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Mapping soil and pasture variability with an electromagnetic induction sensor

João M. Serrano*, José O. Peça, José R. Marques da Silva, Shakib Shaidian

University of Évora, ICAAM, Apartado 94, 7002-554 Évora, Portugal

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ABSTRACT

The general objective of this study was to test a non-contact electromagnetic induction probe to evaluate the soil and pasture variability in a precision agriculture project. Assessment of the variability of soil and vegetation in a permanent pasture is the basis for management of variable rate fertilization, which is the main instrument used by farmers for improvements in permanent pasture in Alentejo, Portugal. The traditional process of sampling and evaluation of the soil is very demanding in terms of time, labour and reagents, and can derail a project of precision agriculture. This paper describes the major steps followed by the authors to simplify the methodology of soil evaluation in a permanent pasture based on measuring the apparent soil electrical conductivity. Tests were carried out in a parcel of approximately 6 ha, which was subdivided into 28 m × 28 m squares. The soil samples and the evaluation of apparent electrical conductivity were geo-referenced with a global positioning system. The geospatial data were processed by ArcGIS software and the statistical analysis resulted in significant correlation coefficient values between apparent electrical conductivity and altitude, soil pH and pasture dry matter yield.

1. Introduction

Previous research has shown that the amount of soil variability across a farm and within a field is of key importance for determining potential benefits of adopting precision farming (King et al., 2005). However, relatively little is known about the degree of within-field spatial variation in grassland and pasture production. Knowledge of this variation and of the underlying variability in soil properties is essential if we are to assess the potential benefits of adopting a site-specific approach to grassland and pasture field management.

Intensive grid mapping is generally regarded as one of the most accurate ways of mapping a field in detail (Brevik et al., 2006). Typically soil sampling, used to describe the variability of soil properties of the field and mapping, comprises grid-sampling and mapping approach as well as laboratory work, which is labour intensive, time consuming and expensive (King et al., 2005; Shibusawa, 2006), and thus impractical at the farm scale (McCormick et al., 2009). Therefore, it is desirable to find other, more rapid means of obtaining information for detailed soil mapping (King et al., 2005; Brevik et al., 2006).

Most of the available technology is currently being applied to arable land but not to grassland or pasture, even though the latter contributes substantially to agricultural land use as well as to capital and income (Schellberg et al., 2008). Site-specific soil and crop management require rapid low-cost sensors that can generate position-referenced data that measure important soil properties that impact crop yields. Apparent soil electrical conductivity (EC_a) is one such measure (Bronson et al., 2005; Corwin and Lesch, 2005b). Soil electromagnetic induction scans have become one of the most reliable and frequently used measurements for characterizing the spatial variation within fields (McCormick et al., 2009). As the soil is not uniform, the term "apparent electrical conductivity", which is the electrical conductivity of a uniform soil with the same reading, is used (Dafonte, 2004). With development of sensors for monitoring the soil, data can be obtained without disturbing the soil and with higher spatial resolution than that obtained through manual or laboratory methods. Apparent soil electrical conductivity mapping, using an electromagnetic induction sensor (EMI) linked to a global positioning system (GPS) provides a simple, inexpensive and non-invasive alternative tool for characterizing within-field differences in the soil (McCormick et al., 2009; Moral et al., 2010). There has been an increase in the interest in this technology as a result of the high spatial resolution that can be obtained by GPS, used for determining the spatial variability of soil properties (Proffitt et al., 2006). Dafonte (2004) has confirmed that development of sensors for measuring electrical conductivity is closely related to implementation of the concept of precision agriculture and the use of GPS in agriculture. EMI is a technique that measures EC_a by inducing an electric current in the soil. The soil EC_a is controlled by a combination of soluble salts content, clay mineralogy, soil water content and soil temperature (Brevik et al., 2006). As well as providing a correlation with soil properties, conductivity mapping can also be used for delineating management zones and soil boundaries (Stafford, 2006; Moral et al., 2010).

* Corresponding author.
E-mail address: jmrs@uevora.pt (J.M. Serrano).

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Fig. 1. Determination of soil profile (left) in top hills (centre) and bottom valley (right) in the experimental field.

Many reports and observations indicate that EC_a values are related to soil properties and fertility parameters and are also related to yield; hence real-time EC_a sensing and mapping has been an attractive approach in precision farming (Shibusawa, 2006). According to Mallarino and Wittry (2004), soil electrical conductivity has been useful in estimating top soil depth and physical and chemical soil properties, as well as explaining yield. This research evaluates analysis of electromagnetic induction soil sensing as a potentially cost-effective method for identifying and mapping soil-determined "management zones" within fields (King et al., 2005). Inamassu et al. (2007) have confirmed that although the electrical conductivity maps of the soil with a 1 m resolution do not replace laboratory sample analysis, they do provide a guide for collecting strategic samples through identifying homogeneous zones.

Various authors have concluded that an EMI sensor can provide useful information regarding the spatial variation of certain soil properties, and more general soil patterns within fields. Such patterns have been related to yield maps and soil type maps within fields, both visually and statistically, and the technique holds promise for a cost-effective way in which the variation of soil properties can be measured rapidly over large areas. According to Netto et al. (2007) electrical conductivity expresses concentration of soluble salts in the soil. Since apparent soil electrical conductivity is a function of some of the soil's properties and is directly correlated with texture variations and the soil's moisture levels, pH value and depth as well as its cation exchange capacity and clay mineralogy, electrical conductivity can be used as an indirect measure of these characteristics if contributions of other soil properties that affect it are known or can be estimated (Dafonte, 2004; Couto et al., 2005; Inamassu et al., 2007). Netto et al. (2007) have verified significant correlation between the pH and concentration of exchangeable sodium in the soil, and have confirmed a significant positive correlation between electrical conductivity and concentration of salts in the soil. Soil factors affecting EC_a vary depending on location and may include one or more of the following: salinity, clay type and percentage, bulk density, moisture, and temperature. With regard to soil moisture content, Brevik et al. (2006) registered greater difference between soil EC_a values when the soils were moist than when the soils were dry. King et al. (2005) carried out EMI surveys across the fields at two times in the year, when the soil was at field capacity and also after harvest, when it was near maximum dryness. Site mean EC_a was only marginally smaller in the summer compared with the winter. However, the difference in moisture contents across the sites in the two contrasting seasons proved insufficient to alter the basic pattern of EC_a maps and hence the technique's value as a site surveying tool is sustained. This demonstrates a basic stability of pattern across wet and dry seasons. The EC_a techniques may prove to be a more effective soil-mapping tool in the spring or at other times when the soil profile is moist and less effective during dry periods. Soil factors contributing to EC_a are also yield limiting. Significant relationships have been found between EC_a, soil characteristics, and crop yields (Johnson et al., 2005). Klar (1988) has found differentiated crop responses as a function of concentration of salts in the soil, assuming that their concentrations can be quantified using electrical conductivity values. Soil properties associated with yield potential, were negatively correlated with EC_a at one or both depths of measurement. Properties indicative of increased salinity and decreased yield (pH) were positively correlated with EC_a. In some cases, apparent soil electrical conductivity mapping can be used to identify the soil fertility gradient (Johnson et al., 2005).

The general objective of this study was to test a non-contact electromagnetic induction probe in order to evaluate the soil and pasture variability in a precision agriculture project through establishing correlations between apparent soil electrical conductivity and soil properties and between apparent soil electrical conductivity and pasture yield.

2. Materials and methods

2.1. Experimental field

The experimental field, with an area of about 6 ha, is located in the Herdade da Revilheira (coordinates 38°27′51.6″N and 7°25′46.2″W), about 40 km Northeast of Évora, in the Alentejo region (Southern Portugal). The predominant soil of this field is classified as LUVISOL (FAO, 1998). Soil depths vary between 0.20 m at the higher elevations of the field to more than 1.0 m at the lower positions (Fig. 1). A permanent bio-diverse pasture was established in this field in September 2000, in a flexible rotation system for grazing sheep, throughout the year. The field was maintained and improved by an annual homogenous application of 54 mg kg^{-1} of P_2O_5, during the months of September/October. Results of various studies confirm that phosphorus fertilization increase pasture dry matter productivity (Martiniello et al., 1995; Gatiboni et al., 2000; Daniels et al., 2001). Between 2004 and 2007 the field was integrated into a precision agriculture project financed by the Portuguese government, in order to demonstrate new technologies for variable rate fertilization. With the help of a Trimble 4700 GPS-RTK, the experimental field was divided into 76 squares, 28 m × 28 m