Aerial Spectral Index Analysis for Differential Management Zone Delineation in a Maize Field

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Abstract

Inhomogeneities of soil properties are responsible for within-field variations on the growth and final yield of crops. In this paper the variations of a Normalized Difference Vegetation Index (NDVI) field map, obtained through a camera mounted on an Unmanned Aerial Vehicle, were correlated with soil and plant properties measured in a typical maize cultivated field. Subsequently, the perspective of organizing the field into differential management zones through the NDVI was evaluated. The coefficient of variation for sand, silt, clay and soil organic matter content at five points was found to exceed 11% while the corresponding value for biomass and yield were greater than 14%, indicating significant spatial field soil heterogeneity and variations on plant growth. When correlated to NDVI, sand content exhibited a negative correlation (r=-0.86), while in the case of silt, clay, organic matter content, biomass and yield the correlation was positive (r>0.8). Lastly, the NDVI confirmed to be a powerful tool for the delineation of deferential management zones.

Keywords: Soil texture, Yield variability, NDVI

1. Introduction

The spatial inherent inhomogeneities of soil biota, chemical, physical and hydrological properties, commonly encountered in fields, can be considered as responsible factors for the within-field observed variations on the cultivated crops' growing rates, vigor and, finally, the produced aerial biomass and yield (Marques da Silva and Silva, 2006; Boling et al., 2007).

Remote sensing and vegetation indices have been proposed as means to identify these spatial variations, to discriminate-delineate the variability of growing plants into zones and propose zone-specific management practices in terms of irrigation and fertilization (Ortega-Blu and Molina-Roco, 2016; Farrell et al., 2018).

In this study we examined the potentiality of organizing a typical farm cultivated with maize in northern Greece into differential management zones utilizing the widely-used Normalized Difference Vegetation Index (NDVI) derived by a Unmanned Aerial Vehicle (drone) mounted camera, in combination to soil and maize-plant traits measurements.

2. Materials and Methods

The experiment was conducted during the 2018 cultivation season (April to August) in a 2 ha field located close to the village of Selino in northern Greece (41.07^{o}N, 25.06^{o}E; 6 m altitude), subdivided into 2 irrigated plots, 1 ha each. The field was sowed on April 11th with Pioneer P1049 maize hybrid (FAO 500), which incorporates the innovative Optimum AQUAMax technology. The plant density within the rows was roughly 7 plants per meter, while the distance between the rows was 0.75 m. Maize maturation was observed on August 10, after the completion of 1,440 growing degree-days (Base temperature 10 ^{o}C; Upper temperature 30 ^{o}C).

The rainfall height and reference evapotranspiration (ET_0) from sowing to maturation were measured at 167 mm and 568 mm, respectively, obtained from a meteorological station installed on-site. Additionally, the sub-plot1 was irrigated with 236 mm of water, while sub-plot2 with 274 mm. The irrigation events were performed with a self-propelled gun sprinkler irrigation system.

Sand, silt and clay percentages, and organic matter (OM) and nitrate-nitrogen (NO_3-N) concentration were measured in soil samples (0–50 cm depth) from 5 geo-referenced points within the field a week before sowing. Moreover, at maturity, maize plants were collected from 8 different geo-referenced points, transferred to the laboratory and the total aerial dry biomass and maize yield weights were determined.

An NDVI survey was carried out on May 16th, with a MAPIR Survey3W RGN NDVI camera mounted on a drone. The obtained photos were then processed via the photogrammetry software Pix4D (v 4.3.33) and a field NDVI map was obtained.

Aiming to ensure that the NDVI pattern observed at this early growing stage is not a random artifact and that it is representative of the conditions prevailing within the field, the NDVI values were correlated against soil and maize plant traits using the SPSS (v 23) bivariate Pearson correlation analysis.

Lastly, the NDVI map was used to delineate potentially different management zones within the field using the QGIS (v 2.18.20) SAGA-GIS (v 2.3.2) K-Means clustering for grids module.

3. Results and Discussion

The mean values measured of the soil and of the plant properties as well as their correlation to the NDVI vegetation index are presented in Table 1. The relationship between soil properties/plant traits and NDVI was found to be in all cases positive, except in the case of sand where a negative relationship was observed. This could be attributed to the fact that increased sand soil content is related to lower soil water holding capacities which, in turn, results to lower NDVI values (Farrell et al., 2018). The highest variation and the least-good-fit were observed in the case of NO_3-N, with the coefficient of variation (CV) and Pearson correlation coefficient (r) to NDVI taking values equal to 53.8% and 0.70, respectively (Table 1). It is noteworthy that, while the r-values were greater than 0.7 for all cases indicating a fairly linear fit between soil properties/plant traits and NDVI, the bivariate statistical analysis showed that this correlation was statistically significant only in the cases of aerial biomass and yield ($p < 0.01$).

Table 1. Mean values, coefficient of determination and Pearson correlation coefficient between measured soil properties/ plant traits and NDVI.

Soil/Plant properties	n	Mean	CV	r
Sand (%)	5	66.80	11.70	-0.86
Silt (%)	5	22.40	23.70	0.84
Clay (%)	5	10.80	25.70	0.81
OM (%)	5	2.69	28.80	0.85
NO_3-N (mg/kg)	5	43.82	53.80	0.70
Yield (tn/ha)	8	11.90	14.70	0.84**
Aerial Biomass (tn/ha)	8	19.20	15.20	0.93**

CV = coefficient of variation;
r = Pearson correlation coefficient;
** *correlation is significant at 0.01 level*

The strong correlation obtained between NDVI and aerial biomass-yield confirmed that the variations observed on May 16 were not random and that they continued to exist in a similar pattern until maturity. Moreover, the fair correlation between NDVI and soil texture-OM indicated that the observed variations are in some extend interrelated.

The K-Means clustering did not reveal well-defined high and low NDVI zones (Figure 1b). However, the northern part of the field exhibited higher NDVI values and accordingly resulted in higher yields than the southern one. This segmentation was more obvious in sub-plot2, while in sub-plot1 the distribution of variances was more scattered, exhibiting low NDVI values along its western side. A rigorous segmentation of the field into differential management zones was not possible, but most likely, a differential management, in terms of irrigation and fertilization, between north and south zones may moderate the observed differences and result in a higher maize yield.

4. Conclusion

In this study, an NDVI variability map obtained early in the maize cultivation season was found to be representative of the differences observed in the yield at maturity. This mapping process indicated that the differential management of parts with different NDVI-values may potentially result in an improved overall yield. Nevertheless, additional field experimentation and the use of crop growth models are needed to quantify the different amounts of water/fertilizers required for each zone and thus assess the economic feasibility of such an endeavour.

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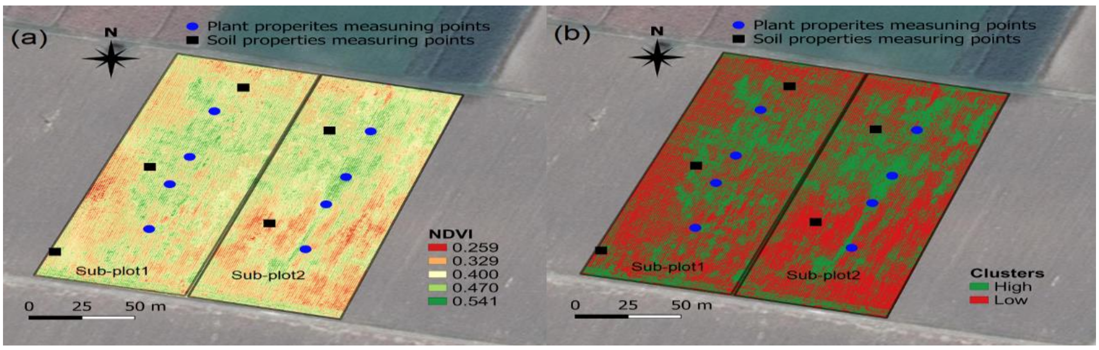

Figure 1. Illustration of sampling points for soil/plant properties and (a) raw NDVI mapping; (b) high and low NDVI zones after K-means clustering.