Innovation in Agriculture and Food Systems in the Digital Age

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Agriculture and the worldwide food system are challenged to feed an estimated global population of 9.7 billion people by 2050 with diminishing land and water resources.[1] Agricultural land areas can no longer be expanded because most global arable lands have already been put into production. The remaining lands are increasingly lost to urbanization or need to be preserved for habitat conservation, biodiversity, and climate buffers.[2] Moreover, the unsustainable overuse of freshwater resources from irrigation is making less water available for future crops, and food security is being affected by increased risk from climate change and an uncertain geopolitical landscape.

Concerns with diminishing resources and expanding populations are exacerbated by changing diets in many developing countries (which are now using more animal-based protein and fresh produce). This will ultimately require higher global production levels of the primary source of protein, carbohydrates, and nutrients: crops. An effective strategy for gaining enhanced agricultural production levels should focus on sustainable improvements in five major areas:

- further optimization of resources in currently productive agricultural regions;
- intensification of production in areas that have good basic agricultural resources but are currently low-producing (e.g., West Africa and Southeast Europe);[3]
- expansion of local and controlled environment production systems such as urban farms, greenhouses, and indoor growing systems that provide high-value crops to local and regional markets;
- improved crop and animal genetics that facilitate higher production levels and result in less susceptibility to yield-depressing agents such as diseases and insects; and
- greater efficiencies and less waste in the food supply chain.

Digital agriculture

Digital data will be getting collected at a rate of 40 zettabytes (ZB—the equivalent of 40 trillion gigabytes, or GB) per year by 2020.[4] Increased storage and computational capacity, coupled with high-resolution environmental and remotely sensed data, have created unprecedented opportunities for data-driven discovery in agriculture and food systems.[5] Many agricultural improvements can be facilitated by these digital innovations.

This chapter defines ‘digital agriculture’ as the deployment of computational and information technologies in farming, which will play a key role in achieving innovation goals. It is a new direction for ‘precision agriculture’, a more established concept that is historically aimed at crop production. Digital agriculture offers new opportunities through the ubiquitous availability of highly interconnected and data-intensive computational technologies as part of the so-called Fourth Industrial Revolution.[6] It can be applied to all aspects of agricultural production systems, and it reflects a shift from generalized management of farm resources towards highly optimized, individualized, real-time, hyper-connected and data-driven management. For example, instead of treating all farm fields uniformly, small field zones may each receive their own highly optimized management prescriptions; animals may be monitored and managed individually rather than as a whole herd. The desired outcomes of digital agriculture are more productive, profitable, and sustainable systems.

Digital agriculture can leverage the smart use of data and communication to achieve system optimization. The tools that enable digital agriculture are multiple and varied, and include cross-cutting technologies such as computational decision and analytics tools, the cloud, sensors, robots, and digital communication tools (Table 1). In addition, field-based activities are enabled by geo-locationing technologies such as Global Positioning Systems (GPS), geographical information systems, yield monitors, precision soil sampling, proximal and remote spectroscopic sensing, unmanned aerial vehicles, auto-steered and guided equipment and variable rate technologies. Animal-focused technologies include radio frequency identification (RFID chips) and automated (robotic) milking and feeding systems, among others. Controlled-environment agriculture (greenhouses, indoor farms, etc.) is also increasingly enabled by digital technologies such as sensors and robots.

Digital agriculture can potentially accumulate large amounts of data, and analytical capabilities that

Table 1: Enabling technologies for digital agriculture

Production environment	Type of technology	Purpose and benefits
Cross-cutting technologies	Computational decision tools	Use data to develop recommendations for management and optimize multitudes of farm tasks
	The cloud	Provide efficient, inexpensive, and centralized data storage, computation, and communication to support farm management
	Sensors	Gather information on the functioning of equipment and farm resources to support management decisions
	Robots	Implement tasks with efficiency and minimal human labour
	Digital communication tools (mobile, broadband, LPWAN)	Allow frequent, real-time communication between farm resources, workers, managers, and computational resources in support of management
Field	Geo-locationing (GPS, RTK)	Provide precise location of farm resources (field equipment, animals, etc.), often combined with measurements (yield, etc.), or used to steer equipment to locations
	Geographic information systems	Use computerized mapping to aid inventory management and to make geographical crop input prescriptions (fertilizer, etc.)
	Yield monitors	Employ sensors and GPS on harvesters to continually measure harvest rate and make yield maps that allow for identification of local yield variability
	Precision soil sampling	Sample soil at high spatial resolution (in zones) to detect and manage fertility patterns in fields
	Unmanned aerial systems (UAS, or drones)	Use small, readily deployed remote-control aerial vehicles to monitor farm resources using imaging UAS
	Spectral reflectance sensing (proximal and remote)	Measure light reflectance of soil or crop using satellite, airplane, or UAS, imaging, or field equipment–mounted sensors, to make determinations on soil patterns, crop, or animal performance, or on nutrient/pest problems
	Auto-steering and guidance	Reduce labour or fatigue with self-driving technology for farm equipment (including robots); can also precisely guide equipment in fields to enable highly accurate crop input placement and management
	Variable rate technology	Allow continuous adjustment of application rates to precisely match localized crop needs in field areas with field applicators for crop inputs (chemicals, seed, etc.)
	On-board computers	Collect and process field data with specialized computer hardware and software on tractors, harvesters, etc., often connected to sensors or controllers
Livestock	Radio frequency ID	Transmit identity data with tags attached to production units (mostly animals) that allow data collection on performance as well as individualized management
	Automated milking, feeding, and monitoring systems	Perform milking or feeding operations automatically with robotic systems, often combined with sensors that collect basic biometric data on animals, thereby reducing labour needs and facilitating individualized animal management

Note: GPS = global positioning system; LPWAN = low-power wide-area networks; RTK = Real Time Kinematic high-accuracy positioning system.

facilitate the effective employment of these data are key implementation factors. The development of computational tools that address system dynamics and optimization are similarly critical; they require a deep understanding of the biological, physical, chemical, and socioeconomic processes that together make agricultural production possible. Therefore digital agriculture technologies require talent in science and entrepreneurship.

Production efficiencies can be gained both from the integration of data associated with multiple technologies and from the real-time transfer of data between field equipment, barn, office, and the cloud. The recent surge in digital agriculture technologies has led to the accumulation of large amounts of data. High-resolution soil data, site-specific weather maps, aerial imagery, nutrient applications, and milking and animal health records are being continuously generated by farms. Much of that information can be sent via broadband or mobile connections to cloud-based services, but inadequate telematics (the long-distance transfer of digital information) often constrains the potential benefits from these technologies. In addition, farmers and researchers are finding it difficult to manage, interpret, or make use of their data as a result of their volume and complexity.[7] Growth in hybrid fields such as computational agriculture, computational sustainability, and data science that aim to use farm data are partial responses to these needs.[8]

In the end, agriculture will follow other industrial sectors in that the benefits from digital technologies will materialize and become a source of increased production efficiencies once ubiquitously available data are effectively employed. In a global economic environment, a nation's agricultural competiveness and ability to sustain critical natural resources will be strongly tied to its ability to innovate in these aspects of the production system. The question is not whether the global agricultural industry should adopt digital technologies, but how this adoption process can occur in an environment that encourages it to fully capitalize on the potential production gains.

Types of innovation

At the farm enterprise level, different types of technology investments may be distinguished:

1. **Capital investments** that promote efficiencies (computer hardware/software, robotic systems, variable-rate technology, sensors, high-precision GPS, etc.). These are invariably offered by established equipment companies that have made significant technology investments and typically compete in global markets.
2. **Service investments** that provide actionable information (remote sensing, cloud-based decision models, etc.). These services are offered by companies ranging from global corporations to small tech companies.
3. **Farm knowledge and human capital investments** that involve the development of highly localized actionable knowledge for a specific farm, herd, or crop-growing environment (optimized seeding, nutrient and pest management, animal feeding, etc.). These investments involve the collection of data—often from investments discussed under (1) and (2)—that are analysed to generate farm-specific recommendations. These knowledge investments are made at the local level, with consultants working in partnership with farm managers.

The above investments each require somewhat different support infrastructures. Large capital investments not only require educated farmers to use the equipment effectively, but also need dealership networks with competent staff and operational farm credit systems. Digital services such as remote sensing and decision models are highly scalable technologies that generally do not involve upfront financial or knowledge investments on the part of farm owners or managers, but are generally pay-as-you-go arrangements. However, in order to effectively incorporate digital technologies, a farm-specific knowledge base that involves a more sustained commitment to technology investments and analytics is still required, and it demands both educated farmers and local consultants who are trained in digital agriculture technologies.

Where does innovation in digital agriculture occur?

Digital agriculture innovation is both knowledge- and skills-intensive because agricultural production systems are complex and multifaceted and solutions require knowledge ranging from broad to specific. For example, tools that optimize nitrogen dynamics (see below) need to consider soil, weather, and crop-related processes that all have interacting physical, biological, and chemical components. These in turn need to be considered in the context of a wide diversity of practices, production environments, and socioeconomic conditions on farms. Solutions are often more complex and less scalable than optimization processes in manufacturing industries or communications. This is arguably the primary reason why digital innovation in agriculture has been relatively slow and the leading global digital technology companies have made few inroads into agriculture.

Currently most digital innovations in agriculture are led by 'Big Ag' companies, smaller innovative agricultural technology (ag-tech) companies, and top agricultural universities. Where are they located? Corporate innovation in digital agriculture technologies is mostly associated with a few global-scale companies that offer durable (farm equipment) and consumable (seed, chemicals, etc.) goods and services. These industries have in recent years consolidated to the point where most major farm purchases are controlled by a small number of companies in a highly competitive global market. These corporate leaders are primarily headquartered in Northern America and Western Europe and increasingly differentiate themselves in the marketplace by their ability to innovate with digital technologies. Yet smaller companies, typically based in the same countries, also offer innovative technology solutions.

University innovations are typically associated with the internationally prominent agricultural institutions in developed countries (mostly in Northern America and Western Europe). A constraint on university-based innovation in many developing countries is the common institutional separation of agriculture from other relevant disciplines—basic sciences, engineering, and medicine—that is, separate agricultural universities cultivate intellectual isolationism at a time when collaboration with other disciplines is critical for innovation. Not unrelated, agricultural universities in developing countries also generally do not attract the most talented students and professors because the profession is considered less prestigious and offers lower remuneration. In all, the primary innovations in digital agriculture occur in a limited set of countries in part because of structural, institutional, and economic barriers.

Issues with digital agriculture adoption

A recent report based on surveys and literature analyses identified a number of concerns and opportunities associated with the penetration of advanced technologies into agriculture.[9] Factors related to infrastructure (e.g., reliable mobile data access), research and development, technical information, and relevant educational resources were all cited in that report as important factors in a recent survey of farmers in New York State, United States of America (USA). Some of those factors are described below.

Farm size: Large farms tend to engage in digital agriculture more readily because capital investments provide earlier returns on investment as a result of scale efficiencies, but the technology competence of farmers is also an important adoption factor.[10] Some digital agriculture technologies are attractive to medium and small farms because they are less scale-dependent or are highly compelling for a specific production environment. For example, organic vegetable growers can benefit greatly from precision planting and equipment guidance systems because they rely on mechanical weed cultivation that risks crop damage if done without precision technologies. Similarly, medium-size farms may be attracted to robotic milking and feeding systems or automated greenhouses because of farm labour shortages.

Data: As farmers adopt digital agriculture technologies they accumulate large amounts of data, increasingly through cloud-based services. They are concerned with data privacy and ownership issues because legal concerns around agricultural data are unresolved at this time. Farmers are generally more comfortable sharing data with trusted partners such as universities and local cooperatives than with large companies that may repurpose the data for corporate interests.[11] Farm data are generally not protected in current statutes, but nonprofit initiatives (e.g., Ag Data Transparency) offer third-party certification on data ownership and privacy issues.[12]

A second, and related, data issue revolves around availability. As data are increasingly accumulated by large corporate entities, concerns arise about their availability for aggregated analytics and the development of next-generation management recommendations. Public-sector and scientific communities do not have universal access to valuable private-sector data, and ventures for community data sharing infrastructure are generally absent in agricultural and economics realms.

A third issue is government agency attitudes towards agricultural research data and associated priority areas. Results of a recent survey of agricultural researchers suggest that widespread data management practices fall short of generally accepted best practices.[13] In this context, legislative proposals calling for greater data sharing among public-sector agencies have been put forward,[14] but, so far, with very little effect.[15] Public-private partnerships such as Socrata, CyVerse, and the Health Data Consortium have emerged to coordinate and increase data sharing and access, which are important steps for data gathered under public auspices.

Analytics and management gap: Production environments (soil, climate, crops, animals, etc.) vary greatly in agriculture. The effective employment of digital technologies therefore requires locally appropriate analytics and management responses. In general, the engineering innovations by means of sensors, robotics, and software are rapidly advancing, but the ability to make the technology smart and applicable to local production environments lags behind.

Education and research gaps: The engagement of digital agriculture requires knowledgeable and skilled farm managers and labourers, as well as a cadre of well-educated consultants and service providers. Most educational institutions are inadequate in offering such instruction, and professional talent tends to favour urban over rural living. In addition, few institutions have the capacity or resources to answer the research questions that advanced farmers ask.

Connectivity and digital divide: Agriculture by its very nature is mostly conducted in rural areas that are poorly connected, even in the most developed countries. The industry is therefore highly impacted by the so-called digital divide. This current state of inadequate connectivity limits the full deployment of digital agriculture technologies in most rural areas, including broadband access for information communication; mobile (cellular) coverage and data transmission speeds for uploading and downloading data from field equipment or remote farm buildings; universal access to precision equipment guidance technology that requires reliable relay stations and mobile connections; and low-power wide-area networks that offer opportunities for the widespread use of sensor technology and equipment communications. Advanced connectivity investments in rural areas are generally expensive because of low customer density and are often not regarded as economically justified by communications companies.

Business development and employment: Many farmers and ag-professionals agree that digital agriculture has a bright future, offers good business and employment opportunities, and will result in environmental benefits and efficiencies.[16] But it may also profoundly impact businesses and employment in rural areas around the globe. In high-wage countries, farmers are eager to employ automation and digital technologies to reduce challenges with their farm labour force—which often depends on migrant workers and therefore poses legal and management challenges. Digital technologies will also facilitate those management farm enterprises that are larger than would otherwise be possible, and may intensify the global trend of farm consolidation. In developing countries where wages are lower and farms generally smaller, digital technologies will help advance improved management practices and better access to markets (e.g., through mobile technologies), but will also impact employment opportunities in rural areas.

Examples of digital agriculture technology implementation

Implementing digital agriculture technology can take different forms. Three of these are considered below.

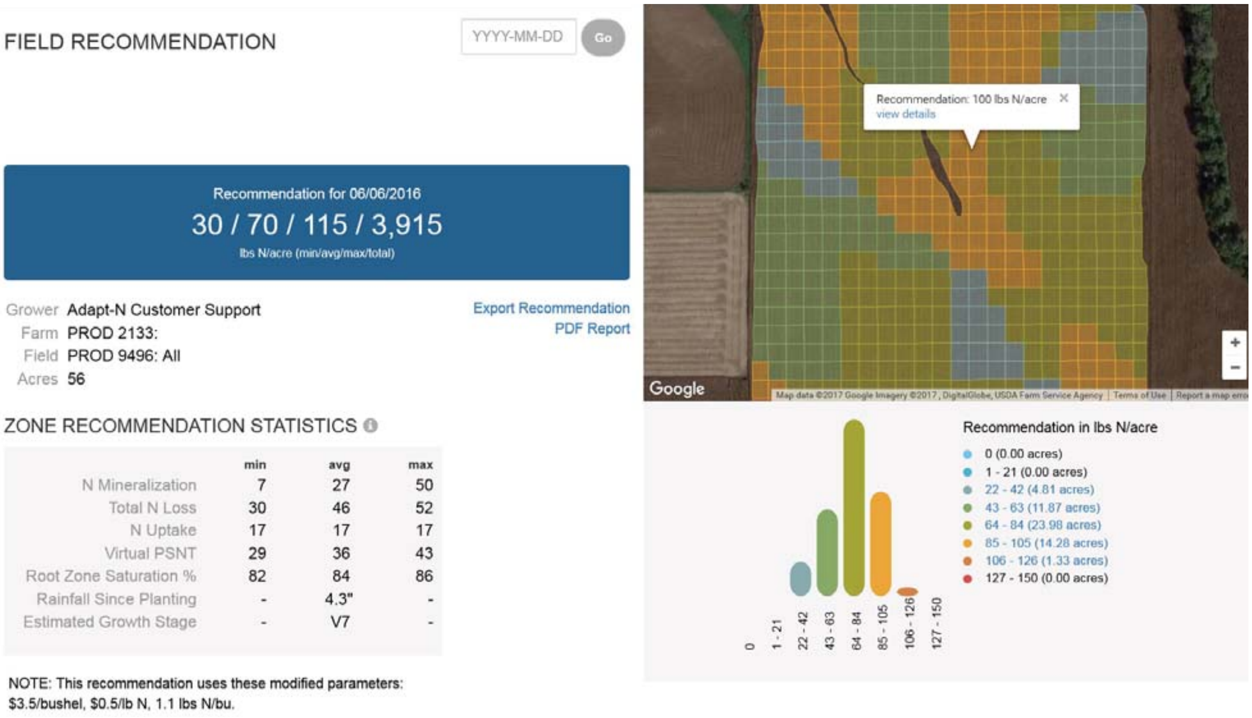
Cloud-based nitrogen advisors

Agriculture includes some 'wicked problems', including the use of nitrogen fertilizer that is needed to grow many of the world's crops at high production levels. The widespread adoption of nitrogen fertilizer use after World War II and especially during the Green Revolution has greatly enhanced food production and reduced malnutrition. But it has also led to serious environmental concerns, including high energy use, greenhouse gas emissions (through nitrous oxide), and water quality degradation. Notably many of the world's estuaries (Gulf of Mexico, Baltic Sea, etc.) experience low oxygen levels (hypoxia) from nitrogen inflows, which in turn result in the high mortality of critical fish species.

These concerns are in large part related to excessive nitrogen use, where more fertilizer is applied than is needed for the crop. This appears wasteful, but where farmers are uncertain about the 'right' amount of fertilizer needed they actually respond in an economically rational manner to the realities of their production environments, avoiding the high risk of under-nourishing their crops and incurring yield losses. Most of the uncertainties are associated with (1) variable production environments (soil, crop, management), and (2) weather variability.

Recent technological developments have proven that data and model computations can address these uncertainties and offer more reliable nitrogen management advice to farmers through cloud-based services. This technology offers real-time nitrogen fertilizer advice, based on weather conditions, that is specific to field zones and thereby allows farmers to more precisely match nutrient additions

Figure 1: Real-time nitrogen field advice through a cloud service



FIELD RECOMMENDATION

Recommendation for 06/06/2016

30 / 70 / 115 / 3,915

lbs N/acre (min/avg/max/total)

Grower Adapt-N Customer Support
Farm PROD 2133:
Field PROD 9496: All
Acres 56

ZONE RECOMMENDATION STATISTICS

	min	avg	max
N Mineralization	7	27	50
Total N Loss	30	46	52
N Uptake	17	17	17
Virtual PSNT	29	36	43
Root Zone Saturation %	82	84	86
Rainfall Since Planting	-	4.3"	-
Estimated Growth Stage	-	V7	-

NOTE: This recommendation uses these modified parameters: $3.5/bushel, $0.5/lb N, 1.1 lbs N/bu.

Recommendation: 100 lbs N/acre ×
view details

Recommendation in lbs N/acre
- 0 (0.00 acres)
- 1 - 21 (0.00 acres)
- 22 - 42 (4.81 acres)
- 43 - 63 (11.87 acres)
- 64 - 84 (23.98 acres)
- 85 - 105 (14.28 acres)
- 106 - 126 (1.33 acres)
- 127 - 150 (0.00 acres)

Source: Adapt-N.com.

with crop needs (Figure 1). In on-farm field evaluations, this technology has proven to offer a win-win opportunity: it increases farmers' profits while reducing negative environmental impacts.[17] Similar technologies can be employed for irrigation and pest management, among others.

Some of the main advantages of employing such cloud-based services are:

- the high scalability such services provide allows the technology to be rapidly employed in many growing environments,
- employment at scale allows for dramatic reductions in per-unit (hectare) expense and can drive down adoption costs, and
- cloud-based and mobile communications allow for continuous access and real-time monitoring of the status of farm resources.

The next phase of technology deployment will likely be the integration of highly computational, data-intensive tools with low-cost field sensor technologies offering management advice based on ensemble technologies.

Precision farming services in Bulgaria

Prior to Bulgaria's political and economic reforms of 1989, the country's agriculture was relatively efficient by Eastern European standards, and included large cooperative farms and highly consolidated production units (fields and livestock facilities). After the reforms, Bulgaria liquidated many of the former collective farms, and the associated land privatization resulted in a subdivision of fields into smaller plots with a great number of heirs—that is, large fields are often owned by multiple absentee landowners (82% of holdings are comprised of fewer than two hectares).[18] But through lease agreements with many individual landowners, private farmers can still cultivate the vast majority of the land through large-scale agriculture, with wheat, sunflower, and maize as primary crops. Furthermore, since its European Union accession in 2007, the EU Common Agricultural Policy invested around US$4 billion in Bulgaria's agriculture, much of it through direct payments intended to support farms, rural employment, good management practices, and stable food supplies.

These developments have resulted in viable large-scale farming in Bulgaria, and also created exceptional opportunities for the adoption of precision farming methods. Many farmers are purchasing advanced field equipment, and regional technical service providers are offering associated products and services. For example, NIK is a company that works with farmers to implement modern precision technologies in

Bulgaria.[19] These technologies are offered through (1) strategic partnerships with Northern American and European technology leaders that allow for capital and service investments (farm management software, mapping and navigation hardware and software, precision application equipment, auto-steering and guidance systems, weather and satellite monitoring, irrigation equipment, etc.), and (2) skilled field professionals who implement technologies on farms and help develop local knowledge. In summary, the rapid adoption of digital farming technology in Bulgaria can be attributed to a combination of:

- large-scale production units that are a result of land reforms under socialist governments prior to 1989,
- a workable land lease system that allows private farmers to manage large land tracks with multitudes of small land owners,
- farm payments from the European Union, and
- strategic partnerships with leading technology providers.

Remote sensing and financial risk management to alleviate poverty

The USA has long had major government programmes in place to facilitate risk management for farmers in various forms. Today the bulk of that funding is allocated to risk management and insurance programmes with great success. However, uptake has been slower in the developing world. This is in part the result of the fact that the programmes are not as well funded in developing countries; furthermore, verifying yields and losses is much more difficult in remote areas of the developing world, despite the fact that those agricultural producers face risk all the same. Several programmes have emerged recently to address these issues using index-based insurance schemes.[20] Initially, pilot programmes in the developing country context relied heavily on station-level weather data. However, these data are often sparse and are themselves difficult to verify. In recent years there has been a movement towards a different solution: using remotely sensed data to determine losses. The Index Based Livestock Insurance programme (IBLI) in Kenya and Ethiopia was one of the earlier adopters of this approach.[21] As newer remote sensing platforms come online, as well as lower-cost custom options (e.g., nano-satellites, unmanned aerial systems, etc.), there will likely be a large movement towards designing the risk management programmes of the future around these sensing technologies to indicate both when losses occur and the extent of those losses.

Conclusions

The penetration of advanced digital technologies into the agricultural industry is progressing rapidly in advanced economies, and is increasingly impacting developing countries. Because of several unique characteristics of agriculture (involving its highly localized and variable resources, poor connectedness in rural areas, education and research gaps, support businesses, and global players), digital agriculture requires special consideration from governments and industry leaders. This will be well worth the effort because it is a primary path towards a sustainable food supply.

Notes

1 UN DESA, 2015.

2 Montgomery, 2007.

3 Foley, 2011.

4 Tien, 2013; Song et al., 2016.

5 Woodard, 2016a.

6 Schwab, 2016.

7 van Es et al., 2016.

8 Woodard, 2016a, 2016b.

9 van Es et al., 2016.

10 Castle et al., 2015.

11 Castle et al., 2015.

12 Further information about Ag Data Transparency is available at http://www.fb.org/ag-data.

13 Fernandez et al., 2016.

14 Murray, 2015.

15 Woodard, 2016a.

16 van Es et al., 2016.

17 Sela et al., 2016; Sela et al. 2017.

18 European Commission, 2015.

19 More information about NIK is available at http://www.nik.bg/en.

20 Woodard et al., 2016.

21 Woodard et al., 2016.

References

Castle, M., B. D. Lubben, and J. Luck. 2015. 'Precision Agriculture Usage and Big Agriculture Data'. *Cornhusker Economics,* University of Nebraska-Lincoln Extension. Available at http://agecon.unl.edu/documents/2369805/20977275/5-27-15.pdf/b80d3d0a-684e-4bdd-993c-96246691bc95.

European Commission. 2015. 'Bulgaria: Common Agricultural Policy'. DG Agriculture and Rural Development, Unit for Agricultural Policy Analysis and Perspective. 15 March. Available at http://ec.europa.eu/agriculture/sites/agriculture/files/cap-in-your-country/pdf/bg_en.pdf.

Fernandez, P., C. Eaker, S. Swauger, and M. L. E. Steiner Davis. 2016. 'Public Progress, Data Management and the Land Grant Mission: A Survey of Agriculture Researchers' Practices and Attitudes at Two Land-Grant Institutions'. *Issues in Science and Technology Librarianship* 83: (Winter).

Foley, J. A. 2011. 'Can We Feed the World and Sustain the Planet?' *Scientific American* 305 (5): 60–65.

Montgomery, D. R. 2007. *Dirt: The Erosion of Civilizations.* Berkeley and Los Angeles, CA: University of California Press.

Murray, P. 2015. S.991: Evidence-Based Policymaking Commission Act of 2015. 114th Congress. Available at https://www.congress.gov/bill/114th-congress/senate-bill/991.

Schwab, K. 2016. *The Fourth Industrial Revolution.* Geneva: World Economic Forum.

Sela,S., H. M. van Es, B. N. Moebius-Clune, S. R. Marjerison, J. J. Melkonian, D. Moebius-Clune, R. Schindelbeck, and S. Gomes. 2016. 'Adapt-N Outperforms Grower-Selected Nitrogen Rates in Northeast and Midwest USA Strip Trials'. *Agronomy Journal* 108 (4): 1726—34.

Sela, S., H. M. van Es, B. N. Moebius-Clune, R. Marjerison, D. Moebius-Clune, R. Schindelbeck, K. Severson, and E. Young. 2017. 'Dynamic Model Improves Agronomic and Environmental Outcomes for Maize Nitrogen Management over Static Approach'. *Journal of Environmental Quality.* doi:10.2134/jeq2016.05.0182

Song M.-L., R. Fisher, J.-L. Wang, and L.-B. Cui. 2016. 'Environmental Performance Evaluation with Big Data: Theories and Methods'. *Annals of Operations Research* March 2016. doi:10.1007/s10479-016-2158-8.

Tien, J. M. 2013. 'Big Data: Unleashing Information'. *Journal of Systems Science and Systems Engineering* 22: 127–51.

UN DESA (United Nations, Department of Economic and Social Affairs), Population Division. 2015. *World Population Prospects: The 2015 Revision,* Key Findings and Advance Tables. Working Paper No. ESA/P/WP 241.

van Es, H. M., J. D. Woodard, M. Glos, L. V. Chiu, T. Dutta, and A. Ristow. 2016. *Digital Agriculture in New York State: Report and Recommendations.* Ithaca, NY: Cornell University. Available at bit.ly/NYSDigitalAgReport.

Woodard, J. D. 2016a. 'Data Science and Management for Large Scale Empirical Applications in Agricultural and Applied Economics Research'. *Applied Economic Perspectives and Policy* 38 (3): 373–88. Available at https://doi.org/10.1093/aepp/ppw009.

———. 2016b. 'Big Data and Ag-Analytics: An Open Source, Open Data Platform for Agricultural & Environmental Finance, Insurance, and Risk'. *Agricultural Finance Review* (Invited Paper, IARFIC Keynote Address). Available at http://www.emeraldinsight.com/doi/abs/10.1108/AFR-03-2016-0018.

Woodard J. D., A. Shee, and A. Mude. 2016. 'A Spatial Econometric Approach to Designing and Rating Scalable Index Insurance in the Presence of Missing Data.' *The Geneva Papers on Risk and Insurance: Issues and Practice* 41 (2): 259–79.