Precision technologies: maximising the value of irrigation

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Abstract

Precision irrigation, by definition, reduces water losses and increases water productivity from irrigated land. This is required as global freshwater scarcity continues to escalate. The concept of precision irrigation can be applied simply and without technology in lower income regions. However, research shows that significant benefits are gained when precision sensor mapping is used to define soil spatial variability, derive management classes, guide placement of sensors for monitoring, and provide timely information for precision irrigation scheduling.

Results from research trials on commercial farms using variable-rate sprinkler irrigation systems with individual nozzle and speed control, used with sensor mapping and monitoring technologies indicate water savings (typically 5–30%, depending on the degree of variability), a major reduction of irrigation-related drainage events, and positive or neutral impact on crop yield. The systems are also used innovatively by farmers for flexible management (e.g. multiple crops under one system; pasture renovation of small irregular areas, precision grazing). This paper presents a case study to demonstrate how precision irrigation practices can be used for best management of irrigation onto variable soils to enhance crop yield and minimise irrigation-related drainage losses.

Background

Globally, freshwater use has been growing at more than twice the rate of population increase in the last century, and an increasing number of regions are reaching the limit at which water services can be sustainably delivered. By 2025, 1800 million people are expected to be living in countries or regions with “absolute” water scarcity (<500 m3 per year per capita), and two-thirds of the world population could be under “stress” conditions (between 500 and 1000 m3 per year per capita) (FAO, 2016). In New Zealand, there are unprecedented demands on fresh water for irrigation, and at the same time evidence that water quality is declining in many water bodies. In response, a National Policy Statement for Freshwater Management took effect on 1 July 2011 (NZ Ministry for the Environment, 2011). This requires regional councils to ensure that their policy statements and plans provide for improved freshwater management, including setting thresholds for water quality and improving and maximising the efficient allocation and use of water.

Precision irrigation addresses these needs, and follows the principle of precision agriculture, i.e. using GPS-equipped sensors to measure and respond to soil variability across landscapes for efficient allocation of irrigation. Recent technological advances in sprinkler irrigation systems, including software-controlled variable rate nozzles, enable precision irrigation to be practised.

In lower income global regions precision methods do not need expensive technologies. For example, affordable plastic drip tape is used in low income regions, where water is scarce. Also, ICRISAT promotes micro-dosing to resource poor farmers in sub-Sahara Africa, and farmers implement this in Niger using bottle caps (van Vark, 2014). However, in higher income global regions, the implementation of innovative technologies is creating highly efficient automated irrigation systems.

This paper presents our research progress in the development of a decision support tool for precision irrigation. Precision sensor mapping is used to derive soil management classes and guide placement of sensors for monitoring. The derived information could then be used for adaptive irrigation control. The method is being developed alongside commercial enterprises, ensuring that it is realistically affordable for private land managers, because each case is site specific, requiring customised mapping and monitoring design.

Methods

Trials are being conducted on commercial farms to develop sensor mapping and monitoring technologies for precision irrigation. The collected data are provided to participating farmers for timely and adaptive management of sprinkler irrigation systems. The method is explained in the following case study example.

Case study

Site description

33-ha field on a mixed arable and grazing farm near Takapau, Hawke's Bay, New Zealand (39.998°S 176.320°E). The field is irrigated by a 240-m towable centre pivot. Land use on the farm is predominantly commercial and fodder cropping (e.g. barley, grass seed, sweetcorn, peas, beans, wheat, maize, lucerne) with some livestock grazing. The main farm is 269 ha, and approximately 132 ha are irrigated. Soils have developed within an extensive basin formed 1.5 to 2 million years BP, filled with a series of gravels, fine sediments and volcanic material. Soils developed in this landscape include: (i) well to moderately well-drained loams with variable texture over a gravel surface (Takapau soils), and (ii) imperfectly and poorly drained sandy and silty loams at lower elevations (e.g. Poporangi soils). Both types of soil occur within the 33-ha field. Here, the Takapau sandy and silty loams (Typic Allophanic Brown) have reasonably deep topsoils over yellowish-brown sandy loam subsoil, sitting on top of weathered but weakly consolidated gravels. The Poporangi gravelly sandy loams (Perch-gley Pallic) are poorly drained, with a shallow silica-rich pan in places, and they overlay a gravel surface (Hewitt, 2010). A barley crop was sown into the field for the 2015/16 season.

Sensor mapping

An EM survey was completed on 18 July 2014, using a DualEM 1s sensor (®Dualem Inc.). Following the method of Hedley et al. (2013), the data were pre-processed and kriged into a raster map, using the R statistical environment (R Development Core team, 2016). Management classes were derived from the raster map by cluster analysis using the SAGA software package in QGIS (QGIS, 2017) classifying the area into relatively homogenous EC regions (e.g. Taylor et al., 2007). These classes are geographically split into 'management zones', which were ground-truthed by conventional soil survey method at a detailed scale of 1:5,000 (2 observations/ha).

Sensor monitoring

Soil moisture was monitored in each management class throughout the irrigation season in three replicated positions. Measurements were collected at 10-cm intervals to 80 cm soil depth, using a neutron probe. Rainfall and irrigation were also recorded for this period.

Yield assessment

Crop yield was assessed for each management class just before mechanical harvest, by manual sampling in four replicated 1-m2 plots in each management class.

Data analysis

The collected data were used for Penman Monteith soil-water balance modelling (Allen, 1998), and this was checked against the actual soil moisture measurements. Drainage events were calculated from the soil moisture measurements and also compared with the modelled results. Water extraction rates were estimated as the decrease in soil moisture measurements during periods of drying when no drainage was occurring, and this was estimated at 10-cm intervals down the soil profile, to indicate where maximum water extraction by roots is occurring.

Results and discussion

Geostatistical analysis of the EM data produced the EC map (Fig. 1) using an exponential variogram model. The range of spatial dependence of these data is 59 m, and cluster analysis was used to derive three management classes to broadly represent major soil differences, as observed at this site.

Soil moisture monitoring within each management class (Fig. 2) during the period of irrigation indicated more drainage occurred in the Class 3 imperfectly drained soils (green colour in Fig. 1), compared with the other two classes. On 2/1/16, before a 35-mm rainfall event the next day, the soil moisture deficit (SMD) reached a maximum of 27 mm for Class 3 soils, compared with 42 mm (in Class 1) and 40 mm (in Class 2). This difference results from different drainage characteristics in the subsoils of the soil classes and was not accounted for by the soil-water balance model (Fig. 2 inset).

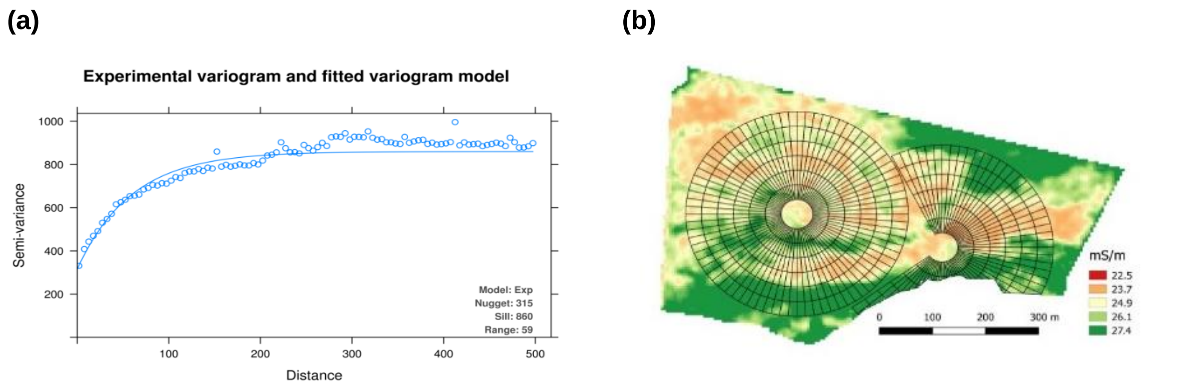

Figure 1. (a) Experimental variogram and fitted model of EC data, and (b) the kriged EC map, overlaid by pivot segments

During the period of our trials 122 mm of rain fell, and 150 mm of irrigation was applied to the whole area during the period 12/11/15 to 21/1/16. Figure 2 indicates that after a period of drying in mid-December, rainfall with some irrigation brought Class 1 and 2 soils back to an optimum soil water deficit, but caused Class 3 soils to reach saturation, with drainage and/or run-off occurring. This suggests it would be preferable to withhold some irrigation from Class 3 soils to avoid these waterlogging conditions, and any associated nutrient leaching. The saturated soil conditions are also likely to be adverse to plant growth, limiting oxygen diffusion through the soil profile to the roots.

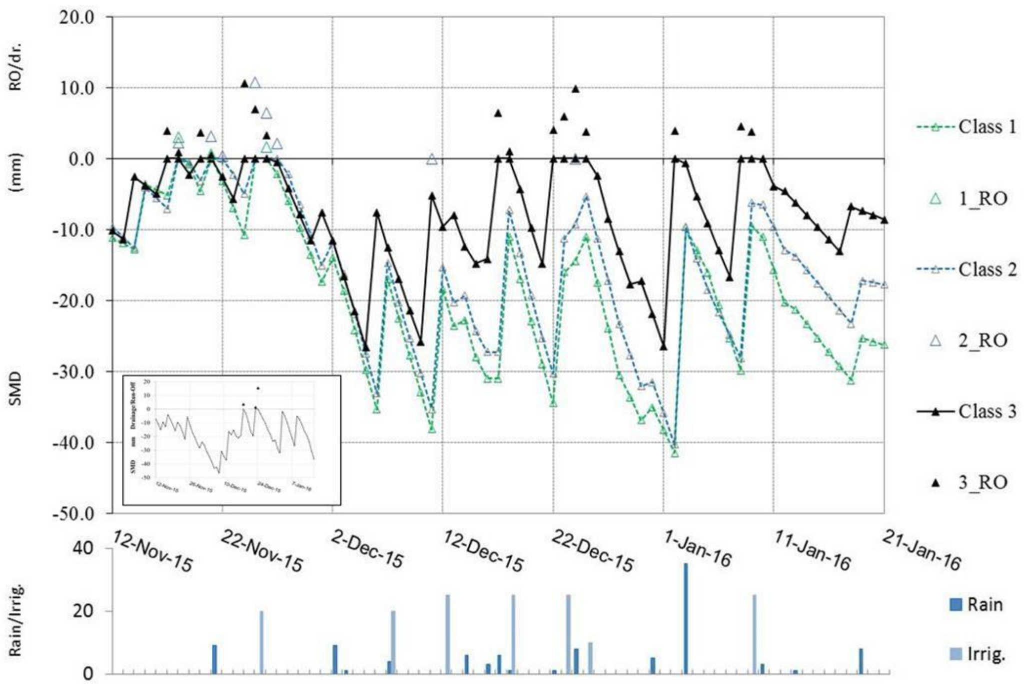

Figure 2. Soil moisture deficit for the three management classes, using neutron probe soil moisture data during the irrigation season. The modelled data are inset.

The results of our analysis to estimate water extraction by the plant roots is shown in Table 1 and Figure 3. Class 1 soils extracted most water between 40 and 50-cm soil depth, and Class 2 and 3 soils extracted most water between 30 and 40 cm soil depth (Fig. 3). Overall, the Class 1 soils (free draining) extracted more water, and Class 3 soils (poorly drained) the least (Table 1).

The implications of the relative differences in water uptake by roots in the three classes are shown in Table 1, where crops in Class 3 soils yield least. This is likely related to the fact that some waterlogging caused poor plant growth. Figure 3c also shows that there was no water extraction below 60 cm, suggesting that the plant roots did not reach this far, either due to waterlogging and/or to the effect of the dense subsoil in this Pallic soil.

Table 1. Soil classes, water use and yield data for an irrigated barley crop in Hawke's Bay, NZ, for the 2015/16 season

Class	soil	Drainage properties	NZSC name	water extraction (mm) [estimated from smm]	drainage/RO [estimated from smm]	drainage/RO [estimated by modelling]	Yield ±1 st.dev. (t/ha)
1	Takapau sl/zl	well drained	Typic Allophanic Brown	489	5	21	10.5±0.9
2	Takapau sl/zl	well – mod. drained	Typic Allophanic Brown	379	26	21	8.9±0.8
3	Poporangi & Rawai sl & zl	Imperfectly drained	Argillic Duric Pallic	173	69	21	2.6±2.3

Note: Class: management class; NZSC: New Zealand Soil Classification (Hewitt, 2010); smm: soil moisture monitoring; sl: sandy loam; zl: silty loam

The amount of drainage that occurred was significantly higher in Class 3 soils (69 mm) compared with the other classes (see Table 1), and the soil water balance modelling exercise was unable to model this effect of impeded drainage characteristics of Class 3 soils (see inset in Fig. 2).

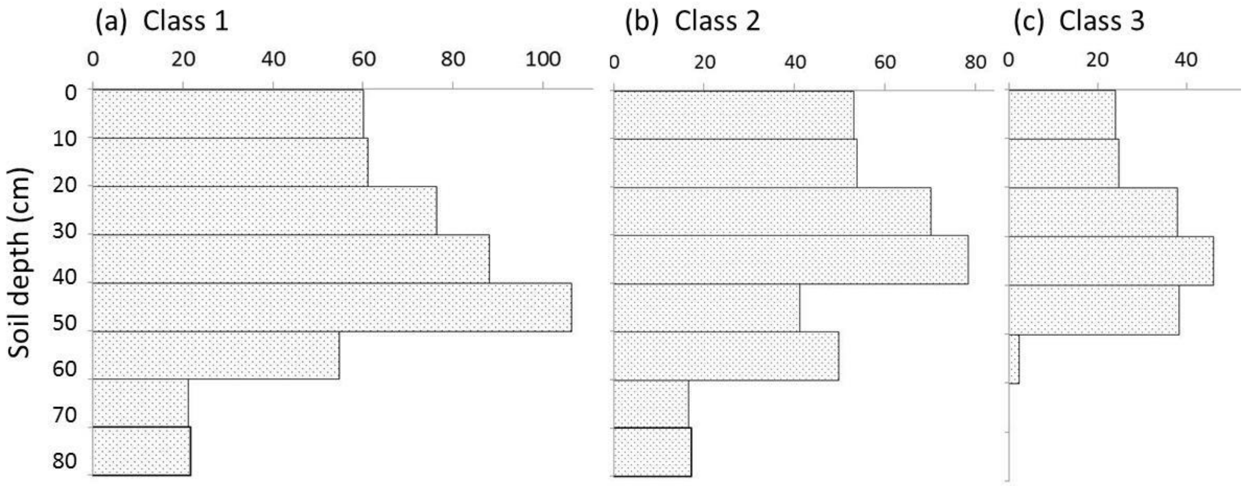

Figure 3. Water extraction (mm) in each Management Class during the period of irrigation, to a depth of 80 cm

Conclusions

Soil variability is a major factor influencing crop yield, and management needs to be modified to address this, e.g. using variable rate irrigation.

- Classification of EM data into management classes is an effective method for delineating soil differences. At this site the management classes separated soils on a basis of drainage characteristics and this was a useful indicator of final yield variability.
- Soil moisture monitoring effectively tracks soil moisture deficit for adaptive management. The differences between the soil classes in drainage characteristics could not be modelled effectively using a standard Penman-Monteith soil-water balance model.
- Mapping and monitoring of soils for precision irrigation needs to be site specific, and therefore the method needs to be affordable for private land managers.
- New technologies (commercial EM mapping, real-time soil moisture monitoring) are becoming affordable for good management of high-value irrigated crops.
- Further research should focus on continual improvement of high resolution mapping and monitoring technologies for irrigated land so that precision irrigation strategies can be implemented.

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