FARMER UPTAKE OF VARIABLE RATE IRRIGATION TECHNOLOGIES IN NEW ZEALAND.

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ABSTRACT

Cost effective technological advances in recent years have allowed the uptake of variable rate irrigation (VRI) systems in New Zealand. Typically an existing sprinkler irrigator is modified for individual sprinkler control, and irrigation management classes are defined by farmer knowledge, or EM (electromagnetic) soil survey data where available. Soil moisture monitoring is conducted within each management class for precision irrigation scheduling.

Farm-scale trials were conducted under three VRI systems (110 ha arable with VRI linear-move sprinkler; 170 ha dairy with VRI centre pivot; 75 ha arable with VRI centre pivot) to compare uniform rate irrigation (URI) with VRI. URI schedules a uniform irrigation event to the whole irrigated area when the most droughty soil class requires irrigation. VRI schedules different amounts of irrigation to different management classes at different times, based on specific soil water status and crop requirement. It also saves water by, for example, shutting off irrigation to exclusion zones such as tracks and drains, and eliminating overlap on linear-move turning circles. Irrigation schedules and yields were monitored at all sites for the 2010–2011 season. Our trials gave 8 – 27% water savings, by varying irrigation to soil differences, with further savings by eliminating irrigation to exclusion areas (e.g. drains) and overlaps. Our trials indicate that VRI enables improved irrigation water use efficiency and soil condition, the latter occurring because irrigation is withheld from wet, poorly draining soil classes.

The temperate climate of New Zealand typically provides some rainfall during the irrigation season, which tends to increase the benefits of VRI. Each rainfall event during the irrigation season which brings the soil close to field capacity allows a staggered approach to the recommencement of irrigation, as different

soil classes with different storage and drainage characteristics dry at different rates.

INTRODUCTION

Variable rate irrigation (VRI) has become a viable commercial proposition to New Zealand farmers over recent years (MAF Policy, 2010; Scott, 2011), with good uptake of VRI technologies for new installations and for modification of existing sprinkler systems (Hedley et al., 2011; Bradbury, 2012).

Irrigation demands about 80% of consumptive allocated freshwaters in New Zealand (Aqualinc Research Limited, 2010), similar to the global average (Jury and Vaux, 2007). VRI systems are being installed to improve irrigation water use efficiency, because this is a cost effective strategy, especially when the consented water take is insufficient to eliminate plant water stress during the growing season, and where regional authorities require best practice.

Individual sprinkler control is enabled by a valve system controlled by wireless nodes mounted onto the boom of the irrigator. This provides a low-cost, low-power wireless network technology for valve control, as outlined by Coates and Delwiche (2009). A software-driven central controller, mounted at one end of the irrigator, calculates the position of each sprinkler using a GPS device attached to the other end of the boom. Maps delineating irrigation management zones are uploaded to the central controller (Bradbury, 2012). These irrigation management zones can be derived from field boundary maps, soil maps, and by using a hand-held GPS device to mark exclusion areas (such as tracks, drains, wet spots). Alternatively they are derived using electromagnetic soil surveys and other covariate datalayers (e.g. digital elevation maps and derived terrain attributes) to delineate the landscape into management classes. The soil available water-holding capacity of each management class is defined by ground-truthing, and then soil moisture sensors are installed for real-time monitoring of wetting and drying events and to determine the precise time when irrigation is required within each management class (Hedley and Yule, 2009). Irrigation is scheduled to each management class at its site specific soil moisture deficit where plant-available water is no longer readily available, which can be monitored in the field at a matric potential of 100 kPa (Allen et al., 1998).

An effective method for monitoring soil moisture is to network in-ground sensors into a second wireless node system transmitting data from the sensors to a base station. This can be a completely autonomous unit to the valve control system, although fully interoperable with it, and used to determine when, where and how much irrigation to apply (Kim and Evans, 2009). Nodes, with sensors attached, are self-powered by a solar panel, and self-assemble into a smart mesh network. Mesh networking allows messages to pass from one node to any other node in the network by routing them through intermediate nodes. One advantage of this is increased network range without using high power radios, and greater flexibility in node placement. If one node malfunctions it does not disable the network since multiple routing paths exist to the base station. Data received at the base station is displayed in a graphical user interface, and accessed remotely via cellular and internet connections. The wireless sensor network (WSN) is therefore a low energy, low cost effective method of site-specific soil moisture monitoring (Coates and Delwiche, 2009).

Our research is conducting farm-scale trials to assess the benefits of farmer decisions to install VRI technologies onto sprinkler irrigation systems (Hedley et al., 2010; Hedley et al., 2011). This paper presents results from our farm-scale trials where we have compared water savings of VRI with conventional uniform rate irrigation (URI), and measured any yield differences to determine irrigation water use efficiency.

MATERIAL AND METHODS

Site Descriptions

Three farms have been selected to trial and assess the benefits of VRI where existing sprinkler irrigation systems have been modified with individual sprinkler control.

Farm 1: Ashburton: 110 ha linear move sprinkler with VRI modification. Soils range from deep Wakanui silt loams at one end of the irrigator to Rakaia very stony sandy loams at the other end. The land use is mixed cropping.

Farm 2: Fairlie: 170 ha centre pivot with VRI modification. Soils range from very stony Eyre soils to deep clayey Ayreburn soils. The land use is dairy pastoral farming.

Farm 3: Manawatu: 75 ha centre pivot with VRI modification. The farm is located in the Manawatu Sand Country, and the sand soils are variably influenced by a high and fluctuating water table, so that some areas of the field remain wet in Spring when other areas dry out very rapidly and require earlier and frequent irrigation. The land use is arable cropping.

Establishing the VRI trials

Defining the irrigation management classes

EM (electromagnetic) soil surveys were conducted at all three VRI sites using a Geonics EM38Mk2 sensor. Survey data points were collected at 1-s intervals, at an average speed of 15 kph, with a measurement recorded approximately every 4 m along transects 10 m apart. EM surveys quantify soil variability largely on a basis of soil texture and moisture in non-saline conditions (e.g. Hedley et al., 2004: Sudduth et al, 2005). EM maps were produced using ordinary kriging in Geostatistical Analyst, in ArcMap (ESRI©), to define the management classes.

A minimum of three replicate soil samples (at three depth intervals) were randomly collected from each of the management classes at each farm to assess available water-holding capacity (AWC); and moisture content at 100kPa, used as the refill point for irrigation requirement, when soil moisture is no longer readily available to the crop. Field capacity was determined in the field if possible, i.e. two days after a rain event large enough to saturate the soils. Otherwise intact soil cores were collected for a simulated field capacity in the laboratory. Intact soil cores (100 mm diameter and 80 mm in height) were taken from the middle of three sample depths (0-200mm, 200-400mm, 400-600mm) for determination of field capacity (10kPa); and smaller cores (50 mm diameter and 20 mm in height) were taken for soil moisture release at 100 kPa. A bag of loose soil was also collected (0-200 mm, 200-400 mm, 400-600 mm soil depth) for laboratory estimation of permanent wilting point (1500 kPa).

Real-time soil moisture monitoring

WSNs were installed at the trial sites, for real-time monitoring of soil moisture in each management class. At two farms we trialled a customised system using nodes (Crossbow Technology®) with wireless mesh technology having a maximum communication range of up to 2 km in line of site, and capable of acting as sleeping routers to conserve power. In-ground sensors attached at each node were: (1) two Delta-T SM300 moisture sensors installed at 20cm and 50cm to monitor volumetric soil moisture content, (2) a Spectrum Technologies Watermark soil matric potential sensor installed at 20cm soil depth to monitor soil moisture tension (in kPa), and (3) a tensiometer equipped with an absolute pressure transducer, to assess depth of water table, installed at one metre soil depth (data not presented in this paper) at the Manawatu site. A rain gauge was also attached to one node to monitor irrigation and rainfall events. Data is relayed to a base station every fifteen minutes, processed in real-time, converted to the necessary format and immediately made available through a cellular or ADSL modem via the Internet to a web page, available for simultaneous remote access by end users.

VRI trials

Trial plots were established under each VRI system to assess the benefits of varying irrigation schedules to each management class, as required. We compared uniform rate irrigation (URI) scheduling with VRI scheduling. URI schedules a uniform irrigation event to all classes when the most droughty soil class required irrigation. VRI schedules different amounts of irrigation to different irrigation management classes, based on soil water status and crop requirement. Irrigation schedules and yield have been monitored at all three trial sites for the 2010–2011 irrigation season. The trial plots established at our Ashburton farm are shown in Fig. 1, where parallel trials were conducted for two crops (faba beans, wheat) grown simultaneously under one irrigation system, and in this paper we report results for the faba bean crop.

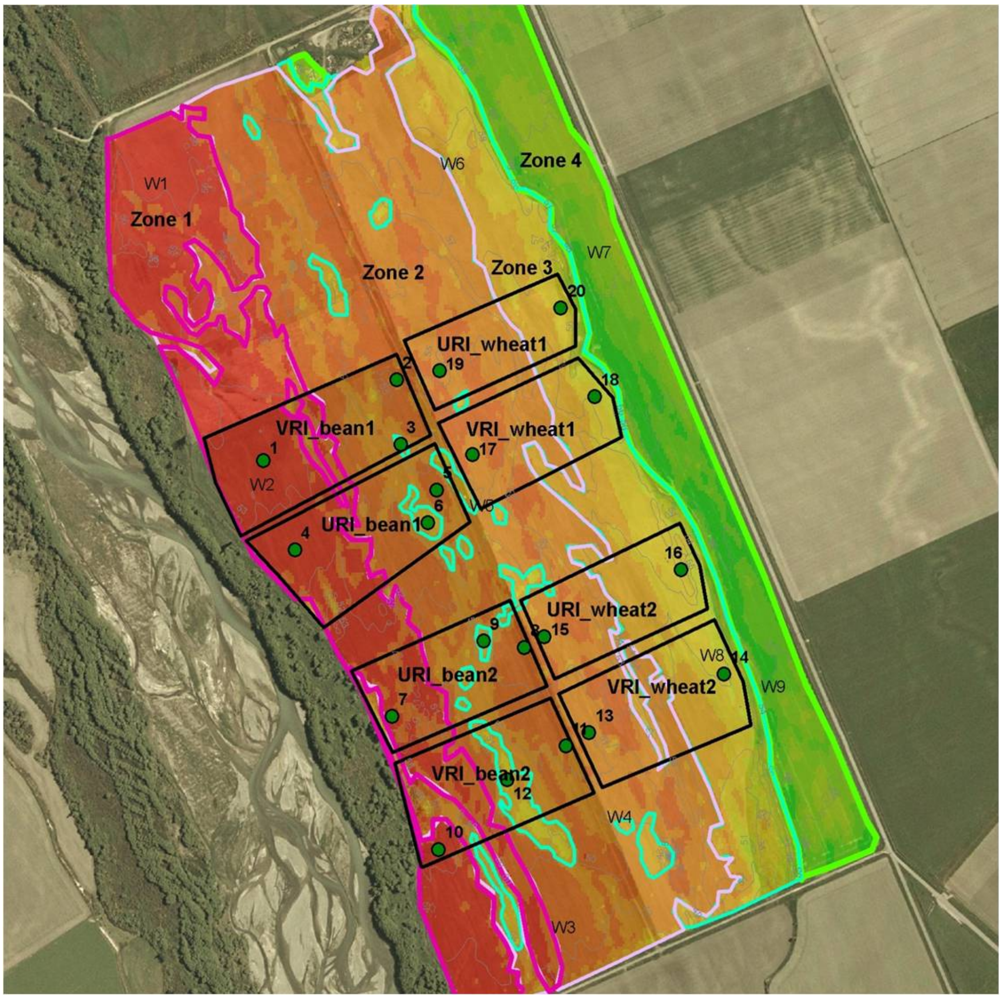

Figure 1: Farm 1-Ashburton VRI trials under a linear move VRI irrigator.

RESULTS AND DISCUSSION

The three sites were selected because of known soil differences occurring under each VRI irrigator, and this was confirmed by our soil analysis results which indicate a two- to three-fold difference in ability of the management classes, at any one site, to store and supply plant available water (Table 1) to the crop.

Table 1: Soil characteristics under the three VRI irrigators

Management Class	Size (ha)	Soil description	Soil electrical conductivity (mS/m)	Available Water-holding Capacity (mm/root zone)
Farm 1 – Ashburton mixed cropping (on Alluvial terrace soils)				
Class 1	23	Well drained, very stony sandy loam	1-13	67 mm/m
Class 2	50	Well drained, stony sandy loam	13-53	85 mm/m
Class 3	22	Mixed sandy loam/ silt loam	53-79	115 mm/m
Class 4	17	Imperfectly drained silt	79-132	163 mm/m

		loam		
Farm 2 – Fairlie dairy pasture (on Alluvial Fans and Terraces)				
Class 1	33	Well drained, very stony, shallow	4-13	39 mm/60cm
Class 2	82	Well drained, stony, shallow	13-28	103 mm/60cm
Class 3	39	Poorly drained, deep clayey soil	16-28	118 mm/60cm
Class 4	20	Impeded drainage, peaty topsoil, stony, shallow	24-55	66 mm/60cm
Farm 3 – Manawatu maize (on Sand Plain soils)				
Class 1	29	Excessively drained, sand	2-5	73 mm/m
Class 2	36	Well drained, sand	5-8	87 mm/m
Class 3	6	Imperfectly drained, loamy sand	8-11	160 mm/m

VRI was used to tailor irrigation scheduling to site-specific soil moisture status. At Farm 1, our trials were conducted in Class 1-3 soils where the faba bean crop was grown (Fig. 1), and so our trials did not include Class 4 soils with the largest AWC. Initially irrigation was delayed to Class 2 and 3 soils, when Class 1 soils required irrigation. Later in the season, weekly irrigation events of 30 mm (to Class 3 soils) were typically reduced by 20% to Class 2 soils and 30% to Class 1 soils. An overall 20% water saving was achieved with improved irrigation water use efficiency at this farm (Table 2). A further 5% water saving was achieved by eliminating overlaps. Overall water savings allowed the farmer to irrigate otherwise dryland parts of the farm enabling further productivity gains.

Similarly, an overall 27% water saving was achieved at Farm 2, with no impact on pasture productivity, assessed by weekly yield monitoring of the trial site. Irrigation was initially delayed to Class 3 and 4 soils, and then as the season progressed irrigation continued to be reduced to Class 3 soils, which are poorly drained heavy clay soils, occupying 39 ha of the 170 ha area under the VRI modified centre pivot. Prior to adoption of VRI, the Class 3 soils tended to be overwatered by irrigation, being adjacent to more droughty free-draining stony soils (Table 1). Further water savings were made by eliminating irrigation to tracks, gateways, streams and water trough areas. An investment of NZD $130,000 in VRI paid back in the first year. Saved water was diverted to irrigate otherwise adjacent dryland pasture through rotorainers, with projected increase in dry matter production of 518,400 kg DM/ season, equal to an additional $155,400 per year.

At Farm 3, the most droughty Class 1 soils required irrigation sooner and more frequently. Here the centre pivot takes 1.5 days to deliver 10 mm irrigation, and typically the irrigator was set at 100% (i.e. 10mm) for Class 1 soils, 50% (i.e. 5 mm) for Class 2 soils and 20% (2 mm) for Class 3 soils. Class 3 soils remained adequately wet for most of the irrigation season being sub-irrigated by a high water table. It was not operationally possible to shut off irrigation completely to Class 3 soils, even when irrigation was not required, due to the limitation of the pump motor, and further water savings would be enabled by installation of a variable speed pump. An overall 8% water saving was achieved in our trial site at Farm 3, and a further 5% was saved by eliminating irrigation to drains.

Table 2 Water savings and water use efficiency indices for three farm-scale VRI trials

Management Class	Treatment	Irrigation	Water saved	Yield	IWUE	WUE*
		mm/season	%	t DM/ha	kg/mm	kg/mm
Farm 1 – Ashburton mixed cropping (on Alluvial terrace soils)						
1	URI	405		5.11±1.63	13	11
	VRI	405		4.40±1.79	11	9
2	URI	405		4.77±2.03	12	10
	VRI	327	19	4.95±1.91	15	12
3	URI	405		7.09±2.03	18	15
	VRI	316	22	5.61±2.04	18	14
Farm 2 – Fairlie dairy pasture (on Alluvial Fans and Terraces)						
1	URI	175		16	91	36
	VRI	175		16	91	36
2	URI	175		16	91	36
	VRI	133	22	16	120	40
3	URI	175		16	91	36
	VRI	55	68	16	291	50
4	URI	175		16	91	36
	VRI	83	51	16	193	46
Farm 3 – Manawatu maize (on Sand Plain soils)						
1	URI	379		7.3 ±2.4	19.2	13.2
	VRI	379		8.3 ±2.6	21.9	15.1
2	URI	379		9.1 ±3.3	24.1	16.7
	VRI	350	8	8.0 ±3.4	22.7	15.3
3	URI	379		11.8±3.2	31.1	21.5
	VRI	230	39	9.7 ±4.0	42.2	24.3

*includes rainfall during the irrigation season

CONCLUSIONS

The availability and uptake of cost effective variable rate irrigation technology by New Zealand farmers has enabled an improved standard for best irrigation practice under sprinkler irrigation systems. Farm-scale trials at three farms gave water savings of between 8 – 27% based solely on tailoring irrigation to soil differences, and further water savings were made by eliminating irrigation to exclusion areas. In addition, farmer initiatives to divert the saved water to otherwise dryland parts of the farm enabled further productivity gains, which have resulted in pay-back on the cost of VRI modification in the first year of installation at our dairy farm site.

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