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Dynamics of Winter Wheat Crop Condition under Adverse Agrometeorological Conditions Based on Satellite Monitoring Data

V. Moshynskyi, S. Vozniuk, N. Vozniuk (*National University of Water and Environmental Engineering*), ***V. Skyba** *(Dmytro Motornyi Tavria State Agrotechnological University),* **O. Likho** (*National University of Water and Environmental Engineering*)

SUMMARY

Climate change is accompanied by an increasing frequency of adverse agrometeorological events, which poses risks to the stable production of winter wheat and heightens the need for real-time monitoring of crop condition. This is of particular importance for the Western Forest-Steppe of Ukraine, where the region's role in grain production is growing. The aim of the study was to assess the seasonal dynamics of winter wheat crop condition under adverse agrometeorological conditions and to examine the potential for its remote monitoring using satellite data. The study was carried out during the 2025–2026 season on a 0.28 ha plot of a small farm in Rivne Oblast, where the cultivar RGT Reform was grown. Crop condition was assessed from the dynamics of the Normalized Difference Vegetation Index calculated from Sentinel-2 data in Google Earth Engine; the spatial pattern was additionally analyzed using EOSDA Crop Monitoring data. Agrometeorological conditions were characterized using meteorological model data. Under winter frosts down to −18…−20 °C, recurrent spring frosts, and summer heat and drought stress, the yield amounted to 7.5–8.0 t/ha. The maximum index value (0.744) was recorded on May 14, after which it declined to 0.274 by June 29. The results obtained indicate the feasibility of using open satellite data for the real-time tracking of the seasonal dynamics of crop condition on small farms.

Keywords: Winter wheat, Agrometeorological conditions, Satellite monitoring, Earth remote sensing, Sentinel-2, Vegetation index, Seasonal dynamics, Western Forest-Steppe of Ukraine.

Corresponding Author: viktoriia.skyba@tsatu.edu.ua

Introduction

In recent decades, the climate system of Europe, and of Ukraine in particular, has been undergoing substantial transformations, manifested in a northward shift of agroclimatic zones. In Eastern Europe, the rate of this shift over the past four decades has amounted to approximately 100 km per 10 years, with a tendency toward further acceleration (Ceglar et al., 2019). For Rivne Oblast, an increase has likewise been established in the recurrence of years with atmospheric drought during the period of active vegetation, from 30% in 1986–2005 to 46% in Polissia and 34% in the Forest-Steppe in 2006–2018, and of years with winterkill of winter crops, from 30% to 55% (Vozniuk et al., 2023).

An additional factor in the instability of agricultural production is the full-scale war. According to data presented by the Minister of Agrarian Policy and Food of Ukraine in March 2025, 20.5% of agricultural land has been lost, which was accompanied by a decline in the production of cereal and industrial crops from 106 million t in 2021 to 77 million t in 2024 (Interfax-Ukraine, 2025; State Statistics Service of Ukraine, 2022). Under these circumstances, the Western Forest-Steppe is acquiring particular importance for winter wheat production.

An important tool for the real-time monitoring of crops is Earth remote sensing. Open Sentinel-2 data are widely used for assessing the condition of agricultural crops and the spatiotemporal dynamics of their development (Segarra et al., 2020), including the monitoring of winter wheat under drought conditions, yield estimation, and the detection of drought stress (Jędrejek & Pudełko, 2023; Segarra et al., 2022; Descals et al., 2025). At the same time, when analyzing small plots, the spatial resolution of satellite data must be taken into account (Meier et al., 2020).

The present study continues the line of research initiated by the authors on the application of satellite methods to the monitoring of soil cover condition (Moshynskyi & Vozniuk, 2025).

The aim of the study is to investigate the seasonal dynamics of winter wheat crop condition under the adverse agrometeorological conditions of the 2025–2026 season in the Western Forest-Steppe of Ukraine on the basis of Sentinel-2 data, and to assess the potential of these data for the remote monitoring of crops.

Theory and Method

The study was carried out on an experimental plot of 0.28 ha located in the village of Velyka Omelyana, Rivne Raion, Rivne Oblast. The plot has an elongated configuration of approximately 30 × 85 m. The soil cover is represented by soils of agro-production group 49d: dark gray podzolized and regraded soils, and podzolized and regraded chernozems, slightly eroded and medium loamy. The plot forms part of a short-rotation three-field crop rotation of soybean – winter wheat – potato; the immediate preceding crop for winter wheat was soybean.

In the 2025-2026 season, the winter wheat cultivar RGT Reform was grown, which was entered into the State Register of Plant Varieties of Ukraine in 2017. The cultivar is characterized by a growing-season duration of 263-277 days, high winter hardiness, and declared drought resistance. Sowing was carried out on October 15, 2025.

The agrometeorological conditions of the season were assessed using data from the World Weather Online global meteorological model with a spatial resolution of approximately 9.2 × 9.2 km. In the absence of a dedicated weather station directly on the experimental plot, these data were used to characterize the regional agrometeorological background.

The 2025-2026 season was characterized by a combination of several adverse events. In late January, the minimum air temperature fell to -18…-20 °C. In April, at least three episodes of spring frost were recorded: on April 10, -2 °C; on April 27 and 30, -1 °C each. In early July, the maximum temperature reached 30-39 °C, coinciding with the critical heading-flowering period of winter wheat (BBCH 60-

70). Total precipitation for the period from October 6, 2025 to July 18, 2026 amounted to approximately 380 mm.

To assess the seasonal dynamics of crop condition, NDVI was calculated from Sentinel-2 Level-2A data for April–August 2026 in Google Earth Engine. Bands B4 (red) and B8 (near infrared) with a spatial resolution of 10 m were used. Cloudy pixels and pixels unsuitable for analysis were masked using SCL (Scene Classification Layer) data, after which the mean NDVI value within the experimental plot was determined for each date.

The spatial structure of NDVI was additionally assessed from Sentinel-2 data in the EOSDA Crop Monitoring platform for June 1 and July 6, 2026.

Methodological limitation. The small area of the plot (0.28 ha) and its elongated configuration (approximately 30 × 85 m) result in a limited number of Sentinel-2 pixels across the plot and possible spatial mixing with adjacent objects. Therefore, the NDVI values obtained should be used primarily for assessing the seasonal dynamics of crop condition, while spatial interpretation should be performed with due regard to the scale of the plot.

Results

The yield of winter wheat on the experimental plot in the 2025/2026 season amounted to 7.5–8.0 t/ha, despite a challenging agrometeorological background that included winter frosts, recurrent spring frosts, and summer drought and heat stress. The result obtained indicates that the crop retained high productivity under adverse conditions. At the same time, the single-season nature of the observations does not allow the contribution of individual factors to yield formation to be distinguished.

The NDVI time series displayed pronounced seasonal dynamics (Fig. 1). At the beginning of the resumption of vegetation, on April 2, the index value was 0.535; during April it rose to 0.717–0.726, and it reached its maximum level of 0.744 on May 14. In early June, NDVI began to decline (0.647 on June 1), and in the second half of the month the decrease became abrupt: to 0.336 on June 21 and 0.274 on June 29. Thus, over only 28 days the index value decreased by approximately 58%. Subsequently, NDVI remained at a low level — about 0.25–0.29 until mid-August.

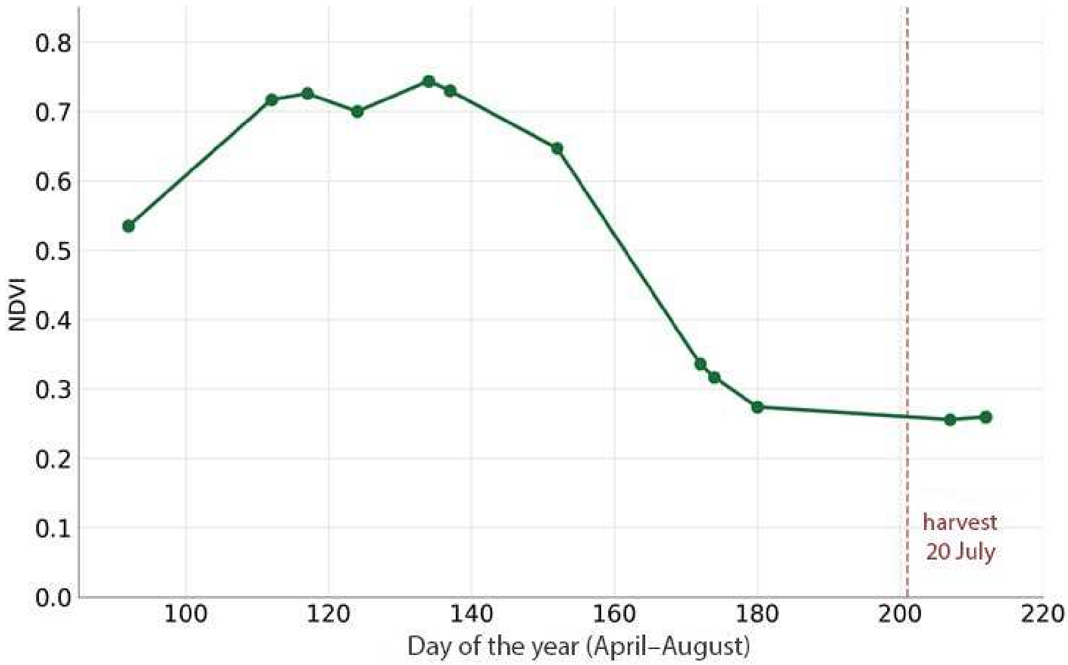
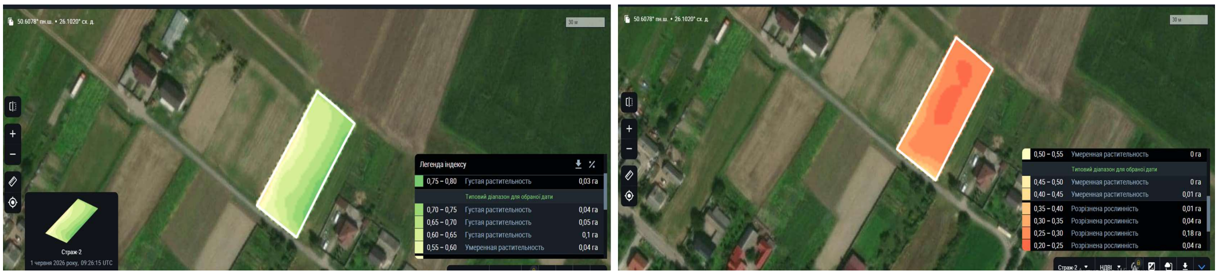


Figure 1. *Dynamics of NDVI of the study field in the 2025-2026 season according to Sentinel-2 data. The dashed line – the harvest date (20.07.2026)*

Spatial data from EOSDA Crop Monitoring confirmed this change: on June 1, 2026, NDVI values of 0.65–0.80 prevailed over most of the plot, whereas on July 6 they were 0.20–0.35 (Fig. 2). Consequently, the satellite data clearly reflected the transition from active spring vegetation to a substantial decline in vegetation activity in June–July.



a) 01.06.2026 b) 06.07.2026

Figure 2. *Spatial distribution of NDVI of the field according to Sentinel-2 data (EOSDA Crop Monitoring)*

The most intensive decline in NDVI occurred prior to the actual harvest on July 20, which amounts to approximately three weeks. Such a discrepancy indicates that under heat and drought stress, an abrupt fall in NDVI should not be automatically interpreted as a direct signal of the onset of harvesting. It may reflect an earlier change in the physiological condition of the crop. Similar capabilities of Sentinel-2 with regard to the detection of drought stress and the deterioration of winter crop condition are confirmed by current research (Jędrejek & Pudełko, 2023; Descals et al., 2025). Spectral indices may also be related to the water status of plants and to yield (Solgi et al., 2023).

The retention of crop productivity was probably facilitated by the biological characteristics of the cultivar RGT Reform, in particular its declared winter hardiness and drought resistance. However, distinguishing the influence of cultivar-related, agrotechnological, and microclimatic factors was not among the objectives of this study. The main focus was placed on the spatiotemporal representation of crop condition by means of remote sensing.

When interpreting the spatial data, the scale of the experimental plot must be taken into account: its width of about 30 m corresponds to approximately three Sentinel-2 pixels with a resolution of 10 m. This may cause adjacent objects to influence the spatial NDVI values, which is a general methodological issue in the application of satellite data to small plots (Meier et al., 2020). At the same time, for assessing the temporal dynamics of crop condition, the results obtained are informative.

Thus, the combination of agrometeorological data with the temporal and spatial indicators of Sentinel-2 makes it possible to identify periods of substantial change in the condition of winter wheat and may be used as an accessible digital tool for the real-time monitoring of agricultural areas, in particular for farms with limited capacity for ground-based agromonitoring (Segarra et al., 2020; Jędrejek & Pudełko, 2023).

Conclusions

In the 2025-2026 season, the yield of the winter wheat cultivar RGT Reform on the experimental plot in the Western Forest-Steppe amounted to 7.5–8.0 t/ha, despite adverse agrometeorological conditions.

The dynamics of NDVI reflected active spring resumption of growth and the subsequent abrupt decline in vegetation activity, which began approximately three weeks before harvesting. This indicates the possibility of using Sentinel-2 to detect changes in crop condition before the completion of the actual growing period, while at the same time pointing to the need to take the agrometeorological context into account when interpreting NDVI.

The combination of satellite and agrometeorological data confirmed the promise of Sentinel-2 as an accessible tool for the real-time monitoring of the seasonal dynamics of winter wheat. Further research should be conducted on a larger number of fields and seasons, with the involvement of UAVs and other spectral indices.

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