Can electromagnetic induction be used to evaluate sprinkler irrigation uniformity for a shallow rooted crop?

Amjed Hussain[A] and Steven R Raine[B]

[A]Scientist Hydrology, Future Farming Systems Research Division, Department of Primary Industries, Tatura, VIC 3616, Australia. amjed.hussain@dpi.vic.gov.au
[B]Professor, National Centre for Engineering in Agriculture & CRC Irrigation Futures, University of Southern Queensland, Toowoomba, QLD 4350, Australia. Steven.Raine@usq.edu.au

Abstract
The application uniformity of sprinkler irrigation systems affects both crop growth and profitability. However, traditional catch can measurements of irrigation uniformity are labour intensive and are normally only conducted in a small area of the field. A trial was established in a lettuce crop irrigated with a solid set sprinkler system to evaluate the potential to use electromagnetic sensing for irrigation performance assessment. After crop establishment, the uniformity of the irrigation applications was deliberately modified within two sprinkler plots (9 m x 11 m) by reducing the sprinkler operating pressures. The uniformity of the water applied during each irrigation was measured using a grid of catch cans. The apparent soil electrical conductivity (EC_a) was measured within the plots for each irrigation during the cropping season using an EM38. Electromagnetic (EM) measurements were taken with the EM38 either on the ground or 35 cm above the ground surface. Elevating the EM sensor above the ground level did not improve the correlation between the point measured catch can volume of water applied and the difference in EC_a measured before and after irrigation (ΔEC_a). However, the coefficient of uniformity calculated using the ΔEC_a data was correlated to the coefficient of uniformity calculated from the catch can data. The correlation was improved where the EM sensor was elevated above the soil surface so that only the root zone was sensed. This suggests that measurements of ΔEC_a can be used to estimate the irrigation uniformity for shallow rooted crops, particularly when the uniformity is low (CU < 70%) and the irrigation application pattern is consistent throughout the season. ΔEC_a measurements also identified the location of irrigation system leakages within the field.

Key Words
Apparent electrical conductivity, irrigation performance, leakage.

Introduction
The uniformity of water application is a key performance measure of an irrigation system. As the uniformity of water application decreases there is an increasing range of volumes applied within the irrigated area (Li and Rao 2003) which may adversely affect crop growth and profitability (Barber and Raine 2002; Elms *et al*. 2001). Catch can measurements are commonly used to evaluate the spatial variability of water application. However, discrete physical sampling can be labour intensive restricting the number of samples collected and the ability to identify all spatial variability in the field (Plant 2001). Electromagnetic (EM) sensors have been used to measure apparent (or bulk) soil electrical conductivity (EC_a) and identify spatial variations in soil moisture (Heiniger *et al*. 2003; Taylor *et al*. 2003). However, there are few reported studies using EM sensing for evaluating irrigation uniformity, particularly where small volumes of water are applied using sprinkler irrigation systems.

Hussain and Raine (2008) reported on a preliminary study using an EM sensor to evaluate the uniformity of application for a sprinkler irrigated lettuce crop. EC_a was found to be correlated with the seasonal pattern in water application where the uniformity of water application was low and the spatial pattern of application was consistent throughout the season. The EC_a was not well correlated with the uniformity of individual application events or where the irrigation uniformity was comparatively high. However, the EM sensor in the preliminary study was placed on the soil surface resulting in the soil measurement depth being much greater than the rooting depth of the crop, possibly reducing the ability of the instrument to resolve the small volumes of water applied. Similarly, there was some uncertainty over the ability to correlate a point measured catch can volume with an EM measurement averaged over a larger spatial area. Hence, this paper reports on a subsequent field study to evaluate whether (a) elevating the EM sensor above the soil surface improves the ability to identify spatial variations in small water applications and (b) correlations exist between the catch can and EM measured uniformity indices calculated for the whole plot. It also presents field scale EM data demonstrating the potential to identify irrigation system leaks.

Methodology

This trial used a similar agronomic methodology to that reported by Hussain and Raine (2008) for an autumn sprinkler irrigation trial of lettuce conducted on a Black Vertosol (Isbell 2002) at the Queensland Primary Industries and Fisheries Research Station, Gatton. This subsequent winter trial (August to October 2007) was also conducted on a 92 × 11 m plot cultivated into seven 1.3 m wide beds separated by 0.3 m furrows. The site was irrigated using a solid set sprinkler irrigation system consisting of ISS Rainsprays fitted with 1.98 mm nozzles on 0.6 m risers and operating at 335-370 kPa. The sprinklers were arranged in a square pattern with 9 m spacings along the laterals and an 11 m lateral spacing. Four week old Iceberg (cv. Raider) lettuce was transplanted on the 8/8/07. Three in-crop irrigations were applied to establish the transplants and then three (Control, Poor-1 and Poor-2) treatment grids (9 ×11 m size) were established. The pressure at three sprinklers in the Poor-1 and the Poor-2 grids were reduced to 138 or 172 kPa using pressure reducers. The pressure of one of the 172 kPa sprinklers was reduced to 103 kPa after the fourth irrigation (18/8/07) in both Poor grids and to further reduce the uniformity worn sprinkler heads and nozzles were installed after the fifth irrigation (1/9/07). The sprinkler pressure and heads in the Control grid were not changed at any time. Irrigations were conducted in the evenings and the catch can data collected the following morning. The Christiansen (1942) Coefficient of Uniformity (CU) was used to evaluate the uniformity of the water application in each plot. The EC_a measurements were taken using an EM38 (Geonics Ltd. Mississauga, Ontario) at ground level in horizontal mode for the 4th, 5th and 6th irrigations. The EM meter was then mounted on a wooden stand 35 cm above the beds for measurements of the 7th and 10th irrigations.

Results and Discussion

Irrigation application and ΔECa

The average volume of water application varied from 6.1 to 24.8 mm whilst the difference in apparent soil electrical conductivity before after irrigation (ΔEC_a) varied from 1.0 to 19.0 mS/m during the season (data not shown). The example contour map of water application (Figure 1) shows that high water application and ΔEC_a values were generally observed close to the sprinklers with low values in the middle of the grid.

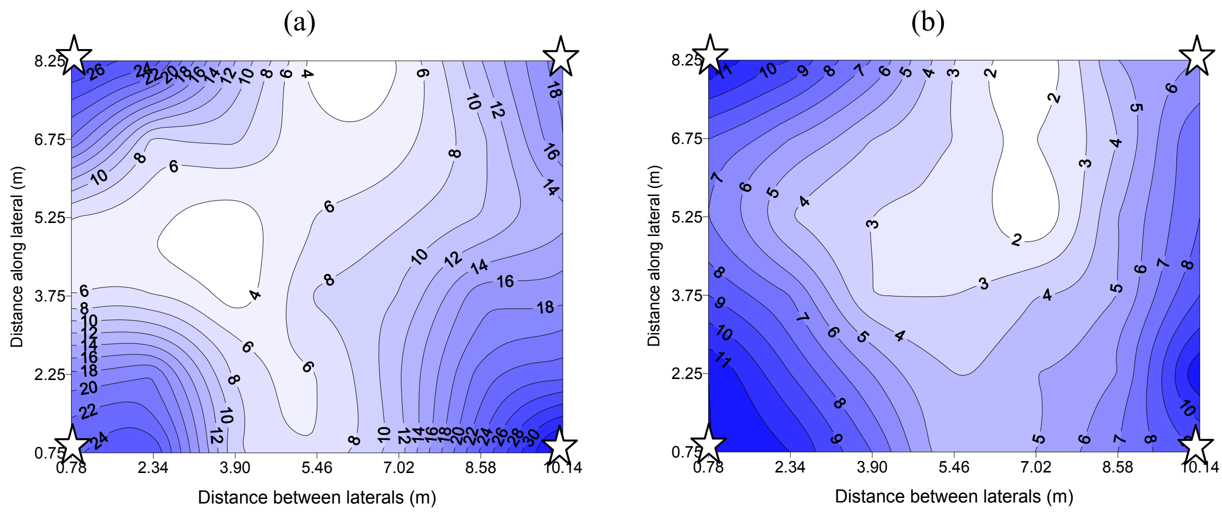

Figure 1. Pattern of (a) water application (mm) and (b) ΔEC_a (mS/m) for the Poor-2 grid (10th irrigation).

The linear correlation between the point measured volume of irrigation water applied and the ΔEC_a was low before the fifth irrigation in all the grids (Table 1). The comparatively high sprinkler uniformity and relatively small volumes of water being used by the crop during this period maintained a moist soil profile and produced small differences in soil moisture across the plot. The correlations between water applied and ΔEC_a were higher in later irrigations (i.e. after the reduction in sprinkler uniformity) reflecting the larger variation in water volume applied and increased differences in the soil moisture across the poor grids. However, there was no correlation between the volume of irrigation water applied and the ΔEC_a in the Control (i.e. high irrigation uniformity) grid suggesting that EM measurements are not able to adequately identify specific spatial patterns of water application where the uniformity of application is high (e.g. CU >

70%). Raising the EM sensor above the ground level (7th and 10th irrigations) did not increase the correlation between the catch can and *ECa* measurements (Table 1).

Table 1. Selected irrigation performance data and correlation between water application and ΔEC_a

No. of irrigation after transplant	Average volume of water applied (mm)			Coefficient of uniformity (CU) calculated from catch can data (%)			Linear correlations between point measured depth of water applied and ΔEC_a (R^2)		
	Poor-1 grid	Poor-2 grid	Control grid	Poor-1 grid	Poor-2 grid	Control grid	Poor- 1 grid	Poor-2 grid	Control grid
4[a]	13.9	14.7	19.2	75.4	82.6	84.9	0.00	0.03	0.09
5[a]	12.1	11.2	16.9	80.0	72.0	84.6	0.31	0.62	0.39
6[a]	13.4	13.2	19.2	48.1	63.7	82.8	0.51	0.40	0.16
7[b]	15.4	14.9	23.9	65.1	58.3	88.0	0.27	0.23	0.02
10[b]	13.6	12.9	21.5	62.0	46.1	87.3	0.21	0.56	0.04

a = EM on the ground, b = EM elevated above the ground

Relationships between CU calculated by catch can and ΔEC_a

The coefficient of uniformity (CU) calculated using the catch can measurements for each whole plot was reasonably well correlated ($R^2 \sim 0.6$) with the CU calculated using the ΔEC_a measurements for both trials (Figure 2a). However, the correlation was substantially improved ($R^2 = 0.93$) when the EC_a measurements were taken 0.35 m above the ground surface compared to the on-ground measurements (Figure 2b). This suggests that variations in ΔEC_a observed when the EM sensor is elevated may better reflect the change in root zone soil moisture with small water applications than on-ground EM measurements.

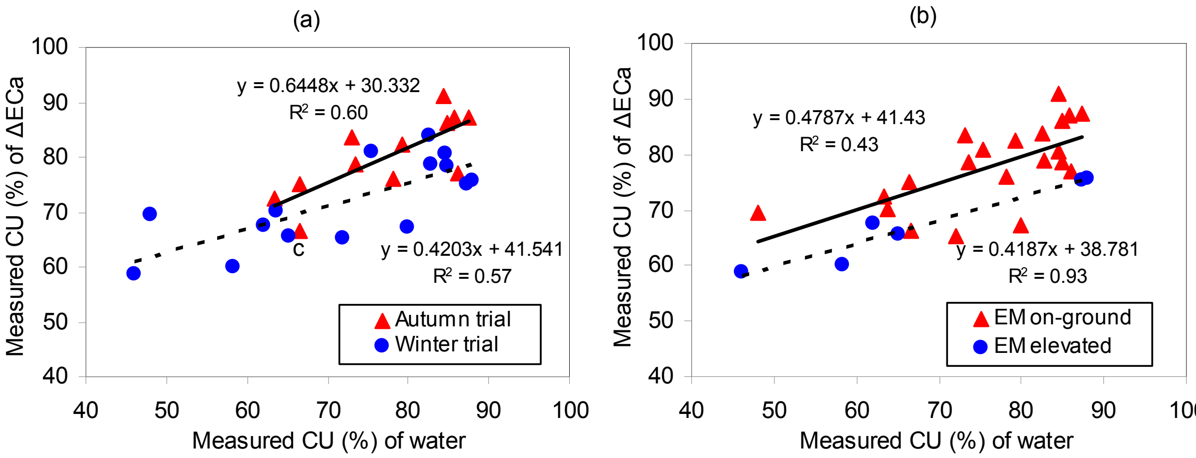

Figure 2. Linear correlations of CU calculated from catch can measurements and ΔEC_a (mS/m) for (a) autumn and winter trial and (b) on-ground and elevated EM measurements.

Utility of whole field ΔEC_a measurements to identify system leaks

EC_a measurements were generally higher after each irrigation (i.e. due to higher soil-water content) and when the EM sensor was placed on the ground rather than elevated (i.e. due to a larger sensed soil volume). Some variations in EC_a were also observed associated with proximity to metallic irrigation infrastructure. However, where ΔEC_a was mapped for the whole field (e.g. Figure 3) significant differences in ΔEC_a were found in areas which were not associated with the non-uniformity in sprinkler applications. For example, higher ΔEC_a values were observed at several in-field locations (e.g. 0 × 10.14, 78 × 10.14 and 82 × 10.14 m) for the 4th irrigation (Figure 3a) and at the top (i.e. 0 m) of the field for the 10th irrigation (Figure 3b). In these cases, the elevated ΔEC_a readings reflect leakage from the irrigation pipe system and suggest that ΔEC_a could be used to identify gross irrigation system problems.

Conclusions

Correlations between the point measured water applied and the ΔEC_a measurements were low, particularly early in the season when crop water use was small and the uniformity of the irrigation relatively high. Elevating the EM sensor above the ground level did not improve the correlation between the point measured catch can volume of water applied and the ΔEC_a. However, the coefficient of uniformity calculated using the

ΔEC_a data was correlated to the coefficient of uniformity calculated from the catch can data. The correlation was improved where the EM sensor was elevated above the soil surface so that only the root zone was sensed. This suggests that measurements of ΔEC_a can be used to estimate the irrigation uniformity, particularly when the uniformity is low (CU < 70%) and the irrigation application pattern is consistent throughout the season. EM measurements also appear useful for identifying irrigation system leakages within the field.

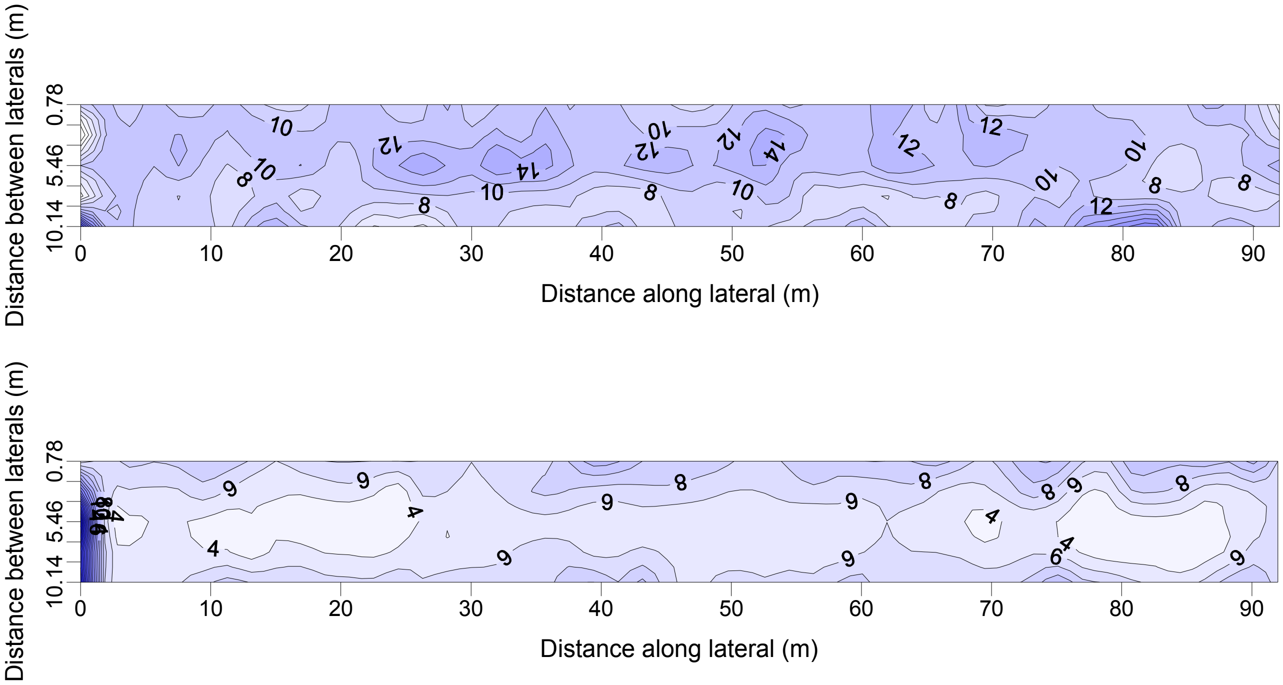

Figure 3. Whole field ΔEC_a (a) for the 4th (on-ground) and (b) 10th (elevated) irrigation measurements.

References

Barber SA, Raine SR (2002) Using commercial distribution uniformity and yield data to improve irrigation management. *International Water and Irrigation* **22**, 17-22.

Christiansen JE (1942) Hydraulics of sprinkling systems for irrigation. *Transactions of American Society of Civil Engineering* **107**, 221-239.

Elms MK, Green CJ, Johnson PN (2001) Variability of cotton yield and quality. *Communications in Soil Science and Plant Analysis* **32**, 351-68.

Heiniger RW, McBride RG, Clay DE (2003) Using soil electrical conductivity to improve nutrient management. *Agronomy Journal* **95**, 508-19.

Hussain A, Raine SR (2008) A preliminary evaluation of the potential to use electromagnetic induction to assess sprinkler irrigation performance in horticultural crops. In ‘proceedings of the Ist Global Workshop on High Resolution Digital Soil Sensing and Mapping’. University of Sydney, 5-8 February 2008.

Isbell R (2002) ‘The Australian soil classification.’ (CSIRO Publishing: Collingwood, Vic.)

Li J, Rao M (2003) Field evaluation of crop yield as affected by nonuniformity of sprinkler-applied water and fertilizers. *Agricultural Water Management* **59**, 1-13.

Plant RE (2001) Site-specific management: the application of information technology to crop production. *Computers and Electronics in Agriculture* **30**, 9-29.

Taylor JC, Wood GA, Earl R, Godwin, RJ (2003) Soil factors and their influence on within-field crop variability, part II: spatial analysis and determination of management zones. *Biosystems Engineering* **84**, 441-53.