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Quantifying Climate Sensitivity of Apple Orchard Vigor Using Sentinel-2 NDVI and Lagged Meteorological Variables

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Abstract

Understanding the extent to which short-term climatic variability regulates orchard canopy dynamics is essential for climate-responsive irrigation management in semi-arid regions. This study quantified intra-seasonal canopy vigor dynamics in a commercially managed, drip-irrigated apple orchard located in Niğde Province, Central Anatolia, Türkiye. Sentinel-2 surface reflectance imagery was processed to derive 15-day NDVI composites for the 2023 growing season, and monthly spatial NDVI maps were generated to evaluate intra-parcel heterogeneity. Concurrent meteorological data were aggregated into 15-day intervals, and lagged climatic variables were incorporated into a multiple linear regression framework. The regression model explained 74% of intra-seasonal NDVI variability (R^2=0.74, $p<0.001$). Lagged mean air temperature exhibited a strong positive effect on canopy vigor (β=0.0131, $p<0.001$), whereas lagged solar radiation showed a statistically significant negative association (β=-0.0275, $p=0.015$). Model diagnostics indicated no substantial residual autocorrelation (Durbin Watson=1.66). Spatial analysis further revealed persistent intra-orchard heterogeneity despite uniform irrigation practices. Results demonstrate that even under continuous drip irrigation, canopy vigor dynamics remain strongly governed by atmospheric forcing. The integration of satellite-based vegetation monitoring with lagged climatic indicators provides a robust framework for evaluating orchard climate sensitivity and supporting adaptive irrigation scheduling. This approach contributes to sustainable water resource management in perennial fruit production systems under increasing climatic variability.

Key Words: *Atmospheric Demand, Lag Analysis, Niğde, Remote Sensing, Semi-Arid*