheld GPS and imported into the customised software. As paddock information is constructed in “layers” many different types of paddock information may be considered when creating irrigation plans.

The software is preloaded with applicable irrigator data, customised for each system, and ready to create irrigation plans. Within the map, different “management zones” are set from the paddock information in which different application rates are applied; zones may be defined by soil type, topography, crop type or obstacles. The VRI controller reads the plan and sends a message to wireless nodes along the length of the pivot. Nodes control each individual sprinkler to turn on or off or pulsate according to position in the paddock and desired application rate. Each sprinkler is controlled by a magnetic latching solenoid valve.

This VRI technology is compatible with centre pivots, laterals, pivoting laterals, and reverse pivoting laterals. It can be installed on new irrigation systems or as an add-on to existing systems.

The VRI Controller guides the irrigator ground speed and the water outlets including individual sprinklers and the end gun (as an optional extra). It reads the irrigation plan and uses data from other inputs (such as GPS coordinates) to calculate which valves need to be actuated at any one time. Communication within the system is via wireless links from the controller to the wireless nodes. Node control signals are digitally packet-based, thus any form of information desirable for control of the irrigator can be transmitted to the wireless nodes.

Wireless Nodes consist of a watertight enclosure and a Printed Circuit Board (PCB) containing the wireless transceiver, processor, and drivers to control four latching relays individually. Each wireless node provides both power and control signals via wired connections to four (or less) valves. The wireless node will either turn the sprinklers on, off or pulse at a duty cycle determined by the VRI controller. Each wireless internet node is powered by a common 24V DC power line. Each wireless node also acts as a wireless repeater to send signals further up and down the length of the irrigator.

The Wiring Loom consists of a power cable that runs between wireless nodes and four wires from the wireless node to control each valve. Each loom is pre-wired into the wireless nodes at the factory.

Magnetic Latching Solenoid Valves control each sprinkler individually via a wireless node. Each valve controls the flow of water through a single outlet. The valve coil is 24V DC and requires a pulse in one polarity to open, and a pulse in the opposite polarity to close. As the valves are magnetic latching solenoid valves, power is supplied only when it is necessary to activate each valve; constant power is not required to maintain the valves in either an “on” or an “off” state. The advantages of the low power latching valve system include reduced costs and power consumption. The solenoid valves are solid brass; however, plastic valves are also available as an alternative where brass is not suitable.

Power Source: The system converts power from the high voltage line and provides 24V DC to the power line.

The GPS system consists of an industrial grade GPS unit with high receiver sensitivity (waterproof –30°C to +80°C operating temperature range). A GPS unit at the end of the pivot (or one GPS unit at each end of a lateral-move) sends a signal back through the wireless node network to notify the VRI controller the position of the irrigator. The VRI controller uses this position to calculate the valve control signals at this point.

PC Software creates the irrigation plans and takes into account both source and paddock information to optimise water application for each irrigation plan. Irrigation plans are loaded into the controller either manually via a USB stick or through a wireless connection.

Performance of the irrigation systems: sprinkler systems have a distribution uniformity efficiency of 80%, with good maintenance and when operated at the correct pressure, etc. When sprinkler systems are modified with a new technology it is important to assess their performance, and the standard uniformity test needs to be applied with appropriate modifications to assess the variable rates of banks of sprinklers.

3 Project Aims

The objectives of the project were to:

- establish the performance of the new VRI technology
- establish crop and pasture trials under variable rate irrigation systems to measure water savings
- establish any yield impacts when variable rate scheduling is adopted
- demonstrate the benefits of careful irrigation scheduling taking into account soil, topographic and crop differences
- deliver paddock demonstrations, rural communications and scientific articles on variable rate irrigation and methods to improve irrigation water use efficiency

The following Methods Section describes the field sites, the method for evaluating the performance of the VRI systems, the method used to assign soil management zones in the area to be irrigated, the trial plot layout, and the method used for soil moisture monitoring and yield assessment.

4 Methods

4.1 Year One

Field Sites

Trial sites were established at three farms, where existing sprinkler irrigation systems had been retrofitted with the new variable rate technology. The three sites were:

- Site 1 (Tahuna): 75 ha VRI centre pivot at "Tahuna", Brandon Hall Road (part of Waitatapia Paddocks property) arable, sheep and beef farm, Bulls, Manawatu. Maize was grown under the irrigator for the first year of our trials, and wheat for the second year. There are 20 sprinkler irrigation systems on the farm in total; 3 have been modified for VRI in the last 4 years.
- Site 2 (Rangitata): 111 ha lateral move sprinkler system with VRI modification, on the River Block at Rangitata Holdings, a mixed cropping farm, Wakanui, Ashburton, Canterbury. The land use is mixed cropping, and in the first season, beans, wheat,

pakchoi, and either buckwheat or corn salad crops were irrigated simultaneously under this system. In Year Two, an EM map was used to derive management zones on the Main Block. There are 8 sprinkler systems on the farm and 7 have been modified with VRI over the last five years.

- Site 3 (Wainono): 170 ha centre pivot with VRI modification at Wainono Dairy Farm, Fairlie, South Canterbury. The land use is dairy farming. There are 3 centre pivots on the farm and they have all been modified with VRI over the last 4 years.

Irrigation system performance evaluations

Two independent assessors were sub-contracted to assess the performance of the irrigation systems (lateral move and centre pivot) with and without the variable rate technology operating. Six evaluations were completed during this project. The three VRI systems were assessed in Year One. In Year Two the Wainono and Tahuna VRI systems were re-assessed. A different VRI system (Irrigator No. 5) was assessed at Rangitata Holdings, with the intention of moving our trial site to this irrigator in the second year of trials.

In each case, the systems were tested to determine application depth, rate, and uniformity. Specifically the aims were to:

- Determine new evaluation protocols for VRI systems in accordance with the Irrigation NZ Code of Practice protocols.
- Conduct VRI system performance tests to support trials on our three case study farms where owners have invested in variable rate modification of irrigation systems.
- Evaluate each machine in standard (URI) mode and in a programmed VRI mode.
- Compare catch can measurements in each mode and determine applied depths, uniformity and variance from target depths.

Method

A prescription map was devised to test the variable rate system. It targeted three different application depths: 100%, 66%, and 33% of full rate (Fig. 4); full rate was typically about 10 mm. Each rate was replicated three times along the machine.

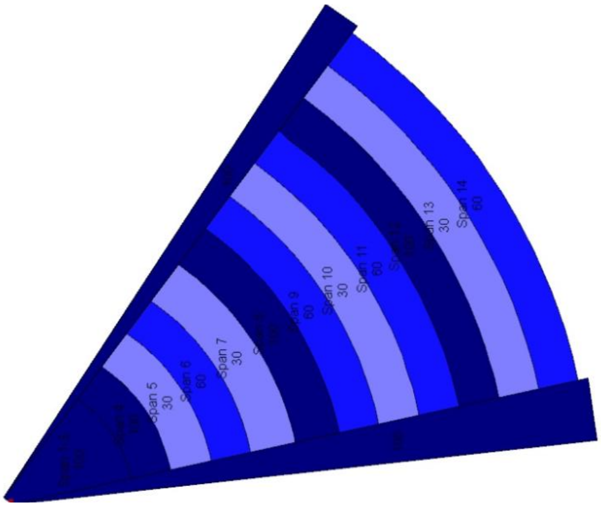

Figure 4 Prescription map used to test the system in VRI mode (the three different blue coloured sections received 33%, 66%, and 100% of the selected application depth).

Eight 9-L bucket collectors were set, alternating in two rows of four, under each span, for each treatment.

The variable rate controller was set to deliver at the three application depths (33%, 66%, and 100%) in VRI mode. The machine was run over the collectors, and the volumes of irrigation water caught in each collector measured.

Collector buckets were replaced in identical positions after readings were made. The VRI system was turned off and the machine run in standard URI mode at 100% application depth backwards over the collectors. The volumes of irrigation water caught in each collector were again measured.

Calculations

The critical performance calculations were for (i) applied depth and (ii) uniformity of application, which are determined from collector (catch can) measurements obtained in the field.

Applied Depth

The applied depth is the rainfall equivalent depth captured in the collectors. The depth is calculated from the volume caught divided by the open mouth area of the bucket.

Applied depth (mm) = Volume caught (L) / Collector mouth area (m2)

Adjusted Applied Depth

An adjustment was made to the measured 33% and 66% applied depths under VRI mode to bring them to a full rate (100%) equivalent, for comparison with the measured application depth in URI mode.

In Year Two a different method was trialled at our Manawatu site, using an analysis of variance to compare URI and VRI for each span.

Uniformity

Distribution uniformity (DU_{LQ}) assesses the evenness of applied depths. DU_{LQ} is calculated as the ratio of the depth measured in the low quartile of the irrigated area to the overall average depth applied. It thus gives a stronger weighting to under application than over application. In the context of ensuring crops get at least enough water, this is a justified approach.

DU_{LQ} = (Mean Low Quarter Depth Applied /Mean Overall Depth Applied)

- The average low quarter depth is determined by inspecting the data collected and calculating the average of the smallest 1/4 of the measured depths.
- The overall average is the arithmetic average of all of the measured depths. The computations are simplified if the total number of measured depths is a multiple of 4.

The DU_{LQ} (URI mode) was compared with the DU_{LQ} (VRI mode) to assess the relative performance of the new VRI technology with the standard system.

Digital mapping of soil variability

EM surveys

EM surveys were conducted at each site, and maps were derived of contrasting EM classes. Geostatistical Analyst (ArcGIS, ESRI, Redlands, California, USA) software was used to produce the maps using a variogram model and ordinary kriging. The data are geostatistically separated using a classification method that re-iteratively compares the sums of the squared difference between observed values within each class and class means. The classification identifies breaks in the ordered distribution of values that minimizes the within-class sum of squared differences to derive geostatistically varying classes. The three EM maps are presented in Fig. 5.

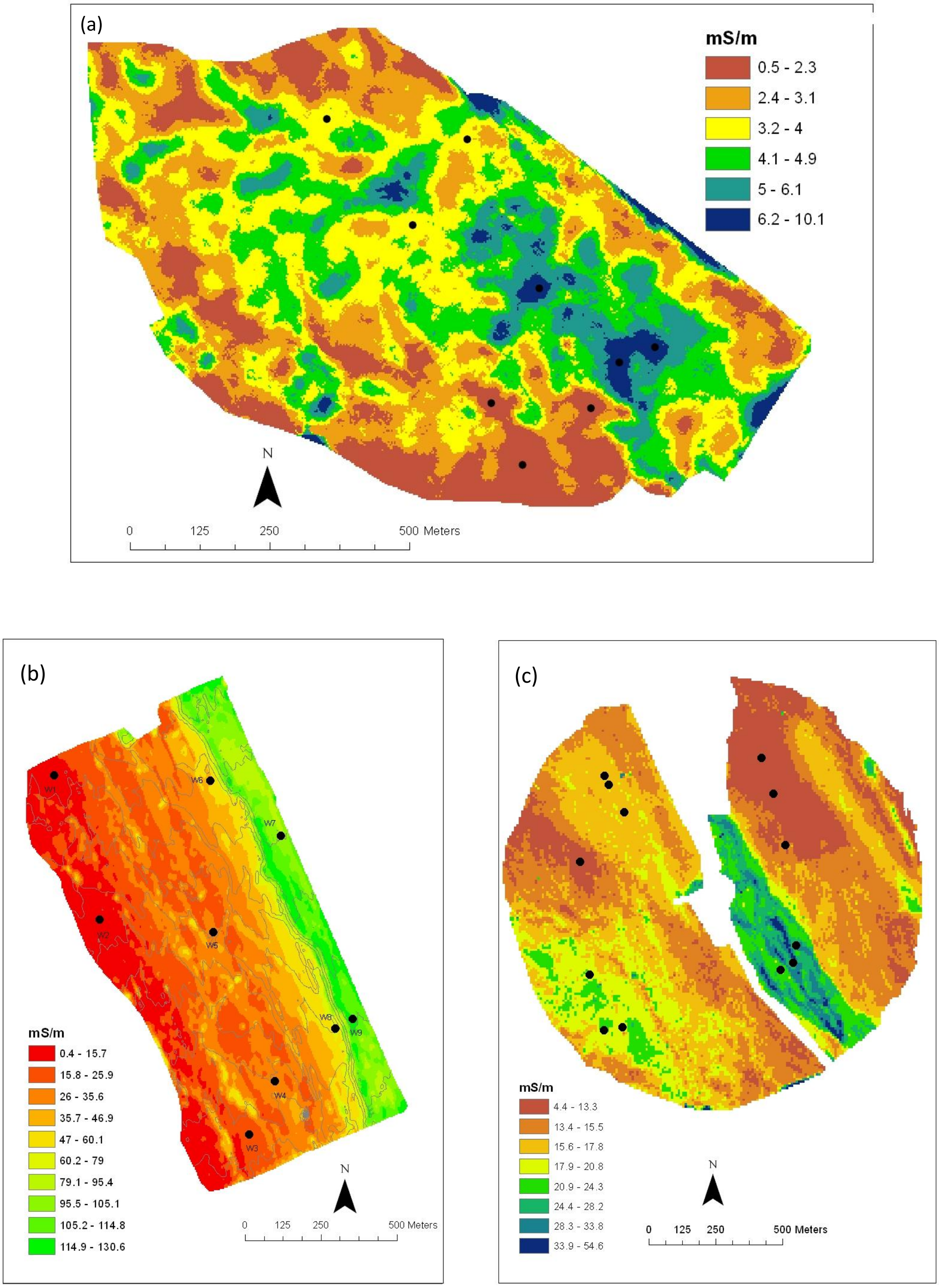

Figure 5 The EM maps of (a) Tahuna pivot area, (b) Rangitata River Block lateral move irrigated area, and (c) Wainono centre pivot, respectively, with soil sampling positions marked (black dots).

Ground-truthing the EM maps

The three EM maps at the three sites were ground-truthed to assess actual soil differences and degree of soil variation. The full range of soils was investigated and sampled to assess their available water holding capacity. The method involved collecting intact soil cores from three depths (0–20 cm, 20–40 cm, 40–60 cm) at selected positions (guided by the EM map) at the three case study sites. These cores were brought back to the lab and available water holding capacity assessed as the difference between field capacity (volumetric soil moisture content at 10kPa) and wilting point (volumetric soil moisture content at 1500 kPa). Where possible, field capacity was also assessed as a field moisture value, i.e. 2 days after a heavy rain, because this is a more direct assessment of field capacity.

The elevation data collected during the EM survey provides a digital elevation map (e.g. Fig. 6), and this ancillary information can also be used to mathematically assign the management classes.

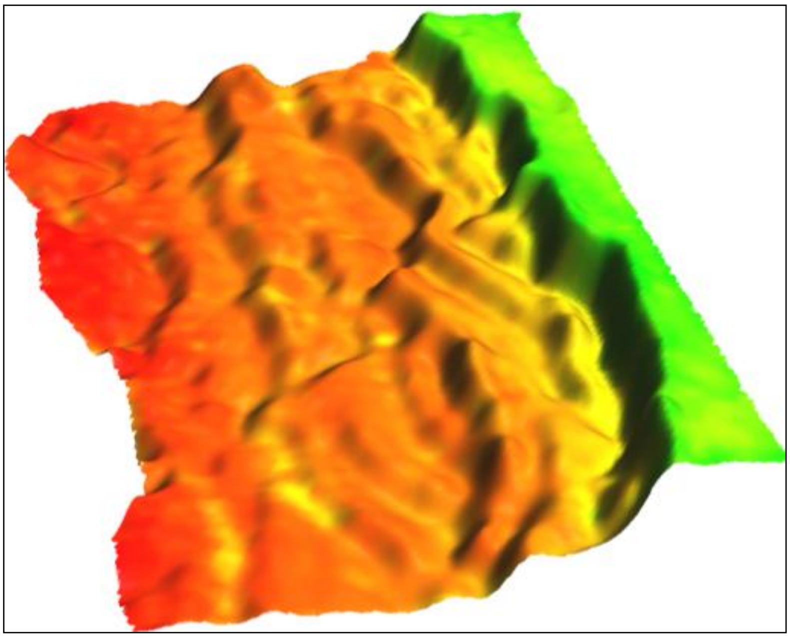

Figure 6 EM map draped on the digital elevation surface for Rangitata Holdings River Block (vertical exaggeration ×25) (Roudier, pers. comm.).

Relating soil variability to AWC

A two- to three-fold difference in soil AWC was measured between zones at each site (see Table 1) providing justification for investment in VRI at these sites, because a soil with a small AWC will require irrigation sooner than an adjacent zone with higher AWC.

The sites were selected because of the variable soils under one irrigation system. This degree of variability is typical of many of New Zealand's soils, but would not occur in all cases.

At sites where relatively uniform soils exist under one irrigation system, the VRI technology is valuable for many other purposes. These include:

- mixed cropping under one system
- avoiding exclusion areas, e.g. farm tracks
- eliminating overlaps on lateral move systems
- improved control at the pivot end
- variable rate fertigation and chemigation
- selective irrigation of individual paddocks, e.g. on a dairy farm for fodder crops, or renovation of pastures.

Table 1 Soil characteristics under the three VRI irrigators

Site	Size (ha)	Soil description	Soil electrical conductivity (mS/m)	Available Water-holding Capacity (mm/root zone)
Farm 1 – Tahuna, Manawatu maize (on Sand Plain soils)				
Zone 1	29	Excessively drained, sand	2–5	73 mm/m
Zone 2	36	Well drained, sand	5–8	87 mm/m
Zone 3	6	Imperfectly drained, loamy sand	8–11	160 mm/m
Farm 2 – Rangitata, Canterbury mixed cropping (on Alluvial terrace soils)				
Zone 1	23	Well drained, very stony sandy loam	1–13	67 mm/m
Zone 2	50	Well drained, stony sandy loam	13–53	85 mm/m
Zone 3	22	Mixed sandy loam/ silt loam	53–79	115 mm/m
Zone 4	17	Imperfectly drained silt loam	79–132	163 mm/m
Farm 3 – Wainono, Otago dairy pasture (on Alluvial Fans and Terraces)				
Zone 1	33	Well drained, very stony, shallow	4–13	39 mm/60cm
Zone 2	82	Well drained, stony, shallow	13–28	103 mm/60cm
Zone 3	39	Poorly drained, deep clayey soil	16–28	118 mm/60cm
Zone 4	20	Impeded drainage, peaty topsoil, stony, shallow	24–55	66 mm/60cm

AWC increased with EM values at Tahuna reflecting soil moisture differences in the relatively uniformly textured sands. Highest EM values relate to the low-lying wet areas influenced by a high and fluctuating water table. Low EM values relate to the tops of sandy ridges in this micro-topography of sand rills superimposed on a sand plain surface.

At Rangitata the EM values decrease with increasing stoniness and are related to AWC (R^2 = 0.83) so that a regression algorithm was used to convert the EM survey data into an AWC map (Fig. 7). The stone content of Zone 1, closest to the river, was estimated to be 71%, reducing to 63% in Zone 2, 59% in Zone 3 and no stones in Zone 4.

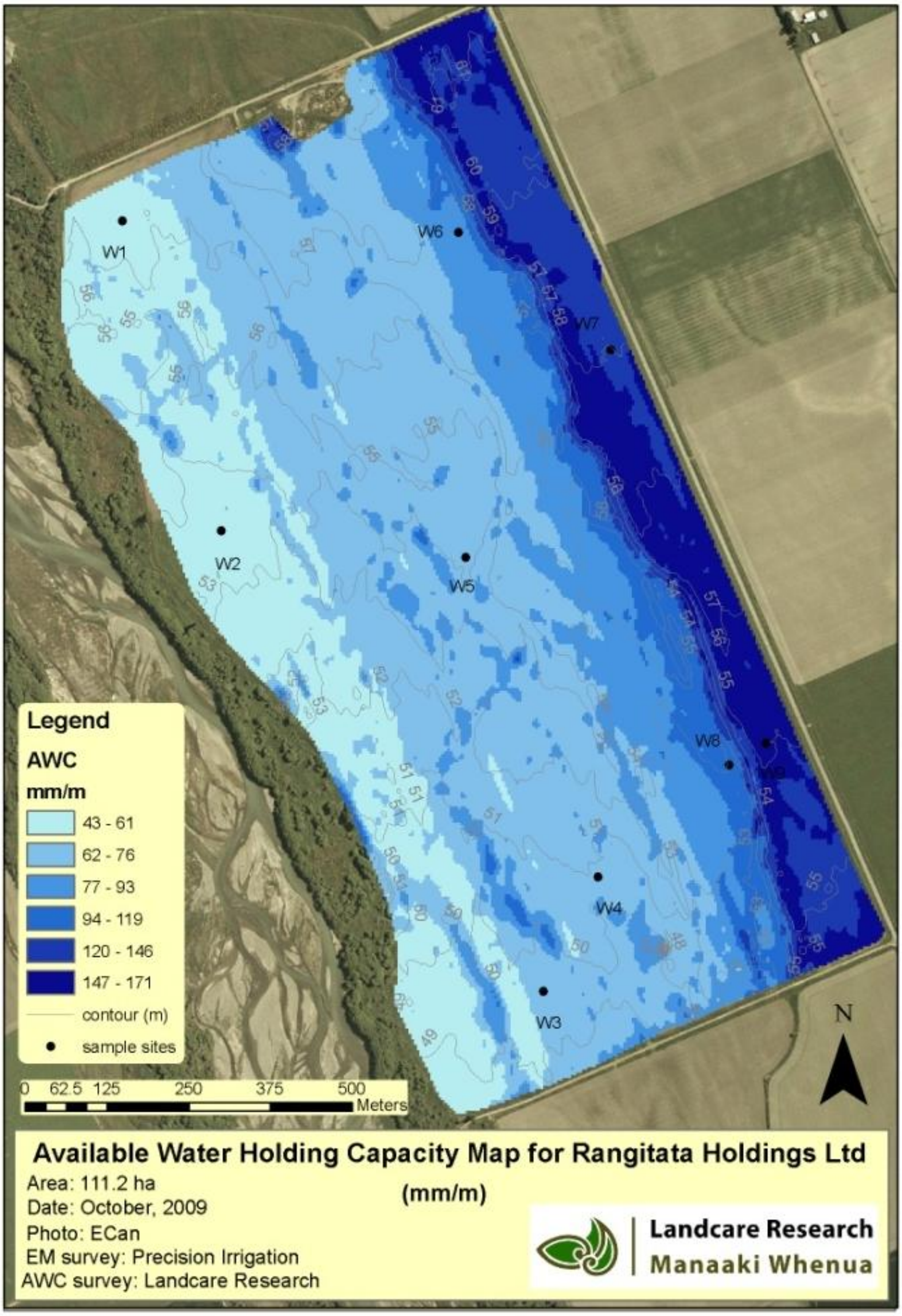

Figure 7 AWC map for Rangitata River Block.

At Wainono, intact soil cores were taken at three depths from thirteen positions, to assess the available water holding capacity of the major soil groupings (Fig. 8). A relationship was not developed for this site between EM and AWC, but an AWC value was assigned to each management zone.

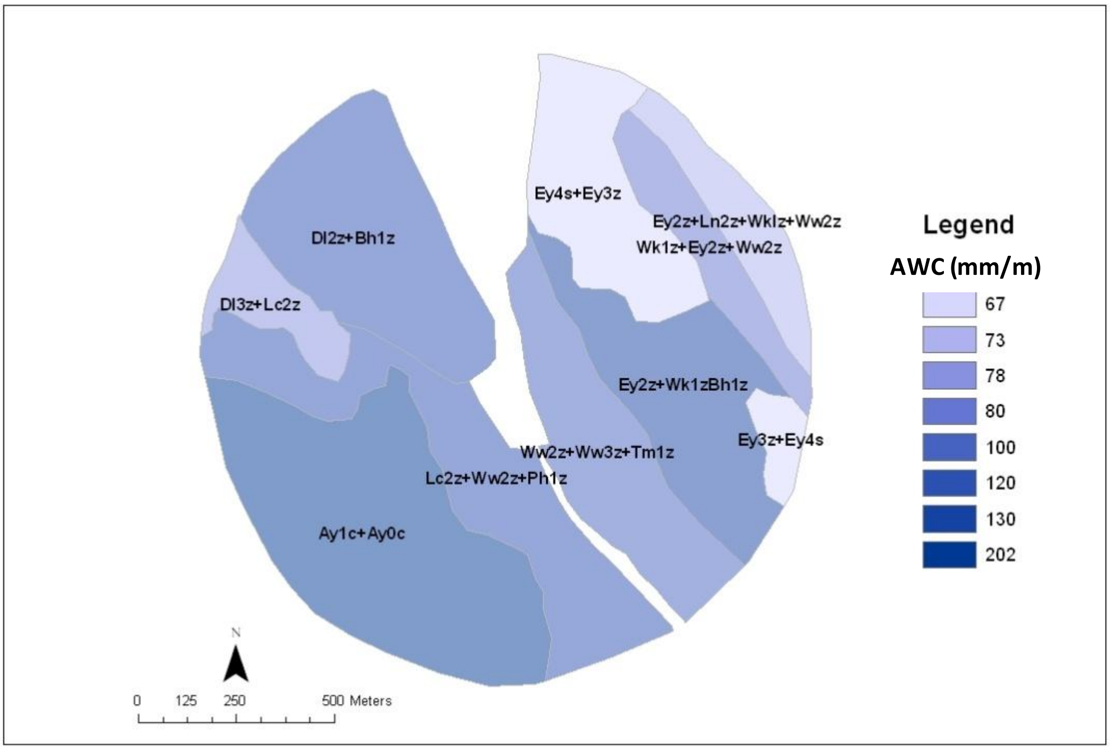

Figure 8 AWC of major soil groups under the Wainono centre pivot (to 1 m).

Having investigated the relationship between AWC and EM values, the management zones were established for our trials to reflect areas of soils with contrasting water-holding characteristics that would benefit from customised irrigation scheduling.

Zonal soil moisture monitoring at each case study site was used to assist the precision irrigation scheduling plans. These plans were loaded into software to control the operation of the VRI systems. At each site, irrigation was delayed to the zones with highest AWCs at the beginning of the irrigation seasons, and then again reduced to these zones after significant rainfall events.

Trials to assess benefits of variable rate irrigation (VRI)

The number of appropriate management zones was derived after ground-truthing and lab AWC analyses were conducted (Table 1).

At Tahuna, three management zones were derived (Fig. 9). The relatively uniformly textured sands variably influenced by a high and fluctuating water table (higher EM areas) are the blue and green colours in Figure 9, whereas other zones that dry out very rapidly and require frequent irrigation (lower EM areas) are shown as orange-brown colours in Figure 9. The most drought-prone zones are prone to hydrophobicity, i.e. once dry they do not wet up easily.

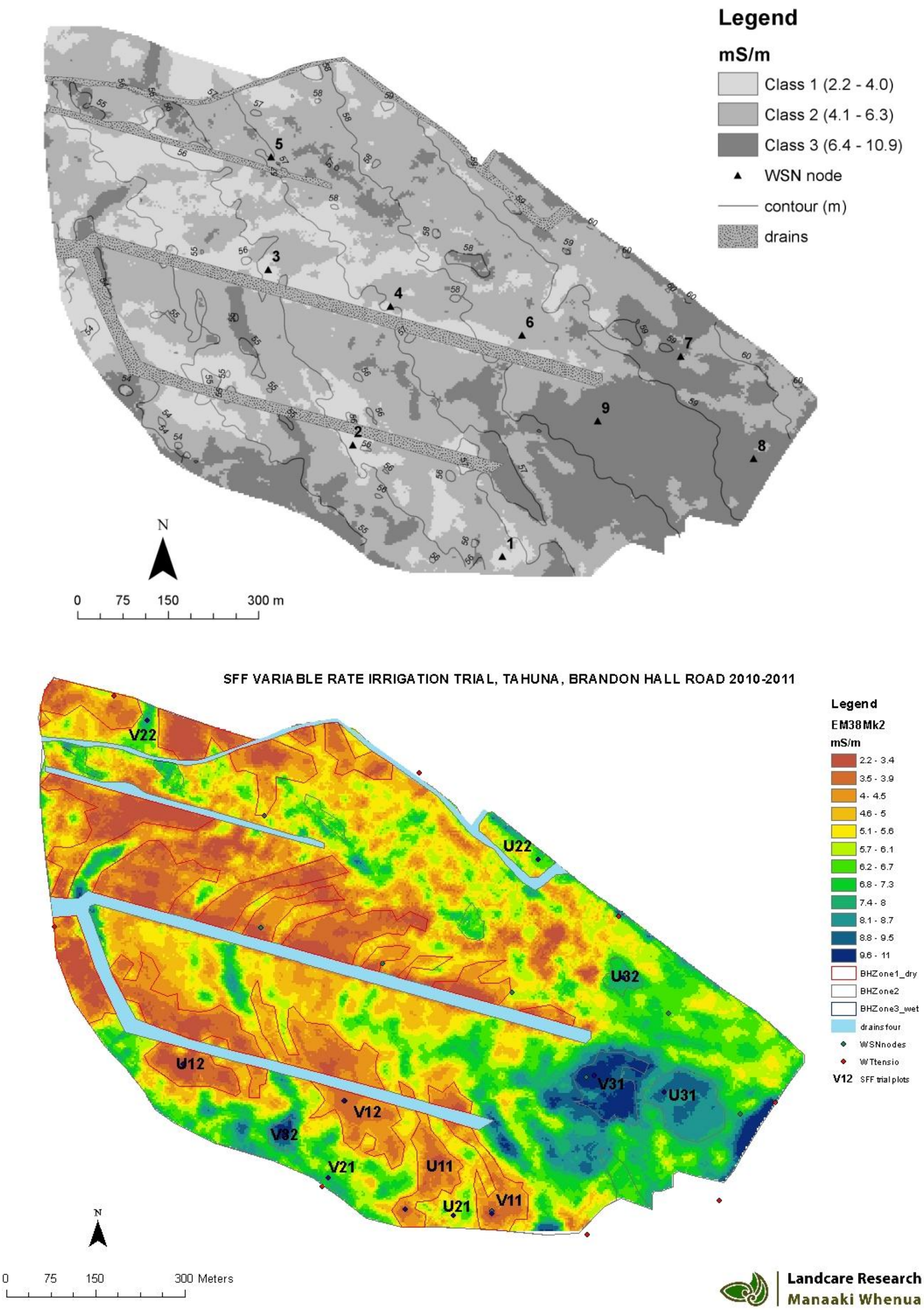

Figure 9 The three management zones (top) and layout of Year One trial plots (bottom) at Tahuna.

At Rangitata River Block four management zones were delineated (Fig. 10). The soils range from deep Wakanui silt loams at one end of the irrigator (green colour) to Rakaia very stony sandy loams at the other end (deep orange), essentially forming four strips of soil parallel to and bordering the adjacent river. The trials were established in Zones 1–3 under a bean crop, and in Zones 2–3 under a wheat crop. Zone 4 could not be included in the trials because a mixture of salad crops was grown here over the irrigation season, requiring different irrigation schedules, making it difficult to compare VRI and URI schedules on a basis of soil differences.

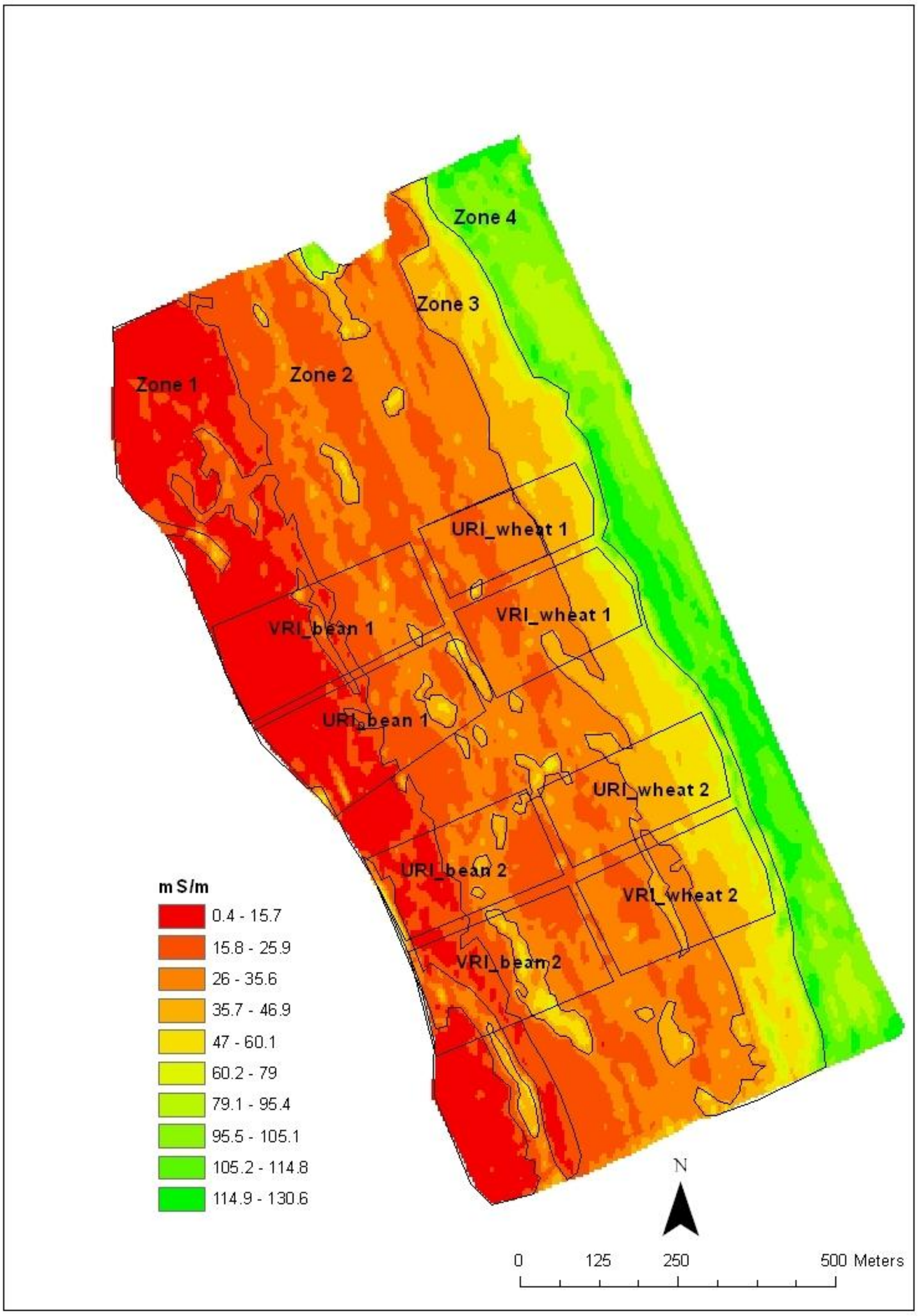

Figure 10 The four management zones and layout of Year One trial plots at Rangitata River Block.

At Wainono (Fig. 11) soils range from very stony Eyre soils (brown colours in Fig. 11) to deep clayey Ayreburn soils (patchy green colours in Fig. 8) and AWC tends to increase with increasing EM value. A relationship was not established between AWC and EM at this site; instead each zone was assigned a characteristic AWC value. Four management zones were defined. Zone 1 was characterised by Eyre very stony and Darnley stony soils, with lowest AWC, typically only storing about 7% plant available water in the top 20 cm. Zone 2 is a mixed soil zone containing Darnley stony loams, Templeton silt loams, Wakanui silt loams, and Lowcliffe silt loam soils. Zone 3 is characterised by poorly drained, clayey Ayreburn soils; and Zone 4 contains Temuka and Willowby peaty stony soils. A peaty surface layer in Zone 4 overlies a stony subsoil, so that this Zone is characteristically very wet in early Spring but then dries quickly once the surface soil has dried out.

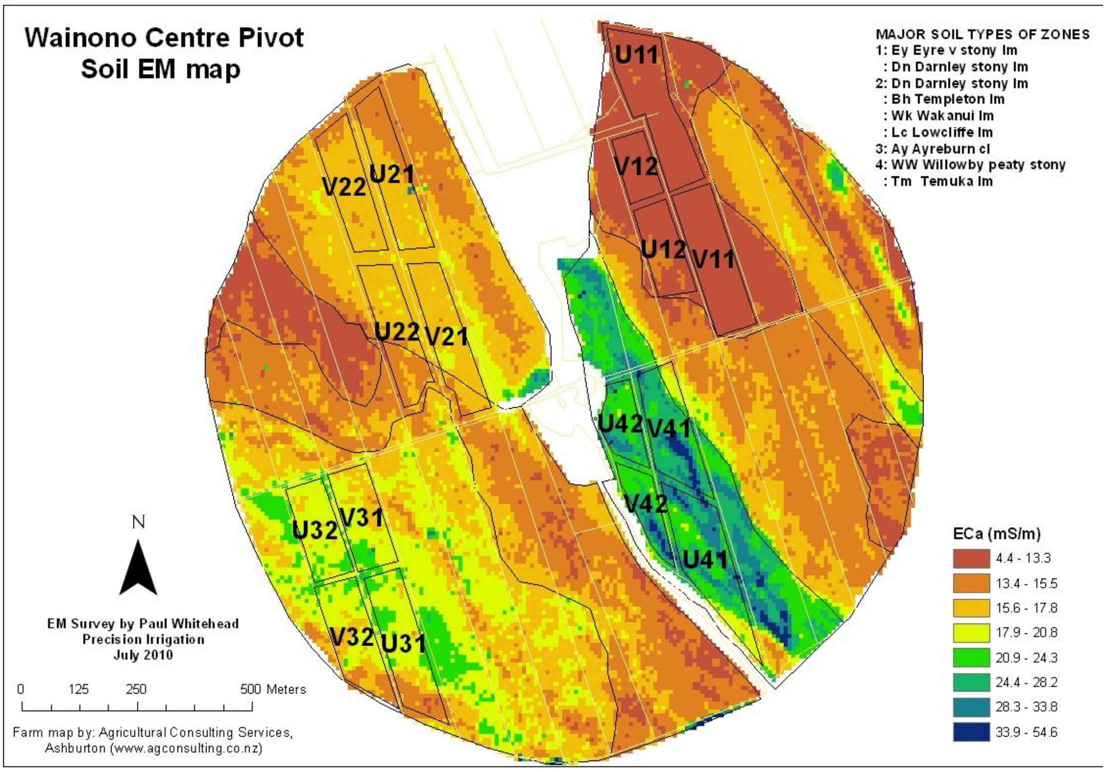

Figure 11 Layout of Year One trial plots to compare URI and VRI at Rangitata Holdings, and (c) Wainono.

To conduct trials over two irrigation seasons trial plot areas were designed to compare two irrigation strategies in each management zone, with each irrigation treatment duplicated.

The irrigation strategies were:

- Uniform rate irrigation (URI), which applies a uniform rate of irrigation to the whole paddock, when one zone dries to its trigger point for irrigation. This was estimated to be the soil moisture at which half the available water has been used by the crop/pasture (50% AWC).
- Variable rate irrigation (VRI), which varies the rate of irrigation according to soil moisture status of each individual management zone on a day to day basis.

Soil moisture monitoring

Having established the management zones and the trial plot areas, soil moisture was monitored in each zone during the irrigation season. Weekly neutron probe measurements were conducted to support the real-time soil moisture sensing at all three sites. Existing Aquaflex soil moisture sensors at Wainono were supplemented so that soil moisture was monitored in real-time at 2 depths (15 cm and 50 cm) in each of the four zones. At Tahuna and Rangitata, prototype soil moisture sensor networks were installed to monitor soil moisture in each zone and at two depths (15 cm and 50 cm). This information was transmitted to a base station, which could be accessed remotely with a web browser.

Yield assessments

Yield was measured to investigate if variable-rate irrigation enables more efficient conversion of irrigation water to plant production, by calculating the water use efficiency (WUE), defined as the kg dry matter produced per mm of irrigation plus rainfall received during the irrigation season. Irrigation water use efficiency (IWUE) was also calculated as the kg dry matter production per mm of irrigation applied.

At Tahuna, subsamples of the crop were destructively hand-harvested in each management zone for each treatment (URI, VRI), (two 1-m^2 plots in each treatment plot, i.e. 4 replicates per treatment), and at Rangitata, plot harvesting (10 2-m plots) was used. Regular (almost weekly) pasture yield monitoring was undertaken at Wainono dairy farm, using a C-Dax pasture yield sensor during the irrigation seasons.

A yield map was used in the second year of trials for Tahuna, obtained by a GPS enabled yield monitor on the harvester. In this case the yield data were extracted for each treatment plot area to derive a mean and standard deviation value. While the yield data from the yield monitoring are able to measure the yield from the whole trial plot area, they only provide an indirect estimate of yield. Hand cuts and plot cuts provide a direct measurement of a subset of the total population.

At Tahuna, the duplicate square metre plots were selected randomly within the treatment plot area and hand cut. Grain was removed using a Plant & Food Research thresher, dried at 60ºC and dry weight determined for the known area. At Rangitata a plot harvester was used to harvest two 10-m strips just before the actual crop harvest.

At Wainono a C-Dax pasture meter was used (Fig. 12). The sensor is pulled behind a farm bike, with outrigger wheels as stabilisers. The meter measures the height of the pasture sward and averages the readings to report height in millimetres. Internal software then converts the averaged readings to kg dry matter per hectare (kg DM/ha) by using a calibration equation that can be changed for different times of the year. Regular (almost weekly) measurements were taken in each trial plot area during the two irrigation seasons to estimate average pasture cover.

Figure 12 C-Dax pasture meter in operation. (Photo: NZCPA, Massey University).

4.2 Year Two

- The performance of Rangitata Holdings VRI Irrigator No. 5 on the Main Block was tested by an independent consultant.
- The performance of the Tahuna and Wainono VRI systems were re-assessed, after maintenance had been undertaken on them.
- The 2011/2012 irrigation season was characterised by more rainfall during the period of irrigation at all three sites. From Year One to Year Two rainfall increased from 170 mm to 256 mm at Tahuna; from 63 mm to 175 mm at Rangitata; and from 180 mm to 270 mm at Wainono. Irrigation began one month later, in November, at all three sites, and irrigation equipment breakdown at Rangitata, coupled with the shorter irrigation season, meant we did not conduct trials at this farm in Year Two.

A summary of Year 2 activities are:

Tahuna: The zones were redefined using new EM data for the second year of trials, to account for new and extended drains influencing soil moisture patterns relative to Year One. The area was resurveyed with EM38 and EM31 sensors, the EM31 sensor exploration depth being 5 metres compared with 1.5 metres for the EM38 sensor. The greater exploration depth provides a covariate dataset to refine the derivation of management zones. Covariate datalayers selected were EM38, EM31, a SAGA wetness index, and the 2010/2011 yield map. The SAGA wetness index (Fig. 13b) was derived from the digital elevation data obtained in the EM survey as a relative vertical distance from a channel. It therefore detects potential soil wetness, and works at a subcatchment level, in contrast with the more commonly used "Topographic Wetness Index' (TWI). Further details of this method are provided in Hedley et al. (2013), and the resulting zonal map is presented in Figure 13.

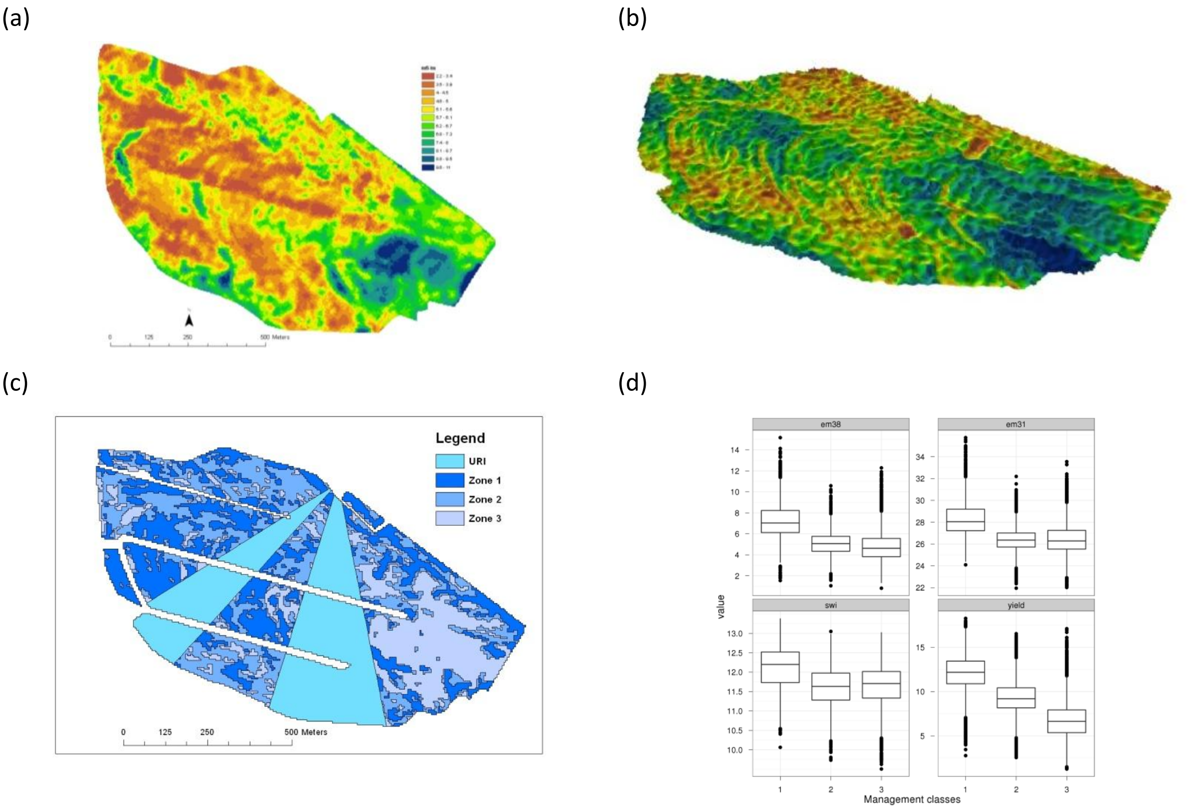

Figure 13 A new EM map (a) and a wetness index derived from the elevation data (b) were used to refine the three management zones at Tahuna for Year 2 trials (c) using a statistically representative subsample of the total population of data (d).

Wainono: The trials were conducted with the same trial plots areas. In addition, the EM map was used to extrapolate the management zones to the other two pivot areas.

Rangitata: The EM map was used to delineate management zones for the Main Block, by ground-truthing the soil differences, in collaboration with Lincoln University.

The following Results and Discussion section provide the results for the performance evaluation of the VRI systems, and the results of the trials to compare VRI and URI. The section also discusses some implications of the trial results and how these were used to manage other VRI systems in these farms.

5 Results and Discussion

5.1 Evaluation of the performance of the VRI systems

A summary of the six tests assessing the performance of the new VRI technology is presented in Table 2. The tests compared the system operating in VRI mode with operation in URI mode, and were based on the Irrigation NZ standard protocol for sprinkler irrigation system evaluations. Typically, one test was conducted in standard mode (100% application rate) and one test in VRI mode (simultaneous 33%, 66%, and 100% application rate), with the 100%

application depth either 10 mm or 14 mm. In Year Two a different method was trialled at Tahuna, which directly compared the target depth and applied depth for each span statistically, using analysis of variance, in contrast to the other method, which scales up the 33% and 66% application depths to 100% before comparison of the VRI with the URI mode. The Distribution Uniformity (DUlq) was compared for URI compared with VRI modes, and a DUlq > 0.85 is desirable, but only achieved by a well-designed, maintained, and managed system (Table 3).

Table 2 Summary table of irrigation performance test results

Farm	Date	Irrigation system	DUlq	
			URI mode	VRI mode
1	2011	VRI Irrigator	0.54	0.59
	2011	VRI Irrigator	0.87	0.79
	2012	VRI Irrigator	0.89	0.79
2	2011	VRI pivot	0.68	0.68
	2012	As above	0.65	0.45
3	2011	VRI pivot	0.73	0.60
	2012	As above	0.85 (100%)**	0.88 (100%)**
			0.91 (100%)	0.82 (66%)
			0.92 (100%)	0.69 (33%)

**Note at Farm 3 (2012) the Heerman-Hein adjusted DUlq was used to account for increasing paddock areas represented by collectors placed further from the pivot centre. The three URI mode DUlq values correspond in the same order to the DUlq values of the equivalent spans used for the VRI test.

Three of the tests showed that the systems performed poorly in standard mode, and VRI did not change this.

Table 3 DUlq Ratings for Irrigation System Performance (Irrigation New Zealand)

	Perfect	**Excellent**	**Good**	**Fair**	**Poor**
DUlq	1.00	0.99 – 0.92	0.89 – 0.85	0.84 – 0.75	0.74 – less

The results for Farm 3 in 2012 showed a slight improvement in VRI mode for the 100% application rate, and smaller DUlq values in VRI for the 66% and 33% application rates.

Factors that need to be considered relating to these test methods and results are:

- The VRI method scales up the 33% and 66% values to 100% and then calculates the DUlq to compare with the DUlq in 100% URI mode. Assume 100% is 10 mm application depth, and that there is a constant offset in application depth of 1 mm. Then, for example, the 33% application rate (3.3 +1) mm is scaled up to 100% as 4.3 x 3 = 12.9 mm. This is then compared with a value of 10 + 1 = 11 mm (URI). So the adjustment of 33% to 100% is not a fair test, because the constant offset is accounted for three times for the 33% test, twice for the 66% test but only once for the 100% and URI mode tests.

- It is harder to apply a small depth accurately, because of the smaller amount of time the irrigator has to go over the area. It is therefore recommended that future evaluations test the URI mode at 33% and 66% as well as at 100% application depth to provide a fairer comparison with the VRI performance. Recommended application depths are 5 mm, 10 mm and 15 mm.

Subcontractors provided the following reasons for reduced performance of irrigation systems in both URI and VRI modes:

- Sprinklers not rotating, and some partially blocked
- Some droppers tangled in machine structure
- Machines straightened themselves at the start of the run (test). This may have influenced depth applied along the machine length if one end of the irrigator travelled faster across collectors
- Small leaks observed – indicative of significant internal corrosion of the irrigators.

It is concluded that the sprinklers performed equally well in VRI to URI mode.

5.2 Trial results

Tahuna:

Trial results for the first year showed that variable rate irrigation of the three soil zones gave an overall water savings of 8% (Table 4). Irrigation was also excluded from 5 ha of drains, dug to remove excess water from low lying areas, which saved additional 5% water. The overall water savings for the 76 ha site were therefore 13%, including 5 hectares of drains. Irrigation started on 16 December and continued until 21 March in the 2010/2011 season. Zone 3, the low-lying areas where plants are sometimes sub-irrigated by capillary rise above a high water, received 39% less irrigation than Zone 1 (Table 4) with improved water-use efficiency (Table 5).

Table 4 Tahuna trial results – Year One Water Use Assessment (2010/2011)

Zone	ha	Treatment	Mm/season	Mm saved	Mean mm saved	% saved per zone	Overall % saved
1	*25*	URI	379				
		VRI	379				
2	*40*	URI	379				
		VRI	350	29		8	
3	*6*	URI	379				
		VRI	230	149	29	39	8

The overall savings (in mm and %) are calculated using the following formula:

$$\left\{\left(mm\ saved(Zone\ 1)\ x\ \frac{Size\ Zone\ 1\ (ha)}{Total\ Area\ (ha)}\right) + \left(mm\ saved(Zone\ 2)\ x\ \frac{Size\ Zone\ 2\ (ha)}{Total\ Area\ (ha)}\right) + \left(mm\ saved\ in\ Zone\ 3\ x\ \frac{Size\ Zone\ 3\ (ha)}{Total\ Area\ (ha)}\right)\right\}$$

Therefore, for example, for Tahuna Year One, VRI water saving:

$$\text{mean mm saved } = \left(0\ x\ \frac{25}{71}\right) + \left(29\ x\ \frac{40}{71}\right) + \left(149\ x\ \frac{6}{71}\right) = 29\ mm$$

During the period 3–12 January, the centre pivot was switched off due to pump overheating problems, despite high water demand from the crop during its rapid vegetative growth stage. It is likely that plants in the more drought-prone Zone 1 were most affected by water stress, causing yield reduction. Previous research has shown that there is an approximate 0.10% yield reduction per mm of deficit above the critical soil moisture deficit (Martin & Thomas 2007). Yield assessments suggest that Zone 3 was highest yielding, perhaps impacted less by water stress. However, there was no significant difference in yield between the VRI and URI treatments in each Zone (Table 5).

Table 5 Tahuna trial results – Year One Yield Assessment (2010/2011)

	Zone	Yield	Std dev.	irrig_mm	IWUE kg/mm	rainfall	WUE KG/MM
Zone 1	URI	7.26	2.44	379	19.2	170	13.2
	VRI	8.30	2.58	379	21.9	170	15.1
Zone 2	URI	9.15	3.33	379	24.1	170	16.7
	VRI	7.96	3.44	350	22.7	170	15.3
Zone 3	URI	11.80	3.32	379	31.1	170	21.5
	VRI	9.71	4.04	230	42.2	170	24.3

The 2011/2012 irrigation season, when wheat was grown at this site, was a wetter season (256 mm cf. 170 mm rain) than the 2010/2012 season. Soil moisture monitoring indicated that Zone 3 required little or no irrigation all season, whereas Zone 1 and Zone 2 required some strategic irrigation during the periods of rapid growth between 30 November and 11 January. The greater overall water saving of 36% reflects the wetter season, and the contrast between the soil moisture characteristics of Zone 1 and Zone 3 (Table 1, Table 6).

Table 6 Tahuna trial results – Year Two Water Use Assessment (2011/2012)

Zone	ha	Treatment	Mm/season	Mm saved	Mean mm saved	% saved per zone	Overall % saved
1	*25*	URI	86				
		VRI	86				
2	*40*	URI	86				
		VRI	46	40		47	
3	*6*	URI	86				
		VRI	22	64	55	74	36

The yield assessments for 2011/2012 by hand harvesting are reported in Table 7. Overall, the wheat yields were low, with little difference between treatments, although with some evidence that the reduced water applied to Zone 3 positively impacted on wheat yield.

Table 7 Tahuna trial results – Year Two Yield Assessment (2011/2012)

	zone	Yield	Standard deviation	irrig_mm	WUE KG/MM
Zone 1	URI	4.3	0.9	86	12.6
	VRI	5.2	0.4	86	15.2
Zone 2	URI	5.8	1.0	86	17.0
	VRI	6.5	0.8	46	21.5
Zone 3	URI	2.9	2.2	86	8.5
	VRI	5.8	1.7	22	20.9

The yield map data were also analysed, by extracting all yield data for the area within each treatment area. This method provided an improved analysis of the total crop variability and indicated that there was no significant difference between yields between treatments.

Rangitata:

A range of crops were grown in the 111 ha paddock. Zones 1, 2 and 3, closest to the river were sown into faba beans. Part of Zone 2 and Zone 3 were sown into wheat, and the upper terrace Zone 4 was sown into a variety of seed and salad crops; including pakchoi, buckwheat and corn salad. To eliminate the effect of different crop water requirements we therefore restricted our trials to areas where one crop was grown. Two trials were conducted (a) across Zones 1, 2 and 3, sown into faba beans and (b) across Zones 2 and 3, sown into wheat.

The major soil difference between Zones 1, 2 and 3 is the amount of stones in the soil profile. The application rate during each irrigation cycle of 30 mm (Zone 3) was therefore reduced to 25 mm (Zone 2) and 20 mm (Zone 1) to avoid leakage of water and nutrients past the root zone in the stony, rapidly draining soils. The soil moisture sensors installed into this zone tracked the wetting profile during irrigation events, showing when drainage past the lower sensor occurred (Fig. 13).

An overall 9% water savings was achieved in the area under faba beans and 3% under wheat (Table 8). Operationally, the allocated 40 L/s each for two lateral move irrigator systems on this river block were reduced to 32 L/s and 36 L/s, an overall saving of 12 L s.

It is estimated that this saved water is equivalent to 2 additional irrigation events on another 10 ha (35 mm onto 20 ha), which could boost wheat yield by approximately 1 t/ha (approximately $400 per ha); or high value seed crop ~$500–600 per ha, especially at the critical bolting and flowering period.

Therefore in a dry summer the 9% saving on the River Block can be diverted to another part of the farm to increase productivity. If this is possible at the critical period for irrigation, which lasts 3–4 weeks, it can be converted to increase productivity.

Table 8 Rangitata – Year One Water Use Assessment (2010/2011)

Crop	Zone	ha	Treatment	Mm/season	Mm saved	Mean mm saved	% saved per zone	Overall % saved
Faba beans	1	*23*	URI	405				
			VRI	341	64	38	16	9
	2	*50*	URI	405				
			VRI	363	42		10	
	3	*22*	URI	405				
			VRI	405				
Wheat	2	*50*	URI	420				
			VRI	396	24	13	6	3
	3	*22*	URI	420				
			VRI	420				

The yield assessments, by plot harvester (Table 9) and yield map (Table 10) are presented below, and a t-test showed that was no significant difference between treatments. Therefore the effect of reducing irrigation by 16% in Zone 1 did not impact on yield, but did reduce drainage and leaching events. The real-time soil moisture monitoring was used to assess whether drainage occurred past 50 cm during an irrigation event (Fig. 15).

Table 9 Rangitata– Year One Plot Harvester Yield results (2010/2011)

Crop	Zone	Treatment	Yield (t DM/ha)	IWUE	WUE
Beans	1	URI	6.35±1.75 a, b	16	14
		VRI	5.90±0.96 a, b	17	15
	2	URI	5.96±0.03 a, b	15	13
		VRI	3.54±1.32 b	10	8
	3	URI	5.11±2.53 a, b	13	11
		VRI	8.05±0.07 a	20	17
Wheat	2	URI	10.37±0.77 a	25	21
		VRI	9.17±1.10 a	23	20
	3	URI	8.94±0.01 a	21	19
		VRI	10.09±0.73 a	24	21

Note: yield values followed by the same letter are not significantly different. There is no treatment difference between URI and VRI

Table 10 Rangitata – Year One Yield Monitor Results (2010/2011)

Crop	Zone	Treatment	Yield (t DM/ha)	IWUE	WUE
Beans	1	URI	5.11±1.63	13	11
		VRI	4.40±1.79	11	9
	2	URI	4.77±2.03	12	10
		VRI	4.95±1.91	15	12
	3	URI	7.09±2.03	18	15
		VRI	5.61±2.04	18	14
Wheat	2	URI	8.03±2.22	19	17
		VRI	8.83±2.23	23	20
	3	URI	9.69±2.05	22	19
		VRI	8.85±2.23	21	18

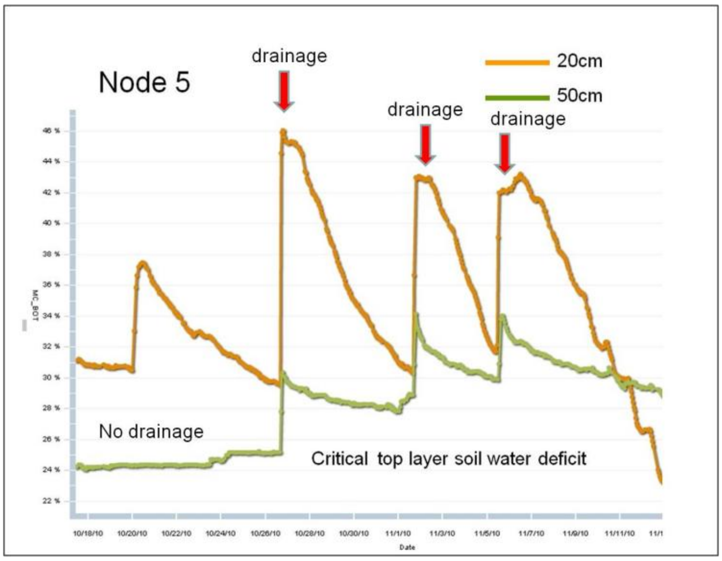

Figure 14 Screen shot of soil moisture graph for one node in Zone 1 at Rangitata Holdings. The graph shows that irrigation water moves rapidly past 20 cm and to a lesser extent past 50 cm during irrigation events. The sensor network allows real-time monitoring of irrigation events, to minimise the risk of water moving past the root zone (i.e. wasted) during an irrigation event.

Wainono:

Irrigation started on 16 October in 2010/2011, and on 5 November in 2011/2012. Irrigation was withheld from Zone 3, the poorly draining Ayreburn clay soil at the beginning of the irrigation season and then again after significant rainfall events (2010/2011: mid-January; 2011/2012: mid-February). Water savings measured in the trial plots were 23% in Zone 2, 57% in Zone 3, and 46% in Zone 4 compared with Zone 1. This provides an overall water saving of 27%. The trials were repeated in 2011/2012 and provided a similar result (Table 11).

Table 11 Wainono – Water Use Assessment 2010/2011 & 2011/2012

Zone	Treatment	ha	Irrigation (mm/season)	mm saved	mean mm saved	% saved per zone	mean % saved
Year One							
1	URI	33	175				
	VRI		175				
2	URI	82	175				
	VRI		133	40		23	
3	URI	39	175				
	VRI		55	100		57	
4	URI	20	175				
	VRI		83	81	51	46	27
Year Two							
1	URI	33	155				
	VRI		155				
2	URI	82	155				
	VRI		120	35		23	
3	URI	39	155				
	VRI		66	89		57	
4	URI	20	155				
	VRI		83	72	45	46	29

The impact of treatments on pasture production was assessed by monitoring pasture growth with a C-Dax pasture meter over the two irrigation seasons (Fig. 14). The regular measurements of dry matter production per hectare for each treatment plot were averaged for the whole season to obtain an estimate of average pasture cover (APC). The results show that there was no significant difference in average pasture cover between treatments in 2010/2011 and 2011/2012. Good management maintained APC between 2000 and 2500 kg DM/ha for the period of study. An APC that is too low can result in slow re-growth, and if it is too high, pasture quality will decline and production will also suffer.

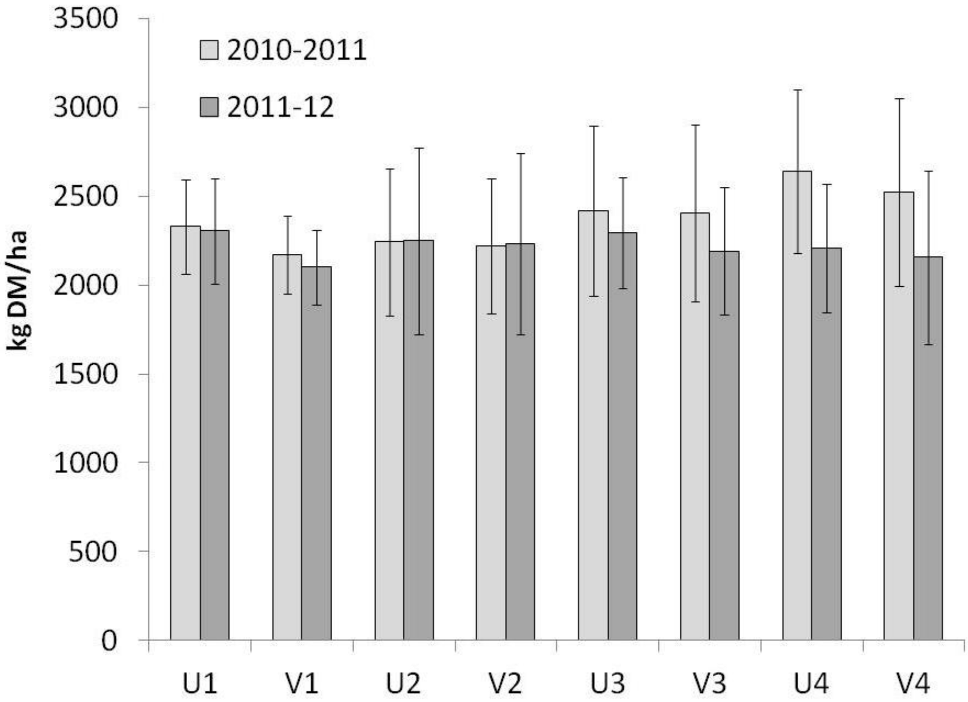

Figure 15 Average pasture cover for each treatment for 2010/2011 and 2011/2012, showing that the variable irrigation scheduling had no significant impact on yield.

Decision support for Variable Rate Systems on other parts of the farm

At Rangitata Holdings the entire farm has been EM surveyed, and there are a total of 7 VRI systems. The major soil differences on the Main Block (Fig. 15) were therefore investigated, in conjunction with Lincoln University, to assist precision irrigation scheduling decisions with these other VRI systems.

The soil boundaries defined by the pedological survey have been overlaid onto the EM map in Figure 15. There is some good correspondence between EM boundaries and the soil map; and other areas where the correspondence is not as good. In general, the lower EM values (brown colours) correlate with the coarser textured, stony soils, e.g. Darnley soils, while the higher EM values correspond with finer textured soils, e.g. the Pahau soils. The area irrigated by Irrigator 5 is shown on the map, and the corresponding soil zones would ideally require different irrigation scheduling. For example, soil moisture monitoring in the 2011/2012 season showed that the topsoils of the Pahau soils dried out very quickly, but the very wet subsoils remained wet, indicating that root extension was impeded into this subsoil. The more stony Darnley soils are likely to require irrigation earlier in the season.

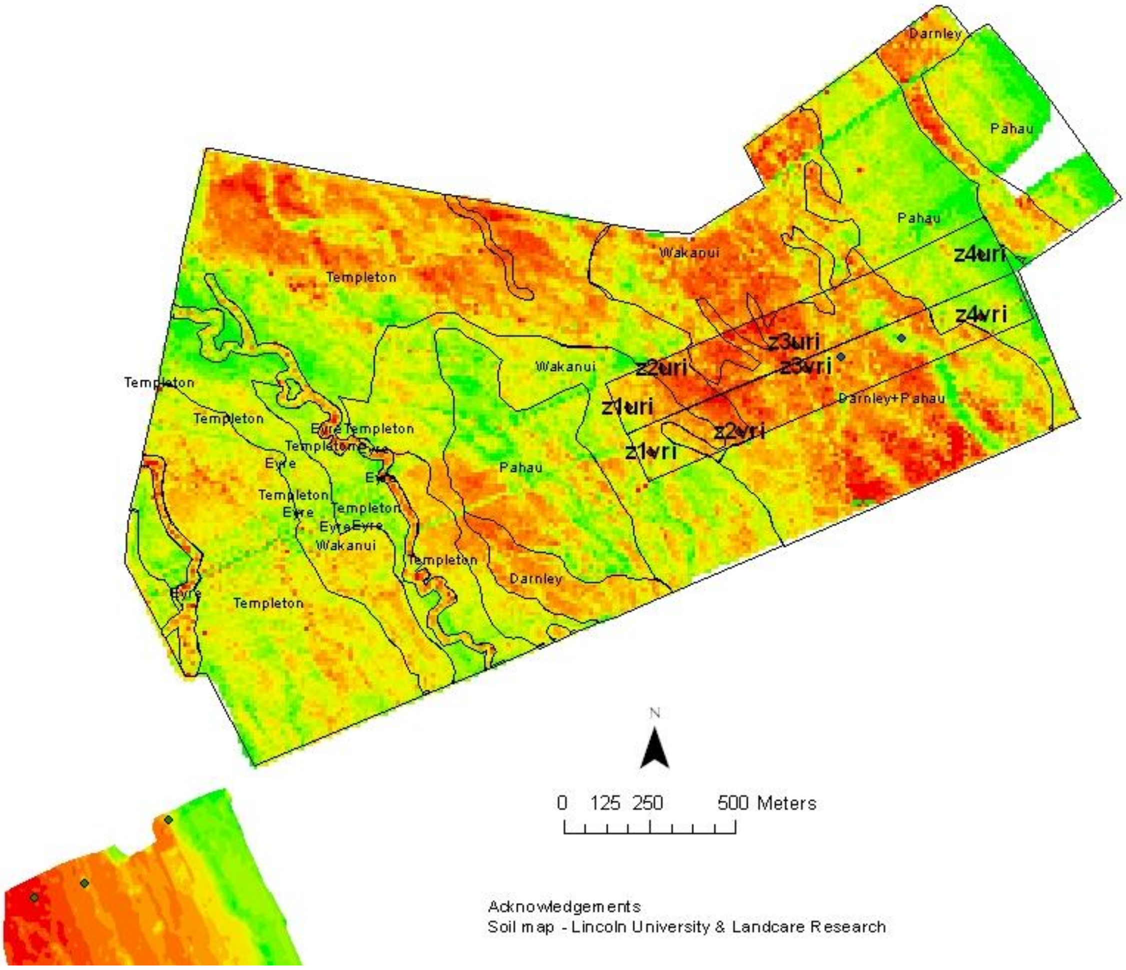

Figure 16 Soil map overlaid onto the EM map for Rangitata Holdings Main Block.

At Wainono, the whole area under the three VRI pivots was EM surveyed. The soil zones that were delineated for the big pivot were extrapolated to the two smaller pivots using the EM map, without ground-truthing, based on farmer knowledge that the EM map reflected the same soil differences under the other two pivot areas. Two zones were therefore defined for the half pivot, and three zones for the small pivot (Fig. 16). These zones were then loaded into the VRI controlling software so that irrigation could be varied on a basis of soil differences. In addition, at this dairy farm, irrigation water was excluded from tracks, and around water troughs and gateways. It was also used to vary irrigation to individual paddocks, e.g. when new pasture renovation was occurring, or to fodder crops that required different irrigation regimes. Water saved by VRI in the three pivot areas was diverted to rotorainers where it irrigated otherwise dryland pastures, to increase overall productivity.

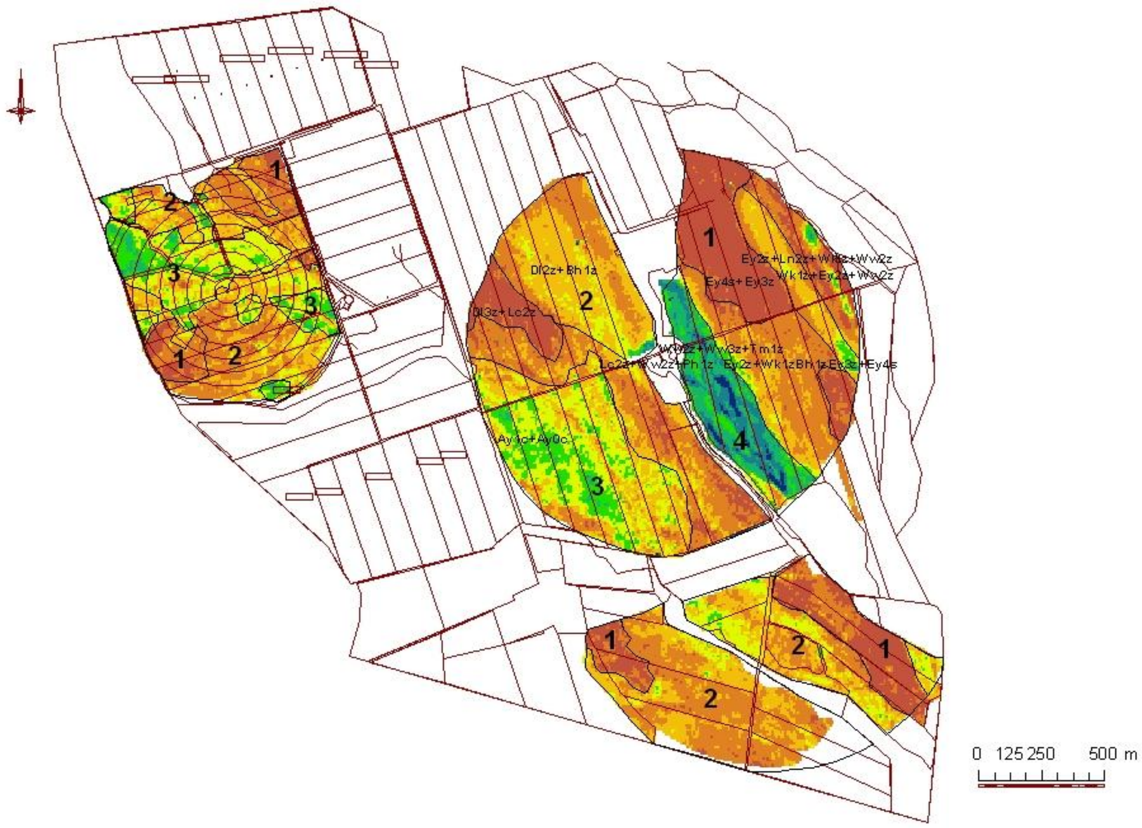

Figure 17 The EM survey at Wainono was used to delineate soil zones in two adjacent centre pivots.

6 Conclusions

On-farm trials using new variable rate irrigation (VRI) technologies have shown that irrigation water can be used more effectively if scheduling is tailored to the soil differences that occur under the irrigator. The controlled trials that were conducted to compare uniform with variable applications of irrigation to defined soil management zones achieved water savings of up to 36%. At two of the three case-study farms this water was diverted to otherwise water-stressed pasture or crops to increase overall farm productivity. This was estimated to increase productivity by $300–400 ha for a 20-ha area at the cropping farm, and $155,400 at the dairy farm. At the dairy farm, the calculated increased productivity paid back the cost of installing VRI onto the 750-m centre pivot in one year.

Yield assessments showed there was no negative impact on crop yield and pasture production by withholding up to 36% water. Although our results were unable to substantiate yield increases, it is expected that yields will increase when irrigation is withheld from very wet or waterlogged areas.

Variable rate irrigation scheduling delayed irrigation to soils with larger available water-holding capacities, to allow improved utilisation of water stored in the soil profile and rain events, also to mitigate unnecessary drainage and nutrient leaching. The VRI technology controls each individual sprinkler so that irrigation can be withheld or reduced to areas of soil where there is a high risk of nutrient leaching (e.g. connectivity with a high water table).

The VRI systems were also used to vary irrigation to different crops under one system, avoid drains and tracks, eliminate overlaps where lateral move irrigators swing and turn at the end of a run, withhold irrigation to bare ground where pasture is being renovated, and irrigate individual paddocks (e.g. new pasture).

To ensure a fair test, methods to assess the performance of the VRI systems by comparison with URI systems should be refined. The methods compared simultaneous rates of 33%, 66%, and 100% (VRI mode) against 100% (URI) mode. For comparison, the URI mode tests should also be conducted at the 33% and 66% application rates, because it is more difficult for any system to apply a small depth of irrigation accurately; and it is suggested that the minimum 33% rate should be no less than 5 mm. The one test that directly compared the VRI mode (in 100%) against URI mode (in 100%) showed a comparable performance of the two systems.

The digital maps obtained from electromagnetic soil surveys were used to establish soil sampling positions and management zones, and to develop irrigation scheduling plans. The exact timing, placement, and depth of irrigation schedules were based on plant demand and site-specific soil moisture status, and informed by real-time soil moisture monitoring, which also tracked drainage events, providing an effective decision-support system to avoid drainage and nutrient leaching under irrigation.

7 Recommendations

- Further refinement of methods to evaluate the performance of variable rate irrigation systems, allowing a fair comparison of the equipment run in conventional uniform rate mode with variable rate mode.
- Further refinement of methods to assign irrigation management zones using EM data by inclusion of terrain attributes (e.g. slope position, wetness index) derived from the elevation data.
- Further develop web-enabled real-time soil moisture monitoring by including improved data management and automated processing systems, with feedback control of the irrigation systems.
- Further refine the irrigation-scheduling tool, by accounting for crop type and crop stage, because different crops are especially vulnerable to moisture stress at different times of development, e.g. maize silking stage, potato early tuber development stage.
- Include predictive climate forecasting in the precision irrigation-scheduling tool.
- Further work is required to develop customised equipment and software for automation of VRI systems, e.g. smart phone applications.
- Scope the application of VRI concepts to all other forms of irrigation, e.g. drip, fixed hose, irripods.
- Scope the opportunities for using remote sensing imagery to assist in the delineation of soil management zones, and real-time tracking of soil moisture changes.
- Further research to refine our understanding of water retention for plant use by different types of soils, e.g. stony soils.

- Further research to relate the magnitude of water savings to degree of soil variability, using this to inform new irrigation installations, e.g. in new scheme regions such as the Ruataniwha in Hawke's Bay, Central Plains Water, Canterbury, and Wairarapa proposed freshwater augmentation schemes.

8 Acknowledgements

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9 References

Aqualinc Research Ltd 2010. Update of water allocation data and estimate of actual water use of consented takes 2009–10. Prepared for Ministry for the Environment (Report No H10002/3, October 2010). 124 p.

Bradbury S 2009. Variable-rate irrigation for centre-pivot and lateral move irrigators. http://www.precisionirrigation.co.nz/index.php [accessed 10 July 2009].

Bramley R, Panten K 2007. Optimising vineyard management through whole-of-block experimentation. Proceedings of the 11th Australasian Symposium on Precision Agriculture, 14 September 2007, Palmerston North, New Zealand. Pp. 18–21.

Chapagain AK, Hoekstra AY 2004. Water footprints of nations. Vol. 1: main report. Value of Water Research Report Series No.16. Delft, The Netherlands, UNESCO-IHE.

Doolittle JA, Sudduth KA, Kitchen NR, Indorante SJ 1994. Estimating depths to claypans using electromagnetic induction methods. Journal of Soil and Water Conservation 49: 572–575.

Hedley CB, Yule IY, Eastwood CR, Shepherd TG, Arnold G 2004. Rapid identification of soil textural and management zones using electromagnetic induction sensing of soils. Australian Journal of Soil Research 42: 389–400.

Hedley CB, Roudier P, Yule, IJ, Ekanayake J, Bradbury S 2013. Soil water status and water table modelling using electromagnetic surveys for precision irrigation scheduling. Geoderma 199: 22–29.

Jury WA, Vaux HJ 2007. The emerging global water crisis: Managing scarcity and conflict between water users. Advances in Agronomy 95: 1–76.

Kim Y, Evans RG, Iversen WM 2008. Remote sensing and control of an irrigation system using a distributed wireless sensor network. IEEE Transactions on Instrumentation and Measurement 57(7): 1379–1387.

Lal R 2009. Soils and world food security. Soil and Tillage Research 102: 1–4.

Martin D, Thomas S 2007. Irrigation management – costs and benefits of getting it wrong or right. Landwise meeting, Palmerston North, May 2007.

Mu J, Khan S, Hanjra MA, Wang H .2009. A food security approach to analyse irrigation efficiency improvement demands at the country level. Irrigation and Drainage 58: 1–16.

Parliamentary Commissioner for the Environment (PCE) 2004. Growing for good – summary of key messages. Retrieved 24 February 2008 from www.pce.govt.nz

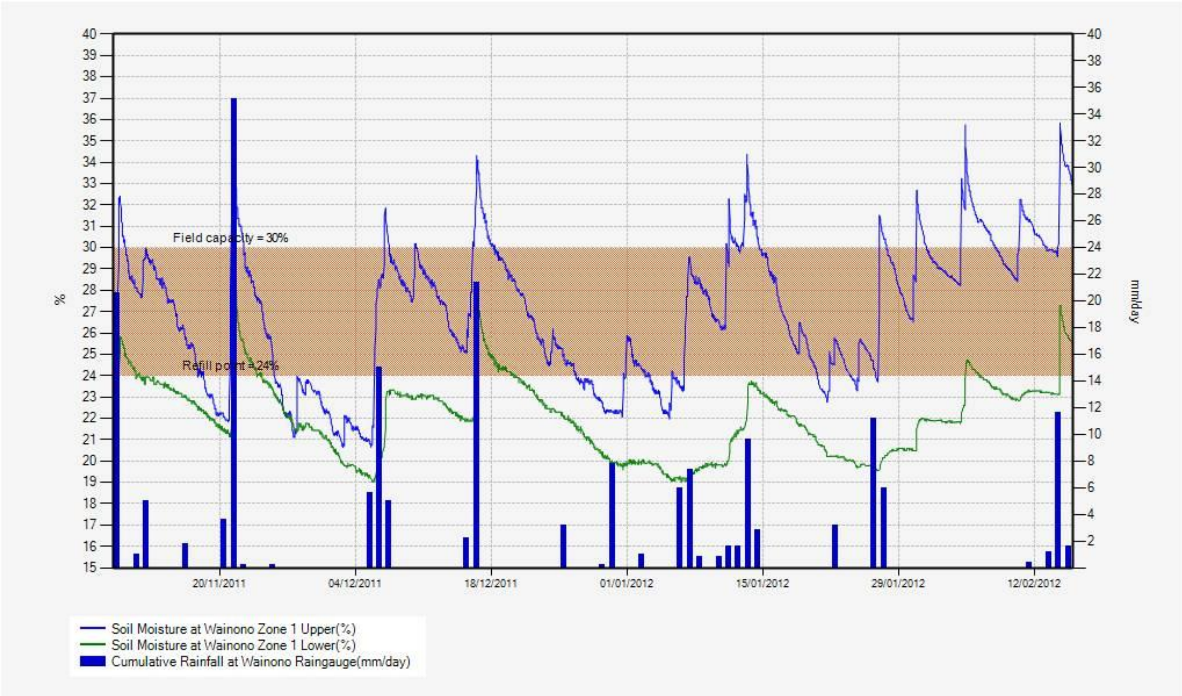
Swaminathan MS 2007. Can science and technology feed the world in 2025? Field Crops Research 104: 3–9.

UN/WWAP (United Nations/World Water Assessment Programme) 2003. 1st UN world water development report: water for people, water for life. Paris, New York and Oxford, UNESCO (United Nations Educational, Scientific and Cultural Organization) and Bergham Books.

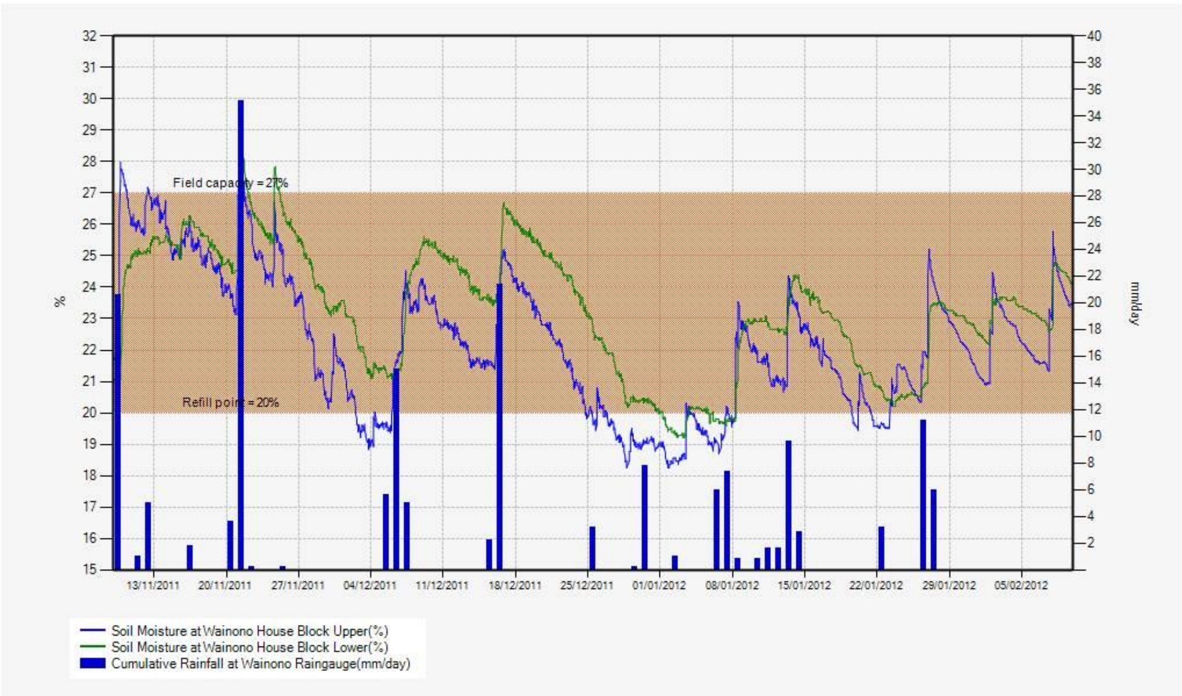
Appendix 1 – Irrigation enhancement investment at Wainono (prepared by in collaboration with Streats Instruments and Boraman Consultants

For all graphs: left-hand axis: % volumetric water content; right-hand axis: mm rain/day; blue bars are rainfall; blue line is soil moisture at 20 cm; green line is soil moisture at 50 cm; the brown band depicts the zone of soil moisture between field capacity and refill point.

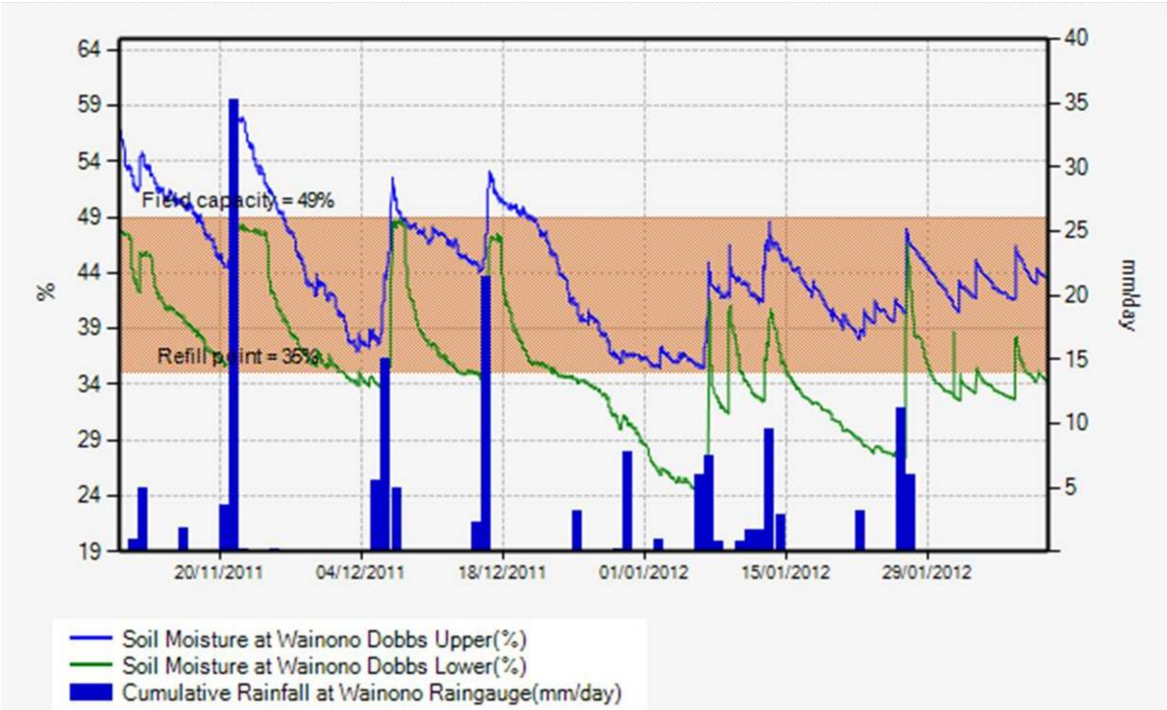
Zone 1



Zone 2

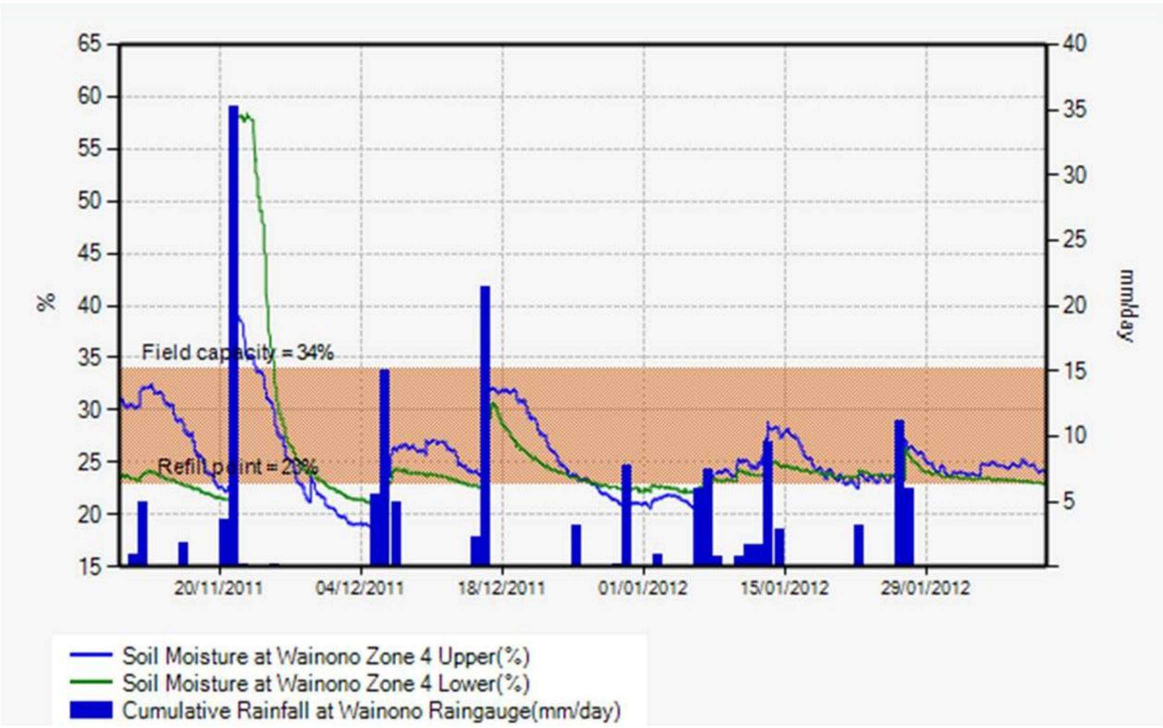


Zone 3



64
59
54
49
44
39
34
29
24
19
%
40
35
30
25
20
15
10
5
mm/day
Field capacity = 49%
Refill point = 35%
20/11/2011
04/12/2011
18/12/2011
01/01/2012
15/01/2012
29/01/2012
Soil Moisture at Wainono Dobbs Upper(%)
Soil Moisture at Wainono Dobbs Lower(%)
Cumulative Rainfall at Wainono Raingauge(mm/day)

Zone 4



65
60
55
50
45
40
35
30
25
20
15
%
40
35
30
25
20
15
10
5
mm/day
Field capacity = 34%
Refill point = 23%
20/11/2011
04/12/2011
18/12/2011
01/01/2012
15/01/2012
29/01/2012
Soil Moisture at Wainono Zone 4 Upper(%)
Soil Moisture at Wainono Zone 4 Lower(%)
Cumulative Rainfall at Wainono Raingauge(mm/day)