Chapter 8
Digital Technologies, Big Data, and Agricultural Innovation

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8.1 Introduction

For the future well-being of the global society, agricultural innovation is a necessity. As it has been throughout history, having access to adequate amounts of food is an uncertainty for many individuals across the world. For others, availability of reasonably safe, affordable food is somewhat taken for granted. For both groups, simply continuing the practices of our current agricultural and food system is not sufficient nor tenable as we look to the future.

Among the many stressors facing that system, four are of key importance. Global population growth is expected to continue, particularly in those areas of the world where food security is relatively weak. While this challenge suggests the need for more food to be produced, the environmental effects of agricultural production increasingly are recognized as having both immediate and long-term consequences that are undesirable. Furthermore the prospects of a changing, more variable climate contribute to the need to enhance the resilience of current agricultural practices. And, fourth, consumers in both developed and developing countries are demanding an even more nutritious and safe food supply.

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From one perspective, these challenges are daunting and may seem insurmountable. Yet this setting is not new to mankind and, from a historical perspective, is more the norm rather than the exception. If society is to maintain itself and advance, agricultural innovation is essential. Indeed, 50 years ago, eminent scholars employing sophisticated mathematical models confidently predicted that within a decade massive famine caused by chronic food scarcity would characterize the world's future (Meadows et al. 1972). However agricultural innovation, along with other changes in society, rose to the challenge and led to reductions in the number of malnourished in the world.

Today, new tools such as digital technology and big data are being developed and applied within agricultural production systems. Effective implementation of these tools offers unprecedented capabilities to fuel innovation and contribute to our response to the challenges just noted. (These terms will be described more fully later in this chapter.) It is important to recognize both (1) that their implementation is itself a key form of innovation and (2) that the use of these technologies can foster additional innovation by making existing innovation systems even more effective (Sonka 2016).

While an exciting prospect, the extent and impact of the use of these technologies are themselves uncertain. The purpose of this chapter is to explore that potential for effective implementation. A managerial, not a technological, perspective will be employed as the primary lens for this chapter.[1] A key premise of this perspective is that the existence of a technology does not guarantee immediate or future adoption nor value creation for its users and the market. Rather, the extensive use of technology will hinge on its ability to enable managers to better achieve their goals. These managers can be operating in either the public or private sector or in developed or developing agricultural settings.

Framed by this perspective, this chapter contains the following five sections. First, key elements of digital technology and big data will be described and the most profound decision-making aspect of their application will be identified. This element can be captured by a simple question, "What is, or can be, agricultural data?" While the capabilities of technologies being developed are continually more advanced, the use of what is commonly known as precision agriculture has been in process for the last two decades. Those experiences and lessons learned will be the subject of the second section which follows. The term "big data" has become common throughout much of society, although the term's meaning is not well defined. In next section of this chapter, the characteristics of big data are identified and particular attention is devoted to the central role of analytics. The fourth section of this chapter will depict the digital agriculture that is emerging. Also, that concept will be linked to the broader needs and opportunities associated with the adoption of digital technologies throughout the food system. A brief concluding section ends this chapter.

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[1] Other perspectives are relevant to the application of digital technologies and big data in agriculture. Space limits preclude their analysis here. For example, Weersink et al. (2018) explore environment implications and Wiseman et al. (2018) consider data ownership and management issues.

8.2 "What Is, or Can Be, Agricultural Data?"

To many, maybe most, of us, the word data tends to generate little excitement. Frankly data was just boring, as it suggested rows and columns of numbers on a spreadsheet offering scant guidance or insight. Yet data in either its implicit (that which we sense or feel) or explicit (that which is written down) forms is essential to how we make decisions. Farmers, throughout time, have been constrained to making decisions based upon what they could observe, sense, and feel. This constraint was imposed by technology and economics. Digital technologies and big data are changing the parameters associated with those constraints. However, those forces will continue to determine the extent and effectiveness of technology adoption.

This section addresses the links of technology, data, and decision making. Its first segment employs a very simple example to demonstrate the interactions of technology, economics, and farmer decision making. The second segment illustrates how emerging technologies are fundamentally changing what is available as explicit data for agricultural decision making. The section's final segment provides a more complete description of some of terms associated with digital technologies.

8.2.1 Measurement

"You can't manage what you don't measure!" is a phrase attributed to both Peter Drucker and W. Edwards Deming. This phrase is as applicable to farmers as it is to managers at Toyota or Amazon (Brynjolfsson and McAfee 2012). The relationship between measurement and the ability to make improved decisions is critically important in understanding the potential for digital technologies to affect agricultural management.

The author of this paper had the benefit of growing up on a small farm in the Midwest region of the United States and, throughout his career, has learned extensively from farmers in the United States and globally. With apologies for a small digression, let me use personal experience to focus on the linkage between measurement and management. Growing up on a farm, the linkage between what could be measured and our ability to improve performance was straightforward. In those days, we had to carry the, hopefully, full milking machine from the cow to the milk tank. The weight of the bucket gave direct evidence as to which cows were producing more. And because there were less than 20 cows in the herd, it also was possible to remember which were the higher-producing cows and give them an extra portion of grain. Laggard producers received less grain.

On this same farm, about 120 egg producing chickens were housed in a building, with ample room to roam outdoors as well. Eggs were collected twice a day. Performance of the entire group was observable. Information that could lead to improved performance of individual birds, however, was not observable. Technically, it would have been possible to establish a production system where measurement of individual bird performance could have been accomplished. However, the economics of egg production and the technologies available at that time did not justify the costs of such a system.

There are two important points illustrated by this story. One is that the desire to link measurement of outcomes and management actions in farming is not new. However, the economics of measurement (the cost of measurement versus the benefits of doing so), given the available technology, inhibited my father and other farmers from capturing and exploiting more data. The second point, then, is that measurement is both an economic and a technical issue for agricultural managers.

8.2.2 *What Is or Can Be Data in Agriculture?*

Suddenly (at least in agricultural measurement terms), the "what is data" question has new answers. Figure 8.1 provides a visual illustration of the change. In its upper left hand corner, we see data as we are used to it – rows and columns of nicely organized, but basically boring, numbers.

The picture in the upper right hand corner is of a pasture in New Zealand. Pasture is the primary source of nutrition for dairy cows in that country and supplemental fertilization throughout the growing season is a necessary and economic practice. The uneven pattern of the forage in that field is measured by a sensor on the fertilizer spreader to regulate how much fertilizer is applied – as the spreader goes across the field. In this situation, uneven forage growth is now data.

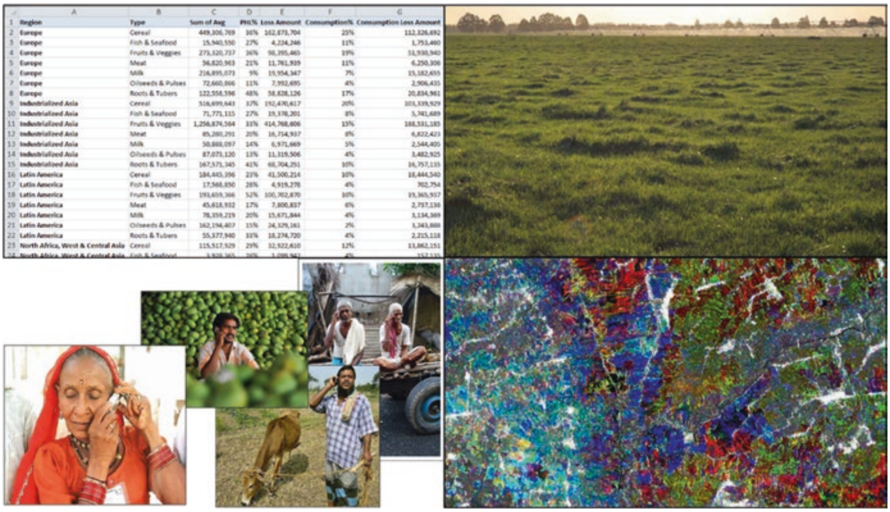


Fig. 8.1 Sources of agricultural data. (Graphics courtesy of: agrioptics.co.nz; T. Abdelzaher, Champaign, IL.; Mock, Morrow & Papendieck; International Rice Research Institute)

The lower left hand corner of Fig. 8.1 shows the most versatile sensor in the world – individuals using their cell phone. Particularly for agriculture in developing nations, the cell phone is a phenomenal source of potential change – because of both information sent to those individuals and information they now can provide.

As illustrated in the lower right hand quadrant of Fig. 8.1, satellite imagery can measure temporal changes in reflectivity of plants to provide estimates of growth (RIICE 2013). The picture is focused on rice production in Asia. Such information has numerous potential uses. One is to provide a low-cost means of identifying fields where adverse conditions have caused major production shortfalls. Once that field is identified, similar low-cost means could be used to provide insurance payments to farmers eligible for that insurance.

While satellite imagery is one source of remotely sensed data, recent years have seen a pronounced increase in the capabilities and interest in unmanned aerial systems (UASs) as a source of data for agriculture. There are numerous ongoing efforts to transform UAS technology originally focused on military purposes to applications supporting production agriculture. “Universities already are working with agricultural groups to experiment with different types of unmanned aircraft outfitted with sensors and other technologies to measure and protect crop health” (King 2013). A few, of many, example applications include the following:

- Monitoring of potato production (Oregon State University)
- Targeting pesticide spraying on hillside vineyards (University of California, Davis)
- Mapping areas of nitrogen deficiency (Kansas State University)
- Detecting airborne microbes (Virginia Polytechnic Institute and State University)

8.2.3 Technologies Transforming What Can Be Data?

Terms such as precision agriculture, big data, digital technology, and big data analytics are frequently used in society and among farmers. While such use is common, a common understanding of what these terms precisely mean has not been achieved. (Because of the rapidly evolving nature of the technologies, the problem is not the lack of definitions, rather it is that numerous definitions, all with some validity, exist.)

This section will provide a brief perspective of the terms digital technology, precision agriculture, and big data analytics. The intent is not to provide precise or universal definitions. Instead, the goal is to provide a general perspective that will contribute to a better understanding of the chapter’s contents. Further discussion and example applications are included later in this chapter.

The following two-part explanation of digital technology often is useful:

1. Digital technology in agriculture involves:
    - Employing sensors and technologies to capture digital data and operating machines which use digital information to differentially apply inputs

  - Using digital tools and techniques to summarize, analyze, synthesize, and communicate digital and other information to improve decision-making

2. Within that broad perspective, it also is useful to distinguish between three types of digital technology application:

  - Precision agriculture: Although having 20+ years of history, precision agriculture technologies continue to markedly improve. Powered by GPS-enabled equipment and machine-based sensors, precision agriculture focuses on measurement and differential input application at sub-field levels. Managerial analysis focuses on the use of data captured from individual farm fields to improve productivity. Over the last two decades, farmers have been exposed to and, in many cases, have had experience with precision agriculture. However, today's advances in sensor capabilities continue to enhance the effectiveness of precision agriculture practices meaning that farmers have an on-going opportunity to choose whether to employ new practices or not.
  - Big data analytics: The ability to cheaply capture extraordinarily large sets of data has fueled numerous big data applications throughout society. However, the existence of massive datasets is only part of the story. Big data analytics requires extensive computational power as well as application of fundamentally different means of analysis to provide probabilistically based insights to improve decision making.

  – A potential for the application of big data analytics in farming is the pooling of production-related data from many farming operations across potentially millions of acres to discern previously unknown managerial insights.
  – Terms such as "big data" and "artificial intelligence" are relatively new to society, let alone agriculture. Tracking of the mention of those terms in media publications (for all uses) indicates that such mentions barely existed in 2007. However, over 150,000 mentions were identified by the year 2014, only 7 years later (Gandomi and Haider 2015). The media hype associated with such rapid growth, however, often contributes to confusion and uncertainty regarding the managerial application of such innovations (Sonka 2015).
  – Some applications of big data analytics in agriculture (weather forecasting, autonomous steering of machines in the field) do not require that detailed farm production data from one field/farm be compared with data from other farm operations.

  - Communication and social media: This category includes two somewhat different applications:

  – The use of social media to communicate with personal and business contacts.
  – The use of telecommunication-based wireless, WIFI, and the Internet

    - To transfer production-related data captured from sensors to devices where that data can be stored/analyzed
    - To transfer findings to the farmer and/or instructions directly to machines as activities that should be conducted

  - While typically not featured in discussions of precision agriculture or big data analytics, advances in communication capabilities based upon digital technology often are essential to enhancing performance.

8.3 Precision Agriculture: Precursor to Big Data

This section will provide a brief overview of the precision agriculture experience. It is not intended as comprehensive assessment. It is intended to provide a sense of the evolution of precision agriculture, identify the more popular technologies employed, and discuss the admittedly scant evidence as to the economic gains from the use of these innovations.

It is important to note that precision agriculture and big data are not synonymous. As noted above, the current tools and techniques of precision agriculture have existed largely without the application of big data concepts. However, it is hard to foresee that big data approaches could have significant impact without employing precision agriculture technologies to capture at least of the data required.

Precision agriculture has several dimensions; indeed the concept itself is not precisely defined. A *1997 report* of the National Research Council (National Research Council 1997) refers to precision agriculture, "...as a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production." Key technologies and practices included within precision agriculture are as follows:

- Georeferenced information
- Global positioning systems
- Geographic information systems and mapping software
- Yield monitoring and mapping
- Variable-rate input application technologies
- Remote and ground-based sensors
- Crop production modeling and decision support systems
- Electronic communications

The term precision agriculture primarily has been linked to crop production. However, precision practices (and big data techniques for that matter) are equally applicable in animal agriculture, where georeferencing can refer to both sub areas of a field and individual animals. The tracking processes and required tools may differ but the managerial goal is still to separately manage increasingly smaller units of observation.

Farmers and agribusiness managers played a significant role in the development of precision agriculture. For example, in the mid-1990s, a group of agribusiness professionals in Champaign County, Illinois, came together to explore the opportunities associated with two emerging technologies — site-specific agriculture and that strange thing called the Internet (Sonka and Coaldrake 1996). This group, called CCNetAg, was part of an initiative co-sponsored by the local Chamber of

Commerce and the National Center for Supercomputing Applications at the University of Illinois. A voluntary enterprise, CCNetAg provided a vehicle for farmers, agribusiness managers, and university researchers to jointly explore adoption of these tools. The key elements of precision farming are as follows:

- Georeferencing as indicated by satellites linking to the farm field.
- Key farming operations are being directed by and are capturing digital information on the following:
- Soil characteristics
- Nutrient application
- Planting
- Crop scouting
- Harvesting

Since 1997, technologies have advanced, although the general categories remain relevant. For example, auto-steer capabilities on farm machinery have become much more prevalent. And active, detailed measurement of the planting process (recording where "skips" occur) is now feasible. Furthermore, the ability to monitor the status of farm machinery as it operates is now paired with electronic communications to signal when machine operations may be out of acceptable bounds. While there have been many publications describing precision agriculture, reports with independent evaluation of the economics of adoption are much less numerous. One means to assess whether there are net benefits of a technology is to monitor its marketplace adoption. For several years the Center for Food and Agricultural Business at Purdue University and CropLife magazine have surveyed agricultural input suppliers regarding the adoption of precision agriculture. Focused primarily on the Midwest and Southern regions in the United States, this work is a particularly useful assessment of the technology's application. From the *2017 report*, there is clear evidence of adoption for key precision agriculture practices (Erickson et al. 2017).

The crop input dealers who provided input for this study are uniquely well positioned to understand and report on adoption of these technologies. Their firms provide inputs (fertilizer, pesticides, and seeds) and services to producers evaluating and adopting precision agriculture.

Early interest in precision agriculture focused on site-specific application of inputs and on the use of yield monitors. As shown in Fig. 8.3, grid sampling, a practice associated with site-specific lime and fertilizer application, is currently employed on nearly half of the crop acres. Increased coverage to 6 out of 10 acres is expected by 2020. Similar adoption rates have been experienced for GPS-assisted yield monitors. Over the last decade, the use of GPS guidance systems has increased rapidly to a current use estimated to exceed 60%. Continued strong growth to 2020 is expected. The use of satellite imagery and UAVs as tools to support crop production is more recent. Current use affects 19% and 6% of acreages, respectively. Interesting, acreage covered by UAVs is expected to increase by over threefold, to 22%, in just 3 years.

Erickson et al. (2017) describe a relatively consistent adoption pattern for variable rate technology (VRT) practices. In the early 2000s, adoption was at

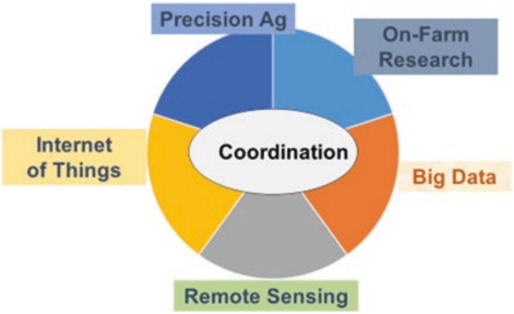


Fig. 8.3 Components of a potential digital agriculture

single-digit levels. Since then, steady increases in the extent of acreage covered have occurred. However, the most utilized practice, application of lime, is only now achieving coverage on 40% of the total acreage. These patterns also are interesting because of the very different price regimes that existed for corn and soybeans over these 15 years. When output prices were low prior to 2008, the driver for adoption likely was cost reduction. Possibly, increasing yields were a more significant factor in later years when prices were higher.

Media and marketing attention sometimes blur distinctions between precision agriculture and big data. Some communications seem to suggest that big data is just an updated buzzword for precision agriculture practices. That is not the case, and the main differences among these two concepts are as follows:

- While the farmer has several types of precision data from each field, additional sources of data naturally reside and originate beyond the fencerow. Accessing that information raises both technical and organizational challenges.
- Precision agriculture employs comparisons across field map layers as its dominant method of analysis. The effect of a single factor, such as a blocked tile line or a buried fencerow, often is observable from a map. However, identifying complex interactions across several production factors and multiple years requires much more sophisticated tools.
- As noted previously, precision agriculture has had 20+ years of experience. Aggregating all the digital information collected from yield monitors and site-specific input operations would result in an extremely large set of data. However, that data currently is located on innumerable thumb drives, disk drives, and desktop computers. Large-scale analysis would not be possible unless/until that data can be accessed and aggregated.

Both precision agriculture and big data arise from the advent and application of information and communication technologies. As noted previously, they are not synonymous. That said, it is hard to foresee that big data approaches will have significant impact without employing the data generated by precision agriculture practices.

8.4 Dimensions of Big Data

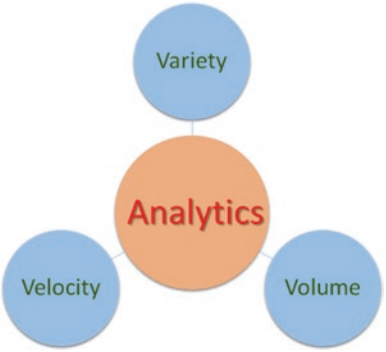
Although of relatively recent origin, numerous attempts have been made to define big data. For example:

- The phrase "big data" refers to large, diverse, complex, longitudinal, and/or distributed datasets generated from instruments, sensors, Internet transactions, email, video, click streams, and/or all other digital sources available today and in the future (National Science Foundation 2012).
- Big data shall mean the datasets that could not be perceived, acquired, managed, and processed by traditional IT and software/hardware tools within a tolerable time (Chen et al. 2014)
- Big data is where the data volume, acquisition velocity, or data representation (variety) limits the ability to perform effective analysis using traditional relational approaches or requires the use of significant horizontal scaling for efficient processing (Cooper and Mell 2012).
- Big data is a high-volume, high-velocity, and high-variety information asset that demands cost-effective, innovative forms of information processing for enhanced insight and decision making (Gartner IT Glossary 2012).

Three dimensions (Fig. 8.2) often are employed to describe the big data phenomenon: volume, velocity, and variety (Manyika et al. 2011). Each dimension presents both challenges for data management and opportunities to advance business decision making. These three dimensions focus on the nature of data. However, just having data is insufficient. Analytics is the hidden "secret sauce" of big data. Analytics, discussed later, refers to the increasingly sophisticated means by which useful insights can be fashioned from available data.

"*90% of the data in the world today has been created in the last two years alone*" (IBM 2012). In recent years, statements similar to IBM's observation and its emphasis on volume of data have become increasingly more common. The volume dimension of big data is not defined in specific quantitative terms. Rather, big data refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze. This definition is intentionally subjective; with

Fig. 8.2 Dimensions of big data



no single standard of how big a dataset needs to be considered big. And that standard can vary between industries and applications.

An example of one firm's use of big data is provided by GE—which now collects 50 million pieces of data from ten million sensors everyday (Hardy 2014). GE installs sensors on turbines to collect information on the "health" of the blades. Typically, one gas turbine can generate 500 gigabytes of data daily. If the use of that data can improve energy efficiency by 1%, GE can help customers save a total of $300 billion (Marr 2014).

The velocity dimension refers to the capability to acquire, understand, and respond to events *as they occur*. Sometimes it is not enough just to know what has happened; rather we want to know what is happening. We have all become familiar with real-time traffic information available at our fingertips. Google Maps provides live traffic information by analyzing the speed of phones using the Google Maps app on the road (Barth 2009). Based on the changing traffic status and extensive analysis of factors that affect congestion, Google Maps can suggest alternative routes in real time to ensure a faster and smoother drive.

For analysts interested in retailing, anticipating the level of sales is important. Brynjolfsson and McAfee (2012) report on an effort to monitor mobile phone traffic to infer how many people were in the parking lots of a key retailer on Black Friday — the start of the holiday shopping season in the United States — as a means to estimate retail sales.

Variety, as a dimension of big data, may be the most novel and intriguing of these three characteristics. For many of us, data referred to numbers meaningfully arranged in rows and columns. For big data, the reality of "what is data" is wildly expanded. The following are just some of the types of data available to be converted into information:

- Financial transactions
- The movement of your eyes as you read this text
- "Turns of a screw" in a manufacturing process
- Tracking of web pages examined by a customer
- Photos of plants
- GPS locations
- Text
- Conversations on cell phones
- Fan speed, temperature, and humidity in a factory producing motorcycles
- Images of plant growth taken from drones or from satellites
- Questions

The variety dimension is closely linked to the discussion of "what is or can be agricultural data?" presented earlier in this chapter. Essentially digital technologies, including those employed in precision agriculture practices, are capturing information as explicit data which previously could only be observed or sensed. Furthermore, in many cases, this process can be accomplished at costs which are economically justifiable. Often times, that newly available data can be directly employed without further analysis. In other instances, the effective use of that information requires the application of newly available analytical approaches – the analytics dimension of big data.

Some agriculturally oriented scholars (Coble et al. 2016; Weersink et al. 2018) will include veracity as a fourth dimension of big data. In this context, veracity references data quality that is employed within big data analyses. Indeed agricultural analysis has a long tradition which emphasizes the need for accurate data, with the oft-used phrase "Garbage in; garbage out," exemplifying this concern. However, as will be discussed in the following section, Analytics, the tools and techniques can produce useful insights from less than perfectly accurate data. Therefore veracity is not included here as a big data dimension.

8.4.1 Analytics

Access to lots of data, generated from diverse sources with minimal lag times, sounds attractive. Managers, however, quickly will ask, "What do I do with all this stuff?" Without similar advances in analytic capabilities, just acquiring more data is unlikely to have significant impact within agriculture.

Analytics and its related, more recent term, data science, are key factors by which big data capabilities can actually contribute to improved performance in the agricultural sector. Data science refers to the study of the generalizable extraction of knowledge from data (Dhar 2013). Tools based upon data science are being developed for implementation in the sector, although these efforts are at their early stages.

The associated concept of analytics similarly is maturing and its use refined (Davenport 2013; Watson 2013). Analytic efforts can be categorized as being of one of three types:

- Descriptive efforts focus on documenting what has occurred.
- Predictive efforts explore what will occur.
- Prescriptive efforts identify what should occur (given the optimization algorithms employed).

One tool providing predictive capabilities was recently unveiled by the giant retailer, Amazon (Bensinger 2014). This patented tool would enable Amazon managers to undertake what it calls "anticipatory shipping," a method to start delivering packages even before customers click "buy." Amazon intends to box and ship products it expects customers in a specific area will want but have not yet ordered. In deciding what to ship, Amazon's analytical process considers previous orders, product searches, wish lists, shopping-cart contents, returns, and even how long an Internet user's cursor hovers over an item.

Relative particularly to agricultural applications and analytics, two key points warrant specific consideration:

- The first continues the veracity discussion introduced in the prior section. Of course, it is prudent to strive to capture and use data which is accurate. However, perfect data generally is expensive to acquire and, given big data approaches, often is not necessary to produce information that can improve decision making.

- For example, it might be technically possible to put sensors to measure actual traffic along every mile of every road in the country. However, the cost of the sensors and the underlying system to aggregate and communicate that information has been prohibitively expensive. However, the use of proxy information (primarily from cell phones and sensors put in place for other purposes) allows for useful predictions of real-time traffic conditions to be created and communicated at low cost.
- Although there are numerous mathematical and statistical approaches available to data scientists, a key principal is the use of Bayesian inference and conditional probabilities (Polson and Scott 2018). Essentially, through the analysis of very large amounts of relevant data, analysists can predict with confidence that the presence of certain factors indicates that the condition of interest exists. As a simple example, if it is 8 am on a weekday morning (that is not a holiday) and cell phone signals along a major highway are moving very slowly from one tower to the next, it is likely that there is heavy traffic along that highway.
- Of course, such a prediction is probabilistic and may not be accurate in each circumstance, especially if there is a change in the underlying conditions. However, with careful analysis and implementation, data that is not perfect can be effectively employed to improve decision making in agriculture. For example, consider the large maize farmer who receives satellite maps of the fields for which the farmer is responsible. Colors are used to identify conditions in the field, with green indicating heavy vegetative growth. As one farmer reported to the chapter's author, an area marked in heavy green means either that the crop is doing really well or that there is a heavy infestation of weeds. In either case, it is worth the farmer's time to physically investigate.
- In agriculture, as in most fields, descriptive efforts have been most common and even those are relatively infrequent. However, within production agriculture, knowing what has occurred – even if very accurately and precisely – may not provide useful insights as to what should be done in the future.
- Production agriculture is complex, where biology, weather, and human actions interact. Science-based methods have been employed to discern why crop and livestock production occurs in the manner in which they do. Indeed, relative to the big data topic, it might be useful to consider this as the "small data" process.
- The process starts with lab research employing the scientific method as a systematic process to gain knowledge through experimentation. Indeed, the scientific method is designed to ensure that the results of an experimental study did not occur just by chance (Herren 2014). However, results left in the lab do not lead to innovation and progress in the farm field. In the United States, the USDA, Land Grant universities, and the private sector have collaborated to exploit scientific advances. A highly effective, but distributed, system emerged where knowledge gained in the laboratory was tested and refined on experimental plots and then extended to agricultural producers.

- In agriculture, therefore, knowledge from science will need to be effectively integrated within efforts to accomplish the goals of predictive and prescriptive analytics. Even with this additional complication, the potential of tools based upon emerging data science capabilities offers significant promise to more effectively optimize operations and create value within the agricultural sector.

8.5 Digital Agriculture and the Food System

To this point, this chapter has focused on individual technologies and concepts that can affect the manner in which big data and digital technologies affect agricultural innovation. This section will attempt to depict a more unified picture of the future setting that we might call digital agriculture. First, the emphasis will continue at the level of production agriculture. The focus will emphasize managerial capabilities, which in most cases will rely upon multiple technical factors. Illustrative examples will be provided. Second, production agriculture is just one component of the broader food system. A system which increasingly is employing digital technologies and big data to improve efficiency and effectiveness. Linkages between those efforts and implementation within production agriculture will be explored in the section's second segment. The role of societal expectations for that system will be discussed as well.

8.5.1 Components of a Potential Digital Agriculture

This section will attempt to paint a picture of the multiple components that could inform farmers in tomorrow's digital agriculture. This is not intended to be a prediction, as these components currently are being employed to some extent. Rather, the discussion will hopefully provide insights as to the potentials that exist as integration across technical capabilities occurs. Of course, one needs to keep in mind the reality that just because something is technically possible, there may not be sufficient justification for managers to adopt that innovation.

Figure 8.3 graphically identifies several components that could form digital agriculture. Examples of each will be provided to illustrate their potential application.

Precision agriculture has been discussed at length previously. While routinely employed by many farmers, advances in technical capabilities are continually offering new opportunities. For example, sensors embedded in the maize planter now can sense soil moisture, depth, and other factors in each furrow to optimize the placement of seed as planting is being done.

Similarly prior discussion addressed big data applications. Farmers now can subscribe to services that provide extremely localized weather information and/or receive agronomic guidance based upon insights gained from analysis of production on thousands of acres, in addition to their own experience. As more data is captured and as research and development continues, the capabilities of such services are likely to increase.

The Internet of Things is a concept closely linked to precision agriculture, although it is worthy of separate consideration. Sensors that monitor conditions in the field to inform irrigation decisions are one example. Similarly sensors in grain bins can continually monitor conditions in the bin. In both instances, the associated systems can inform managers of the actual and past status, can initiate action when warranted, and can record information that can be employed (possibly with big data approaches) to improve the algorithms within the system.

A key difference between factory-based manufacturing and much of agriculture is that agriculture occurs in the open and across significant distances. Therefore monitoring what is happening as it happens has been a historic challenge on the farm. As noted previously remote sensing is being employed to overcome this constraint. The source of the data can be from satellites, fixed wing aircraft, UASs, stationary devices, or some combination of them. For example in Australia, efforts are underway which link satellite monitoring of pasture conditions with sensors that monitor animal weight. Algorithms are being estimated which use that data to recommend when to move animals from a paddock that is in danger of being overgrazed to another more suitable one. Applications in developing countries are particularly exciting as the prior methods of gathering information have been both expensive and insufficient. Possibly, remotely sensed data, in combination with other information sources, can improve agricultural and food systems in those settings. A marked improvement might be possible in a fashion similar to the way cell phones markedly improved communications in developing countries.

This chapter's second section described a story from the 1950s to illustrate that farmers have always wanted to use evidence from their operations to improve the farm's performance. The high cost or infeasibility of measurement historically limited their capabilities to do so. Labelled here as on-farm research, there appears to be is considerable innovation and experimentation focused on the means by which farmers can apply the digital technologies to learn how to improve their own operations (Grains Research Development Council 2016). This interest is being expressed in terms of actions by individual farmers, efforts of groups of farmers (including cooperatives), and in collaboration with input providers. These efforts are exciting because of the possibility of gain, but also because of the potential for enhanced managerial control which previously was never available to farmers.

Finally, coordination is a critically important aspect of digital agriculture. Such coordination may involve relatively simple technologies. For example, a group of woman farmers in an African country who learn that the trader can pay higher prices for their chickens if they use a cell phone to inform the trader when there are enough chickens available to fill the trader's truck. In contrast, coordination may involve combining localized weather forecasts with a logistics model of the most efficient use of equipment for a large farming operation.

8.5.2 *Digital Technologies Throughout the Food System*

Figure 8.4 provides a high-level view of the key subsectors within agriculture that has proved useful for consideration of future competitive dynamics relating to big data. In that graphic, the genetics subsector is separately identified because of its linkages with big data. A number of firms in that category have capabilities to operate as input suppliers as well. The input supply category refers to providers of equipment, seed, fertilizer, and chemicals to farmers as well as providers of financial and managerial services. The production agriculture segment is comprised of farming firms, which can range from low-resourced smallholders to family corporations to subsidiaries of major corporations. The first handler segment refers to firms which aggregate, transport, and initially process agricultural produce but do not directly market to consumers. The final segment relates to food manufacturers and retailers. These types of activities are combined here because of their common interest in employing big data tools to better understand consumers.

From a strategic perspective, it is important to stress that big data tools already are extensively employed, particularly at both "ends" of the sector. Firms at the food manufacturing and the food retailing levels expend considerable resources to continually develop a better understanding of consumers. Insights gained through application of big data analytics can allow managers both to anticipate and respond to consumer concerns. Far upstream in the sector, bioinformatics and other big data tools are employed to accelerate research and development processes, advancing genomic capabilities of the sector. Figure 8.4 identifies, at a general level, key interests that "naturally" reside within each subsector and have the potential to be important within big data applications.

Agricultural operations occur across time and space. Therefore, the logistics of providing inputs, production, and aggregating output consume considerable

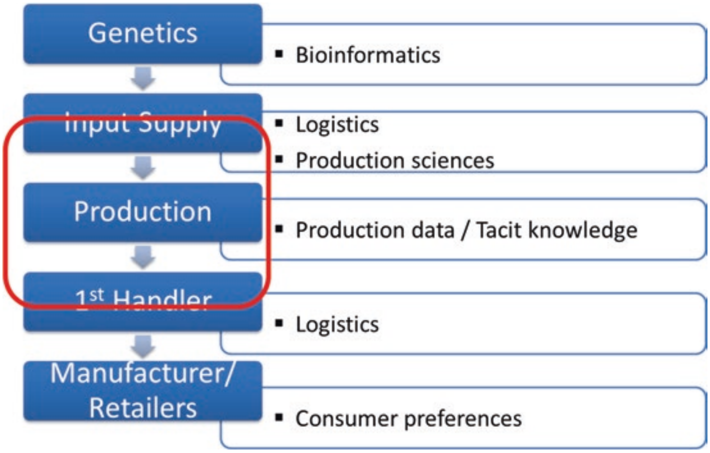


Fig. 8.4 Subsectors and their key strategic interests relating to big data

resources. Advances in information and communication technology combined with big data analytics offer the potential to reduce the amount of resources needed. Deadweight loss is a term that describes system inefficiencies that can be reduced by enhanced coordination within and between firms. Even in advanced agricultural settings, reduction of deadweight loss is perceived to be an attractive potential use of big data innovations.

In this context, deadweight loss refers to the processes by which inputs and outputs are delivered (when and where). A more intriguing issue for many is whether application of big data can fundamentally alter decision making as to "what" should be done. Can we further optimize the biology of agricultural production, especially in the context of the larger food and agricultural system? Earlier it was noted that new sensing technologies offer the potential to monitor and document what actually occurs as agricultural production takes place. The resulting data potentially would be available at never before levels of detail, in terms of time and space, and at low cost. Furthermore, analytic capabilities could combine diverse sources of data to discern previously unknown patterns and provide insights not available previously.

A result of application of these innovations would be optimization of agricultural production systems, simultaneously reducing its environmental impact and improving profitability. There are two interrelated factors that need to be addressed in considering the possible evolution of this optimization:

- Production agriculture involves biologic processes subject to considerable uncertainty. Therefore, even if one knows exactly *what* occurred in one production season and what actions would have optimized performance under those circumstances, that information may not be a good predictor of what actions should occur in the next season.
    - Some assert that capturing massive amounts of agricultural data, spread across large geographic regions, will provide sufficient information so that the effects of weather and location can be estimated. Doing that would enable big data analytics to answer the question, "why does production variability occur?"
    - Agricultural science has been devoted to discerning the why of agricultural production. Rather than solely relying on big data analytics, others assert that agricultural science techniques and knowledge will need to be integrated within big data techniques to truly optimize system performance.
- In most systems of agricultural production today, even the knowledge of what occurred does not necessarily reside within one organization. Furthermore, as was noted for precision agriculture, individual entities at the production level typically do not have the scale to produce sufficient data nor to have the capabilities needed to analyze that data.

Because of these two factors, collaboration across organizational boundaries will be required to fully exploit the potential benefits of big data's application to agriculture. A host of factors, beyond technological effectiveness, will influence the speed and extent of this exploitation. These relate to intellectual property and competitive dynamics as well as the magnitude of economic benefits available. Such impediments are not insurmountable and can be viewed as much as opportunities as they are impediments. How they are resolved, however, will have a major impact on big data's eventual contribution to performance within agriculture.

Beyond its direct economic impact, society has intense interest in the social and environmental effects of agriculture. Food safety and security are of public interest in every society. Interest in mitigating negative environmental impacts of agricultural operations is increasingly a concern and that concern is not constrained to just citizens in developed nations. In addition to public sector interest, some consumer segments express interest and concern regarding the practices and methods employed to produce food. Therefore, in addition to public sector-based regulation, documentation as to practices employed is increasingly being required by private sector food manufacturers and retailers.

Interestingly, technological innovations, such as those noted previously, have the potential to provide much better evidence as to their societal and environmental effects. These include both tools to more precisely measure and monitor and analytical methods to better understand and predict effects.

8.6 Final Remarks

Historically, agricultural innovation has been a key factor in the improvement of individual and societal well-being. While much progress has been achieved through that innovation, more needs to be accomplished especially as the world addresses the needs of a growing population while simultaneously reducing the stress that agricultural production can have on the natural environment. This chapter explores factors affecting the extent to which effective implementation of digital technologies and big data can contribute to that urgently needed agricultural innovation.

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