

Digital agriculture and data-driven farming

solutions for sustainable development

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Indian agriculture is undergoing a digital shift, propelled by technologies such as drones, farm robots, and smart soil sensors, particularly in regions dominated by small and marginal farmers. This transition addresses pressing challenges including labour scarcity, water limitations and climate variability. Since the last decade, rapid integration of robotics, remote sensing, GIS, artificial intelligence, machine learning and IoT has enabled precise crop monitoring, targeted input delivery, and efficient resource management. These tools operate by collecting and analyzing real-time field data, translating it into actionable decisions for irrigation, fertilization and pest control. The outcome is a resilient, resource-optimized farming model capable of sustaining productivity while reducing environmental impacts across diverse agro-climatic zones in India. The convergence of digital tools is not only modernizing farm operations but also empowering smallholders with decision support systems and mobile-based advisories. This evolution underscores the potential of digital agriculture to transform Indian farming into a climate-resilient and sustainable enterprise.

Keywords: Artificial intelligence, CropX sensors, Digital agriculture, Drones, Precision farming

THE digital revolution is expected to transform traditional farming into a smarter and efficient enterprise. The integration of innovative tools such as agricultural drones, robots and advanced soil sensor technologies is reshaping monitoring mechanism of crop health. These advancements are being tailored to meet the needs of small and marginal farmers too. Drones now facilitate accurate spraying, seeding and crop monitoring, reducing chemical use and labour costs. Farm robots reduce drudgery and improve operational efficiency, while soil sensors enable data-driven decisions for precise input management. Furthermore, the blend of Remote Sensing (RS), Geographic Information Systems (GIS), Artificial Intelligence/Machine Learning (AI/ML) and the Internet of Things (IoT) is driving dynamic and responsive farming. Together, they drive climate smart farming by overcoming extreme events, resource scarcity paving the way for sustainable agriculture.

Digital agriculture solutions

Drones in agriculture-Operational applications:

Precision spraying: Ensures accurate chemical application with minimal wastage and investment, enhanced safety, and lower environmental impact.



Drone-mounted seed and fertilizer spreader in rice

Granular application (Dry spreading): Provides precise, timely material placement without crop damage or soil compaction, lowering per-acre costs.

Seed and fertilizer spreader in rice: Improves planting efficiency, reduces labour, and enables operation in difficult terrains while offering real-time seeding data.

Drone aided broadcasting with 10 kg capacity seed and fertilizer spreader achieved 85–90% distribution uniformity, 65–70% less labour cost with 80% time savings leading to reduction in seeding cost to ₹ 1000–1125/ha from ₹ 1750–2000/ha in rice dry direct seeding (DDSR) in Andhra Pradesh.

CropX sensor- Data-driven soil intelligence: The CropX soil sensor system uses IoT-based sensors to continuously measure soil moisture, temperature, and electrical conductivity at multiple depths, enabling precise irrigation and nutrient management. It combines hardware, telemetry, soil sensors, real-time environmental data, crop models, and farm machinery inputs to provide holistic assessments. Advanced analytics generate predictive insights and recommendations, accessible through a customizable dashboard that supports multi-farm management, tailored visualizations, and inter-user communication. It offers a suite of modules for smart farm management, including field data integration, irrigation scheduling, nutrition monitoring and disease forecasting. It also supports connectivity across farm sensors and machinery, and standardized tracking and reporting. The sensors acquire data on soil moisture, temperature and electrical conductivity, enabling the system to generate recommendations prior to the manifestation of plant stress symptoms. The CropX system in Andhra Pradesh has achieved 70% increase in sugarcane yield, 90% reduction in supplemental feed requirements for pastures, 15% decrease in fertilizer consumption and 68% reduction in water usage.

FarmRobo R: It is the India's first multi-purpose electric agricultural robot designed for small to medium Indian farms, capable of precision weeding, spraying and produce transport. Its modular quick coupler supports attachments like weeder blades, rotary tillers and a 10-foot boom sprayer. It include AI + RTK-guided navigation with obstacle avoidance, battery power for 6–8 h (covering 1.25–1.75 ha/day), OTA software updates and intuitive controls suitable for women operators. It helped in reducing weeding time to 2–3 h from 2–3 days, spraying reduced to minutes from hours and chemical use by 30%, overall costs and environmental impacts.

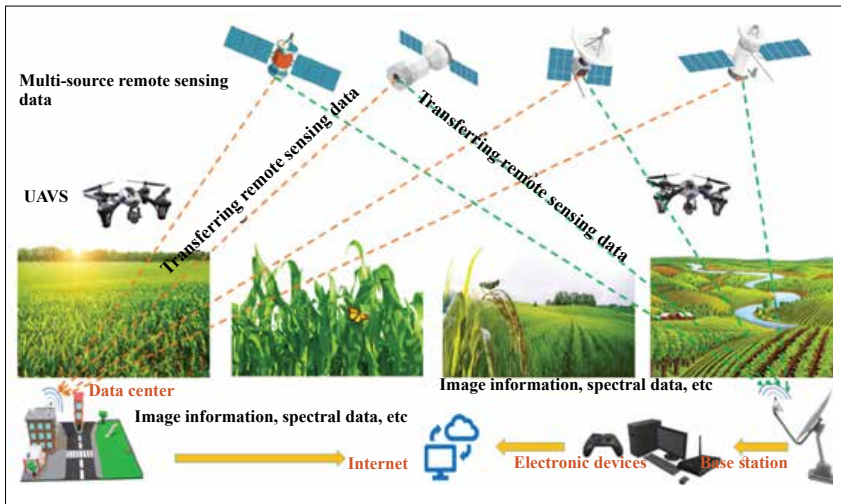
Remote sensing in agriculture: RS and GIS are being used widely in agriculture for crop identification, area and yield estimation, soil moisture monitoring, water management, pest/disease forewarning and agro-advisories. It offers advantages such as synoptic views, rapid surveys, repetitive coverage, cost-effectiveness, high accuracy and multispectral data use and enables large-scale, dynamic monitoring of crops, supporting productivity forecasting at district and regional levels.

Table 1. Application of remote sensing in agriculture

Application	Description
Crop monitoring and health assessment	Uses vegetation indices like NDVI NDWI etc. to track plant vigor, stress and growth over time. It also helps in detecting biotic stress (Pest and disease) and abiotic stress (drought, nutrients, etc.)
Crop type mapping	Identify and classify different crops based on their spectral signatures during various growth stages using time-series satellite data
Yield estimation	Predicts crop yield based on the real time satellite data combined with weather and soil parameters
Soil mapping	Helps identify soil texture, salinity and moisture variability, enabling targeted soil management
Precision agriculture	Supports variable rate applications of water, fertilizer, and pesticides by mapping field variability
Non arable land identification	Detects uncultivated or underutilized lands between cropping seasons using time-series data
Change detection studies	Maps agricultural areas, forests water bodies and built-up regions to monitor land use changes.
Irrigation planning	Assists in monitoring irrigation coverage and evaluating the effectiveness of irrigation systems over time
Agroforestry area estimation	Facilitates monitoring of agroforestry areas and estimation of biomass to assess carbon sequestration
Smart farming	NaviCs high accuracy (<2m) helps in field mapping, precision input application, infrastructure planning, time synchronization, and supply chain monitoring

Table 2. Indian satellites and their applications

Satellite	Purpose/Applications	Sensors/Features
IRS-1A/1B (1988/1991)	First generation Earth observation; used for land and vegetation studies	LISS-I, LISS-II
IRS-1C/1D (1995/1997)	High-resolution imaging for agriculture, forestry, water bodies	LISS-III, PAN, WiFS
Resourcesat-1 (2003)	Agricultural monitoring, land use, forest, soil mapping	LISS-III, AWiFS
Resourcesat-2 and 2A (2011 and 2016)	Advanced resource monitoring (cropping patterns, soil, forest)	LISS-IV, LISS-III, AWiFS
Cartosat Series (1 to 3)	High-resolution cartographic mapping; useful for watershed, soil, urban planning	PAN, high-res stereo imaging
RISAT Series (Radar Imaging)	All-weather, day-night imaging for disaster management, crop monitoring, soil moisture	Synthetic Aperture Radar (SAR)
Oceansat Series	Ocean parameters, weather forecasting, monsoon prediction, fisheries, monitoring sowing progress and crop area estimation	OceanColour Monitor (OCM), Scatterometer
INSAT Series (Meteorological)	Weather monitoring, rainfall estimation, agro-meteorology	CCD cameras, sounders, radiometers
HySIS (Hyperspectral Imaging Satellite) (2018)	Mineral mapping, vegetation health, soil properties mapping	Hyperspectral sensor (400+ bands)



Process of remote sensing

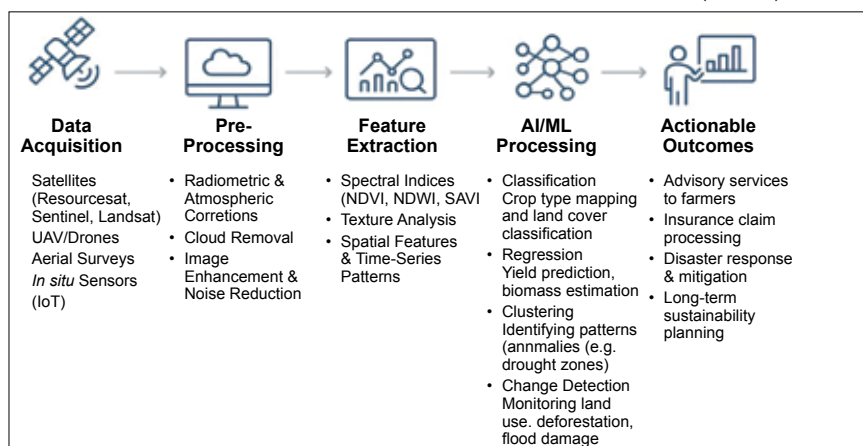
How AI and ML tools can assist in RS?

AI and ML tools can significantly enhance RS by automating data analysis, improving accuracy and enabling faster, more insightful decision-making.

Handling large and complex data: RS generates huge datasets (multispectral, hyperspectral, SAR). AI can process and analyze this high-dimensional data efficiently, finding patterns humans might miss. For e.g. ISRO's Bhuvan Portal prepares the National-scale land cover classification using multi-source satellite imagery. AI/ML assist in processing petabytes of imagery to produce high-accuracy thematic maps.

Automated image analysis:

- **Object detection and classification:** ML models can detect land cover, crops, water bodies, and infrastructure from satellite images. Using multier solution segmentation in eCognition, agroforestry in Khammam and Warangal (Telangana) was mapped with 81.5% and 86% accuracy, respectively.
- **Change detection:** AI detects time-based changes like crop growth or urban sprawl more accurately. NRSC uses it for Smart Cities, and Delhi authorities use ML and RS to monitor illegal buildings and urban trends.



Atomization flow chart showing the frame work for RS data collection, processing, feature extraction and output generation

Predictive modeling:

- **Yield prediction:** AI models predict crop yields from field to national scales. MNCFC applies AI/ML with Sentinel-1, Sentinel-2, and Resourcesat data under FASAL to estimate acreage and yield at regional level, while Pradhan Mantri Fasal Bima Yojana employs AI-powered RS models for crop loss assessment for insurance claims.
- **Disaster impact forecasting:** ML predicts flood, drought, or pest impacts. The Central Water Commission and ISRO use AI-enhanced RS data for real-time flood mapping and forecasting in Assam and Bihar.

Enhancing accuracy:

AI-based filtering removes atmospheric effects, sensor noise, or cloud interference. ISRO's MOSDAC (Meteorological and Oceanographic Satellite Data Archival Centre) uses AI algorithms to remove cloud contamination and atmospheric distortions from INSAT and Oceansat imagery for improved weather and ocean parameter monitoring. IIRS Dehaze and Denoise Project applies deep learning-based dehazing to high-resolution Cartosat and Resourcesat images for clearer land and vegetation analysis. ML combines data from multiple sources (optical, radar, LiDAR) to produce more reliable results. National Agricultural Drought Assessment and Monitoring System (NADAMS) combines optical (Resourcesat, Sentinel-2) and microwave (RISAT, Sentinel-1) RS data via ML models for accurate drought monitoring. Chandraprabha River Basin Study uses AI-driven fusion of LiDAR elevation data, SAR, and optical imagery for floodplain mapping and water resource planning.

Real-time monitoring: Integration with IoT sensors allows AI to process RS data in near real-time for precision agriculture, forest fire alerts, or water resource monitoring. NRSC's National Hydrology Project uses RS + AI for real-time reservoir monitoring and groundwater potential mapping. Water Resources Information System (WRIS) uses RS and ML for reservoir storage forecasting and irrigation planning.

Jal Shakti Ministry Projects employs AI-based RS analysis for detecting groundwater stress zones and optimizing irrigation schedules. Forest Survey of India uses ML models on RS data for forest fire detection and burned-area mapping.

Customized decision support: AI-powered decision systems can suggest best farming practices, irrigation schedules, or resource allocation based on RS-derived insights as used by Digital Agriculture Mission in India. Indian Meteorological Department (IMD) uses RS data and

ML algorithms for monsoon rainfall prediction and drought early warning making predictions more robust over time. Central Water Commission Flood Forecasting combines RS imagery with ML models to predict flood extent and support disaster response.

Climate and environmental monitoring: In Andhra Pradesh and Karnataka, NICRA integrates MODIS and Sentinel-2 imagery with AI-based vegetation indices (NDVI, VCI) and ML models (Random Forest, SVM) to classify drought intensity and generate early warning maps using multi-year climate data. In Bihar, long-term RS data with climate projection models are applied to predict rice and wheat yield changes for adaptive crop planning. Similarly, ICAR-NBSSLUP uses ML regression on hyperspectral imagery to map soil organic carbon, nitrogen, and texture in Maharashtra and Punjab, while ICAR-IARI combines hyperspectral data with deep learning to detect nutrient deficiencies in wheat and paddy, delivering fertilizer advisories through mobile apps.

Integration of digital technologies: The integration of RS, GIS, AI/ML and the IoT is transforming agriculture into a data-driven, precision-based industry. The following steps gives us an insight of the procedure followed.

- **Data acquisition:** RS captures satellite/drone imagery, IoT collects field-level sensor data.
- **Data processing and GIS mapping:** GIS integrates and geo-references spatial data.
- **AI/ML analysis:** Models analyze multi-source datasets for insights.
- **Decision support:** Generates precise, timely advisories for irrigation, fertilizer application, pest control, and harvesting.

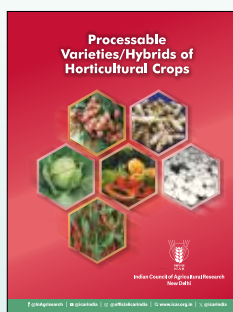
Such integration offer smart farming solutions and help enhance crop productivity, reduces costs and negative environmental impact while supporting data-driven decisions for all stakeholders.

SUMMARY

Recent advances are equipping Indian farms with highly specialized digital capabilities. Aerial platforms perform site-specific spraying and seeding with uniform coverage, lowering wastage and operational costs. Multi-tasking robots handle soil preparation, weeding and spraying in a fraction of the time, reducing manual effort and chemical dependency. Intelligent soil monitoring networks provide continuous updates on subsurface conditions, allowing accurate irrigation timing and fertilizer adjustment. Digital mapping and analytics platforms process large-scale spatial and environmental datasets to deliver targeted agronomic insights. Collectively, these solutions improve field efficiency, safeguard resources, and contribute to sustainable production systems while creating measurable gains in both crop output and farm profitability. The progression towards a fully digital agricultural framework in India will depend on strategic policy, infrastructure expansion, and farmer engagement. Rural broadband coverage must be broadened, and low-cost sensor networks should be made accessible to all farming categories. Partnerships among research bodies, private innovators, and grassroots organizations can stimulate rapid development and diffusion of context-specific technologies. Training programmes should focus on practical, hands-on exposure, enabling farmers especially women and youth to manage, troubleshoot, and adapt equipment effectively. Establishing common data standards will help integrate diverse hardware and software, avoiding system incompatibility. Future efforts should emphasize environmentally sound practices, such as minimizing energy use, protecting water resources and lowering emissions, ensuring that digital adoption aligns with national sustainability and climate resilience objectives.

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This book will be useful for the processing industry as it provides information on the recent varieties /hybrids of horticultural crops and their availability. The information provided in this document will help the Indian farmers and Food Processing Industry in identifying suitable crops and varieties/hybrids based on their processing qualities for strengthening entrepreneurship.

TECHNICAL ASPECTS

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