[DA-001] GIS&T and Agriculture

Abstract

Agriculture, whether in the Corn Belt of the United States, the massive rice producing areas of Southeast Asia, or the bean harvest of a smallholder producer in Central America, is the basis for feeding the world. Agriculture systems are highly complex and heterogeneous in both space and time. The need to contextualize this complexity and to make more informed decisions regarding agriculture has led to GIS&T approaches supporting the agricultural sciences in many different areas. Agriculture represents a rich resource of spatiotemporal data and different problem contexts; current and future GIScientists should look toward agricultural as a potentially rewarding area of investigation and, likewise, one where new approaches have the potential to help improve the food, environmental, and economic security of people around the world.

Keywords: data modeling, decision-making, globalization, precision agriculture, soil, water

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Explanation

1. Background and context
2. Role of GPS and remote sensing data collection methods
3. Improving agricultural decision making
4. Democratizing GIS&T applications in agriculture
5. Emerging themes and issues

1. Background and context

Agricultural systems are fundamentally spatial. Regardless of the scale of agriculture production, farmers are charged with managing their fields from before planting to after harvesting, in order to ensure a bountiful harvest. At the same time, farmers are faced with many challenges and a great deal of uncertainty. From the selection of the most appropriate seed for their specific environmental conditions, to unpredictable weather, to highly localized variability in soils, nutrient and water availability, agriculture is a complex and highly spatially dependent process.

Spatial information has long been a part of agriculture and has played a critical role in successful agriculture for as long as plants have been domesticated, with indigenous (spatial) knowledge serving important roles in mediating the highly complex and dynamic nature of agricultural systems (Orlove, Roncoli, Kabugo, & Majugu, 2010). The natural complements between geographic information and farmer knowledge have been long recognized (Lawas & Luning, 1996) and, through the years have evolved into sophisticated systems to support real-time, automated decision-making, in many instances more by farmers' equipment then by the farmers themselves (Gerhards & Christensen, 2003).

GIS&T is found throughout the agriculture sector and in agriculture systems throughout the world; from the embedded systems of large industrial scale tractors and combines to the cellphone found in the hands of a smallholder farmer, spatial information is everywhere. Why is this?

2. Role of GPS and remote sensing data collection methods

Throughout the many application areas in which GIS&T plays an important role, one of the early challenges was, almost universally, the collection of data. In an agricultural context this is especially true as agricultural data has a great deal of temporal variability, spatial variability, and usually variability in both space and time. That spatial and temporal variability were omnipresent in agriculture formed the basis for the precision approaches that would later emerge wherein it was recognized that management at the farm scale would often miss highly local phenomena (Mcbratney, Whelan, & Shatar, 1997). The first wave in the development of precision agricultural can largely be attributed to a combination of increasingly accurate GPS data coupled with analysis of remotely sensed imagery in order to make "spot" decisions regarding crop management. As the applications advanced, the inclusion of instrumented tractors into the equation and even higher resolution imagery offered even more resource use efficiency and ever greater capacity for data collection and spatiotemporal analysis (Seelan, Laguette, Casady, & Seielstad, 2003).

The preponderance of geospatial data and analytic approaches in large scale precision agriculture often masks the relevance of the same technologies to smallholder producers. GPS and remote sensing have helped in increasing understanding of the drivers of spatial patterns of developing world agriculture (Sibanda & Murwira, 2012), as well as in the quantification of landscape scale greenhouse gas emissions in areas dominated by smallholder agriculture (Milne et al., 2013).

Smallholders can also benefit directly from GPS and remote sensing. Around the world, novel approaches are being implemented that specifically build sustainable business models around the provision of geospatial information-based services, including index-based crop insurance, early warning systems, and integrated pest management among other uses (see the Geodata For Agriculture and Water of the G4AW Facility of the Netherlands Space Office for cutting edge examples of this approach).

As remote sensing and data processing capability evolves, the use of very high resolution imagery is becoming increasing commonplace. New remote sensing platforms bring higher resolution electro-optical imagery into agriculture applications and new ensemble learning approaches facilitate the use of such imagery to revisit classic problems such as accurate crop cover identification (Colkesen & Kavzoglu, 2017). Machine learning approaches coupled with high resolution imagery also allow for better characterization of structural aspects of the landscape such as soil conversation measures (Eckert, Tesfay Ghebremicael, Hurni, & Kohler, 2017). Finally, with very high temporal, spatial and spectral resolution imagery, precision agriculture is moving toward even greater fidelity and, in turn, more efficient and tailored management of production systems (Zarco-Tejada, González-

Dugo, & Fereres, 2016).

3. Improving agricultural decision-making

The value proposition of GIS&T in agriculture is based principally on importance of geographic information as an ingredient in better agricultural decision-making. In this vein, precision agriculture as described above is essentially about making better spot decisions about what treatment is required in a very specific location. Though precision agriculture has received much attention in the GIS&T community, other aspects that can be more broadly considered “precision agriculture” merit the attention of both researchers and practitioners in GIS&T.

From this perspective, precision agriculture is any activity that helps agricultural stakeholders make more informed decisions given their local environmental context. Broadly, GIS&T is an integral component of improved decision-making in several key areas:

3.1 **Agricultural suitability analysis** borrows from the many different areas of suitability analysis in GIS, but with a focus on understanding the potential of agriculture in different geographic contexts. Suitability analyses have been a mainstay of GIS&T in agriculture for many years, with multi-criteria decision support (MCDS) approaches figuring prominently (Mendas & Delali, 2012). Given the inherent uncertainty in agriculture systems, fuzzy MCDS approaches are also highly relevant and allow for specification of parameter spaces with less than crisp boundary conditions (Mbũgwa, Prager, & Krall, 2015). With the heterogeneity associated with impacts of climate change, understanding future suitability is also a key priority. In coffee, for example, integration of climate model projections into a pixel-based random forest models for coffee agro-ecological zones offers new insights into geographies where the viability of Coffea arabica is expected to change over time (Bunn, Läderach, Pérez Jimenez, Montagnon, & Schilling, 2015).

3.2 **Effective community engagement** to improve agricultural output, lower the environmental impact of agricultural activity, or to increase the overall sustainability of the agricultural enterprise is critical and typically involves developing understanding around either a set of spatial or spatiotemporal questions. Spatial analytic approaches that map the “socioecological network” of smallholders on the landscape demonstrate how interventions tailored to individual farmers’ geographic and socioecological contexts may have the potential to improve the effectiveness of the rainwater management (Prager & Pfeifer, 2015). GIS&T also serves as an important tool for facilitating stakeholder participation in decision making and long-term planning through participatory approaches (King, 2002). As with many aspects in GIS&T, however, careful consideration of how the technology is used is required so as to understand how the use of technology and the participatory approach itself may empower or disempower different members of the community (Chambers, 2006), underscoring the importance of critical GIS in agriculture and related issues (Galt, 2011).

3.3 **Management and targeted improvement of genetic resources** is inherently a spatial problem. Understanding the way in which different crops are adapted to specific environmental conditions requires understanding the ecological and geographic patterns of gene bank and herbarium collections. This need led to the development of a geographic information system explicitly designed for those without access to expensive commercial software but with a need to perform relatively sophisticated analyses of climate and ecological data (Hijmans, Guarino, Cruz, & Rojas, 2001). Similar spatial analyses have become a mainstay for those interested in conserving crop biodiversity with a focus on identifying priority conservation areas around the world for different for crop “wild relatives” (Castañeda-Álvarez et al., 2016). Conventional crop breeders also take advantage of both geographic information and spatial analyses in order to identify “target population environments” or combinations of environment and management conditions analogous to future needs. The breeders can than orient their strategies to these present geographic conditions and the crop varieties that are expected to function best in the context of the expected future characteristics (Heinemann et al., 2015; Hyman, Hodson, & Jones, 2013).

The range of applications of GIS&T is limited only by the creativity of those involved. GIS&T in agriculture is here to stay; as agricultural experts become more deeply familiar with GIS&T approaches, an abundant range of new potential applications will emerge.

4. Democratizing GIS&T applications in agriculture

One of the turning points in GIS&T for agricultural was the wide availability and access to relevant spatially explicit information. Early databases such as the US Department of Agricultural Soil Survey database (known as SSURGO) enabled some of the early modeling of the climate-environment interface (Wilson, Inskeep, Wraith, & Snyder, 1996). The value and importance of soil and other wide-area coverage databases has led to the development of a number of regional and global tools to access and consolidate this type of information, including the Web Soil Survey distributed in the United States and global datasets such as those from the International Soil Reference and Information Centre.

As with the general proliferation of geospatial technologies and databases, the proliferation of GIS&T applications in agriculture has largely been facilitated by the development of relatively simple web-based interfaces (Haklay, Singleton, & Parker, 2008). Though not without their own set of potential perils related to uncertainty, fitness for use, and timeliness, these web-based interfaces have served to bring more information to an increasingly broad base of next users.

One of the early widely known applications in the agricultural community was the Famine Early Warning System (FEWS) Network. Developed by USAID and its implementing partners in 1985, the FEWS Network has become one of the leading resources for generation and distribution of information on potential situations of acute food insecurity. The FEWS implementation offers users with near real-time updates on how both slower, longer-term trends and more immediate pressures combine to create food insecurity (Funk & Verdin, 2010).

Another interesting example in the use of near real-time information is the Terra-I system developed by the International Center for Tropical Agriculture. Terra-I was designed to support the monitoring of forest cover change and to generate alerts in cases where forest cover change is different that would be expected given prevailing environmental conditions (Leisher, Touval, Hess, Boucher, & Reymondin, 2013). The easily usable interface and available data bring the ability to monitor changes in forest cover to a very broad range of potential users.

With the growing availability of increasingly high spatial and temporal resolution remotely-sensed characterization of land cover, new tools are emerging to plan and monitor specific implementations intended to improve agricultural systems. The SERVIR division of USAID has led the way in the development of many agricultural related applications, including the AGRISERV and ECO-DASH for on-demand analysis of climate-vegetation relationships. These systems allow for users from a variety of disciplines to access both geographic information and vetted analytic approaches in order to support improved decision-making and more efficient monitoring and evaluation of prior agricultural and related development interventions.

5. Emerging themes and issues

Many of the trends that are influencing GIS&T more broadly are having similar impact in GIS&T in agriculture. The emergence of citizens as sensors (Goodchild, 2007), for example, is directly related to site specific agriculture and other participatory approaches leveraging the ever increasing reach of smartphone technology.

As in many applied sciences, automated and autonomous aerial vehicles have the potential to offer a range of important applications in agriculture. Ranging from aerial phenomics (Guzman, González-Navarro, Selvaraj-Gomez, Valencia, & Delgado, 2015) to agricultural survey, decision support, and long-term monitoring (Herwitz et al., 2004), drones are rapidly becoming yet another complement to other high fidelity sources of spatiotemporal information about agriculture. In contrast to satellite-based remote sensing, drone technologies can offer near real-time on-demand monitoring and can be used to quickly assess field status following a management decision or unexpected biophysical shock.

There is already an extensive range of applications of GIS&T in agriculture and the uptake of GIS&T in agriculture happened quickly. The reader is reminded of the need for critical approaches supporting GIS&T in agriculture that analogous to those seen in other disciplinary areas (O'Sullivan, 2006). With a science-informed approach and engagement with the technology (from a critical perspective or otherwise), we will hopefully be able to better anticipate and inform the direction of future research related to GIS&T in agriculture.

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