How should we turn data into decisions in AgriFood?

Article

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Title

How should we turn data into decisions in AgriFood?

Running title

Turning Data into Decisions in AgriFood

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Abstract

The AgriFood supply chain is under significant pressures related to food security, climate change, and consumer demands for affordable and higher quality food. Various technologies are already deployed producing a large amount of data, which can be utilised to guide decision-making to improve productivity, reduce wastage, and increase traceability across the AgriFood supply chain. Several examples of the use of data are given, including improving efficiency in livestock production, supporting automation and use of robotics in crop production, increasing food safety and evidencing its provenance. The opportunities and ways forward were discussed at a workshop in November 2017, run by the Society of Chemical Industry and the Knowledge Transfer Network in the UK. This paper presents a summary of the key messages from the presentations and focus-group discussions during this event, as interpreted by the authors. A number of challenges in digitalisation of the AgriFood supply chain are discussed, such as low inter-operability of different data sets, silo mentality, low willingness to share data and a significant skills gap. Various approaches are presented that could help to unlock the benefits of using data, from practical support to producers and addressing skills gaps, to industrial leadership and the role of government departments and regulatory bodies in leading by example. Looking forward, data are already revolutionising the AgriFood supply chain, however, the benefits will remain piecemeal until the leaders of today are able to bring together the disparate groups into a cohesive whole.

Keywords

AgriFood, supply chain, Big Data, decision support, Artificial Intelligence (AI), digitalisation

Introduction

A revolution in food production, processing and distribution is underway [1, 2, 3]. Various technologies are already transforming the flow of food from field to consumer: technologies such as artificial intelligence (AI), cloud computer processing, remote sensing and robotics. Can these changes benefit the AgriFood supply chain and consumers? If so, how should we move forward? These were the questions addressed in the workshop 'Turning Data into Decisions in AgriFood' hosted by the Society of Chemical Industry (SCI) and the Knowledge Transfer Network (KTN) on 22 November 2017. This workshop brought together 74 professionals to hear about how these technologies are already having an impact and to consider how things might develop in the future.

Lessons can be learned from previous revolutions in farming. In the 1970s, the pioneering work of Norman Borlaug with plant breeding and nitrogen fertiliser rates led to higher yields, an expansion of irrigation and a rapid increase in mechanisation[4].

Having enjoyed the benefits of the Green Revolution, we are witnessing the fact that the yield growth this revolution unlocked has stagnated. Between 1985 and 2005, the total global crop production increased by only 28%[5]. Whilst there are still green revolution benefits to be realised, the easy wins have been made. Thus to move forward we have to broaden the scope of the technology we deploy. Digitalisation and big data allows us to do this through enabling much more precise and targeted management of the production process.

This paper summarises the key themes of the workshop leading to an action list for how best to implement the data revolution across production and supply chains.

Drivers of change

Globally, not only is population growth projected to continue to at least mid-century, but this is combined with a rapidly expanding wealth and consumers adopting a more ‘westernised diet’ rich in protein and demanding cheaper food and increased traceability and provenance. At the same time, the growth of cities means that more sophisticated food supply chains are needed. These mega-trends create a need for greater efficiency and improved data collection, analysis and application have key roles.

The AgriFood sector is a *value network*, comprising and connecting players within their own sectors, *e.g.* farmers, various suppliers (machinery, fertiliser, crop protection, *etc*.), food processors, manufacturers, and retailers. Each component has its own drivers, objectives and issues, which interface with those of connected players and of the whole sector. For example, the importance of data technologies and sharing platforms in the livestock industry is widely recognised and includes a range of applications, such as feed production and quality, animal productivity, health, welfare, breeding and fertility, environmental footprint and product quality, traceability and marketing.

Current state of the industry

Numerous sensors and connected devices are deployed to help AgriFood companies to collect data related to production, processing and distribution of products, referred to as the Internet of Things (IoT). Software applications with machine learning are required to collect, analyse, and integrate data, connect devices and guide decision-making. Data can help farmers to optimise inputs and adjust land management regimes, which depend on many variables, e.g. soil types, crop varieties and weather. Data can also help suppliers of crop protection products to produce more accurate recommendations, or to gather evidence on their efficacy with more precision, reducing their use and environmental impact.

Examples where the analysis of large volumes of data are benefiting the AgriFood sector are already available. Syngenta made a commitment to the Good Growth Plan and publish datasets on productivity, soil health, biodiversity, compliance with labour standards across their supply chain, etc.[6]. G's Growers, one of the largest producers of salad and vegetables in Europe, integrate agronomic, environmental and operational data to meet daily targets for supply of iceberg lettuces which enables the them to amend production schedules to mitigate against potential shortfalls (G's Growers, personal communication). IMB Research and Mars collaborate to conduct the largest-ever metagenomics study to improve food safety by developing an index of food-borne diseases and minimize the risk[7]. Data are being used to analyse the shopping habits of millions of consumers, to help suppliers develop effective marketing strategies based on purchasing patterns and demographic breakdown[8].

Turning data into decisions is the key for harnessing the power of data. Examples of whole food chain decisions include productivity, finance, insurance, supply chain management, food security, research & development and environmental stewardship. The recent Global Open Data for Agriculture and Nutrition (GODAN) review[3] is highly instructive in setting the context for the data revolution. The authors list a range of potential uses for large data sets in supporting decisions in these areas:

- Early, accurate detection and prediction of problems (pest outbreaks, resistance, water shortages, floods, low yields)
- What to grow, what treatment to apply and when to plant, treat or harvest
- Risk management (hedging, yields, insurance) and damage control (drought, pests)
- Managing subsidies (funding history, financial data)
- Informing consumers (individuals or companies)
- Fast responses to challenges

The GODAN report described key actions required to maximise the use of data in AgriFood supply chains[3]:

- Building trust
- Developing standards and linking data
- Ensuring sustainability
- Providing incentives
- Data publishing principles (e.g. the FAIR principles, a set of guiding principles to make data Findable, Accessible, Interoperable, and Reusable)

Similar opportunities and actions were discussed during the event itself and are described later in this paper.

Turning Data into Decisions 2017: summary of the event

In November 2017, SCI and KTN organised the event on Turning Data into Decisions in AgriFood. The purpose of the event was two-fold: firstly, to allow participants to meet each other and develop their networks, and secondly, to generate discussion on the how this area might develop over the coming years.

This event gathered over 70 representatives from crop and livestock agri-businesses, farm and agronomy advisers, precision agriculture companies, machinery and equipment manufacturers, companies developing and using sensors, input manufacturers, food and feed manufacturers, producer organisations, agricultural traders, retail, analytical and measurement services, data analysisists, modellers, software engineers, robotics experts, insurance providers, academics, researchers, research councils and government departments.

The event covered the following themes:

- Why we need data and how to make it meaningful
- Examples of data collected from sensors and connected devices, and software applications for data analysis and integration
- Data analysis, integration, and the role of machine learning
- Use of data for financial models and models related to the environment and climate
- Using data for decision-making. e.g. development of software for customer interface and integrating data with AgriFood practice
- Data sharing platforms and standards
- Governance around data ownership, privacy, and security

The morning contained presentations covering example applications of data-driven food production and supply. In the afternoon the audience split into four moderated discussion workshops, each with a chair and rapporteur who took notes (the rapporteurs are listed within the list of authors of this paper). Each of the four workshops considered the above themes in the context of specific stakeholder groups: crop and livestock production, hardware and software developers, or the entire supply chain. Participants in the discussions were encouraged to share their own examples and use-cases as well as their perspectives on the future.

Thus, the opportunities, challenges and action points below are not simply the views of the authors, but an amalgamation of the views of over 70 professionals in this area, as interpreted and brought together by the authors with the context of the cloud of literature that is already available and known use-cases. Many of the conclusions may be found in other sources[1, 2, 3]. Although our method of collecting data was different from that used by other authors, the themes that emerged were not so different.

What opportunities exist to derive value from data?

It is very important to demonstrate that data could drive decision-making in food growing and production with a view to meeting end-customers specifications and satisfaction. Some examples of use of data follow.

Improving efficiency in livestock production

Variability in meat production systems may result in inefficiencies and reduced business value. Different parameters determine efficiency during each stage of the chain: pre-birth (fertility, gestation length, birth rate); rearing (growth rate, feed conversion ratio, disease resistance, mortality); finishing (weight, yield, fat class); slaughter (abattoir process); processing (butchery, processed meat products); and retail (meat colour, fat content, pack size, price, consumer experience). The fragmented supply chain results in highly variable output. Using data at key points in production, alongside tighter specifications, could help analyse where most value is created and reduce inefficiencies. Sensors enable real-time remote monitoring. An important target is the development of diagnostics and predictive analytics for real-time data-based decision-making to optimise management strategies. A growing number of professional services for dairy and meat farmers deliver hardware and software applications that can automate data analysis and integrate it into farm management systems and online trading platforms. These big data sets can create value to farmers when incorporated in decision support tools that demonstrate the advantages of using data from various key points that determine efficiency during each stage of the chain. Digital platforms bring buyers and sellers together and enabling vital information to flow up and down the supply chain, enabling proper comparison across multiple key indicators, improving transparency and traceability.

Use of data to support automation and use of robotics

The adoption of robotics in AgriFood is becoming more urgent. Farmers and food manufacturers need to produce more food to higher environmental and quality standards, while experiencing severe labour shortages. Therefore, there is a huge potential in improving productivity through efficiency gains that can be achieved via automation and use of data. The development of ‘co-bots’, where robots work alongside humans, utilising autonomous or partly autonomous behaviour is a possible option.

Robotic systems need data to perceive, make decisions and move. For example, the harvesting process is only partially automated and is relatively inefficient. To automate a process, information may be needed from several machines. To achieve higher levels of automation in harvesting, rule-based systems and modelling can be deployed to optimise process configuration. This can be achieved through the use of data on machine operation and the development of ‘training’ data sets (Claas KGaA mbH, personal communication).

Increasingly, robotic platforms, besides performing manual functions, are used to collect useful in-process data (in-field or during food manufacturing). Data gathered by robotic systems can be especially valuable due to the ability to capture data repeatedly and consistently from precise locations.

Food provenance and safety

Data could help to increase consumer trust and safety by helping to establish the provenance of products and the conditions under which they have been brought to market. Data can help to develop real-time prediction of emerging risks to food safety and fraud, e.g. the horsemeat scandal in 2013. Data on prices of commodities, consumer price index, exchange rates, extreme weather, pest and disease incidents, changes in regulation and standards, profit margins, production capacities, etc. can be used to develop early warning systems for food fraud. Deploying algorithms based on machine learning and statistical methods that aggregate all layers of such data and detect anomalies can collectively highlight any potential issues.

Development of shorter supply chains and new operating models

Digitalisation is enabling all farmers and food companies, whether small or larger scale to understand consumer needs and target higher value markets. Digital technologies could facilitate development of on-line trading platforms, or virtual online co-ops. These online trading platforms may also help to open-up the food market to smaller farms and food producers allowing them to sell direct and bypass the main existing distribution channels. Differences in purchasing behaviour between different consumer segments may be significant and require special attention to guide business planning, marketing and new product development. Data collected from retailers via consumer membership cards may elucidate factors such as geo-demographics, retail channel and consumer lifestyles.

Managing risks and uncertainties in food production

Inelastic supply and demand in agricultural commodities create volatile prices. Farm businesses succeed or fail on productivity and prices. Historically, mixed farming systems with crops and livestock provided a natural hedge against price falls in any single commodity. As farming modernised and became more capital intensive, most family farms specialised on either cereal farming, or pig farming, etc. to benefit from economies of scale. However, specialisation increased their vulnerability to fluctuating prices. Within the next Common Agricultural Policy (CAP) framework, the development of risk management tools might play a significant role[9]. In the UK, future support to farmers is more likely to be based on environmental land management scheme (i.e. paying farmers for habitat enhancement), replacing current direct payments to farmers in England[10]. Risk management tools might become even more important for UK farmers too. Data analysis can play a significant role in developing new insurance products. Algorithms can be developed to look at the precise correlations between each commodity over time and help to accurately forecast future price risk.

Challenges

The above examples demonstrated how data are benefiting the AgriFood sector, however, there are still a number of road blocks or difficulties in achieving a wider adoption of digitalisation. These challenges were discussed during the event described above, “Turning Data into Decisions 2017”, and summarised below.

Variety of data types

The depth and breadth of data needed to predict events, assess risks accurately and make decisions are huge. Available data form a multi-disciplinary matrix from soil and weather conditions and animal-related observations to product quality and consumer preferences. Analysing and using such diverse data sets is challenging. Moreover, diverse data sources collated over long periods of time are often needed. This time factor brings potential problems of changing relevance (*e.g.* crop varieties) and context (*e.g.* climate change). A further challenge is how to link user experience and qualitative factors so that agricultural decision-making is based on a data driven system.

Inter-operability of data sets

The potential of connectivity between systems is being constrained by a lack of common data standards or easy-to-use ontologies. Therefore, extraction of value becomes expensive and time-consuming. The collation of data can be very challenging, particularly where management decisions or control systems need inputs from multiple sources. A comparison could be made with the telecoms or air traffic control sector, where very rigorous international standards have existed for many years, defined in terms of both the data format and terminology to allow interoperability.

Standardisation of data acquisition and analysis will help to integrate different data sets and create more value. The FAIR principles were first published in 2016[11] and have since been widely adopted, requiring data to be Findable, Accessible, Interoperable, and Re-usable.

The GODAN report sets the goal of a ‘Global Data Ecosystem’, which means amassing varied and pertinent datasets in a way that allows straightforward access to and use of the data. Until recently there has been wide acknowledgement of the potential, but little progress in bringing together fragmented data infrastructures. There is some way to go to ensure that the FAIR principles are at work in the AgriFood sector.

It is not clear whether one widely accepted data standard or multiple standards would be more effective. A consistent approach to areas such as data terminology, structure, provenance and interoperability could enable better handling and transfer of data across the AgriFood system and develop trust and transparency in the sector. There is a question whether an industry or a government gatekeeper could or should be in place for these standards.

Silo-mentality

There is a flow of heterogeneous data, information and knowledge through the network of individual sectors that comprise AgriFood, which are traditionally stored in 'silos'. A 'silo mentality' means that the potential to create value from synergies arising from sharing and collaborating is not realised.

This can be attributed to the wide range of people and organisations involved in the supply chain. There are the 'doers' who create, move and process commodities and generate new technological solutions (private companies from start-ups through to international agri-tech companies; farmers from smallholders through to large estates). There are the 'influencers' who set out protocols and standards, provide ethical and legal frameworks and are involved in communication and knowledge transfer (government policy-makers, the media, academic researchers, agricultural advisers); and, in fact, everyone is involved as food consumers.

Value of innovations

In order to encourage companies and individuals to collect and exchange data, it is critical to demonstrate its value. Whilst distinct parts of the supply chain (e.g. manufacturers, retailers) have the capacity to invest in research, development and innovation, most benefits from use of data can be accrued at farm level. The evidence of value for the farmer is not yet clear and, consequently, implementation of new technologies, which generate and analyse data is limited. Farmers face significant productivity and profitability challenges, long working hours and often with thin and fluctuating profit margins. When allied to historically free access to numerous data sources, this means that many farmers are unclear about the business rationale for investing. This can negate the capacity and enthusiasm for them to invest in innovation and use of data in the first place.

The relatively small market and limited marketing opportunities for the services of data generation, organisation and analysis (for example remote sensors feeding data, satellite image analysis software, or agricultural inputs calculator), result in a number of small-scale innovators finding it difficult to secure a sustainable market share. There are many start-ups and technology companies operating in this market, however, 75% of them lack a visible revenue model[12].

Current uptake tends to focus on larger progressive farms or farms in integrated supply chains which have the financial capacity, interest and in-house staff expertise to take advantage of the data generated. For smaller farms, the business case is seen as being uncertain. The challenge, therefore, is to support key stakeholder groups to realise the value of data, which will enable them to prioritise investment in areas that make the biggest difference to their businesses; and share knowledge with those that do not have the capacity to invest.

Skills gap

One of the key barriers to adoption is the accessibility of these technologies to different stakeholders in the AgriFood sector. The skills available to implement and fully exploit the use of data driven technologies is constrained and there is a lack of instructors and teaching resources to deliver appropriate training. There is a need for well-trained operators for complex agricultural machinery which nowadays has not only GPS with machine guidance and automatic steering, but a multitube of additional sensors and software, along with its associated products and services.

Use of decision support tools and willingness to share data

As shown above in the example on improving efficiency in livestock production, real-time data-based decision-support tools can help to optimise management strategies and improve efficiency. There is a lack of commercial and widely acknowledged decision support tools that can help to demonstrate the advantages of using big data. In addition, this is limited by willingness to share the data especially when developing decision support tools that span several points in the supply chain.

However, it is unclear whether the attitudes of data owners or the lack of opportunities to share are more limiting. There is a fast-developing issue over the ownership of data and liability. A fear of erosion of competitive advantage was one reason suggested for the perceived reluctance to share data. In more collaborative agricultural systems, such as the Netherlands, where farmers and the food chain are focused on collaborating to drive exports, it is more common to share data in benchmarking groups and similar voluntary structures. Sharing of risk and reward in the food chain was a perceived major constraint for many farmers adopting digitalisation as they were afraid that any improvements in performance would be quickly captured by other players in the supply chain. It was felt that the incentive for being an innovator was unclear to many farmers.

Trust in data

One challenge is to provide industry with the confidence that the technology and data can be trusted. Reliability of data (data quality and integrity – both perceived and actual) is still an issue as the quality control of the mechanisms generating and organising the data may sometimes be questionable. Clear legislation and regulation are essential, but not necessarily in place.

What do we need to do now to unlock the benefits?

This was another question discussed during the event "Turning Data into Decisions 2017". Over 70 participants worked in different groups to discuss what in needed to make use of data more widespread in the AgriFood sector.

The suggestions below are not new in a sense that a number of other papers were published on this subject[1,3,12]. However, the aim of the event was not only to discuss the challenges and the way forward, but also to get a buy in from stakeholders through discussion and facilitate future collaborative working on realising some of these suggestions. This workshop was well represented and the conclusions are well balanced with wide consultation across the community.

Data standards

As data standards become harmonised, there will be greater transparency and understanding of data provenance, quality and integrity. This will help to develop trust and build consensus.

Equity

It is essential to avoid solutions where the big players get richer and the small players suffer. Those groups who are developing solutions must allow all stages of the supply chain to 'win'. Such solutions will build trust throughout the supply chain and encourage participation in the sharing of data.

Evidence

The investment in data collection and processing will be relatively expensive. In order to avoid waste of resources, there should be a considerable effort in building an evidence-base including an analysis of user needs. In this way, the expected outcomes from the technology will be well aligned with the problems facing the industry.

This paper discusses what opportunities exist to derive value from data and how data could drive decision-making in AgriFood sector. Collecting examples of these "use cases" provides valuable evidence that can help to close the gap between the decision support tools and implementation of big data. Without evidence, there will not be enthusiasm to develop new things. Without new things, there will be no evidence. What should we do first? Bold players have already seen the potential and built some new things, so the evidence should be gathered from what already exists. As the situation develops, there should be a continuing energy in cataloguing and demonstrating what works. This will lead to enhanced storytelling (as discussed below).

Regulation

Clear legislation and regulation on data privacy, storage, sharing and utilisation, are essential to overcome the barrier of low trust towards data practices. Data must be handled ethically and transparently, with clarification of the role of the owners and handlers of data platforms and defining the exact deliverables and benefits to producers. The conditions (or licensing) for reuse of data need to be clear with rigorous data management and quality assurance[3].

Reinforcement

Cultural barriers to openness in such a rich and diverse environment remain solid in places. To help to overcome these barriers, it will help if there is positive reinforcement through accreditation, or payment for associated services. Incentives to producers for investing in data collection, analysis and subsequently sharing are required, although these may not be restricted to monetary ones. Other means of reward can be the provision of real-time advice for quick decision-making applications, farm benchmarking and identification of strengths and weaknesses, and/or periodical performance records to assess efficiency.

Innovation support

There should be facilitation of engagement between data producers and partners who have or can develop analytics, visualisation and decision support tools. Innovation in the use of data in AgriFood could be incentivised through competitions and start-up incubation[3] and greater access to data funded by the taxpayer, e.g. government data.

Practical support

Capacity should be built across the sector through training, workshops and the development of assets that help people learn how to use relevant data. Such support should cover: developing good practices; guidelines, workflows and tools for publishing and linking data; making the process of data sharing easy and well supported[3].

Long-term commitment

There should be appropriate support to help organisations sustain their data resources, services and capabilities, ideally bringing private resources in line with public e-infrastructure. The sustainability of services will depend on brokering either government or private sector ongoing support[3].

Storytelling

To promote engagement, there needs to be a high visibility of example and success stories involving data in AgriFood. All channels should be explored, for example: government links; advisory organisations; the media; farmers' co-operatives; academic institutes; and related industries[3]. A crucial role is to help organisations working on complementary efforts be aware of each other, as well as providing gap analysis on missing initiatives (an area in which SCI and the KTN are attempting to add value through the publication of this paper).

Governmental participation

There is a significant role for government departments and regulatory bodies to lead by example. UK has already taken steps to coordinate the appropriate developments. Initially, several UK Government Departments published the 'UK Strategy for Agricultural Technologies'[13], leading to the formation of Agrimetrics, the Agri-Tech Centre driving ground-breaking solutions from a range of valuable data sources influencing how we produce, supply and ultimately consume food. In another example, the UK Food Standards Agency (FSA) uses data to identify and addressing food safety risks, and applies legislative and non-legislative tools to influence business behaviour in the interests of consumers and working closely with the food industry. Their portal[14] holds a range of valuable data about food and food safety including food hygiene ratings, allergy alerts, food contaminants and residues, novel foods and GM labelling, animal welfare incidents etc., all of which can be used without charge by any external organisations to add value to their business and by consumers to guide decision-making.

Industrial leadership

In the UK, there are organisations and initiatives such as the Open Data Institute, the FSA, Agrimetrics and the Digital Systems Catapult providing leadership and direction. The 'Made Smarter Review', led by Professor Juergen Maier, supported by over 200 organisations across the UK, provided analysis of the benefits of digitalisation across all sectors of the UK economy[15]. "Made Smarter" identified that digital technologies offer the potential for substantial gains in UK food chain productivity (on p. 155 there is a reference to "Digitalisation will secure the future of food supply chains"). The review also identified that in some technology areas the UK is already a global leader e.g. food and refrigeration monitoring systems via IoT, food safety and traceability systems, with the potential to unite

UK food sector expertise with UK IoT and block chain expertise to create globally leading disruptive technologies.

Keeping an international view

The "Turning Data into Decisions in AgriFood" meeting in November 2017 had a UK focus, but the problems and solutions are common to other countries. The European Commission is providing a framework for developing actionable plans to support digitalisation in industry, such as the Digitising European Industry initiative (DEI), which produced sector specific plans for how digitalisation could add value in various industry sectors, including one for AgriFood. DEIs vision for the future is one of increased connectivity and interoperability between platforms, whereby more services could be provided through gathering and combining information from a wide range of smaller platforms gathering data from sensors, machinery, animals, etc. This would increase resilience within farming, e.g. to manage resource efficiency, health and welfare of animals, and it could also be used to decrease bureaucracy for farmers[16]. Examples of other international initiatives include those led by Wageningen University and Research (Netherlands)[1,2,17], INRA (France)[18], Agroknow (Greece and Belgium)[19], and AgGateway (USA)[20]. International organisations and initiatives supporting the digitalisation of AgriFood sector include GODAN, CGIAR, and FAO (with a dedicated Interest Group on Agricultural Data).

Forward look

The above measures and activities open opportunities for specialist data integration and data analysis business that can help to "fine-tune" data delivery channels, customise data delivery to various customers, develop new business models, shorten supply chains, develop new services and products, and give more control to food producers and customers. These actions can change the balance of power in the AgriFood supply chain.

The future will be bright if the power of private-sector innovation and idea generation can be harnessed with public-sector support and in a form of public-private partnerships. The challenges are similar in all sectors of AgriFood (e.g. resistance to technology uptake, data kept in silos, inconsistent standards) and there are similarities in the underlying solutions across sectors. Data-driven agriculture feeds into many societal agendas, such as sustainability, climate-change responses, food pricing and rural economic development. The UK has already taken steps to coordinate the appropriate developments and outlined the actions that need to be taken[15].

The Data Revolution is underway, we already use data, but in a piecemeal and fragmented way. The real benefits will not be realised until the leaders of today are able to bring together the disparate groups into a cohesive whole.

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Glossary

Big Data

Massive volumes of probably complex data acquired in real time from diverse sources subjected to powerful and innovative modelling and analysis to create valuable information.

Cloud computing

The use of a network of remote servers hosted on the Internet, which provide a shared pool of computer resources to store, manage and process data.

Decision support tools

Usually software-based interactive systems using specific and often diverse data to make evidence-based recommendations to help users make better decisions.

Digitalisation

Enabling, improving and/or transforming systems and operations by leveraging digital technologies and a wider use of digitised data to create valuable information.

Internet of things

The connections via the Internet of computers and sensors embedded in machines and other devices allowing the collection and exchange of data.

Machine learning

The ability of computers and the devices they control to autonomously and continuously improve their capabilities as a result of data they collect and process.

Open data

Data that anyone can access, use, modify and store free of charge, but subject to attributing sources and preserving openness.

Remote sensing

The detection and/or identification of objects or landscapes from various distances without direct contact.

References

1. Wolfert S, Gea L, Verdouw C, Bogaardt MJ. Big Data in Smart Farming – A review. Agricultural Systems 153: 69-80. https://doi.org/10.1016/j.agsy.2017.01.023
2. van Evert FK, Fountas S, Jakovetic D, Crnojevic V, Travlos I and Kempenaar C. Big Data for weed control and crop protection. Weed Research 57: 218–233. https://doi.org/10.1111/wre.12255
3. GODAN (2016). A Global Data Ecosystem for Agriculture and Food, Allemang D and Teegarden B. Available from: http://www.godan.info/documents/data-ecosystem-agriculture-and-food [Cited 2018 May 17].
4. Borlaug N. The Green Revolution, Peace, and Humanity. Nobel Lecture, December 11, 1970. Available from: https://www.nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-lecture.html [Cited 2018 August 08].
5. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, Balzer C, Bennett EM, Carpenter SR, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Siebert S, Tilman D, Zaks DP. Solutions for a cultivated planet. Nature 478, 337–342. https://doi.org/10.1038/nature10452
6. Syngenta. Good Growth Plan Open Data. Available from: https://www.syngenta.com/what-we-do/the-good-growth-plan [Cited 2018 December 04].
7. IBM. IMB Research and Mars, Inc. launch pioneering effort to drive advances in global food safety. Press release 29 Jan 2015. Available from: https://www-03.ibm.com/press/us/en/pressrelease/45938.wss#release [Cited 2018 December 04].

8. Donnelly C, Simmons G, Armstrong G, Fearne A. Digital loyalty card ‘big data’ and small business marketing: Formal versus informal or complementary? International Small Business Journal 33: 422–442. https://doi.org/10.1177/0266242613502691
9. European Parliamentary Research Service. Briefing July 2016, Price volatility in agricultural markets: risk management and other tools. Available from: http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/586609/EPRS_BRI(2016)586609_EN.pdf [Cited 2018 September 18].
10. HM Government. A Green Future: Our 25 Year Plan to Improve the Environment (2018). Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf [Cited 2018 September 18].
11. Wilkinson M, Dumontier M, Aalbersberg I, Appleton G, Axton M, Baak A, Blomberg N, Boiten JW, da Silva Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJ, Groth P, Goble C, Grethe JS, Heringa J, 't Hoen PA, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone SA, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B. The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data 3:160018 https://doi.org/10.1038/sdata.2016.18.
12. PA Consulting. Transforming agriculture with data-driven insights (published 19 Feb 2018). Available from: https://www.paconsulting.com/insights/2018/digitalagriculture/ [Cited 2018 May 17].

13. HM Government. A UK Strategy for Agricultural Technologies (2013). Available from: https://www.gov.uk/government/publications/uk-agricultural-technologies-strategy [Cited 2018 May 17].
14. Food Standards Agency. Open Data platform. Available from: https://data.food.gov.uk/catalog/datasets?keyword=fhrs [Cited 2018 September 11].
15. UK Government. Made Smarter, Industrial Digitalisation Review (2017). Available from: https://www.gov.uk/government/publications/made-smarter-review [Cited 2018 May 17].
16. European Union. Digitalising European Industry. Working Group 2 Digital Industrial Platforms (2017). Available from: https://ec.europa.eu/futurium/en/system/files/ged/dei_wg2_final_report.pdf [Cited 2018 May 17].
17. Akkerweb. Farm Management Information System, Stichting Akkerweb, Apeldoorn, Netherlands. Available from: https://akkerweb.eu/en-gb/ [Cited 2018 May 17].
18. European Commission. SmartCow: an integrated infrastructure for increased research capability and innovation in the European cattle sector. Description of the Horizon 2020 project, 1 February 2018 till 31 March 2022. Available from: https://cordis.europa.eu/project/rcn/212581_en.html [Cited 2018 May 17].
19. eROSA project webpage. Available from: http://www.erosa.aginfra.eu/ [Cited 2018 May 17].
20. AgGateway project webpage. Available from: http://www.aggateway.org/Home.aspx. [Cited 2018 May 17].