



Remote Sensing and Satellites in Modern Crop Management

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INTRODUCTION

Remote sensing and satellite technologies have transformed modern agriculture enabling the acquisition of information about crop health, soil moisture, weather condition, nutrient status, and pest attacks on a continuous and large scale. Together with artificial intelligence (AI), drones, cloud computing and the Internet of Things (IoT), the technology provides real-time monitoring of crops, efficient use of resources, low cost of production and high yield. With increasing climate change and resource limitation, satellite informed crop management has become a necessity for sustainable and climate-resilient agriculture.

What is Remote Sensing

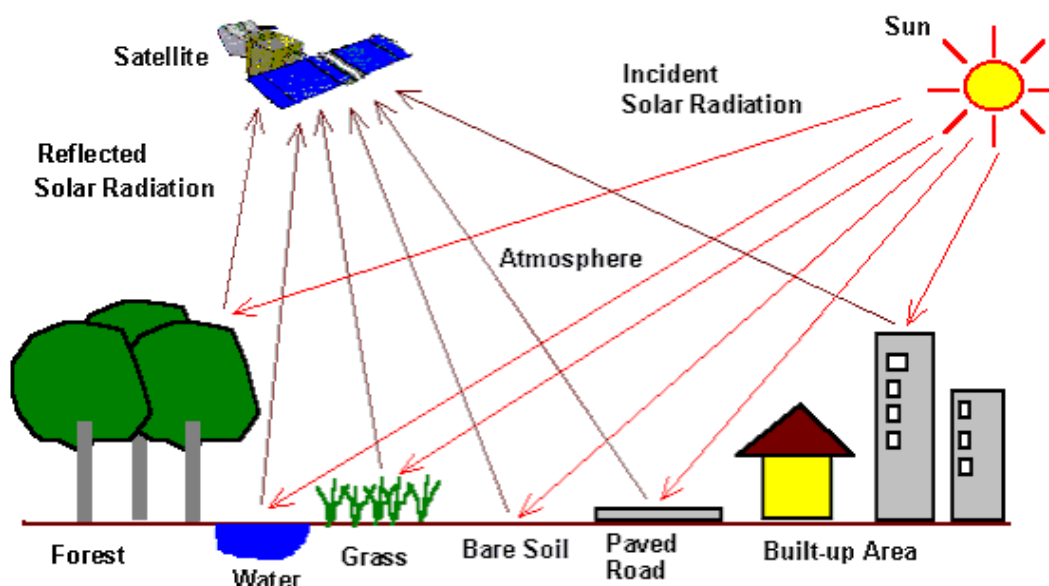
Remote sensing is the science of obtaining information about the earth's surface without making physical contact, which is commonly performed by using satellite or airborne (drones, aircrafts) platforms and on-ground-based sensors. By monitoring electromagnetic radiation reflected or emitted by plants and soils, it allows for early identification of modifications in plant health, soil moisture, nutrient status, water stress, and diseases. Information collected in visible and near-infrared (NIR), SWIR at shortwave infrared, thermal infrared and microwave wavelengths can be resulted useful for plant vigour, chlorophyll, biomass and canopy temperature analyses which contribute to make timely and accurate decisions for crop management.

Satellite Technology Revolutionizing Agriculture

Earth observation satellites have transformed agriculture through the provision of frequent, high-resolution images for monitoring crops over extensive areas. Free to access Sentinel and Landsat missions alongside commercial satellites such as PlanetScope and Maxar provide information to monitor crop health, soil moisture and land management.

In India, India's ISRO Resourcesat, Cartosat, RISAT, Oceansat and EOS provide support to crop forecasting, drought monitoring, irrigation management, and environment and natural resource management. Cloud computing

platforms like Google Earth Engine make satellite data even more accessible, enabling affordable precision agriculture and decision-making.



How Satellites Monitor Crop Health

Satellite sensors evaluate crop conditions by detecting sunlight reflected off plant canopies at multiple wavelengths. Healthy and stressed plants have characteristic spectral signatures, where healthy plants reflect more near-infrared (NIR) and absorb more red light than stressed plants. Vegetation indices like NDVI, EVI, NDWI and Red-Edge NDVI in combination with thermal infrared are commonly applied for assessment of crop vigor, biomass, chlorophyll content, water status, and canopy temperature. This technology allows monitoring for early signs of nutrient deprivation, water stress, and disease outbreaks to foster early intervention and enhanced crop productivity.

Precision Crop Monitoring Throughout the Growing Season

Remote sensing enables precision crop management from land preparation to harvesting with an update at each stage in the crop growth cycle. Satellite-based soil moisture maps allow farmers to determine when to plant

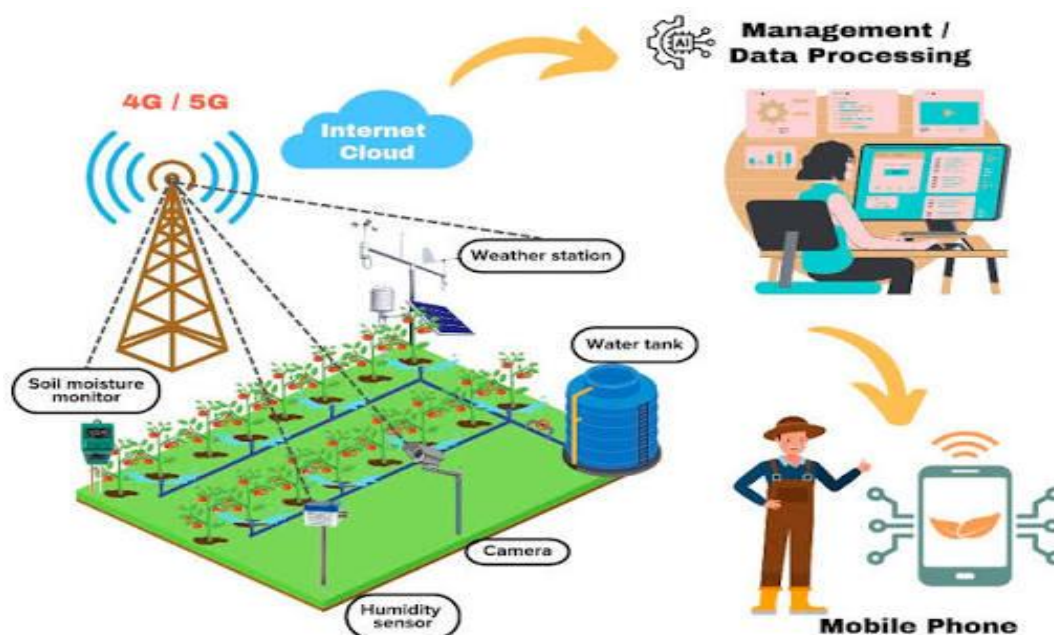
prior to sowing. Satellite images monitor germination, plant stand and initial growth during crop establishment. As crops grow, satellites track canopy cover, biomass production, leaf area index, nutrient status and crop health on an ongoing basis. Close to harvest, satellite measurements predict crop maturity and yield with remarkable precision. That data, when combined with GIS, is translated into field variability maps, which guides farmers on how best to manage their soil. Since crop performance can be tracked over multiple years using continuous seasonal surveillance, this can enable rationale planning for improving farm sustainability.

Smarter Irrigation Through Space Technology

Water-saving irrigation management is now indispensable as water resources become more and more limited, and satellite technology contributes remarkably in precise water management. Thermal IR images can identify water stress-induced canopy temperature increases, and microwave sensors can provide

reliable estimates of soil moisture content under all-weather conditions. Satellite-based evapotranspiration models estimate the actual water use of the crops, and hence we can schedule irrigation application on crop demand and not on fixed intervals. When combined with weather forecasts, IoT sensors, and automated

irrigation systems, the use of satellite irrigation guidance can bring better results in water-use efficiencies, minimizing groundwater depletion and energy consumption and decreasing irrigation costs. This technique enables the farmers to save their precious water resources and grow crops at desired optimal conditions.

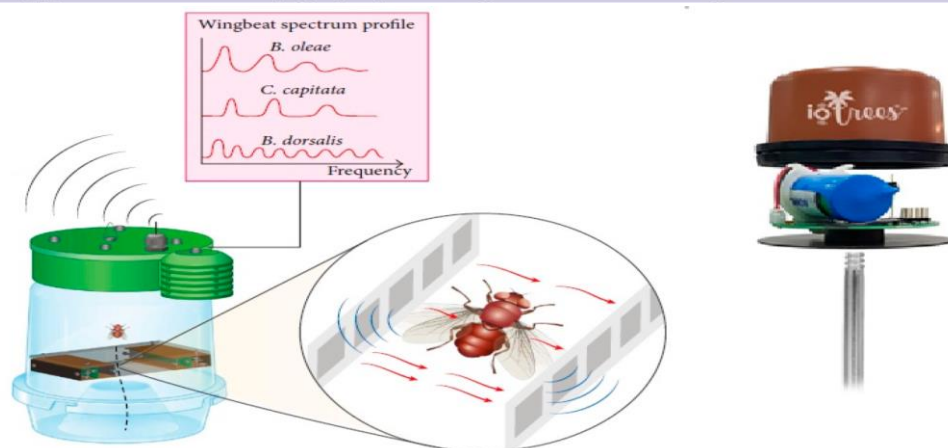


Early Detection of Nutrient Deficiencies

Remote sensing facilitates fast and nondestructive detection of nutrient deficiencies before the appearance of visible symptoms in plants. Satellite-based sensors detect minute variations in leaf chlorophyll content, a proxy for nitrogen deficiency, using red-edge spectral reflectance. Current generation satellites such as Sentinel-2 can provide a much more precise assessment of crop nutrient status and thus be used to generate variable rate fertilizer application maps. Thus, the farmers should apply the fertilizers where it is required and not more than what is required. Precision nutrient management enhances fertilizer use efficiency, decreases production cost, minimizes nutrient leaching and environmental pollution, and promotes sustainable agricultural production. Early nutrient diagnosis also promotes healthier crop growth and higher yields.

Detecting Pests and Diseases Before Major Damage

Satellite images combined with artificial intelligence have emerged as a powerful tool for early pest and disease monitoring. Pest and pathogen attacks change the physiology of crops, causing slight changes in reflectance patterns, which satellites can pick up even before the symptoms are visible. AI-powered image analyses detects unusual crops situation and integrates satellite data with weather information to forecast disease spread. These warnings systems allow for farmers to apply pest control at the right time and place not just spraying pesticides all over the place. This results in reduced crop loss, less pesticide application, protection of beneficial organisms, and more efficient and environmentally sustainable IPM practice.



Yield Prediction and Food Security Planning

Prediction of crop yield is now required in a broad range of applications, including by farmers, governments, insurance agencies and agribusiness. Based on satellite imagery combined with machine learning, this analysis of vegetation indices, crop growth, weather patterns, soil moisture and production history predicts yields up to several weeks prior to harvest. Good forecasts help farmers plan their harvest operations, marketing, and storage, and they are used by governments for procurement planning, food distribution, market stabilization, and disaster preparedness. Accurate estimation of the yield enables insurance evaluation of crops, and contributes to the assurance of food security at the national and global level in the face of a changing climate.

Climate-Smart Agriculture Through Satellite Intelligence

Contributions of satellite technology to climate-smart agriculture include the continuous monitoring of climatic variables affecting crop production. It monitors the rainfall distribution, drought severity, flood extent, temperature anomalies, evapotranspiration and phenological changes over the growing season. Long-term satellite-based observations allow construction of climate risk maps that inform decisions regarding choice of crops, planting date, irrigation scheduling, and other adaptation measures. Remote sensing is also used in monitoring carbon, estimating greenhouse gases, conservation agriculture and regencag farming systems. These serve to increase the resilience of agriculture and sustainable natural resource management under changing climate conditions.



Artificial Intelligence Enhances Satellite Agriculture

The benefits of satellite remote sensing have been greatly increased in recent years with the application of artificial intelligence to enable the rapid processing of huge amounts of farming data. Deep learning methods can accurately classify crop types, detect diseases, quantify biomass, perform land use classification, and predict yields. Satellite images are processed by cloud computing platforms in near real time, and digital twins combine satellite data with IoT sensors, weather data and crop models to offer intelligent decision support. Generative AI also translates sophisticated geospatial analysis into succinct advisory messages on smartphones in local languages, helping make cutting-edge precision agriculture technologies ever more accessible to smallholder farmers.

Indian Initiatives in Satellite-Based Agriculture

India has achieved significant milestones in the application of satellite technology for enhancement of agriculture through concerted efforts of ISRO, Ministry of Agriculture and Farmers Welfare and other research agencies. National programmes like FASAL, MNCFC, NADAMS and the Digital Agriculture Mission are leveraging satellite imagery, weather data, GIS and artificial intelligence based tools for crop area estimation, production forecasting, drought monitoring, irrigation scheduling, and disaster management. Satellite-based advisory services through mobile apps are also increasingly enabling farmers to take better decisions on when to irrigate, apply fertilizer or manage pests, farm insurance and more, leading to higher productivity and a more resilient agricultural sector.

Benefits Beyond the Farm

Satellites have more to offer to agriculture than only crop monitoring, bolstering the entire agri-value chain. Governments utilize satellite information technology to track crop area,

forecast production, evaluate drought effects, and deliver rapid relief. Remote sensing is used by insurance companies to assess crop damage quickly and by banks to assess the credit risk of agriculture. Long-term satellite data sets are used by scientists to investigate climate change, biodiversity, land degradation and sustainable resource management. In addition, agribusinesses are using satellite technology to enhance supply chain management, to track contract farming, to document product traceability and to provide food quality assurance. These are some of the ways in which agriculture is becoming more resilient, more transparent, and ultimately more sustainable.

Current Challenges

#Humanized output

Although impressive advancements have been made, a few hurdles remain that preclude mass utilization. The availability of an optical satellite image can be reduced due to persistent clouds during rainy season, but radar satellites are now increasingly used to handle this limitation. Very high-resolution commercial imagery is still expensive for many farmers. Precision management is difficult to implement with the small, scattered plots in developing countries. Digital illiteracy, poor internet infrastructure, lack of trained personnel, and low awareness are also barriers. As in other areas of the IoT, data interoperability, cybersecurity, and now also the standardization of ag-related data sets/streams and data privacy are key challenges in digital agriculture. Continued support for investment in digital infrastructure, farmer training, open-access satellite platforms and user-friendly decision-support tools will be necessary if agriculture is to continue to reap the benefits of satellite agriculture.

CONCLUSION

Remote sensing and satellite technology have revolutionized contemporary crop management by offering information based on time, precision, and field specificity conducive to

making well-informed decisions along the crop production process. From assessing crop status and irrigation management to yield prediction, pest identification, climate risk management and precision application of inputs, satellite-enabled agriculture is turning farming into a more productive, resource-efficient and environmentally friendly activity. With satellite constellations increasingly

sophisticated, artificial intelligence increasingly powerful, and digital advisory services increasingly available, soon even the smallestholder farmers will be able to benefit from the best of these innovations. The future of agriculture will not just be decided on the farm, but also from space satellites will become the real “eyes in the sky” for resilient, profitable and sustainable crop production.