Satellite Remote Sensing Data for Decision Support in Emerging Agricultural Economies

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This article considers the tremendous potential for satellite remote sensing information delivered via mobile digital agriculture applications to improve agricultural 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 still is not widely used by farmers for day to day decision making beyond 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 that is 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 $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 penetration of information and communication technology (ICT) in farming, and the 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 which 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 transform raw materials into finished products, allowing for the generation of income. Fig. 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 a 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 are rapidly becoming an important way 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], the potential for relevant information derived from satellite remote sensing to transform decision making in agriculture is high [13]. Thus, it is imperative to gain a better understanding of the use of satellite remote sensing information for decision making in emerging agricultural economies to inform the development of future products and instruments in the Earth science sector.

Uses of Satellite Data within Different Sectors

Satellite data have the potential to transform agricultural practices if the data 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. However, as the saying goes, "the devil is in the details" – and there are many details that must be understood and a host of practical considerations to be addressed in order 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 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 offer suggestions for addressing those challenges.

A. Commercial Farmers

In emerging economies, agricultural, and technological conditions are often vastly different from that in the United States and Europe. However, a massive shift is starting to occur as digital technologies are introduced into developing economies, thereby creating new opportunities for these farmers to utilize digital platforms that employ satellite imagery to identify individual plots and access data on cultivating

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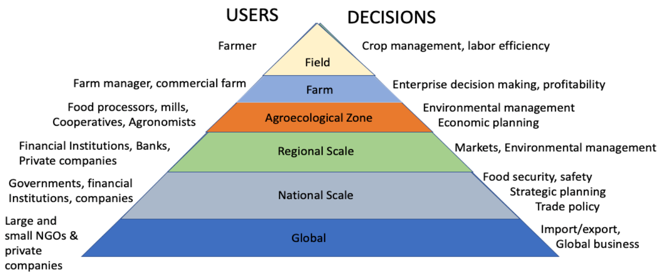

Fig. 1. Decisions made on and users of information derived from satellite remote sensing. Derived from Jones et al 2017

activities and yields over successive planting seasons. In fact, a frequently overlooked contribution that 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. Overuse and misuse of agricultural chemicals can be a significant source of negative health impacts, despite chemicals' contribution to improved yields [9].

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 [10].

For midsize and larger farms, satellite-based data decision support offers a number of benefits and may be paired with targeted agronomic guidance. Normalized difference vegetation index (NDVI) [11] from optical satellite data helps to identify the location of unhealthy crops and excessive greenness may represent a weed infestation. These signals can be used to trigger an alert that directs the farmer to assess the location in question.

Remote monitoring of crops often allows farmers to identify problem areas sooner than is possible through traditional scouting techniques, in which farmers or staff from a contracted scouting company drive to the site and monitor the conditions through binoculars and by walking through the field in a "W" pattern. Large farms, spanning 5,000 to 10,000 hectares or more, are impossible to monitor through traditional scouting given the long distances a scout would need to walk. 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.

B. *Agribusinesses*

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 neighbor farmers.

Agribusinesses are increasingly using satellite-based information to become more proactive in monitoring and managing contracted fields, particularly given that 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 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 farmers and to the 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" [10]. 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 also can be used to compare farmers' fields. If one farmer is growing sugarcane extremely well at 80 to 90 percent of potential NDVI values and a nearby farmer's field is at 70 to 75 percent, 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 [12].

C. *Agricultural Processors*

Digital agriculture companies are developing partnerships with agricultural processors, such as sugar factories and rice millers, since 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, these factories do not know if they will receive the same volume of sugar cane as last year, twice that volume, or a small fraction thereof. Combining Earth observation data with field-level data that farmers provide through a mobile application gives processors much better estimates of the volume they can expect. Furthermore, if farmers follow recommended management practices, their yields are expected to increase, positioning both farmers and factories for greater profits.

Rice millers face similar challenges and have the potential to realize similar benefits from the use of satellite data. In addition to needing better estimates of the amount of rice they will receive after 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 the protocols to a digital app, farmers can receive this information on their mobile phones on a regular basis. To enhance adherence to the protocols, farmers can be asked to provide pictures or use QR codes to demonstrate the application of recommended products.

D. *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. 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 risk 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 farmer negligence. This simple form of analysis has long been available to lenders and is gradually being incorporated into some institution's 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 [13], the key is linking the 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 [14].

In Africa, loan repayments are particularly low compared to other regions [15]. 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, 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 meets the needs of this essential industry [16].

Data collected by unmanned aerial vehicles (UAVs or 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 in 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 that would be required to collect substantial volumes of data [17].

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

Table 1. The Challenges of Using Satellite Data in Agriculture.

	Types of Data Available	**Limitations of Use**
Government-provided Free Satellite Data	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.
Commercial Satellite Data	Very high resolution optical commercial imagery is available, but not for all agroecological regions.	Cost of commercial data is prohibitive for most farmer decision support using existing business models.
Atmospheric Contamination	Radar data that can see through clouds, dust, and smoke. Atmospheric correction of optical vegetation data.	Challenges in interpreting radar data for typical user, and inability to retrieve agricultural signal when there are many clouds during rainy season.
Frequency of Observations	Most free satellite data provides images of a farm every 3 to 16 days.	Daily observations preferred for growth stage and crop health, particularly in cloudy regions.
Ground Information on Agricultural Productivity	Lack of geospatially referenced, field specific, high quality ground observations of crop type and yield.	Ground data required for using satellite remote sensing directly in yield and crop type classification models.
Expertise in Remote Sensing	Satellite data calibration, version, availability, and overpass time change as the sensor ages	Substantial expertise and experience necessary for downloading, processing, subsetting.
Accessing Satellite-based AgTech Tools	Requirement of wifi or cellular services and a smartphone or computer.	Digital literacy of marginal groups presents a substantial barrier to access.
Data Privacy and Use Concerns	Satellite data acquisitions and transformations to produce high quality cropped area and yield information by third parties.	Fear of information being used for regulatory or economic purposes without permission.

languages would enable many more farmers to access Earth observation information and apply it to field level decision making processes [18].

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 timeframe, the need for high quality, specific guidance on how to monitor fields, understand regional changes in agricultural activity, and improve yields continues to be critical. Particularly in regions that are data-poor, satellite data are essential for enhancing understanding of evolving production trends and climate-related disasters [19], [20].

Low income countries that lack high quality, high resolution agricultural statistics [21] 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 increases 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 for use in agricultural decision making. Fritz et al [22] discussed the use of data across multiple, public agricultural monitoring systems that aim to provide up-to-date information regarding food production to different actors and decision makers in support of national and global food security. Improving tools that can be used to access calibrated, cloud-free data that are comparable over multiple years is a pressing policy need. Given the urgent and ongoing need to improve agricultural productivity and efficiency across the world, agricultural applications such as those discussed here deserve priority as NASA and 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, multi-year training data from the ground, satellite data will remain a “nice to have” information source and will not become central to decision making processes at multiple scales for the private sector. The cost of gathering, cleaning, and evaluating ground data means 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 ground 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, which leverage expertise in translating the raw data into public and private goods, improving productivity across the agriculture sector [26].

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 [14]. 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 the Earth observation data can significantly affect business outcomes in the financial sector.

As remote sensing data and technology continue to evolve, awareness of user needs becomes increasingly important to inform the development of tools and products that will impact global agricultural value chains. 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 are not only dependent on the technology, delivery, and awareness of the satellite data itself, but on relationships and trust with users in the agricultural community.

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