Optimal transect spacing for EM38 mapping for dryland agriculture in the Murray Mallee, Australia

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Abstract

We measured the increased error in mapping the apparent electrical conductivity (ECa) with increasing transect spacing from 10 to 150 m at six 15-100 ha sites across the Murray Mallee. Punctual (point) Kriging was used on a 5x5 m common grid for all sites at each transect spacing using a local spherical variogram model determined from the software package Vesper (University of Sydney). Mean paddock standard errors were regressed against transect spacing and linear models were derived. These errors (ECa, dS/m) were converted to drainage error (mm) by using previously measured drainage - ECa functions from Lysimeter studies at Walpeup. The cost of error was calculated by assuming that error in drainage would result in a significant loss (in water use or more correctly transpiration) at one standard deviation. The drainage loss was then derived by applying a production efficiency loss at a particular gross margin. The optimal transect spacing was determined from marginal cost analysis and varied from around 30 to 60 m depending upon the variance of ECa and the production capability of the field.

Media summary

Optimal transect spacing for EM38 mapping in dryland agriculture varied from 30 to 60 m depending upon ECa variance and production capability of the field.

Key Words

Precision Agriculture, subsoil constraints.

Introduction

In recent years the use of electromagnetic induction technology to map soil properties in order to help interpret yield maps and crop production in a spatial context is becoming increasingly popular. The notion of an optimal transect spacing for EM38 mapping in dryland applications is straightforward. Some attempts have been made to determine the optimal spacing. Most are very subjective and appear to be without clear criteria. One interesting attempt determined the optimal spacing from the point of maximum variance (sill and range) from a variogram (Miller et al., 2001). There is, however, an urgent need to develop objective criteria for the industry. From an economic perspective it will depend upon the cost of mapping ($/ha) and the savings in reduced error gained from the mapping process ($/ha) such that the total cost is minimised. The cost of EM38 mapping can be obtained from contractors for which individual negotiation is necessary, but the cost will normally decrease inversely as transect spacing is increased. The cost of increasing mapping error with increasing transect spacing is, however, more involved, requiring the error to be defined with respect to transect spacing and a monetary value assigned to the error. If the cost of error is zero then an infinitely spaced transect would be optimal, i.e. EM mapping would not be economical nor justified. However, mapping error can be determined and if this can be assigned a cost then an optimal transect spacing can be determined from the minimisation of the total cost of mapping plus the cost of mapping error.

We determined the mapping error from a selection of six sites across the Murray Mallee region of Australia and assigned a range of costs in an effort to study likely optimal transect spacing for EM38 mapping application that should be relevant in dryland agriculture. Thus, the basis for a comprehensive economic analysis of EM mapping for dryland farms is built on the concept that error in EM maps can be ascribed a cost. This may be opportunity costs of lost production caused by misapplication of inputs or loss of water for production to drainage or a pollution cost imposed by an environmental authority. This paper describes the first steps in this process by developing a framework for the development of optimal transect spacings for EM38 mapping relevant in dryland agriculture.

Methods

Experimental sites

We selected six farm fields across the Murray Mallee region of Australia (each 15-100 ha) that had a history of yield maps and for which the farmers had intentions of continuing to map yield for subsequent crops (Sadras et al. 2002). These sites were selected because they comprised a wide range of salinity from near zero to severe that are typical of the region and represent crop rotations containing largely cereal crops (wheat, barley and triticale). These were located near Balranald (lat. S 34^{o} 45', Long. E 143^{o} 27', elev. 80 m), Loxton (lat. S 34^{o} 30', Long. E 140^{o} 34', elev. 65 m), Swan Reach (lat. S 34^{o} 32', Long. E 139^{o} 45', elev. 50 m), Waikerie (lat. S 34^{o} 17', Long. E 140^{o} 2', elev. 65 m), Walpeup (lat. S 35^{o} 07', Long. E 141^{o} 59', elev. 85 m) and Wemen, (lat. S 34^{o} 49', Long. E 142^{o} 40', elev. 65 m).

EM38 mapping

Ground-based position and Geonics EM38 data (vertical dipole) were collected after harvest (except at Walpeup) by a mobile data logging system supplied by contractors. One contractor used an OmniStar differential corrected Trimble GPS/TSC1 data logger whilst the other used an OmniStar differential corrected Fugro GPS/Fujitsu Stylistic 1200 Logging system. Transects were made at 10 m spacings and data collected at nominally 1 s intervals. Since the GPS antenna cannot be placed above the EM sensor, due to electrical interference to the EM signal and also for practical construction reasons, all data was position-corrected for antenna offset arising from distance and velocity (O'Leary, 2003). To obtain wider transect spacing we constructed data files by deleting respective transects of data from the original data set. Data sets of increasing transect spacing from 10 to 120 m in 10 m intervals were created and increased to 150 m for the final data set. The Geocentric Datum of Australia (GDA94) grid was used for all comparative map and statistical analyses. Erroneous data, such as low velocity data (< 3.6 km/hr), were removed. Position corrected EM38 data was kriged to a 5 x 5 m grid with the Software Vesper V1.0c (Minasny et al. 1999). We employed a punctual (point) spherical model with a local variogram using a minimum of 90 and maximum of 150 data points per grid estimate. The kriging interpolation provides estimates of the grid mean and variance.

Mapping error

All files for each transect spacing were trimmed to common boundaries for each site. Mapping error was determined as the mean of the kriging variance of each kriged grid point mean and expressed as the standard error. Mean errors were plotted against transect spacing and linear functions fitted. Linear functions provide simple algebraic solutions to solving the point at which optimal spacing can be determined, but they can be more complex where numerical solutions are preferred.

Assigning mapping error a cost

The mapping standard errors (ECa, dS/m) were converted to drainage error (mm) from the derivative of previously measured drainage/ECa functions from lysimeter studies at the Walpeup site (-71.6 mm/dS/m, O'Connell et al., 2003). For example, an increase in ECa will decrease drainage by 71.6 mm/dS/m. The cost of error was calculated by assuming that error in drainage would result in a significant loss (in water use or more correctly transpiration) at one standard deviation. The production loss due to drainage was then derived by applying a production efficiency. This would comprise a production efficiency for the crop (e.g. 20 kg/ha/mm for wheat) at a particular value or gross margin on an area basis (e.g. \$200/ha). The actual production losses will depend upon the expected returns from any given paddock and crop, and thus is dependent on season, so we chose a range of values typical of Mallee crops in Australia to explore the sensitivity of the optimal spacing to changing productivity value.

Cost of EM mapping

EM mapping costs were obtained from commercial contractors. For our analysis this cost was fixed at \$5.55/ha at 15 km/hr at 30 m transect spacing. We have not included costs for soil sampling and specific EM calibration as this would be a constant amount per hectare and therefore not affect the optimal spacing. The cost of EM mapping then is represented by the following equation: EMc = 166.66/T, where T is the transect spacing (m) and EMc is the cost of EM mapping (\$/ha).

Marginal cost analysis

We applied a marginal cost analysis to determine the optimal transect spacing. The optimal spacing occurs at the point of lowest total cost (sum of cost of EM mapping and cost of mapping error). This can be derived algebraically where the derivative of the cost of mapping equals the derivative of the mapping error with respect to transect spacing, but alternatively can be derived numerically.

Results and Discussion

The standard error of ECa increased linearly with increasing transect spacing at all sites (Figure 1a). The rate of change of ECa error (slope of Figure 1a) with respect to transect spacing was different at all sites and was strongly related to a surrogate measure of the corner-to-corner (X-X) paddock error measured over the distance travelled (Figure 1b).

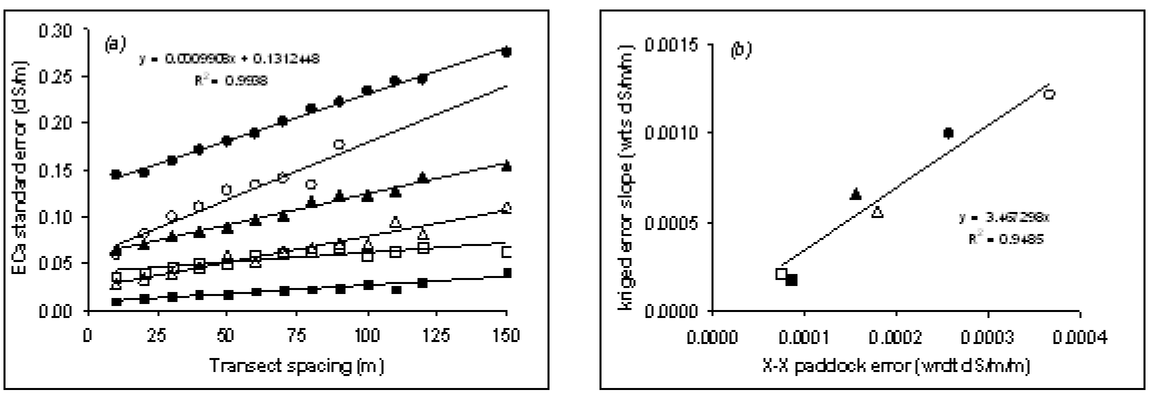

Figure 1. Mean standard error of ECa as a function of transect spacing measured at each site (Balranald ●, Loxton ○, Swan Reach ■, Waikerie □, Walpeup ▲ and Wemen ∆ (a) and slope of this function (ECa error with respect to transect spacing, wrts) plotted against the corner-to-corner (x-x) paddock error (ECa error with respect to distance travelled, wrdt) for all sites (b). Symbols as per (a).

The cost of mapping decreased inversely with increased transect spacing while the cost of mapping error increased linearly with increasing transect spacing (Figure 2). For example, at Balranald with a gross margin of \$200/ha and transpiration efficiency of 20 kg/ha/mm the optimal spacing occurs where the total cost is minimised (Figure 2a) or where the respective derivatives intersect (Figure 2b), ie. at 24 m.

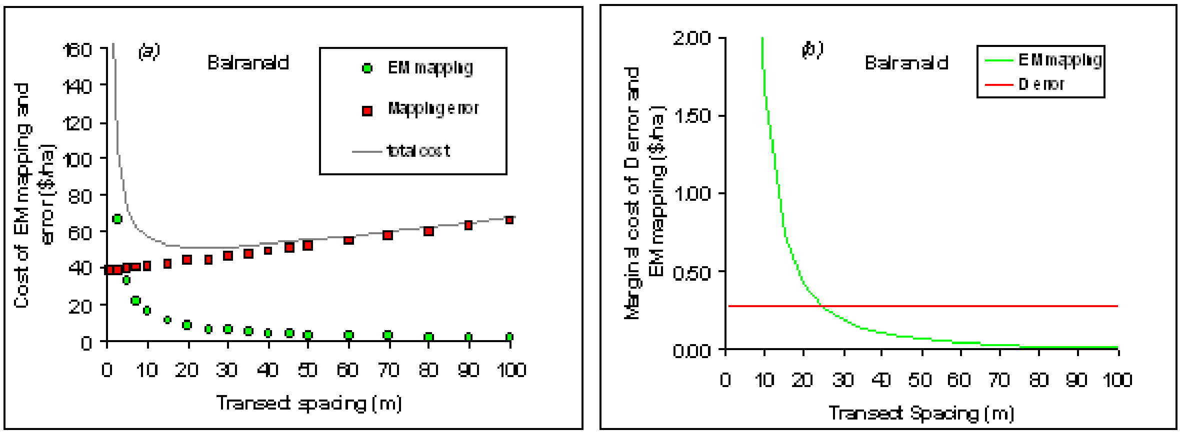

Figure 2. Cost of EM mapping (○), and mapping error (□), and total cost (---) (a) and derivative of these costs with respect to transect spacing at Balranald (b).

The cost of mapping error will depend upon the value of the production and the production efficiency in terms of water use or loss. Figure 3a shows how the optimal spacing increases with lower value production (gross margin) and lower overall ECa error. Similarly, the optimal spacing increases with lower efficiencies of crop production.

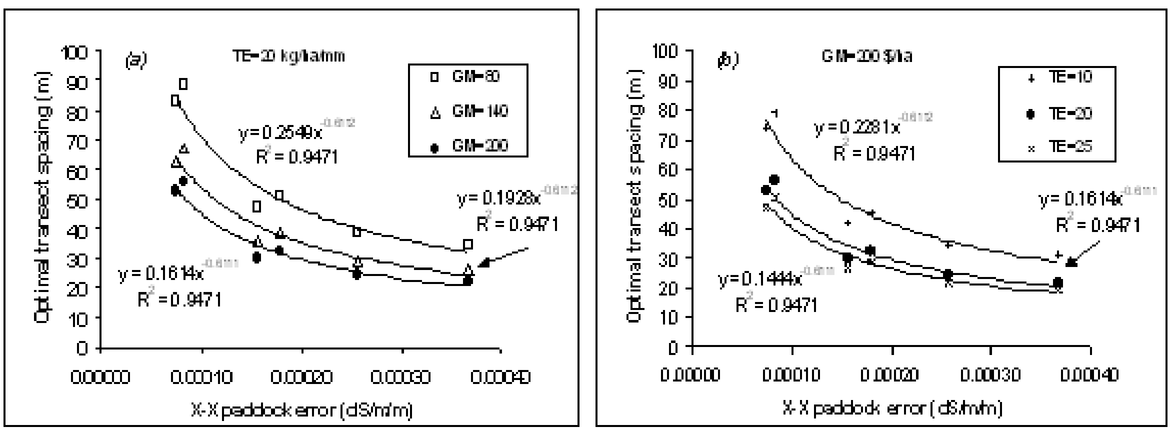

Figure 3. Optimal transect spacing as a function of mean paddock error (corner-to-corner, X-X) and value of production (gross margin $/ha, a) and mean transpiration efficiency (kg/ha/mm, b) across all sites.

Assuming a typical gross margin of $200/ha for grain production in the Murray Mallee and a range of transpiration efficiencies from 10 to 25 kg grain/ha/mm the optimal transect spacing ranged from 20 m to 79 m across all sites depending upon the production efficiency (Figure 3b). For the more typical efficiency of 15 kg/ha/mm optimal spacing range from 25 m (Loxton) to 65 m (Swan Reach).

The closer spacing required at Loxton reflects the greater overall variance in ECa across that site compared to the Swan Reach site. However, the area of our Loxton site was 15 ha and is probably too small to be representative of nearby farms. Thus, optimal transect spacings of the order of 30 to 60 m across much of the rainfed agricultural areas are likely, provided our assumptions and costings are realistic.

Conclusion

It is possible to determine the rate of change of error in any field by various sampling techniques (in our case corner-to-corner transects) and assign a cost to this error. This cost may, however, be quite subjective but assuming our costing is reasonable, optimal transect spacings will be in the range 30 to 60 m across much of the Mallee dryland agricultural areas. Our methodology should be generally applicable in other areas where EM mapping has been found to be useful.

Acknowledgments

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