A preliminary evaluation of the potential to use electromagnetic induction to assess sprinkler irrigation performance in horticultural crops

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Abstract

In irrigated environments the uniformity of the water application has a major effect on the soil water content and the subsequent spatial variation in crop stress and yield. However, the evaluation of sprinkler irrigation uniformity using traditional catch can analyses is resource prohibitive and commonly results in only small grids being used to infer whole field performance. 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 one sprinkler plot (9 m x 11 m) by reducing the sprinkler operating pressures. The uniformity of the water applied at each irrigation was measured using a grid of catch cans. The apparent soil electrical conductivity (EC_a) was measured within the plot at multiple times during the cropping season using an EM38 (Geonics Ltd Canada). The EC_a was found to be poorly correlated with the applied irrigation depths prior to sprinkler modification when the uniformity of the irrigations was relatively high. However, the correlation improved after sprinkler modification due to the increasing differences in soil moisture. There was generally a poor relationship between the volumes applied at each irrigation and the difference in EC_a measured before and after irrigation. However, this relationship was marginally better for the irrigations immediately after sprinkler modification. This data suggests that EM sensing may be used to identify the spatial variations in irrigation application where the irrigation uniformity is poor (i.e. CU < 70%) and the application patterns are consistent throughout the season but that the technique is not suitable to evaluate individual application events or where the irrigation uniformity is comparatively high.

Keywords. Spatial variability, Irrigation, Soil tension, ECa.

1. Introduction

Spatial and temporal yield variability within fields has been reported for many crops (Barber and Raine 2002; Bramley and Hamilton 2004; Cox et al 2003). The factors responsible for this variability include irrigation uniformity, soil physical and chemical properties, field topography, fertiliser uniformity, genetic variation, micro-climatic differences, pest infestation and diseases (Zhang et al 2002). Soil-water commonly has a leading role amongst all of these factors (Cavero et al 2001; Sadler et al 2000). In irrigated systems, the uniformity of the irrigation application is a key performance measure as it directly affects the spatial distribution of soil-water and may vary from one irrigation to the next. However, measurements of irrigation uniformity are time consuming and costly commonly resulting in only small areas of the field being evaluated at adhoc intervals. Thus, there is a need for a tool to enable routine spatial evaluation of irrigation uniformity at the field scale.

Measurements of apparent soil electrical conductivity (EC_a) using electromagnetic (EM) sensors have been used to evaluate spatial variability in soil moisture at field scales (Hanson et al 2000; McCutcheon et al 2006). However, there have not been any detailed studies to evaluate the potential to use these sensors for measuring irrigation uniformity. Hence, the main objective of this preliminary study was to evaluate the potential to use EM sensors for irrigation performance evaluation.

2. Materials and Methods

This trial was conducted between April and June 2007 at the Department of Primary Industries and Fisheries Gatton Research Station, Queensland. The soil at the site is a moderately self-mulching Black Vertisol. The work reported in this paper was part of a larger field trial site (92 × 11 m in size) which was cultivated into seven beds (1.3 m wide) 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 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. Three rows of five week old lettuce (Titanic variety) were transplanted onto each bed on the 12/4/07.

A total of ten irrigations were applied in this trial. The first four irrigations were applied to establish the transplants using the standard sprinkler irrigation system. The uniformity of sprinkler application was then deliberately reduced in one grid by fitting pressure reducers (138 and 172 kPa) to the sprinklers for the subsequent irrigations. The uniformity of irrigated water application was measured using plastic catch cans arranged on a square grid (1.5 × 1.56 m spacing) within the sprinkler plot. Irrigations were conducted in the evenings and the catch can data collected the following morning. Tensiometers (at 0.15 m depth) were installed next to each catch can and soil tension recorded from 17/4/07 at twenty-four hour intervals. Only the tensiometer data measured in high, medium and low water application areas of the grid are reported here. The EC_a was measured by placing an EM38 (Geonics Ltd., Ontario, Canada) operating in horizontal mode on the ground next to each catch can before and after each irrigation. EC_a measurements were taken on three different sprinkler grids within the field plot area after each of the first four irrigations but subsequently on only the one grid for which the sprinkler pressures had been reduced. Additional EC_a measurements were also taken at various times between irrigations for some events. EC_a measurements were only able to be collected for the first seven irrigations as it was not possible to place the instrument on the ground surface after the 17/5/07 due to increasing plant size.

3. Results and Discussion

3.1 Effect of irrigation uniformity on soil moisture

The average volume of water applied in each irrigation event during the trial varied from 15.6 to 30.6 mm with the largest two events occurred immediately after transplant (Table 1). The measures of sprinkler uniformity reported in this paper are the Coefficient of Uniformity (CU) proposed by Christiansen (1942) and the Distribution Uniformity (DU) as described in Walker and Skogerboe (1987). The uniformity of the irrigations were barely acceptable for sprinkler systems (i.e. CU > 70%) prior to fitting the pressure reducers (on the 1/5/07) and lower (i.e. CU < 70%) thereafter. However, the sprinkler uniformity varied substantially between irrigations both before and after fitting the pressure reducers presumably due to differences in operating conditions (e.g. hydraulic line pressure) and environmental variables (e.g. wind).

Table 1. Average volume applied and sprinkler uniformity for each irrigation event

Irrigation date	**Average volume applied (mm)**	**Coefficient of uniformity (CU) (%)**	**Distribution uniformity (DU) (%)**
13/4/07	30.6	81.5	76.6
15/4/07	24.5	86.1	80.8
20/4/07	16.7	73.5	60.5
26/4/07	18.5	73.1	64.6
2/5/07	15.6	66.5	56.0
8/5/07	16.3	63.4	53.1
14/5/07	16.7	66.6	50.1

Significant differences in soil moisture tension were observed between the low, medium and high water application areas after the sprinkler pressures in the grid were reduced (Figure 1). The high water application area was maintained with a soil moisture tension of <20 kPa throughout the season while the soil moisture tension in the low water application area typically ranged from 70 to 90 kPa. The medium water application area soil moisture tension showed the largest intra-irrigation variation ranging from 10 kPa immediately after irrigation to between 40 and 60 kPa prior to the next irrigation.

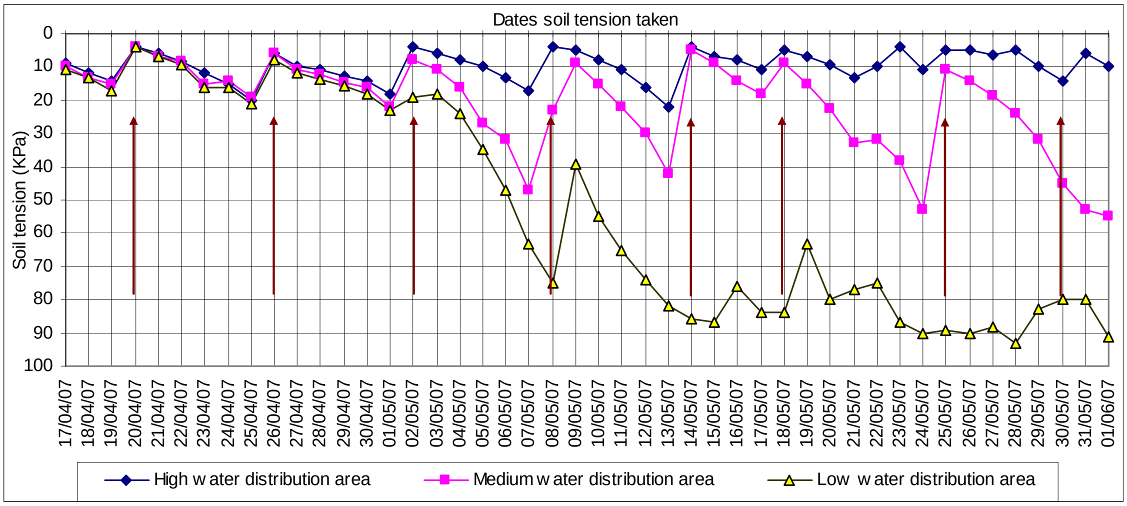
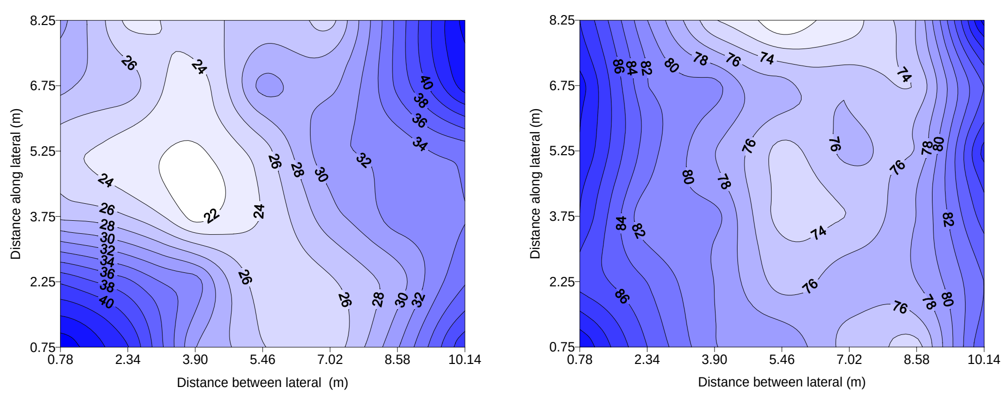


Figure 1. Soil moisture tension in low, medium and high water application areas of the sprinkler plot. Arrows indicate irrigation events.

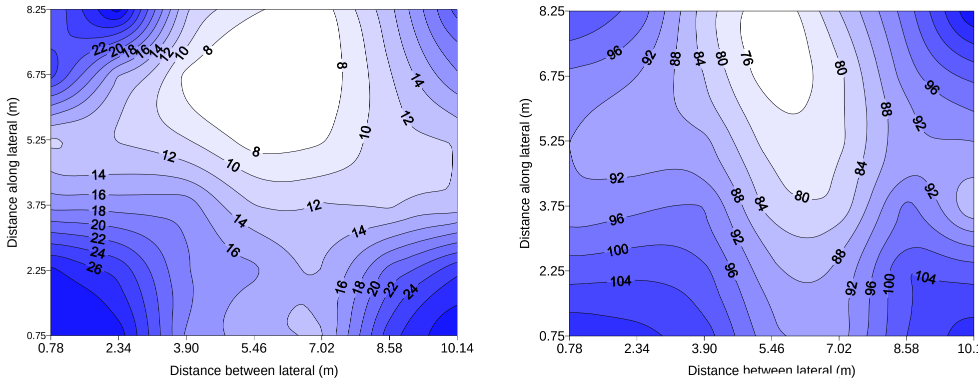
3.2 Relationships between irrigation application volumes and EC_a

Example contour maps of (a) the irrigation water application as measured by the catch cans and (b) EC_a within the plot are presented here for an irrigation conducted before (Figure 2) and after (Figure 3) sprinkler modification. High water application and EC_a values were generally observed close to the sprinklers. The higher CU and average volume of water applied on 13/4/07 resulted in a poor relationship between water applied and EC_a (Figure 2). However, the lower CU and average volume of water applied on 8/5/07 resulted in a higher correlation (R^2 = 0.69) between water applied and EC_a.



(a) (b)

Figure 2. Pattern of (a) irrigation water application (mm) and (b) EC_a (mS/m) on 13/4/07



(a) (b)

Figure 3. Pattern of (a) irrigation water application (mm) and (b) EC_a (mS/m) on 8/5/07

The correlation between the volume of irrigation water applied and the EC_a measured after the irrigation application was generally low (i.e. $R^2 < 0.4$) for the first four measured irrigations (Table 2). The large volumes of water applied, comparatively high sprinkler uniformity and relatively small volumes of water being used by the crop during this period acted to maintain a moist soil profile (Figure 1) and produced only small differences in soil moisture across the plot. However, the correlation between water applied and EC_a progressively improved (up to $R^2 \sim 0.7$) after the sprinkler pressures were reduced on the 1/5/07. There was no substantive difference in the relationship irrespective of the period of time after irrigation that the EM readings were taken. The increased correlation after the reduction in sprinkler performance reflects the greater range of irrigation volumes applied and increased differences in the soil moisture profiles across the plot. It is also consistent with the EC_a more accurately identifying progressive soil profile drying in areas where smaller irrigation volumes were applied. This suggests that EM measurements may be used to identify gross differences in soil moisture at high resolution across sprinkler irrigated plots where the pattern of irrigation water application and extraction is consistent throughout the season. The correlation between the volume of irrigation water applied and the difference in the EC_a measured before and after irrigation was generally poor (Table 2).

These correlations were also generally worse than the correlations between the irrigation applications and the absolute EC_a. This is consistent with the measurement errors associated with using the EM data in differential mode being greater than for single EC_a measurements and suggests that differential EC_a is not likely to be an appropriate substitute for traditional sprinkler irrigation performance evaluations.

Table 2. The correlation between irrigation water applied, EC_a measured after irrigations, and the difference in EC_a measured before and after irrigations.

Irrigation date	***ECa* measured date**	**Correlation between depth of water applied and EC_a (R^2)**	**Correlation between depth of water applied and ΔEC_a (R^2)**
13/4/07	13/4/07	0.18 (± 0.09)	
	14/4/07	0.13 (± 0.10)	
15/4/07	15/4/07	0.30 (± 0.02)	0.11 (± 0.09)
	19/4/07	0.37 (± 0.15)	
20/4/07	20/4/07	0.36 (± 0.16)	0.19 (± 0.23)
	25/4/07	0.31 (± 0.18)	
26/4/07	26/4/07	0.20 (± 0.17)	0.13 (± 0.11)
	1/5/07	0.42	
2/5/07	2/5/07	0.53	0.26
	6/5/07	0.57	
	7/5/07	0.53	
8/5/07	8/5/07	0.69	0.49
	9/5/07	0.71	
	10/5/07	0.69	
	12/5/07	0.68	
	13/5/07	0.70	
14/5/07	14/5/07	0.56	0.21
	15/5/07	0.63	
	17/5/07	0.60	

However, the highest correlation ($R^2 \sim 0.5$) for the differential EC_a data occurred for the second irrigation after changing the sprinkler pressures. This was during a period when the soil moisture tension variations associated with the individual irrigation applications appear to be largest (Figure 1). Hence, further work should be focused on determining if differential EC_a measurements could be used to identify the performance (i.e. non-uniformity) of individual irrigation events when either the spatial pattern or volume of water applied varies greatly between irrigations.

4. Conclusions

This preliminary evaluation suggests that electromagnetic sensing may be used to identify non-uniformities in sprinkler irrigation applications where the uniformity of application is poor (e.g. CU < 70%) and the application patterns are consistent throughout the season. In these cases, variability in EC_a was consistent irrespective of when irrigation occurred relative to the EM measurement. However, electromagnetic induction does not appear to be suitable for evaluating the uniformity of individual sprinkler irrigation applications in shallow rooted crops or where the uniformity of the irrigation is comparatively high. There was no difference between using either the EC_a measurements or the difference in EC_a measured pre-irrigation and post-irrigation.

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5. References

Barber, S. A. and Raine, S. R., 2002. Using commercial distribution uniformity and yield data to improve irrigation management. Int. Water. Irrig., 22(4): 17-22.

Bramley, R. and Hamilton, R., 2004. Understanding variability in wine grape production systems: 1. Within vineyard variation in yield over several vintages. Aus. J. Grape. Wine Res., 10: 32-45.

Cavero, J., Playan, E., Zapata, N. and Faci, J. M., 2001. Simulation of maize grain yield variability within a surface-irrigated field. Agron. J., 93(4): 773-782.

Christiansen, J. E., 1942. Hydraulics of sprinkling systems for irrigation. Trans. ASCE., 107: 221-239.

Cox, M. S., Gerard, P. D., Wardlaw, M. C. and Abshire, M. J., 2003. Variability of selected soil properties and their relationships with soybean yield. Soil Sci. Soc. Am. J., 67(4): 1296-1302.

Hanson, B., Peters, D. and Orloff, S., 2000. Effectiveness of tensiometers and electrical resistance sensors varies with soil conditions. Cal. Agric., 54(3): 47-50.

McCutcheon, M. C., Farahani, H. J., Stednick, J. D., Buchleiter, G. W. and Green, T. R., 2006. Effect of soil water on apparent soil electrical conductivity and texture relationships in a dryland field. Biosys. Engg., 94(1): 19-32.

Sadler, E. J., Bauer, P. J., Busscher, W. J. and Millen, J. A., 2000. Site-specific analysis of a droughted corn crop: II. Water use and stress. Agron. J., 92(3): 403-410.

Walker, W. R. and Skogerboe, G.V., 1987. Surface irrigation. Theory and practice. Prentice-Hall, New Jersey.

Zhang, N., Wang, M. and Wang, N., 2002. Precision agriculture-a worldwide overview. Comp. Electron. Agric., 36(2-3): 113-132.