Climate Challenges and GIS Solutions:

Monitoring Crop Health with Copernicus Data

CZU – Emerging GIS Tools for Agriculture | Technical Review

ABSTRACT

Spring marks the beginning of a critical period for many crops. Increasing solar radiation combined with early frosts can lead to photooxidative damage to crop stands in Central Europe, affecting plant vitality and ultimately reducing yields. This article presents the potential of freely available Copernicus satellite data — both optical (Sentinel-2) and radar (Sentinel-1) — as practical tools for early stress detection and precision crop management under increasing climate variability.

1. CLIMATE STRESS AND CROP VULNERABILITY

Early spring presents a convergence of climatic stressors that are particularly damaging to cereal crops in Central Europe. High solar irradiance coinciding with sub-zero night temperatures can trigger photooxidative injury — a condition in which light energy exceeds the plant's capacity for safe dissipation, damaging chloroplast membranes and compromising photosynthetic efficiency.

Early detection of these stress signals is becoming an essential component of modern crop management. Conventional field scouting is time-consuming and spatially limited; remote sensing offers the means to assess crop status across entire landscapes at regular intervals and at operational cost.

2. OPTICAL REMOTE SENSING: SENTINEL-2 AND SPECTRAL INDICATORS

The Copernicus Sentinel-2 mission provides multispectral imagery at 10–20 m resolution with a revisit frequency of approximately five days. Its spectral configuration — particularly the Red Edge and Near-Infrared (NIR) bands — is well suited for evaluating plant tissue health at the cellular level.

Spectral reflectance analysis of damaged versus healthy winter wheat sites reveals the diagnostic value of the NIR spectral region (700–1000 nm). In the visible wavelengths (443–665 nm), differences between stressed and healthy tissue are not immediately apparent. However, NIR reflectance clearly differentiates the two: healthy tissue exhibits high NIR reflectance due to intact spongy mesophyll structure, while damaged tissue shows markedly reduced values. This contrast is exploited by three complementary analytical inputs:

- **Band B8 (NIR).** Direct reflectance in the near-infrared; the most sensitive single indicator of cellular integrity in plant tissue.
- **RGB composite (visible spectrum).** Provides spatial context and phenological background, though insufficient for early stress detection on its own.

- **NDVI (Normalised Difference Vegetation Index).** Combines Red and NIR reflectance to produce a standardised vitality index widely used in operational crop monitoring programmes.

Figure 1 (referenced in original article).
Locations and spectral reflectance curves of damaged (Pin 1, Pin 3) and undamaged (Pin 2, Pin 4) winter wheat sites. Left panel (a): B8 NIR band; centre panel (b): RGB true-colour composite; right panel (c): NDVI index. Differences in the NIR spectral region (700–1000 nm) discriminate between healthy and photooxidatively damaged tissue, while visible-spectrum data show no apparent contrast.

3. RADAR REMOTE SENSING: SENTINEL-1 AND ALL-WEATHER MONITORING

A key limitation of optical satellite data is its dependence on clear-sky conditions. Sentinel-1 Synthetic Aperture Radar (SAR) data overcomes this constraint: microwave backscatter is unaffected by cloud cover, enabling continuous monitoring throughout the growing season regardless of meteorological conditions.

The Radar Vegetation Index (RVI), derived from Sentinel-1 polarimetric data, provides quantitative information on three agronomically relevant parameters:

- **Crop biomass,** reflecting canopy volume and structural development.
- **Structural canopy development,** including growth stage transitions relevant to fertilisation and protection scheduling.
- **Water content,** a critical indicator of plant water status and potential drought stress before it becomes visible in optical data.

4. GIS INTEGRATION AND PRECISION AGRICULTURE APPLICATIONS

The analytical value of satellite data is substantially amplified when integrated within a GIS environment. Spatial layers derived from Sentinel-1 and Sentinel-2 can be combined with field management data, soil maps, and weather records to produce decision-support outputs tailored to individual farms or regional management zones.

Key operational applications include:

- **Within-field variability mapping.** Identification of spatially distinct zones of crop performance, enabling targeted agronomic interventions rather than blanket field treatments.
- **Stress zone detection.** Early flagging of areas showing NIR or RVI anomalies, prompting timely field scouting and corrective action before yield losses materialise.
- **Variable-rate application maps.** Spatially differentiated prescriptions for fertilisation and crop protection, reducing input costs and environmental impact.

> *With increasing climate variability, the combination of remote sensing and GIS will play an increasingly important role in ensuring sustainable crop production and improving resilience to environmental stress.*

5. DATA ACCESS AND PRACTICAL IMPLEMENTATION

Sentinel-1 and Sentinel-2 data are freely accessible through the Copernicus Data Space Ecosystem, lowering the barrier to entry for practitioners and researchers alike. The open-access model enables adoption by agricultural advisory services, regional authorities, and individual farmers, expanding the reach of evidence-based crop management well beyond large research institutions.

Integration with standard GIS platforms (QGIS, ArcGIS, Google Earth Engine) requires no specialised hardware and is increasingly supported by pre-built processing workflows, making operational deployment accessible to users with moderate technical capacity.

REFERENCES & FURTHER READING

[1] Copernicus Data Space Ecosystem. https://dataspace.copernicus.eu

[2] Sentinel-2 Mission Overview – ESA. https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2

[3] Sentinel-1 Mission Overview – ESA. https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1

[4] Google Earth Engine Platform. https://earthengine.google.com

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