Mapping soil parameters of irrigated properties using geostatistics

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Abstract An understanding of the variability of soil characteristics is required in the proper design of irrigation systems and their management. Such understanding comes from a geostatistical analysis of the sample data recorded in excavated pits. A case study is presented in which irrigation valve areas of about 1.3 ha were watered by above canopy sprinklers prior to 1980. These sprinklers covered an area 24 m x 22 m. The variation of readily available water for areas associated with individual sprinklers is not high within such irrigation valve areas and the system management comprised irrigation shifts which grouped irrigation valve areas of similar readily available water values. Changes to sub-canopy watering because of high salinity levels in the river involve much smaller areas, 3 m x 3 m, being watered by the new individual sprinklers. However, geostatistical analysis shows that the extra variation is not substantial and there was no need for redesign of the irrigation valve areas.

1. INTRODUCTION

When planning to develop a new property or to upgrade an existing one it is necessary to obtain all relevant information. An understanding of the variability of the soil is an important input to the planning process as changes in soil characteristics, which may occur over small distances, have a significant bearing on such matters as selection of variety and rootstock, the type of irrigation system, the design of the system, management of the irrigation schedule as well as surface soil management and improvement programmes. Sluggett and Adams [1989] describe the typical soil survey and the various soil plans produced by the Irrigated Crop Management Service (ICMS) of the South Australian Department of Primary Industries on the basis of this sampled data. Soil variables recorded include the depth and texture of each soil layer, assessed by hand texturing as described by McDonald et al. [1990]. The carbonate classes, classified by Wetherby and Oades [1975], which underlie the topsoil, the depth and extent of root zone activity in developed properties, soil salinity and pH are also measured.

In the assessment of the water holding capacity of a soil between irrigations, the parameter readily available water (RAW) is calculated. For the Riverland of South Australia, which sustains citrus, vegetables and wine production under irrigation, this is defined as the reservoir of soil water (in mm) which can be stored between -8 kilopascals (full point) and -60 kilopascals (refill point). These suction pressures correspond to a soil water depletion range which maintains maximum crop production for a broad range of horticultural crops in the Riverland. The depth and the texture of the various soil layers which are measured in the soil survey are the main determinants of readily available water, each soil texture encountered having a readily available water value (mm/cm of soil) determined from a soil moisture retention curve which is experimentally calculated from cores using a range of suction pressures as outlined by Loveday [1974]. The readily available water value for the whole profile is obtained by summing the values within each soil layer. Readily available water is always calculated for the full topsoil depth. Developed properties can also have the root zone readily available water calculated as this reflects the actual depth to which the roots of established plants are able to absorb water.

The availability of the soil survey data allows the possibility of geostatistical analysis (see Brooker [1991], Journel and Huijbregts [1978], Webster and Oliver [1990], Zirschky [1985]), which can provide an enhanced quantitative description of the variables of interest to the irrigation manager. Although developed for the mining industry, geostatistics is now widely applied in other scientific areas where variables are measured against a spatial position.

Brooker et al. [1995] carried out a geostatistical analysis of soil profile data from an irrigated vineyard 15 km northwest of the South Australian town of Waikerie which is situated on the River Murray. The specific objective of that study was to provide maps of best estimates and associated confidence intervals of two variables for the irrigation valve areas (IVA) in place on the property. (Irrigation valve areas are those areas watered by opening the valves.) Variables treated were topsoil depth and root zone readily available water (RAW). The map of root zone readily available water allows the irrigation manager to make efficient use of water by delivering the appropriate quantity to the varying soils throughout the property, whilst the map of topsoil depths is important in ensuring that vines are not planted on too shallow a soil.

The geostatistical technique of kriging, (see Brooker [1991], Journel and Huijbregts [1978]) was used to get the estimates and requires that the semivariogram for these variables first be determined. As noted above, soil characteristics may vary considerably over small distances and a geostatistical treatment quantifies this variation in the semivariogram, a function which measures the spatial correlation between data pairs as a function of the displacement between the pairs. It is the fundamental tool in the analysis and is also important in the understanding of soil variability in an area. For example, in the cited study the semivariogram was clearly anisotropic, with variation in the NS direction much more rapid than in the EW and this was related to the topography of the area where a dune swale system strikes EW. A similar study, Brooker and Warren [1997], for a property twenty kilometres distant and on the other side of the river indicated no such anisotropy. This is a reflection of the fact that the second study involved predominantly first slope topography rather than the highland topography of the first study where the dune swale system develops. Discussion of the topography of Riverland soils may be found in Herriott and Johnston [1941].

In both previous studies the objective was to accurately map readily available water and topsoil depth. Further, the efficiency of different sampling grids was discussed using the calculated estimation variances from the geostatistical analysis in order that recommendations could be made as to the appropriate sampling grids for the conditions applying in the Riverland.

In this study the focus changes to consideration of the suitability of various watering systems for the first property. A change was necessary because of the high salinity of the River Murray during the early 1980's. Geostatistics can again give a quantitative measure to address this situation.

2. VARIABILITY OF AREAS WATERED BY INDIVIDUAL SPRINKLERS

For undeveloped properties, or where conditions dictate a change to a different irrigation system may be necessary, it is important to investigate the extent of the variability of the areas watered by individual sprinklers within the irrigation valve areas. This variation must be able to be accommodated within the irrigation system design and its management. Another geostatistical statistic, the dispersion variance, is used in this case to measure the variance of values of areas of size a in a larger area A. As with the estimation variance, which measures the accuracy of an estimate, this dispersion variance is also a function of the semivariogram $\gamma(h)$. It may be written;

$$\sigma^2(a|A) = \overline{\gamma}(A,A) - \overline{\gamma}(a,a)$$

where $\overline{\gamma}(A,A)$ is the average value of the semivariogram function, $\gamma(h)$, as each end of the argument h, independently covers all positions within A.

An example of such sprinkler replacement occurred on the property of the first study mentioned above in the 1980's when salinity of the river was high. At that time the irrigation system in place on this vineyard comprised above canopy sprinklers which watered 24 metres (E-W) x 22 metres (N-S). These were replaced with sub-canopy sprinklers watering areas 3 metres x 3 metres around the base of the vines. Whilst the latter system is more subject to maintenance costs the problems of salt encrustation on the leaves was avoided and the amount of water used was reduced because of a more efficient placement.

From the previous study, Brooker et al. [1995], the semivariograms were seen to be anisotropic for both topsoil depth and root zone readily available water. Using the notation of the cited paper for semivariogram parameters (Co is the nugget effect, Co+C is the sill and a the range) the parameters for the semivariogram function are tabulated below.

Parameter	Root Zone RAW	Topsoil Depth
Co	100 mm^2	600 cm^2
C	130 mm^2	2950 cm^2
a(N-S)	200 m	220 m
a(E-W)	650 m	995 m

Table 1. Spherical semivariogram model parameters for topsoil depth and root zone readily available water.

Using these parameters and calculating dispersion variance for both above and sub-canopy sprinklers within the typical irrigation valve area, 225 metres (E-W) x 75 metres (N-S), results in the following table.

Dispersion Variance for each system within IVA		
	Root Zone RAW	Topsoil Depth
above canopy (24m x 22m)	28.0 mm^2	495.1 cm^2
sub-canopy (3m x 3m)	34.9 mm^2	631.0 cm^2

Table 2. Dispersion variance for above canopy and sub-canopy sprinkler systems within irrigation valve area, 225 m (E-W) x 75 m (N-S), for root zone readily available water and topsoil depth.

These variances must be seen relative to the summary statistics obtained from the sampled data and which are presented in Table 3 below.

Statistics	Root Zone RAW	Topsoil Depth
number	764	928
mean	39.9 mm	90.5 cm
variance	254 mm^2	3995 cm^2

Table 3. Summary statistics for the vineyard.

Thus, for RAW, a dispersion variance of 34.9 mm^2 (standard deviation 5.9 mm) for the sub-canopy system within the IVA is not a major variation when considered against the typical value of about 40 mm. The coefficient of variation, which is the ratio of the standard deviation to the mean, is 15%. This dispersion variance for the new system is not significantly different from the dispersion variance of 28.0 mm^2 (standard deviation 5.3 mm, coefficient of variation 13%) which applied for the above canopy situation. The smaller sub-canopy areas are scarcely more variable than the above canopy and this small extra variation did not warrant redefinition of the IVA in the new system.

3. VARIABILITY OF IRRIGATION VALVE AREAS WITHIN THE PROPERTY

The extent of variation of the IVA values within the property as a whole can be calculated in a similar fashion. It is more substantial as Table 4 shows.

For root zone RAW the dispersion variance is 92.5 mm^2, which corresponds to a standard deviation of 9.6 mm and a coefficient of variation of 24%. This reaffirms the necessity to treat individual areas separately when it comes to irrigating the property.

Dispersion Variance for irrigation valve areas within the property	
root zone RAW	topsoil depth
92.5 mm^2	2243.5 cm^2

Table 4. Dispersion variance for irrigation valve areas, 225m (E-W) x 75m (N-S), within property, 1.575 km (E-W) x 3.9 km (N-S), for root zone readily available water and topsoil depth.

4. CONCLUSION

This paper has investigated the variability of subareas of a vineyard which were irrigated by different watering systems at different times. The statistic, dispersion variance, which is obtained from a geostatistical analysis in which the spatial variability of the soil is first determined by calculation of the semivariogram, allows this variability to be quantified. The system first in place involved above canopy sprinklers covering an area of 24m x 22m, whilst the second used smaller sprinklers which watered an area 3m x 3m at the base of plants. In both cases the variation of watered areas within the irrigation valve areas is similar. The small increase in variability which occurs on installation of the sub-canopy system is not large enough to warrant redesign of the valve areas. However the variability of irrigation valve areas within the vineyard shows a coefficient of variation about twice these and reaffirms the need to treat individual valve areas separately. The map of root zone RAW provided in the previous study is then useful in defining the amount of water to be provided for an area. Linkage of IVAs with similar values then defines the irrigation shifts in the management of the system.

5. REFERENCES

Brooker, P.I., *A Geostatistical Primer*, World Scientific Publishing, 95 pp., Singapore, 1991.

Brooker, P.I., J.P. Winchester, and A.C. Adams, A geostatistical study of soil data from an irrigated vineyard near Waikerie, South Australia, *Environment International*, 21: 699-704, 1995.

Brooker, P.I., and S.K. Warren, Modelling of irrigated vineyards in the Riverland of South Australia, *Environment International*, 23(2),: 215-219, 1997.

Herriot, R.I., and E.J. Johnston, A soil survey of the Waikerie irrigation area, South Australia, *Bulletin of the Council of Scientific & Industrial Research*, 141, 1-44, 1941.

Journel, A.G., and C. Huijbregts, *Mining Geostatistics*, Academic Press, 600 pp., London, 1978.

Loveday, J., *Methods for Analysis of Irrigated Soils*, Commonwealth Agricultural Bureaux, 208 pp., Farnham Royal , 1974.

McDonald, R.C., R.F. Isbell, J.G. Speight, J. Walker, and M.S. Hopkins, *Australian Soil and Land Survey Field Book*, Inkata Press, 198 pp., Melbourne, 1990.

Sluggett, T., and T. Adams, Survey soils before developing or upgrading vineyards, *The Australian Grapegrower and Winemaker*, 32-33, November 1989.

Webster, R., and M.A. Oliver, *Statistical Methods in Soil and Land Resource Survey*, Oxford University Press, 316 pp., Oxford, 1990.

Wetherby, K.G., and J.M. Oades, Classification of carbonate layers in Highland soils of the Northern Murray Mallee, S.A. and their use in stratigraphic and land use studies, *Australian Journal of Soil Research*, 13,119-132, 1975.

Zirschky, J., Geostatistics for environmental monitoring and survey design, *Environment International*, 11, 515-524, 1985.