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Integrated System for Precision Agriculture through Aerial Remote Sensing and Soil Characterization: A Case Study In Hungary

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ABSTRACT This paper outlines the creation and deployment of a holistic system for precision agriculture, combining aerial remote sensing and in-depth soil analysis. Conducted in Kömlö, Hungary, within the framework of the INSAC AGRIS project, the study focused on corn, sunflower, and high oleic sunflower plots. Soil profiles were mapped detailing key parameters like pH, humus, and nutrient levels. Drones captured aerial imagery to construct orthophoto maps and track crop development. Vegetation indices were computed using multispectral data, guiding variable rate fertilizer application. The system efficiently profiled the experimental plots and monitored crop metrics, showing promise in optimizing resource use and enhancing yields. Future work aims to develop predictive algorithms by integrating aerial, soil, and plant data, reinforcing the value of this multi-faceted approach for targeted crop management.

KEYWORDS: agriculture, digitisation, integrated system, soil characterisation, precision agriculture.

I. INTRODUCTION

If we refer to background and importance, the continuously expanding field of precision agriculture aims to maximize agricultural yields while minimizing environmental repercussions through the nuanced management of in-field variability (Smith et al., 2019). This approach capitalizes on real-time data acquisition, analytics, and decision-making processes to implement site-specific resource allocation (Williams and Miller, 2016). Remote sensing technologies, facilitated by satellites, aerial devices, and ground-based systems, serve as pivotal sources of spatiotemporal data for enabling precision agriculture (Li et al., 2018).

When we speak about the recent technological advancements, emerging technologies in unmanned aerial systems (UAS) have greatly expanded the ability to perform swift, adaptable, and cost-effective remote sensing, further enriching our understanding of crop conditions (Johnson and Addington, 2018). Utilizing multispectral and hyperspectral imagery, these aerial platforms can provide critical insights into plant health, water stress, and nutrient levels (Sanchez et al., 2019).

Nevertheless, referring to the challenge of Data Integration, the successful conversion of remote sensing data into actionable insights for site-specific management hinges on its effective amalgamation with comprehensive soil data. Assessing soil properties, both chemical and physical, is crucial for delineating targeted zones for variable-rate applications, which can then be customised to local environmental conditions (Thompson et al., 2015).

II. OBJECTIVE AND SCOPE OF THE CURRENT STUDY

The paper presents the development and evaluation of an integrated system using UAS remote sensing and soil characterization to enable precision agriculture. For the first year of the project, field experiments were conducted on plots of corn, sunflower and high-oleic sunflower in Kömlö, Hungary. Orthomosaic maps were constructed from aerial images collected using a multispectral camera mounted on a UAS. Soil sampling was optimized based on apparent electrical conductivity and terrain attributes. Soil analysis included laboratory testing to map pH, organic matter, macronutrients and micronutrients. Variable rate fertility plans were derived from integrated soil-landscape models. Crop growth was monitored by calculating vegetation indices from multispectral imagery across the season. Yield and quality data were analysed to evaluate system performance.

III. CONTRIBUTIONS AND METHODOLOGY

Variable fertility plans were crafted by synthesizing soil data with landscape models. Crop health was routinely assessed by computing vegetation indices derived from seasonal multispectral images. Subsequent yield and quality metrics were then employed to gauge the effectiveness of this integrated system.

- **Experimental plots**

The experimental plot area established in Kömlö, a village in Heves County, Northern Hungary Region has carried out the management of the experimental fields, as well as the acquisition of the equipment necessary for the preparation, maintenance and harvesting activity.

- **Setup, cultivation and maintenance of experimental plot**

The choice of a number of three crops (corn, sunflower and sunflower high-oleic) was based on the fact that, in this way, it will be possible to achieve an optimal crop in the three years of field testing in parallel with the crops established in Romania, covering in this way the proposed number of crops established at the beginning of the project.
Initiated in Hungary in March 2021, the agricultural project focused on spring crops due to its late start in the farming year. The initial phase involved equipment evaluation, followed by procurement decisions based on the specialized machinery for differentiated fertilization. A consistent technological framework was thus established to ensure uniform testing throughout the project.
Agricultural Parcel Identification System (MePAR) was used, which uniquely identifies agricultural parcels, and its data supersedes any other registry. Integrated with a GIS system, it provides aerial map-based views essential for applications. The data has also been inserted in the map interface of the MePAR browser to support the application, the system being used to start to build the Technological scheme for the experimental plot, which was divided in three parcels for the three cultures, corn, sunflower and high oleic sunflower.

Figure1. Technological scheme of experimental plot Kömlö, Hungary

Starting from the technological scheme presented in Figure 1, in each parcel of the plot of 9 hectares were delimited three plots (Table 1), in the central part to be further monitored, at the same time eliminating the side effect and that of the pedo-climatic conditions.
Within the INSAC AGRIS project, Soil Sampling (SS) and Soil Testing (ST) were pivotal elements for advancing precision agriculture, our SS protocol aimed at creating targeted management zones and prescription maps, optimizing the application of fertilizers and lime for pH adjustment, this not only boosting yields but also promoting sustainable farming by reducing waste and environmental impact.
Concurrently, our ST approach served as a robust soil fertility management tool, the careful planning yields detailing data on soil fertility, shaping precise fertilizer and lime application recommendations. Continuous monitoring also tracked fertility changes, allowing targeted treatment of less fertile areas.

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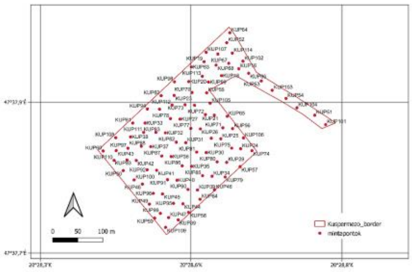

Figure 2. Calculated soil sampling plan

By integrating SS and ST, the project aimed for peak on-farm nutrient efficiency, yielding higher ROI for fertilizer and lime applications while minimizing environmental risks.

- **Physical-chemical characterization map of experimental plots**

The obtained soil composition analysis maps are presented below:

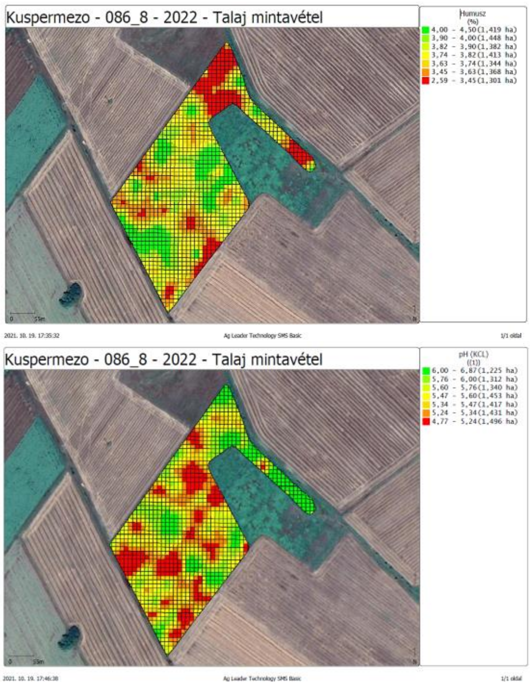

Figure 3. Humus and pH distribution

These maps provide a high-resolution snapshot of soil attributes such as pH, nutrient content, and organic matter, captured through meticulous soil sampling and testing. The detailed layering of these attributes allows for a nuanced understanding of the soil ecosystem within the experimental plots, serving as a foundation for data-driven decision-making.

Figure 4. N, P, K distribution

The importance of PCCMs extends beyond simple soil assessment. They enable the customization of fertilization and irrigation strategies, thus optimizing input application and minimizing wastage. When combined with remote sensing data, these maps offer a holistic view of both above-ground and below-ground conditions, empowering a symbiotic relationship between soil and crop management.

- **Recommendations for distributed fertilisation**

The creation of fertilization maps was a pivotal component in the realm of precision agriculture, particularly within the scope of the INSAC AGRIS project. These maps served multiple essential functions, each contributing to increased agricultural efficiency, productivity, and sustainability.

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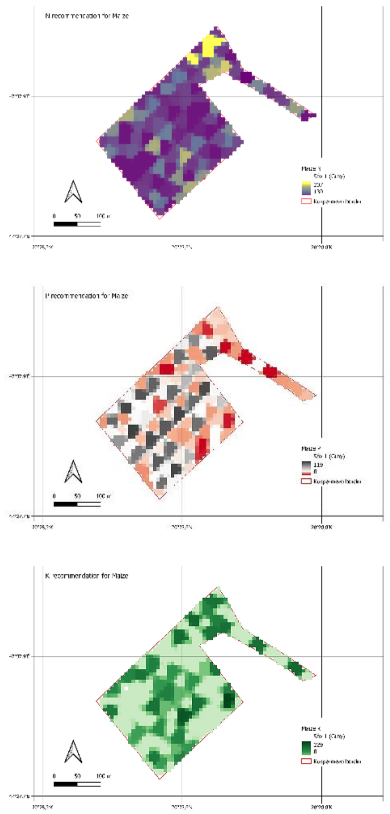


Figure 5. Fertilization maps. Recommendations of points for distributed fertilization (N, P, K)

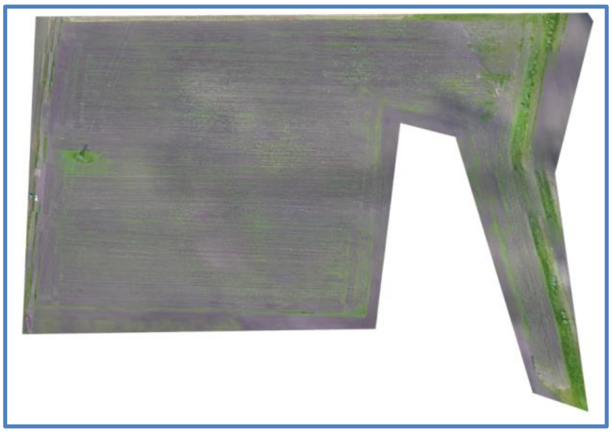
Integrated with Soil Sampling and Physical-Chemical Characterization Maps, fertilization maps provided a comprehensive, data-driven strategy for soil management. The maps enabled the targeted application of nutrients, mitigating the risks of over-fertilization that can lead to soil degradation and water pollution. Moreover, they facilitated ongoing monitoring and adjustments, enabling us to fine-tune their fertilization strategies over time.

- **Preliminary aerial imagery acquisition**

The equipment used for the first year of imagery acquisition had the following characteristics:

- Drone: DJI Phantom 4 Multispectral
- Camera: Six 1/2.9” CMOS, including one RGB sensor for visible light imaging and five monochrome sensors for multispectral imaging.
- Each Sensor: Effective pixels 2.08 MP (2.12 MP in total)
- Drone monitoring Dates: August, 04. 2021; August 25. 2021; September 14. 2021.

One of the advantages of the sensor is that it is sensitive in the near-infrared range (infrared image) in addition to detecting visible light (true colour image). For the second year is planned to use infrared imaging equipment that uses the near-infrared (700-1000 nm) and possibly red-wavelength ranges of blue (400-500 nm), green (500-600 nm), and red (600-700 nm).
Aerial imagery acquisition played a pivotal role in yield estimation and prediction, offering timely, high-resolution data for data-driven agricultural decision-making, the images capturing crucial field metrics across various crop growth stages.



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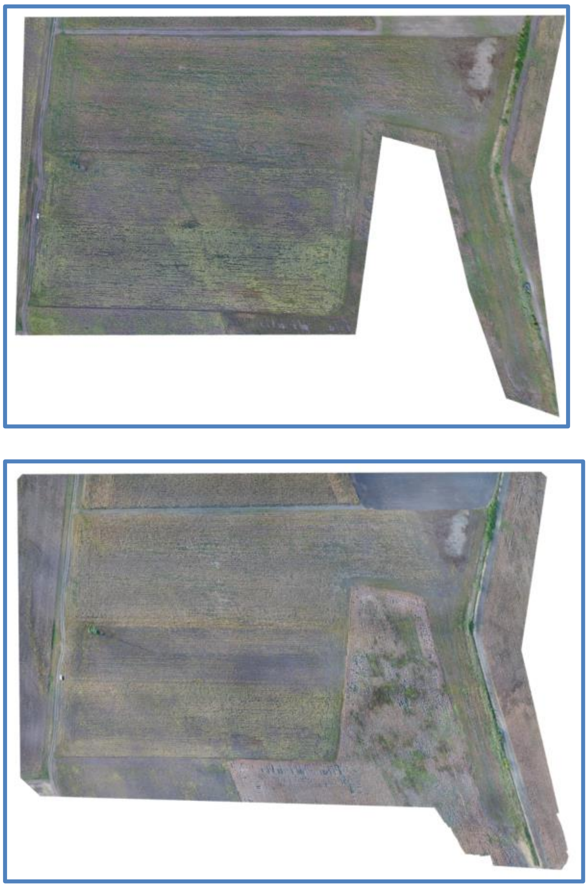

Figure 6. Aerial imagery acquisition (preliminary, 04.08.2021, 25.08.2021 and 14.09.2021)

When processed into vegetation indices like NDVI, these images acted as reliable indicators of plant health and yield potential. Integrated with soil and weather data, aerial imagery depicted a comprehensive picture of yield-affecting factors, enabling early identification of stress or disease, and allowing for targeted interventions.

In order to establish Aerial photography as a function of weather parameters, was created a database for meteorological conditions. Thus, the temperature history for the two crops (corn and sunflower) was recorded during the entire period of crop lifetime, summarised in the figure below.

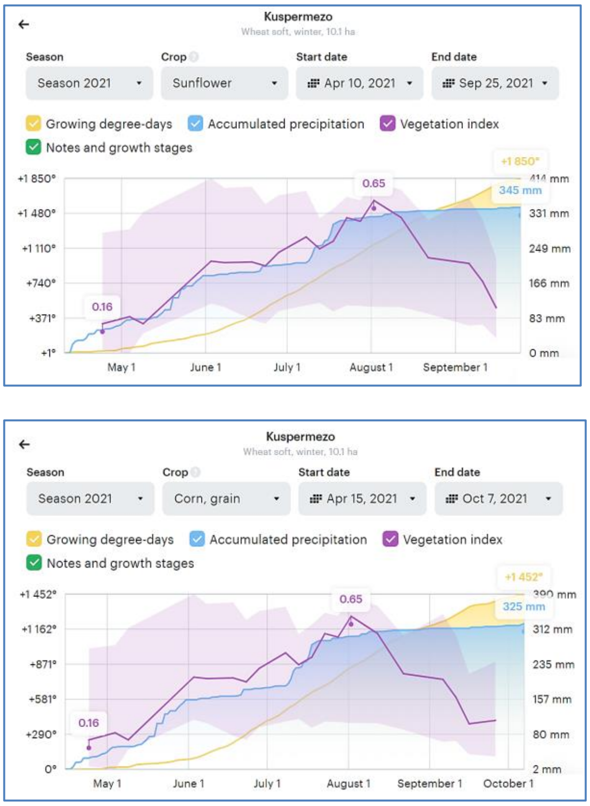

Figure 7. Meteorological condition evolution for sunflower (left) and corn (right) crops

The used equipment was a meteorological station GoGEN ME 3900 WiFi, which monitored the weather conditions. Aside from working as a classic thermometer, it also displayed the weather forecast, the monitored parameters being barometric pressure, temperature, humidity and wind speed and direction, parameters registered also on the Weather Underground website, in order to be used for showing on the INSAC-AGRIS website the real-time meteorological conditions and the desired crop lifetime growing degree days, accumulated precipitation quantity, vegetation index and growth stages.

Crop	Variety/hybrid	Sowing date	Harvesting date	Estimated production	Realised production
Corn	LG 32.58	21.04.2021	05.10.2021	9000 kg/ha	11000kg/4,5ha = 2,44 t/ha
Sunflower HO	DUET CL HO	28.03.2021	25.09.2021	3100 kg/ha	5100kg/2,1ha = 2,43 t/ha
Sunflower	DRIVER CL	28.03.2021	25.09.2021	2300 kg/ha	4600kg/2,2ha = 2,11 t/ha

Table 1. Main data about the experimental parcel and yield/plots

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- **Quantitative and qualitative production/ harvest map**

For both corn and the two types of sunflower yields, the calculation was made considering the number of plants per acre, the head diameter, the seed size, the number of filled seeds per head, observing how much of the centre of the head is filled, and estimating the damage done by birds. Yield estimate was made based on a sample space of 10 m^2: for plants with a burr row spacing of 10 m^2 / 0,75 m row spacing = 13,3 flow meters (an area of 13,3 flow meters corresponds to an area of 10 m^2). Sampling was performed of 3 replicates, knowing the variability of the land due to the collected soil samples.

Based on the acquired information yield potential map was created of the experimental plot, presented in the picture below.

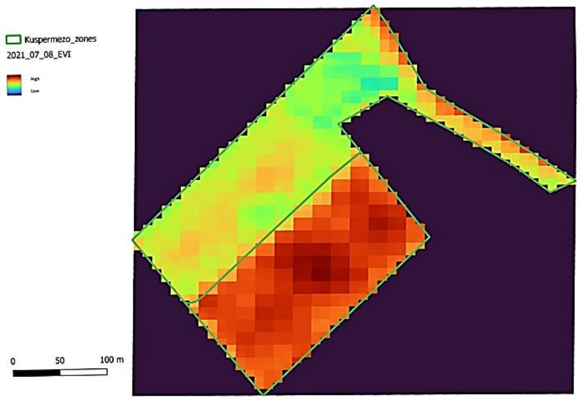

Figure 8. Yield potential map of the experimental plot

The map confirmed the higher yield potential for the plots were both sorts of sunflower, confirmed by the obtained production compared with the corn one, and a lower crop potential for the plot where corn was sowed, owed to soil composition and the fact that it is a zone where in case of precipitations, the water stays for longer period.

IV. **ONGOING RESEARCH AND IMPLICATIONS** The initial phase of the INSAC-AGRIS project has yielded key findings that underline its potential and chart a course for future work. Crucially, physicochemical characterization of crops and soil analysis is foundational for creating differential application maps. Initial yield estimates, especially for sunflowers, closely matched actual production, validating the yield potential map. Future work will expand the database by incorporating soil resistance, SPAD, and NPK variance data. Additionally, sensor networks will be introduced in the second period to enrich data sets. The practice of differentiated application has proven not just agronomically effective but also economically efficient, reducing input costs. Timely plant analyses and sample collections offer valuable insights into crop quality and input effectiveness and will be instrumental in developing more accurate predictive algorithms. Overall, the project shows promising avenues for optimizing agricultural practices through integrated data-driven approaches.

This first period of this case study emphasized the substantial promise of fusing UAS-mediated remote sensing with soil analytics for site-specific crop management. Current endeavours were centred around the creation of algorithms for harmonizing multiple streams of spatial data. Further field studies are required to ascertain the agronomic and economic impacts of this approach. Collectively, this integrated model offers farmers enhanced tools for resource optimization, thereby augmenting both productivity and environmental sustainability.

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