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Use of Remote Sensing Data for the Ecological and Economic Assessment of Sunflower Cultivation Conditions in Ukraine

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SUMMARY

This publication addresses the application of GIS technologies and remote sensing methods to the ecological and economic substantiation of the feasibility of sunflower cultivation under conditions of variability in the indicators of different agroclimatic zones. On the basis of the satellite Vegetation Health Index (VHI) (NOAA/NESDIS/STAR, 2020–2025), a spatiotemporal analysis of agrometeorological droughts was performed for the period critical for sunflower (weeks 26–35 of the year) across all oblasts of Ukraine. A sharp intensification of drought stress and its territorial polarization in 2024–2025 were established, with the highest risk in the southern and eastern regions. The remote sensing data were compared with official statistics on sown areas, yields, and gross harvests of sunflower for 2021–2025, which made it possible to identify the oblasts with the most favorable combination of production scale, yield, and yield stability. An approach is proposed for integrating satellite VHI data into a GIS together with agroclimatic, soil, and economic layers for the purpose of drought risk mapping and the approximate assessment of economic losses. The results may be used for the zoning of cultivation technologies, targeted crop insurance, and the planning of processing capacities.

Keywords: GIS technologies; Remote sensing; Vegetation Health Index (VHI); Agrometeorological drought; Sunflower; Ecological and economic assessment.

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Introduction

Under current conditions, the domestic agro-industrial complex is confronted with the synergistic influence of global and local challenges. Russia's full-scale invasion has a destructive effect on agricultural production and intensifies soil degradation, while global climate change is shifting the agroclimatic boundaries of Ukraine's natural zones, necessitating new adaptive approaches to land use. In the authors' previous studies, it was established that the Forest-Steppe zone is the most productive for sunflower cultivation, whereas the Steppe zone is characterized by an increased sensitivity of yield to agrometeorological droughts (Vozniuk et al., 2023).

The economic feasibility of sunflower cultivation depends on yield, production costs, selling prices, and adherence to crop rotation (Slobodianyk et al., 2021; Zymaroieva et al., 2021; Dehtiarova et al., 2024; Romanchuk et al., 2025); therefore, the expansion of sown areas in itself does not guarantee economic efficiency. According to data from the State Statistics Service of Ukraine (2026), the average sunflower sown area for 2021–2025 amounted to 5.48 million ha, the yield to 2.25 t/ha, and the gross harvest to 12.38 million t. Between 2021 and 2025, the sown area decreased by 22.5%, the yield by 19.5%, and the gross harvest by 37.5% (coefficient of variation of the gross harvest – 17.6%). Regional analysis showed that ten leading oblasts accounted for 73.6% of the gross harvest. The most favorable combination of a substantial share, a yield not below the national average, and low variability was observed in Poltava, Cherkasy, Sumy, and Chernihiv oblasts; Vinnytsia oblast was distinguished by the highest yield (2.89 t/ha), while Odesa and Mykolaiv oblasts exhibited the lowest yields and the highest variability (22–28%).

Under present-day conditions, one of the key instruments for the timely identification of such risks is satellite monitoring of the condition of sown areas. Unlike ground-based observations, remote sensing makes it possible to track the moisture availability and thermal stress of sunflower crops regularly and within a single coordinate system across the entire territory of the country, including areas temporarily inaccessible for field surveys. The integration of such data into a GIS is a necessary prerequisite for the operational mapping of drought risk and the approximate assessment of the associated economic losses, which determines the appropriateness of their use in the present study.

Method and Theory

The remote assessment of the condition of sunflower crops was performed using the weekly Vegetation Health Index (VHI), which is calculated by NOAA/NESDIS/STAR from polar-orbiting satellite data (https://www.star.nesdis.noaa.gov/star/index.php) and combines the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI): $VHI = a \cdot VCI + (1 - a) \cdot TCI$, where a is conventionally set at 0.5 (Kogan, 1997). VHI is a satellite-based indicator of the moisture and thermal stress of vegetation rather than a direct measurement of precipitation, soil moisture reserves, or economic losses (NOAA STAR, 2026). Province-averaged weekly VHI values over sunflower crops for 2020–2025 were used. For each oblast, the proportion of the sunflower area with VHI ≤ 35, ≤ 25, ≤ 15, and ≤ 5 (cumulative thresholds of drought, severe, extreme, and exceptional stress) was calculated for weeks 26–35 (late June to early September), along with the mean values of these proportions for 2020–2025 and for 2024–2025 and the weekly maxima. To assess the interannual variability of production indicators, the coefficient of variation was applied ($CV = \sigma/\bar{x} \times 100\%$). Data on sown areas, yields, and gross harvests of sunflower for 2021–2025 were obtained from the State Statistics Service of Ukraine; the share of an oblast in the national harvest was determined as the ratio of its mean gross harvest to the sum of the mean gross harvests of all oblasts.

Examples

The processed graphs (Fig. 1) present the weekly proportion of the area under sunflower in which the Vegetation Health Index (VHI) fell within the established stress categories in 2020–2025. VHI combines the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI) and ranges from 0 to 100, with lower values corresponding to a poorer condition of vegetation. The graphs employ cumulative VHI thresholds: 0–35 – drought conditions, 0–25 – severe drought, 0–15 – extreme drought, 0–5 – exceptional.

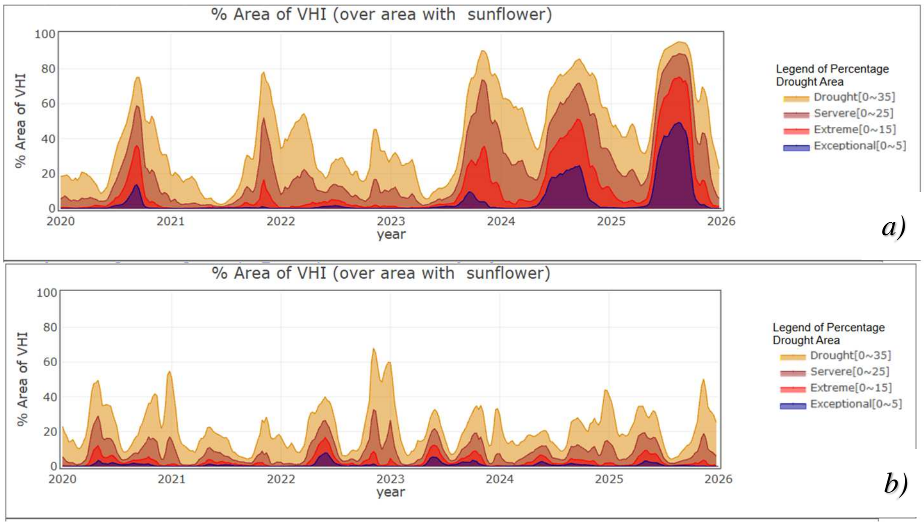

Figure 1. *Example of the Weekly Percentage of Drought assessment automatically generated from VHI data by NOAA/NESDIS/STAR (a – Kherson oblast; b – Zhytomyr oblast) (NOAA STAR, 2026)*

For the comparison of regions, it is appropriate to take into account not only the maxima within a calendar year, but also the timing of their occurrence. Sharp autumn or winter peaks in individual graphs are of limited significance for sunflower yield formation. The quantitative comparison was therefore performed for weeks 26–35 of the year, which approximately cover the period from late June to early September and in most regions coincide with the period of active vegetative growth and ripening of the crop. For each oblast, the mean proportion of the area with VHI ≤ 35 was calculated for 2020–2025, and, in order to identify recent changes, the mean for 2024–2025. These values characterize the intensity of stress within a region rather than its contribution to the total potential losses of Ukraine.

The temporal dynamics indicate a sharp intensification of the spatial heterogeneity of drought conditions toward the end of the study period. The mean proportion of the area with VHI ≤ 35 during the critical weeks amounted to 22.6% in 2020, 7.1% in 2021, 16.3% in 2022, 12.3% in 2023, 35.1% in 2024, and 32.8% in 2025. The median values were 15.7, 6.3, 16.0, 10.1, 24.7, and 12.7%, respectively. Thus, 2024 was characterized by the most extensive territorial distribution of stress, whereas in 2025 its intensity increased further in the southern and eastern regions but declined across a considerable part of the central, northern, and western areas.

The proportion of the area with VHI ≤ 35 exceeded 50% in seven regions in 2024 and in eight in 2025, which indicates not a uniform deterioration but rather an intensification of the spatial polarization of risk. The highest level of risk was established for the Autonomous Republic of Crimea and Kherson and Zaporizhzhia oblasts. On average for 2024–2025, during the critical weeks VHI ≤ 35 was observed over 88.4, 85.2, and 79.7% of the sunflower area, respectively. The proportion of the area under severe stress (VHI ≤ 25) amounted to 75.7, 73.3, and 64.2%, under extreme stress (VHI ≤ 15) to 55.8, 55.8, and 44.0%, and under exceptional stress (VHI ≤ 5) to 28.3, 33.0, and 21.1%. The maximum weekly values of the total drought-affected area reached 95.6% in Crimea, 95.5% in Kherson oblast, and 90.4% in Zaporizhzhia oblast. The combination of extensive coverage, high intensity, and multi-week duration indicates the systemic nature of the agrometeorological risk: even the drought tolerance of sunflower does not eliminate the probability of a reduction in seed mass, yield, and income per hectare. The group of very high risk also includes Mykolaiv, Donetsk, Odesa, Dnipropetrovsk, and Luhansk oblasts. The mean proportion of the area with VHI ≤ 35 in 2024–2025 amounted here to 68.7, 67.5, 63.5, 61.5, and 51.3%, and with VHI ≤ 25 to 48.8, 50.9, 46.4, 44.9, and 33.2%, respectively. The weekly maxima of the drought-affected area reached 83.7% in Mykolaiv oblast, 76.9% in Donetsk oblast, 89.7% in Odesa oblast, 81.4% in Dnipropetrovsk oblast, and 65.6% in Luhansk oblast. For Mykolaiv, Odesa, and Dnipropetrovsk oblasts, these results are consistent with the lower mean yield and its increased variability established in the preceding part of the study. At the same time, satellite data for the temporarily occupied territories characterize the condition of the vegetation cover but do not reflect restrictions on access to fields, mining, resource shortages, or disruptions to logistics.

Kharkiv and Kirovohrad oblasts form a transitional group: the mean proportion of the area with VHI ≤ 35 in 2024–2025 amounted to 38.7 and 32.8%, yet the maximum values reached 70.5 and 71.3%. In Poltava, Vinnytsia, and Cherkasy oblasts the mean values were lower – 22.7, 22.2, and 21.0% – whereas the weekly maxima amounted to 64.7, 61.8, and 60.3%. Their relative economic advantage is therefore attributable to the shorter duration of the critical condition and to the capacity of a greater share of the crops to maintain a satisfactory condition throughout the season. For these regions, the prompt adjustment of the timing of field operations, the differentiated selection of hybrids, and insurance against short-term extreme events are of particular importance. In the northern and western oblasts, the mean risk during the critical weeks was predominantly lower. For 2024–2025, the proportion of the area with VHI ≤ 35 amounted to 18.0% in Chernivtsi oblast, 15.7% in Kyiv oblast, 15.1% in Volyn oblast, 14.2% in Ivano-Frankivsk oblast, 14.0% in Lviv oblast, 13.4% in Ternopil oblast, 11.4% in both Sumy and Khmelnytskyi oblasts, 10.6% in Chernihiv oblast, 10.4% in Zhytomyr oblast, 7.5% in Rivne oblast, and 4.5% in Zakarpattia oblast. At the same time, a low mean value does not imply the absence of local threats: in Sumy oblast the weekly maximum reached 50.7% and in Kyiv oblast 46.9%, while in 2022 the mean critical proportion amounted to 31.6% in Chernivtsi oblast and 22.6% in Zakarpattia oblast. The high peaks discernible at the end of certain annual curves for Lviv, Ternopil, Chernihiv, and other oblasts occurred predominantly outside the principal period of yield formation and therefore cannot be interpreted directly as equivalent production losses.

The predictive interpretation of the results obtained must be scenario-based. A six-year series is not sufficient to demonstrate a long-term climatic trend or to construct a reliable yield forecast; however, the unidirectional intensification of stress in 2024–2025 provides grounds for identifying the southern and southeastern macroregions as zones of priority monitoring. Should the regime of the last two years persist, the highest risk of yield shortfall will be faced by Kherson, Zaporizhzhia, Mykolaiv, Odesa, Donetsk, Dnipropetrovsk, and Luhansk oblasts; in Kharkiv and Kirovohrad oblasts the risk will be more variable, and in the central, northern, and western oblasts predominantly episodic. Transforming this scenario into a quantitative forecast requires calibration of the relationship between weekly VHI, the developmental stages of sunflower, and actual yield on the basis of panel data for the oblasts.

For ecological and economic analysis, a GIS should integrate weekly VHI rasters with up-to-date sunflower field boundaries, data on soil condition, precipitation, temperature, available soil moisture reserves, relief, irrigation, yield, production costs, and the accessibility of grain elevators and processing enterprises. On this basis, it is appropriate to generate maps of drought coverage, stress duration, and expected economic losses. A baseline estimate of potential economic losses may be determined as the product of the sunflower area, the expected yield, and the price, adjusted by an empirically established loss coefficient depending on the level and duration of VHI. Such a system is suitable for the zoning of technologies, targeted insurance, the selection of drought-tolerant hybrids, irrigation planning, and the early warning of processing enterprises regarding a possible shortage of raw material.

Results

Summarizing the results of the remote sensing and statistical analyses, it should be emphasized that the highest agrometeorological risk for sunflower cultivation was identified for the Autonomous Republic of Crimea and Kherson and Zaporizhzhia oblasts (proportion of the area with VHI ≤ 35 during the critical weeks of 2024–2025 – 79–88%), as well as for Mykolaiv, Donetsk, Odesa, Dnipropetrovsk, and Luhansk oblasts (51–69%); for Odesa, Mykolaiv, and Dnipropetrovsk oblasts, this is consistent with the lower and more variable yields established from official statistics for 2021–2025. Kharkiv and Kirovohrad oblasts form a transitional group. Meanwhile, the most favorable combination of production scale, yield, and yield stability was observed in Poltava, Cherkasy, Sumy, and Chernihiv oblasts, where the mean VHI-based risk also remained comparatively low (21–23%). This indicates the consistency of satellite indicators of drought stress with ground-based productivity indicators and confirms the appropriateness of using VHI as an indicator of the ecological and economic risk of sunflower cultivation.

Conclusions

1. Over the period 2021–2025, Ukraine recorded reductions in the sown area (–22.5%), the yield (−19.5%), and the gross harvest of sunflower (−37.5%); the variability of the gross harvest (CV = 17.6%) was determined by simultaneous fluctuations in both area and yield.
2. The most favorable production preconditions – a combination of a substantial share in the gross harvest, a yield not below the average, and low variability – were characteristic of Poltava, Cherkasy, Sumy, and Chernihiv oblasts.
3. The satellite-based VHI made it possible to identify a sharp intensification of drought stress and its territorial polarization in 2024–2025, with the highest risk in the southern and eastern oblasts (Crimea, Kherson, Zaporizhzhia, Mykolaiv, Odesa, Donetsk, Dnipropetrovsk, and Luhansk).
4. The spatial coincidence of zones of elevated satellite-derived drought risk with lower and less stable yields according to official statistics confirms the suitability of integrating VHI data into a GIS for the ecological and economic zoning of sunflower cultivation.
5. Further research should provide for the calibration of the quantitative relationship between weekly VHI and yield on the basis of panel data for the oblasts, as well as the inclusion of cost and selling price indicators for a comprehensive assessment of economic efficiency.

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