RELATIONSHIP BETWEEN SATELLITE-DERIVED NDVI AND SOIL ELECTRICAL RESISTIVITY: A CASE STUDY

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Abstract

Efficient and reliable methods for measuring spatial variations in soil properties are fundamental in precision agriculture.

In the present work a survey on soil variability and within-farm plant is reported, coupling a multi-depth automatic resistivity profiler (ARP©, Geocarta, France) and the NDVI index derived from Sentinel-2 imagery data. Based on the relationship between resistivity and NDVI index, the objective of the analysis was to test the possibility to monitor the evolution of vegetation index and modulate the agricultural operations depending on soil features and soil tillage techniques management on soft wheat (Triticum Aestivum L.).

A comparison of the same homogeneous zones managed with different soil tillage techniques shows an increase of NDVI index from conventional tillage (CT) to minimum tillage (MT) and no-tillage (NT). This is caused by conservation tillage techniques which allow a mitigation of cooling phenomena, higher availability of nutrients and lower number of passages across the field preventing soil compaction.

Key words: geophysical mapping, normalized difference vegetation index, durum wheat, soil spatial variability, remote sensing, precision agriculture.

INTRODUCTION

Efficient and reliable methods for measuring spatial variations in soil properties are fundamental in precision agriculture (PEZZUOLO ET AL., 2014; BASSO ET AL., 2016). Over the last decade geophysical sensors based on the non-destructive measurement of soil electrical conductivity (or its inverse resistivity) have been extensively used in precision agriculture (PERALTA AND COSTA, 2013; ROSSI ET AL., 2015). These advantages may include lower cost, increased capacity and efficiency, and more timely results (MARINELLO ET AL., 2015). In addition, the ability of a sensor to collect data at many more points, as compared to sampling and removal methods, provides an overall increase of spatial estimation accuracy even if the accuracy of individual measurements is lower (SUDDUTH ET AL., 2013).

At the same time, satellite and airborne sensors offer an increasing amount of information about soil properties and ground cover (NOUVELLON ET AL., 2001). In particular, vegetation indices, based on remotely-sensed spectral reflectance in the near-infrared and visible bands, have been widely used for monitoring vegetation cover and health condition, plant phenology, and ecosystem changes (GONG ET AL., 2012). Among many vegetation indices such as Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Enhanced Vegetation Index (EVI), NDVI has been most commonly used for vegetation-related monitoring in numerous studies (KE ET AL., 2015). However, the increasing number of satellite sensors provides great opportunities for NDVI derivation at various spatial and temporal scales, and enables the synergistic use of observations from other sensors to better understand land processes (TUCKER ET AL., 2005) such as spatial variations or delineate the homogeneous zones at farm scale.

In the present work a survey on soil variability and within-farm plant is reported, coupling a multi-depth automatic resistivity profiler (ARP©, Geocarta, France) and the NDVI index derived from Sentinel-2 imagery data.

Based on the relationship between resistivity and NDVI index, the objective of the analysis was to test the possibility to monitor the evolution of vegetation index and modulate the agricultural operations depending on soil features and soil tillage techniques management on soft wheat (Triticum Aestivum L.).

MATERIALS AND METHODS

Site description and experimental management

The study was carried out in the 2015-2016 season in a farm located in Caorle (VE) – Veneto, Italy (45.63°N 12.95°E). From a climate point of view, the average annual rainfall in 20 years recorded by an agro-meteorological station located in nearby Lugugnana (VE) were equal to 935 mm·year^{-1}.

The study considered wheat (Triticum Aestivum L.) crop cultivation, managed with three soil tillage techniques (Tab. 1), characterized by the different impact to the soil, and by decreasing order are: conventional tillage (CT), minimum tillage (MT) and no tillage (NT). Each plot was characterized by an average 1.5 ha area.

Tab. 1. – Agricultural practices for each tillage systems adopted by the farm

Tillage System	Agricultural practices	Date	Product	Rate
CT	Pre-sowing fertilization	27/10/2015	NPK fertilizer (8-24-24)	400 kg·ha^{-1}
	Sowing	27/10/2015	Wheat – var. Solehio	450 seeds·m^{2}
	Tillering fertilization	28/01/2016	Ammonium nitrate (26 %)	200 kg·ha^{-1}
	Stem elongation fertilization	15/03/2016	Urea (46 %)	200 kg·ha^{-1}
MT	Pre-sowing fertilization	27/10/2015	NPK fertilizer (8-24-24)	400 kg·ha^{-1}
	Sowing	27/10/2015	Wheat – var. Solehio	450 seeds·m^{2}
	Tillering fertilization	28/01/2016	Ammonium nitrate (26 %)	200 kg·ha^{-1}
	Stem elongation fertilization	15/03/2016	Urea (46 %)	200 kg·ha^{-1}
NT	Pre-sowing fertilization	27/10/2015	NPK fertilizer (8-24-24)	400 kg·ha^{-1}
	Sowing	27/10/2015	Wheat – var. Solehio	500 seeds·m^{2}
	Tillering fertilization	28/01/2016	Ammonium nitrate (26 %)	200 kg·ha^{-1}
	Stem elongation fertilization	15/03/2016	Urea (46 %)	200 kg·ha^{-1}

Automatic resistivity profiling

On-the-go multi-depth resistivity measurements (ARP©, Geocarta) were carried out on the whole 4.5 ha area. The ARP instrument consists of a console that collect electrical data derived from a succession of electrodes represented by four toothed metal wheels; the electrodes are inserted into the soil through the movement of rotation of the same wheels along the ground surface. The first dipole enters a stabilized current to the subsoil, the following three wheels measure the potential that derives from the injected current. The distance between the three dipoles increases with the current introduction distance (equatorial dipole). The distance is respectively 0.5 m, 1 m and 2 m. Data were real-time referenced by differential global positioning system (DGPS). Data were collected along parallel transects at 5 m apart.

Remote sensing data collection

Data needed to assess NDVI vegetation index during crop cycle were derived from Sentinel-2 mission's satellites. Sentinel-2 mission provides continuity to services relying on multi-spectral high resolution optical observations over global terrestrial surfaces. The mission is characterized by a high quality multi-spectral Earth observation system implementing the Multi Spectral Instrument (MSI) with 13 spectral bands spanning from the visible to the short wave infrared. The spatial resolution ranges between10 m and 60 m (depending on the spectral band) with a 290 km field of view (DRUSCH ET AL., 2012). The present work took into consideration 5 satellite spectral bands, from 20 January 2016 to 30 March 2016, selecting only high signal to noise rate clear maps and excluding those presenting a marginal interference caused by clouds or fog.

Data elaboration and statistical analysis

Data derived from Sentinel-2 images are relative to different dates. In this way, it was possible to collect multispectral-data during crop development. These data were useful to assess NDVI index of the wheat. In order to evaluate such vegetation-index, red and infrared multispectral bands are needed: in this study the so called B4 and B8 spectral bands were specifically considered, featuring respectively 665 and 842 nm central wavelength with 30 and 115 nm band width.

Firstly, ARP data were divided in classes representing step values of resistivity of 5 Ohm·m in order to evaluate the correlation between ARP and NDVI. Then, ARP data derived from all 3 depth levels were processed using the statistical software MZA-Management Zone Analyst - University of Missouri-Columbia (FRIDGEN ET AL., 2004). MZA uses a fuzzy c-means unsupervised clustering algorithm that assigns field information into like classes, or potential management zones (Fig. 1).

In order to performs the analysis, NDVI and ARP data were standardized building a 10 x 10 m reference grid with a total of 488 control points ("pixels"). Each pixel of the grid has an average value of NDVI and ARP defined as the mean of the values included into the same pixel area.

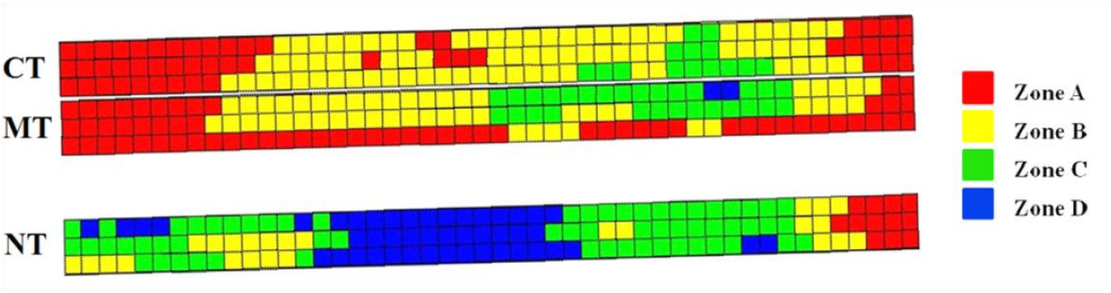

Fig. 1. – Homogeneous zones derived from MZA analysis

RESULTS AND DISCUSSION

Data analysis relationship

Soil resistivity data showed that the study area is characterized by high variability in terms of soil features. In fact, a wide range of resistivity was observed. Soil resistivity is mostly influenced by texture, water content and salinity. Therefore, high resistivity levels characterize sandy soil with high water drainage, while low resistivity levels distinguish clay soil with high salinity that can occurs in stagnant situation if affected by soil compaction. To this end, the result of classes division based on the ARP depth level 0-50 cm was 18, each one ranged in 5 Ohm·m. In order to avoid interference related to unexpected data the average of the 5 dates NDVI data was taken into consideration. As shown in Fig. 2, a clear correlation can be detected between soil features and vegetation vigour. Increases in ARP value correspond to high vegetation vigour expressed as NDVI.

On the other hand, high values of standard deviation of several classes shows high variability within data. This can be ascribed to the presence of other factors affecting the relation between NDVI and ARP. Different soil tillage techniques adopted in the study area are certainly one of the first factors causing such variability, as discussed in the following.

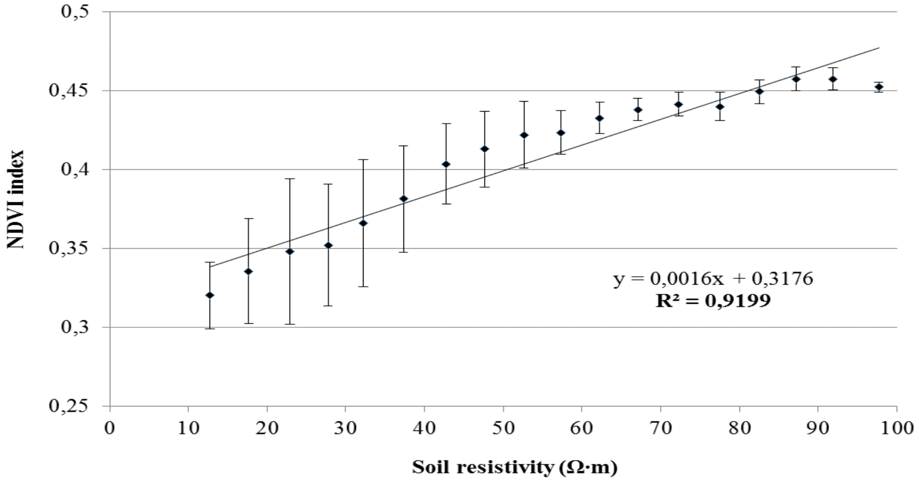

Fig. 2. – Correlation between soil features and vegetation vigour. Increases in soil resistivity value correspond to high vegetation vigour expressed as NDVI index.

Relationship under MZA's homogeneous zone characterization

In this second step, a characterization of homogeneous zones of the study area based on ARP data has been made. In this way it is possible to compare NDVI index belonging to the same homogeneous zones managed with different soil tillage techniques. From the MZA analysis, 4 homogeneous zones have been characterized: 3 of them cover all the tillage conditions, while the forth zone affects only the side of the field managed with MT and NT. These homogenous zones (namely A, B C and D) are characterized by increasing ARP values. Again a high correlation between NDVI and ARP was found (Fig. 3).

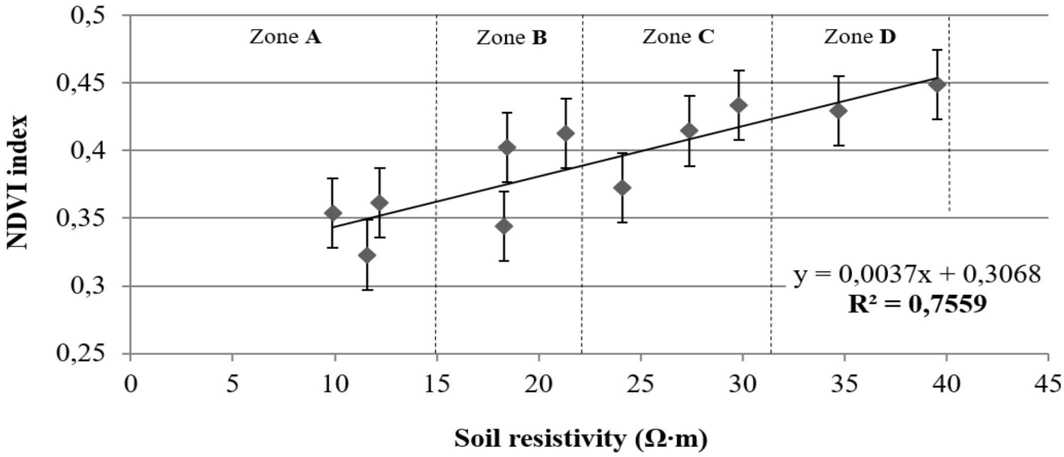

Fig. 3. – Homogenous zones are characterized by increasing soil resistivity values and NDVI index

Besides, standard deviation was approximately the same for each point meaning that the homogeneous zones characterization made by MZA software is more representative of the relation between NDVI and ARP than the first classification approach made by the authors. This is due to the fact that MZA use the ARP data derived from all the 3 depth level to classify homogeneous zones. Homogeneous zone A, having lower level of resistivity, has lesser NDVI value than other zones. This trend is repeated for B, C and D zones. This evolution of the vegetation vigour in wheat could be ascribable to the higher soil temperature, a higher drainage efficiency and a more suitable seedbed characterizing homogeneous zones with increasing resistivity level.

Soil tillage system effect

Finally, it is possible to observe the NDVI temporal trend of the single homogeneous zones under different soil tillage techniques management. Correspondingly the contribution of the soil tillage technique on NDVI index and the influence on soil features can be investigated (Fig. 4).

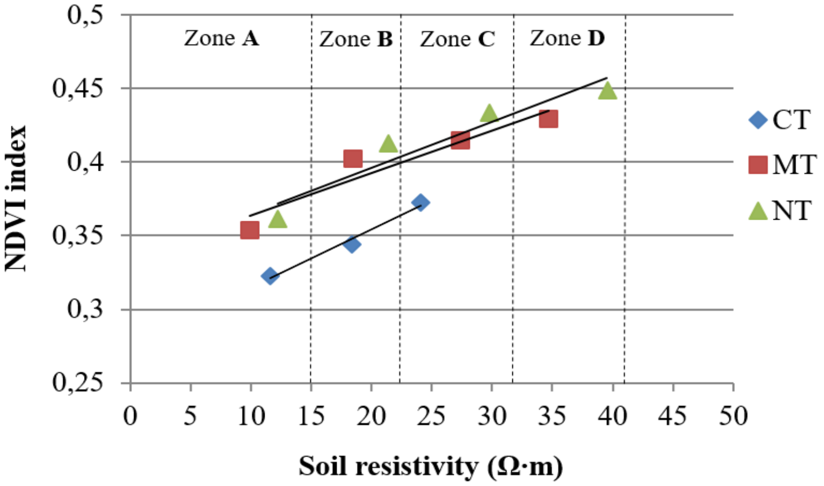

Fig. 4. – NDVI trend of the single homogeneous zones under different soil tillage techniques management

Considering approximately similar the sowing dates and the soil features characterizing the study area, CT shows lower NDVI than MT and NT for all homogeneous zones. This is caused by its features: indeed, CT tends to cool soil faster than MT and NT. In addition, continually inversion of soil layer leads to a decrease in soil fertility and nutrients availability. Finally, the higher number of passages distinguishing CT for the seedbed preparation could affect soil compaction leading to a stress condition for plants growing in the field defined by clay soil. Conversely, MT and NT do not include inversion of soil layer and they need a lower number of passages across the field. Besides, their features lead to a mitigation of soil cooling phenomena allowing fast seeds germination.

NDVI trend during crop development

All of these information can be seen under two complementary points of view. The first one considers the possibility to assess the vegetation vigour starting by soil features, and its evolution under different soil tillage techniques management. The second one is to monitor crop during its cycle and to take decision about agricultural operations taking advantage of vegetation indexes, soil features and soil tillage techniques management. Fig. 5 shows the NDVI trend during the time from the first monitoring date (day 0, on 20 January 2016) to the fifth one (day 69) and the dates of the two nitrogen fertilizer applications.

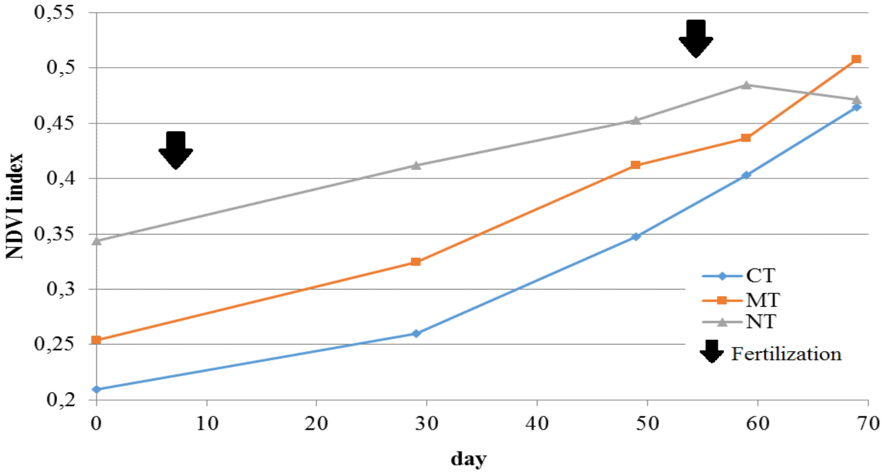

Fig. 5. – NDVI trend during the time from the first monitoring date (day 0, on 20 January 2016) to the fifth one (day 69) and the dates of the two nitrogen fertilizer applications

It is interesting to note that the CT's curve slope is more accentuate than other theses, suggesting in a later increase of the NDVI index during the crop cycle. In fact, the NDVI values related to the last monitoring date are close for all the theses, even observing a decrease in NT. This condition could be due to the CT soil warming faster than other theses and to a better response to nitrogen fertilization.

CONCLUSIONS

Monitoring vegetation vigour during crop cycle and relating its evolution to soil features is useful to identify the optimal agricultural operation to carry out under different soil tillage techniques management. Besides, collecting information derived from other sources such as climate data and historical crop yield data it is possible to modulate those operations which provide fertilizer application. Regarding wheat, a correlation was verified between vegetation index expressed as NDVI and soil feature represented by ARP analysis. In addition, the implementation of MZA allows to obtain steady homogeneous zones derived from the interpolation of different data highly correlated with NDVI. A comparison of the same homogeneous zones managed with different soil tillage techniques shows an increase of NDVI index from CT to MT and NT. This is caused by conservation tillage techniques which allow a mitigation of cooling phenomena, higher availability of nutrients and lower number of passages across the field preventing soil compaction. Repeating and validating the results of this work in the next years in order to model the correlation between NDVI and ARP data for the different soil tillage techniques management could be useful in the future to predict crop yield in wheat.

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