Assessment of soil variation by multivariate geostatistical analysis of EMI and gamma-radiometric data

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Abstract
An EMI survey provides data on the apparent soil electrical conductivity of the soil profile and this is often locally correlated with soil properties such as texture and pH. Occurrence of salinity, gravels and rocks in the landscape interferes with interpretation of the data. Complementary measurements are often used to infer soil properties. We surveyed a 200 ha cropping field in Western Australia with EMI and complementary gamma-ray spectrometer to delineate management zones. We applied a multivariate approach called multi collocated factor cokriging using seven variables measured during the survey: natural gamma-emission from potassium, thorium, uranium, total emission, measurements from two EMI sensors (EM38, EM31) and GPS height. A salty stream along the north-west boundary of the field influenced the spatial pattern of variation. The first anisotropic factor along the direction of the stream had a range of 900m and was mostly influenced by k emission. On the contrary, the first factor at shorter range on the orthogonal direction to the flow of the creek was dominated by topography. Factor cokriging resulted in partitioning of the field into three areas using the interquantile values as breakdown points after filtering outliers. The resulting spatial classification did not show clear spatial long-range structures.

Key Words
Management zones, electromagnetic induction, gamma emission, geostatistics, factor cokriging, GPS.

Introduction

Variation in soil properties across a field interacts with seasonal conditions and management to give rise to large variations in crop yields, deep drainage and nitrate leaching in rain-fed Mediterranean-type environment (Wong *et al.* 2006; Wong and Asseng 2006). This results in corresponding variation in fertiliser requirement. Delineation of management zones to represent clustering of soil properties relevant to crop productivity allows increased precision in field management. Traditional clustering techniques produce natural groupings of soil data in the attribute space without reference to geographical position, which may cause several spots of disjoint clusters to occur. We then preferred to use a multivariate geostatistical approach, based on Principal Component Analysis and called multi collocated factor cokriging, to enable us to estimate some synthetic indices describing the continuous spatial variation in the soils (Castrignanò *et al.* 2000).

An EMI survey provides data on the apparent soil electrical conductivity of the soil profile and this is often locally correlated with soil properties such as texture, plant available soil water storage capacity and pH. EMI-based methods cannot distinguish between sandy soils and gravels which have similar and low apparent electrical conductivities (EC_a). To overcome these shortcomings, we complemented EMI with gamma-radiometric survey which shows promise in high resolution soil property mapping (Wong *et al.* 2009). The spectrometer measures natural γ-emissions from the top 30-45 cm of the soil due to emitters such as ^{40}K and daughter radionuclides of ^{238}U and ^{232}Th. Ambiguity in the interpretation of radiometric data arises when soils with varying gravel and clay contents occur across the surveyed area: increases in clay content or proximity of gravels to the soil surface both result in strong signals. This problem is not encountered with EC_a-based methods since clays and gravels give rise to markedly different EC_a-values.

The objective of this work was to apply a multivariate geostatistical approach for delineating management zones based on complementary EMI and gamma-radiometric survey to improve management of field variation.

Methods

The 200 ha cropping field is situated 350 km north of Perth, at Buntine in Western Australia. We simultaneously measured (1) apparent soil electrical conductivity (ECa) across the field on 30 m line spacing with electromagnetic induction equipments (EM31, EM38 GEONICS, Ltd, Ontario-Canada), (2) γ-ray emission using an *Exploranium* γ-ray spectrometer with a large (8 l) thallium activated sodium iodide crystal scintillation detector and (3) differential corrected GPS location. EC_a, γ-ray emission and GPS location were recorded at 1 second intervals. The γ-ray spectra were resolved into the individual emissions from potassium, thorium and uranium according to their characteristic peaks.

Geostatistical analysis

Even if ordinary cokriging does not require the data to follow a normal distribution, variogram modelling is sensitive to strong departures from normality. Therefore, we transformed each initial attribute into a Gaussian-shaped variable with zero mean and unit variance (Chilès and Delfiner 1999)

To produce the maps of the original variables and of synthetic scale-dependent indices of spatial dependence, the multivariate spatial data were analysed by multi collocated cokriging and Factor Cokriging Analysis (FCKA) (Wackernagel 2003). The latter consists of a scale-dependent decomposition of the set of original second-order random stationary variables into a set of reciprocally orthogonal regionalized factors. The approach efficiently uses the auxiliary variable only at the target grid node and at all the locations where the primary variable is defined (Rivoirard 2001).

Results

Distributions of ECa, gamma-radiometric values were found to be strongly positively skewed (skewness varying between 1.37 and 2.31), whereas height distribution was symmetric (skewness = 0.02) but bimodal. An anisotropic LMC was fitted because the field slopes towards a salty creek, which forms its north-west boundary, and this creek drives zonal anisotropy along the direction 60 N, characterised by greater continuity (longer range and smaller sill) compared with the other directions. The model includes four basic structures: 1) a nugget effect, 2) an isotropic cubic model with range= 400 m, 3) an anisotropic Bessel K model in direction N150 with range = 500 m and parameter=1 and 4) an anisotropic Bessel K model in direction N60 with range = 900 m and parameter=1. The estimated maps are reported in fig.1 and show more uncertainty along the western boundary due to the scarcity of samples in the interpolation neighbourhood. Thorium, uranium and total counts look quite similar, whereas the information obtained from the potassium channel differs (Wong *et al.* 2009).

Low EM38 values of <10 mS/m, occurring approximately along the axis 442000 east, coincides approximately with a similar area for low emission from K. Areas of high EM38 values >45 mS/m, occurring along the western boundary of the field due to the presence of a salty creek, are not matched by high gamma-radiometric values.

To synthesise the multivariate variation of the field, the multi collocated factor cokriging analysis was applied to the seven Gaussian transformed variables. The sum of the eigenvalues at each spatial scale gives an estimation of variance at that scale. The main components of variation (about 44 and 36% of the total variance) occur at longer range (900 m) along the creek direction and in the orthogonal direction at shorter range (500 m), respectively. On the contrary, the contributions of the isotropic and the spatially uncorrelated (nugget effect) component to the total variance are lower (16% and 4%, respectively).

Only the eigenvectors producing eigenvalues greater than one should be retained, because their variation is assumed statistically different from residual variation. We focused in particular on the first factor at shorter and longer scale, which account for about 59% and 72% of the variation at the corresponding spatial scales, respectively. The loading values for the two factors indicate elevation and the radionuclides as the most inversely influencing the first factor at shorter range along the direction N150, whereas K and total gamma–ray emissions, and elevation and EM38 data at a less extension, weigh positively on the long range factor along the direction of the creek. All the variables, with the exception of elevation and k emissions, affect the isotropic variation at short range, but EMI data do that positively whereas gamma emissions negatively. Summarising we could say that there are three main factors controlling the spatial variation of this field: salinity, acting along the direction of the creek flow, topography along the orthogonal direction to the flow and texture acting isotropically.

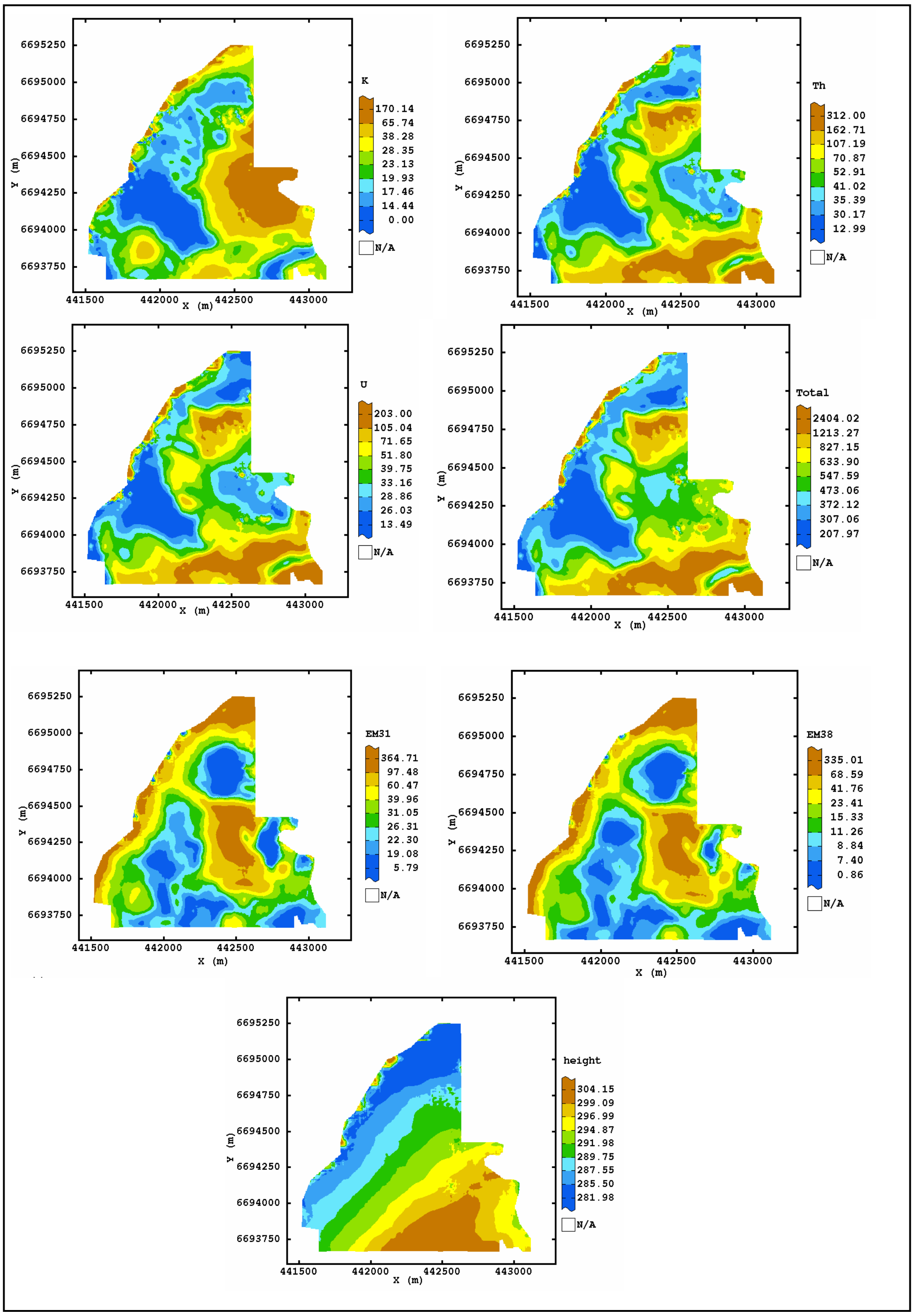

Figure 1. Spatial estimates of emission from potassium (K), thorium (Th), uranium (U), total emission (Total), apparent electrical conductivity measured by EM38 (EM38) and by EM31 (EM31) and GPS height (height).

Figure 2 shows the maps of the scores of the first factor for the two main components of variation at range 500 and 900 m. The scores were split into three zones by using interquantile values as breakdown points after filtering outliers. The map at shorter range shows a sequence of alternating strips parallel to the direction of the creek flow and a wide homogeneous area on the eastern side, corresponding approximately to the high values of k emission and EM38. The map at longer range does not reveal clear structures of spatial dependence but looks more variable and characterised by many stripes.

These results show that delineating “homogeneous” zones of such size to be differentially managed by the farmer might not be an efficient way to implement precision agricultural in this field, whereas a very fine VRT application of agronomic inputs would be preferred.

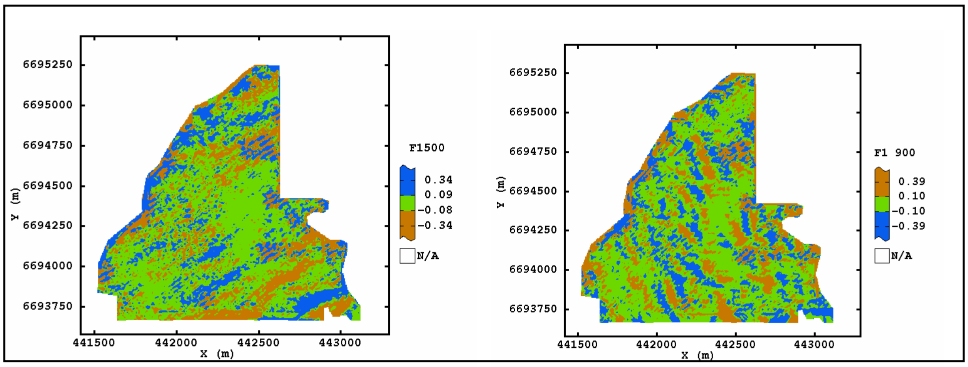

Figure 2. Short range (500 m) and long range (900 m) spatial estimates of the regionalized factors

Conclusions

In this study EMI and complementary gamma-radiometric data were used to delineate agricultural management zones by adopting a multivariate geostatistical approach. The resulting partitioning has not shown large areas to be differentially managed, probably owing to the interference of different soil processes.

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