UAV-based heterogeneity analysis of soil-plant-water system of small-plot experiment with different oat genotypes under Si and S foliar fertilization treatments

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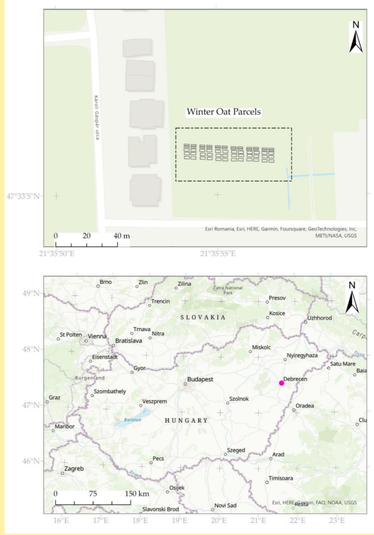
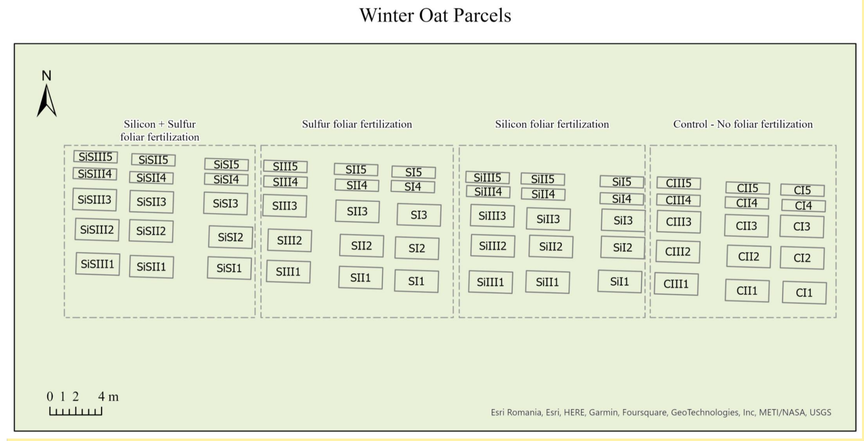
Introduction

Five winter oat (*Avena sativa L.*) varieties were set in a small-plot field experiment to examine **the abiotic stress** considering silicone (Si) and sulphur (S) foliar fertilization treatments under temperate and **dry climatic conditions in Hungary**. Numerous in situ and laboratory measurements were performed to describe the crop's condition at various phenological stages. Drones **with multispectral, thermal and LiDAR payloads monitored** the field both with high temporal and spatial resolution. A high level of GIS data assimilation was performed in order to handle the different spatial-related parameters in one interface.

It is a multi-purpose experiment, and for all of them it is an important criterion whether the study was carried out in **a truly homogeneous area**. Practically, it means that we ignore the patterns of the crop or the soil. If this is not the case, the various parameters measured should be evaluated accordingly. Hence, our study's main goal here is to reveal the soil and crop heterogeneity level. For this, all the measured parameters are involved in the **multi-parameter analysis by which the heterogeneity level of the site can be assessed**. Practically, by this, we can answer the main question: is the field suitable to carry out analysis such as abiotic stress studies or yield prediction modelling on it or shall we handle certain parts differently? Based on the example of our experiment we design a workflow by which the heterogeneity level of a small-plot field can be assessed and provide a solution for how to handle it in order not to involve data which may mislead analysis.



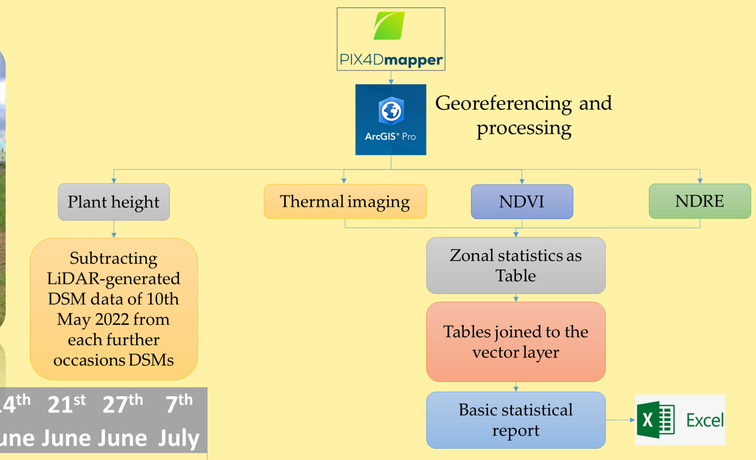


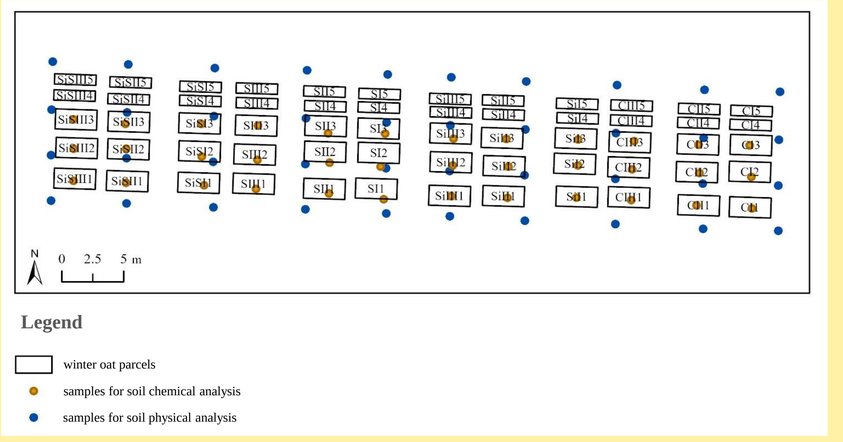
Study site and settings. Foliar fertilization treatments: C - control, Si - silicon, S - sulfur, Si&S - Silicon and Sulfur combined; Repetitions: I, II, III; Varieties: 1: GK Arany, 2: Mv Hópehely, 3: Mv Imperiál, 4: Mv Kincsem, 5: Mv Istráng.

Methods

The measurements involved into this research include 1) **UAV** measurements (multispectral and thermal); 2) **soil chemical** (Ca, Cu, K_2O, Mg, Mn, N, P_2O_5, Zn); 3) **soil physical** (bulkdensity, median, modus, porosity, unicoefficient); 4) **general crop management** measurements.

UAV + Sensor		10th May	17th May	23rd May	31st May	7th June	14th June	21st June	27th June	7th July
GSD: 0.6 cm/pixel Height: 20 m Survey speed: 2 m/s Side overlap: 60 %	DJI Mavic 2 Zoom + Sentera Double 4K multispectral	X	X	X	X	X	X	X	X	harvest
GSD: 0.68 cm/pixel Height: 25 m Survey speed: 3 m/s Side overlap: 20 %	DJI Matrice 300 RTK + DJI Zenmuse L1 LiDAR sensor	X		X		X		X		
GSD: 4.80 cm/pixel Height: 25 m Survey speed: 1.6 m/s Side overlap: 70 %	DJI Matrice 300 RTK + Zenmuse HT20 TIR sensor	X		X		X		X		





The different types of data collection require different types of data management. UAV data analysis demanded a complex process, during which raster map series were generated from tiles and in **ArcGIS Pro** environment statistical queries were executed the result of which were exported to MS Excel for further analysis and data assimilation.

The **R Studio-2022.12 statistical software** was used for the analysis and evaluation of the collected data. Generalized Lineal Models were utilized to determine the differences between the treatments and varieties in each one of the variables, thus, according with the normality behavior of the data, the family and the link was checked and used.

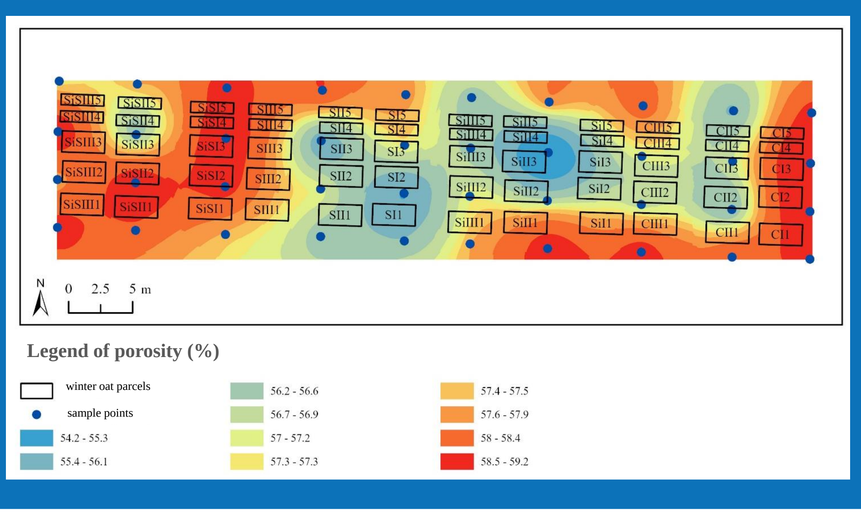
Results and Discussion

Significant differences among the foliar fertilization treatments were found at a $p < 0.001$ level for all the measurement dates except for the last one of 27th of June which had a significance level of $p<0.01$ (Figure below). The highest values were found in the treatment with sulfur and silicon together (SiS) in almost of them except for the last measurement as well and the peak values for all the treatments were reached in the 17th of May.

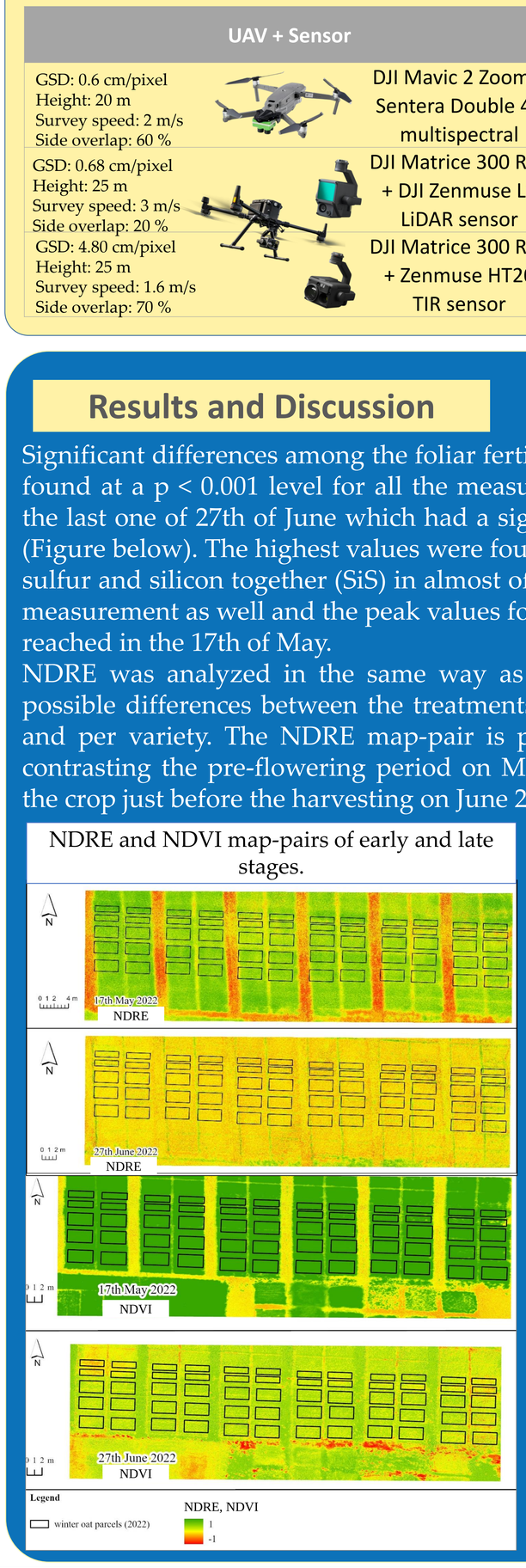
NDRE was analyzed in the same way as NDVI in order to find possible differences between the treatments per measurement date and per variety. The NDRE map-pair is presented in also below, contrasting the pre-flowering period on May 17th and the state of the crop just before the harvesting on June 27th.

Spearman correlation coefficient (r) values between NDVI and NDRE in all dates, in chronological order.

The spatial distribution of some studied parameters:

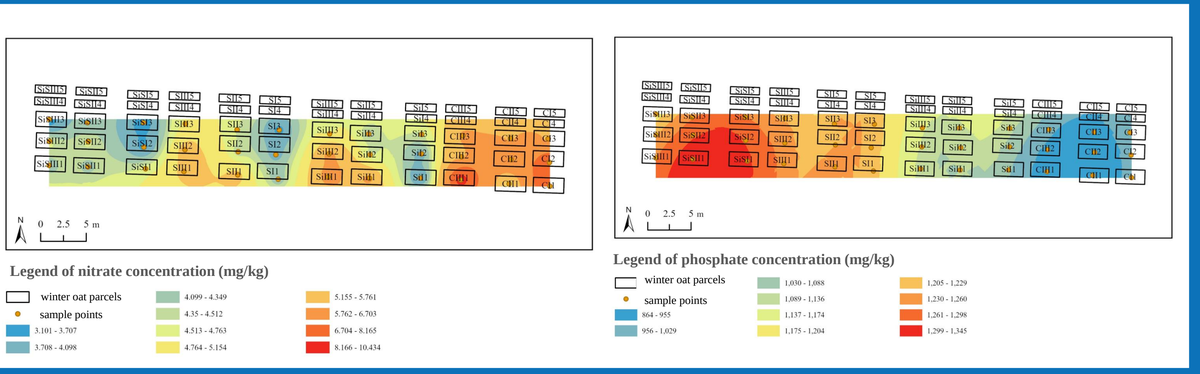


NDRE and NDVI map-pairs of early and late stages.



A Spearman correlation have been done to observe the relationship between the NDVI and NDRE throughout the dates averaging the variety and the treatment influence (Figure above). The intensity of the blue color and the number mean the grade of correlation among the parameters and the significance level was set to $p<0.05$.

As it was expected, the correlation between the NDVI values and the NDRE in the first dates for the same measurement are positive and strong ($r>0.65$), but it decreased from the 6th data to the end of the phenological period ($r>0.45$), CSAJBÓK et al. (2022) found similar results. The blank spaces shows that there's no significant correlation among the variables at $p<0.05$ and in this sense, the first measurements are not influencing the final behavior of the crop, suggesting that the variation increased at its final lifetime in both indexes and furthermore the chlorophyll content.



Harvesting of winter oat (*Avena sativa L.*).

The spatial analysis of all parameters including the ones not presented here due to lack of space, can show significant differences within even a small parcel-like environment (figures above). Their effects on the yields must be studied applying further multi-parameter analysis to adequately analyse the effect of foliar fertilization.

It is strongly recommended to investigate the **site before the experiment setting, during the vegetation season (even several times), and after it**. It requires huge amount of work from many fields but this seems to be the cleanest way to exclude spatial environmental anomalies.

ACKNOWLEDGEMENT

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