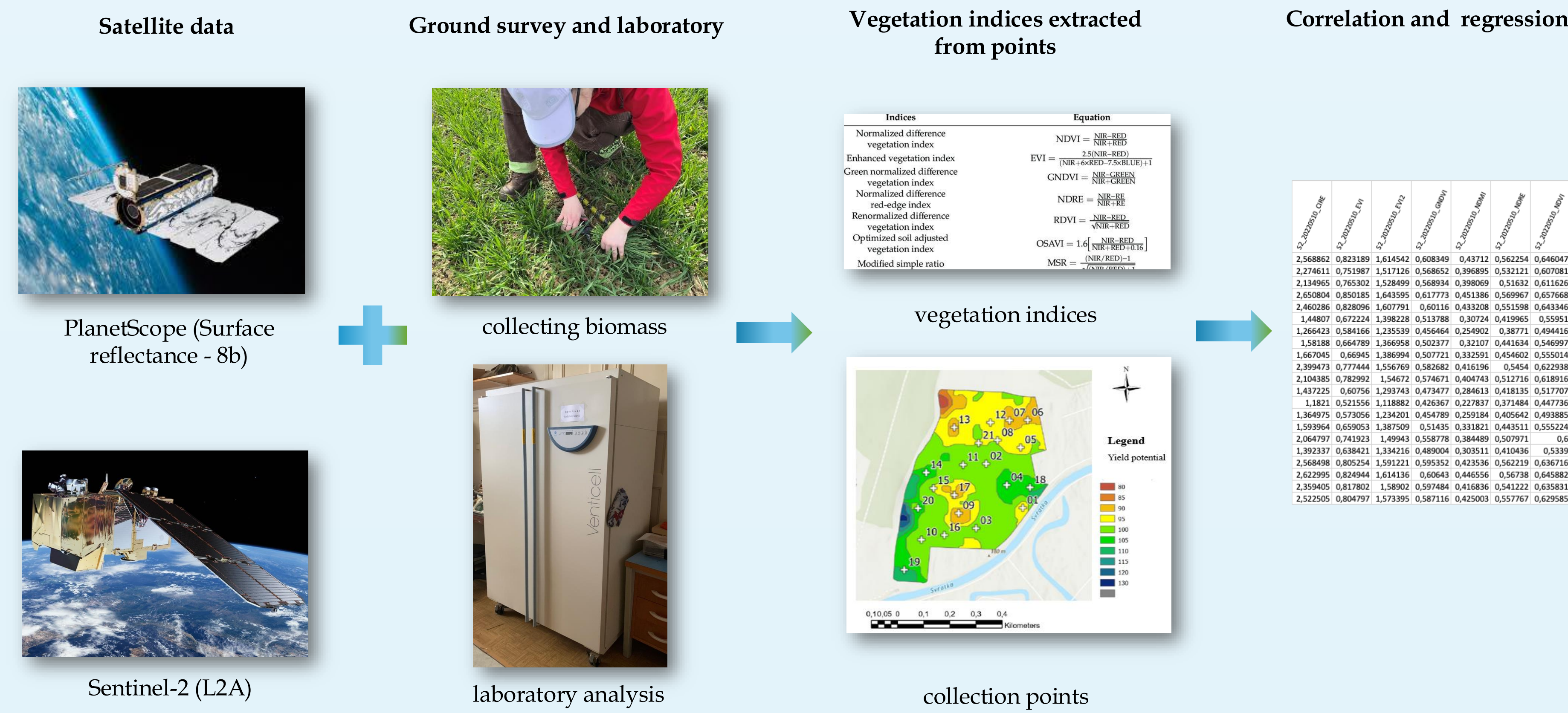




## Introduction

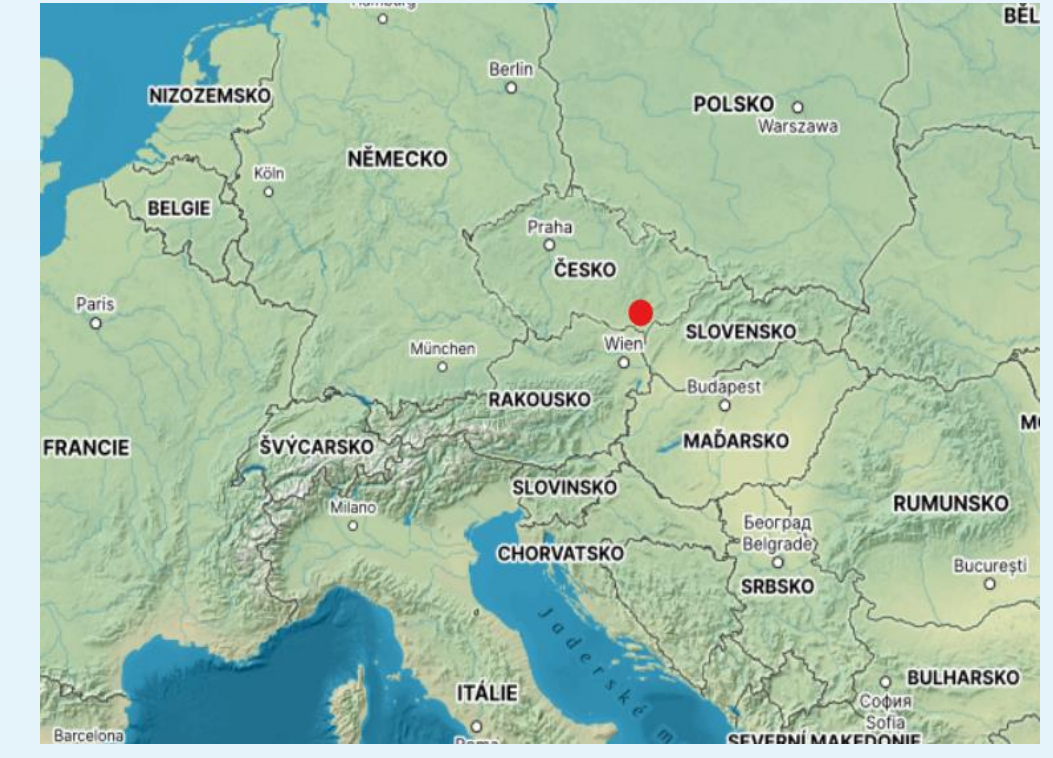
This study focuses on the use of modern methods in precision agriculture, such as remote sensing (Sentinel-2, PlanetScope), to optimize inputs based on temporal and spatial variability of vegetation. The study evaluates the nutritional status of field crops at critical growth stages (BBCH 30, BBCH 37, 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



## 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 barley (2023)
- biomass parameters: fresh and dry biomass
  - nitrogen uptake (Nupt)
  - nitrogen content (Ncont)
  - nitrogen nutrition index (NNI)



Date of biomass collection	BBCH	2022		2023	
		Image download date		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

### BBCH 29-30

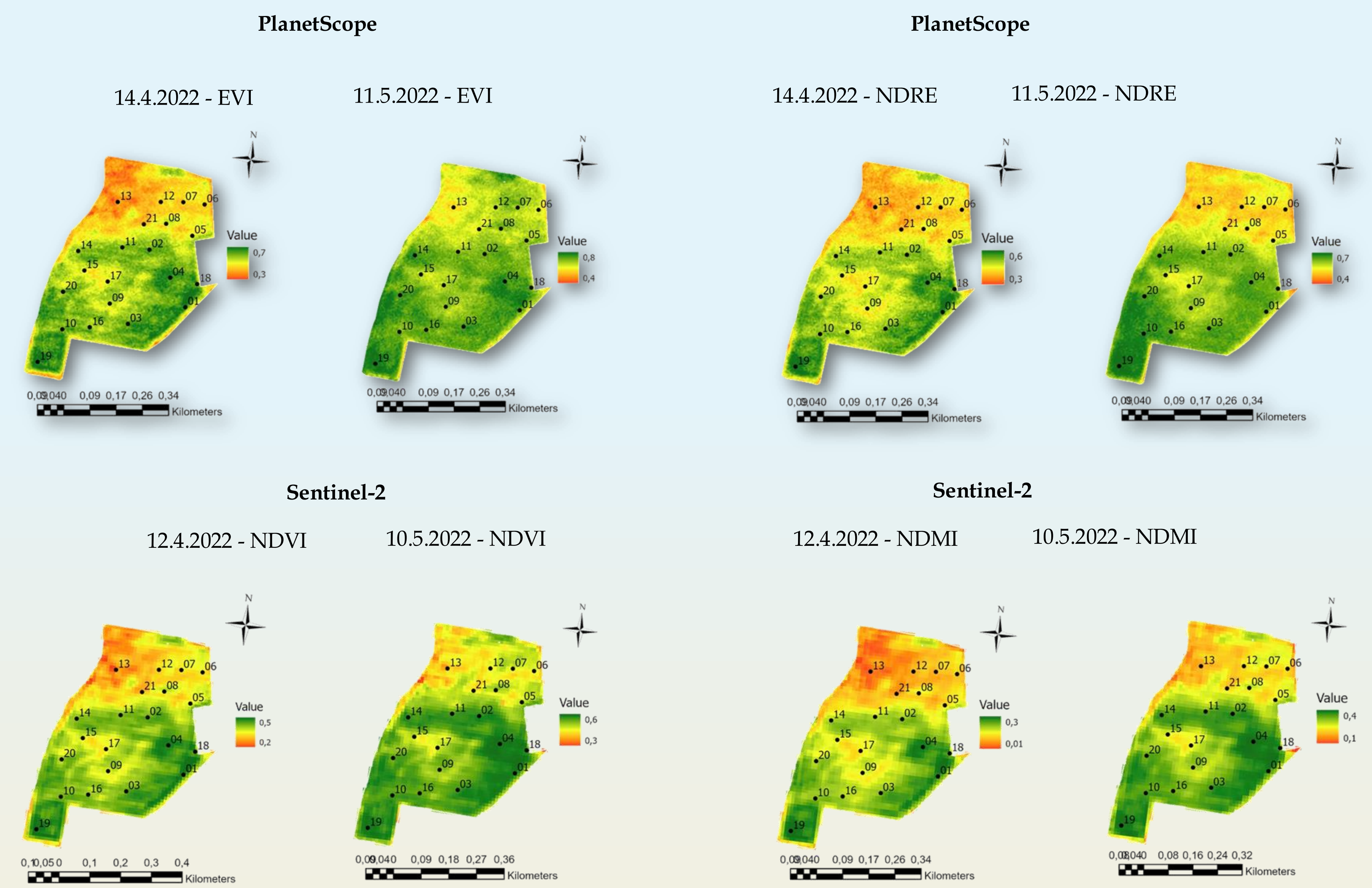
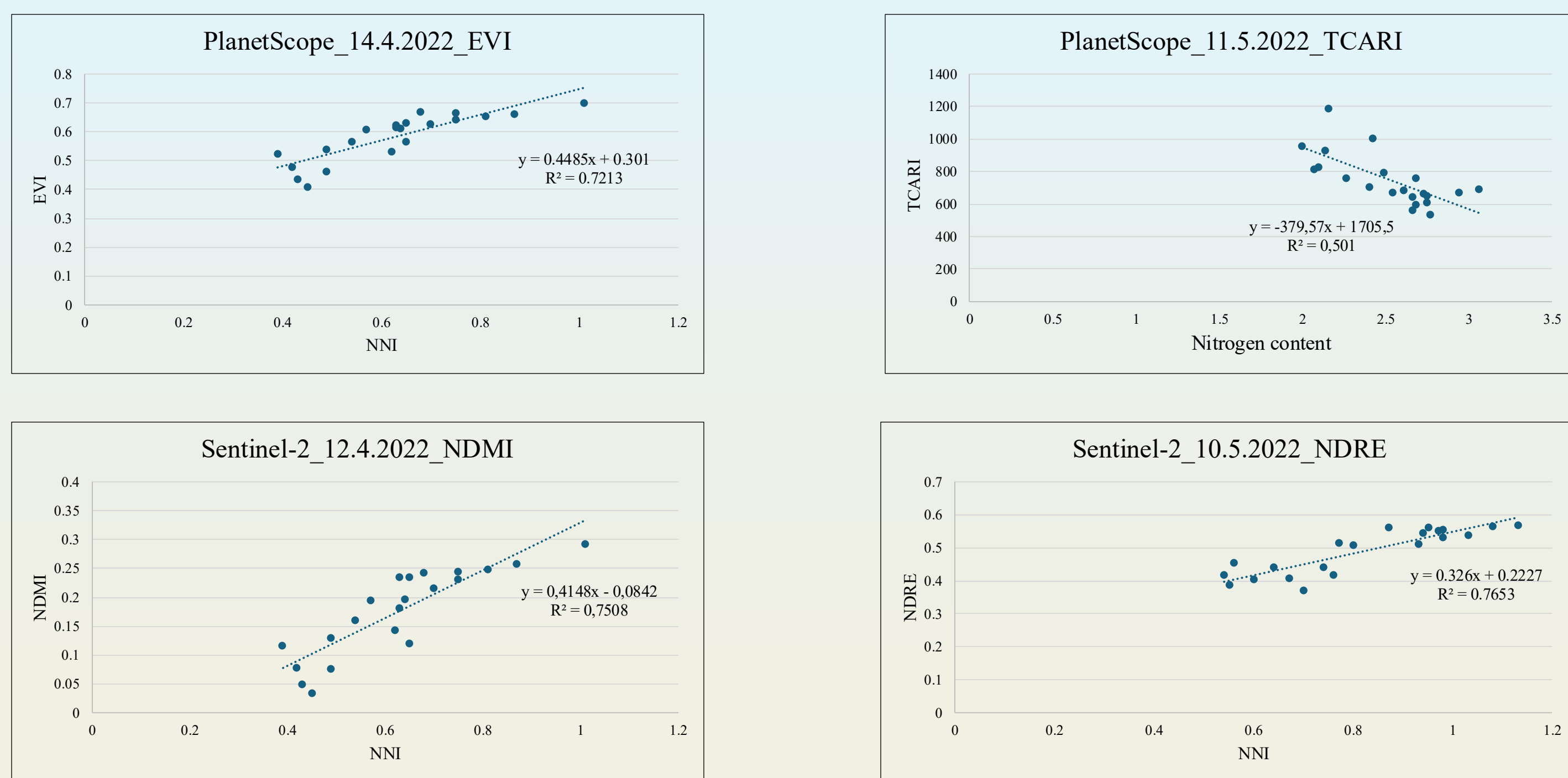
Correlation coefficients between biomass parameters and vegetation indices calculated from Sentinel-2 and PlanetScope satellite systems for vegetation stages BBCH 29-30 and BBCH 50-51. Values in bold are significant at the  $p < .05$  level.

Sentinel-2				PlanetScope			
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI
CIRE	0.775	0.684	0.833	0.812	0.844	0.732	0.918
EVI	0.795	0.747	0.876	0.836	0.817	0.753	0.886
EVI2	0.821	0.733	0.871	0.853	0.821	0.746	0.888
GNDVI	0.800	0.735	0.867	0.842	0.791	0.709	0.855
NDMI	0.858	0.697	0.891	0.887	0.817	0.753	0.886
NRE	0.775	0.684	0.833	0.812	0.817	0.753	0.886
NDVI	0.821	0.733	0.871	0.853	0.817	0.753	0.886
NREI	0.813	0.715	0.815	0.823	0.817	0.753	0.886
SRI	0.821	0.733	0.871	0.853	0.817	0.753	0.886

### BBCH 50-51

Sentinel-2				PlanetScope			
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI
CIRE	0.776	0.687	0.843	0.836	0.758	0.688	0.771
EVI	0.787	0.694	0.824	0.807	0.800	0.669	0.792
EVI2	0.765	0.690	0.808	0.791	0.792	0.703	0.795
GNDVI	0.774	0.708	0.818	0.799	0.826	0.720	0.823
NDMI	0.776	0.678	0.837	0.818	0.800	0.669	0.792
NRE	0.796	0.687	0.843	0.826	0.800	0.669	0.792
NDVI	0.765	0.690	0.808	0.791	0.800	0.669	0.792
NREI	0.804	0.692	0.839	0.832	0.762	0.757	0.799
SRI	0.765	0.690	0.808	0.791	0.762	0.757	0.799

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.



### BBCH 29-30

### BBCH 37-39

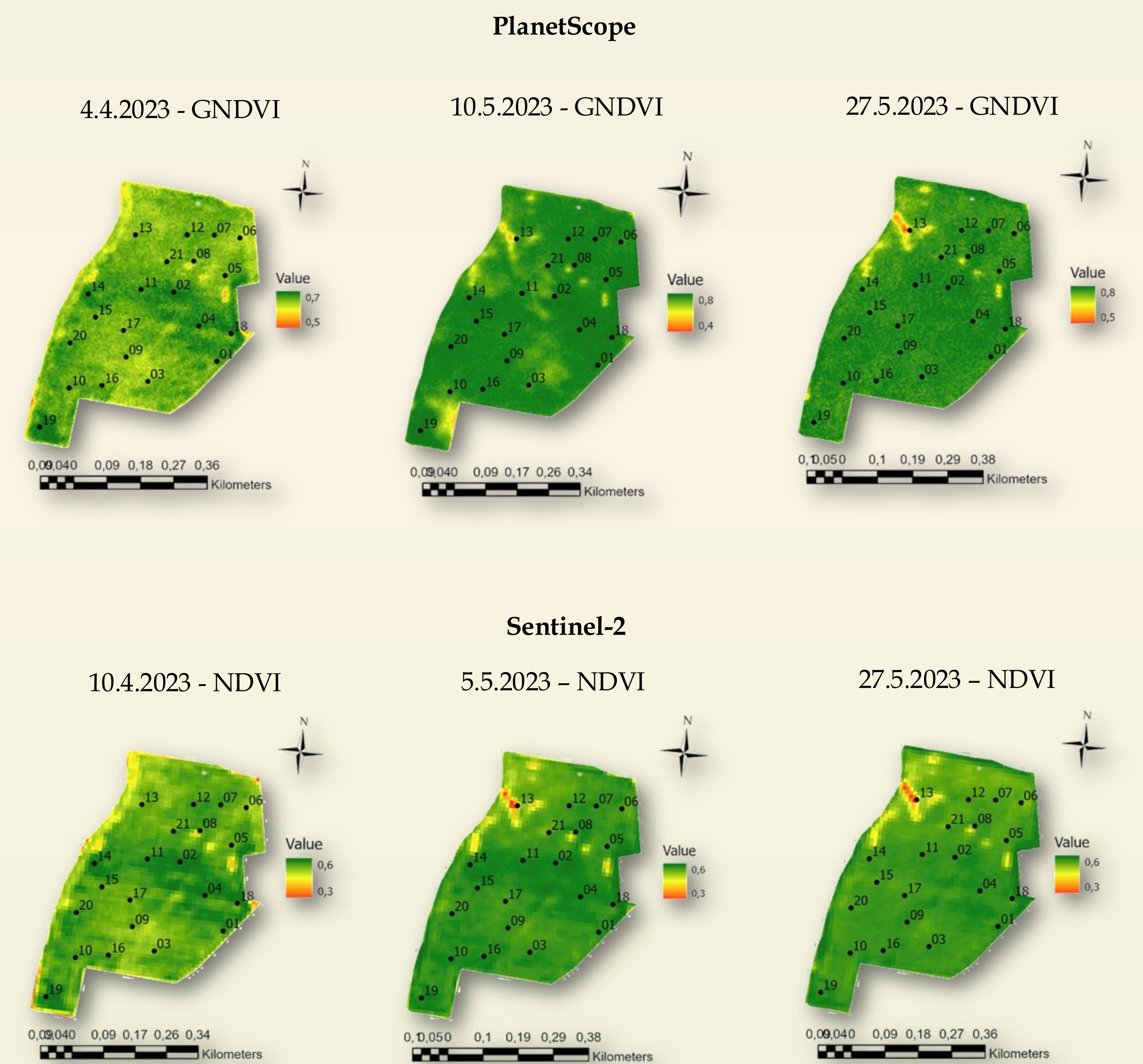
### BBCH 50-51

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.

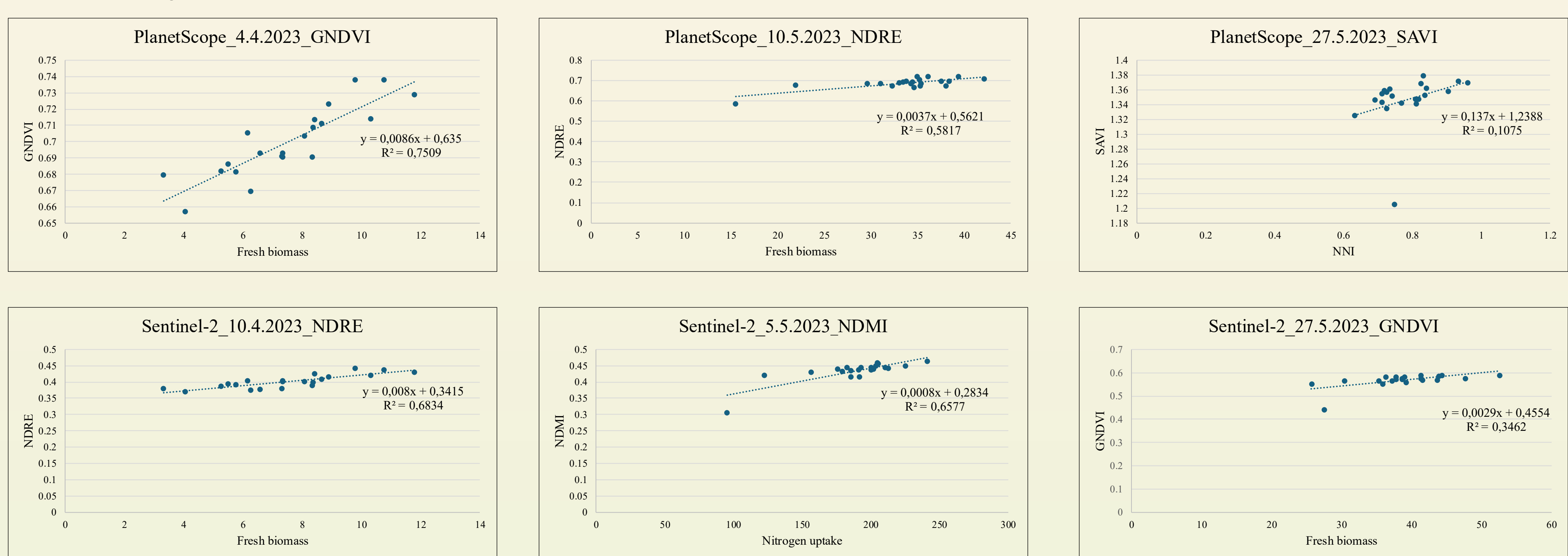
Sentinel-2				PlanetScope			
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI
CIRE	0.823	0.340	0.714	0.863	0.512	0.148	0.449
EVI	0.779	0.258	0.666	0.756	0.799	0.340	0.729
EVI2	0.795	0.264	0.695	0.779	0.904	0.448	0.882
GNDVI	0.819	0.291	0.714	0.799	0.888	0.409	0.797
NDMI	0.791	0.260	0.698	0.774	0.799	0.340	0.729
NDRE	0.823	0.340	0.714	0.863	0.799	0.340	0.729
NDVI	0.795	0.264	0.695	0.779	0.799	0.340	0.729
NREI	0.536	0.144	0.512	0.538	0.732	0.228	0.637
SRI	0.795	0.264	0.695	0.779	0.799	0.340	0.729

Sentinel-2				PlanetScope			
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI
CIRE	0.690	0.324	0.503	0.587	0.179	0.059	0.074
EVI	0.742	0.410	0.626	0.709	0.278	0.178	0.248
EVI2	0.700	0.430	0.575	0.639	0.464	0.120	0.253
GNDVI	0.713	0.418	0.569	0.666	0.500	0.206	0.344
NDMI	0.740	0.442	0.708	0.704	0.278	0.178	0.248
NDRE	0.690	0.324	0.503	0.587	0.278	0.178	0.248
NDVI	0.700	0.430	0.575	0.639	0.278	0.178	0.248
NREI	0.760	0.518	0.679	0.771	0.725	0.311	0.510
SRI	0.700	0.430	0.575	0.639	0.725	0.311	0.510

Sentinel-2				PlanetScope			
Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI	Vegetation index	Biom_F (t/ha)	Ncont (%)	NNI
CIRE	0.488	0.090	0.118	0.370	0.387	0.213	0.368
EVI	0.509	0.014	0.227	0.390	0.419	0.459	0.579
EVI2	0.561	0.002	0.217	0.414	0.475	0.195	0.410
GNDVI	0.656	0.078	0.133	0.430	0.277	0.069	0.062
NDMI	0.540	0.171	0.313	0.399	0.419	0.459	0.579
NDRE	0.488	0.090	0.118	0.370	0.419	0.459	0.579
NDVI	0.561	0.002	0.217	0.414	0.419	0.459	0.579
NREI	0.527	0.422	0.553	0.473	0.343	0.299	0.360
SRI	0.561	0.002	0.217	0.414	0.343	0.299	0.360



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.



## 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

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