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EVALUATING THE APPLICABILITY OF PASSIVE REMOTE SENSING TECHNOLOGY WITH A MULTIROTOR DRONE IN PRECISION VITICULTURE

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Abstract

In recent years, there has been a notable increase in the use of Unmanned Aerial Vehicles (UAVs) for precision viticulture. This study investigates the practical applications of passive remote sensing with drones in vineyards. Three distinct winegrowing regions in Romania were chosen, each characterized by varying grape varieties and climatic conditions. Utilizing a semiprofessional drone equipped with a high-resolution multispectral sensor, the study aimed to rapidly identify missing vines, generate parcel-level elevation maps, and validate the correlation of the NDVI vegetation index with vine vigour. The study unveiled significant results, covering plant counting reports, elevation maps detailing the exposition and inclination of various parcels, and NDVI vigor maps. In summary, this research contributes to the progression of precision agriculture in viticulture through the application of remote sensing and vegetation indices. The implications of the findings and potential applications are discussed, with a SWOT analysis providing insights into future prospects.

Key words: *precision viticulture, UAV, elevation map, missing vines, NDVI vigor map.*

INTRODUCTION

Remote sensing is the branch of geomatics that deals with the detection, measurement, and recording of electromagnetic radiation reflected or transmitted by an object, area, or phenomenon without the sensor being in direct contact with the subject being analyzed. Remote sensing relies on recording images with color differences, and its main objectives are the identification and evaluation of Earth components along with their physico-chemical properties. In the case of passive remote sensing, reflected solar radiation is primarily measured in the visible, near-infrared, and mid-infrared spectra. In the visible and infrared spectrum, the measured energy is influenced by properties such as pigmentation, moisture, and cellular structure in the case of vegetation, mineralogical composition and moisture in the case of soil, and sedimentation level in the case of water. The specific spectral signatures are exemplified in Figure 1 (Portengen, 2017). Due to the potential for the rapid delivery of comprehensive maps regarding the shape, size, and vigor of the vineyard, passive remote sensing represents a powerful tool in precision viticulture. The interpretation of multispectral images can efficiently support the optimization of winery activities by facilitating optimal grapevine management decisions. "Remote sensing applications include mapping and monitoring soil properties, grapevine variety classification, pest management, plant water stress detection, analysis of leaf chemical content, and weed control monitoring." (Zhang, 2012).

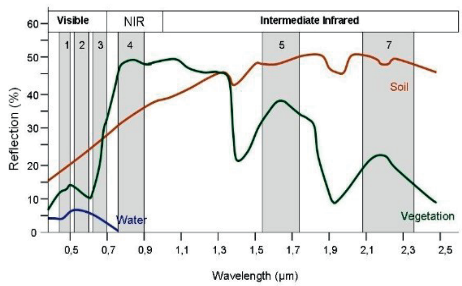

Figure 1. Typical spectral signatures for vegetation, water, and soil

Over 150 vegetation indices have been documented in scientific literature; however, only a subset undergo systematic testing and practical application. The most widely utilized index is the Normalized Difference Vegetation Index (NDVI). Developed by NASA in the 1970s, NDVI represents the nonlinear transformation of the red and near-infrared (NIR) bands, calculated as the difference between these two bands divided by their sum (Nerțan A., 2016):

$$\mathrm{NDVI} = \frac{(\mathrm{NIR}-\mathrm{RED})}{(\mathrm{NIR}+\mathrm{RED})}.$$

The underlying concept of this index is that plants reflect near-infrared light to prevent drying and absorb red light for photosynthesis. NDVI is recognized as a good measure of vegetation development and density, associated with biophysical parameters such as biomass, leaf area index, vegetation cover percentage, and vegetation photosynthetic activity. "Parcel separation can be successfully achieved using NDVI, correlated with soil electrical conductivity and the number of clusters" (Urretavizcaya 2017). The optimal period for obtaining NDVI for this analysis is after flowering and until veraison. "NDVI is directly correlated with the amount of active photosynthetic radiation a plant can absorb." (Kavak et al., 2014).

The overall objective of this work is to evaluate the applicability of remote sensing technology in vine cultivation through the analysis of digital maps. This idea further branches into three specific objectives. In the first phase, elevation maps will be generated to understand more precisely the geographical characteristics of mesoclimates, such as altitude, slope, exposure, and even soil water reserve flow. The second objective is to assess gaps in the plantation, missing grapevines that lead to a waste of phyto-sanitary substances and a decrease in yield. The third objective, the most complex one, involves correlating canopy vigour with the NDVI vegetation index map.

MATERIALS AND METHODS

For the research a semi-professional multirotor drone DJI Phantom 4 Advanced was used, equipped with a 25.4 mm CMOS sensor capable of recording 4K video and 20-megapixel photos and a multispectral camera, Sentera Double 4K NDVI/NDRE fitted with a BSI CMOS - Sony Exmor R™ IMX377 sensors having a resolution of 12.3 megapixels. The software programs used to generate content were Pixel4D Fields for elevation maps, Agremo for plant counting reports, with trial subscriptions, and Field Agent from Sentera for NDVI map, with monthly subscription. All flight campaigns took place on clear sky conditions at noon when the sunlight falls perpendicularly on the canopy to minimize shadows between rows.

The research was conducted throughout the 2020 vintage in several viticultural areas: Marcea Winery (Marcea) – DOC Stefanesti, Pietroasa-Istrita Research and Development for Viticulture and Pomiculture Didactic Station (Pietroasa)– DOC Pietroasa, and Girboiu Winery (Girboiu) – DOC Cotesti. At Marcea two plots of Feteasca Neagra were analysed one with a surface of 2.3 hectares, shortly named as FN1, and the second one with a surface of 2.4 hectares briefly noted as FN2. Distance between plants was 1 meter and row spacing 2.1 meters, resulting in a planting density of 4,545 plants per hectare. In plot FN1, the row orientation was North-South, while for plot FN2, the row orientation was Northwest-Southeast. At Pietroasa, the study was conducted on two plots, first planted with Italian Riesling on a surface of 2.5 hectares, briefly noted as IR. The second plot planted with Cabernet Sauvignon on a surface of 2.46 hectares, shortly named CS. For both plots the distance between plants was 1.2 meters and 2 meters between rows, with rows orientation North-East – South-West. At Gîrboiu Winery, the research took place on one plot of Sauvignon Blanc located near the winery with a surface of 6.3 hectares, referred to as SB. The space between plants was 1 meter and 2.3 meters between rows, resulting in a planting density of 4670 vines per hectare. The row orientation was North - South.

For each plot, various research studies were conducted, as presented in Table 1.

The control method for NDVI vigour map was done by correlation with two vine measurements: the Leaf Wall Area (LWA) and the Leaf Row Volume (LRV) obtained by calculating the height and width of the canopy according to the formulas:

$$Leaf\ Wall\ Are = Canopy\ Height\ \times 2\ \times 10000$$

(where 2 is the number of faces of a row and 10000 is the area of a hectare expressed in meters).

$$Leaf\ Row\ Volume = Canopy\ Height\ \times Canopy\ Width \times 10000$$

(where 10000 is the area of a hectare expressed in meters).

All measurements were taken using a retractable tape measure. For each parcel a different number of vines were sampled to ensure a better representativity cover of the entier variability. In FN2 parcel were measured 37 vines, in IR parcel were measured 44 vines and in SB1 parcel were measured 77 vines.

Table 1. Research done by parcel and phenological stage

Winery	Parcel	Date	Phenological stage	Research
Marcea	FN 1	11.May	Before flowering	Elevation map
Marcea	FN 2	11.May	Before flowering	Elevation map
Marcea	FN 2	2.July	After flowering	NDVI map
Pietroasa	IR	9.July	After flowering	NDVI map
Pietroasa	CS	19.May	Before flowering	Elevation map
Pietroasa	CS	19.May	Before flowering	Missing plants
Gîrboiu	SB	8.May	Before flowering	Elevation map
Gîrboiu	SB	8.May	Before flowering	Missing plants
Gîrboiu	SB	6.June	Flowering	NDVI map

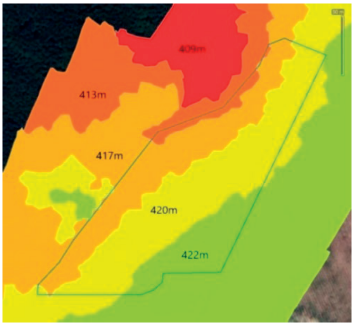

Figure 2. FN1 elevation map

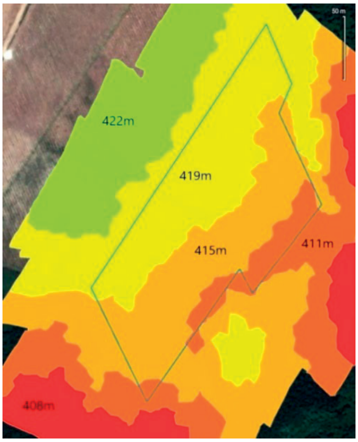

Figure 3. FN2 elevation map

RESULTS AND DISCUSSIONS

At Marcea Winery the altitude detected in both parcels was high, over 400 meters, which could be an advantage in the context of global warming. If in the past, the area was suitable for the production of white wines, but the potential for red wines has increased in last decades. The exposition of parcel FN1 is North West (Figure 2), and the exposition of parcel FN2 is South East (Figure 3). A very warm year favors the ripening of the grapes in parcel FN1, while a normal or cooler year favors the ripening of grapes in parcel FN2. The slope of parcel FN1 is medium to high, being from 5% to 18%. Mechanized work in the northern part of the parcel being almost impossible. The slope of parcel FN2 is gentle to moderate, being 8% and 10%. Except for the northern zone of parcel FN1 where the slope is high, the locations of the parcels are very good.

At Pietroasa the altitude detected in CS parcel was around 100 meters with an exposition to South (Figure 4), benefiting uniformly from the maximum number of hours of solar radiation, and a slope of approximately 9%, representing a gentle to moderate slope.

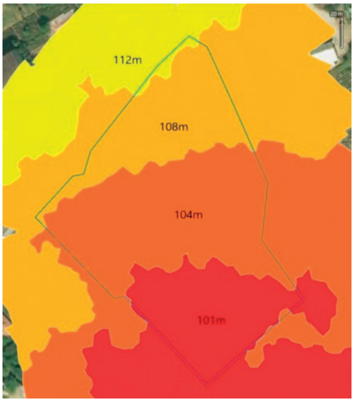

Figure 4. CS elevation map

At Girboiu the average altitude found was around 170 meters, representing a medium altitude for Romania, in the context of grape growing. The exposition of the SB parcel is East (Figure 5), benefiting from rapid morning warming and a decrease in solar radiation in the afternoon. The slope of the SB parcel is approximately 3%. Having a small slope the location of the parcel allows easy mechanized work of the vineyard, with the strong point being the North-South orientation of the rows.

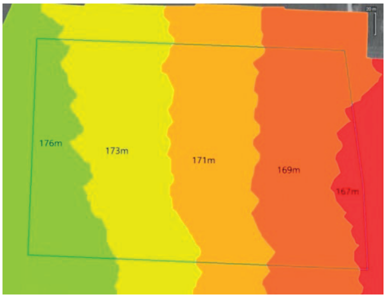

Figure 5. SB1 elevation map

Plant count report is crucial for obtaining a more accurate understanding of gaps in the plantation and helps optimize the cost of planting vine material acquisition. Using a drone for such calculations could be time effective. For the CS parcel at Pietroasa, the calculations resulted in approximately 8,340 plants, 1,908 plants less than the potential for the plot. The land occupancy rate is 19% below the norm, indicating a need to replant 1,908 vines (Figure 6).

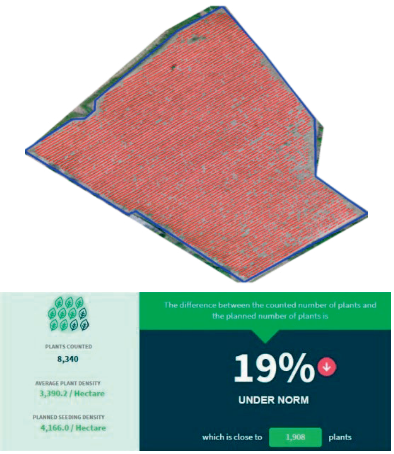

Figure 6. CS plant count report & map

At Girboiu, for the SB parcel, approximately 25,305 plants were calculated, with 2,168 plants less than the potential for the land.
The land occupancy rate is 8% below the norm, indicating a need to replant 2,168 vines (Figure 7).

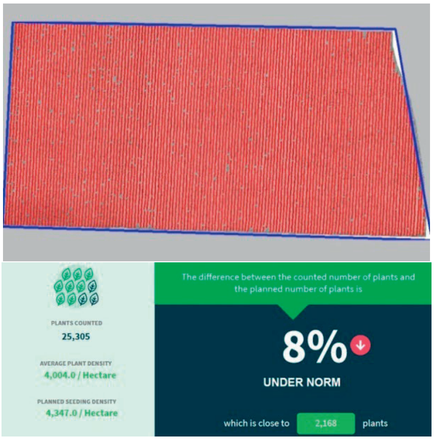

Figure 7. SB plant count report & map

NDVI vigor map. To demonstrate, correlation values were calculated for the LWA and LRV, which were subsequently associated percentage-wise with the colours resulting from the processing of the NDVI maps.

Table 2. FN2 canopy measurements

	Vine 8	17	24	34	40	51	56	68
Row 9	2/0.5		2.2/0.5					
18		2.2/0.5		2.2/0.4		2.2/0.45		2.2/0.4
27	2.3/0.4		2.6/0.4		2.2/0.4		2.5/0.4	
36		2.5/0.4		2.5/0.5		2.4/0.55		2.6/0.4
45	2/0.6		2.4/0.4		2.95/0.4		2.15/0.5	
54		2.7/0.6		2.6/0.6		2.5/0.5		
63	2.2/0.6		2.2/0.55		2.1/0.5		2.3/0.6	
72		2.4/0.5		2.5/0.4		2.1/0.35		2.6/0.4
81	2.2/0.4		2.2/0.5		2.1/0.5		2.3/0.5	
90		2.5/0.4		2.65/0.5		2.5/0.5		2.3/0.4

For parcel FN2 at Marcea Winery, canopy height and width measurements are recorded in Table 2, organized by rows and vine number. Table 3 contains LWA values and Table 4 contains LRV values. The values in Tables 3 and 4 were correlated with the vegetation index NDVI map shown in Figure 8, and small differences were found-below 0.12% for both LWA and LRV, as indicated by the calculations in Table 5.

Table 3. FN2 LWA calculations

	Vine 8	17	24	34	40	51	56	68
Row 9	19047		20952					
18		20952		20952		20952		20952
27	21904		24761		22857		23809	
36		23809		23809		22857		24761
45	19047		21904		28095		20476	
54		25714		24761		23809		
63	20952		20952		20000		21904	
72		22857		23809		20000		24761
81	22857		20952		20000		21904	
90		23809		25238		23809		21904

Table 4. FN2 LRV calculations

	Vine 8	17	24	34	40	51	56	68
Row 9	4761		5238					
18		5238		4190		4714		4190
27	4380		4952		4571		4761	
36		4761		5952		6285		4952
45	5714		4380		5619		5119	
54		7714		7428		5952		
63	6285		5761		5000		6571	
72		5714		4761		3500		4952
81	4571		5238		5000		5476	
90		4761		6309		5952		4380

The orange and red colors in the tables and NDVI map correspond to LWA values ranging from 19,047 to 20,952 m²/ha and LRV values between 3,500 and 4,761 m³/ha, representing approximately 38% of the analyzed area for the FN2 plot. The dark green and light green colors correspond to LWA values ranging from 21,904 to 28,095 m²/ha and LRV values ranging from 4,952 to 7,714 cubic m³/ha, representing approximately 62% of the analyzed area.

Figure 8. FN2 NDVI vigor map

Table 5. FN2 NDVI & LWA-LRV correlation

	NDVI map		
Colour	Value	Surface (ha)	Percent
Green	0.26-0.92	1,42	62.28%
Orange	0.19-0.25	0.86	37.72%
		2.28	
	Leaf Wall Area		
	Number of vines	Interval (m²/ha)	Percent
	14	21904-28095	62.16%
	23	19047-20952	37.84%
	37		
	Leaf Row Volume		
	Number of vines	Interval (m³/ha)	Percent
	14	4952-7714	62.16%
	23	3500-4761	37.84%
	37		

For the IR plot at Pietroasa, height and width measurements in meters are recorded in Table 6 by rows and vines. LWA values are found in Table 7, LRV values in Table 8, and the NDVI map is shown in Figure 9. The values from Tables 7 and 8 were correlated with the NDVI map, resulting in differences below 3.7% for LWA and below 0.3% for LRV, as indicated by the analysis in Table 9.

Table 6. IR canopy measurements

	Vine 9	23	35	45	60	80	95	110
Row 8	1.35/ 0.45	1.35/ 0.55	1.4/ 0.5	1.45/ 0.5				
16	1.35/ 0.45	1.25/ 0.5	1.35/ 0.55	1.3/ 0.5	1.15/ 0.5			
24	1.4/ 0.6	1.45/ 0.5	1.2/ 0.5	1.35/ 0.4	1.2/ 0.5			
32	1.35/ 0.45	1.3/ 0.45	1.45/ 0.45	1.2/ 0.45	1.45/ 0.45	1.4/ 0.4		
48	1.3/ 0.45	1.4/ 0.45	1.45/ 0.5	1.2/ 0.45	1.15/ 0.4	1.25/ 0.4	1.2/ 0.45	1.5/ 0.5
64	1.1/ 0.4	1.15/ 0.4	1.1/ 0.35	1.15/ 0.4	1.3/ 0.35	1.2/ 0.45	1.4/ 0.45	1.25/ 0.4
72	1.15/ 0.35	1.05 /0.3	1.1/ 0.45	1.15/ 0.3	1.1/ 0.45	1.3/ 0.4	1.25/ 0.45	1.1/ 0.35

Table 7. IR LWA calculations

	Vine 9	23	35	45	60	80	95	110
Row 8	13500	13500	14000	14500				
16	13500	12500	13500	13000	11500			
24	14000	12500	13500	13000	12000			
32	13500	13000	14500	12000	14500	14000		
48	13000	14000	14500	13000	11500	12500	12000	15000
64	11000	11500	11000	11500	13000	12000	14000	12500
72	11500	10500	11000	11500	11000	13000	13000	11000

Table 8. IR LRV calculations

	Vine 9	23	35	45	60	80	95	110
Row 8	3000	3700	3500	3600				
16	3000	3100	3700	3250	2800			
24	4200	3600	3000	2700	3000			
32	3000	2900	3250	2700	3250	2800		
48	2900	3150	3600	3250	2300	2500	2700	3750
64	2200	2300	1900	2300	2300	2700	3150	2500
72	2000	1500	2400	1700	2500	2600	2800	1900

Figure 9. IR NDVI vigor map

Interpretation of the tables and NDVI map for the IR plot in Pietroasa: The red color represents approximately 32% of the total plot and corresponds to LWA values ranging from 10,500 to 11,500 m²/ha and LRV values between 1,500 and 2,500 m³/ha. The yellow color represents approximately 34% of the total plot and corresponds to LWA values ranging from 12,000 to 13,000 m²/ha and LRV values between 2,600 and 3,000 m³/ha. The green color represents approximately 34% of the total analyzed area and corresponds to LWA values ranging from 13,500 to 14,500 m²/ha and LRV values between 3,500 and 4,200 m³/ha

Table 9. IR NDVI & LWA-LRV correlation

	NDVI map		
Colour	Value	Surface (ha)	Percent
Green	0.26-0.45	0.81	34%
Yellow	0.20-0.25	0.82	34.3%
Red	0.11-0.20	0.76	31.7%
		2.39	
	Leaf Wall Area		
	Number of vines	Interval (m²/ha)	Percent
	16	13500-14500	36%
	16	12000-13000	36%
	12	10500-11500	28%
	44		
	Leaf Row Volume		
	Number of vines	Interval (m³/ha)	Percent
	16	3100-4200	34%
	16	2600-3000	34%
	12	1500-2500	32%
	44		

For the SB plot at Girboiu, height and width measurements in meters are recorded in Table 10. LWA values are found in Table 11, VRF values in Table 12, and the NDVI vigor map is depicted in Figure 10. All three tables were correlated, with differences below 3.26% for LWA and below 1.96% for VRF, as indicated by the analysis in Table 13.

Table 10. SB canopy measurments

	Vine 18	22	53	65	88	106	122	148	159	190	194
Row 5	0,9/ 0.7		1/ 1		0.8/ 0.7		0.9/ 0.9		1/ 0.9		1/ 0.7
14		0.9/ 0.8		1.2/ 0.75		1.1/ 1.05		1.2/ 0.85		0.9/ 1.1	
23	0.75/ 0.75		1/ 0.75		1/ 0.4		1/ 0.6		0.7/ 0.4		0.8/ 0.5
32		1/ 0.6		1.1/ 0.6		0.75/ 0.65		1.05/ 0.65		0.9/ 0.8	
41	0.9/ 0.6		0.75/ 0.55		0.9/ 0.7		0.9/ 0.6		0.9/ 0.65		0.5/ 0.4
50		0.6/ 0.5		0.5/ 0.4		0.9/ 0.7		0.7/ 0.5		0.75/ 0.6	
59	0.8/ 0.7		0.9/ 0.5		0.9/ 0.5		0.9/ 0.7		0.8/ 0.5		0.7/ 0.5
68		0.7/ 0.7		0.6/ 0.5		0.7/ 0.6		0.9/ 0.7		0.8/ 0.65	
77	0.85/ 0.7		0.7/ 0.6		0.9/ 0.6		0.8/ 0.6		0.7/ 0.6		0.8/ 0.5
86		0.6/ 0.5		0.7/ 0.6		0.8/ 0.7		0.75/ 0.6		0.8/ 0.6	
95	0.7/ 0.5		0.6/ 0.6		0.6/ 0.4		0.6/ 0.6		0.7/ 0.65		0.8/ 0.6
104		0.85/ 0.5		0.9/ 0.7		0.6/ 0.5		0.9/ 0.6		0.9/ 0.6	
113	0.9 /0.6		0.6/ 0.5		0.5/ 0.4		0.9/ 0.6		0.65/ 0.6		0.8/ 0.5
122		0.9/ 0.55		0.7/ 0.5		0.9/ 0.6		0.8/ 0.5		0.7/ 0.6	

Table 11. SB LWA calculations

	Vine 18	22	53	65	88	106	122	148	159	190	194
Row 5	2739		4347		2434		3521		3913		3043
14		3130		3913		5021		4434		4304	
23	2445		3260		1739		2608		1217		1739
32		2608		2869		2119		2967		3130	
41	2347		1793		2739		2347		2543		869
50		1304		869		2739		1521		1956	
59	2434		1956		1956		2739		1739		1521
68		2130		1304		1826		2739		2260	
77	2586		1826		2347		2086		1826		1739
86		1304		1826		2434		1956		2086	
95	1521		1565		1304		1565		1978		2086
104		1847		2739		1304		2347		2347	
113	2347		1304		869		2347		1695		1739
122		2152		1521		2347		1739		1826	

Table 12. SB LRV calculations

	Vine 18	22	53	65	88	106	122	148	159	190	194
Row 5	7826		8695		6956		7826		8695		8695
14		7826		10434		9565		10434		7826	
23	6521		8695		8695		8695		6086		6956
32		8695		9565		6521		9130		7826	
41	7826		6521		7826		7826		7826		4347
50		5217		4347		7826		4347		6521	
59	6956		7826		7826		7826		6956		6086
68		6086		5217		6086		7826		6956	
77	7391		6986		7826		6086		6086		6956
86		5217		6086		6956		6521		6956	
95	6086		5217		5217		5217		6086		6956
104		7391		7826		5127		7826		7826	
113	7826		5217		4347		7826		5652		6956
122		7826		6086		7826		6956		6086	

Interpretation of the tables and NDVI map for the SB plot at Girboiu:
The orange and red colors correspond to LWA values ranging from 4,500 to 6,500 m²/ha and LRV values between 870 and 1,800 m³/ha, representing approximately 39% of the analyzed area. The dark green and light green colors correspond to LWA values ranging from 7,000 to 10,400 m²/ha and LRV values between 2,000 and 5,000 m³/ha, representing approximately 61% of the analyzed area.

Figure 10. SB NDVI vigor map

Table 13. SB NDVI & LWA-LRV correlation

	NDVI map		
Colour	Value	Surface (ha)	Percent
Green	0.19-0.51	3.58	60.37%
Orange	0.06-0.16	2.35	39.62%
		5.93	
	Leaf Wall Area		
	Number of vines	Interval (m²/ha)	Percent
	48	6956-10434	62.33%
	29	4347-6521	37.66%
	77		
	Leaf Row Volume		
	Number of vines	Interval (m³/ha)	Percent
	46	1956-5021	59.74%
	31	869-1847	40.26%
	77		

As a final point of the study, a SWOT analysis has been compiled for the proposed theme.
Strengths: Maps obtained through passive remote sensing technology represents a source of information for the vineyard area and the evolution of a plantation.
Easy and rapid evaluation of cultivated areas without knowing the vineyard's history. A useful tool for choosing an optimal harvest date. Better understanding of plot variability, allowing for more precise implementation of necessary uniformization measures. Image resolution obtained surpasses satellite quality and is much more efficient than human eye observation. Weaknesses: Applicability may be challenging to understand and implement regarding the current processes in Romanian viticulture. An emerging technology in its early stages of adoption in agriculture. Very low interest in research regarding the use of new remote sensing technologies. Very low theoretical knowledge base among personnel who could use this technology in a winery.
Opportunities: Wineries that understand and use drone technology and remote sensing will have a significant competitive advantage in the coming years. Once the applicability of drone data collection is understood, working with drones for phytosanitary spraying will be easily implementable. A very new research branch with enormous exploitation potential. Future studies could explore relationships between NDVI and grape pH before harvest, harvested quantity and the weight of 100 berries.
Threats: The need for winery personnel to undergo retraining for use of new technologies. The primary need for wineries to solve already known problems or at least those easier to

identify. Initial significant investments in hardware, software, or remote sensing services may seem unsustainable or unnecessary. With the development of remote sensing infrastructure, wineries will need to stay technologically up-to-date with other precision viticulture equipment.

CONCLUSIONS

The paper explores the integration of passive remote sensing technology in Romanian viticulture, highlighting its strengths in providing valuable information for vineyards and efficient evaluation of cultivated areas. While presenting promising opportunities for wineries adopting this technology, the analysis emphasizes the need to address challenges such as applicability concerns, low research interest, and the necessity for personnel retraining.

Continued research through more complex analyses for a more detailed understanding involve the following proposals. Demonstrating the correlation of the NDRE vegetation index with leaf nitrogen levels and, consequently, photosynthesis performance. Planning pruning during the dormant period based on NDVI map data to establish the load for the following year. Correlating NDVI and NDRE index maps, resulting in a third index, CCCI (Canopy Chlorophyll Content Index), to identify areas with high potential of disease. Efficientizing phytosanitary treatments by administering substances in quantities according to the NDVI map. Applying selection of sampling points before harvest based on vegetation indices. Plotting the harvest for differentiation of grapes into different quality tiers and vinifying them separately. Understanding soil structure and texture through extracting vegetation indices over successive periods of multiple years. Identifying and demonstrating a crop estimation model using passive remote sensing techniques.

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