An approach for delineating homogeneous zones by using proximal and remote sensing

R. Tamborrino[1], D. De Benedetto[1], A. Castrignanò[1]*, D. Sollitto[1], M. Rinaldi[1], S. Ruggieri[1], F. Santoro[2], B. Figorito[2], and S. Gualano[2]
[1] *CRA SCA - Research Unit for Cropping Systems in Dry Environments, 70125 Italy*
[2] *CIHEAM MAIB - Mediterranean Agronomic Institute of Bari, 70010 Italy*
annamaria.castrignano@entecra.it

Abstract

Spatial heterogeneity in soil properties has an impact on crop response. There is a growing demand for rapid and non-invasive acquisition of fine-scale information on soil and plant variation for site-specific management. Proximal (Electromagnetic Induction sensing (EMI), Ground Penetrating Radar imaging (GPR), hyperspectral spectroscopy (HS)) and remote sensing (RS)) can complement direct sampling. However, sensor data fusion techniques jointly analysing data from different sources, are still being developed.

In this work, homogenous zones within an 1.5-ha arable field were delineated through an approach combining EMI, GPR, HS and RS.

The multi-sensor data were split into four groups: 1) bulk electical conductivity (EC) from EMI data, 2) amplitude of GPR signal, 3) the first principal components related to five bands (green, yellow, red, rededge, near-infrared) of hyperspectral reflectance and 4) the vegetation indices (NDVI, NDRE and Near/Green) calculated from the remote sensing images. The data of each group were separately analysed and interpolated at the nodes of a 0.5 x 0.5 m-grid by using cokrigingor kriging. To obtain spatially contiguous clusters, a combined approach, based on multivariate geostatistics and a non parametric density function algorithm of clustering, was applied to the overall multivariate data set of the estimates.

This approach proved to efficiently analyze data from different sources and to be suitable for delineation of homogeneous sub-field zones in site-specific management.

Keywords: EMI, GPR, Hyperspectral Spectroscopy, Remote Sensing, Geostatistics.

Introduction

Spatial and temporal variation in soil properties and meteorological conditions may affect crop growth, yield and quality of produce. To increase farmers' profitability and environmental protection, management practices need to be adapted to variable site conditions. Recent research has focused on the use of management zones (MZs) in precision agriculture, that are defined as sub-field regions where the effects on the crop of seasonal differences in weather, soil, management, etc. are expected to be more or less uniform (Lark 1998). The final target is the production of 'treatment maps' for spatially variable-rate applications (VRT) of inputs such as water or fertilizer.

To produce accurate and cost-effective assessment of spatial variation, there is a growing demand for rapid, relatively cheap and non-invasive acquisition of fine-scale information on soil and plant. The traditional techniques of manual soil and plant sampling and conventional laboratory analyses are time consuming and too expensive at the required spatial resolution. Therefore, alternative methods are being considered to complement conventional survey for estimation of soil and plant properties. Geophysical methods provide indirect fine-scale information on various physical soil properties, whereas remote sensing, using recently launched satellites at fine spatial resolution, and on the ground hyperspectral sensors give fine-scale information on vegetation at different spectral resolutions.

The objectives of this study were to combine data coming from different sensors through geostatistical methods and to delineate spatially contiguous homogeneous subfield areas.

Materials and methods

Electromagnetic Induction

EMI soil survey is based on the principle of electromagnetic propagation in the subsoil. The apparent electrical conductivity was determined by an EM38DD (Geonics, Ltd, Ontario-Canada) with two identical dipole units, fixed perpendicular to each other.

Ground Penetrating Radar (GPR)

GPR produces a high-frequency electromagnetic wave, which propagates through the subsurface materials at the velocity determined by the soil dielectric permittivity. (Davis and Annan,1989). The data were acquired with a mono-static equipment (IDS Ing-manufactured, Italy) with an antenna of 600 MHz frequency.

World View 2 Satellite

WorldView-2 is a high resolution satellite providing images at half-meter panchromatic resolution and 1.8 meter multispectral resolution across 8 spectral bands in the visible to near-infrared range: coastal, blue, green, yellow, red, red edge band and two near infrared bands.

Fieldspec

ASD FieldSpec is a hand held hyperspectral radiometer (325-1075nm) with a high spectral resolution of 1nm and a wavelength accuracy of 3.5nm.

Mapping protocol

A 1.5 ha arable field, located in south-eastern Italy, was densely surveyed in May, between cabbage harvesting and tomato planting, and in September, after the tomato harvesting, using EMI sensor. A GPR survey was carried out in September, immediately after the EMI survey. The same field was also investigated with one WorldView-2 satellite image in July, when the tomato crop was grown.The spectroradiometric survey, using the hyperspectral radiometer was performed on tomato crop on three days: August 9th, 13th, and 19th. The tomato cultivation was submitted to two different water treatments: the south-eastern block with Optimal (OP) irrigation and the north-weastern block with Deficit (DE) irrigation.

Data analysis

The EMI data, in both horizontal and vertical orientation and the elevation measured by a DGPS, were jointly interpolated by using multigaussian cokriging (Goovaerts, 1997).

GPR data were preprocessed using some filters to suppress noise before calculating envelope of the signal, which gives an estimation of the energy distribution of the traces (De Benedetto et al., 2010).

The data were interpolated with block kriging and, in order to make the 3D estimates of GPR comparable with the 2D estimates of the other variables, were treated by sections parallel to the surface with a depth step of 0.30 m.

Raw WorldView-2 data were submitted to a radiometric correction process. The spectral radiance data were converted to spectral reflectance before the calculation of the vegetation indices: NDVI index = $(R_{NIR} – R_{red})/(R_{NIR} + R_{red})$, NDRE index = $(R_{NIR} – R_{rededge})/(R_{NIR} + R_{rededge})$ and the ratio index R_{Near}/R_{Green}.

For interpolation a Linear Model Kriging was used, which requires fitting a linear spatial covariance model.

For each date of August, Principal component analysis (PCA) was separately performed on the FieldSpec data of five spectral bands of the World View 2 satellite. The PCA approach was implemented by using the FACTOR procedure of the SAS/STAT software package (SAS, 2010). The retained principal components, relative to each date and each band, were jointly interpolated using cokriging.

To divide the fields into a number of soil clusters or classes without any previous information about the existence and the number of the groups, an algorithm, based on nonparametric density function estimate, was used (Scott, 1992).

The method can perform approximate nonparametric significance tests on the number of clusters. The clustering approach was implemented by using the MODECLUS procedure of the SAS/STAT software package.

All geostatistical analyses were performed with the software ISATIS (Geovariances, France, release 10.05.2011).

Results

There is a general consistency among the four EMI maps in the two polarization modes and on the two dates (Fig.1, only horizontal mode is shown), which means both a spatial continuity along the soil profile to approximately 1-m depth and a temporal consistency. In particular, the maps show an area with higher electrical conductivities in the SE part of the field. This area, as results from the elevation map (not reported here), corresponds to the lowest parts of the field. Moreover, since these maps were obtained with bare soil, they quite probably reflect differences in topography, texture and residual water content of the field.

The GPR maps, relative to the different depths (not reported) show a high consistency along the whole profile, with higher values of amplitude in the OP portion and along the W border of the DE portion of the field, and a wide central area characterized by lower values of amplitude. Variability generally decreases as a function of the depth because of the attenuation and might be due to differences in soil structure.

The maps of RS vegetation indices (not reported) do not show any clear spatial structure, probably due to the early growth stage of the crop.

The first principal components (PC_S), explaining most of the variance related to each wavelength group and at the three dates were retained and considered as new variables, replacing the original set of wavelengths.

Since variogram maps indicated zonal anisotropy along the longitudinal axis of the field, occurring for the green, yellow, red edge and NIR PC_S, whereas showing isotropy for the red PC_S, an anisotropic LMC was fitted to all variograms of the first 4 groups of PC_S, whereas an isotropic LMC for the red PC_S.

All the PC maps show a clear discrimination between the OP and DE blocks: green, yellow, red edge and NIR maps with higher reflectance in the irrigated area, whereas the opposite occurs in the red maps (Fig.2, only the green maps are shown).

The clustering approach delineated three compact homogeneous zones of different size (Fig.3). In particular cluster 1, corresponding to DE treatment, is characterized by the lowest bulk electrical conductivity and GPR amplitude, and by the highest red PC_S. The SE part of the field, corresponding to OP treatment, shows two clusters: cluster 2 with the highest values of green, yellow, red edge and NIR PCs, and the cluster 3 with the highest values of bulk electrical conductivity and vegetation indices, most likely because of higher water content in the soil and more luxuriant vegetation.

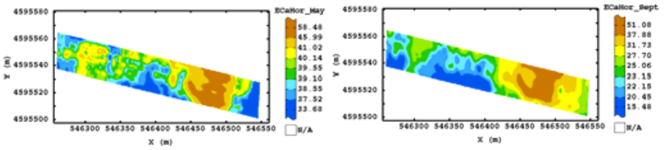

Fig.1. Maps of the electrical conductivity in horizontal orientation at the two dates.

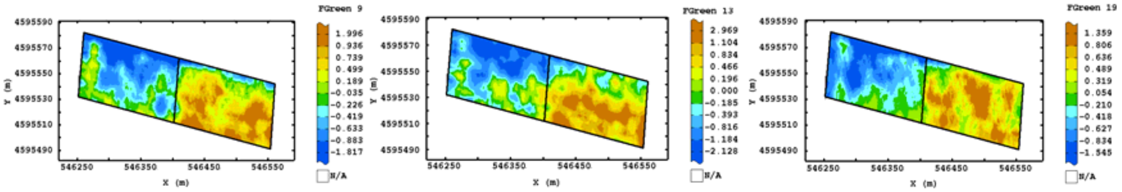

Fig.2. Maps of the green PC$_S$ on the three dates.

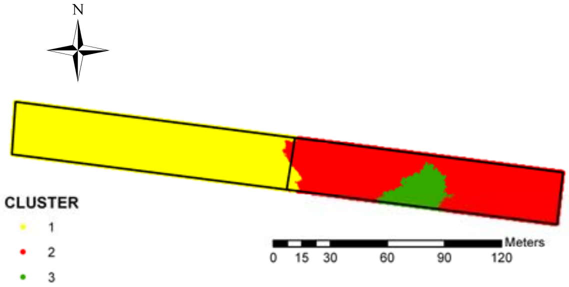

Fig.3. Cluster map.

Discussion and Conclusions

The cluster partition mostly reproduced the splitting of the field into the two irrigation treatments. However, the OP area showed higher variability, that migth be due to differences in topographic and/or physical soil properties. The proposed approach of sensor data fusion and clustering was then efficient to discriminate tomato plants in different water status.

Acknowledgements

This study is framed within the **AQUATER** project – A decision support system to manage water resources at irrigation district scale in Southern Italy using Remote Sensing Information.

References

Davis, J.L., Annan, A.P. 1989. Ground penetrating radar for high resolution mapping of soil and rock stratigraphy. Geophysical Prospecting **37** 531-551.

De Benedetto, D., Castrignanò, A., Sollitto, D., and Modugno, F. 2010. Spatial relationship between clay content and geophysical data. Clay Minerals **45** (2) 197-207.

Goovaerts P., 1997. Geostatistics for natural resources evaluation. Oxford University Press, New York 483.

Lark R.M. 1998. Forming spatially coherent regions by classification of multivariate data: An example from the analysis of maps of crop yield. Int. J. Geogr. Inf. Sci. **12** 83-98.

SAS Institute Inc. - 2010. SAS/STAT Software Release 9.1, Cary, NC, USA.

Scott, D. W. 1992. Multivariate density estimation: theory, practice, and visualization. New York: Wiley.