Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 05 (SEP-OCT, 2026)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Remote Sensing and GIS Applications in Monitoring Conservation Agriculture Practices

*Sakshi Priya, Dr. Anshuman Nayak and Dr. Ipsita Kar
College of Agriculture, OUAT, Bhubaneswar, Odisha, India
*Corresponding Author's email: riyash192002@gmail.com

Conservation agriculture (CA) is an important approach for improving soil health, conserving water and reducing the environmental impacts of intensive farming. It is based on three principles: minimum soil disturbance, permanent soil cover and crop diversification. Monitoring these practices over large agricultural areas through conventional field surveys can be difficult, time-consuming and expensive. Remote sensing (RS) provides an effective alternative by collecting information about agricultural fields from satellites and unmanned aerial vehicles without requiring frequent visits to every field. Geographic Information System (GIS) helps organise, analyse and map this information. Freely available satellite missions such as Landsat and Sentinel provide repeated observations that can help identify crop residues, vegetation cover, tillage patterns and crop sequences. Recent advances in machine learning and multi-date satellite analysis are further improving the identification of conservation practices. In India, these technologies are particularly promising for monitoring zero tillage and residue management in rice–wheat systems. Integrating RS, GIS and artificial intelligence can support large-scale assessment of conservation agriculture and better soil and water management.

Introduction

Agriculture must produce sufficient food while protecting soil, water and other natural resources. Intensive tillage, removal or burning of crop residues and continuous cultivation can contribute to soil degradation, erosion, loss of organic matter and inefficient use of water. Conservation agriculture offers a practical approach to address some of these problems. CA is based on minimum mechanical soil disturbance, permanent soil cover and diversification of crop species. Zero tillage, reduced tillage, residue retention, cover crops and crop rotation are commonly associated with these principles. However, an important challenge is determining where and to what extent these practices are adopted. Field surveys are useful but become difficult and costly when thousands of fields must be monitored. Remote sensing can repeatedly observe large areas, while GIS converts these observations into maps that can support agricultural planning.

Understanding Conservation Agriculture

Minimum soil disturbance aims to reduce repeated soil inversion and intensive land preparation. Zero tillage allows crops to be established with little or no conventional soil disturbance. Permanent soil cover protects the soil surface from raindrop impact, wind erosion and excessive evaporation; crop residues and cover crops are important components. Crop diversification involves growing different crops through rotation or association, which can improve nutrient cycling and system resilience. These principles work together: reduced disturbance, protected soil and diversified cropping create a more resource-conserving production system.

CA practice	Main feature	Possible remotely observable indicator
Zero tillage	Little or no soil disturbance	Residue cover and surface condition
Reduced tillage	Reduced soil disturbance	Residue and exposed-soil pattern
Residue retention	Crop residues remain on soil	Residue spectral response
Cover crops	Vegetation during otherwise bare periods	Seasonal vegetation indices
Crop rotation	Different crops over seasons	Multi-date crop signatures
Mulching	Protective material on soil surface	Surface-cover characteristics

How Remote Sensing Helps Monitor Conservation Agriculture

Remote sensing means obtaining information about the Earth's surface without directly touching or sampling every location. Satellites are especially useful in agriculture because they repeatedly observe large areas. Sentinel-2 provides multispectral observations from visible, near-infrared and short-wave infrared regions, which are useful for crop growth, vegetation cover and residue monitoring. Landsat provides a long historical record that is valuable for studying changes in agricultural land management. Sentinel-1 uses Synthetic Aperture Radar (SAR). Radar can provide observations under cloudy conditions and can give information related to surface roughness and moisture. Unmanned Aerial Vehicles (UAVs), or drones, provide much finer spatial detail and are useful for field-level monitoring and validation. Multi-date observations are particularly valuable because residue, soil moisture and crop growth change during the season.

Platform	Main data	Important application
Landsat	Multispectral	Long-term crop and residue monitoring
Sentinel-2	Multispectral	Vegetation, residues and crop rotation
Sentinel-1	SAR	Surface condition and moisture
UAV/drone	RGB/multispectral	Detailed field-level monitoring
Hyperspectral sensors	Narrow spectral bands	Detailed material discrimination

Monitoring Major Conservation Agriculture Practices

Zero and reduced tillage

Tillage changes the amount of exposed soil and crop residue present on the soil surface. These differences can be detected in satellite imagery, particularly during the early part of the crop season. A 2024 study in Punjab used Sentinel-2 imagery and a change-detection approach to distinguish zero, shallow and conventional tillage and reported 81% accuracy. This demonstrates the potential of satellite observations for monitoring tillage adoption over large areas.

Crop-residue management

Crop residues are an important part of soil cover. Their spectral behaviour, particularly in the short-wave infrared region, can help distinguish residue-covered surfaces from bare soil and green vegetation. Recent research has also used Sentinel-2 data and Random Forest models to map maize residue cover at regional scale. Such information can help identify areas where residue retention is being practised and where residue-management interventions may be needed.

Cover crops

Cover crops maintain vegetation during periods when the main crop is absent. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) can help detect this green cover. Multi-date imagery is especially useful because cover crops may appear as vegetation during an otherwise bare period.

Crop rotation and diversification

Different crops have different growth patterns and spectral signatures. By analysing images throughout the year, satellite data can identify seasonal crop patterns and help distinguish fields with different crop sequences. This makes time-series imagery useful for assessing crop diversification.

Mulching

Mulching creates a protective layer over the soil. Depending on the material used, its spectral response may differ from bare soil. Remote sensing can assist in identifying surface cover, although distinguishing different mulch materials remains more difficult than detecting green vegetation.

Role of GIS and Machine Learning

Remote sensing provides observations, while GIS provides the framework for storing, analysing and displaying them spatially. Satellite images can first be processed to remove clouds and other unwanted effects. Vegetation and residue-related indicators can then be combined with field boundaries, soil information, elevation and other GIS layers. Machine learning methods such as Random Forest and Support Vector Machine can learn relationships between satellite observations and known field-management classes. A typical workflow is: satellite or UAV data → image processing → spectral and spatial features → machine learning → GIS mapping → conservation-practice map. Cloud-based platforms can make it possible to process large volumes of satellite data efficiently.

Applications in Indian Agriculture

India offers a major opportunity for RS- and GIS-based CA monitoring because of its large and diverse agricultural area. The rice–wheat system of the Indo-Gangetic Plains is particularly important. Zero-tillage wheat, residue retention and improved residue-management machinery are important conservation approaches in this region. Satellite monitoring can help identify fields adopting different tillage systems and provide information on their spatial distribution. Recent research has demonstrated this potential. Deshpande et al. (2024) used Sentinel-2 data to map zero-tillage adoption in Punjab over three years and achieved 81% accuracy. A 2026 study using Sentinel-2 time series across Punjab and Haryana developed a Conservation Practice Spectral Index and reported 92% overall accuracy for distinguishing conventional from conservation tillage. These developments show how early-season satellite monitoring could support extension, programme assessment and future monitoring, reporting and verification systems.

Advantages and Limitations

Advantages	Limitations
Large-area monitoring	Cloud cover affects optical imagery
Repeated observations	Field observations are still needed
Spatially explicit maps	Small fields can be difficult to classify
Historical satellite records	Soil and residue can have similar spectral responses
Supports automated analysis	Models may not work equally well everywhere
Useful for monitoring adoption	One indicator cannot represent complete CA

Remote sensing should therefore complement rather than completely replace field observations. Ground observations are essential for developing and validating reliable classification models.

Future Prospects

The future of CA monitoring lies in combining multi-sensor satellite data, artificial intelligence, GIS and field observations. Optical and radar data can complement each other, while time-series analysis can provide information throughout the crop season. Artificial intelligence may help automatically identify fields under zero tillage, residue retention, cover cropping and crop rotation. An important future direction is to move beyond identifying practices towards assessing their outcomes, such as changes in soil cover, moisture, erosion risk, productivity and soil organic carbon.

Conclusion

Remote sensing and GIS are powerful tools for monitoring conservation agriculture over large areas. Sentinel-1, Sentinel-2 and Landsat can provide repeated information on vegetation, crop residues, soil-surface conditions and cropping patterns. When combined with GIS and machine learning, these observations can be converted into useful maps of CA practices. Their application is particularly promising for zero tillage and residue management in India's rice–wheat systems. However, reliable ground observations and regional validation remain essential. Integrating remote sensing, GIS, artificial intelligence and field data can support better monitoring of sustainable farming practices and improved soil, water and crop management.

References

1. Ahmed, Z., Shew, A., Nalley, L., Popp, M., Green, V.S. and Brye, K. (2024). An examination of thematic research, development, and trends in remote sensing applied to conservation agriculture. International Soil and Water Conservation Research, 12(1): 77-95. DOI: 10.1016/j.iswcr.2023.04.001.
2. Deshpande, M.V., Pillai, D., Krishna, V.V. and Jain, M. (2024). Detecting and quantifying zero tillage technology adoption in Indian smallholder systems using Sentinel-2 multi-spectral imagery. International Journal of Applied Earth Observation and Geoinformation, 128: 103779. DOI: 10.1016/j.jag.2024.103779.
3. Du, J., Jacinthe, P.-A., Song, K., Zhang, L., Zhao, B., Liu, H., Wang, Y., Zhang, W., Zheng, Z., Yu, W., Zhang, Y. and Jiang, D. (2025). Maize crop residue cover mapping using Sentinel-2 MSI data and random forest algorithms. International Soil and Water Conservation Research, 13(1): 189-202. DOI: 10.1016/j.iswcr.2024.09.004.