Assessment of plant nutrition parameters in cereals by PlanetScope and Sentinel-2 multispectral data

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Introduction

This study focuses on the use of modern methods in precision agriculture, such as remote sensing (Sentinel-2, PlanetScope), to optimize inputs based on temporal and spatial variability of vegetation. The study evaluates the nutritional status of field crops at critical growth stages (BBCH 30, BBCH 37, BBCH 50), primarily chlorophyll content and biomass. Using vegetation indices, we can estimate the nutritional status of vegetation across the entire area from spectral data. The aim of this study was to compare data from satellites with different temporal, spatial, and spectral resolutions for estimating the nutritional status of field crops (winter wheat, winter barley). The result is the determination of the most suitable vegetation indices for each satellite system in a specific growth stage.

Methods

Satellite data

PlanetScope (Surface reflectance - 8b)

Sentinel-2 (L2A)

Ground survey and laboratory

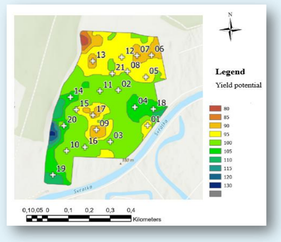
collecting biomass

laboratory analysis

Vegetation indices extracted from points

Indices	Equation
Normalized difference vegetation index	$NDVI = \frac{NIR-RED}{NIR+RED}$
Enhanced vegetation index	$EVI = \frac{2.5(NIR-RED)}{(NIR+6RED-7.5cBLUE)+1}$
Green normalized difference vegetation index	$GNDVI = \frac{NIR-GREEN}{NIR+GREEN}$
Normalized difference red-edge index	$NDRE = \frac{NIR-RE}{NIR+RE}$
Renormalized difference vegetation index	$RDVI = \frac{NIR-RED}{\sqrt{NIR+RED}}$
Optimized soil adjusted vegetation index	$OSAVI = 1.6\left[\frac{NIR-RED}{NIR+RED+0.16}\right]$
Modified simple ratio	$MSR = \frac{(NIR/RED)-1}{\sqrt{(NIR/RED)+1}}$

vegetation indices



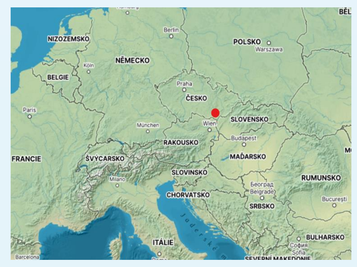
collection points

Correlation and regression

O_20220510_CIRE	O_20220510_EVI	O_20220510_EVI2	O_20220510_GNDVI	O_20220510_NDMI	O_20220510_NDRE	O_20220510_NDVI
2,568862	0,823189	1,614542	0,608349	0,43712	0,562254	0,646047
2,274611	0,751987	1,517126	0,568652	0,396895	0,532121	0,607081
2,134965	0,765302	1,528499	0,568934	0,398069	0,51632	0,611626
2,650804	0,850185	1,643595	0,617773	0,451386	0,569967	0,657668
2,460286	0,828096	1,607791	0,60116	0,433208	0,551598	0,643346
1,44807	0,672224	1,398228	0,513788	0,30724	0,419965	0,55951
1,266423	0,584166	1,235539	0,456464	0,254902	0,38771	0,494416
1,58188	0,664789	1,366958	0,502377	0,32107	0,441634	0,546997
1,667045	0,66945	1,386994	0,507721	0,332591	0,454602	0,555014
2,399473	0,777444	1,556769	0,582682	0,416196	0,5454	0,622938
2,104385	0,782992	1,54672	0,574671	0,404743	0,512716	0,618916
1,437225	0,60756	1,293743	0,473477	0,284613	0,418135	0,517707
1,1821	0,521556	1,118882	0,426367	0,227837	0,371484	0,447736
1,364975	0,573056	1,234201	0,454789	0,259184	0,405642	0,493885
1,593964	0,659053	1,387509	0,51435	0,331821	0,443511	0,555224
2,064797	0,741923	1,49943	0,558778	0,384489	0,507971	0,6
1,392337	0,638421	1,334216	0,489004	0,303511	0,410436	0,5339
2,568498	0,805254	1,591221	0,595352	0,423536	0,562219	0,636716
2,622995	0,824944	1,614136	0,60643	0,446556	0,56738	0,645882
2,359405	0,817802	1,58902	0,597484	0,416836	0,541222	0,635831
2,522505	0,804797	1,573395	0,587116	0,425003	0,557767	0,629585

Material

- area: 29 ha of field near the village of Uherčice in the Czech Republic
- 21 collection points based on yield potential
- crops: winter wheat (2022), winter barly (2023)
- biomass parameters: fresh and dry biomass
  nitrogen uptake (Nupt)
  nitrogen content (Ncont)
  nitrogen nutrition index (NNI)



2022				2023			
Date of biomass collection	BBCH	Image download date		Date of biomass collection	BBCH	Image download date	
		Sentinel-2	Planet			Sentinel-2	Planet
14.4.2022	BBCH 29–30	12.4.2022 (-2 days)	14.4.2022 (0 days)	**5.4.2023**	BBCH 29–30	10.4.2023 (+5 days)	4.4.2023 (-1 day)
11.5.2022	BBCH 50–51	10.5.2022 (- 1 day)	11.5.2022 (0 days)	**10.5.2023**	BBCH 37–39	5.5.2023 (-5 days)	10.5.2023 (0 days)
				24.5.2023	BBCH 50–51	27.5.2023 (+3 days)	27.5.2023 (+3 days)

Results

2022

BBCH 29-30

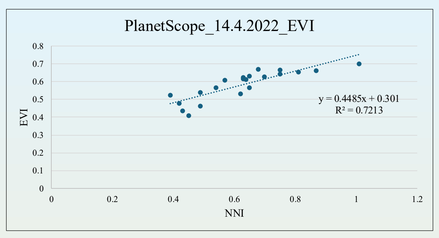
Correlation coefficients between biomass parameters and vegetation indices calculated from Sentinel-2 and PlanetScope satellite systems for vegetation stages BBCH 29-30 and BBCH 50-51. Values in bold are significant at the p < .05 level.

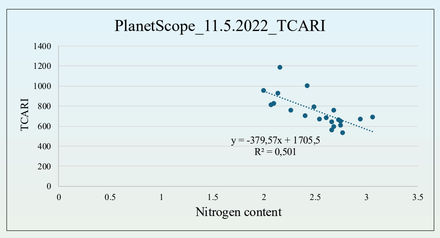
Sentinel-2					PlanetScope				
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)
CIRE	**0.775**	**0.684**	**0.832**	**0.812**	**EVI**	**0.844**	**0.732**	**0.910**	**0.884**
EVI	**0.795**	**0.747**	**0.870**	**0.836**	**EVI2**	**0.817**	**0.753**	**0.886**	**0.853**
EVI2	**0.821**	**0.733**	**0.871**	**0.853**	**GNDVI**	**0.821**	**0.746**	**0.889**	**0.858**
GNDVI	**0.800**	**0.735**	**0.867**	**0.842**	**NDRE**	**0.791**	**0.709**	**0.855**	**0.825**
NDMI	**0.858**	**0.697**	**0.891**	**0.887**	**NDVI**	**0.817**	**0.753**	**0.886**	**0.853**
NDRE	**0.775**	**0.684**	**0.832**	**0.812**	**SAVI**	**0.817**	**0.753**	**0.886**	**0.853**
NDVI	**0.821**	**0.733**	**0.871**	**0.853**	**SRI**	**0.817**	**0.753**	**0.886**	**0.853**
NRERI	0.213	0.315	0.218	0.223	**TCARI**	0.404	0.191	0.313	0.386
SRI	**0.821**	**0.733**	**0.871**	**0.853**					

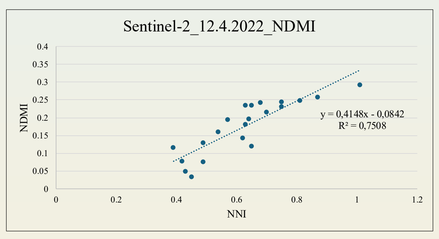
BBCH 50-51

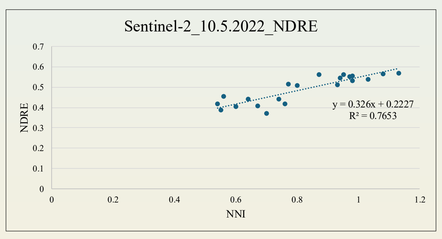
Sentinel-2					PlanetScope				
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)
CIRE	**0.796**	**0.687**	**0.843**	**0.826**	**EVI**	**0.738**	**0.688**	**0.773**	**0.779**
EVI	**0.787**	**0.694**	**0.824**	**0.807**	**EVI2**	**0.800**	**0.669**	**0.792**	**0.791**
EVI2	**0.765**	**0.690**	**0.808**	**0.791**	**GNDVI**	**0.792**	**0.703**	**0.795**	**0.782**
GNDVI	**0.774**	**0.708**	**0.818**	**0.799**	**NDRE**	**0.826**	**0.720**	**0.823**	**0.822**
NDMI	**0.796**	**0.698**	**0.837**	**0.818**	**NDVI**	**0.800**	**0.669**	**0.792**	**0.791**
NDRE	**0.796**	**0.687**	**0.843**	**0.826**	**SAVI**	**0.800**	**0.669**	**0.792**	**0.791**
NDVI	**0.765**	**0.690**	**0.808**	**0.791**	**SRI**	**0.800**	**0.669**	**0.792**	**0.791**
NRERI	**0.804**	**0.692**	**0.839**	**0.832**	**TCARI**	**-0.762**	**-0.757**	**-0.799**	**-0.753**
SRI	**0.765**	**0.690**	**0.808**	**0.791**					

Graphs with regression lines show the relationship between selected vegetation indices and crop parameters.. Higher R^2 values indicate better predictive ability of a given vegetation index for estimating the monitored parameter



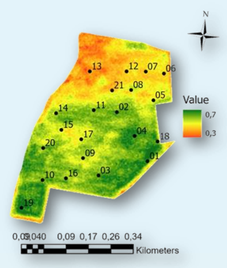




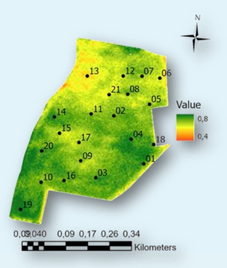


PlanetScope

14.4.2022 - EVI

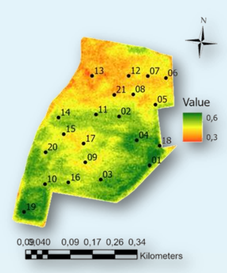


11.5.2022 - EVI

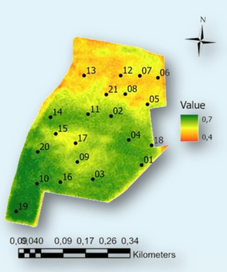


PlanetScope

14.4.2022 - NDRE

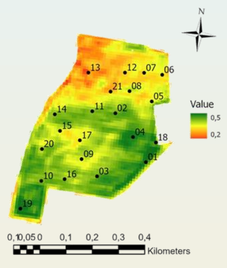


11.5.2022 - NDRE

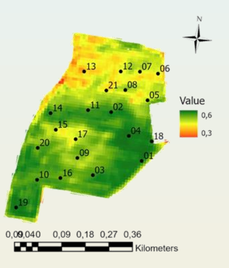


Sentinel-2

12.4.2022 - NDVI

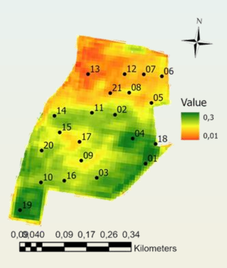


10.5.2022 - NDVI

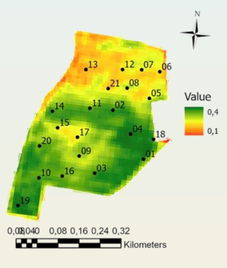


Sentinel-2

12.4.2022 - NDMI



10.5.2022 - NDMI



2023

BBCH 29-30 **BBCH 37-39** **BBCH 50-51**

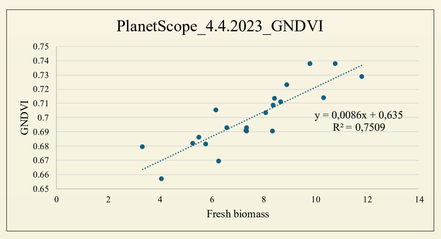
Correlation coefficients between biomass parameters and vegetation indices calculated from Sentinel-2 and PlanetScope satellite systems for vegetation stages BBCH 29-30, BBCH 37-39 and BBCH 50-51. Values in bold are significant at the p < .05 level.

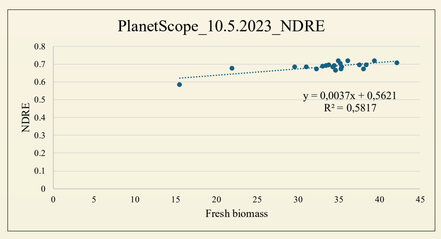
Sentinel-2					PlanetScope				
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)
CIRE	**0.823**	0.340	**0.714**	**0.803**	**EVI**	**0.512**	0.148	0.449	**0.496**
EVI	**0.779**	0.258	**0.666**	**0.756**	**EVI2**	**0.799**	0.340	**0.729**	**0.786**
EVI2	**0.795**	0.264	**0.695**	**0.779**	**GNDVI**	**0.904**	**0.448**	**0.852**	**0.896**
GNDVI	**0.819**	0.291	**0.714**	**0.799**	**NDRE**	**0.888**	0.409	**0.797**	**0.868**
NDMI	**0.791**	0.249	**0.698**	**0.774**	**NDVI**	**0.799**	0.340	**0.729**	**0.786**
NDRE	**0.823**	0.340	**0.714**	**0.803**	**SAVI**	**0.799**	0.340	**0.729**	**0.786**
NDVI	**0.795**	0.264	**0.695**	**0.779**	**SRI**	**0.799**	0.340	**0.729**	**0.786**
NRERI	**0.536**	0.144	**0.512**	**0.538**	**TCARI**	**-0.732**	-0.298	**-0.637**	**-0.714**
SRI	**0.795**	0.264	**0.695**	**0.779**					

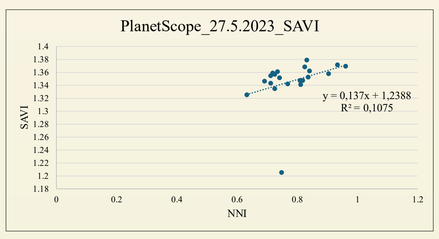
Sentinel-2					PlanetScope				
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)
CIRE	**0.600**	0.324	**0.503**	**0.587**	**EVI**	-0.179	-0.059	-0.074	-0.144
EVI	**0.742**	0.410	**0.626**	**0.709**	**EVI2**	0.278	0.178	0.248	0.313
EVI2	**0.700**	0.430	**0.575**	**0.639**	**GNDVI**	**0.464**	0.120	0.253	0.334
GNDVI	**0.713**	0.418	**0.569**	**0.666**	**NDRE**	**0.500**	0.206	0.344	**0.479**
NDMI	**0.740**	**0.542**	**0.708**	**0.794**	**NDVI**	0.278	0.178	0.248	0.313
NDRE	**0.600**	0.324	**0.503**	**0.587**	**SAVI**	0.278	0.178	0.248	0.313
NDVI	**0.700**	0.430	**0.575**	**0.639**	**SRI**	0.278	0.178	0.248	0.313
NRERI	**0.760**	**0.518**	**0.679**	**0.771**	**TCARI**	**-0.725**	-0.311	**-0.510**	**-0.648**
SRI	**0.700**	0.430	**0.575**	**0.639**					

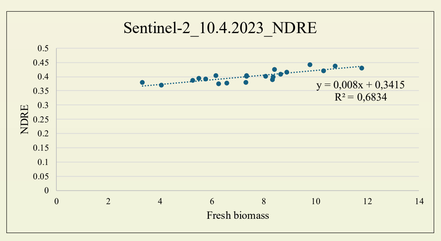
Sentinel-2					PlanetScope				
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Nupt (kg/ha)
CIRE	**0.488**	-0.090	0.118	0.370	**EVI**	0.387	0.213	0.368	0.414
EVI	**0.509**	0.014	0.227	0.390	**EVI2**	0.419	**0.459**	**0.579**	**0.562**
EVI2	**0.561**	0.002	0.217	0.414	**GNDVI**	**0.475**	0.195	0.410	**0.496**
GNDVI	**0.656**	0.078	0.313	**0.510**	**NDRE**	0.277	0.009	0.062	0.165
NDMI	**0.510**	0.173	0.313	0.399	**NDVI**	0.419	**0.459**	**0.579**	**0.562**
NDRE	**0.488**	-0.090	0.118	0.370	**SAVI**	0.419	**0.459**	**0.579**	**0.562**
NDVI	**0.561**	0.002	0.217	0.414	**SRI**	0.419	**0.459**	**0.579**	**0.562**
NRERI	**0.527**	0.422	**0.523**	**0.473**	**TCARI**	**-0.343**	**-0.209**	**-0.360**	**-0.401**
SRI	**0.561**	0.002	0.217	0.414					

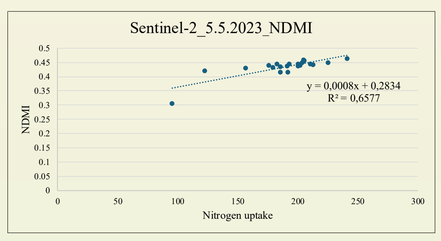
Graphs with regression lines show the relationship between selected vegetation indices and crop parameters.. Higher R^2 values indicate better predictive ability of a given vegetation index for estimating the monitored parameter

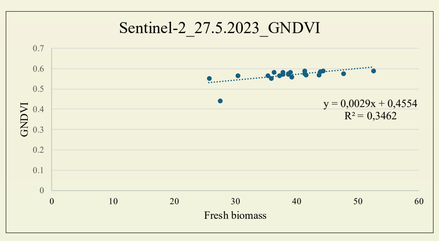






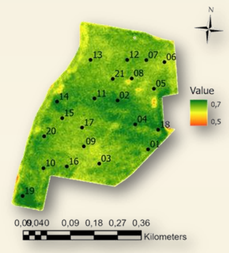




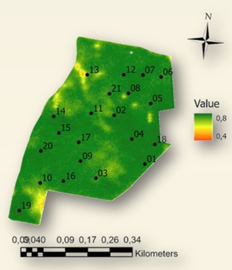


PlanetScope

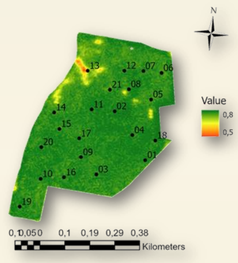
4.4.2023 - GNDVI



10.5.2023 - GNDVI

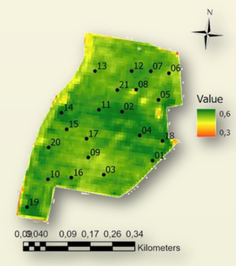


27.5.2023 - GNDVI

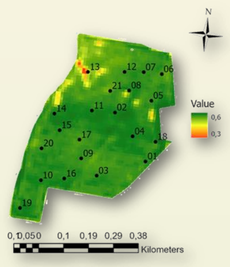


Sentinel-2

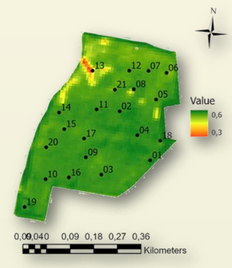
10.4.2023 - NDVI



5.5.2023 – NDVI



27.5.2023 – NDVI



Conclusions

Based on the results of this study, it can be concluded that both Sentinel-2 and PlanetScope satellite data show potential for estimating the nutritional status of winter cereal crops. Thanks to its wider spectral range, especially the presence of red-edge bands, Sentinel-2 achieved higher and more stable correlation coefficients across vegetation phases. Despite its more limited spectral range, PlanetScope provided comparably high correlations in some cases, especially in BBCH stages 29–30. The highest correlations were repeatedly achieved for the GNDVI, NDRE, and SRI indices, which use the red-edge or green band. The results also confirmed that the predictive ability of individual vegetation indices varies depending on the growth phase and the type of parameter monitored. In 2022, the correlations for both satellites were statistically significant to a greater extent than in 2023, which may have been due to different climatic conditions or crop development. The NDRE index from Sentinel-2 proved to be highly reliable for estimating NNI, especially in the BBCH 29–30 phase. For the PlanetScope satellite, the best results were achieved with the GNDVI and NDVI indices, which proved to be robust even at lower spectral resolution. The TCARI vegetation index repeatedly showed negative correlations and low reliability. Overall, Sentinel-2 can be recommended for more detailed assessment of crop nutrient status, while PlanetScope may be a suitable alternative in cases where high spatial and temporal resolution is a priority.

Acknowledgments

This study is supported by research projects of the Technology Agency of the Czech Republic SS01020309 “Precision farming on agricultural land with controlled drainage runoff as a tool to protect water and increase crop production efficiency” and research project of Mendel University in Brno AF-IGA2023-IP-036.