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Satellite Remote Sensing Data for Decision Support in Emerging Agricultural Economies

How satellite data can transform agricultural decision making

This article considers the tremendous potential for satellite remote sensing information delivered via mobile digital applications to improve decision making in emerging agricultural economies. Earth observations have been available for use in weather and other models to support decision making since the late 1970s, with the launch of the advanced very-high-resolution radiometer and the Landsat sensors [1]. Despite early recognition of the potential for satellite remote sensing to transform farm-level decision making, information from satellite data is still not widely used by farmers day to day except in highly mechanized precision agricultural systems that represent a very small minority of farmers globally [2].

With the advent of cloud computing, high-speed Internet, expanding rural cellular coverage, and powerful mobile devices, the potential to use Earth observations for improving agricultural decision making is growing. However, two key issues are less well understood: how information derived from satellite remote sensing, delivered via mobile phones, is used and how it can change agricultural outcomes outside Western contexts. Digital agriculture is a new industry combining data sources, such as Earth observations and weather data, with advanced crop and environment models to provide actionable on-farm decisions in low-income settings. According to market research, the digital agriculture sector is expected to reach US$23.14 billion by 2022, rising at approximately 20% a year [3]. This explosive market growth is primarily attributed to the increasing demand for higher crop yield, the growing penetrate of information and communication technology into farming, and an increasing need for climate-smart agriculture.

This discussion focuses on organizations and individuals in agricultural value chains that are far from the data-rich environments of the United States and Europe but still need actionable, high-quality information to support decision making. A value chain is a series of activities conducted by a set of actors that transforms raw materials into finished products, allowing for the generation of income. Figure 1 outlines how satellite remote sensing information can inform decisions made by various actors at different points along the chain [4].

The challenge of feeding a growing global population with a constrained resource base and rapidly changing climate underscores the need for enhanced labor efficiency and higher productivity in agriculture. In both high and low-income countries, digital tools delivered via mobile devices increasingly offer opportunities for farmers to receive and respond to information. Given the growing global demand for food and a persistent yield gap between low and high-income countries [5], there is significant potential for relevant information derived from satellite remote sensing to transform decision making in agriculture [13]. Thus, to inform the development of future products and instruments in the Earth science sector, it is imperative to gain a better understanding of the use of satellite remote sensing information for decision making in emerging agricultural economies.

USES OF SATELLITE DATA WITHIN DIFFERENT SECTORS

Satellite data have the potential to transform agricultural practices if they are made available to farmers and other important actors along the agricultural value chain in ways that support decision making in an accessible and effective manner. This is particularly true in countries with infrequently updated agricultural statistics and poorly developed supporting infrastructure—settings in which small farms dominate [9]. However, as the saying goes, "the devil is in the details," and many details must be understood and a host of practical

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considerations addressed to provide accessible and effective decision support. The following discussion outlines the ways in which satellite data are positioned to support decisions by various actors, including farmers, agribusinesses and nongovernmental organizations (NGOs) that interface with farmers, agricultural processors, and banks that offer loans to farmers. Thereafter, we describe challenges that limit the use of remote sensing data and identify opportunities for addressing those challenges.

FOR MIDSIZE AND LARGER FARMS, SATELLITE-BASED DATA DECISION SUPPORT OFFERS A NUMBER OF BENEFITS AND MAY BE PAIRED WITH TARGETED AGRONOMIC GUIDANCE.

COMMERCIAL FARMERS

In emerging economies, agricultural and technological conditions are often vastly different from those in the United States and Europe. However, a massive shift is starting to occur as digital technologies introduced into developing economies create new opportunities for farmers to utilize digital platforms that employ satellite imagery as a means of identifying individual plots and accessing data on cultivation activities and yields over successive planting seasons. In fact, a frequently overlooked contribution remote sensing can make in under-resourced areas is that of providing an accurate assessment of field size, which enables more precise purchasing and application of agricultural products such as fertilizers, herbicides, and pesticides in keeping with product specifications. The overuse and misuse of agricultural chemicals can be a significant source of negative health impacts, despite such chemicals' contribution to improved yields [10].

Before delving into the types of decisions satellite data may support at the field level, it is important to acknowledge that Earth observation data provide little to no direct decision-making support to smallholder farmers in Africa and Asia. Farmers in these settings often tend fields of less than one hectare in size, enabling them to directly monitor their plots for any emerging problems and estimate yields [11].

For midsize and larger farms, satellite-based data decision support offers a number of benefits and may be paired with targeted agronomic guidance. The normalized difference vegetation index (NDVI) [12] from optical satellite data helps identify the location of unhealthy crops and excessive greenness that may represent a weed infestation. These signals can be used to trigger an alert that directs the farmer to assess the location in question.

The remote monitoring of crops often allows farmers to identify problem areas sooner than is possible through traditional scouting techniques, which require farmers or staff from a contracted scouting company to drive to the site and monitor conditions through binoculars and/or by walking through the field in a "W" pattern. Given the long distances a scout would need to walk, large farms spanning 5,000–10,000 hectares or more are impossible to monitor through traditional scouting. With remote sensing-based information accessed through mobile apps, owners can monitor their lands from any location and alert their employees to respond as needed.

AGRIBUSINESS

In emerging economies, agribusinesses interface with farmers through a diverse network of retailers. Through the supply chain, these large input providers sell seeds, fertilizers, pesticides, and herbicides to farmers around the world. In addition, global agribusinesses that produce seeds manage contractors that produce hybrid seed for resale. They also have demonstration fields where local farmers get discounted seeds and chemicals in exchange for posting promotional signs near their fields and letting the company host marketing events with neighboring farmers.

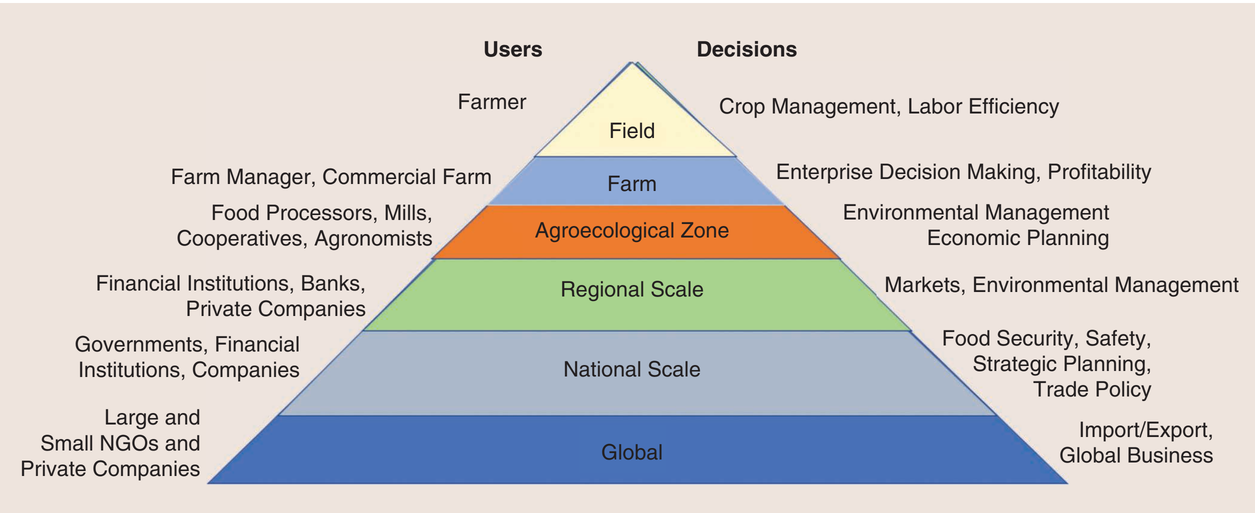

FIGURE 1. The users of and decisions based on information derived from satellite remote sensing. Derived from Jones et al. [4]. NGO: nongovernmental organization.

Agribusinesses are increasingly using satellite-based information to become more proactive in monitoring and managing contracted fields, particularly because each of the company's agronomists may be responsible for overseeing several dozen fields located hundreds of kilometers apart. Satellite-based information enables agronomists to be much more efficient via remote monitoring to identify the subset of fields in the most need of attention.

Some agribusinesses are also providing their customers with mobile apps, paired with variety-specific agronomic guidance, at no charge. Once farmers are given mobile tools that enable them to digitize their fields, company agronomists can provide guidance throughout the growing season—indicating when to apply fertilizer, insecticide, and herbicide and when to scout for potential problems. Some experts hypothesize that such services will result in substantial increases in yields and profits, ultimately returning greater revenue to both farmers and participating companies, as farmers realize the advantages and increase their purchasing.

This level of integration and real-time interaction between input providers and farmers has the potential to help address the perennial challenges of delivering goods to farmers when and where they are most needed. As a remote sensing scientist at a digital agriculture company stated, "One of the biggest problems and least talked about issues providers face is getting the right product to the right place at the right time in the right quantity" [11]. Digital platforms that identify a farm's location, along with the particular products the farmer needs at a given time, enable suppliers to strategically position their products and sales agents based on real-time data. Increasingly, it appears that digital extension is moving toward end-to-end digitization that promises to be mutually beneficial to farmers and input providers, particularly in regions with relatively underdeveloped commercial agricultural sectors.

Digital tools can also be used to compare farmers' fields. If one farmer is growing sugarcane extremely well at 80–90% of potential NDVI values and a nearby farmer's field is at 70–75%, company agronomists can advise the latter farmer of management practices to boost yield, such as applying certain fungicides, insecticides, and fertilizers. These remote monitoring and advisory functions are key to improving yields in regions where information on appropriate management strategies is often lacking [13].

AGRICULTURAL PROCESSORS

Digital agriculture companies are developing partnerships with agricultural processors, such as sugar factories and rice millers, because their business processes could be greatly informed by remote sensing information. Some processors, such as sugar factories in India, operate with a dearth of information, including how much sugarcane is planted in their catchment area. At the beginning of harvest season, staff members of these factories do not know if they will receive the same volume of sugarcane as the previous year, twice that volume, or a small fraction thereof. Combining Earth observation data with field-level data provided by farmers through a mobile application gives processors much better estimates of the volume they can expect. Furthermore, if farmers follow recommended management practices, their yields can be expected to increase, positioning both farmers themselves and factories for greater profits.

THESE REMOTE MONITORING AND ADVISORY FUNCTIONS ARE KEY TO IMPROVING YIELDS IN REGIONS WHERE INFORMATION ON APPROPRIATE MANAGEMENT STRATEGIES IS OFTEN LACKING.

Rice millers face similar challenges and have the potential to realize comparable benefits from the use of satellite data. In addition to needing better estimates of the amount of rice they will receive after the harvest, the quality of the rice is critical for getting the best price in export markets. Enhancing quality production through the use of digital platforms that combine field monitoring and agronomic recommendations benefits farmers and processors alike. Exporters source vast quantities of rice from contract farmers, spanning broad geographic regions, so it is critical to obtain reliable estimates of production totals. By developing specific protocols for each contracted farmer and uploading them to a digital app, exporters can ensure that the farmers receive this information via their mobile phones on a regular basis. To enhance adherence to established protocols and demonstrate the application of recommended products, farmers can be asked to provide geolocated pictures or take photos of quick response (QR) codes connected to a database and an object, such as a telephone pole or tree, that identify the location of the photographer.

BANKS THAT ADMINISTER AGRICULTURAL LOANS

The ability to observe farm fields and monitor farming practices through satellite data has the potential to greatly influence commercial lending. The increased transparency and accountability provided by remote sensing information can reduce uncertainty and benefit both lending institutions and farmers seeking loans. Banks can offer better terms for loans if they have a clearer picture of the risk. Two relevant categories of risk are weather and farmer negligence. Looking at historical NDVI information alongside weather data for the plots of land under consideration, lenders can determine whether a lack of productivity was caused by extreme weather conditions, including natural disasters, or by farmer negligence. This simple form of analysis has long been available to lenders and is gradually being incorporated into some institutions' decision-making processes.

Providing banks with crop growth-stage maps presents another promising use of Earth observation data. Although this basic monitoring capacity has been available for years [14], the key is linking plant health compared to its predicted growth stage to lending decisions. For instance, loan disbursements can be tied to appropriate crop growth throughout the growing season. Similarly, loan collection can be timed more precisely to the harvest date based on monitoring data. Bank representatives could check on field conditions by driving out to the fields to assess the situation in person. However, the time and expense required are cost-prohibitive. If the use of satellite data reduces the cost of administering loans, financial services are poised to become a huge new market for digital agriculture companies [15].

In Africa, loan repayments are particularly low compared to other regions [16]. Crop failures and other causes of underproduction lead to loan defaults in many instances. However, overproduction poses major problems as well. A bumper crop creates a glut and drops the price. If banks can predict this outcome with a small investment in remote sensing and prediction modeling, they are much better positioned to address the issue.

IMPROVING THE UTILITY OF SATELLITE REMOTE SENSING

It would be advantageous for governments to invest in launching more satellites that can provide higher-resolution imagery on more frequent bases. By reducing the cost of each sensor, the European Space Agency (ESA) and NASA could launch many more satellites, increasing the frequency of images available. By focusing on critical applications, such as agriculture, more appropriate data could be developed that meet the needs of this essential industry [17].

Information collected by unmanned aerial vehicles (also known as drones) flying at much lower altitudes can complement satellite data gathered from space. For instance, drones can fly below the clouds and thus capture images under weather conditions that hinder data collection by satellite. However, the use of drones for data gathering is too costly to implement at large scales given the number of drones required to collect substantial volumes of data [18].

Enhancing the use of satellite data in emerging agricultural economies will also require outreach activities that introduce farmers to the benefits of decision support and address data privacy and use concerns (Table 1). In addition, simplifying satellite-based mobile applications and delivering them in local languages would enable many more farmers to access Earth observation information and apply it to field-level decision-making processes [19].

IMPLICATIONS FOR EMERGING AGRICULTURAL ECONOMIES

Satellite remote sensing data have been available to the agricultural community for nearly four decades. Although much has changed in agriculture during that time frame, the need for high-quality, specific guidance on how to monitor fields, understand regional changes in agricultural activity,

TABLE 1. CHALLENGES AND OPPORTUNITIES FOR ENHANCING THE USE OF SATELLITE DATA IN AGRICULTURE

CONTEXT	TYPES OF DATA AVAILABLE	LIMITATIONS OF USE	OPPORTUNITIES
Government-provided free satellite data	They provide free coarse- or moderate-resolution optical, radar, precipitation, and temperature data.	Free data do not provide sufficient spatial information necessary for field-level decision making.	The low price point enables the development of sustainable business models.
Commercial satellite data	Very-high resolution (VHR) optical commercial imagery is available, but not for all agroecological regions.	The cost of commercial data is prohibitive for most farmer decision support using existing business models.	VHR data enable identification of small fields and buildings.
Atmospheric contamination	One form of data is radar data that can see through clouds, dust, and smoke. Another is atmospheric correction of optical vegetation data.	Limitations include challenges in interpreting radar data for the typical user and the inability to retrieve agricultural signals when there are many clouds during rainy season.	The growing availability of radar data sets will foster new applications for agriculture.
Frequency of observations	Most free satellite data provide images of a farm every three to 16 days.	Limitations include daily observations preferred for growth stage and crop health, particularly in cloudy regions.	Data fusion using artificial intelligence will enhance the utility of data sets.
Ground information on agricultural productivity	Information includes a lack of geospatially referenced, field-specific, high-quality ground observations of crop type and yield.	Ground data are required for using satellite remote sensing directly in yield- and crop-type classification models.	The increasing penetration of mobile phones in rural areas will provide opportunities for data gathering.
Expertise in remote sensing	Satellite data calibration, version, availability, and overpass time change as the sensor ages.	Limitations include the substantial expertise and experience necessary for downloading, processing, and subsetting.	New open source geospatial data platforms will allow affordable access to satellite data.
Accessing satellite-based AgTech tools	Data available include the requirement of Wi-Fi or cellular services and a smartphone or computer.	The digital literacy of marginal groups presents a substantial barrier to access.	The increased use of smartphones will greatly expand information on farm management.
Data privacy and use concerns	Data available include satellite data acquisitions and transformations to produce high-quality crop area and yield information by third parties.	Limitations include the fear of information being used for regulatory or economic purposes without permission.	Data provision and collection could become a new income source in regions with very poor data availability.

AgTech: agricultural technology.

and improve yields continues to be critical. Particularly in regions that are data poor, satellite data are essential for enhancing the understanding of evolving production trends and climate-related disasters [20], [21].

Low-income countries that lack high-quality, high-resolution agricultural statistics [22] depend on satellite remote sensing to better characterize their agricultural system. However, individuals who need field-level management advice and decision support encounter challenges finding and accessing relevant data. Recent growth in satellite data availability, reductions in the cost and time required to transform large volumes of data, and the enormous expansion of mobile technologies in rural areas increase the likelihood that farmers will actually use satellite data for decision making.

Widespread need exists for high-quality, calibrated, and free satellite remote sensing to inform the development of high-quality statistics for use in agricultural decision making, particularly in the context of the United Nations' Sustainable Development Goals (SDGs) and other international targets. Earth observation data provide important information for national adaptation plans (NAPs), related to climate change that connect national commitments to achieving SDGs. The agricultural sector is particularly vulnerable to climate change, and it is thus critical that reliable information infrastructure, operating on national and regional levels, is available to support the effective implementation of NAPs.

Improving tools that can be used to access calibrated, cloud-free data comparable over multiple years is a pressing policy need. Given the urgent and ongoing requirement to improve agricultural productivity and efficiency across the world, agricultural applications, such as those discussed here, deserve priority as NASA and the ESA consider new sensors and investments [23].

A significant constraint to improving the utility of satellite data is having access to ground-truth data to which the satellite imagery can be connected. Analytics, such as image segmentation, classification, feature extraction, and photogrammetry, all need training data [24]. Fundamentally, crops look different in each country and region because of differences in soil color, row spacing, and field size. Without specific, comprehensive, multiyear training data from the ground, satellite data will remain a "nice to have" information source but will not become central to decision-making processes at multiple scales for the private sector.

The cost of gathering, cleaning, and evaluating ground data and the issues of data ownership and privacy mean that no private and very few public organizations have shared the data they have despite widespread acknowledgment that this is important to advance the science [25]. There are a number of ongoing efforts to increase comprehensive ground data available in the public domain for use by scientists, notably by the Bill and Melinda Gates Foundation, but it will take a concerted effort to gather, analyze, distribute, and utilize the data in ways that are already widespread in regions with high-quality agriculture information, such as the United States and Europe. This is a critical need for improving the utility of satellite data for commercial agricultural systems. That said, publicly available satellite data will continue to fuel innovative businesses that leverage expertise in translating the raw data into public and private goods, improving productivity across the agriculture sector [26].

THERE ARE A NUMBER OF ONGOING EFFORTS TO INCREASE COMPREHENSIVE GROUND DATA AVAILABLE IN THE PUBLIC DOMAIN FOR USE BY SCIENTISTS.

A great potential exists for remote sensing to be used within the financial services industry. Currently, there is a substantial gap between the need for financial services, including loans and commercial banking services, and the availability of those services to the millions of smallholder farmers [15]. Credit provided by informal and formal financial institutions, as well as other value chain actors, currently meets only a quarter of the need for smallholder finance in the regions of sub-Saharan Africa, Latin America, and South and Southeast Asia [27]. Agricultural insurance, which can be triggered directly with remote sensing observations, reaches just 10% of smallholders [28], [29]. Satellite remote sensing observations can be transformative in insurance companies' ability to assess risk, trends, climate impacts, and yields across large areas for low cost. Future changes in the use of Earth observation data can significantly affect business outcomes in the financial sector.

As remote sensing data and technology continue to evolve, the awareness of user needs becomes increasingly important to inform the development of tools and products that will impact global agricultural value chains. The awareness of user needs has become indispensable in the data-rich environments of the United States and Europe, and this pattern is likely to hold true for emerging agricultural economies. Realizing the potential societal value and impact of remote sensing data depends not only on the technology, delivery, and awareness of the satellite data themselves but also on relationships and trust with users in the agricultural community.

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