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Field-scale electrical resistivity profiling mapping for delineating soil condition in a nitrate vulnerable zone

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ABSTRACT

Venice Lagoon is an extremely heterogeneous environment conditioned by natural changes and anthropogenic pressures. The area is a particularly vulnerable system characterized by high spatial geomorphological variability. Site-specific crop management, defined as the best strategies to manage heterogeneous farmlands, has the potential to maximize agricultural production while preserving soil and water resources. This work was aimed at identifying and characterizing spatial variability within the fields in terms of soil fertility and productive potential using precision agriculture principles. Automatic resistivity profiling (ARP) was implemented to study spatial variability of the field and to define the best localization of twenty soil sampling points. Three years' historical yield maps were used to determine homogeneous zones within the study area. The application of a fuzzy c-means clustering algorithm led to classification of four homogeneous zones, which were assigned with productive potentials using an ANOVA test of soil features and historical yield data. Such classification was validated by a comparison of the homogeneous zone's productive potential with five-year average production.

1. Introduction

The Venice Lagoon (Italy, North-Adriatic Sea) is an extremely heterogeneous environment conditioned by natural and anthropogenic pressures (De Franco et al., 2009). The area is a particularly vulnerable system characterized by high spatial geomorphological variability (Scudiero et al., 2013).

Regarding arable lands, crop-yield response is influenced by spatial and temporal soil variability (Basso et al., 2016; Pezzuolo et al., 2017). Therefore, variability of soil features within a field cannot be managed using conventional farming practices (Robert, 2002). Site-specific crop management, defined as the best strategies to manage heterogeneous farmlands, has the potential to maximize agricultural production while preserving soil and water resources (Wallace, 1994; Pezzuolo et al., 2014).

Adoption of new technologies to investigate the field-scale variability (Pezzuolo et al., 2016; Dubbini et al., 2017) is the first step to achieve a successful site-specific management plan (Marinello et al., 2017a). Despite recognition of the heterogeneous nature of soil features, the lack of sensitive tools to detect subtle shifts among soil properties has limited spatial characterization of such variability. In fact, the implementation of traditional sampling methods is inadequate for assessing the interrelated physical, chemical, and biological soil properties responsible for variations in crop yield (Cillis et al., 2017).

Over the last decade, non-destructive geophysical sensors designed to measure the soil electrical conductivity (or its inverse resistivity) have been extensively used to map the complex patterns in soil conditions that contribute to agronomic yield potential (Peralta and Costa, 2013; Marinello et al., 2017b). The purpose of Electrical Resistivity (ER) surveys is to determine the resistivity distribution of the surrounding soil volume (Johnson et al., 2001). Artificially generated electric currents are applied to the soil and the resulting potential differences are measured.

Potential difference patterns provide information on the form of subsurface heterogeneities and their electrical properties (Kearey et al., 2002; Lardo et al., 2012). High level of soil matrix heterogeneity leads to a change in ER detection that allows to better investigate soil-spatial variability. ER of the soil can be considered as a proxy for the variability of a soil's physical properties (Banton et al., 1997; Samouelian et al., 2005; Basso et al., 2010) including texture (Brus et al., 1992; James et al., 2003; Saey et al., 2009), type (Anderson-Cook et al., 2002), and moisture (Reedy and Scanlon, 2003; Sherlock and McDonnell, 2003; Zhu et al., 2010). These advantages may include lower cost, increased capacity and efficiency, and more timely results (Marinello et al., 2015). Moreover, the ability of a sensor to provide high resolution characterization, as compared to sampling and removal methods, allows for an increase of overall spatial estimation accuracy even if the accuracy of individual measurements is lower (Valckx et al., 2009;

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Sudduth et al., 2013). Furthermore, ER can be implemented as an indirect measure of other soil properties (Jaynes, 1996) and thus used as an indicator of crop production.

The increasing number of soil and crop sensors provides an opportunity for definition of a site-specific crop management plan, and enables the synergistic use of observations from different sensors for a better understanding of land processes (Marinello et al., 2016) such as spatial variations or delineation of homogeneous zones at farm scale (Tucker et al., 2005). In this regards, Precision Farming (PF) plays an important role in term of within field management variability. In fact, PF describes the application of technologies, principles and strategies that are variably managed over space and time to increase crop production and protect environmental resources. (McBratney et al., 2005). Independent management of spatial and temporal variability of different portion of a field is one of the primary advantages of PF (Basso et al., 2001, 2007). Besides, variable rate treatments (VRT) on stable homogenous zones promote high crop yields, improve economic returns and reduce negative environmental consequences (Bertocco et al., 2008; Basso et al., 2016).

The present work aims to study within-farm soil variability using a multi-depth automatic resistivity profiler (ARP©, Geocarta, France). The objective was to test the ability to delineate the homogeneous zones at farm scale and productive potential through an analysis of the relationship between resistivity and historical yield data.

2. Material and methods

2.1. Experimental site and agronomic management

The experimental study was carried out in the demonstrative farm of Vallevecchia (45.63° N, 12.95° E) within the AGRICARE LIFE^{+} project (LIFE13 ENV IT AGRICARE 0583).

The study area covers a surface of 23.5 ha (500 m long by 470 m wide). Soil type is mainly sandy-loam (Molli-Gleyic Cambisols, FAO, 2001). It belongs to the Venice-Lagoon district, and most of the surface is below average sea level (asl) (Fig. 1). This condition leads to high-spatial variability derived from saltwater intrusion affecting crop production (De Franco et al., 2009). From the agronomic point-of-view, the study area was managed with conventional tillage technique, provided by ploughing, in a specific crop rotation: corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and wheat (*Triticum aestivum* L.).

The average annual rainfall (935 mm year^{-1}) and temperature (13.7 °C) were determined from a 20-year dataset recorded at a nearby agro-meteorological station. Rainfall was distributed mostly in the Fall and the Spring, while a monthly maximum of 23.8 °C in July and a minimum of 3.6 °C in January.

2.2. Study of the field-variability

In order to get a quantitative characterization of variability, field-data regarding soil and crops features must be collected accurately. To collect data representative of the whole field, a non-random pattern of sampling was used. The definition of homogeneous zones can be achieved in different ways, taking advantage of proximal or remote sensors providing information on soil, vegetation, and yield. The study started in September 2014 before the new crop-cycle started.

The study of soil-variability includes information derived from aerial-image, yield-maps of previous years, and soil-analysis. Satellite image gave preliminary information about the field, and it was also useful to define the boundaries and select the yield and soil resistivity data belonging to the study area. Besides, it represents the first layer in which all the collected data were overlapped for their interpolation.

Technological developments in soil analysis have led to new, non-invasive analysis methods. Such methods are not based on collection of soil samples but, allow high-resolution characterization of the soil-surface and have the potential to provide information at different depths. Non-invasive methods don't replace classic soil sampling approaches but can enhance efficiency which allows for a reduction of the number of soil-samples. One of the most important non-invasive soil analysis methods is the Automatic Resistivity Profiling (ARP© GEOCARTA, Paris, France) (Tabbagh et al., 2000). ARP is an on-the-go multi-depth resistivity technique able to rapidly develop an accurate resistivity profile of soils. It is composed by four pairs of toothed wheels that function as electrodes. The first pair of wheels inject current into the ground while the following three pairs of wheels, spaced at increasing distances, work as receiving electrodes (Fig. 2).

The equipment is pulled through the field to collect data at three different depths simultaneously (0–0.5; 0–1; 0–2 m) which is then referenced in real-time by the differential global positioning system (DGPS). Acquired spatial information and computation of a Digital-elevation-Model (DEM) provides topographic attributes as slope and position; generating complementary information that facilitates the interpretation of resistivity variation and the definition of homogeneous zones. The ARP system creates the ability to both analyze the variability of the entire fields' surface and collect information at three different depth levels. In addition, all data is geo-referenced, therefore, the ARP system can be used as an indicator for precise spatial recognition of soil characterizations. In this study, the resistivity measurement was taken on transects spaced 5 m apart. Twenty sampling points were selected to verify field variability, as depicted in Fig. 3.

For each-sample point, soil samples were collected at three depths (0–0.1; 0.1–0.3; 0.3–0.6 m) in order to assess pH, soil-organic-matter (SOM), texture, salinity, electrical-conductivity, nitrogen and phosphorus content. All of the sample points were geo-referenced for future analysis of changes in soil features. Crop-yield data was collected and geo-referenced by a combine equipped with sensors able to assess yield at a specific point (AgroCOM – Claas Agrosystems GmbH Germany) and a DGPS system that provides localization of yield-data. The study considered three years of historical yield-maps, specifically corn-2012, soybean-2013, and wheat-2014. To obtain a representative information of the real field crop production, the yield-mapping system was calibrated each year for the different crops following the instruction provided by the company. In addition, yield-maps were post-processed, filtered, and adjusted before starting the analysis. Yield-maps were

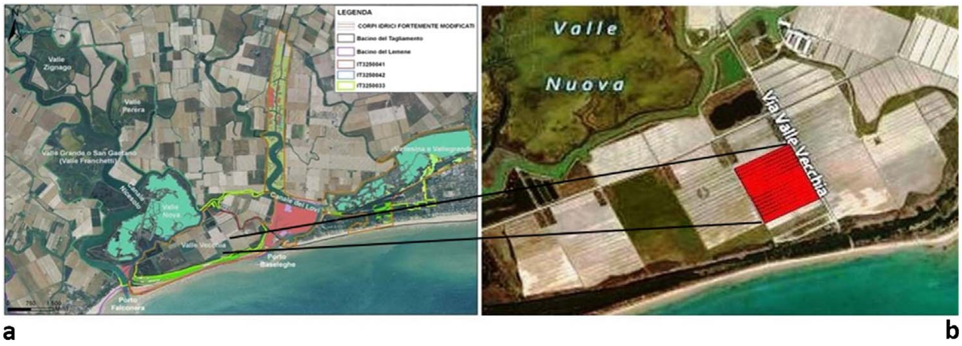

Fig. 1. Map of the study area showing the canal network of the study area side of Venice Lagoon (a), and the study area located in proximity of the sea (b).