CULTIVATION ZONE DELIMITATION BASED ON MULTISPECTRAL DRONE SURVEYS IN VINEYARDS

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Abstract

The aim of the research is to precisely define the sample areas of the 3-year cover crop experiment planned in the Eger wine region. For the experiment it is necessary to delineate plots and plot sections with both nearly homogeneous and heterogeneous characteristics. For this purpose, five vineyard plots were first selected and their spatial heterogeneity was investigated. The plots were surveyed with real-time and multispectral sensors from low altitude on a drone platform. The resulting orthophotos, topography models and multispectral mosaics were used to zone and delineate the experimental vineyard rows. The GNDVI index, which is sensitive to both chlorophyll content and water volume, was used to establish the zones.

Keywords: UAV, multispectral, vine, geospatial, remote sensing, cover crop, agroecology

1. Introduction

This paper presents the results of preliminary plot surveys of a 3-year agroecological vineyard cover crop experiment. During which five selected plots of the experimental vineyards were surveyed using multispectral RGB sensors on a drone platform [1].

The aim is to assess the environmental conditions of the 0.8-7.8 ha sample plots and to select the few rows that are heterogeneous or uniform enough for the experiment. A further objective is to compare the sample plots and quantify differences in topography and vegetation. For each survey, we used different altitudes, speeds and overlaps to optimise the three-year experiment based on flight experience.

The use of vineyard cover crops can play an important role in increasing biodiversity and sustainability [2]. The experiment aims to complement ground sampling with new remote sensing measurement methods and to quantify site characteristics.

Unmanned Aerial Vehicles, popularly known as UAVs, are the latest technology that can be used to study many features of an object without physical contact [3]. Images captured by the drones provide the opportunity to create orthophotos and digital surface models, the accuracy of which depends largely on the number and placement of the deployed GCPs (Ground Control Points) [4].These methods can be used to survey potentially large areas with high resolution images in a non-destructive way and to acquire georeferenced output to evaluate the data [5]. Digital Elevation Models (DEM) or Digital Surface Models (DSM) are commonly used to model agricultural areas [6]. Such 3D models are well suited for spatial analysis of natural and man-made objects [7].

Ultra-high resolution multispectral vineyard monitoring on a drone platform can provide fast and accurate spatial spectral data [8]. of the entire surveyed area and its surroundings.

2. Materials and Methods

T The sample areas were flown with a DJI MATRICE 210 RTK V2 Enterprise series quadrocopter (Figure 1), a 4.9 kg drone made of aluminium, magnesium and carbon fibre reinforced plastic. Equipped with two redundant batteries, the drone can spend a maximum of 24-33 minutes in the air at a time. In addition to a built-in high-accuracy satellite positioning system, ultrasonic, infrared and optical sensors help the drone navigate and operate autonomously. Navigation is further enhanced by the also redundant IMU (Inertial Measurement Unit), compass and barometer (www.dji.com).

The drone was equipped with two measuring cameras, one of which was a DJI Zenmuse XT2 with a 640×512-pixel thermal sensor and a 12 MP RGB (red, green, blue) sensor (www.dji.com).

Multispectral images were captured with a Micasense RedEdge-MX dual camera system. The sensor has 10 multispectral sensors, each capable of 1.2 MP resolution.

Detected spectral ranges:

1. Coastal Blue 444 nm (28 nm bandwidth).
2. Blue 475 nm (20 bandwidth)
3. Green 531 nm (14 nm bandwidth)
4. Green 560nm (20 nm bandwidth)
5. Red 650 nm (16 nm bandwidth)
6. Red 668 nm (10 nm bandwidth)
7. Red Edge 705 nm (10 nm bandwidth)
8. Red Edge 717 nm (10 nm bandwidth)
9. Red Edge 740 nm (18 nm bandwidth)
10. NIR 840 nm (40 nm bandwidth)

The camera system includes a sunlight sensor to compensate for changes in ambient light intensity, a dedicated IMU, a magnetometer and a satellite positioning system. Calibration was performed with a dedicated calibration table before each flight. We accessed the settings and configured the acquisition via the instrument-generated WiFi network, and our experience has shown that the "time lapse" method is the most effective, where images are taken at calculated intervals based on flight speed, altitude and overlap (www.micasense.com).

The ground control points (GCP) were located with a Leica GS18T GNSS (Global Navigational Satellite System) rover with 555 channel GPS+Glonass+Galileo+BeiDou signal reception capability. The GNSS receiver was controlled by Leica Captivate installed on a Leica CS30 tabletop computer (www.leica-geosystems.com). The RTK (Real-Time Kinematic) correction service was provided by www.gnssnet.hu, operated by the Lechner Knowledge Center for Spatial, Architectural and Information Technology Non-Profit Ltd. - Cosmic Geodetic Observatory - GNSS Service Center. The GCPs are made of two thin wooden panels, 5 cm wide and 55 cm long, with a screw joint in the middle, painted white.

The measurements were carried out using the DJI Pilot flight planning application with a fully autonomous solution. The flight altitude varied between 50-70 m from the take-off point depending on the terrain, as there was no significant elevation difference, no terrain tracking was used. The flight speed varied between 3-4 m/s, with a lateral coverage between 75-80% and within rows between 80-85%. Since the multispectral sensor was used manually, the flight parameters were adjusted to it, and the other camera could have had a higher overlap.

Figure 1. Measuring instruments (own photo).

The remotely sensed data were processed using Pix4Dmapper Professional 4.9.0 photogrammetric software, and the resulting orthophotos, surface and elevation models were exported in .tif format. Multispectral indexes were performed in QGIS 3.28.0 geospatial software. Further processing and thematic maps were produced using ArcMap 10.4 and ArcGIS Pro 3.1.0 geospatial software. The photogrammetric and geospatial processing was performed using a DELL Precision 5820 workstation with an Intel Xeon W-2295 (18 cores, 36 threads) processor, 128 GB (DDR4 - 2400MHz) memory and two Nvidia GeForce GTX 4070 (12 GB/db) video cards.

3. Results

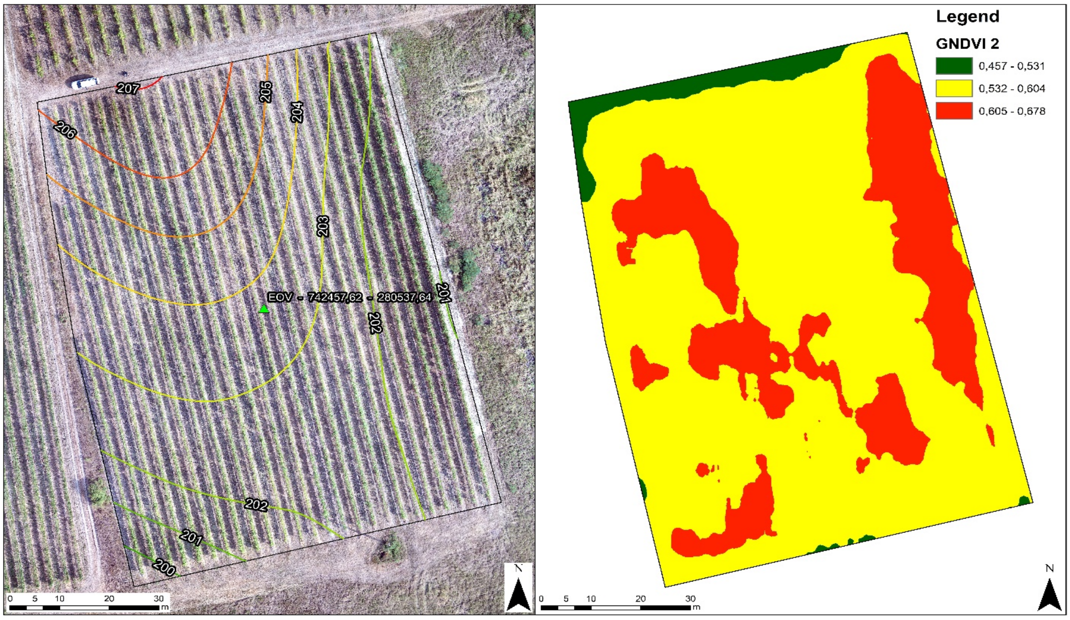
The first survey of the 5 sample plots in the Eger wine region was already completed in early summer 2024, but due to the wet spring the vegetation was homogeneous. The reason for this is that the variation in soil and topography was not reflected in the vegetation activity of the plants, as the higher altitude areas with poorer soil conditions were also supplied with water. Therefore, the areas were remeasured at the end of the summer and this publication covers this period of 27.08.2024- 03.09.2024.

Orthophotos, surface and topography models were created for all the areas, a 1 m contour line was generated from topography models and placed on the thematic maps, and exposure and slope steepness were investigated. Different multispectral index maps were generated for all sample areas, of which GNDVI $\left(\mathrm{GNDVI} = \frac{\mathrm{NIR-green}}{\mathrm{NIR+green}}\right)$ was used, as it is five times more sensitive to chlorophyll concentration than NDVI and thus saturates later, making it well suited for late vegetation stages [9, 10]. The GNDVI map was averaged for 6-7 m using the "Focal Statistics" tool for zonation. In each case, the results were divided into three groups, defined at equal intervals, to adapt to the different spatial characteristics and cultivation patterns, and to largely eliminate the effect of line effect.

Egerszalók - Boldogságos vineyard

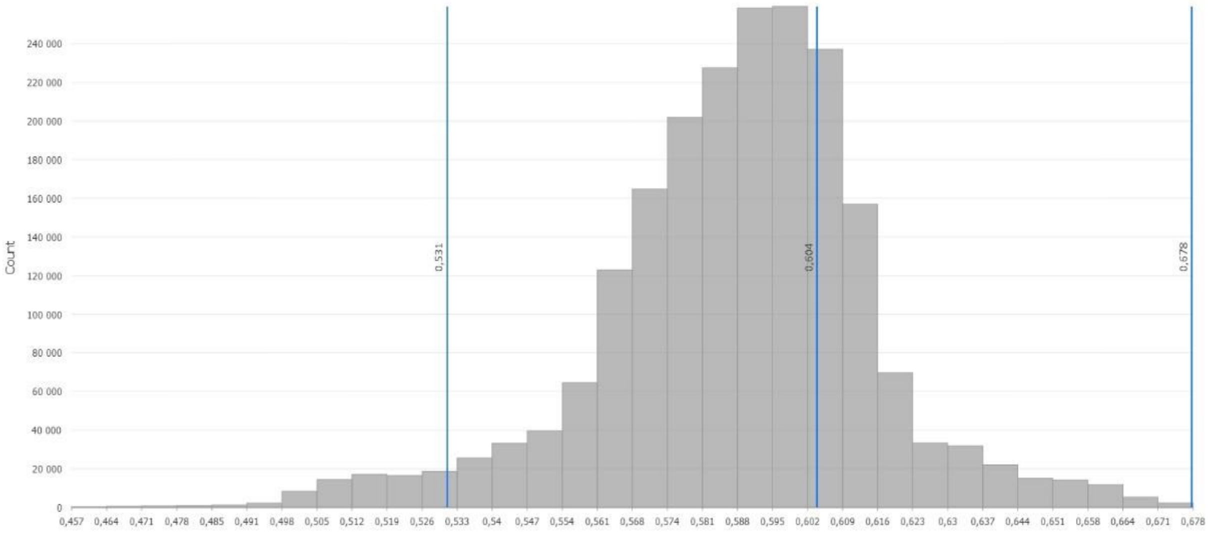
The parcel is located south of Egerszalók in the Boldogságos vineyard. The survey started from the highest point in the north at an altitude of 50 m. The lateral coverage of 9 flight lines was 75%, and the RGB camera within a line was 80%. The multispectral sensor took a picture every 3 seconds, the flying speed of the drone was 2 m/s. During the flight 369 RGB images and 2630 multispectral images were taken. For RGB photogrammetric processing, 5 GCPs were used, which were marked with a 1.9 cm error margin on the coarse point cloud (mean RMS error = 0.019 m), with an additional 2 control points measured in the sample area. The processed orthophoto and surface model has a GSD (Ground Sampling Distance) of 1.5cm/pixel and the derived elevation model has a GSD of 7.4 cm/pixel. The GSD of the multispectral reflectance mosaics was 4 cm. The sample area is 7927 square meters, with an average elevation of 203 meters above sea level, mostly south facing, with an average slope of 4.2%

Figure 2a. The average NDVI was 0.51 on 27.08.2024.



For the zonation of the area, the GNDVI map was used, with a resolution of 6.1 cm/pixel for the sample plot in the Boldogságos vineyard. An average of 100*100 pixels were used to eliminate the line effect. The resulting map was divided into equal intervals, which in the case of the plot were: zone 1 0.457 - 0.531 (4%), zone 2 0.532 - 0.604 (72%), 0.605 - 0.678 (24%) (Figure 2b and Figure 3). The area shows a varied pattern, with the better endowed zones within the parcel being well distinguishable.

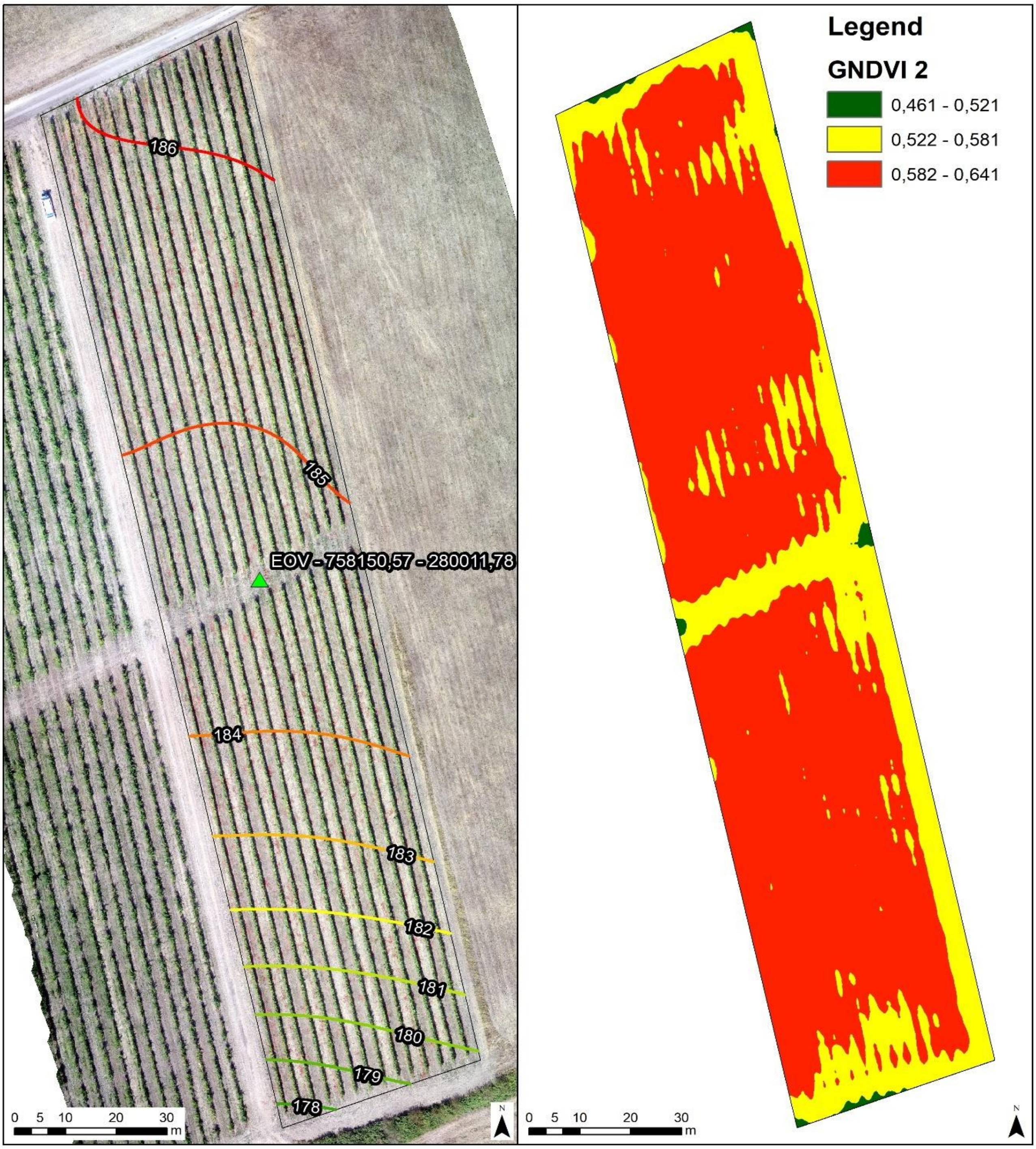
Figure 3. Histogram of the GNDVI values of the the Egerszalók - Boldogságos vineyard (own editing)



Novaj – Szeszfőzde-tető vineyard

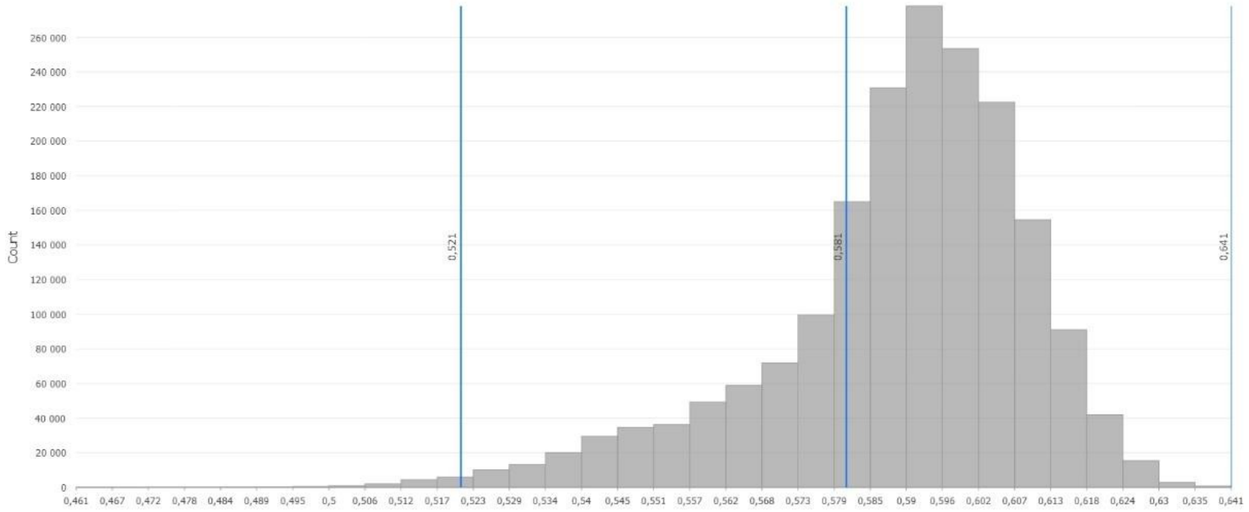
The plot is located east of the village of Novaj in the Szeszfőzde-tető vineyard. Starting from the highest northern point of the long ribbon-like parcel, the flight took place at an altitude of 40 metres. The lateral and intra-row overlap of the 8 flight lines was 80%. The multispectral sensor captured images every 2.3 seconds, and the flying speed of the drone was 3 m/s. During the flight 223 RGB and 2100 multispectral images were taken. For the RGB photogrammetry, 5 GCPs were used, they were marked with an error margin of 1.8 cm on the coarse point cloud (mean RMS error = 0.018 m), 4 additional control points were also measured in the sample area. The processed orthophoto and surface model had a resolution of 1.64 cm/pixel, and the derived elevation model had a GSD of 8.1 cm/pixel. And the resolution of the multispectral mosaics was 4.36 cm/pixel, with an accuracy of 0.9 cm (mean RMS error = 0.009 m). The sample area was 9029 square meters with an average elevation of 183.9 m above sea level, mostly south facing with an average slope of 2.3% (Figure 4a). The average NDVI was 0.51 on 27.08.2024.

Figure 4a. - 4b. Orthophoto of the Novaj – Szeszfőzde tető sample area, surface contour lines, GNDVI zonal map (own editing).



The GSD of the GNDVI map of the sample area located in the Szeszfőzde-tető vineyard was 6.9 cm/pixel, in this case also averaged to 100*100 pixels. The zones of the area divided into equal intervals: zone 1 0.461 - 0.521 (1%), zone 2 0.522 - 0.581(25%), 0.582 - 0.641 (74%) (Figure 4b and Figure 5). The area shows a very homogeneous picture, practically only the bare surface and the vineyards could be distinguished, no cultivation zones could be detected with this methodology.

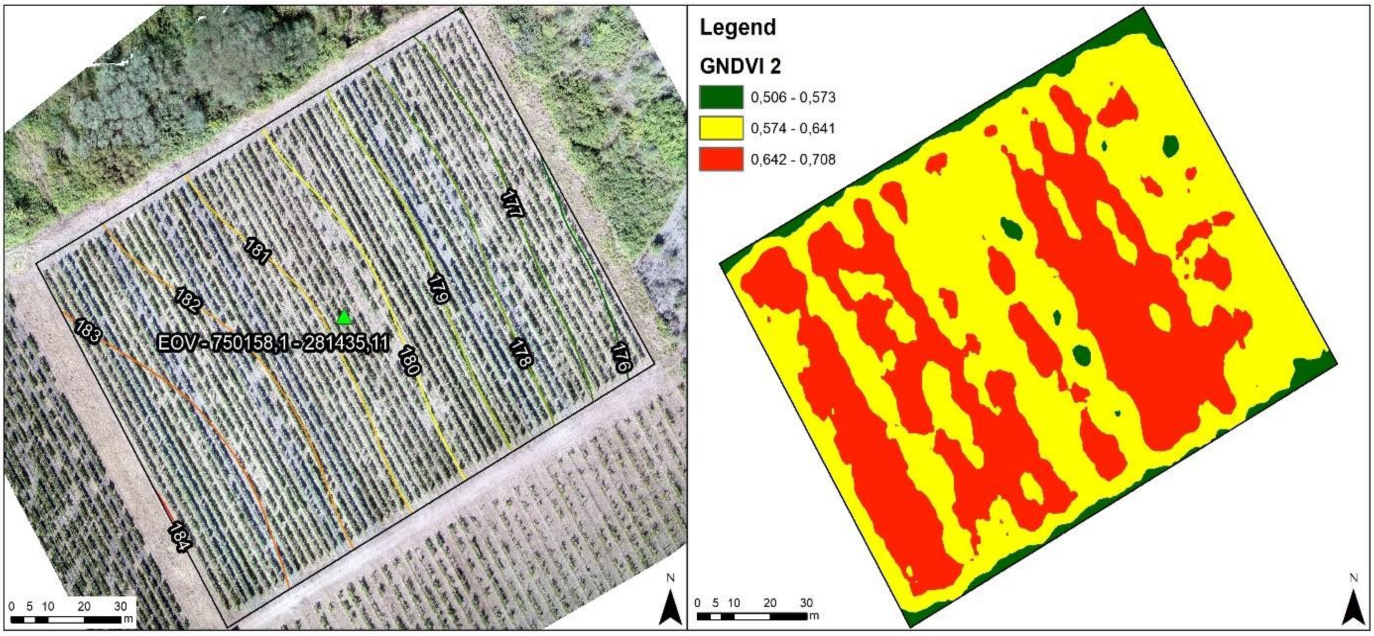
Figure 5. Histogram of the GNDVI values of the Novaj – Szeszfőzde tető sample area (own editing)



Eger - Kőlyuk-tető

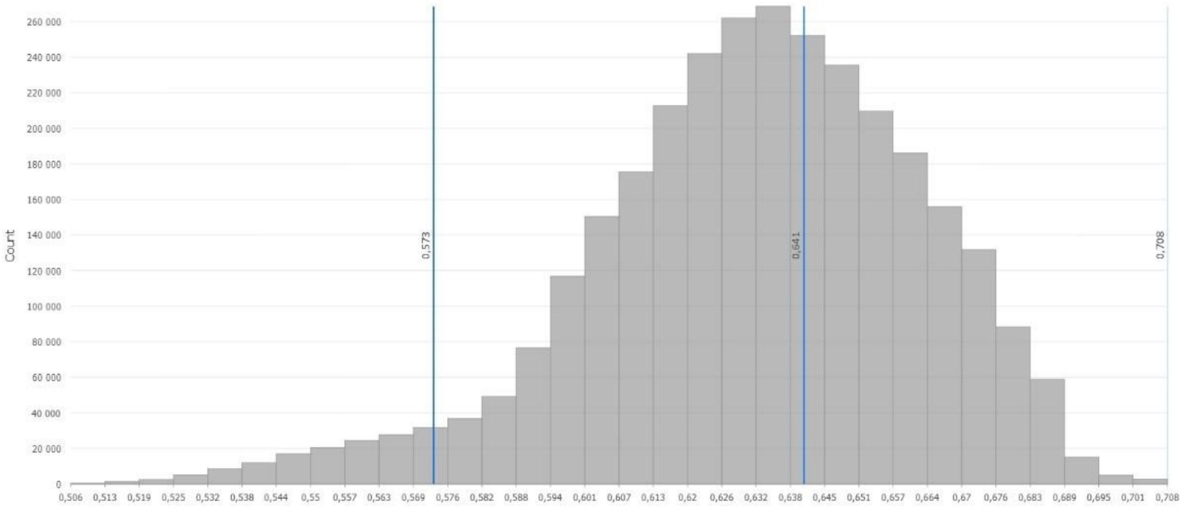
The plot is located south of the city of Eger, in the area of the Eszterházy Károly Catholic University - Experimental Vineyards and Winery. The flight started from the highest south- western point at an altitude of 60 m, the 14 flight lines had 80% side coverage, the RGB camera in the line had 80% coverage, the multispectral sensor took pictures every 2 seconds and the drone speed was 3.4 m/s. During the flight 250 RGB images and 2120 multispectral images were taken. For the RGB photogrammetric processing, 5 GCPs were used, which were marked with an error margin of 3.4 cm on the coarse point cloud (mean RMS error = 0.034 m), with an additional 3 control points measured in the sample area. The processed orthophoto and surface model had a resolution of 1.68 cm/pixel, and the derived elevation model had a GSD of 8.3 cm/pixel. The resolution of the multispectral mosaics was 4.55 cm/pixel (mean RMS error = 0.009 m). The study area was 1.4 ha with an average elevation of 180 m, facing east-northeast for most of its area, with an average slope of 2.3% (Figure 6a). The average NDVI was 0.56 on 03.09.2024.

Figure 6a - 6b. Orthophoto of the Eger - Kőlyuk-tető sample area, surface contour lines, GNDVI zonal map (own editing)



The resolution of the GNDVI map of the sample area was 6.8 cm/pixel, also averaged to 100*100 pixels. We also used equal intervals for zoning, which were as follows: zone 1 0.506 - 0.573 (4%), zone 2 0.574 - 0.641(55%), zone 3 0.642 - 0.708 (41%) (Figure 6b, Figure 7). The zonal map showed a high variability.

Figure 7. Histogram of the GNDVI values of the Eger - Kőlyuk-tető sample area (own editing)

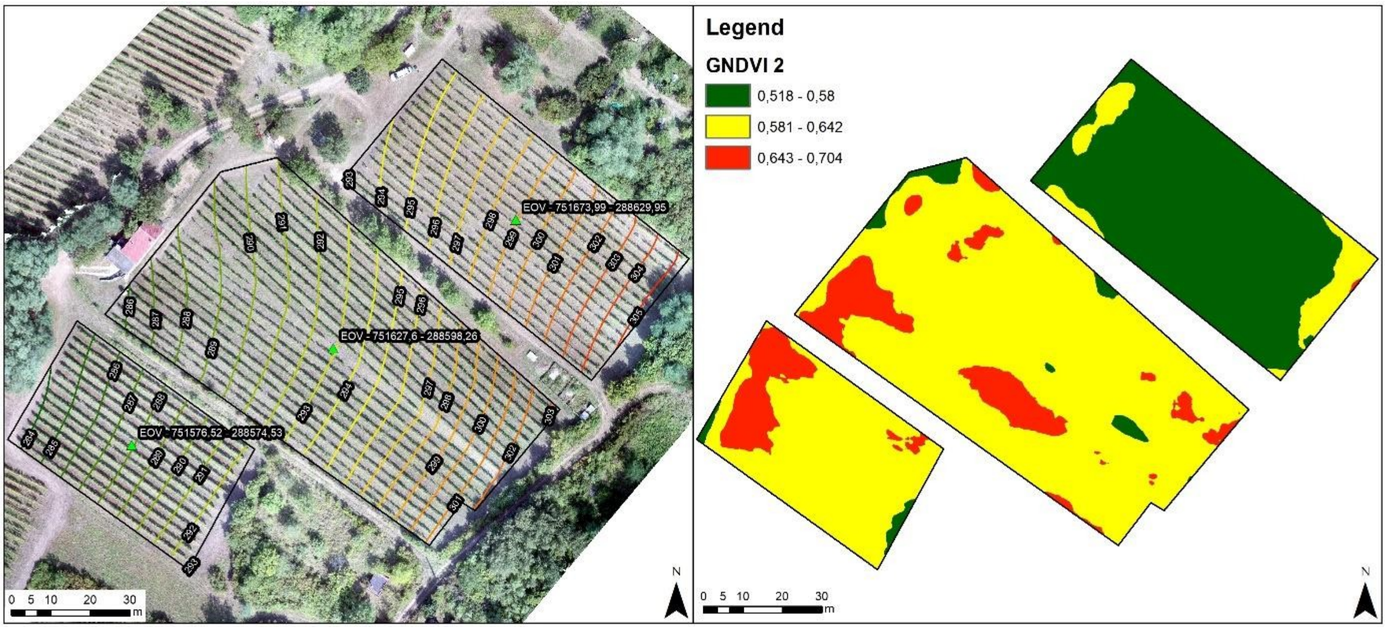


Eger - Tiba vineyard

The parcel is located north of the town of Eger, at the western foot of the Nagy-Eged hill. The sample area is divided into three separate smaller parcels. Due to the characteristics of the area, the drone took off from the northern part at an altitude of about 295 meters. The flight took place at an altitude of 60 m, the lateral coverage of the 13 flight lines was 78%, the RGB camera within the line had an overlap of 82%, the multispectral sensor took a picture every 2.3 seconds and the flying speed was 3.1 m/s. During the flight, 224 RGB and 1950 multispectral images were taken. For RGB photogrammetric processing, 7 GCPs were used, which were marked with an error margin of 2.3 cm on the coarse point cloud (mean RMS error = 0.034 m), with an additional 3 GCP measured in the sample area. The orthophoto and surface model had a resolution of 1.61 cm/pixel, and the derived elevation model had a GSD of 8 cm/pixel. The multispectral mosaics had a resolution of 4.36 cm/pixel and an accuracy of 0.6 cm (mean RMS error = 0.06 m).

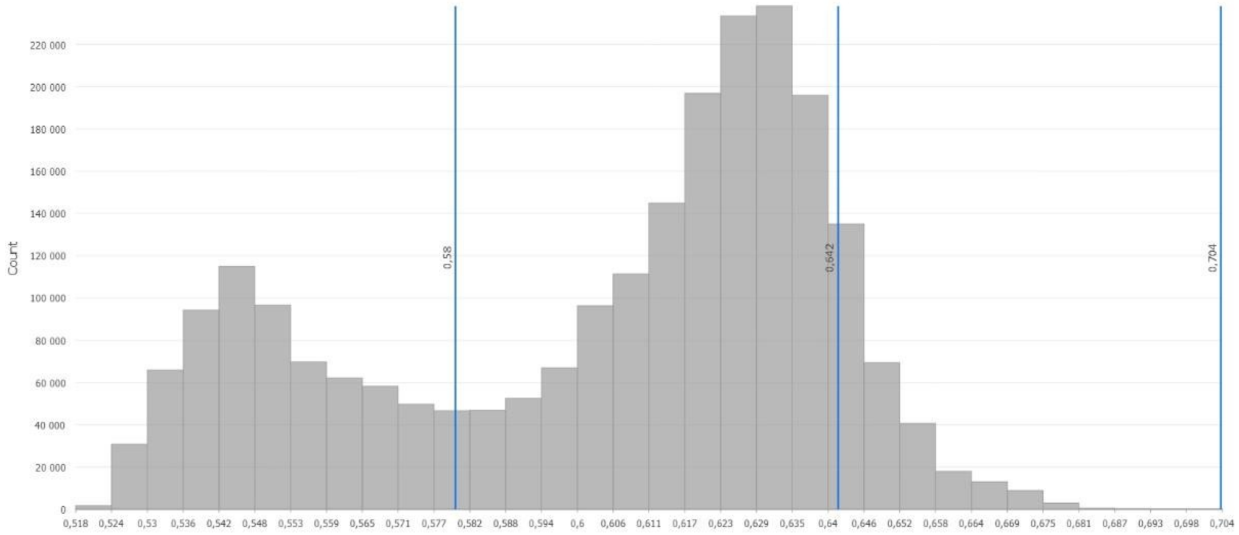
The three parcels cover an area of 1.2 hectares, located at an average elevation of 294 m above sea level. The parcels are oriented west-northwest and have the steepest average slope (8.7%) (Figure 8a). The average NDVI was 0.55 on 27.08.2024.

Figure 8a - 8b. Orthophoto of the Eger - Tiba vineyard, surface contour lines, GNDVI zonal map (own editing).



The zonal map was processed from a 6.5 cm/pixel resolution GNDVI mosaic, also averaged to 100*100 pixels. The equal intervals in the area were as follows: zone 1 0.518 - 0.58 (29%), zone 2 0.581 - 0.642 (61%), zone 3 0.643 - 0.704 (10%) (Figure 8b, Figure 9). The GNDVI zonation in this case compares the 3 parcels, the northern parcel stands out, that parcel is much more homogeneous due to the cultivation.

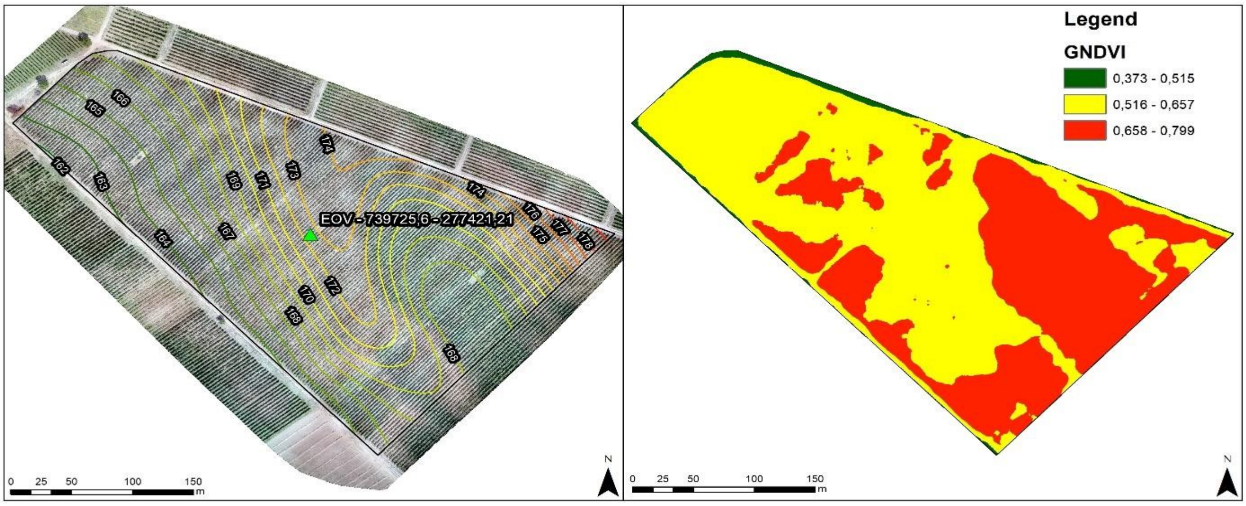
Figure 9. Histogram of the GNDVI values of the Eger - Tiba vineyard (own editing)



Verpelét – Ácsok Vineyard

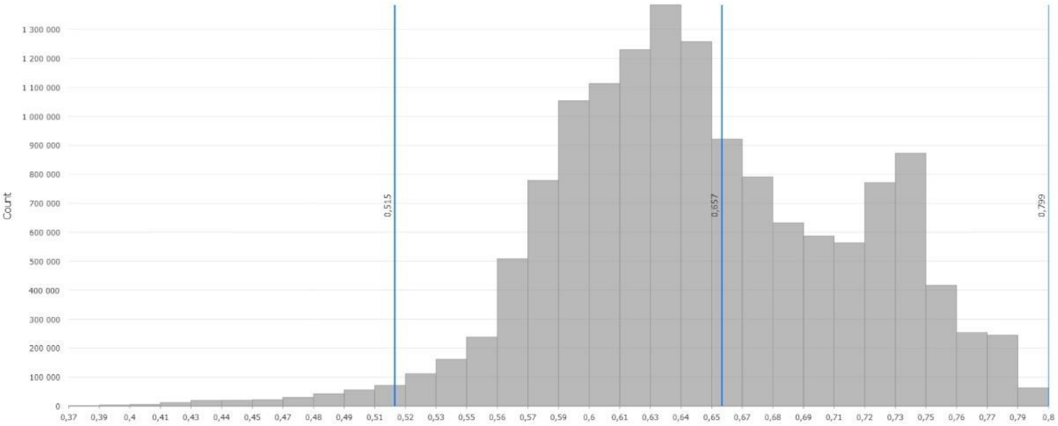
The largest sample area is located south of Verpelét on an area of 7.9 hectares. The flight took place at an altitude of 70 meters. The 27 flight lines had a side coverage of 75%, the RGB camera had an overlap of 80% within each line, the multispectral sensor took a picture every 2 seconds and the drone flying speed was 4 m/s. During the flight, 664 RGB and 6080 multispectral images were taken. 7 GCPs were used for the RGB photogrammetric processing, which were marked with an error margin of 4.3 cm on the coarse point cloud (mean RMS error = 0.043 m), with an additional 3 control points measured in the sample area. The resolution of the processed orthophoto and surface model was 1.8 cm/pixel, and the derived elevation model has a GSD of 8.3 cm/pixel. The multispectral mosaics had a resolution of 5 cm/pixel and an accuracy of 1 cm (mean RMS error = 0.001 m). The area lies at an average elevation of 168 m above sea level, with a southern exposure and a large erosion gully in the eastern part. The area has an average slope of 3.9% (Figure 10a). The average NDVI was 0.56 on 03.09.2024.

Figure 10a - 10b. Orthophoto of the Verpelét - Ácsok vineyard sample area, surface contour lines, GNDVI zonal map (own editing).



The GNDVI map of the Verpelét Ácsok sample area has a resolution of 7.4 cm/pixel, averaged to 100*100pixel for zoning. Equal intervals were as follows: zone 1 0.373 - 0.515 (2%), zone 2 0.516 - 0.657 (57%), zone 3 0.658 - 0.799 (41%) (Figure 10b, Figure 11). The area is defined by the top two categories, the first category is mostly influenced by the road running around the area, which is covered with sand.

Figure 11. Histogram of the GNDVI values of the Verpelét Ácsok vineyard (own editing)



4. Discussion

In our research, we collected data using UAV tools and multispectral remote sensing to produce GNDVI index maps for each sample area. GNDVI is excellent for detecting green plant parts even in late vegetation stages due to its chlorophyll sensitivity. NDVI mainly uses the red (red) and near infrared (NIR) bands, while GNDVI uses the green (green) and NIR bands. The use of the green band may provide some improvement in the detection of high biomass areas because green light is reflected differently by vegetation. The GNDVI is slightly more sensitive to changes in chlorophyll content, so could potentially alleviate saturation problems in high biomass. However, at higher biomass levels, especially in areas with closed canopy or dense vegetation, GNDVI may also show saturation.

The sampling date fell at the end of a long summer drought period, which highlighted differences in water supply and the resulting differences in vegetation activity. Our aim was to detect this, which would allow us to delineate zones of differing activity based on vegetation activity. Based on these zones, a seeding plan will be developed for a future row-cropping experiment, which will continue to be monitored in the coming years. Our work will also form the basis for precision viticulture, where different management approaches can be applied within a field or even at the capital level.

Choosing the right time window has a significant impact on the results of remote sensing imagery, especially for applications such as assessing the health of vegetation, monitoring soil moisture or determining different land use types. Timing is key as many factors can affect the quality and accuracy of data collection. One example is the vegetation development cycle, as spectral reflectance varies during different phases of plant growth (sowing, growth, flowering, ripening, etc.). The choice of the optimal time window is necessary to accurately determine the health and type of plants. In terms of meteorological factors, cloud-free periods, adequate sunshine and rain-free weather provide clearer and more accurate images. Cloudy, humid weather can reduce the accuracy of spectral sensors. Regarding soil moisture, it is important to take measurements after rainfall or after dry periods, as excessive or even no moisture can distort the reflected radiation. In addition, the angle of incidence of the sun and shadow effects affect the quality of the recordings, so choosing the right time of day is also important for accurate data collection.

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