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Analysis of spatial interpolation for optimising management of a salinized field cultivated with lettuce

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Abstract

The lack of randomisation in irrigation experiments is usually a disadvantage. The introduction of spatial variable experimental design offers a convenient tool to help solving this problem. In order to understand the variation of some soil physical and chemical properties in an experimental block and its effect on lettuce (*Lactuca sativa* L.) production, graphical interpretation of those soil properties was done with the use of geostatistics in a geographic information system (GIS). In this work three techniques of geostatistics were used for the creation of several maps of soil properties in an experimental plot cultivated with lettuce. Lettuces were evaluated for individual weight and diameter at the end of the cropping season. The soil properties studied were: total mineral nitrogen, phosphorus, potassium, pH, electric conductivity and saturated soil hydraulic conductivity. The techniques used were: ordinary kriging, inverse distance and Thiessen polygon. Cross validation used to compare the prediction performances of the three geostatistical interpolation algorithms determined that kriging was the best technique for each soil property. Prior to the creation of the maps, semivariograms were produced for each soil property. The maps resulting from the interpolation techniques were introduced in a GIS and their values reclassified. After that, spatial modelling was used to develop a final overlay map from all the information of the analysed soil properties simulating a "lettuce production capability map". This final map was created with the objective to determine which areas in the plot had optimal conditions for lettuce development. It was concluded that the plot did not had an optimal area for lettuce production. Localized problems with soil properties were found that could be solved with simple geographically restricted amendment treatments. Final lettuce yield had high correlation ($r^2 = 0.83$) with the lettuce capability map derived.

Keywords: Geostatistics; Geographic information system; Salinity; Precision agriculture; Spatial variability

1. Introduction

Crops in the Mediterranean region are generally produced in fields that have a high degree of variability in soil type, topography, soil moisture and other major factors that affect crop production. Recent technological developments have paved the way for important and far-reaching changes in agricultural production practices. The geographical information systems (GIS), modelling and geostatistics are tools becoming progressively more suitable in fields of research like Agriculture (Ben-Asher et al., 1998; Gary et al., 1998; Bocchi et al., 2000; Basso et al., 2001). More specifically, these technologies can enable micro-management techniques on a site-specific basis to account for the natural and human induced variations that exist in agricultural fields such as variation in soil type, moisture, topography, chemistry, physical properties, and other factors. These technologies promise the possibility of optimising profit and reducing the adverse environmental impact of farming (Larson et al., 1997).

In recent years, major advancements have been made in the technologies required to implement precision farming practices (Yalouris et al., 1997). Traditional surveys of soil fertility, together with data from soil survey maps, can be used in combination with geostatistics by decision-makers to support management planning and to predict indicators related to soil quality as a measure of sustainability (Couto et al., 1997). Many authors used classical statistics and geostatistics to analyse the spatial variability of soil properties and crop yield (Sylla et al., 1995; Usowicz et al., 1996; Stevenson et al., 2001). Results obtained for a year can be used to suggest field specific improvements of management allowing a relatively high efficiency of natural resource-use also in years for which no statistical analysis were made (Casanova et al., 1999).

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Precision farming is an emerging technology and therefore limited research is available to practitioners who adapt precision agriculture for Mediterranean soils and crops. Christensen and Krause (1995) pointed out that computer literacy, GIS, global positioning system (GPS), expert systems, and remote sensing can provide knowledge-based management of agricultural production to reduce environmental impact.

While precision agriculture shows to be promising with respect to environmental quality, it also could increase profit margins. The variability within the field implies inefficient use of resources. Precision agriculture defines different management practices to be applied within single variable fields, potentially reducing costs and limiting adverse environmental side effects (Booltink et al., 2001).

Use of precision farming technologies requires better understanding of soil variability in physical, hydraulic and chemical properties. Some of that variation is natural and some is the result of the management history of the field (Sparovek and Schnug, 2001). Soils vary widely in their soil properties and in their ability to supply nutrients in quantities sufficient for optimal crop growth. Soils deficiency to supply nutrients to crops is aggravated by the fact that many modern cultivars of major crops are highly sensitive to low nutrient levels (White and Zasoski, 1999).

When irrigation water contains a large concentration of soluble salts, it could affect crop production if not properly managed (Letey et al., 1985). The mechanism affecting crop yield reduction is due to the fact that at high salinity, the water content at wilting point is higher than at low salinity, resulting in an insufficient amount of available water and, therefore, a reduced yield (Beltrão and Ben-Asher, 1997). Generalized results from crop yield models with saline water were developed by Solomon (1985) and Warrick (1989) and Plaut (1997) and Beltrão et al. (1997) have obtained the production of horticultural crops under salinity stress. However, lack of randomisation is usually the main disadvantage of this kind of experiments.

Geostatistics provides descriptive tools such as semivariograms to characterize the spatial pattern of continuous and categorical soil properties (Goovaerts, 1999). Various interpolation techniques take advantage of the spatial correlation between observations to predict attribute values at unsampled locations using information related to one or several attributes. From them, Thiessen polygon creates a polygon of influence for each sample and assumes that all values inside the polygon are equal. The inverse distance interpolator assumes that each input point has a local influence that diminishes with distance. It weights the point closer to the processing cell greater than those farther away. It does not allow assumptions required for the data, but it is good to take a first look in the interpolated surface (Longman et al., 1995). The kriging interpolator assumes that the distance or direction between sample points reflects spatial correlation that can be used to explain variation in the surface (Chilès and Delfiner, 1999).

An important contribution of geostatistics is the assessment of the uncertainty about unsampled values, which usually takes the form of a map of the probability of exceeding critical values for soil quality (Castrignano et al., 2002). This uncertainty assessment can be combined with expert knowledge for decision making such as description of contaminated areas where amendment measures should be taken or areas of good soil quality where specific management plans can be developed (Kitanidis, 1997). Ordinary kriging appropriately estimates values in unsampled areas and identifies places where more intensive sampling is required because the method yield estimates of the errors associated with interpolation.

Establishing relationships between spatially variable attributes is very important and will allow the development of new understanding that can be used in precision farming. To establish those relationships the impact of spatial field parameters on spatial distribution of crop yield and yield potential was evaluated and quantified. The main aim of the present work was to use geostatistical techniques to quantify the spatial variation of soil attributes and to improve the estimates of lettuce yield in a field irrigated with saline water.

2. Materials and methods

Spatial soil and crop data was collected for soil and lettuce in an experimental field of 46 m × 48 m located in Gambelas Campus at the University of Algarve. Lettuces were transplanted in the field on the 12th August, with spacing between plants 2 m × 1 m. The lettuces were irrigated during summer with saline water (ECw of 8 dS/m) with a sprinkler line passing in the middle of the field. The salinity gradient of the plot was obtained according to the concepts of Hanks et al. (1976) and Magnusson and Bem Asher (1990). Seedbed and basic fertilization of N, P_2O_5 and K_2O were made according to conventional agrotechniques and soil fertility analysis. Weeds were controlled manually and the control of pests and diseases was not needed. At the 22th October lettuces were harvested and it was measured weight and individual diameter. Experiment was repeated twice.

A total of 25 soil samples were collected as suggested for small heterogeneous fields by, Webster and Oliver (1990) and Carter (1993). Soil sampling was carried out at the end of the crop in a grid scheme of 6 m × 6 m, starting 4 m from the plot borders and the sprinkler line. Individual soil samples of about 1 kg were collected from each sampling position at a depth of 10–30 cm. The mixture of soil and coarse fragments was air-dried, weighed and carefully sieved through a 2 mm screen without breaking up fragile fragments. The fraction passing through the 2 mm sieve was split with a stainless steel riffle and saved for analysis. This fraction was analyzed for physical properties (texture, coarse fragments, particle density, specific weight), pH, electrical conductivity, as well as, the main macronutrients (available phosphorus, total nitrogen and exchangeable potassium).

Specifically, soil texture was determined with the Bouyoucos densimeter method (FAO, 1984). The pH and electric conductivity were measured in 1:2 slurry of soil and distilled water at 25 °C (Black, 1965). The Kjeldahl digestion method was used for nitrogen and the Olsen method by extraction with sodium bicarbonate at pH of 8.5 for the available phosphorus (Page, 1982). The exchangeable potassium was determined by atomic absorption using ammonium acetate extraction at pH 7 (Carter, 1993). Field-saturated hydraulic conductivity was determined