

Book of Abstracts

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Symposium Objectives

The 2nd ISDTA will enhance exchange and dissemination of knowledge and experience, ideas and results and promote internationalization and friendships among researchers and professionals in all research fields associated with digital technologies in agriculture, with a focus on precision agriculture, agronomist education in digital agriculture, data collection and all the other aspects of digital technologies in agriculture.

The major theme of the 2nd ISDTA will be interdisciplinary application of technologies towards sustainable digital agriculture.

Symposium Topics

1. Data collection, analysis and management
2. Precision crop production
3. Decision support systems and models in digital agriculture
4. Digital technologies in agriculture
5. Agroeconomic insights into digital agriculture

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Sadržaj

- 2 **A DIGITAL DATABASE OF AGROFORESTRY SYSTEMS IN CROATIA**
Vladimir Ivezić, Martina Kičić, Vladimir Margeta, Marin Kovačić, Ras Lužaić, Jurica Jović
- 3 **SPATIAL DISTRIBUTION OF SOIL TYPES IN THE MAVROVO NATIONAL PARK, REPUBLIC OF NORTH MACEDONIA**
Mile Markoski, Tatjana Mitkova, Ivan Minchev, Marija Todorovska
- 4 **DATA VS. INFORMATION: ARE THE NOVEL SENSING SOLUTIONS THE ASSETS OR THE LIABILITIES?**
Vlatko Galić, Andrija Brkić, Miroslav Salaić, Antun Jambrović, Zvonimir Zdunić, Lucija Galić, Domagoj Šimić
- 5 **A SPATIAL DISTRIBUTION OF COPPER (Cu), LEAD (Pb), CADMIUM (Cd), AND ZINC (Zn) IN THE GAZI BABA FOREST PARK REGION**
Mile Markoski, Tatjana Mitkova, Ivan Minchev, Vjekoslav Tanaskovik, Marija Todorovska
- 6 **THE APPLICATION OF DIGITAL RECORDING TECHNOLOGIES IN THE MONITORING OF AGRICULTURAL SURFACES**
Snježana Tolić, Tomislav Vranješ
- 9 **A FIELD CONDITION ASSESSMENT OF MAGNESIUM - ENRICHED TOMATO FRUIT'S WORKFLOWS FOR AN INDUSTRIAL AGRIFOOD PROCESSING**
Diana Daccak, Ana Coelho, Cláudia Pessoa, Inês Luís, Ana Marques, José Kullberg, Paulo Legoinha, Graça Brito, José Ramalho, Paula Scotti-Campos, Isabel Pais, José Semedo, Maria Manuela Silva, Carlos Galhano, Fernando Reboredo, Manuela Simões, Fernando Lidon
- 10 **CROP DAMAGE MAPPING BY REMOTE SENSING FOR A SITE-SPECIFIC APPLICATION OF PESTICIDES AND FERTILIZERS IN PRECISION AGRICULTURE**
Tomáš Kaplánek, Vojtěch Slezák, Kateřina Kuchaříková, Vojtěch Lukas, Petr Škarpa
- 11 **VINEYARD UNIFORMITY ANALYSIS AND HARVEST PLANNING USING THE UAVS AND MULTISPECTRAL DATA**
Tin Batur, Sara Škifić, Josip Barišić, Igor Frljužec
- 13 **THE INFLUENCE OF THE NUMBER OF SOIL SAMPLES ON THE DETERMINATION OF NEEDS FOR A SITE-SPECIFIC FERTILIZATION**
Zdenko Lončarić, Karolina Kajan, Vladimir Zebec, Vladimir Ivezić, Jurica Jović, Iva Nikolin, Suzana Kristek, Dario Iljkić, Darko Kerovec, Zoran Semialjac, Lucija Galić, Darko Miklavčić
- 15 **WEED DETECTION IN WINTER WHEAT FROM THE UAV IMAGERY USING THE GIS TOOLS AND PIX4DFIELDS: A COMPARISON**
Vojtěch Slezák, Kateřina Kuchaříková, Tomáš Kaplánek, Vojtěch Lukas, Jan Křen

- 16 THE MAPPING OF WEED INFESTATION BY THE DRONES FOR THE SAKE OF A SITE-SPECIFIC HERBICIDE APPLICATION**
Kateřina Kuchaříková, Vojtěch Lukas, Kornél Czíria, Petr Širůček, Vojtěch Slezák, Tomáš Kaplánek, Jan Křen
- 19 ESA-ECOSYSTEMADAPT, A TOOL FOR THE DECISION SUPPORT AND MANAGEMENT OF THE MONTADO AREAS**
Paulo Legoinha, Nuno Carvalho, Edward Rodriguez, Graça Brito, Manuela Simões, Diana Daccak, Cláudia Pessoa, Ana Coelho, Ana Marques, Inês Luís, Manuela Silva, Ana P. Rodrigues, José C. Ramalho, José Kullberg, Fernando Reboredo, José Rafael, Fernando Lidon
- 21 CHARTING CHAOS: CRAFTING A SPATIOTEMPORAL MODEL FOR THE BROWN MARMORATED STINK BUG IN EMILIA ROMAGNA**
Luis Grilo, José Rafael Silva, Lara Maistrello, Elena Costi, Cristina M. Pinotti, Manuela Simões, José Almeida
- 22 MEASURING THE DIGITAL TRANSFORMATION MATURITY IN AGRICULTURE**
Darko Lugonja, Mladen Fruk, Tihana Sudarić, Ivan Plaščak, Mladen Jurišić, Dorian Radočaj
- 24 THE CONCEPTUAL FRAMEWORK OF ENVIRONMENTALLY DRIVEN DECISION SUPPORT SYSTEM FOR GRASSLANDS MANAGEMENT (GM)**
Zdenko Lončarić, Ranko Gantner, Ružica Lončarić
- 26 iMAP PLATFORM AND ITS CORE MODELS IN THE CONTEXT OF CAP ANALYSES**
David Kranjac, Krunoslav Zmaić, Tihana Sudarić, Lucija Bencarić, Magdalena Zrakić-Sušac, Maja Petrač
- 29 INNOVATING POTATO CULTIVATION: THE IMPACTS OF FOLIAR CALCIUM BIOFORTIFICATION ON THE SOLANUM TUBEROSUM L. CV. PICASSO, ASSESSED VIA THE NDVI TO PREDICT THE YIELD**
Ana R. F. Coelho, Inês Luís, Ana C. Marques, Cláudia Pessoa, Diana Daccak, Fernando C. Lidon, Maria M. Simões, Maria M. Silva, Paulo Legoinha, Maria G. Brito, José C. Kullberg, José C. Ramalho, José M. Semedo, Isabel P. Pais, Paula Scotti-Campos, Fernando H. Reboredo
- 30 MULTISPECTRAL IMAGES APPLIED TO THE ENRICHMENT OF ORGANICALLY PRODUCED TOMATOES WITH IRON AND ZINC**
Cláudia Pessoa, Ana Marques, Ana Coelho, Diana Daccak, Inês Luís, José Kullberg, Paulo Legoinha, Graça Brito, José Ramalho, Paula Scotti-Campos, Isabel Pais, José Semedo, Maria Manuela Silva, Carlos Galhano, Fernando Reboredo, Manuela Simões, Fernando Lidon
- 31 ENHANCING RICE (*ORYZA SATIVA* L.) PRODUCTION EFFICIENCY AND SUSTAINABILITY THROUGH PRECISION AGRICULTURE**
Ana Coelho Marques, Manuela Simões, Diana Daccak, Inês C. Luís, Ana R. F. Coelho, Cláudia C. Pessoa, Ana S. Almeida, Paula Scotti-Campos, Fernando C. Lidon, Maria G. Brito, José C. Kullberg, Maria M. Silva, Paulo Legoinha, Isabel P. Pais, José C. Ramalho, José N. Semedo, Lourenço Palha, Fernando H. Reboredo

- 33 THE OPTIMIZATION OF OLIVE-CROP PRODUCTION USING THE REMOTE DATA FROM THE SENTINEL-2 SATELLITE AND THE NORMALIZED DIFFERENCE VEGETATION INDEX'S IMAGES: A CASE STUDY OF AN OLIVE GROVE IN A HEDGE AT HERDADE DAS ROMEIRAS, PORTUGAL**
Duarte L. da Silveira, Manuela Simões, Ana R. F. Coelho, Ana C. Marques, J. Rafael, M. da Silva
- 34 PARTICLE SIZE MEASUREMENT OF FOUR DIFFERENT TYPES OF FLOURS WITH A LASER-DIFFRACTION ANALYZER**
Karolina Kajan, Cláudia Pessoa, Diana Daccak, Ana Coelho, José Almeida, Carlos Galhano, Paulo Legoinha, Fernando Lidon, Fernando Reboredo, Maria Manuela Silva
- 35 THE USE OF DIGITAL TECHNOLOGIES TO CREATE A NEW INFORMATION ON THE AVAILABILITY OF SOIL MICRONUTRIENTS**
Hrvoje Hefer, Milena Andrišić, Daniel Rašić, Ivana Zegnal, Darko Kerovec, Darko Miklavčič, Brigita Popović, Zdenko Lončarić
- 37 THE USE OF PRECISION AGRICULTURE IN THE INTERPRETATION OF THE INFLUENCE OF SOIL PROPERTIES ON THE VINES AND MUST**
Zdenko Lončarić, Mato Drenjančević, Toni Kujundžić, Vladimir Zebec, Jurica Jović, Dario Iljkić, Miro Stošić, Daniel Rašić, Darko Kerovec, Darko Miklavčič, Miroslav Palinkaš
- 40 DIGITAL NOMAD - A BUSINESS MODEL OR A GLOBAL PHENOMENON?**
Tihana Sudarić, Slađana Katušić, Krunoslav Zmaić, David Kranjac, Lucija Pečurlić
- 42 DISRUPTIVE INNOVATIONS IN THE AGRICULTURAL SECTOR**
Ljubica Ranogajec, Jadranka Deže, Tihana Sudarić
- 44 PROS AND CONS OF ONLINE SURVEYES IN AGRICULTURAL MARKETING**
Ružica Lončarić, Sanja Jelić Milković, Zdenko Lončarić
- 46 THE ATTITUDE OF CROATIAN AGRICULTURAL PRODUCERS TOWARD THE USE OF SATELLITE TECHNOLOGIES IN AGRICULTURE**
Sanja Jelić Milković, Ružica Lončarić, Vedran Stapić, Zdenko Lončarić

Section 1

Data collection, analysis and management

A DIGITAL DATABASE OF AGROFORESTRY SYSTEMS IN CROATIA

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Abstract

In a response to the recent adverse impacts of climate change on agricultural production, various management practices have been implemented to mitigate these effects, aiming to ensure a long-term sustainability and resilience in food systems. Among these practices, agroforestry systems have emerged as a key strategy, recognized for their ability to enhance biodiversity, improve soil health, and sequester carbon, thereby contributing to the climate change mitigation. These systems, which integrate the trees and shrubs into the agricultural landscapes, are now acknowledged within the eco-schemes and supported by the policy initiatives to promote sustainable farming practices.

In Croatia, agroforestry systems have long been an integral part of traditional agricultural practices, particularly in the regions in which the mixed farming has been a way of life for generations. Despite their prevalence, these systems have not been formally classified as agroforestry, and there has been a lack of structured data or official recognition of their existence and value. This gap in recognition has limited the ability to promote and expand agroforestry as a viable practice in the face of climate change challenges.

The AGFORWEB project was initiated to address this gap by establishing a comprehensive database of agroforestry systems in Croatia. One of the primary goals of the project is to catalog and map the existent agroforestry practices, providing a foundation for further research, policy development, and the promotion of these systems across the country. The creation of this database has begun in the regions of Istria and Slavonia, the areas known for their diverse agricultural landscapes and rich traditions in mixed farming. By documenting and analyzing the

agroforestry systems in these regions, the project aimed to showcase their benefits, encourage a wider adoption, and integrate them into the national and regional agricultural strategies, ultimately contributing to the resilience of Croatian agriculture in the face of climate change.

The initial study revealed that most agroforestry systems in the examined regions are silvopastoral, whereby the animal husbandry is integrated with forestry, indicating that the animals are raised beneath a tree canopy. The next most common type of agroforestry system is forest farming, including truffle plantations and forest areas used for beekeeping. The silvoarable systems, in which the trees are incorporated into arable land for field protection, are the least common. These include the windbreak systems in Istria and Dalmatia and the experimental alley-cropping sites in Slavonia. The database was digitized and is in its early stages, requiring further updates to encompass all of Croatia.

Keywords: agroforestry, database, Croatia

Acknowledgement

The results are an output of the Erasmus+ project Agroforestry Practices in the West Balkans for a Sustainable Development: Weaknesses and Strengths (AGFORWEB).

SPATIAL DISTRIBUTION OF SOIL TYPES IN THE MAVROVO NATIONAL PARK, REPUBLIC OF NORTH MACEDONIA

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Abstract

This paper is a result of many years of field and laboratory research of the soils at the Mavrovo National Park. The Mavrovo National Park occupies an area of 73,088 hectares and is the largest among the three national parks in Macedonia. It was declared a national park in 1949, and its geographical position is 41°40'N and 20°46'E. The following mountains are situated within the boundaries of the Park: Korab, Deshat, the southwestern branches of Shar Mountain, most of Bistra, and the northern parts of Krcin. The central part of the National Park occupies the valley and basin of the Radika River. The Mavrovo artificial lake is a part of the National Park.

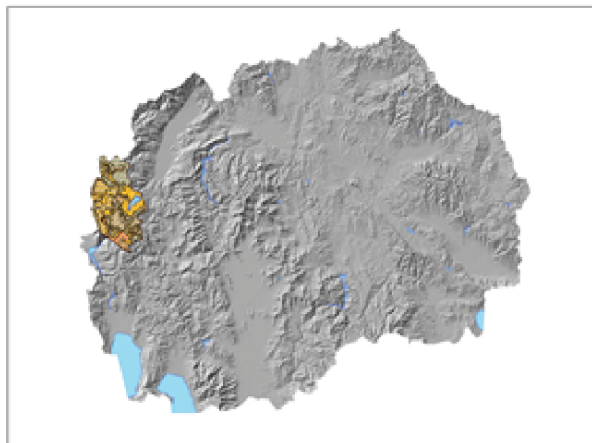


Figure 1. The location of the Mavrovo National Park.

From a geological point of view, a parent substrate of the Mavrovo National Park territory belongs to the West Macedonian geotectonic unit. The rock masses, which are of different age and mineralogical composition, can be grouped into three geo-

logical formations: the Paleozoic metamorphic and igneous rocks, the Mesozoic sedimentary rocks, and the Quaternary deposits. The entire territory of the Mavrovo National Park's Protected Area is basically included in the catchment area of the Radika River, whose average annual water flow for a period of 50 years (1961-2010) was 19.63 m³/s at the measuring station Boshkov Most. Concerning the Park's vegetation, a community of mountain beech forest has the largest representation. In the Mavrovo National Park, there are over 52 mountain peaks with an altitude of over 2,000 m, the most famous of which are the Medenica peak on the Bistra mountain, Velivar, Sandaktash, and the like. The Golem Korab peak (2,764 m a. s. l.), which is also the highest one in the province, has a special significance for the Mavrovo National Park in south Macedonia and is thus the highest point of the Park too. The lowest point of the Mavrovo National Park is situated at an altitude of 600 meters above the sea level and is located at the very confluence of the Mala Reka into the Radika River. Soil erosion is identified as the most significant, dangerous, and widespread type of soil degradation and is a limiting factor for a sustainable land use. Taking into account a great heterogeneity of natural conditions of the Bistra mountain massif, a large number of soil types and subtypes has been formed. The mapping was performed using the available CORINE land cover data, as well as the 1:50 000 soil map (MASIS) and the reservoirs of the same published and unpublished scientific data. The national and project databases, as well as the GIS tools, were the main sources of parameter data.

Keywords: soil types, third, National Park, soil map

DATA VS. INFORMATION: ARE THE NOVEL SENSING SOLUTIONS THE ASSETS OR THE LIABILITIES?

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Abstract

The goal of increasing information density in the plant-science experiments is shared by the scientists across various fields, especially given the rising importance of plant production.

With the technological advancements achieving the unprecedented levels in both temporal (a high-frequency signal acquisition) and spatial (sub-molecular resolutions) domains, one might expect a corresponding boost in crop yields. However, this has not been the case. While energy limitations are a factor, it may be more effective to focus on the optimization of secondary traits, rather than continuously developing the novel sensing solutions. These solutions are often expensive, slow to increase information entropy, and may thus represent a liability in terms of cost-effectiveness. In contrast, a computer-vision sensing stands out for its high information density, substantial data output, and relatively low cost, especially with the SiO₂ CMOS sensors covering the electromagnetic radiation from 400 nm to 1 micron.

In our maize hybrid selection trial for the inspection of nitrogen-use efficiency, we utilized the three data sources: the handheld hyperspectral leaf spectroradiometers, a DJI Mavic M3M UAV, and the Sentinel 2A satellite imagery. The satellite imagery, with its low granularity (10-60m), was inadequate for making inferences about the densely planted experimental plots.

In spite of producing a high data output, the handheld spectroradiometers identified only a limited number of discriminant features, highlighting the potential liabilities of such technologies in plant production and breeding programs. Conversely,

the UAV, equipped with a 20M RGB camera and four monochrome 5M cameras with the optical bandpass filters (central wavelengths measuring 560, 650, 730, and 860 nm), demonstrated the effectiveness of RGB cameras in capturing a high number of discriminant features between the hybrids and treatments. This capability, combined with the photogrammetry tools like a point-cloud reconstruction, allowed for an efficient field-variability analysis. The multispectral imaging device further extended this capability into the infrared spectrum, enabling the calculation of numerous plant production-relevant indices.

These findings underscore the growing relevance of vision-based sensing in plant sciences, positioning the cameras of various types as the leading assets in this domain.

Keywords: computer vision, vegetation indices, NUE, maize

A SPATIAL DISTRIBUTION OF COPPER (Cu), LEAD (Pb), CADMIUM (Cd), AND ZINC (Zn) IN THE GAZI BABA FOREST PARK REGION

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Abstract

The soils in the Gazi Baba Forest Park were examined. The field research was conducted in 2022, during which 22 surface soil samples were taken. In the framework thereof, an examination of some physical and chemical properties of the soil, as well as of the content of the total forms of heavy metals (Cu, Pb, Cd and Zn), was carried out too.

Several soil types were formed in the area covered by the Gazi Baba Forest Park: the regosols, cinnamon forest soils, colluvial soils, and the complexes thereof. Based on the obtained values for a mechanical composition, the soils in the surface part were mostly a sandy clay loam (SCL) up to 41%, sandy loam (SL) up to 36%, and loamy (L) soils up to 23%. The content of the total forms of heavy metals in all samples was analyzed using the atomic emission spectrometry with the inductively coupled plasma (AEICP). The obtained results were processed statistically, and the maps were made for a spatial distribution of all analyzed elements and parameters. The obtained results allow us to distinguish between the possible anthropogenic influences on the presence of heavy metals in the soils of the Gazi Baba Forest Park and their lithological origin. The mapping was performed using the available CORINE land cover data, as well as a 1:50,000 soil map (MASIS) and its reservoirs that is, the published and unpublished scientific data. The national and project databases, as well as the GIS tools, were the main sources of parameter data.

Keywords: physicomechanical properties, characteristics, heavy metals

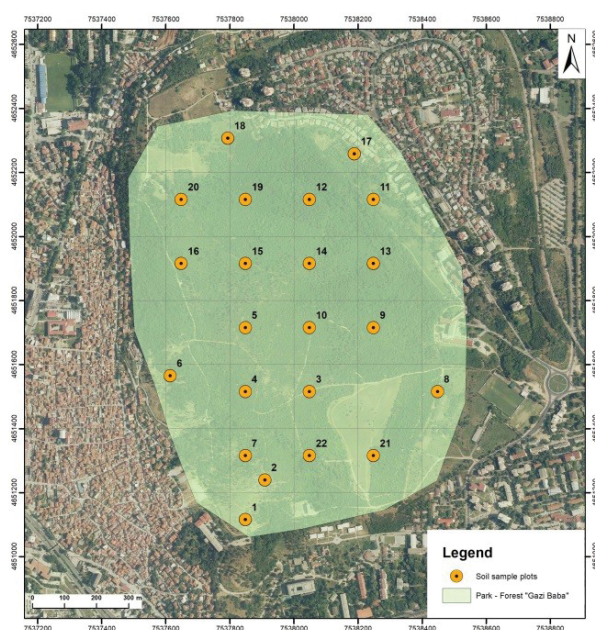


Figure 1. The location of the investigated area in the Republic of North Macedonia.

THE APPLICATION OF DIGITAL RECORDING TECHNOLOGIES IN THE MONITORING OF AGRICULTURAL SURFACES

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Abstract

This paper's objective was to investigate and present to the general public the new ways of monitoring the use of agricultural land with the help of digital technologies that ensure monitoring of agricultural activities during the growing season in order to fairly allocate the incentives to the agricultural producers.

With the adoption of digital technologies in precision agriculture, the concept of agriculture has changed, making it simpler, more profitable, and safer. The most popular digital technologies applied in agriculture are the GIS software and GPS, satellite images, drones and other aerial images, agricultural software and network data. With the help of satellite images and the obtained satellite data, it is possible to predict the yield, but also to carry out inspections in the field with the aim of detecting various threats in the system of agricultural subsidies. The new recording technologies, such as the Copernicus Sentinel 1 and 2 satellites owned by the EU, have brought the radical changes in the implementation of common agricultural policy with simultaneous benefits for the farmers and the environment (appprrr.hr).

Prior to the use of Sentinel, the CAP reform of 2003 introduced an obligation for all EU Member States to establish a computerized geographic information system of all agricultural land. Based on the 2013 CAP, an obligation was introduced that the Land Parcel Identification System (LPIS) must be used together with a request for geospatial support. The said system has been gradually introduced since 2015, in order to improve the checks of support requests. The LPIS is based on aerial imagery and

satellite images that are corrected in terms of geometric distortions. The orthophoto from the air in the LPIS program is visible on the following image.



The European Commission encourages agricultural payment agencies in the EU Member States to apply the new technologies, especially for monitoring the support allocations per area in the form of direct payments.

As a part of the CAP, satellite or aerial images have been used for many years in the territory of the EU, including Croatia, within the framework of the AGRONET system. From 2023, the images obtained by the Sentinel satellite within the Copernicus program have very high spatial resolution, which ensures a high quality system for the surveillance and monitoring of agricultural activities such as tillage, mowing, harvesting, surface maintenance and more. The monitoring results obtained are also used to check the results of individual measures

and are the indicators of the achieved objectives of the CAP. Monitoring at the level of agricultural areas also determines the presence of unacceptable areas and unacceptable land use. It also detects a change in the type of use of agricultural land that is listed as arable land or as a permanent grassland.

The primary purpose of a monitoring system is to send the early warnings to the farmers regarding the fulfillment of eligibility requirements with regard to the support requests for the aforementioned agricultural activities. A communication between the APPRRR and grant beneficiaries is carried out through the AGRONET, a protected online application that serves a payment agency for sending e-mails or text messages that is, the SMSs to the grant beneficiaries via cellphones. The advantages of this application are the timely warnings that encourage compliance with the conditions for action, enabling the application to be waived if it is impossible to carry out an agricultural activity. Support users can see the monitoring results for the current production year in the form of a traffic light in the AGRONET system. Traffic light indications are red, yellow, and green. Each of the aforementioned colors has a certain meaning: red is unacceptable, yellow means that the data are insufficient, while green means that the reported agricultural activity on that area is acceptable for a support approval.

Conclusively, it is clear even from this brief overview that digital technologies have a significant impact on the development of modern agriculture. On the one hand, the application of digital technologies improves the system of agrotechnics in agriculture, and on the other hand, the monitoring of agricultural areas is improved. With the help of the Copernicus Sentinel satellite, which includes a regular and systematic observation and digital platforms and applications used by the agricultural payment agencies, it is possible to closely monitor agricultural activities and practices on agricultural areas which agricultural producers have registered for the realization of the right to agricultural subsidies under the EU's 2023-27 Common Agricultural Policy.

Keywords: digital technologies, recording of agricultural areas, monitoring of agricultural activities, CAP

Section 2

Precision crop production

A FIELD CONDITION ASSESSMENT OF MAGNESIUM - ENRICHED TOMATO FRUIT'S WORKFLOWS FOR AN INDUSTRIAL AGRIFOOD PROCESSING

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Abstract

Magnesium (Mg) is considered an essential nutrient for humans, and an adequate intake is important to maintain health. Following this assumption and taking into consideration that tomato is globally one of the most consumed horticultural crops, an agronomic enrichment workflow of a tomato variety for industrial processing (H1534) was performed in Beja (Portugal). The fruits were sprayed six times during the productive cycle with different concentrations of MgSO_4 (c. a. 0, 44, 176, and 702 g ha^{-1}) while using the PREV-MAG fertilizer - that is, an equivalent to 5.25% of MgO soluble in water. Applying smart farming, a field characterization was performed by virtue of soil sampling and the UAVs, enabling the classification of drainage capacity and the detection of slopes in the field. Thus, it was detected that the field had a moderate slope, with a potential for surface water drainage and/or accumulation of surface water of around 1/3 (392 m^2) of the total field area (with the slopes inferior to 5%). Also, humidity, organic matter, pH, and conductivity oscillated between 9.96 and 19.8%, 2.20 to 3.03%, 6.89 to 7.28%, and between 139 to 243 $\mu\text{S cm}^{-1}$. Complementarily, the water quality was assessed by a potentiometer, high-performance liquid chromatography, titration, and photometer, being categorized as C3S1 (when considering the agricultural use) and as magnesium calcium bicarbonate (with regard to the hydrochemical facies). During

the harvest, the levels of Mg (atomic absorption spectrometry) in the H1534 variety demonstrated a tendency to increase with the increasing concentrations applied, although only the highest concentration was significantly higher (MgSO_4 - 702 g ha^{-1}), reaching a 1.17 - fold increase. In conclusion, no major conditioning with regard to the mineral enrichment was identified in this tomato variety.

Keywords: mineral analysis, soil characterization, UAVs, water analysis, industrial tomato

Acknowledgement

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CROP DAMAGE MAPPING BY REMOTE SENSING FOR A SITE-SPECIFIC APPLICATION OF PESTICIDES AND FERTILIZERS IN PRECISION AGRICULTURE

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Abstract

The technology of unmanned aerial vehicles (UAVs) can detect the objects with a very high spatial resolution measured in centimeters. This can be applied in crop management for an improved mapping of crop damages caused by the weather events, diseases, or pests, such as the field mice. This study aimed to propose and validate the methods for a comprehensive mapping of the crop damage caused by the common vole (*Microtus arvalis*) on the select agricultural fields using the satellite and UAV imagery. The collected data were used to assess the crop damage and subsequently propose potential applications of the data for an agronomic decision-making. Another aim was to verify the feasibility of using the acquired data for a subsequent site-specific application of pesticides and liquid fertilizers by sprayers, with the expected economic and environmental benefits.

The research was conducted in the crops of oilseed rape, winter wheat, and alfalfa in the spring of 2024. A DJI Mavic 3 Multispectral drone, equipped with a multispectral sensor and an RGB camera, was used to collect the UAV image data at an altitude of 120 m. The satellite data were obtained using the PlanetScope system with a spatial resolution of 3.7 m per pixel. The ground surveys were conducted using the RTK-GNSS to record the precise positions for the sake of a comparison with the remote-sensing data. The drone images were processed by the Pix4Dfields software and the GIS tools to analyze the resulting raster data. A damage was detected using the Normalized Difference Vegetation Index (NDVI) from the multispectral data and an RGB classification, with the supervised classification methods employed to evaluate the damaged areas.

The analyses of remote-sensing imagery demonstrated the feasibility of crop-damage assessment in the field crops. The satellite images could effectively identify the damaged areas provided that the contiguous damage exceeded 100 square meters; however, classification accuracy was diminished in smaller areas. The UAV image analyses achieved a high accuracy, having detected the damaged areas as small as several square meters. The damaged areas ranged from 5 to 50% per field.

Currently, the monitoring of the common vole is conducted via field surveys, which are labor-intensive, invasive, and relatively inaccurate. Thus, a remote-sensing data analyses represents an effective complement to the vole damage monitoring. The satellite data allow for a damage estimation and are advantageous for monitoring the damage progression over time. The UAV imagery can be used for a precise identification of the damaged areas, facilitating subsequent targeted applications of sprayed substances. This approach reduces the economic costs and provides the associated environmental benefits.

Keywords: crop damage, rodents, remote sensing, drone, GIS

Acknowledgement

The study was supported by the research project of Internal Grant Agency of the Mendel University in Brno as IGA24-AF-IP-055: *Detection of Crop Damage by Common Vole (Microtus arvalis) Using Remote Sensing Methods*.

VINEYARD UNIFORMITY ANALYSIS AND HARVEST PLANNING USING THE UAVS AND MULTISPECTRAL DATA

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Abstract

This research focuses on the application of the unmanned aerial vehicle (UAV) data collection and multispectral data analysis for a more efficient resource management, valuable in grape production for a large-scale wine production company. The vineyards, being the subject of the research, are located in Istria, Croatia, and are owned by the Agrolaguna company.

The four most important objectives were as follows:

- to develop and implement a workflow suitable for the processing and analysis of more than 500 ha of vineyards in an acceptable timeframe within a growing season
- to isolate a non-uniform canopy growth and vineyard areas in need of replanting or other agro-technical measures for a precise execution
- to set up a baseline dataset for future monitoring and work planning, such as a multiannual biomass comparison, irrigation system planning, yield monitoring, and the like
- to categorize the biomass for selected vineyard plots using the vegetation indices as maturity indicators to selectively harvest and separately process the grapes by category

The study sites were named in conformity with the corresponding nearby neighborhoods: Vižinada, Starići, Devići, Funtana, and Vrsar. The flight missions were planned using the vineyard-plot data provided by the Agrolaguna, QGIS, and DJI Pilot 2. For the sake of data collection, the DJI Mavic 3 Multispectral UAV was deployed. The raw images were processed in the Pix4Dfields, a precision agriculture software with the necessary tools for a vegetation-data analysis, the use of Normalized Difference Vegetation Index (NDVI), Normalized Difference

Red Edge (NDRE), or the Digital Surface Models (DSM). The first flights, processing, and analysis began in May 2024 and ended in September 2024.

The areas with biomass variability were identified, measured, geotagged, and paired with the on-site observations to determine the cause of variability. The following figures are the selected examples from the Starići and Vrsar plots, where the UAV data were used to gain useful information.

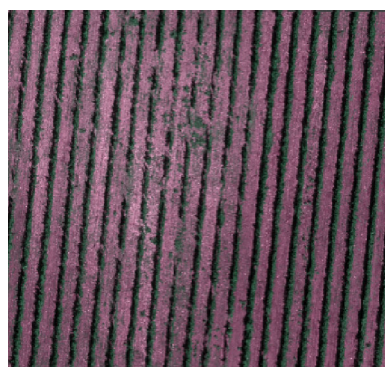


Figure 1. Orthomosaic, Starići

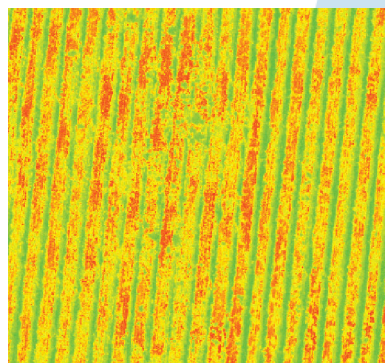


Figure 2. NDVI, Starići

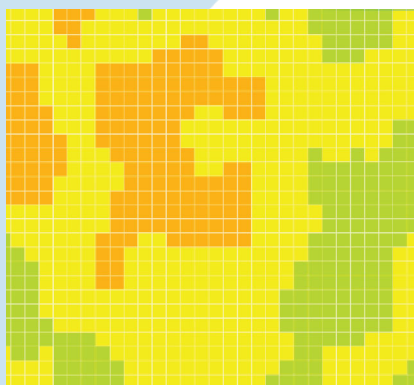


Figure 3. Biomass classification: green – high, yellow – medium, orange – low, Starići

On Figures 1-3, a detail is shown by which it was determined that the cause of a low biomass was a shallow rooting zone caused by a rocky substrate, which was producing more water and a temperature stress to the vines.

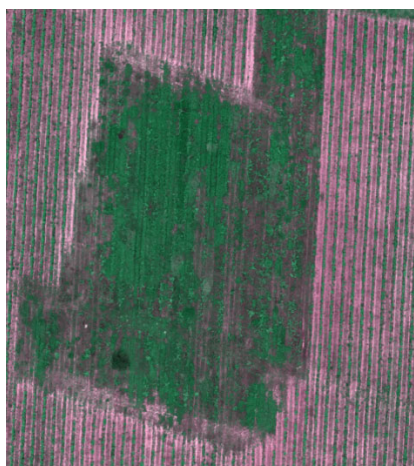


Figure 4. Orthomosaic, Vrsar

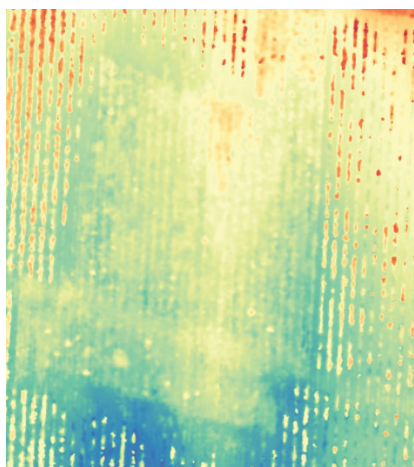
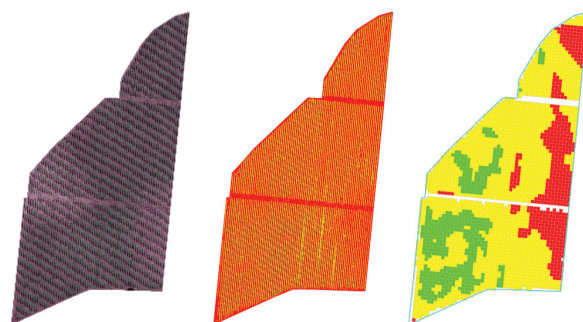


Figure 5. DSM, Vrsar

On Figures 4 and 5, the details are shown to illustrate a segment of a vineyard that was clear-cut to prevent the spread of *Flavescence dorée*.



Picture 6. Left - Orthomosaic, center - NDVI, right - harvest planning areas, Starići

Figure 6 depicts a harvest-planning map for the entire vineyard plot that was determined using the NDVI or the NDRE index as an input dataset. The vegetation was classified and colored by the average NDVI or NDRE values. The differences suggest different dynamics of grape maturation and grapes' chemical composition, and the grapes will be harvested and processed in three stages, what provides more control in the vinification process, as well as a higher quality assurance.

In conclusion, the UAV technology and multispectral data analysis can be a useful tool in work planning, especially during the harvest season and during the monitoring of vine growth throughout the growing season. A suitable workflow was developed to process the large amounts of raw images and extract valuable information for viticulture and wine technologists to use in a more informed, justified, and timely manner. A data archive was established, containing the classification, index, DSM, and orthomosaic data that can be accessed in a short time to be included in the new comparisons and analyses in the coming growing seasons.

Keywords: vineyard, UAV, multispectral data, classification, vegetation index

THE INFLUENCE OF THE NUMBER OF SOIL SAMPLES ON THE DETERMINATION OF NEEDS FOR A SITE-SPECIFIC FERTILIZATION

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Abstract

The assessment of spatial variability of soil properties is a very important component of modeling in agroecosystems and therefore for the performance of optimal fertilization. The site-specific fertilizer applications strongly depend on the accuracy of a soil-property map from which the fertilizer needs are recommended. The main objective of the present study is to measure the effect of sampling a different number of soil samples from the same production area on the interpretation of spatial variability of soil properties and the consequent needs in a site-specific fertilization and liming. With that aim, a total of 164 composite soil samples (topsoil 0-30 cm) were collected in the field in Trnava in Osijek-Baranja County (Croatia) in October 2021 applying a 25 × 16.8 m rectangular sampling grid (total area 5.38 ha). Therefore, it is possible to compare spatial variability and fertilization recommendations based on a grid sampling of 25×16.2 m, 25×32.4 m, 50×32.4 m, and up to 200×320 m (i.e., for the area range of 420 m² up to 5.38 ha per one sample, or 0.2 to 24 samples per ha). The basic soil properties of pH, soil organic matter (SOM), plant available phosphorus (P) and potassium (K), and additional soil property's cation exchange capacity (CEC), soil texture, and total content of elements were estimated while applying the standard analytical methods. A correlation, multiple regression, and descriptive statistics were calculated to evaluate these properties. The analyzed soil was very acidic to weakly acidic (pH_{H₂O} in the range 4.49-6.33; pH_{KCl}

3.48-5.45), with a low SOM content (1.03-2.00%), with a low to very significant hydrolytic acidity (2.05-6.91 cmol kg⁻¹), poor to very rich in P (60.6-409.4 mg kg⁻¹), and poor to well-supplied with K (101.9-283.2 mg kg⁻¹). The coefficient of variation for plant available phosphorus was the highest at 44.61%, indicating a significant spatial variability, while a fine silt content demonstrated the lowest variation at 3.71%.

The coefficients of variability of the most important soil properties for fertilization needs ranged from 8.1% for pH and 10.74% for clay content, 15.67% for SOM, 19.13% for CEC, 20.63% for available K, 24.25% for hydrolytic acidity, and to 44.61% for available P. The coefficient of variability of total concentrations of macronutrients ranged from 12.27% for Mg to 31.53% for K, microelements from 8.74% for Fe to 19.7% for Mn, and harmful elements from 7.36% for Pb to 32.58 % for Cr.

It is clear that the greatest variability of soil properties was determined for the properties that are most significantly affected by fertilization and soil degradation (e.g., available P, hydrolytic acidity, available K, and SOM content), and, to a lesser extent, for the properties with a smaller impact of agricultural activities (e.g., total macronutrients, trace elements, and harmful element content).

A reduction of the number of samples did not significantly affect the average value of basic soil properties (variability coefficients amounted to

2.91-6.93%, but they were 11.74% for hydrolytic acidity), macronutrient content (CV 1.61-4.81%), and micronutrients (CV 1.52-4.20%) with the highest variability of average Cr content (8.02%). However, there were significant changes in the maximum and minimum values of certain soil properties due to the reduction in the number of samples. Thus, for example, the coefficient of variability of the maximum values of the available P depending on the number of samples was 33.49%, K 26.85%, CEC 35.53%, and the variability of the minimum values was similar.

In this research, the most significant interpretation is the influence of the number of samples on recommendations in fertilization. There was almost no variability in the nitrogen fertilization plan, as it amounted to 155-165 kg ha⁻¹ N for wheat and 185-200 kg ha⁻¹ N for corn, regardless of the number of samples. The reason is the very low level of SOM, the very low mineralization potential, and the fact that the variable N fertilization on poor soils affect the topdressing in a greater extent, based on the status of the soil and the crops during the growing season, and to a lesser extent the N fertilization based on the properties of the soil prior to the growing season.

A certain variability of the required potassium fertilization was determined because, for instance, wheat fertilization amounted to 25-155 kg ha⁻¹ K₂O (average 131) and that of corn to 30-210 kg ha⁻¹ (average 178) for 64 samples. However, using the results of only 4 samples (i.e., a soil sample every 1.3 ha), the fertilization rates were 95-150 kg for wheat and 130-205 kg ha⁻¹ for corn, respectively, and using 2 samples (i.e., a soil sample every 2.7 ha) they amounted to 130-150 and 175-200 kg ha⁻¹ for wheat and corn. Considering the analyzed availability of K, there would be no zones without potassium fertilization regardless of the number of samples.

On the other hand, the zones without phosphorus fertilization were determined, depending on a number of samples, on 6.25 to 15.6% of the area, and with the need <30 kg ha on an additional 15.62-25% of the area (in total low fertilization on 25-39% of the area). With the use of 1-8 samples (a sample every 0.67-5.4 ha), there would be no zones without phosphorus fertilization, and already with 16 samples (a sample every 0.34 ha) there would be 12.5% of the area without fertilization and 25% of the area with low fertilization.

Significant differences were detected in the need for liming, because, with the use of 16 (samples every 0.34 ha) up to 128 samples, the need of 0-13 t ha⁻¹ of limestone (average 7.2-8.0) was determined, with 6.2 to 12.5% of the area where liming is not required. Using only 8 soil samples or less, 7-8 t ha⁻¹ limestone would be required, and there would be no zones with no liming recommended.

The presented results show that only one composite sample per 3 or 5 ha is insufficient for a site-specific fertilization and liming on such a heterogeneous soil, because fertilization would be significantly more precise with the results of analyzes every 0.34-0.67 ha. Considering that the feasibility and profitability of such a large number of samples is questionable according to the current sampling and analysis technologies, it is necessary to create a more precise model of the prediction variable availability of nutrients (especially of P, K, and pH) in the soil. The best scenario for such a model would most likely be a combination of laboratory-based and non-contact soil analysis, vegetation indices, and yield mapping.

Keywords: soil properties, sample number, spatial variability, site-specific fertilization

Acknowledgement

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WEED DETECTION IN WINTER WHEAT FROM THE UAV IMAGERY USING THE GIS TOOLS AND PIX4DFIELDS: A COMPARISON

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Abstract

One of the key objectives is to minimize the amount of agrochemicals used in crop management through the optimization of herbicide application. Understanding the spatial diversity of the weed plants in the field is necessary for an effective site-specific weed management. For this use, the unmanned aerial vehicles (UAVs) with a high spectral and spatial resolution have proven to be successful. Modern sprayer application technology enables a section-oriented or individual nozzle control based on the prescription map, what adds confidence to the efficacy of weed management. Usually, this map is made up of polygons that show the application area.

In this paper, a field infested with field thistle (*Cirsium arvense*) was scanned by a UAV. This study evaluates four possible detection techniques related to the agricultural practices. The two algorithms, Supported Vector Machine (SVM) and Maximum Likelihood (ML), respectively, are the supervised classification techniques. The ML and SVM classification algorithms have been utilized in the ESRI ArcGIS Pro. Other techniques include the thresholding approach and the Pix4Dfields (Magic Tool) classification algorithm. The Kappa coefficient and the total accuracy determined the accuracy of each method. An RGB orthomosaic was employed for the other three techniques, while a NDVI obtained by a multispectral sensor was utilized for the thresholding method.

Based on the Kappa coefficient and Overall accuracy, the results demonstrate that the thresholding approach obtained the best accuracy, whereas the Pix4Dfields had the lowest one. The SVM did better than ML when it came to supervised approaches. According to the UAV imagery used to identify the

weed infestation, only up to 5.56% of the field area was covered by weeds. Thus, a herbicide use can be greatly decreased by a site-specific spraying. With an accuracy of 98.6%, the thresholding method outperformed the other four confirmed weed-detection algorithms (Kappa index: 0.836).

Table 1: The values of overall accuracy, Kappa coefficient, and weed coverage in the investigated methods

Method	Overall accuracy	Kappa coefficient	Weed coverage
ML	97.8 %	0.633	2.29 %
SVM	98.2 %	0.792	3.30 %
Pix4Dfields	96.2 %	0.599	5.01 %
Thresholding	98.6 %	0.836	5.56 %

Keywords: precision agriculture, SSWM, Pix4D, thresholding, remote sensing

Acknowledgement

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THE MAPPING OF WEED INFESTATION BY THE DRONES FOR THE SAKE OF A SITE-SPECIFIC HERBICIDE APPLICATION

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Abstract

The optimalization of herbicide use is a key topic in weed management to minimize the environmental risks while achieving a sufficient crop-yield productivity. Nowadays, the farmers can use the most precise technique for the application of herbicides, such as the individual sprayer-nozzle control, which allows a patch or spot spraying, based on the identification of weed infestation. Although there are the prototypes of the on-the-go sensors for a real-time detection of weeds, currently the most widely used mapping method is remote sensing by the unmanned aerial vehicles (UAVs). Orthomosaic with a high spatial resolution provides an ability to design the maps for the application of selective or non-selective herbicides. Based on the UAV data, this varies according to a herbicide treatment application - that is, with regard to the non-selective (green on brown) and selective applications (green on green), respectively. The "green on brown" method is used to determine the location of weed infestation without the presence of crop vegetation. In that case, it signifies that all vegetation is being considered as weed-infested. The "green on green" method is a differentiation of weed and crop species for the sake of a spot application of selective herbicides. A detection of weed plants in the crops is more demanding, being performed while applying various trained machine-learning models and mostly resulting in the bounding boxes of objects (plants) to be sprayed.

A field experiment was performed in the period between 2001 and 2023 for the validation of a "green on brown" mapping of perennial weeds (ma-

inly *Cirsium arvensis*) on 22 field plots of arable land in the Czech Republic, Slovakia, and Romania, with a total area of 1095 ha. The fields were mapped by the low-cost UAVs, such as the DJI Phantom 4 Multispectral and the DJI Mavic 3 Multispectral but also with the professional drone DJI Matrice M300, equipped with multispectral camera. The image data processing was carried out in the Skymaps software platform Cultiwise.

The evaluation of economic benefits of the proven technology is based on the size of the field plots and on the design of an application map for that area. The results confirmed the need to spray 17–100% of the experimental area, depending on the intensity of weed infestation. More than 40% of the area (i.e., 442 ha) indicated possible savings of 25% of herbicides by spot spraying (see Table 1).

Intensity of weed infestation	Cumulative area
50%	135 ha
75%	442 ha
90%	699 ha
100%	1095 ha

Table 1: A sum of the area with weed coverage (in hectares) within the weed infestation intensity classes (%)

The performed patch spraying on three parcels with an area of 78.4 ha featured a spray application on 29.9 ha - that is, an area saving of 62%. This already represents a significant saving of spraying substances compared to the uniform application,

not only from a perspective of herbicide-cost saving but also in relation to the minimalization of phytotoxicity, environmental and health hazards. It must also be considered that a spot spraying is not appropriate (and economically viable) for all chemical weed-control treatment. Thus, the application can be expected to be particularly adequate for a repeated spraying targeting the perennial weeds, such as the species of *Cirsium*. The unmanned aerial vehicles fulfill an indispensable role in the identification of weed infestation or in the detection of vegetation damage, featuring the RGB or multispectral data with a very high spatial resolution of few millimeters to a centimeter. A technique presented in the study demonstrates a possibility to apply these technologies for a site-specific weed management. In combination with an advanced nozzle-control spraying technology, there are the new possibilities to open up a targeted application of the plant-protection products, with significant savings in the applied substances amounting up to the tens of percent.

Keywords: site specific weed management, UAV, weed mapping, herbicides application

Acknowledgement

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Section 3

Decision support systems and models in digital agriculture

ESA-ECOSYSTEMADAPT, A TOOL FOR THE DECISION SUPPORT AND MANAGEMENT OF THE MONTADO AREAS

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Abstract

The project was conducted in 2022 and 2023 as a part of the study of resilience of the Montado territories faced with a risk of desertification, through the actions aimed to increase the carbon and nutrient fixation in the soil and reforestation. *Montado* is a Portuguese term that refers to a traditional agroforestry system commonly found in the Iberian Peninsula's Mediterranean ecosystems. It involves the cultivation of cork-oak and holm-oak trees alongside grazing livestock, primarily pigs, cows, and sheep. In Portugal, the analyses on four scales (i.e., on a macro-, meso-, micro-, and nanoscale) were performed with regard to the three selected properties named "Herdade do Azinhal," "Herdade Casal das Balsas," and "Herdade das Cabanas."

A digital tool was developed to manage the ecosystem services based on the new methodologies and analyses in the field: on a macroscale, the satellite images of the study areas were analyzed; on a mesoscale, a more detailed analysis of the previous scale was carried out using the drones; on a microscale, the ecophysiological performance of plants was monitored using the equipment and sensors at a plant and soil level; and on a nanoscale, an analysis of the micro- and macronutrients in the soil and in the leaves were carried out, besides water characterization through the sensors and laboratory analysis. The remote sensors (i.e., the European

Space Agency's satellites) for the segmentation of ecosystems and ecosystem services and the nearby IoT sensors for local surveillance of climate parameters (fire risk), biodiversity, soil, and water monitoring were used (Fig. 1).

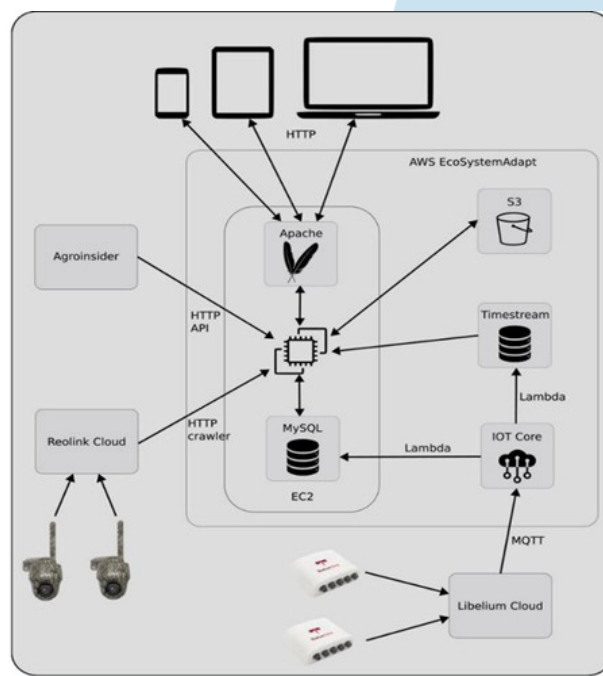


Figure 1. A data-capture principle scheme of the ESA.

On a macroscale, based on the Sentinel data, a land surface temperature (LST) and vegetation information (i.e., plant structure and water) were used to identify the crop anomalies related to the soil-water-plant complex, the management of zones that allow the definition of different land uses, a selection of sampling locations, and the installation of sensors. On a mesoscale, a GIS tool based on the revised universal soil-loss equation (RUSLE) was developed to map a potential water erosion and monitor soil conservation (Fig. 2).

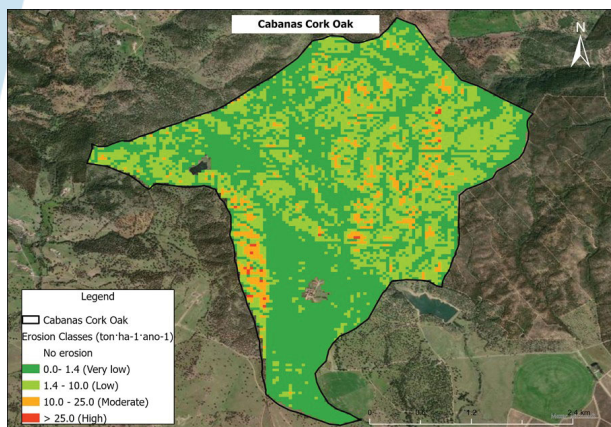


Figure 2. An example of soil-water erosion map from the GIS RUSLE tool.

On a microscale, a monitoring system based on the IoT technologies consisted of the following:

- a system of sensors in the ground equipped with the autonomous electrical supply systems through photovoltaic panels and batteries and with continuous readings over time (soil oxygen, soil temperature, soil conductivity, soil water content, and soil voltage)
- a system of water-quality sensors installed on a floating infrastructure, developed and equipped with an autonomous electrical power system with photovoltaic panels and batteries for a real-time monitoring of the in situ water-quality parameters (pH, electrical conductivity, salinity, turbidity, dissolved oxygen, and temperature)

Both systems can be used to visualize their evolution using the graphs with the data from selected time intervals and a possibility to use an alert system for the defined maximum and minimum values—for instance, as an image capture system using a wildlife surveillance camera with night vision and automatic detection of animal passages, or as a storage system developed for georeferenced photographs taken, for example, by a cellphone.

Furthermore, both image systems have a classification system according to a defined nomenclature, and they are georeferenced on a property map, allowing a graph analysis of animal visualizations in time intervals - for instance, the evaluation of ecophysiological performance at a plant/leaf level based on the thermal imaging, stomatal conductance, C-assimilation, and water use, as well as on a photochemical and non-photochemical (dissipative) use of energy.

On a nanoscale, chemical elemental analysis of soil samples and cork-oak leaves was carried out using an X-ray fluorescence analyzer.

The *ESA-EcosystemAdapt* is a dynamic platform that aggregates all information from the different data of heterogeneous sources and supports its users in the management of forestry exploitation and in reporting to all managing and certifying entities to which they are obliged (cf. <http://34.249.113.172/>).

The development of this platform allows monitoring the evolution and exploration of agroforestry systems over time, providing various alert systems. The automation and digitalization of processes and analyses facilitate decision-making at the intervention level in large geographical areas far from each other.

Keywords: agroforestry system, ecosystem services, GIS, IoT, monitoring, *EcoSystemAdapt* platform.

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CHARTING CHAOS: CRAFTING A SPATIOTEMPORAL MODEL FOR THE BROWN MARMORATED STINK BUG IN EMILIA ROMAGNA

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Abstract

Halyomorpha halys (Hemiptera: Pentatomidae), commonly known as the brown marmorated stink bug (Stål, 1855), is a highly polyphagous insect native to eastern Asia. It has established itself as an invasive species with a global distribution, causing significant damage to the agricultural crops worldwide. In Italy, it reached its peak in 2019, resulting in the estimated damage costs in orchards amounting to 600 million euros. To control this pest, both chemical and biological approaches have been applied, targeting the specific stages of the brown marmorated stink bug's short lifecycle on the locations where its presence had been confirmed.

In this study, we have developed a spatiotemporal model using the geostatistical direct sequential simulation method during the three consecutive years (2020-22) in the Emilia Romagna region in northern Italy. The conditioning information was derived from the weekly counts of this pest in the traps installed throughout the region, focusing on the second and on the third instar of this insect (young nymphs). A direct sequential simulation proved to be a suitable methodology, effectively incorporating the densely sampled temporal data and scattered spatial data without generating the artifacts. Furthermore, the simulation model efficiently managed the abrupt transitions between the zero and non-zero counts and allowed for the conditioning of results to a model of accumulated temperatures throughout the year, being an essential indicator for the appearance and development of this stink bug.

The proposed spatiotemporal model is valuable for the temporal and spatial management of the application of chemical and biological pest-control approaches. Additionally, it provides insights into locations with a higher likelihood of infestation in subsequent years.

Keywords: *Halyomorpha halys*, invasive species, space-time modeling, agricultural impact, pest control, direct sequential simulation.

Acknowledgements

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MEASURING THE DIGITAL TRANSFORMATION MATURITY IN AGRICULTURE

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Abstract

The digital transformation in agriculture (DTA) is one of the turning points in each of its aspects, domains, and components—from the production planning, analysis, development, research, and innovation to the most recent and innovative technology implementation (smart agriculture, precision agriculture, and the related areas). Following the recent trends in the new technology implementation, agriculture opens various opportunities of information and communications technology (ICT) implementation in various areas (livestock, plant production and protection, propagation material, and literally every agricultural activity). The recent papers on the DTA are progressively present due to its growing importance and complexity, as well as due to its social impact, globally and locally. Achieving a digital transformation in agriculture depends on various components and influences, leading to an agricultural digital-transformation maturity in various aspects and levels. Measuring digital transformation maturity in any of the industries (either in agriculture or in other sectors) may provide the picture of a general transformation and a potential guideline for further activities. This paper aims to provide an overview of the digital transformation in the agricultural achievements, implementation, and measures. The recent practices, trends, and technologies, from the GNSS, unmanned aerial vehicles (UAVs), the Internet of things (IoT), artificial intelligence (AI) to the innovative production lines, are leading us to the set of benefits and challenges.

The relevant technologies and terms were considered and presented upon the citation topic's microcriteria in the WoSCC. The most represented citation topics' micros based on a digital transfor-

mation in agriculture were "Engineering," "Computer Science," "Agriculture," "Business Economics," "Environmental Sciences Ecology," "Science Technology—Other Topics," "Mathematics," "Physics," "Plant Sciences," "Food Science Technology," and "Instruments Instrumentation." "Engineering," "Computer Science," and "Agriculture" were the key areas and topics related to the digital transformation in more than 67% of the studies indexed in the WoSCC.

Through a comprehensive literature review, a total of 36 relevant studies were identified, encompassing 12 different models with a particular focus on the diverse characteristics of digital maturity models. A special emphasis was placed on the dimensions employed to assess the digital maturity within various models applied to agriculture. The findings highlight significant variations in the dimensions used to measure digital maturity, both generally and specifically, within the agricultural enterprises. Notably, only a few models incorporate not only the digital capabilities but also the transformative aspects. This review ultimately reveals that most of the existing models offer an incomplete perspective of digital maturity particularly in the context of agriculture and that the models tailored to the service sector are noticeably underrepresented. Furthermore, it clearly demonstrates that the research examining the digital transformation maturity as a holistic concept is scarce, signaling the need for a greater attention to this area in future studies.

Keywords: Digital transformation in agriculture (DTA), digital transformation maturity, measuring digital transformation maturity, information and communication technologies (ICT)

Acknowledgement

The results presented in the paper are an excerpt from the paper by Darko Lugonja, Mladen Fruk, Tihana Sudarić, Ivan Plaščak, Mladen Jurišić, and Dorian Radočaj entitled “Digital Transformation’s Maturity Measuring as a Paradigm for a Digital Transformation Implementation—The State of the Art in the Agricultural Digital Transformation,” covering the period from 2004 to 2024.

THE CONCEPTUAL FRAMEWORK OF ENVIRONMENTALLY DRIVEN DECISION SUPPORT SYSTEM FOR GRASSLANDS MANAGEMENT (GM)

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Abstract

Decision Support System (DSS) is a computer-supported interactive system—that is, a software product to assist decision-making at any level of management, with an emphasis on making a directly applicable decision.

The purpose of this paper is to describe the conceptual framework of the environmentally driven DSS for various types of grasslands, which include: 1) permanent grasslands (meadows and pastures); 2) short- and medium-term grasslands on arable land (intended either for hay and silage production and/or grazing); and 3) lawns.

The environmentally driven DSS integrates data collection, knowledge incorporation into the model, environmentally driven simulation modeling of herbage growth, simulation of economic efficiency, and decision-making on agrotechnical interventions into a complete grassland management (GM) system. The conceptual framework consists of five major subdivisions: 1) data collection; 2) modeling of herbage growth; 3) simulation; 4) economic efficiency forecasting; and 5) conjoint DSS.

The collection of data includes the collection of previous data (from previous years and decades) on the agroclimatic characteristics of certain production areas, on the physical and chemical properties of the soil, and of the empirical data on agrotechnical measures in certain cultivation systems.

Modeling of the effects of various grassland management interventions includes the incorporation of theoretical and experiential knowledge about certain types of grasses, legumes, and their mixtures in the processes of grassland establishment and subsequent exploitation. The grassland management model should include the predicted mutual

influence of all factors (temperature, soil humidity, available nutrients, other soil properties, plant species, stand density, and defoliation regime) on the dynamics of herbage growth.

Environmentally driven simulation modeling of herbage growth represents running the model in certain time iterations (for a day or longer), whereby the new input values of the model will be set in each new iteration, either as current (final) values simulated in the previous iteration or as the new (corrected) values due to decisions made, that is, due to the agrotechnical measures implemented. The term “environmentally driven” refers primarily to the temperature, but it also includes a very significant influence of soil moisture and nutrient availability. The simulation model will serve to forecast the different herbage growth scenarios, with a basic goal of providing information necessary for decision-making. Simulated values can be calibrated at any time, that is, they can be compared or adjusted to the actual condition of the grassland, for which periodic or continuous data collection would be necessary (e.g., agrometeorological stations, remote or proximal sensing, in situ sensors, or in general IoT-based dynamic data collection system).

The forecast of economic efficiency (or profitability) is actually a model for simulating the economic efficiency of grassland management based on a relationship between the costs (consumable materials, mechanization and human labor, and other costs) and the simulated value of the product at a certain production moment while applying different scenarios, either in terms of the type of grassland and different methods of production or in terms of different final products (fresh forage, hay, silage, or final animal product like milk and milk products).

Conjoint DSS is a system that will serve to make decisions based on the information obtained from simulation models. A user will have a possibility to simultaneously compare several simulated output values (variables) of the simulation models (e.g., a simulated amount and quality of herbage mass, of hay, simulated product value, etc.) but also an instant, almost unlimited, comparison of the same variables in the different scenarios with certain modified values (e.g., the amount of fertilizer, fertilization time, amount of precipitation, temperature, prices of consumables, etc.).

A GM system could be used to analyze the previous real production systems and seasons, but its most useful purpose would be to make timely decisions in grassland management using the information based on real data, knowledge embedded in models, and simulated system (grassland) states. Real data during the use of GM system can be continuously used for validating and improving the GM system (more precisely, for the improvement of the model), for which it is necessary to incorporate the elements of an expert system which will enable self-learning from the new datasets.

Keywords: data collection, simulation modelling, environmentally driven model, pasture management, grass-legumes mixtures

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iMAP PLATFORM AND ITS CORE MODELS IN THE CONTEXT OF CAP ANALYSES

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Abstract

The iMAP project (Integrated Modelling Platform for Agro-economic and Resource Policy Analysis) seeks to deliver reliable scientific evidence to support the implementation, monitoring, and evaluation of the CAP, with a focus on environmental and climate change objectives. The platform was initiated in 2005, with an aim of creating a hub for hosting agro-economic modeling tools, funded by the European Commission, particularly through the European Union's (EU's) Research Framework Programs. Primarily financed by the Joint Research Center (JRC) and the Directorate General for Agriculture and Rural Development (DG-AGRI), it has since evolved into a policy support-focused platform that incorporates several partial equilibrium (PE) and computable general equilibrium (CGE) models (M'barek and Delincé, 2015.). The models are utilized either independently or in combination to address a wide array of topics related to the economic evaluation of agricultural and rural development policies, as well as the issues concerning trade, energy, environment, and climate change.

As a part of the iMAP platform, the following PE models are currently present: CAPRI (including CAPRI-FARM), AGLINK-COSIMO, ESIM, and AGMEMOD, the CGE models GLOBE/STAGE and MAGNET, and the farm-level model IFM-CAP (Individual Farm-Based Model for CAP Analysis), in order to conduct a comprehensive ex ante evaluation of the CAP.

Partial equilibrium (PE) models represent the behavioral interactions within one or more economic sectors while treating the outcomes in other sectors as external and unaffected by the changes in the depicted sector(s). These models are used to analyze the direct effects of changes on the most relevant sectors, without accounting for feedback

from other sectors. In the iMAP, the PE models primarily focus on the agricultural sector, but they increasingly incorporate additional sectors, such as vegetable oil processing, dairying, biofuel production, and the feed concentrate industry, which have strong links to primary agriculture or to the broader economy. The core PE models of iMAP are AGLINK-COSIMO and CAPRI, though other models, such as AGMEMOD and ESIM, are also included.

The AGLINK-COSIMO is a recursive dynamic partial equilibrium (PE) model of global agriculture, developed by the Organisation for Economic Co-operation and Development (OECD) Secretariat in collaboration with the member countries and select non-member economies. The model tracks annual supply, demand, and prices for key agricultural commodities produced, consumed, and traded across the regions it covers. The AGLINK is built upon the existing country models, and its structure reflects the perspectives of the participating nations (Burell and Nii-Naate, 2013.).

The CAPRI modeling system is a global agro-economic model that iteratively connects a supply module, focused on the EU, Norway, Turkey, and the Western Balkans, with a global multi-commodity market module. It comprises specialized databases, a defined methodology, software implementation, and the researchers responsible for its development, maintenance, and application. Specific modules ensure that CAPRI data are consistent and complete across time and space. The system covers around 50 primary and processed agricultural products for the EU, ranging from the regional to global level, including input and output coefficients. The CAPRI enables both economic and environmental analyses of various policy scenarios related to

the reform of the CAP and its subsequent reforms (Witzke et al., 2014.).

The AGMEMOD is an econometric, partial equilibrium (PE), recursive dynamic modeling system that operates across multiple countries and markets at both national and various aggregation levels. The model offers comprehensive insights into agricultural markets and agricultural policies (Salputra et al., 2013.).

The ESIM is a recursive dynamic partial equilibrium (PE) model that focuses on the agricultural production, consumption of agricultural products, and some initial processing activities. It represents the agricultural sectors of EU Member States, Turkey, the USA, other global regions, and the world market as a whole. The model encompasses 41 products and 29 regions, with the world market prices being endogenous and trade modeled as the net trade.

The MAGNET model is a global general equilibrium model characterized by its modular design, which allows the model structure to be customized to address specific research questions. Built upon the extensively used LEITAP model, the MAGNET provides greater flexibility in model aggregation, such as defining regions and sectors, and offers more options for modifying the model structure (Boulanger & Philippidis, 2014.).

In conclusion, the iMAP must deliver results and recommendations promptly while adhering to the high standards of scientific quality and transparency. It is essential to maintain strong connections with the current policy agenda. Additionally, the harmonized and publicly accessible databases should be utilized whenever feasible. For the ex-ante analyses, a baseline that is harmonized across the models and accepted by the stakeholders should serve as a benchmark for counterfactual evaluations.

Keywords: iMAP platform, agro-economic modeling, CAP, analyses

Section 4

Digital technologies in agriculture

INNOVATING POTATO CULTIVATION: THE IMPACTS OF FOLIAR CALCIUM BIOFORTIFICATION ON THE SOLANUM TUBEROSUM L. CV. PICASSO, ASSESSED VIA THE NDVI TO PREDICT THE YIELD

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Abstract

The digital technologies-namely, the remote sensing-have been applied to monitor the potato crops. This technology leads to the collection of valuable data for decision-making to optimize the crop management, improve agricultural practices, and to estimate crops productivity. This study aimed to analyze a relationship between the NDVI (Normalized Difference Vegetation Index) and yield productivity in *Solanum tuberosum* L. cv. Picasso, subjected to a Ca biofortification process with calcium chloride and calcium chelated with the EDTA (12 and 24 kg ha⁻¹), cultivated in the western region of Portugal (Lourinhã). The soil and irrigation water were characterized, being a soil suitable for potato cultivation, and the irrigation water was classified as calcium bicarbonate. The NDVI was assessed during the biofortification process and varied according to the Ca biofortification treatments, indicating a lower NDVI for calcium chelated with the EDTA treatment with 12 kg ha⁻¹. In fact, this treatment also presented the highest Ca content in the tubers after harvest, as well as a lower yield when compared to a control and the remaining biofortification treatments. Moreover, there were significant differences between the treatments regarding the Ca content in tubers. Additionally, the NDVI index can be used in deci-

on-making to enhance crop productivity as it serves as an indicator of plant growth and vigor, and it can also be employed for a preliminary yield prediction, as verified in our data. However, it is necessary to combine other field-monitoring techniques to achieve a more accurate yield prediction.

Keywords: calcium biofortification, NDVI, remote sensing, *Solanum tuberosum* L.

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MULTISPECTRAL IMAGES APPLIED TO THE ENRICHMENT OF ORGANICALLY PRODUCED TOMATOES WITH IRON AND ZINC

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Abstract

Micronutrient deficiency, namely that of Zn and Fe, is considered a public health problem affecting more than two billion individuals worldwide. To minimize this problem, an enrichment itinerary with four foliar sprays during the productive cycle of two tomato varieties (*Coração de Boi* and *Chucha*) was performed in Ourém (Portugal). The fruits were sprayed with a mixture of two products: 0.4–1.2 kg ha⁻¹ of Zitrilon (15%) and 1–4 kg ha⁻¹ of Maxiblend. An unmanned aerial vehicle (UAV) was used to acquire the images that were later processed to obtain a field morphology and drainage capacity, as well as to detect the plant vigor in the experimental field. Furthermore, a quality-assessment analysis was performed to classify the water used in irrigation in terms of the dominant ions (i.e., potentiometric, titration, chromatography [HPLC], and photometric analyses). Considering the drainage capacity and slopes, it was observed that the plot used for the production of the *Coração de Boi* variety indicates a tendency toward greater surface drainage, although both plots generally demonstrated a predominance of moderate water infiltration. Water analyses proved the hydrochemical facies of calcium bicarbonate and a classification for the agricultural use of C3S1. Additionally, the similar NDVI values pointed to both varieties having the same physiological status. During the harvest period, mineral enrichment was assessed by an atomic absorption spectrometry, manifesting

significant increases only in Zn for the *Coração de Boi* variety with both products applied (reaching a 2.6fold increase in case of the mixture with the inferior amount of Zitrilon). Yet, the mixture with a higher amount of Maxiblend manifested a tendency to increase (although not significantly) the Fe amount in both varieties. In conclusion, the *Coração de Boi* variety manifested a better response to the Zn and Fe enrichment, but more studies are necessary to optimize the itinerary.

Keywords: irrigation water analysis, *Lycopersicum esculentum* L., mineral enrichment, organic production, UAVs

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ENHANCING RICE (*ORYZA SATIVA* L.) PRODUCTION EFFICIENCY AND SUSTAINABILITY THROUGH PRECISION AGRICULTURE

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Abstract

Remote sensing data are a powerful tool that significantly improves the efficiency and sustainability of rice production (*Oryza sativa* L.). There is an increasing necessity of strategic actions that ensure efficient water use, sustainable agricultural production, and food security. Agricultural productivity can be substantially improved by adopting the precision agriculture practices, including an advanced water-quality management and the integration of cutting-edge remote sensing technologies. These practices enable a more precise monitoring and management of crops, leading to an optimized resource use and improved yields.

The aim of this work was to use a synchronized unmanned aerial vehicle (UAV) to evaluate the growing conditions of rice (Ariete variety) subjected to a biofortification flow with the two forms of selenium (sodium selenate and sodium selenite). In this context, a digital elevation model, water lines, and slope classes/infiltration suitability were obtained, and the crop status was assessed using the Normalized Difference Vegetation Index (NDVI). This study also aimed to monitor the crop water (supply, irrigation, and flooding) and evaluate the effectiveness

of enriching the whole and refined flour with Se. In this sense, the parameters of pH, pHs, electrical conductivity, temperature, Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, PO₄³⁻, SO₄²⁻, were analyzed. It was observed that the water runoff pattern followed the artificial pattern created by the grooves between the plots.

Based on the Piper diagram, the samples were categorized as sodium chloride bicarbonate for the supply water and sodium bicarbonate chloride for the irrigation and flooding water. According to the Wilcox classification for agricultural use, the samples were classified as C2S1 for the supply and irrigation water and as C3S1 for the flooding water. The NDVI index ranged from 0.76-0.79, without significant differences regarding control. In addition, significant differences in Se were observed in the flours, with a maximum content of 10.3 mg kg⁻¹ in the whole flour (selenite treatment).

In conclusion, using the precision agriculture techniques it was possible to efficiently monitor the growing conditions of rice biofortified with Se.

Keywords: NDVI, *Oryza sativa* L., precision agriculture, water management and quality

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THE OPTIMIZATION OF OLIVE-CROP PRODUCTION USING THE REMOTE DATA FROM THE SENTINEL-2 SATELLITE AND THE NORMALIZED DIFFERENCE VEGETATION INDEX'S IMAGES: A CASE STUDY OF AN OLIVE GROVE IN A HEDGE AT HERDADE DAS ROMEIRAS, PORTUGAL

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Abstract

In this study, we propose a simple and cost-effective methodology to identify the areas with varying productivity levels within a 22,000 m² hedge olive grove plot located at Herdade das Romeiras in Santa Vitória do Ameixial, Estremoz, Southern Portugal. A primary goal was to adopt a differentiated management strategy for the optimization of the use of resources such as the soil, water, and nutrients. Eighty-one *Arbequina* olive trees, planted in 2018, were studied. The NDVI (Normalized Difference Vegetation Index) images were produced using the *ArcGIS Pro*[®] software by the Sentinel-2 images, acquired by the Copernicus Open Access Hub and utilizing the bands four and eight that correspond to the red and near-infrared bands. Nine sampling points, each consisting of nine olive trees, were selected, and biometric characteristics (height, width, and canopy length) were measured to estimate the volume. The weight of the produced olives was also recorded. Additionally, the Pearson correlation was calculated, resulting a coefficient of 0.67. An analytical tool was developed to identify the areas with different productivity levels while associating the NDVI with the canopy volumes using a polynomial equation that relates a canopy volume to an olive weight produced.

The different zones were delimited with a productivity ranging from 7,000 to 22,000 kg per 10,000 m², and a minimum production of 9 kg per tree was defined. The maps obtained by a graphical representati-

on analysis of a function that fits the collected data at its best showed that a defined minimum production corresponded to a minimum canopy volume of 3.56 m³, and the maximum production (11.20 kg per tree) corresponded to a canopy volume of 5.60 m³. Moreover, the trees with the larger canopy volumes, consuming more resources and having a lower cultural operation efficiency, did not achieve the maximum average production values per tree due to an excessive volume. There were also the zones where the trees with the smaller canopies did not reach the average production per tree despite a similar agronomic treatment and production costs. In this context, the knowledge of areas with different productivity is essential to implement the treatments adapted to the variability of conditions and the adoption of differentiated site-specific management strategies, which are also important for sustainability.

Keywords: hedge olive grove, NDVI, precision agriculture, site-specific management, sustainability

Acknowledgement

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The authors express their gratitude to the Ameixial Agricultural Society and to the Eng. Henrique Chia.

PARTICLE SIZE MEASUREMENT OF FOUR DIFFERENT TYPES OF FLOURS WITH A LASER-DIFFRACTION ANALYZER

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Abstract

This study aims to characterize and compare the particle sizes of four different types of flour. An accurate particle size is essential for the comprehension of functional properties of flour in various applications. A particle-size distribution of four different types of flour was studied using a laser-diffraction analyzer. In addition to a laser diffraction, surface morphology and particle characteristics were further examined while applying the Hitachi (SU3800) Scanning Electron Microscopy (SEM).

In this research, integral wheat flour, refined wheat flour, maize flour, and arrowroot flour were used. Approximately 1 g of each flour sample was dispersed in the distilled water and mixed to ensure homogeneity prior to the measurement. The laser-diffraction technique provided detailed particle-size distributions, revealing significant differences between the flour types. The results demonstrated significant variations in particle size and shape across the flour types, with the arrowroot flour having the smallest particle-size distribution, with 100% of the particles reaching a cumulative undersize at the smallest diameter. This indicates that this sample type consisted of finer particles when compared to the other flour types, what may have influenced its texture and processing behavior. In contrast, the maize-flour sample had the largest particle size distribution, with 100% of the particles reaching a cumulative undersize at a conspicuously larger diameter, suggesting a much coarser particle structure. The SEM provided the high-resolution images that complemented the qu-

antitative size data, revealing the detailed particle structures (Fig. 1).

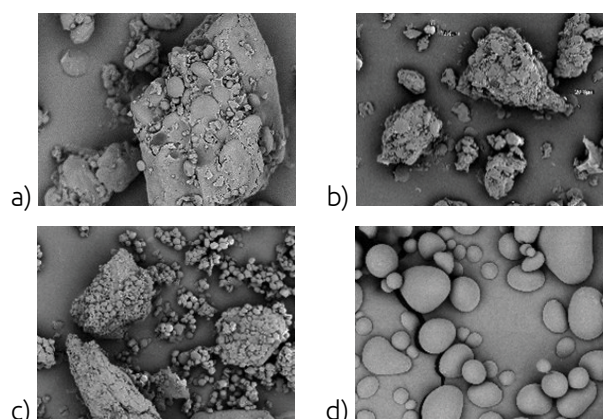


Figure 1. Flour particles scanned by the SEM, as follows: a) integral wheat-flour particles, b) refined wheat-flour particles, c) maize-flour particles, and d) arrowroot-flour particles.

These analyses have important implications concerning the functionalities of flour in food processing, particularly in terms of texture and dough formation. The application of advanced digital technologies, such as that of the Analysette 22 laser-diffraction analyzer, has facilitated the precise and reliable measurements, having enhanced our understanding of flour characteristics.

Keywords: flour, food technology, laser diffraction analysis, particle size, Scanning Electron Microscopy

THE USE OF DIGITAL TECHNOLOGIES TO CREATE A NEW INFORMATION ON THE AVAILABILITY OF SOIL MICRONUTRIENTS

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Abstract

Soil is a basic and irreplaceable resource in the cultivation of plants for food production. In such an environment, any information about the influence of the soil and of the entire ecosystem on the success of farming and the quality of the food produced is very valuable.

A usual field- and laboratory-based approach to the determination of soil suitability is focused on the basic soil properties (i.e., on the pH value and the SOM content) and the basic nutrients (i.e., N, P, and K), while the micronutrients are usually analytically neglected. However, there have always been the areas and soils with a lack of available trace elements. The information about their availability in the soil is usually obtained from the results of a laboratory-based analysis, what requires an additional field and laboratory work and cost. The development of digital technologies allows us to use various new tools and create the more accurate models for the prediction of micronutrients' availability in the soil, including the mapping tools, without an additional laboratory-based soil analysis.

With an aim of creating and comparing the different models for the prediction of availability of the Fe, Mn, Zn, and Cu trace elements in soils, 221 composite arable-soil samples (with a layer measuring 0–30 cm) of the Croatian Pannonian region were collected and analyzed. The soils were selected based on the pH value and the SOM content, so that the soils of all combinations of soil reaction (i.e., from a very acidic to an alkaline soil) and the SOM content (i.e., from a very poor to a humus-rich soil) were evenly represented in the initial set of samples. The total contents of trace elements and their

available fraction in the soil were not a factor in the initial soil-sample selection. The soil pH value (i.e., the soil suspension in the water and in 1 M KCl); organic matter content; the total concentrations of Fe, Mn, Zn, and Cu extracted with the aqua regia; and the concentrations of the plant-available Fe, Mn, Zn, and Cu extracted with the EDTA solution were analyzed in the soils.

Based on the laboratory results, two regression models were created for the prediction of availability of each microelement in the soil: (1) one model based on the soil reaction (pH), SOM content, and the total concentration of micronutrients in the soil (extracted with the aqua regia), and (2) the other model based on the soil reaction (pH) and the SOM content only. The laboratory results of the available fraction of each micronutrient (extracted with the EDTA) were also used to create the model. The basis for an evaluation of accuracy and convenience of the model is a comparison of the available laboratory-determined and model-predicted concentrations of microelements.

The models were created based on the correlations of soil-solution acidity in the range of 4.60–8.81, substitution acidity of 3.51–8.29, SOM of 0.21–3.50%, total Fe content of 9.63–51.23 g kg⁻¹, Mn of 194.6–1,170 mg kg⁻¹, Zn of 19.79–164.50 mg kg⁻¹, and Cu of 3.48–54.11 mg kg⁻¹, respectively.

The regression model predicted the average availability of Fe with the value of 109.96, and the analytically determined average was 115.58 mg kg⁻¹, but the predicted range was 0–214.59 and the measured range was 5.33–791.80 mg kg⁻¹. There was no correlation between the total and available Fe in

the soil, and the availability of Fe was most significantly affected by a substitute acidity and by the acidity of the soil solution ($r = -0.866$ and -0.777). Although there was a significant correlation between a predicted and a determined value of the available Fe ($r = 0.37$), the model was not sufficiently accurate, because the average model error was 70.36 mg kg^{-1} (i.e., 63.99% of the measured value). Almost the same values of the available Fe were predicted with regard to the another model with no use of the total amounts of Fe in the soil, which means that the available amounts practically did not depend on the total amounts of Fe, or that the developed models were not sufficiently good. The model error correlated very significantly ($r = 0.882$) with the measured concentration of the available Fe.

Also, the regression model predicted the average availability of Zn to have the value of 5.25, and the analytically determined average was 5.29 mg kg^{-1} , but the predicted range was 2.19–11.68 and the measured range was 1.14–23.23 mg kg^{-1} . The predicted available Zn correlated with the total amount of Zn in the soil ($r = 0.858$) and the SOM content ($r = 0.800$) mostly, without the influence of the soil pH value. The average error of the model, amounting to 2.16 mg kg^{-1} and 40.81% (from 5.29), was lesser than that of the model for Fe, but that model was not sufficiently accurate either, which was confirmed by a low correlation coefficient of the predicted and measured available Zn of only 0.294 (although the r was significant at $p < 0.01$). The second model, without the use of total Zn concentrations in the soil, was even more imprecise ($r = 0.225$, significant at the $p < 0.01$ level), and the predicted Zn availability was highly correlated with the SOM content ($r = 0.975$) only.

The Mn availability prediction model had a good accuracy, as the model's average error was 19.05 mg kg^{-1} (28.4% of 67.09 mg kg^{-1}). A correlation between the predicted and the measured available Mn was very high ($r = 0.724$, significant at the $p < 0.01$ level). The predicted available Mn correlated very significantly with total Mn in the soil ($r = 0.96$), exchangeable acidity ($r = -0.637$), and with the soil-solution acidity ($r = -0.619$). The model's accuracy without the available data on the total Mn in the soil was significantly lower ($r = 0.395$), with an average error of 26.52 mg kg^{-1} (39.5% of 67.09 mg kg^{-1}).

The most accurate model was the prediction of Cu availability ($r = 0.829$), with an average model error of 1.50 mg kg^{-1} (24.2% of 6.20 mg kg^{-1}). The model predicted the availability of Cu in the range of 0.33 to 22.46 mg kg^{-1} , and the measured values were $1.19\text{--}37.91 \text{ mg kg}^{-1}$. The highest correlation was the one between the predicted availability of Cu and the total Cu in the soil (0.971) and a significantly lower correlation with the SOM content (0.422).

The model without the total Cu content in the soil was less accurate, with the average error of 2.18 mg kg^{-1} (35.17%) and a correlation between the predicted and the determined available Cu being significantly lower ($r = 0.444$).

In conclusion, we may say that the linear regression models for the prediction of availability of microelements in the soil are the least accurate for Fe and Zn, sufficiently accurate for Mn, and very accurate for Cu. Analyzing the regression models and their accuracy, we have obtained a new information from the soil-property data: for the prediction of availability of Fe, the most important soil data are the exchangeable ones and the soil-solution acidity; for Mn, the content of total Mn in the soil and slightly less the exchangeable data and the soil-solution acidity; for Zn, the content of total Zn in the soil and the content of the SOM; and for Cu the content of total Cu and, slightly less significantly, the content of SOM in the soil.

Keywords: soil acidity, SOM content, total soil micro-nutrient content, plant available soil micronutrient

Acknowledgement

The presented results are an output of the project KK.01.1.1.07.0053 *The Application of Innovative Bio-agents in the Sustainable Plant-Production Technologies (InoBioTeh)*.

THE USE OF PRECISION AGRICULTURE IN THE INTERPRETATION OF THE INFLUENCE OF SOIL PROPERTIES ON THE VINES AND MUST

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Abstract

Regardless of their size, agricultural production particles can be very heterogeneous either as a result of geographical and orographic characteristics or as a result of an anthropogenic influence. The soil of the same production plot can have many heterogeneous properties that significantly limit the cultivation success, as well as the maintenance of soil fertility. With the digitalization of agriculture, the tools, equipment, and procedures have been developed that enable the adaptation of agrotechnical operations to any significant variation in soil properties.

A possibility to apply precision agriculture is particularly important in the management of permanent plantations, in particular during a multiyear exploitation.

The aim of this paper is to investigate soil heterogeneity and a connection between the vineyard-soil properties and vine's nutritional status and must quality. During the multiyear cultivation of grapevines, variety Žlahtina, a large difference in the yield was determined despite the same cultivation technology on an area amounting to 3.58 ha. According to the regulations on soil-fertility control in Croatia, one composite soil sample is sufficient for a plot amounting to 3.58 ha. Concerning the determined difference in yield, however, the two composite soil samples were initially sampled from the plot, each as a sample for a plot area amounting to 1.79 ha, at two depths (0–30 cm and 30–60 cm, respectively).

The analysis of the two aforementioned soil samples indicated the mostly uniform soil properties (for a layer with the depths of 0–30 cm): pH_{KCl} (7.21 and 7.17), SOM (2.89 and 2.92%), total N (0.28 and

0.23%), sand contents (4.89 and 3.66%), silt (54.44 and 58.21%), and clay (40.67 and 38.13%), available Fe (25.67 and 28.37 mg kg^{-1}), Mn (24.13 and 26.21 mg kg^{-1}), Zn (2.30 and 2.15 mg kg^{-1}), and Cu (13.58 and 12.07 mg kg^{-1}), but with a slightly different CEC (39.31 and 33.59 cmol kg^{-1}) and available K content (321.4 and 391.8 $\text{mg K}_2\text{O kg}^{-1}$) and the high differences in the available P (109.9 and 442.0 $\text{mg P}_2\text{O}_5 \text{ kg}^{-1}$).

Also, 51 geopositioned soil samples were sampled on the same plot according to a $30 \times 30 \text{ m}$ grid, the vine leaves were sampled during the growing season, and the grapes were sampled at 10 geopositioned locations during the harvest in order to compare the soil, leaf, and must properties (Fig. 1).



Figure 1. Sample grid and SOM content.

A very small variability of some properties, for example, soil reaction (pH_{KCl} 7.26–7.43; coefficient of variation (cv) = 0.86%), CN ratio (9.75–12.10; 4.45%), silt (29.16–49.20; 7.27%), and clay content

(31.93–41.82; 6.19%), was determined. Simultaneously, a higher variability was detected in the content of SOM (2.69–4.64%; 9.93%), total N (0.17–0.31; 10.27%), CEC (24.64–46.01 mg kg⁻¹; 13.40%), available Cu (10.79–17.49 mg kg⁻¹; 12.42%), Fe (20.7–41.79 mg kg⁻¹; 14.30%), and K (321.7–603.8 mg kg⁻¹; 15.10%), as was even a higher variability of available Mn (16.12–47.41 mg kg⁻¹; 20.41%), Zn (1.42–6.20 mg kg⁻¹; 28.75%), and P (CV 61.23%).

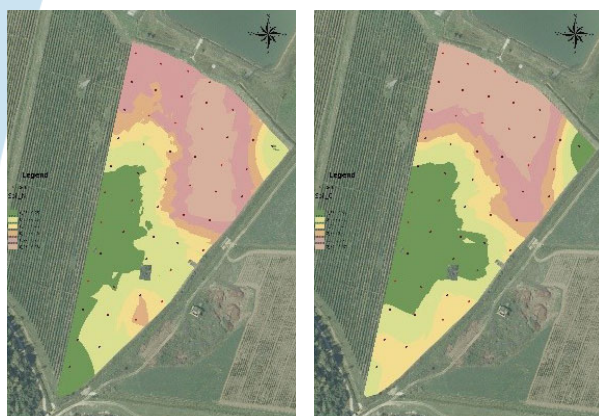


Figure 2. Total N (left) and total C contents (right) at the depths of 0–30 cm

Total soil N, total C (Fig. 2), and SOM content (Fig. 1) form one group of soil properties, with the highly significant correlations. On the other hand, the correlation between the CEC and exchangeable Ca is statistically even more significant (Fig. 3).

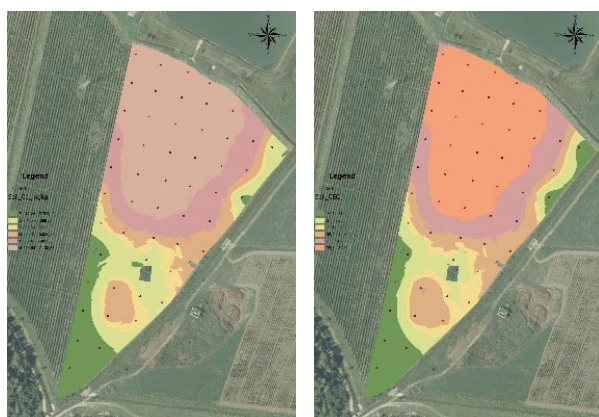


Figure 3. Exchangeable Ca in the soil and CEC

Regarding the nutrient content in the leaf, the highest variability was detected in the content of Mn (38.5–92.8 mg kg⁻¹; CV 29.4%) and K (0.65–1.27%; CV 23.64%) and the lowest in the P content (0.11–0.14%; CV 7.38%), although a large variability of available P in the soil was determined. A high posi-

tive correlation of the content of Mn and Fe and a negative correlation of the content of P and Zn in the leaf were established. A very significant positive correlation was determined between the soil N and leaf Zn, and a negative correlation between the soil P or K and leaf Fe. By comparing the properties of the must and leaves, a positive correlation was established between a total soluble DM in the must and the leaf Mg, volatile acid in the must and the leaf P, and a negative correlation between the ammonia in the must and the leaf Zn.

At the same time, a positive correlation was detected between the SOM content and a total soluble DM in the must, soil pH and ammonia content in the must, soil CN and the content of alpha-amino N, or of the tartaric acid in the must, whereas a negative correlation was detected between the clay content in the soil and the ammonium content in the must (Fig. 4).

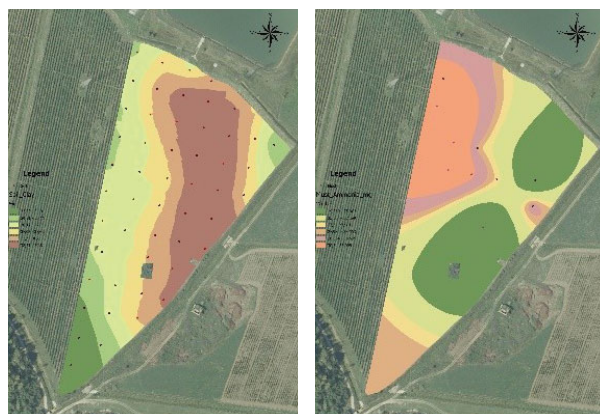


Figure 4. Soil's clay content and the leaf ammonia.

The conclusion of this research was that only two average soil samples on 3.58 ha of vineyard lead to a misconception about a necessary fertilization. On the other hand, more soil samples, along with a leaf and must analysis, enable a determination of the influence of properties of such soil on the nutrients in the leaves and the properties of the must. Regression models and the GIS tools are particularly useful for this purpose.

Keywords: soil-nutrient availability, leaf-nutrient content, must properties

Section 5

Agroeconomic insights into digital agriculture

DIGITAL NOMAD - A BUSINESS MODEL OR A GLOBAL PHENOMENON?

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Abstract

Digital nomads are the people who use digital technologies to perform the tasks at remotely while changing their places of residence. This term was first mentioned in the book *Digital Nomad* in 1997, written by Tsugio Makimoto and David Manners. The book explores a remote work combined with a nomadic lifestyle, all through portable technology and travel. The history of digital nomads actually follows the development of technology, and technology plays a key role in the development of this phenomenon. The rise of digital nomadism is not just a passing trend but a profound change in our understanding of work, freedom, and a balance between them. This movement introduces a new way of thinking about career and lifestyle.

Technology is advancing faster than ever, and digital nomadism is a direct result of digitalization, which is changing traditional work patterns. The aim of this paper is to determine social, organizational, and administrative frameworks in the digital nomads' businesses in the Republic of Croatia. For the sake of the paper, a survey was conducted (N=128), having examined the respondents' opinions and attitudes about familiarity with the concept of digital nomads, as well as the advantages and disadvantages of this type of business model.

The results in the paper indicate that some of the advantages of this business model are as follows: flexible working hours; a possibility of to travel; the exploration of new destinations, cultures, traditions, and customs; and new acquaintances. Nevertheless, one of the basic motives of digital nomads is lower living costs (in an environment that suits them). The disadvantages can be as follows: inadequate Internet connection, isolation, and a lack of social contacts; individual difficulties in wor-

king hours' organization, and the like. The results also demonstrate that the public opinion in the Republic of Croatia is not sufficiently familiar with the concept of digital nomads. In the paper, this is indicated by the results of an empirical survey, which proves that 30.5% of respondents do not know the term, and the other 10.5% are not sure what the term implies. The most significant survey responses (multiply answers) related to the benefits of the involvement of digital nomads in local environment are the promotion of the Republic of Croatia as a destination (82.8%), a positive effect on the development of local economy, and small businesses (49.2%) - that is, consumption (43%).

Attracting digital nomads can be a part of the strategy of territories that wish to position themselves as technology and innovation hubs, as well as leisure destinations. It can be assumed that the most common digital nomads' occupations are the jobs of programmers, data analysts, creative writers, or even journalists; however, there is a wide spectrum of occupations that exist and are emerging daily. The jobs related to consulting, content creations, virtual assistance, and all the forms of marketing expertise are becoming increasingly attractive. Digital nomads can also be involved in local events and foster connection with local residents, reducing isolation and improving the locals' quality of life, especially the one of elderly people.

The Adriatic part of the Republic of Croatia is very attractive for living, but rural areas have their benefits too. On the one hand, digital nomads can strengthen rural population's environment, and, on the other hand, they can work in a healthy environment, landscape, and stress-free life.

Local authorities need to develop strategies that entice people to stay, or—for those who left to the more urbanized centers—to go back while structuring the programs to attract new labor and new entrepreneurship. This can be done by highlighting rural regions as destinations that provide a cheaper cost of living and a calmer and safer place, with closer connections to the local community. These factors could entice remote workers, such as digital nomads, the individuals who can travel and work remotely, relying on technology to sustain mobility.

In order to increase attractiveness for this business model, it is necessary to adapt the infrastructure, to expand the number of coworking spaces/communities, and to provide administrative support.

This global phenomenon represents a challenge for many countries, including the Republic of Croatia, which has made significant progress in attracting digital nomads in the last few years. Some of the most important measures are the introduction of a special visa for digital nomads, as well as numerous tax benefits. Organizational and administrative frameworks in the digital nomads' businesses are becoming increasingly adapted, and, with its comparative natural beauty of life, the Republic of Croatia is becoming a suitable country for digital nomads.

Keywords: digital nomad, business model, global phenomenon, Republic of Croatia

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The results in the paper are a part of the research conducted by the student Slađana Katušić during her Master Study Program in Agroeconomics at the Faculty of Agrobiotechnical Sciences Osijek, Croatia.

DISRUPTIVE INNOVATIONS IN THE AGRICULTURAL SECTOR

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Abstract

The term disruption is recognized in all areas of activity, because its meaning is the interruption of a standard or usual process. A Harvard professor Clay Christensen was the first to describe the term "disruptive technology" in 1995, and he renamed it later as "disruptive innovation." He claims that it was not technology that was disruptive but changes in business models that arose on the basis of these innovations. The same author states that there are two types of technologies: a sustainable and a disruptive one. Sustainable technologies encourage product improvement, and they have in common that they improve the performance of existing products that are accepted by the customers on the market. Such technologies can be discontinuous, radical, or incremental in nature. A discontinuous innovation can be considered a radical, or a truly new, innovation depending on (macro/micro) level and the discontinuities it causes, being market-related, technological, or both, when the innovation is introduced on the market. Most examples of discontinuous innovations are categorized as the really new innovations. An example of what can be considered as sustainable technology is the improvement of a tractor by adding a GPS system to enable a more precise tractor guidance during plowing or sowing of crops. This improves the efficiency and productivity but does not change the fundamental way farming is performed.

Christensen (2017) states that incremental technology most often provides new opportunities to the existing technology namely, to a product or service but with a low level of development. On the other hand, radical technology denotes a major advance in a particular technology. In contrast, disruptive technologies bring a significantly different value to the market than the one previously available. They usually have weaker initial results than the existing and already recognized products on the market, but they have other features that are appreciated

by the customers in the neglected markets, as well as by the new customers. An increasing number of business models includes disruptive innovation as a strategy to achieve competitiveness.

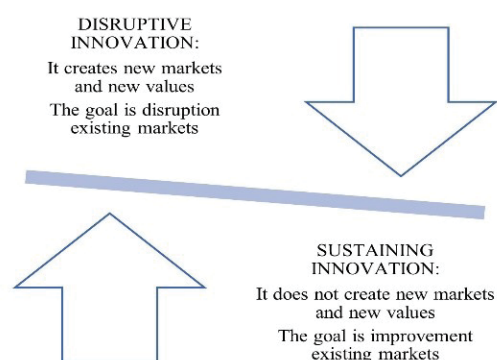


Figure 1. Disruptive vs. sustaining innovation

A key difference between the disruptive and sustaining innovations is that disruptive innovations often change market relations, creating the entirely new ways of production or the new products that can displace the existing business models (Fig. 1). On the other hand, sustaining innovations are aimed at improving the existing practices and products in order to achieve a greater efficiency or competitive advantage, but they do not change the existing business models.

Disruptive innovations in agriculture change traditional production technologies, enabling a more efficient and profitable cultivation of plants and animals. The most significant disruptive innovations in agriculture are:

- vertical farming: growing plants in layers indoors using hydroponic or aeroponic systems instead of growing them in the fields; the need for land is reduced, what enables food to be grown closer to consumers, reducing carbon dioxide emissions and water, and transport costs

- precision agriculture: the use of sensors, drones, satellite imagery, and data analytics to precisely monitor the fields and optimize resource use; the way the resources are managed is transformed, and a negative impact on the environment is reduced by optimizing the use of water, pesticides, and fertilizers
- blockchain technology in food tracking: a transparent tracking of every step in the food supply chain, from the field to the fork; disrupts the food supply chain by creating a transparent, safe, and efficient system that solves the long-standing problems such as fraud, irregularities, and non-transparency
- laboratory-grown meat: meat products grown from animal cells in laboratory conditions instead of conventional animal breeding enable meat production without the need for breeding, slaughtering, and large resources; livestock breeding is reduced, which reduces the emission of greenhouse gases and excessive water consumption while also affecting the ethical aspects associated with conventional animal husbandry
- CRISPRCas9 in the genetic modification of crops: a technology that enables precise editing of genes in plants to make them more resistant to diseases, drought, or other challenges without introducing foreign genes, as in the traditional GMO techniques; it enables faster and more precise adaptation of crops to the changes in the environment, as the genetically engineered crops can provide higher yields with a lesser use of pesticides or fertilizers
- hydroponics and aquaponics: hydroponics is the cultivation of plants without soil using a nutrient solution in water, while aquaponics combines hydroponics with fish farming; both techniques enable agriculture in the areas with poor soil or limited resources such as water and integrate a food-growing system that is ecologically sustainable
- biotechnology for biodegradable packaging: the use of agricultural residues and biological materials for the production of biodegradable packaging reduces the need for plastic packaging; this innovation helps reduce the ecological footprint of food production and enables a better utilization of agricultural residues.

Disruptive innovations in the agricultural sector do not only represent technological changes, but they represent fundamental transformations in the way

of production and resource management. Through examples such as vertical farming, precision agriculture, blockchain technology, and laboratory-grown meat, it is clear that these innovations have a potential to significantly improve efficiency, sustainability, and transparency throughout the food-production chain. On the other hand, CRISPRCas9 and hydroponics enable greater adaptability and resilience of crops in conditions of climate change and the lack of resources while biotechnology for biodegradable packaging contributes to the reduction of waste and the ecological footprint of agriculture.

While they bring new opportunities, disruptive innovations also impose challenges in terms of regulation, consumer acceptance, and adaptation of existing business models. However, their long-term impact can enable a more globally sustainable food production system that meets the needs of a growing population while preserving the environment.

Keywords: disruptive innovations, market, biotechnology, agricultural sector

PROS AND CONS OF ONLINE SURVEYES IN AGRICULTURAL MARKETING

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Abstract

Data are the basis of any research. Data should primarily be of a high quality, and then they should be analyzed and interpreted in order to become an information. Scientific research is largely based on primary data. One of the most common ways of collecting primary data in the field of social sciences, marketing, and consumer behavior are surveys.

With the arrival of the Internet, traditional (paper) and telephone surveys are gradually replaced by the online ones.

Based on the Oxford Dictionary, a survey is a research of opinions or experiences of a group of people based on a series of questions. The questions in the survey are mostly predetermined and are aimed at extracting specific data from the responses of a certain group of people regarding their preferences, attitudes, opinions, or behavior, depending on the purpose of the survey. A single survey includes at least a sample population and a data-collection method—a survey tool of individual questions that generate data that need to be statistically analyzed. The data collection can be categorized into two groups: manual and electronic. The advantages of electronic versions of records if compared to the paper ones are an easier availability for analysis (data mining). Primarily, the research depended on paper surveys that used the techniques of home visits, face-to-face conversations, interviews, distribution of questionnaires, and the like. The challenge was to convert these paper data into an electronic system for data processing and analysis. Sometimes the already available data in electronic form were reduced to a papered form for a better data overview, which is an inefficient and expensive method that results in inadequate data.

Today, online surveys are much easier and faster, because software packages are created and used to create surveys/questionnaires. This paper aims to discuss the pros and cons of electronic data collection/online surveys. The methods used today for electronic data collection are electronic mail surveys and web surveys.

Electronic mail surveys: a questionnaire is sent to a person's e-mail address, and a respondent sends back a filled-out form. It is a simple and cost-effective method that enables a higher geographical spread of respondents. The cons are a required capability for dealing with a software and certain level of computer literacy. **Web surveys:** the surveys posted on the web platforms that can be completed by the web-platform users.

The software packages deployed today to create the online survey questionnaires in the field of marketing and consumer behavior (e.g., the Qualtrics) have a number of capabilities that are compatible with different marketing tools for data analysis - for instance, with the design of a choice experiment, setup of an auction, and the like. Their disadvantage is that they are relatively expensive, and a license has to be paid for a certain period of time. For simpler surveys, the free tools (e.g., Google Forms) which have much more modest capabilities are mostly used.

Many additional challenges of online surveys generally occur. The challenges relate to the sampling, response rate, non-respondent characteristics, maintenance of confidentiality, and ethical issues.

The principal goal of **survey sampling** is to make reliable and accurate inferences to a broader population. For the purposes of scientific work in the field of agromarketing, the representativeness of the sample whose participants will reflect the opinions and attitudes of the entire population must be met

in order to guarantee the credibility of the results. For small countries like Croatia, it is necessary to ensure the representativeness of the sample from the entire country. The size of the sample depends on who is the subject of the research and on their total number - that is, the consumers, producers, traders, public institutions, and the like. The sample should represent the entire population in terms of all characteristics, and these characteristics in agricultural marketing and consumer behavior are mainly sociodemographic, or they might be some other characteristics that describe the subject of survey. An additional problem for conducting serious research is the absence of a database (e.g., a customer database), or these databases exist but must be obtained on request from the competent institution (e.g., in case of manufacturers or traders). Serious researchers mostly rely on commercial service institutions that have their own paid respondents and that ensure representativeness of research according to the agreed criteria. Such research is quite expensive, what represents a problem for junior researchers without provided funds. The main problem with this type of examination is that the respondents who are familiar with the subject are often missed out because of their lack of computing and Internet skills.

A basic standard of **ethical research** is that prospective participants can make an informed choice whether to consent to it or participate in it. Privacy, anonymity, and confidentiality are critical ethical considerations in online survey research. The GDPR (General Data Protection Regulation) represents an additional obstacle for survey research.

The challenge to the interpretation of results (e.g., the attitudes and opinions of respondents on a certain topic) is that the surveys are mostly declarative in nature, and actual consumer behavior may differ from therefrom. Today, a methodology is implemented that tries to overcome these problems and present the results more realistically (e.g., a choice experiment and an auction experiment).

A significant issue of online surveys is the **participation rate**. The response rate is significantly lower when compared to offline research. A comparison of various survey methods showed an average response rate for all methods to be around 33%. The reason for a poor response is a faulty e-mail addresses when the e-mails are the primary mode of recruitment, irregular or inaccessible e-mails by potential participants, the e-mails being filtered to the spam folder, and survey fatigue, a phenomenon common in all surveys (Siva Durga Prasad Nayak and Narayad, 2019).

Online surveying is an online tool that has the advantages and disadvantages in each phase of surveying. The researcher must decide how to use the Internet survey tool considering the settings and objective of the research, the population he or she is studying, and the methodology he or she plans to apply.

Keywords: online survey, agromarketing, scientific research, data, representativeness

THE ATTITUDE OF CROATIAN AGRICULTURAL PRODUCERS TOWARD THE USE OF SATELLITE TECHNOLOGIES IN AGRICULTURE

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Abstract

The main challenges in agricultural production include climate change; soil degradation; water scarcity, pests, and diseases; high input costs; and a limited access to technology. Agricultural producers also face unstable markets, labor shortages, strict environmental regulations, and increasing pressure to meet the food needs of a growing population. These challenges require sustainable practices and technological innovation to improve productivity and ensure food security. Satellite services in agriculture use satellite technology to monitor and manage crops, providing valuable data such as imagery, weather conditions, and vegetation status. These services are essential for precision agriculture, resource optimization, and early detection of problems, helping producers to improve efficiency, reduce input costs, and increase yields. They also help in climate monitoring and sustainable practices. By providing a real-time insight, satellite services enable agricultural producers to make better decisions, leading to a higher productivity and profitability. In Croatia, agricultural producers have access to a range of satellite services and platforms that help optimize agricultural production. Croatian farmers can increase their productivity, reduce input costs, and improve the sustainability of their farming practices. Adopting these technologies can lead to the more efficient and sustainable agricultural systems. Therefore, a survey was conducted to determine the extent of application of satellite technologies in agricultural production and the current and potential role of agronomists in the use of satellite (and digital) technologies in the agricultural production in Croatia. The primary data were collected by a survey applying an online questionnaire (n = 261) as a research instrument. A target respondent group

were the stakeholders in agricultural production (i.e., the owners or employees in agricultural enterprises, family farms, or cooperatives). The data were collected via the Agroclub information system, an agricultural portal for agricultural producers of an informative and educational character. According to the research results, 47.5% of respondents want to apply the satellite technologies in agricultural production if the price of the services is commensurate with the benefit obtained, and 29.9% of them want to apply these technologies, but they do not want to pay for the services of satellite technology. Yet, 41.1% are willing to pay up to €10 per month, while 28.2% are willing to pay €20 per month for satellite technologies in agriculture. What is more, 58.6% of respondents believe that an organized advisory role for agronomists in this area would significantly increase the application of satellite technologies. Thus, 42.1% of them are willing to hire an agronomist for assistance in the application of satellite technologies, 48.8% are willing to pay up to 50 € per month, and 29.3% are willing to pay as much as it takes if they will benefit from it. Still, 54.4% of respondents are willing to be self-educated in the use of satellite services through a course, an online consulting service, engagement of an agronomist as a consultant, lifelong learning, or attendance of a degree program. The results of the chi-square test to determine whether there was a difference between the observed frequencies and the expected frequencies of respondents' answers to the question about training in the application of satellite technologies - that is, of the satellite services - in relation to the sociodemographic characteristics of respondents showed that there was a statistically significant difference in the characteristics of res-

pondents' age ($\chi^2 = 35.184$, $p < 0.01$), years of professional experience in agriculture ($\chi^2 = 24.097$, $p < 0.05$), and agricultural holding size ($\chi^2 = 57.681$, $p < 0.01$). Younger respondents (up to 45 years of age) and the respondents having 20 years of professional experience in agriculture, as well as the respondents whose agricultural holdings are up to 50 ha in size, were more willing to participate in a personal training on the application of satellite technologies in agriculture than the more experienced and older respondents with larger farms. On the Likert scale (1 to 5), the respondents rated the frequency of use of individual satellite services and attitudes toward the use of satellite technologies in agriculture. The respondents indicated that they sometimes use satellite images of production areas and agrometeorological data (temperature, precipitation, humidity, light intensity, etc.). They also believe that the satellite technologies - that is, the applications of satellite services in agriculture - provide timely information on the condition of crops and reduce the risk of untimely and inappropriate agronomic measures. Furthermore, they believe that the costs of the services they use are commensurate with the expected benefits - namely, with the production success. They also agree that their production scale is too small to apply these technologies and that the use of this data is too expensive, but they are of an opinion that the use of these technologies can significantly help them in their production. The study circumstantiates that a multi-faceted approach is required for the integration and acceptance of satellite technologies and digital agriculture. This includes making the technology affordable, user-friendly, and relevant, providing education and training and ensuring close collaboration between the producers, governments, and technology providers. Addressing issues of connectivity and sustainability, as well as financial incentives, will encourage a wider adoption and make these technologies an integral part of modern farming practices.

Keywords: agriculture, Croatia, agricultural producers, satellite technologies

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