

From Spectral Signals to Harmonized Statistics: Upscaling Sentinel-2 Yield Stability for Regional Reporting

Quantitative anomaly-based yield productivity monitoring in the Danubian Lowland, Slovakia

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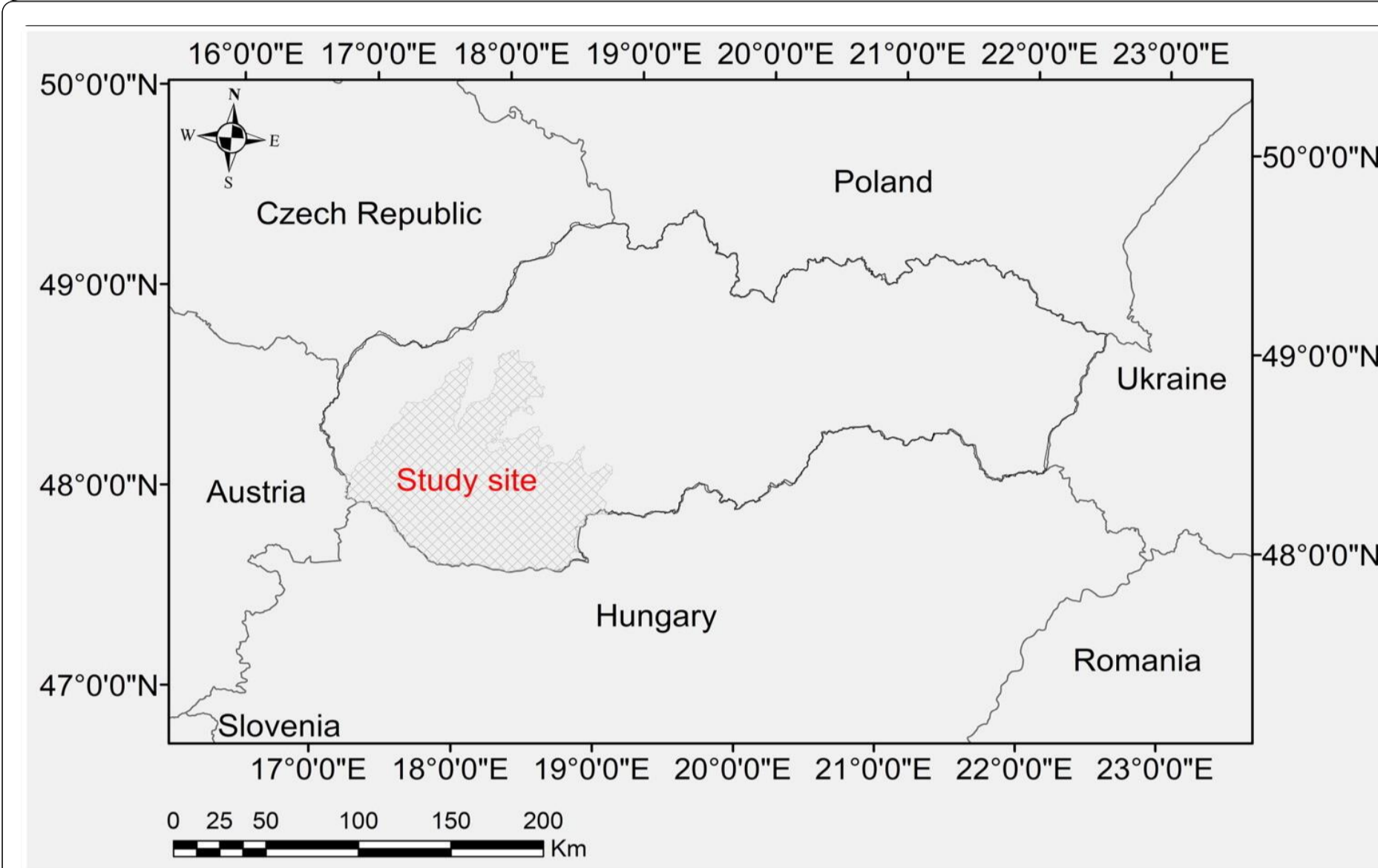


Abstract

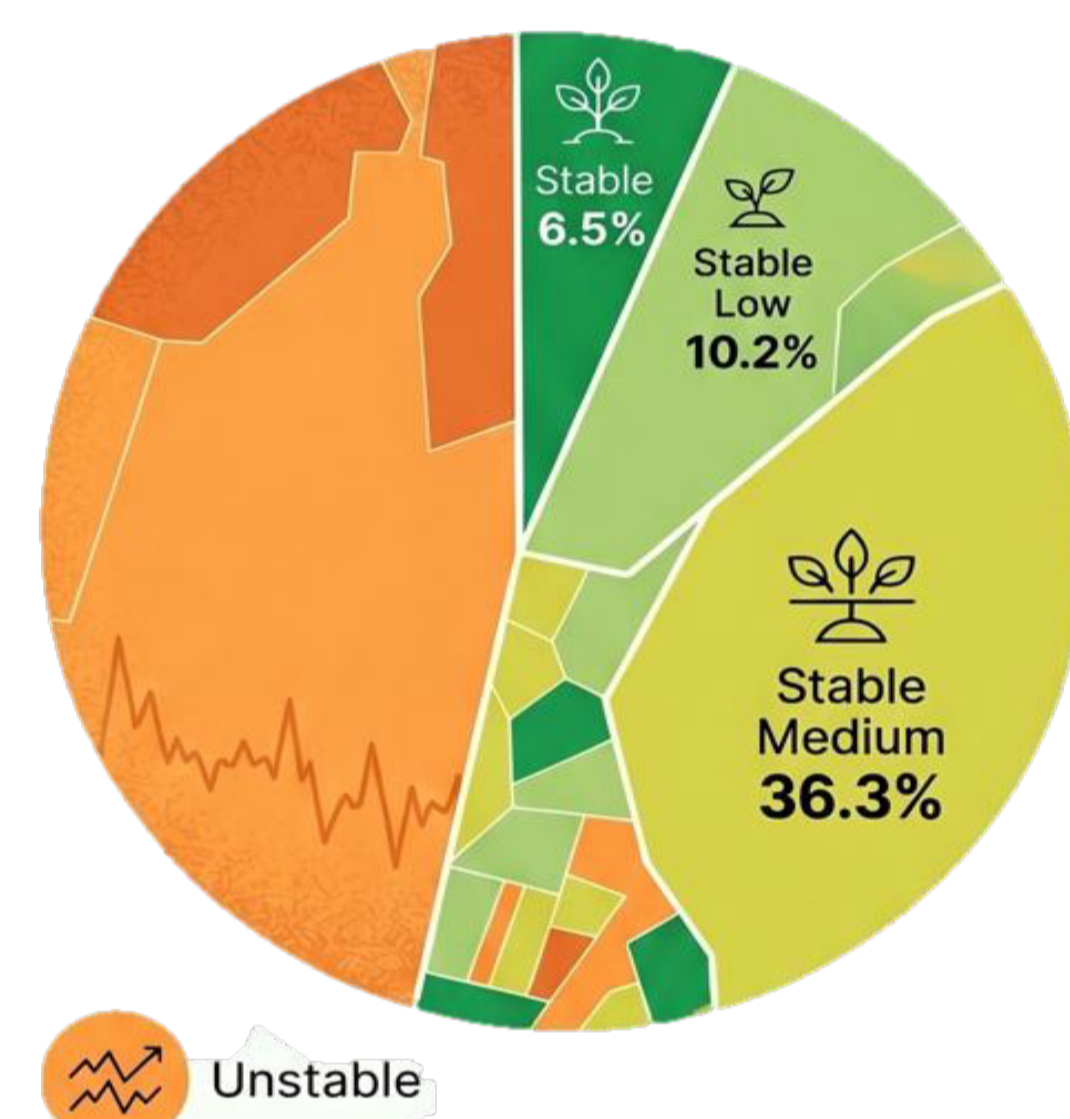
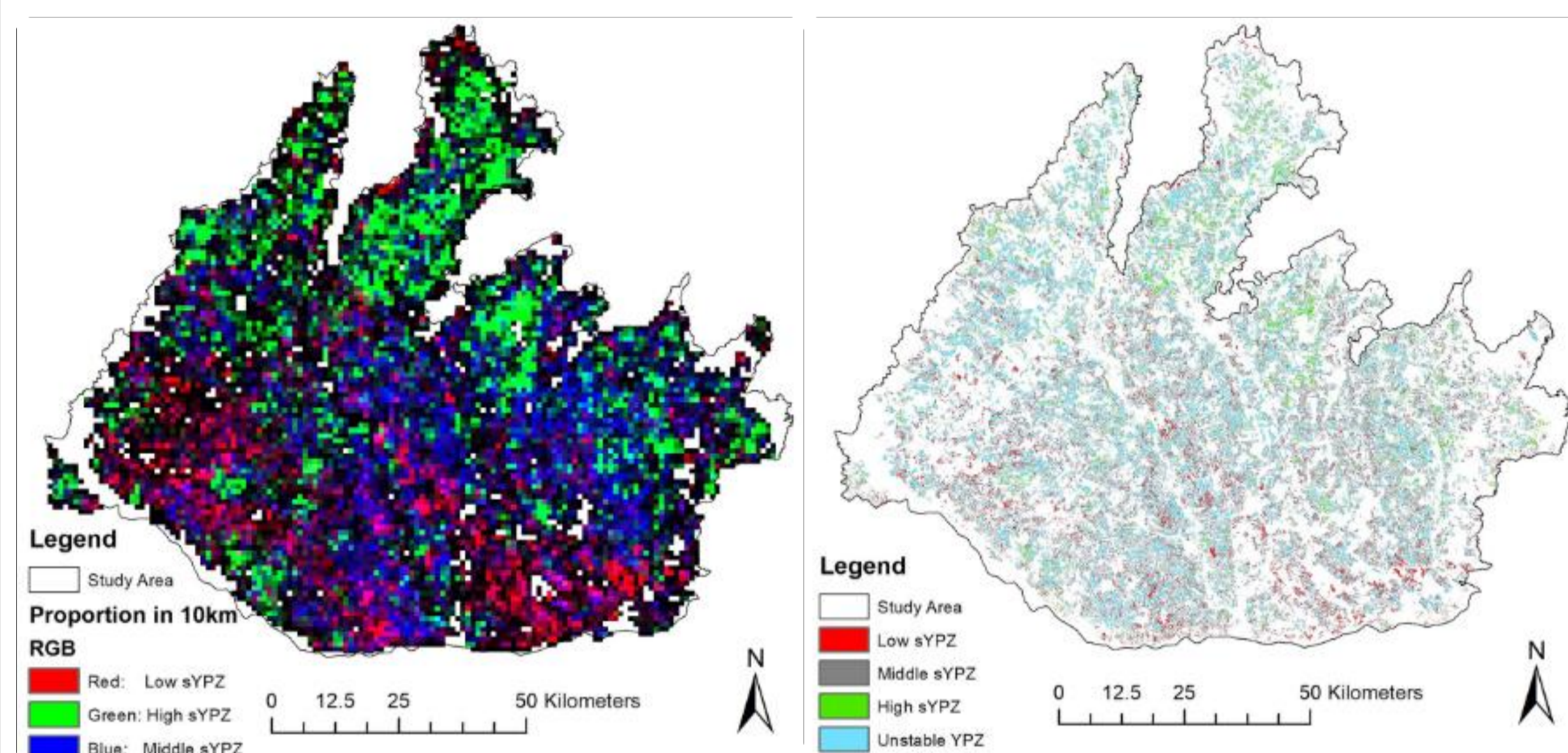
This study transforms Sentinel-2 time series (2018–2024) into 10m Yield Productivity Zones (sYPZ) using a regional normalization strategy. Analysis identified 6.5% stable high and 47% unstable yield patterns across the Danubian Lowland. Validation against official NUTS3 statistics confirmed strong correlations (Pearson: 0.74 for high and 0.64 for low productivity), proving that pixel-level EO data effectively capture regional trends. Machine learning (XGBoost, AUC 0.88) and SHAP analysis identified elevation and topsoil reflectance as primary drivers of yield stability. This framework provides the explainable, granular intelligence required by statistical authorities for data-driven agricultural policy and sustainable land management

Why this matters

Official agricultural statistics need indicators that are spatially detailed, consistent over time, and suitable for aggregation to administrative units. Absolute yield estimation remains difficult and often poorly transferable. Here we focus on qualitative yield potential monitoring based on long-term Sentinel-2 stability patterns



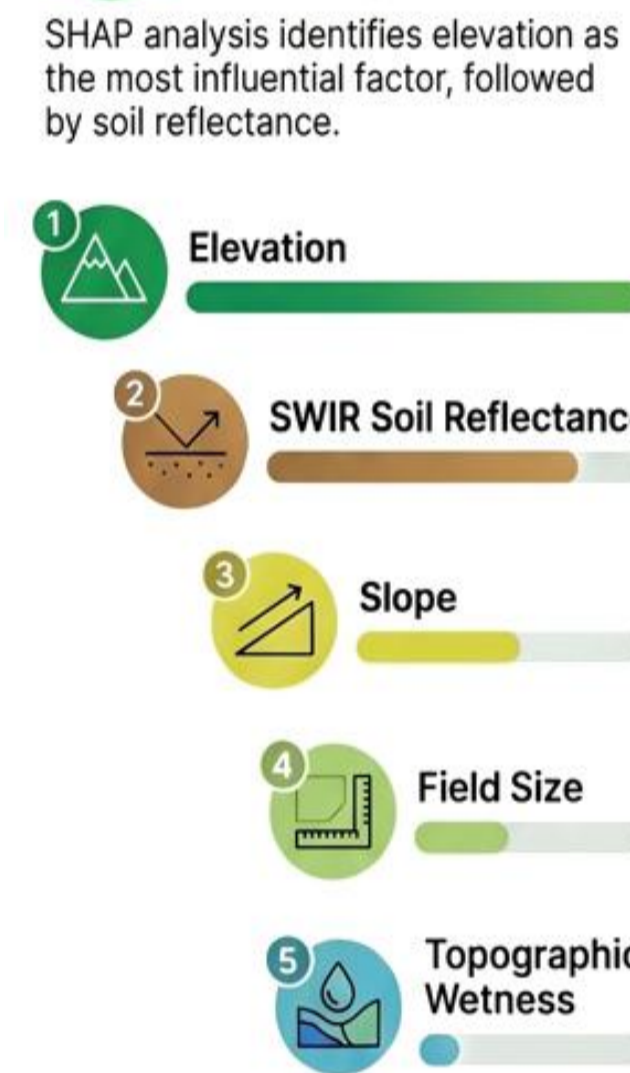
- **Agricultural Core:** Represents over 52% of all arable land in Slovakia.
- **Fertile Soils:** Dominated by highly productive Chernozems and Phaeozems.
- **Diverse Management:** A unique mix of large-scale industrial and smallholder farms.
- **Tech Gap:** Minimal adoption of precision agriculture despite intensive use.
- **Soil Threats:** High rates of degradation from compaction and erosion.
- **Research Hub:** An ideal "natural laboratory" for studying crop productivity patterns.



47% Unstable Yield Zones
Nearly half of the analyzed cropland lacks consistent year-to-year yield performance.

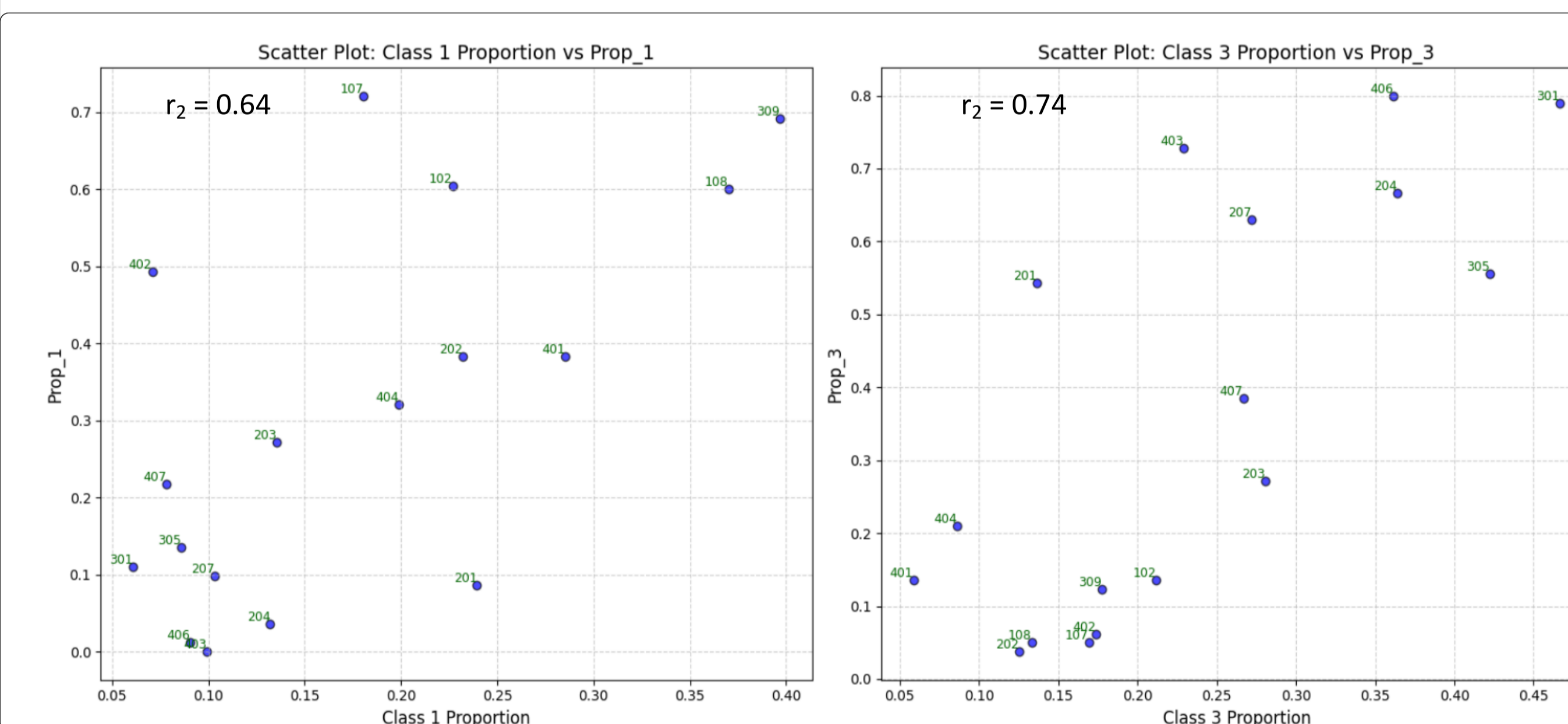
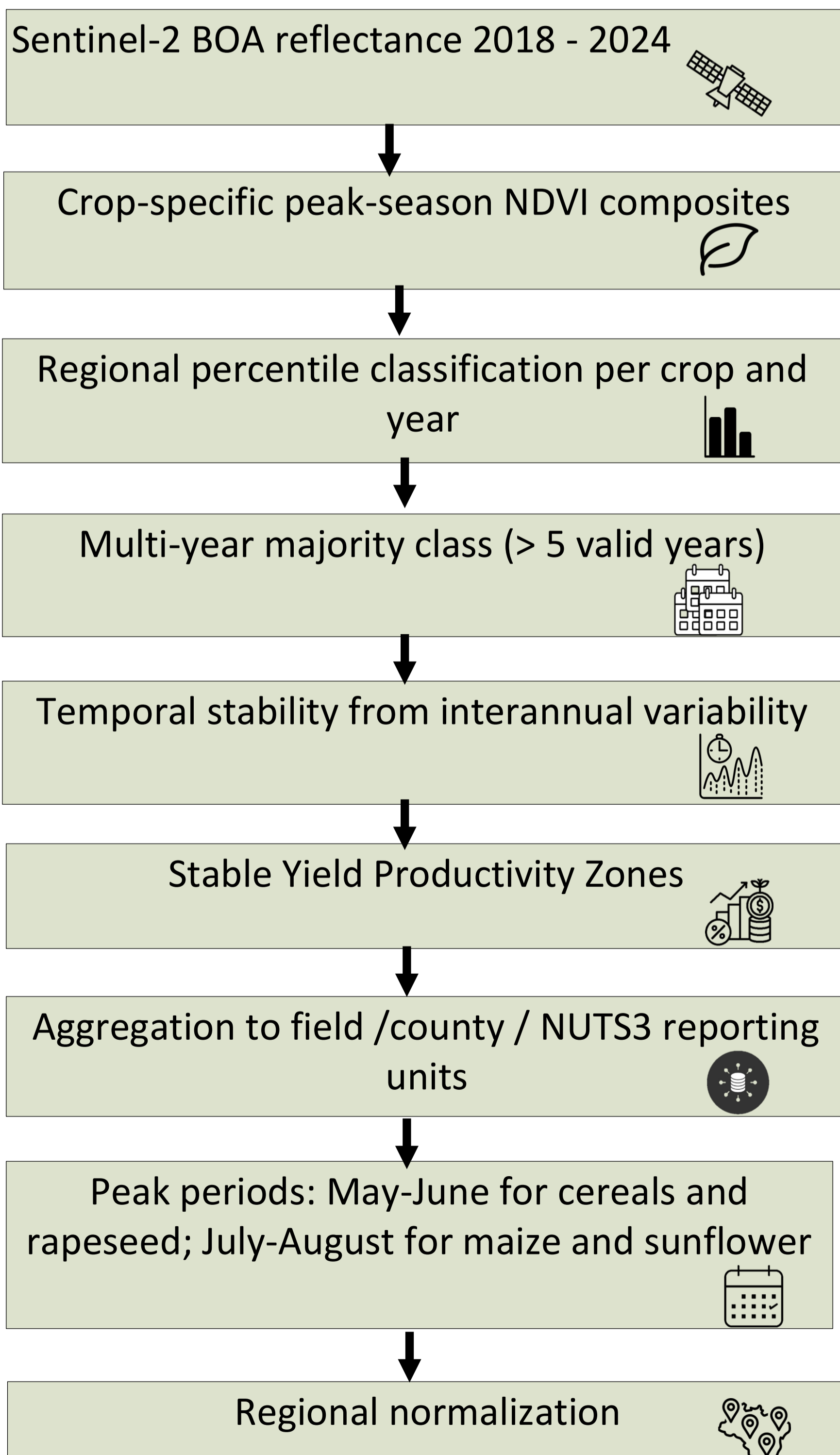
DRIVERS AND POLICY IMPACT

Elevation is the Primary Driver
SHAP analysis identifies elevation as the most influential factor, followed by soil reflectance.



Key messages

- Sentinel-2 stability patterns provide a scalable qualitative proxy of long-term yield potential.
- Regional normalization helps capture climate and soil gradients rather than only local management effects.
- EO-derived sub-field indicators can be aggregated into policy-relevant reporting units.
- Operational use requires threshold standardization and inter-calibration across regions.
- Scale Effect: Smaller field sizes (<20 ha) and smaller farm operations are statistically linked to lower yield stability.



- **Stable High (6.5%):** Zones with consistently high production, concentrated mainly in the more northern and higher-elevated parts of the region.
- **Stable Medium (36.3%):** The largest share of stable zones, representing standard regional production.
- **Stable Low (10.2%):** Areas with consistently low yields, often associated with lighter soils and southern gradients.
- **Unstable (47%):** Zones with high interannual variability, which are the most susceptible to climatic anomalies and require increased policy attention.



Precision Policy Interventions

Satellite maps support data-informed management, regenerative programs, and sustainable resource optimization.

Acknowledgement

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Based on Košanová et al. (2025), Geocarto International.

