POSSIBILITIES OF SAR IMAGES FOR POPPY EVALUATION

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Abstract
Poppy (Papaver somniferum L.) is oil plant and also an export commodity of the Czech Republic. This crop is demanding to grow, especially in terms of agro-ecological conditions of the field and agricultural management. For this reason, remote sensing appears to be a suitable method for monitoring whole growth for proper treatment timing. As optical remote sensing has its limitations in the form of frequent cloud coverage, synthetic aperture radar images are becoming an alternative source of information about the crop state. The results showed that synthetic aperture radar satellite images can be helpful in case of time evaluation of poppy growth when optical images are not available. The Radar Vegetation Index could explain the yield spatial distribution from 32 % only when the crops were in elongation growing stage.

Key words: *crop production; satellite images; spectral indices, radar vegetation index.*

INTRODUCTION

Poppy belongs among the special crops grown in the Czech Republic in the area with altitude from 300 to 700 m above sea level. Poppy cultivation requires special conditions as confirmed by the study of *Hong et al. (2022)*. They stated that it is appropriate to focus on choosing a suitable place for growing poppies. Areas with strong winds are unsuitable for poppies because the crop may be uprooted. It is also not appropriate to grow poppies near forests where moisture is retained. Poppy has a small seed, so it is very demanding in the initial phenological stages. It is advisable to properly manage soil moisture and adhere to the sowing depth. Poppy is sown up to 2 cm. Like other oilseeds, poppies need little water to germinate. Subsequently, however, poppies are demanding moisture from emergence to flowering, the highest demands on moisture are 2-3 weeks before flowering. From the flowering stage to the maturity stage, the moisture requirements are reduced. Lack of water is a significant negative factor affecting poppy yields (*Makovnyka, 2020; Maurya et al., 2019*).

Poppy growth in the field is highly heterogeneous, so it requires a considerable amount of data collection to develop yield models. This phenomenon has been confirmed by several observations of poppy cultivation under controlled conditions (*Harvest et al., 2009; Kang & Primack, 1991; Lisson & Lisson, 2007*). However, few studies have used remote sensing to predict the yield (*Iqbal et al., 2017; Waine et al., 2014*). Data collected from field measurements can usually provide reference information on crop growth, but spatial coverage is often limited, so it is appropriate to use any of remote sensing methods, which can identify spatial variability of key yield indicators on a larger scale. In previous studies, various physiological indicators were evaluated to predict yield. Studies confirmed a significant correlation between Normalized Difference Vegetation Index (NDVI) and the capsule volume in the flower-to-harvest phase (*Jia et al., 2011; Mahdavi-Damghani et al., 2010*).

This article focused on exploring the potential use of the Sentinel 1 synthetic aperture radar (SAR) system to monitor the poppy growth cycle. Radar crop monitoring has several key advantages over ground-based or optical data measurements. Thanks to the use of wavelengths in the C-band, crop monitoring is not affected by clouds and the radar system provides us data for analysis at intervals without outages. This radar feature is very useful in poppies because it is important to manage soil moisture properly, especially in the early phenological stages (*Alonso-González et al., 2020*).

As the use of SAR satellite images in crop production still carries many uncertainties that need to be explored, the main aim of this study was to determine the usability of the Radar Vegetation Index (RVI) index calculated from SAR satellite images when optical data are not available, for the purposes of poppy production management.

MATERIALS AND METHODS

The poppy was grown in 10.7 ha plot near to Kněževes (50° 7'58.65"N, 13°39'41.05"E), in the Czech Republic, during the vegetation season 2020 (sowing: March 27th to harvest on August 17th). The agro-meteorogical data (temperature and precipitation) during the poppy growing season are given in Table 1.

Tab. 1 Monthly temperatures and precipitation for the study site in growing season 2020 until August 17th 2020

Parameters/Months	April	May	June	July	August
Temperature (°C)	9.7	11.6	16.9	18.3	19.7
Precipitation (mm)	18.6	54.8	103.1	41.9	85.8

The evaluation of the whole vegetation season was carried out using satellite (optical and SAR) remote sensing, UAV scanning and crop analysis. The microwave and optical (cloud free) satellite images (Sentinel 1 and 2) were downloaded from Copernicus Open Access Hub. The images were processed in SNAP SW to the form of spectral indices. Sentinel 1 images were pre-processed by Radiometric Calibration, Multi-temporal Speckle Filtering and Range-Doppler Terrain correction (Relative Orbit 44), finally RVI was calculated. NDVI, Green NDVI (GNDVI), Triangular Greenness Index (TGI), Moisture Stress Index (MSI) and Enhanced MSI (EMSI) were calculated from Sentinel 2 images. The satellite data were complemented with images taken from drone multispectral camera. The digital elevation model (DEM) was derived from the UAV images taken on 21 May 2020. The data of acquisition and platforms with sensors used in this study are given in Table 2. Calculated spectral indices are available in Table 3.

Tab. 2 Overview of satellite and UAV data

Platform	Sensor	Calculated Index	Date (2020)
Satellite Sentinel 1	C-band SAR	RVI	15.5.; 21.5; 27.5.; 2.6.; 8.6.; 14.6.; 20.6.; 26.6.; 2.7.
Satellite Sentinel 2	MSI	NDVI, GNDVI, MSI, EMSI	18.5.; 2.6.; 12.6.;
FireFly6 Pro	Micasense RedEdge MX	NDVI, GNDVI, TGI	21.5.; 15.7.
UAV – DJI Mavic Pro	RGB	TGI	23.6.

SAR = Synthetic Aperture Radar; MSI sensor = Multispectral Instrument; RVI = Radar Vegetation Index; NDVI = Normalized Difference Vegetation Index; GNDVI = Green NDVI, MSI = Moisture Stress Index, EMSI = Enhanced MSI; TGI = Triangular Greenness Index; UAV = Unmanned Aerial Vehicle, SAR = Synthetic Aperture Radar

Tab. 3 Overview of spectral indices used in this study

Index	Equation	Reference
Radar Vegetation Index	$RVI = (4\sigma°VH)/(\sigma°VV + \sigma°VH)$	*Charbonneau et al. (2005)*
Normalized Difference Vegetation Index	$NDVI = (NIR-R)/(NIR+R)$	*Rouse et al. (1974)*
Green NDVI	$GNDVI = (NIR-G)/(NIR+G)$	*Gitelson et al. (1996)*
Triangular Greenness Index	$TGI = G-0.39\times R-0.61\times B$	*Hunt et al. (2013)*
Moisture Stress Index	$MSI = SWIR1/NIR$	*Rock et al. (1985)*
Enhanced MSI	$EMSI = SWIR2/NIR$	*Rock et al. (1985)*

R, G, B, NIR, SWIR1 and SWIR2 = reflectance in RED, GREEN, BLUE, NIR (B4, B3, B2 and B8 bands for Sentinel 2 image), SWIR1 and SWIR2 bands (B11 and B12 bands for Sentinel 2 images); σ° backscatter coefficient (sigma nought); VH polarization mode vertical/horizontal; VV polarization mode vertical/vertical.

The crop samples of poppy in the growing stage BBCH 90 (on 12 August 2020) before harvest were taken from 0.5 × 0.5 m grid for 20 selected sampling points designed according to the scale of TGI spectral index from 23 June 2020. The crop samples were analyzed for number of poppyheads and weight of seeds.
The yield was measured during the harvest with Case 8250 combine harvester equipped with yield monitor. The yield data were processed according to a common statistical workflow. All the data (crop samples, yield map and images) were converted into the shapefiles vector or geotiff raster data format with the aim to compare them on the base spatial distribution over the experimental plot. The data in such formats were then processed in QGIS (version 3.16.8) and ArcGIS Pro (version 2.9.2) SWs. The information derived from spatial formats were then analyzed in Statistica (version 13.5.0.17) SW.

RESULTS AND DISCUSSION

Coefficients of determination (R^2) between vegetation indices (NDVI, GNDVI, TGI) calculated from UAV images, number of poppyhead and weight of seeds, and RVI in individual dates of crop scanning are given in Table 4. Coefficients of determination between RVI and vegetation indices (NDVI, GNDVI, MSI and EMSI) calculated from optical satellite images are available in Table 5. The average values of selected indices (RVI, NDVI, GNDVI, MSI, EMSI) throughout the growing season of poppy in terms of Sentinel 1 and Sentinel 2 scanning can be seen in Figure 1. Figure 2 then displays selected spectral indices for individual dates: EMSI for 18 May 2020; RVI for 27 May 2020, GNDVI for 2 June 2020; and RVI for 2 June 2020.
The results showed only very low, or no dependence were found between values of RVI values and spectral indices calculated from UAV images (NDVI, GNDVI and TGI) in scanning dates. Only the date of Sentinel 1 scanning - May 27th showed relatively higher dependence between RVI and NDVI, GNDVI and TGI indices derived from UAV images on May 21st. These dates corresponded to an elongation phenological phase of poppy growth. The result showed that the TGI index can be used as alternative to NDVI or GNDVI if there is no NIR band available, as was also confirmed in the study on poppy evaluation by *Jelínek et al. (2020)*. UAV images can also sufficiently supplement crop growth information if satellite images are not or cannot be used (*Balážová et al., 2021*). The RVI index could explain the yield spatial distribution from 32 % in May 15 when the crops were in elongation phenological phase; and from 21 % (on July 2nd) in the growth phase BBCH 68 (end of flowering). Microwave radiation should carry information about moisture and roughness of canopy. These results therefore showed the possible yield variability noticeable during poppy growth, with regard to biomass increase. Coefficient of determinations 0.27 and 0.28 were found between RVI from June 20 (BBCH 58 – beginning of flowering) and number of poppy heads and weight of seeds. This result could explain the signal's ability to detect reflections from different surface types (flowers vs. canopy of green plants).

Tab. 4 Coefficients of determination (R^2) between spectral indices derived from UAV images (Normalized Difference Vegetation Index = NDVI, Green NDVI = GNDVI, Triangular Greenness Index = TGI), Digital Elevation Model (DEM), Yield, number of poppyhead (NoP) and weight of seeds (W); and Radar Vegetation Index (RVI); at 5% significance level

RVI	NDVI 21.5.	NDVI 15.7.	GNDVI 21.5.	GNDVI 15.7.	TGI 21.5.	TGI 23.6.	TGI 15.7.	DEM	Yield ($t.ha^{-1}$)	NoP	W(g)
15.5.	0.15	0.02	0.18	0.02	0.09	0.00	0.00	0.05	0.32	0.09	0.02
21.5.	0.09	0.06	0.09	0.05	0.07	0.02	0.01	0.04	0.05	0.18	0.05
27.5.	0.28	0.11	0.35	0.13	0.24	0.05	0.07	0.05	0.15	0.02	0.00
2.6.	0.03	0.10	0.03	0.01	0.05	0.12	0.16	0.00	0.00	0.00	0.00
8.6.	0.01	0.05	0.00	0.04	0.00	0.00	0.02	0.01	0.02	0.00	0.01
14.6.	0.03	0.00	0.05	0.02	0.07	0.10	0.01	0.03	0.01	0.17	0.21
20.6.	0.01	0.02	0.01	0.10	0.00	0.05	0.16	0.11	0.03	0.27	0.28
26.6.	0.11	0.01	0.10	0.03	0.13	0.00	0.06	0.08	0.03	0.02	0.01
2.7.	0.04	0.00	0.06	0.01	0.04	0.00	0.01	0.00	0.21	0.00	0.01

Tab. 5 Coefficients of determination (R^2) between spectral indices derived from satellite images in optical (Normalized Difference Vegetation Index = NDVI, Green NDVI = GNDVI, Moisture Stress Index = MSI, Enhanced MSI = EMSI) and microwave (RVI) part of electromagnetic spectra I given dates; at 5% significance level

RVI	NDVI 18.5.	NDVI 2.6.	NDVI 12.6.	GNDVI 18.5.	GNDVI 2.6.	GNDVI 12.6.	MSI 18.5.	MSI 2.6.	MS 12.6.	EMSI 18.5.	EMSI 2.6.	EMSI 12.6.
15.5.	0.06	0.00	0.01	0.06	0.00	0.04	0.32	0.01	0.00	0.28	0.00	0.01
21.5.	0.02	0.00	0.00	0.02	0.00	0.00	0.09	0.01	0.01	0.07	0.01	0.00
27.5.	0.30	0.05	0.00	0.37	0.04	0.00	0.40	0.07	0.00	0.41	0.05	0.00
2.6.	0.07	0.22	0.17	0.15	0.29	0.24	0.10	0.25	0.21	0.09	0.24	0.20
8.6.	0.01	0.07	0.07	0.01	0.06	0.04	0.08	0.10	0.09	0.07	0.08	0.08
14.6.	0.00	0.02	0.03	0.00	0.03	0.04	0.10	0.08	0.09	0.06	0.05	0.06
20.6.	0.09	0.03	0.01	0.06	0.05	0.03	0.00	0.02	0.02	0.00	0.04	0.02
26.6.	0.02	0.01	0.01	0.01	0.02	0.02	0.05	0.06	0.07	0.04	0.04	0.05
2.7.	0.10	0.03	0.00	0.16	0.04	0.01	0.26	0.08	0.07	0.24	0.01	0.00

The dependency between RVI and optical indices was also relatively low. The RVI values are generally in relation to the water content of the canopy and the increase in biomass, which finally corresponded to the higher R^2 on May 27th and June 2nd. The similar results confirmed *Tůma el al. (2021)*. The higher dependence of the MSI / EMSI indices at the beginning of growth rather corresponded to the low moisture content in the soil. The MSI and EMSI values decreased as the biomass increased during the very rainy growing season (see Table 1). The RVI curve followed the tendency of the NDVI and GNDVI indices, although the optical indices were less useful due to frequent clouds. *Gonenc et al. (2019)* found out similar trend in NDVI and RVI curves. The RVI curve clearly showed an increase in values at the end of May, when there was an elongation growth stage during a relatively humid spring and then also a sudden decrease in values during flowering (June 8th). This was followed by an increase and decrease in values from the beginning of plant maturation and death (see Table 5, Fig. 1 and 2).

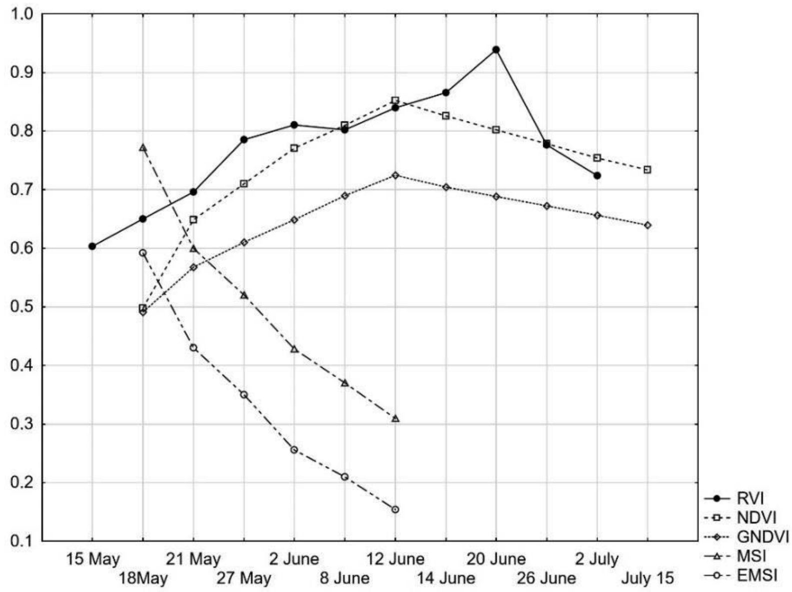

Fig. 1 The average values of selected indices (RVI, NDVI, GNDVI, MSI, EMSI) throughout the growing season of poppy

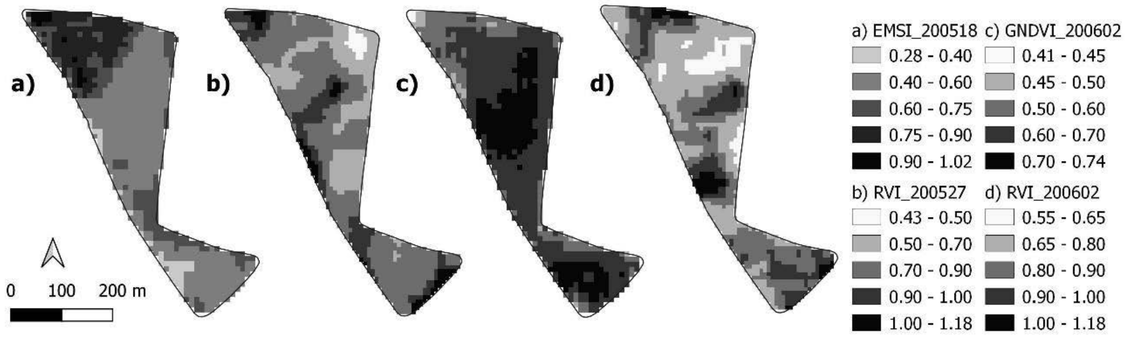

Fig. 2 Selected spectral indices for individual dates: Enhanced Moisture Stress Index (EMSI) for 18 May 2020 (a); Radar Vegetation Index (RVI) for 27 May 2020 (b); Green Normalized Difference Vegetation Index (GNDVI) for 2 June 2020 (c); and RVI for 2 June 2020 (d)

CONCLUSIONS

The poppy was monitored with optical and synthetic aperture radar sensors during 2020 vegetation season. The results showed that development of calculated RVI values in time, can be very helpful in assessing the condition of the poppy stand, especially in cases where optical satellite images are missing, and the stand cannot often be scanned using UAVs. It has been also confirmed that if a common RGB camera is available on the UAV, it is sufficient to calculate the TGI index as an alternative to NDVI or GNDVI. RVI index was also evaluated in terms of use for yield estimation. The spatial distribution of final yield was explained from 32 % by RVI index when the crops were in elongation phenological phase and from 21 % in growing phase at the end of flowering. Future research should focus not only on the use of RVI in poppy stands, but also on other crops commonly grown in the Czech Republic, including the implementation of the RVI index into common agricultural practice.

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