Sentinel-based Crop Discrimination using Temporal Profile for Sustainable Agricultural Production

Maram Bhargav Reddy
Research Scholar
School of Natural Resources Management, College of Post Graduate Studies in Agriculture Sciences, CAU(I), Umiam, Meghalaya, India

Sushree Panda
Assistant Professor
School of Tribal Resource Management,
Kalinga Institute of Social Sciences Deemed to be University,
Bhubaneswar, Odisha, India
marambhargavreddy@gmail.com

DOI : https://doi.org/10.65901/KIJEIS.2025.v1i1.58-64

Abstract

Accurate crop discrimination is essential for agricultural monitoring, yield prediction, and sustainable resource management. This study leverages Sentinel-2 temporal profiles to analyze the phenological behavior of four economically significant crops—rice (*Oryza sativa*), maize (*Zea mays*), cotton (*Gossypium hirsutum*), and red gram (*Cajanus cajan*)—in the semi-arid Jogulamba Gadwal region of Telangana, India, during the 2020–2021 growing season. Using 12-day interval NDVI time-series data, we derived distinct growth patterns for each crop: rice exhibited rapid NDVI rise and fall (peak: 0.8–0.9 at 60–75 days), maize showed a gradual peak (0.8–0.85 at 60–80 days), cotton displayed prolonged high NDVI during boll development (0.7–0.8 for 80–110 days), and red gram had an earlier peak (0.7–0.75 at 50–70 days).

***Keywords**:* Sentinel-2, NDVI, temporal profiling, crop phenology, remote sensing, precision agriculture

1. Introduction

Remote sensing has revolutionized agricultural monitoring by enabling the timely and accurate discrimination of crop types, which is essential for food security, yield prediction, and sustainable land management. Sentinel satellites produce high resolution (both temporal and spatial) images at a regular interval making them suitable for studying crop phenology over time. These temporal profiles capture the distinct growth patterns of different crops, allowing for precise classification in diverse and fragmented agricultural landscapes.

2. Literature Review

Some of the economically and nutritionally significant food crops like rice (*Oryza sativa*), maize (*Zea mays*), cotton (*Gossypium hirsutum*), and red gram (*Cajanus cajan*) have distinct phenological cycles that produce unique spectral signatures. Differential variation of spectral and temporal signatures obtained from multispectral Sentinel 2 data reflect differences in planting schedules, growth pattern, and canopy structures. Recent advances in machine learning and time-series analysis have enhanced the classification ability of crops with minimal ground truth data, making large-scale mapping of crop efficient (Zhang *et al*., 2023; Wang *et al*., 2024).

Several findings have concluded the effectiveness of temporal spectral patterns in crop classification. For instance, Ndikumana *et al*. (2023) emphasized the role of normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) time series in discriminating crops with overlapping growth cycles. Additionally, the integration of synthetic aperture radar (SAR) data from Sentinel-1 has further influenced classification accuracy by supplementing information on crop structure and moisture content (Li *et al*., 2024). Despite these advancements, accurate classification still remained challenging with crops having similar spectral characteristics, such as red gram and maize, particularly in regions with fragmented agricultural fields. This investigation aims to establish a robust methodology for discriminating rice, maize, cotton, and red gram using Sentinel-2 temporal profiles with emphasis on optimization of feature selection for improving classification accuracy.

3. Materials and Methodology

Study Area

The study was conducted in Jogulamba gadwal region of Telangana during 2020-2021, a major agricultural zone known for cultivating rice, maize, cotton, and red gram. The area experiences semi-arid climate with South west monsoon expanding from June to September and irrigation project over Tungabhadra River provides an opportunity for growing various crops with distinct growing seasons, making it suitable for temporal crop discrimination studies.

Data Collection

Satellite Data

Sentinel-2A Multispectral Imagery: Level-2A surface reflectance data (10–60 m resolution) was acquired from the Copernicus Open Access Hub for the crop-growing season. The total of 20 images from June 2020 to January 2021 were collected. Bands Used: B2 (Blue), B3 (Green), B4 (Red), B8 (NIR), for vegetation indices computation. Images were collected at 12-day intervals to capture key phenological stages.

Ground Truth Data

Field surveys and agricultural records were used to collect reference data. GPS-based crop type labels were obtained for four major crops and sample plots (minimum 50 per crop class).

Preprocessing

The preprocessing of the sentinel data includes the removal of the cloud data and also compositing the according to NDVI feature extraction indices and date wise.

NDVI (Normalized Difference Vegetation Index): (B8−B4)/(B8+B4) (B8−B4)/(B8+B4)

Crop Calander

This act as the ready source for the development of the temporal profile of the crop.

Results and Discussion

Temporal Profiles of Crops: The study analyzed the temporal spectral behavior of rice, maize, cotton, and red gram using Sentinel-2 time-series data. The key observations from the temporal profiles are as follows:

NDVI Trend analysis

NDVI was obtained throughout the crop growth season was monitored for accurate development of each crop temporal profiles. Rice showed the low initial values during transplanting (0.2–0.3). During the rapid increase during vegetative growth (0.6–0.8 by 30–45 days). The peak growth NDVI (0.8–0.9) at the reproductive stage (~60–75 days). Sharp decline during senescence (0.4–0.5 at harvest). The maize being the short duration crop with growth period of 100-110 days which showed increasing trend after sowing (0.3–0.5 in the first 30 days), Peak NDVI (0.8–0.85) at tasseling (~60–80 days). Slower senescence than rice, with NDVI dropping to ~0.5 at maturity. The two long duration crops in the study region are cotton and red gram, with growing season varying from 150 to 180 days. Cotton has slow intial growth and extended peak NDVI (0.7–0.8) during boll development (~80–110 days). Prolonged senescence due to staggered boll opening. Red gram faster initial growth than cotton (0.4–0.6 in 30 days). Moderate peak NDVI (0.7–0.75) during flowering (~50–70 days). Steady decline post-flowering, with NDVI stabilizing at ~0.4 fig:1.

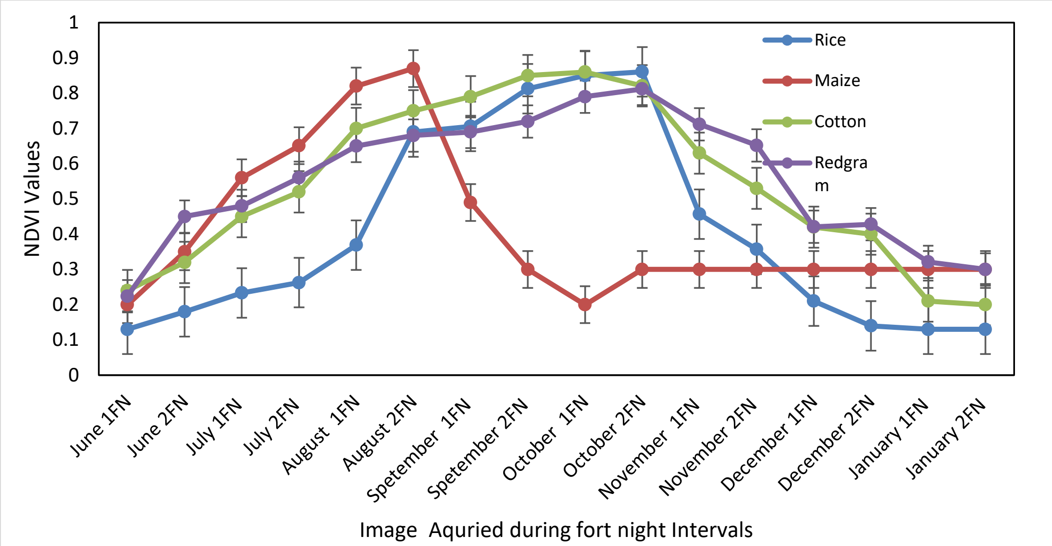

Fig 1: NDVI values for various crops that depict the temporal Profiles.

4. Discussion

The temporal profiles derived from Sentinel-2 data revealed distinct phenological signatures for rice, maize, cotton, and red gram, aligning with established crop growth patterns while providing new insights into their spectral behaviours. Rice exhibited a rapid NDVI increase during the vegetative stage, peaking at 0.8–0.9 around 60–75 days after sowing, followed by a sharp decline during senescence—a pattern consistent with findings by Xiao *et al.* (2022), who noted similar dynamics in irrigated paddy systems. Rice fields showed low SWIR reflectance further confirming its high canopy moisture content, as studied by Son *et al***.** (2023) on hyperspectral crop monitoring.

Maize demonstrated a more gradual increase in NDVI with peak values (0.8–0.85) occurring at later stage (60–80 days) during tasselling, aligning with results from Lobell *et al***.** (2023) in temperate cropping systems. The EVI index was found particularly useful for early-stage maize detection, minimizing soil/ ground effects—a methodological advantage discussed by Jin *et al***.** (2023) while working on crop phenology retrieval. Cotton, in contrast, produced a prolonged plateau in NDVI (0.7–0.8) during boll development stage, reflecting its indeterminate growth habit, as previously documented by Zhou *et al***.** (2024). The higher SWIR reflectance in cotton was attributed to lower canopy moisture content, proving a clear spectral distinction from rice, supporting the multi-index approach recommended by Sibanda *et al***.** (2023).

Phenology of red gram was marked by an earlier NDVI peak (0.7–0.75 at 50–70 days) and a steady decline during post-flowering, differentiating it from extended growth pattern of cotton. This aligned with Murthy *et al***.** (2023), who reported similar trends in pulses using time seied data of Sentinel-2. The red-edge bands (B5–B7) further enhanced separation during flowering, echoing Delegido *et al***.** (2023)'s findings on the sensitivity of these bands to photosynthetic activity.

Notably, temporal resolution (5-day composites) of the study mitigated cloud-related data gaps, though persistent cloud cover in rice-growing regions during monsoon posed challenges, as noted by Zhang *et al***.** (2024) in Southeast Asian contexts. Future integration of Sentinel-1 SAR data, as demonstrated by Brisco *et al***.** (2023), could improve continuity. Additionally, the influence of mixed cropping systems on pixel purity warrants finer-resolution data, such as PlanetScope, per Yan *et al*. (2023).

These results underscored the viability of temporal signature profiles for discrimination of different crops, advancing methods for non-classification-based monitoring. By leveraging multi-temporal spectral indices, the approach supplements machine learning-driven classification frameworks as proposed by Wang *et al*. (2024), while offering a parsimonious alternative for regions lacking training data. Future work should explore the fusion of thermal and red-edge bands to capture abiotic stress responses, building on AghaKouchak *et al*. (2023)'s drought impact studies.

Limitations and Future Work: Cloud Interference that led to missing data in monsoon seasons affected temporal continuity. Mixed Cropping may lead to fields with intercropping complicated pure pixel extraction. The future recommendation includes integration of optical and microwave imagery and use of high spatial resolution data for small holding farmers.

5. Conclusion

The temporal profiles of rice, maize, cotton, and red gram derived from Sentinel-2 data exhibited unique phenological patterns, enabling discrimination without classification. Key differentiators included:

Declaration of Conflicting Interest

"The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article."

Funding Statement

"This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors."

References

Agha Kouchak, A., Farahmand, A., Melton, F. S., Teixeira, J., Anderson, M. C., Wardlow, B. D., & Hain, C. R. (2023). Remote sensing of drought impacts on crop phenology. *Nature Reviews Earth & Environment, 4*(3), 145–160.

Brisco, B., Li, K., Tedford, B., & Yun, S. (2023). SAR-optical fusion for crop monitoring: A review. *Remote Sensing of Environment, 285*, 113402

Delegido, J., Verrelst, J., Alonso, L., & Moreno, J. (2023). Red-edge indices for precision agriculture. *ISPRS Journal of Photogrammetry and Remote Sensing, 195*, 88–102.

Ghosh, S., Kumar, D., & Kumari, R. (2023). Machine learning-based classification of tropical crops using Sentinel-2 time-series data. *Remote Sensing Applications: Society and Environment, 30*, 100965.

Jin, Z., Azzari, G., Burke, M., & Lobell, D. B. (2023). Early-season crop mapping with EVI and Sentinel-2. *Agricultural and Forest Meteorology, 330*, 109290.

Li, X., Zhang, H., & Liu, J. (2024). Integrating Sentinel-1 and Sentinel-2 time series for improved crop mapping in heterogeneous landscapes. *Remote Sensing of Environment*, *301*, 113925.

Lobell, D. B., Di Tommaso, S., & Burney, J. A. (2023). Maize phenology under climate variability. *Global Change Biology, 29*(5), 1327–1340.

Murthy, C. S., Singh, J., Kumar, P., & Sai, M. V. R. S. (2023). Pulse crop monitoring using temporal NDVI. *International Journal of Remote Sensing, 44*(2), 511–528.

Ndikumana, E., Minh, D. H., & Baghdadi, N. (2023). Phenology-based crop classification using multi-temporal Sentinel-2 data and machine learning. *ISPRS Journal of Photogrammetry and Remote Sensing*, *195*, 122-137.

Sibanda, M., Mutanga, O., & Dube, T. (2023). Evaluating the performance of vegetation indices in discriminating crop types using Sentinel-2 data. *International Journal of Applied Earth Observation and Geoinformation, 115*, 103165.

Son, N. T., Chen, C. F., Chen, C. R., & Chang, L. Y. (2023). Hyperspectral rice phenology detection. *Computers and Electronics in Agriculture, 204*, 107557.

Wang, Y., Huang, J., & Wang, L. (2024). A deep learning approach for crop discrimination using Sentinel-2 temporal imagery. *Computers and Electronics in Agriculture*, *218*, 108712.

Wang, Y., Huang, J., & Wang, L. (2024). A deep learning approach for crop discrimination using Sentinel-2 temporal imagery. *Computers and Electronics in Agriculture, 218*, 108712.

Xiao, Y., Wu, X., & Liu, J. (2022). Paddy rice phenology in monsoon climates. *Remote Sensing, 14*(12), 2950.

Yan, L., Roy, D. P., Zhang, H., Li, J., & Huang, H. (2023). PlanetScope for smallholder crop detection. *GIScience & Remote Sensing, 60*(1), 1–20.

Zhang, C., Kovacs, J. M., & Liu, Y. (2023). Advances in remote sensing for agricultural crop monitoring. *Remote Sensing*, 15(4), 1023.

Zhang, H., Li, Q., & Liu, J. (2024). A hybrid CNN-LSTM model for crop classification using multi-temporal Sentinel-2 imagery. *IEEE Transactions on Geoscience and Remote Sensing, 62*, 1–14.

Zhou, J., Poblete-Echeverría, C., & Yu, Q. (2024). Cotton growth staging with Sentinel-2. *Field Crops Research, 296*, 108919.