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Improving data management and decision support systems in agriculture

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Contents

Introduction

The prediction of rapid increase in the world's population and the need to improve food security across the world has led the agricultural sector on a path to improve farm productivity. Farmers are subjected to many risks from changing climate, economic and market volatility. In order to continue to remain viable and increase productivity, they need to be able to make both strategic in-season and long-term decisions. Agricultural decision support systems provide one tool for farmers to improve this decision making.

Agricultural decision support systems (DSS) have made rapid advances in the last 5 years from basic spreadsheet-based tools to sophisticated, interactive systems. Advances in computing techniques, the use of artificial intelligence (AI), geospatial and precision agriculture technologies have provided tools that can improve the granularity of decision making both spatially (to district, farm and field/paddock level) and temporally (from daily to seasonal contexts). The new emerging DSS are data-centric tools which can interface with farm machinery and sensors networks to provide mobile and cloud services with real-time capabilities. The use of these DSS has become widespread across many agricultural enterprises, including broad acre cropping, animal production, horticulture and food supply chains and has shown benefit to both small-scale/subsistence and larger agricultural enterprises.

A number of key factors need to be considered if there is to be continual improvements in these agricultural decision support systems:

1. The increasing quantities of data that have been collected from sources such as satellites, drones, in-field sensors etc. This growth has led to concerns as to how best to collate these enormous quantities of seasonal and historical data to create useful information for making decisions.
2. The need to provide universal data standards for the storage and distribution of these data sets to allow for their effective use.
3. The question as to who owns the data that has been collected and whether open access to data is possible given IP and other concerns such as the cost of collecting data.
4. The increased connectivity of farms through wireless sensor networks, cloud and cloud computing, which has also increased the vulnerability of the data that is being stored and transferred across these networks.
5. The use artificial intelligence (AI) technologies which can now be used in conjunction with more traditional approaches of crop modelling and statistics to develop effective decision support systems.

These issues are discussed in various chapters in the book.

This book reviews and summarises the wealth of research on key challenges in developing better data management and decision support systems (DSS) for farmers and illustrates how those systems are being deployed to optimise efficiency in crop and livestock production. Part 1 reviews general issues underpinning effective decision support systems (DSS) such as data access, standards and security. It also reviews the advances in the use of artificial intelligence (AI), Image processing, GIS and other technologies to improve the effectiveness of these decision support systems. Part 2 contains case studies of the practical application of data management and DSS in areas such as crop planting, nutrition and use of rotations, livestock feed and pasture management as well as optimising food supply chains.

Part 1 General issues

Chapter 1 discusses a key issue in developing decision support systems which is access to good data. The chapter describes various Initiatives which support the sharing of open access data sets. The chapter also discusses challenges such as the need to digitize data as well as issues relating to ownership, accessibility, quality, interoperability and portability which limit the usefulness of data. The chapter shows the various ways these challenges are being addressed in ensuring e.g. that data infrastructures are underpinned by good quality standards. The chapter includes a number of case studies, including the Africa Regional Data Cube and GEOGLAM.

The development of digital agriculture or smart farming highlights the importance of data and data exchange. Chapter 2 discusses how to achieve data standardization as a critical success factor in agricultural decision-making. It emphasizes the importance of understanding business processes and decision-making steps in identifying key issues in data standardisation. The chapter reviews a reference architecture that has been developed in the IoF2020 project to support the interoperability, replicability and re-use of standards and components for integral decision-making in agriculture.

Chapter 3 focusses on data integration, data analytics and decision support methods that can help agriculture to rise to challenges such as climate change adaptation and food security. In this context, smart data acquisition systems, interoperable Information systems, and frameworks for data structuring are required. The chapter describes methods for data identification in phenotyping hybrid information systems (PHIS) and provides recommendations for non-ambiguous universal resource identifiers (URI). The chapter also discusses the enrichment of data with semantics and ways to tag data with relevant ontology. A case study shows these techniques in practice through technologies and methods for plant phenotyping.

Chapter 4 explores how connectivity and information flow are the two key enabling factors for farming enterprise. These elements also represent the most vulnerable aspects open to cyber-attack, with the aim of disrupting food production. The use of a principles-based framework to assess cyber-attack vulnerabilities in precision agriculture technology as well as in the environment to which it is applied can greatly mitigate the risk of cyber-attack. Farmers can then construct a system that is appropriately protected from cyber-attacks and matched to the complexity level of the technology without unnecessary cost. Future areas of research include analyses of cyber-attack consequences through modelling cyber-physical system vulnerabilities, detection design and security architecture.

Chapter 5 reviews developments in the use of artificial intelligence (AI) techniques to improve the effectiveness of decision support systems (DSS) in agriculture. It discusses the use of different AI techniques such as data mining, artificial neural networks (ANN), Bayesian networks (BN), support vector machines (SVM). It includes several case studies of practical application of these techniques to support decision making by farmers, including WAAgData, GeoSense and rice based DSS.

Chapter 6 discusses developments in tools and technologies used in precision agriculture for effective decision making, including remote sensing and geographic information system (GIS) technologies, sensors and sensor networks. There is a particular focus on statistical and crop simulation models for identifying and accounting for variability in crop production systems.

Part 2 Case studies

Chapter 7 offers a comprehensive review of some of the approaches used by decision support systems (DSS) to make fertiliser application decisions. The chapter reviews direct methods and indirect techniques: simulation models, yield forecasts using data-driven approaches and yield forecasts based on water supply. The chapter includes two case studies to estimate season-specific nitrogen requirements of wheat crops at a within-field scale in Australia. These models forecast yield in two key periods of the season in which farmers make decisions for fertiliser applications – pre-sowing, and mid-season.

Crop rotations have formed a fundamental component of agricultural systems for millennia and advanced decision support systems for crop rotations hold great potential for improving soils and agricultural sustainability. Chapter 8 explores new and current opportunities to gather and collect farm data at unprecedented temporal frequency and spatial resolution. These provide adaptive recommendations for multiple sustainability indicators, based on time-varying constraints and real-time data on factors such as climate, markets and pests. At the heart of this new development is the requirement for a better human-centred design with improved efforts to understand how farmers think, aligning their interests between technologists and farming communities, leading to improved access and to facilitate agricultural transformation in the longer term.

Chapter 9 reviews the role of decision support systems (DSS) for pest monitoring and management through information technology like remote sensing, GIS, spectral indices, image-based diagnostics, expert systems and phenology-based degree day models. Applications range from rule-based models to phenology models to help in pest forecasting as well as monitoring, together with intelligent systems able to suggest appropriate integrated pest management (IPM) strategies. The chapter includes case studies of expert systems, crop pest DSS using phenology-based degree day models, and mobile-based artificial intelligence (AI) modules for identification of pests.

Food production takes place in a complex network of enterprises reaching from agriculture to processing, trade and retail. This complex network creates difficulties in the management of data across the food value chain or in coordinating decisions that maintain product supply and quality and serve the needs of all enterprises concerned. Chapter 10 discusses the issues and provides a framework for supporting data management and decision support in food value chains. Starting from a discussion of the decision situation in food value chains, the chapter outlines a selection of tools for decision support and reviews decision problems in data management and food chain organization.

As well as continuing issues about food safety and quality, more concern is being raised about animal welfare and environmental issues caused by livestock. Balancing these conflicting objectives remains an ongoing challenge requiring multidisciplinary research. Chapter 11 reviews the role played by linear and mathematical programming models and other tools in calculating diets for livestock production. Case studies are provided to offer better understanding of the strengths and weaknesses of linear and goal programming. Ultimately, decision support systems (DSS) are essential in balancing economic, environmental and social objectives in order to provide sustainable diets for livestock. Their role is also key in animal product traceability.

Chapter 12 addresses the limited uptake of decision support systems (DSS) in pasture and rangeland farming systems, despite several decades of development. Historically, there has been confusion between use of DSS tools for either farmers, or for learning and research purposes, which has impacted their applicability for farmers. It is highly important to focus on, and involve, the end user early in the development process. Existing DSS development has focussed on relatively static models, that require manual or semi-automated inputs, often needing more time investment from farmers. Opportunities for improvement are focussed on the automation of real time data streams into farm system DSS, linkages to smart middleware and using advanced analytics.

Part 1

General issues

Chapter 1

Improving data access for more effective decision making in agriculture

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1 Introduction

The Food and Agriculture Organization of the United Nations (FAO) estimates that, by 2017, the number of undernourished people globally will have reached 821 million – around one person out of every nine – with the majority being women and children. Undernourishment and severe food insecurity appear to be increasing in almost all subregions of Africa, as well as in South America, whereas the undernourishment situation is stable in most regions of Asia (FAO, 2019). With the increase of data becoming available, and the adoption of digital technologies to advance precision farming, there is also a growing digital divide emerging between more and less technological advanced farming systems (Van Es and Woodard, 2017).

Today, our society is globally connected, and so is our food system. However, not all the data in our food system is equally accessible in different parts of the world. Farmers across the world will benefit from bridging the digital divide(s) (Jellema et al., 2015; Berdou and Miguel Ayala, 2018). The Global Open Data for Agriculture and Nutrition (GODAN) initiative supports proactive sharing of open data to make knowledge on agriculture and nutrition available, accessible and usable, in an effort to deal with the urgent challenge of ensuring world food security (Schaap et al., 2019; Musker et al., 2018).

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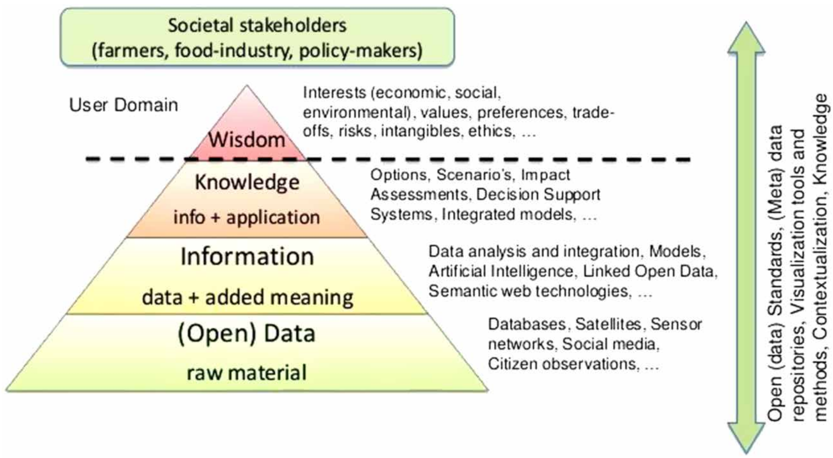

Figure 1 Pyramid of wisdom with open data as raw material. Source: adapted from Janssen et al. (2017).

The modern farmer has access to a growing number and variety of tools to enable better-informed decision making on the farm. Modern farm management information systems (FMIS) allow for better decision making and, thus, more efficient and sustainable agricultural production using an increasing amount of data. With the increased amount of data that is collected on farms, through farm equipment and remote sensing comes the potential for the development of new applications such as precision agriculture (Wolfert et al., 2017).

However, open data by itself will not directly lead to better decision making by farmers (Fig. 1). Generally, open data informs the decision-making tools that farmers use, since applications need to be of value to farm management operations. Additionally, from a user perspective, devices and data need to be trusted in order to make them a reliable part of any decision support system. For any FMIS, good quality data is key to adequate decision support.

2 Key issues in current availability of data

Agricultural reports have been published for a very long time. Agricultural censuses are one of the earliest examples available of data sets in agriculture. They may, in fact, be the first open data sets on record. From the early 2000s, more and more governments have begun to share basic data sets (on land use, for example) that are more or less universally available for public reuse. In many countries in the developing world, records of data such as agricultural statistics have not been fully digitized and thus it is very hard to access the data. Even if the data is made available, there is also sometimes a lack of capacity to be able to utilize the data effectively. One of the key aspects of successful capacity development for utilization of data is localization (e.g. language) to meet local needs and priorities.

Some of the costliest data on farms is soil-related. Due to the technology involved in soil sampling, many of these records are now digitized. Satellite data changed the game in terms of data size and coverage, with a significant amount of this data becoming publicly available. Drones and IoT devices now also produce large amounts of data on a local scale (Liu et al., 2012). These data are often collected by the private sector (farmers and farm machinery manufacturers) and, as a result, the data are not shared widely because of data access rights issues. Besides rights issues, there may also be issues that relate to the quality, interoperability and portability (large size of files) of the data. Figure 2 shows a variety of sensors that can be used on a modern farm. Unfortunately, such variety can create data that is hard to reuse, either due to accessibility problems or due to practical issues such as interoperability.

According to the Open Data Index, most countries provide basic information data sets with creative commons licenses. Much of this data is used by farmers and some is also used by FMIS. For example, national weather data sets and national soil data sets are offered through government open data portals such as www.data.gov. Access to national-level weather data is varied

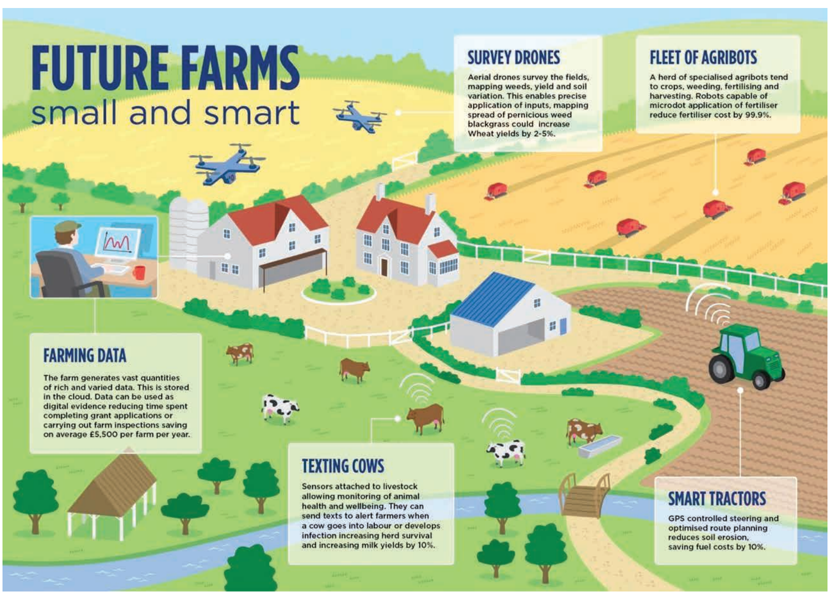

Figure 2 Future farming technologies. Copyright: NESTA. http://nesta.org/precisionfarming.

for different countries. For example, it is difficult to get up-to-date weather data information in some countries in sub-Saharan Africa.

There is a huge global variability in terms of the use of and access to personal computers as well as connectivity to the internet. Many now acknowledge the inability to access and use data as a digital divide (Aaronson and Leblond, 2018). Today's increasing use of available data in the world has been growing at different rates in different regions. It is clear that not everyone is benefitting equally from data, either because they have no access to it, or because there is a lack of capacity to make use of it. In agriculture, we find that this phenomenon is also present (as described by Jellema et al., 2015). In many countries in Africa and Asia, data such as soil data and agricultural statistics have not been digitized at all and thus it is very hard to access. But even if the data is globally offered such as the satellite imagery data from space programs, farmers or extension officers are unable to make use of this data in applications directly due to bandwidth problems. Besides bandwidth, there may also be a lack of storage capacity and general infrastructure to process data. And if the data and technology is available, there is sometimes a lack of capacity to be able to utilize the data effectively. A further digital divide is that women in many situations do not have the same access to technology, predominantly within developing countries. In these environments, a significant part of the farming workload falls to women, whose contribution is too often unreported or ignored. Without access to technology and data, farming work by women is made more difficult, less productive and less competitive.

Most of the data collected on the farm is not stored by the farmer. Soil sample data is stored in a database at the soil testing lab, for example, or sensor data from equipment such as tractors and harvesting machines would be stored by the farm machinery manufacturer. Often this information is available through a cloud application, and sometimes also via an API. Data infrastructures are supported by web standards such as OGC WMS mapping standards for example. However, any data infrastructure needs to be underpinned by good quality standards that are semantically coherent. The Africa Regional Data Cube (ARDC) use case is an example of a data infrastructure that delivers large volumes of earth observation data to decision makers in the region to understand and find solutions for agricultural improvement. An example of a web-based data infrastructure use case is that of Geo-Wiki. Geo-Wiki is a platform for citizen science and crowd-sourced information sources. Use cases presented later in this chapter, like Geo-Wiki, help us understand the potential of initiatives like this for agriculture.

Some initiatives have emerged that aim to facilitate access to farm data on behalf of service providers and app developers. In the United States, OADA provides an open protocol, allowing farmers to share and receive data through

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