

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Improving data management and decision support systems in agriculture

Edited by Dr Leisa Armstrong, Edith Cowan University, Australia



Contents

Series list	x
Introduction	xvi

Part 1 General issues

1	Improving data access for more effective decision making in agriculture	3
	<i>Ben Schaap, Wageningen University and Research, The Netherlands and Global Open Data for Agriculture and Nutrition (GODAN), UK; and Suchith Anand and André Laperrière, Global Open Data for Agriculture and Nutrition (GODAN), UK</i>	
	1 Introduction	3
	2 Key issues in current availability of data	4
	3 Use of data for decision making: case studies	7
	4 Current trends	10
	5 Conclusions	12
	6 Where to look for further information	13
	7 References	13
2	Improving data standards and integration for more effective decision-making in agriculture	17
	<i>Sjaak Wolfert, Wageningen University and Research, The Netherlands</i>	
	1 Introduction	17
	2 Business process modelling to identify data requirements	19
	3 Data flows for a particular process: the example of variable rate fertilization	20
	4 Linking platforms and software	21
	5 Creating a reference architecture for interoperability, replicability and reuse	25
	6 Key elements in data management	27
	7 Conclusions	33

8	Where to look for further information	33
9	References	34
3	Improving data identification and tagging for more effective decision making in agriculture <i>Pascal Neveu and Romain David, MISTEA, INRAE, Montpellier SupAgro, University of Montpellier, France; and Clement Jonquet, LIRMM, CNRS and University of Montpellier, France</i>	37
1	Introduction	37
2	Structuring the data	39
3	Case study: plant phenotyping	49
4	Conclusion and future trends	53
5	Where to look for further information	55
6	Acknowledgements	56
7	References	56
4	Advances in data security for more effective decision-making in agriculture <i>Jason West, University of New England, Australia</i>	59
1	Introduction	59
2	Security challenges in PA systems	62
3	System architecture and legal recourse	68
4	Security framework considerations for PA systems	70
5	Modern cyberattack methods	71
6	Classifying cyberattack source psychology	74
7	Cybersecurity frameworks for PA	77
8	Case study: PA system assessment	79
9	Future trends	82
10	Conclusion	83
11	Where to look for further information	84
12	References	85
13	Appendix	87
5	Advances in artificial intelligence (AI) for more effective decision making in agriculture <i>L. J. Armstrong, Edith Cowan University, Australia; N. Gandhi, University of Mumbai, India; P. Taechatanasat, Edith Cowan University, Australia; and D. A. Diepeveen, Department of Primary Industries and Regional Development, Australia</i>	95
1	Introduction	95
2	Agricultural DSS using AI technologies: an overview	96
3	Data and image acquisition	100

4	Core AI technologies	102
5	Case study 1: AgData DSS tool for western Australian broad acre cropping	109
6	Case study 2: GeoSense	110
7	Case study 3: Rice-based DSS	113
8	Summary and future trends	116
9	Where to look for further information	117
10	References	120
6	Improving data management and decision-making in precision agriculture <i>Soumyashree Kar, Rohit Nandan, Rahul Raj, Saurabh Suradhaniwar and J. Adinarayana, Indian Institute of Technology Bombay (IIT Bombay), India</i>	135
1	Introduction	135
2	Remote sensing technologies	136
3	Geographic information system (GIS) technologies	139
4	Sensors and sensor networks	140
5	Statistical and crop simulation models	142
6	Identifying variability in crop production systems	144
7	Summary and future trends	146
8	Where to look for further information	147
9	References	148
Part 2 Case studies		
7	Decision support systems (DSS) for better fertiliser management <i>Dhahi Al-Shammari, Patrick Filippi, James P. Moloney, Niranjan S. Wimalathunge, Brett M. Whelan and Thomas F. A. Bishop, The University of Sydney, Australia</i>	159
1	Introduction	159
2	Direct methods for determining crop nitrogen requirements for decision support	161
3	Indirect methods for determining crop nitrogen requirements for decision support: simulation models	163
4	Indirect methods for determining crop nitrogen requirements for decision support: yield forecasts using data-driven approaches	165
5	Indirect methods for determining crop nitrogen requirements for decision support: yield forecasts based on water supply	166
6	Decision support in action: case studies	167
7	Case study 1: nitrogen fertiliser applications using a data- driven approach	168

8	Case study 2: nitrogen fertiliser decision-making based on soil moisture predictions	173
9	Comparing the two approaches	175
10	Conclusion and future trends	178
11	References	179
8	Developing decision-support systems for crop rotations <i>Zia Mehrabi, University of British Columbia, Canada</i>	185
1	Introduction	185
2	Key information challenges	187
3	Ecological theory	189
4	Agonomic models	190
5	Encoding farmer decisions	193
6	Design principles	194
7	Outlook	197
8	Where to look for further information	198
9	References	198
9	Decision-support systems for pest monitoring and management <i>B. Sailaja, Ch. Padmavathi, D. Krishnaveni, G. Katti, D. Subrahmanyam, M. S. Prasad, S. Gayatri and S. R. Voleti, ICAR-Indian Institute of Rice Research, India</i>	205
1	Introduction	205
2	Pest identification	206
3	Pest monitoring	208
4	Pest forecasting	210
5	Integrated pest management (IPM)	214
6	Case studies	215
7	Summary and future trends	224
8	Where to look for further information	225
9	References	226
10	Developing decision support systems for improving data management in agricultural supply chains <i>Gerhard Schiefer, University of Bonn, Germany</i>	235
1	Introduction	235
2	Decisions in supporting data management	238
3	Decision tools	241
4	Principal case studies	244
5	Conclusion and future trends	249
6	References	250

11	Developing decision support systems for optimizing livestock diets in farms	253
	<i>Marina Segura, Concepción Maroto, Baldomero Segura and Concepción Ginestar, Universitat Politècnica de València, Spain</i>	
	1 Introduction	253
	2 Mathematical programming models for livestock production: a review	255
	3 Linear programming (LP) models to minimize feed costs: solutions and sensitivity analysis	257
	4 Goal programming (GP) models: balancing costs and environmental impact	262
	5 Decision support systems and data management for sustainable diets	264
	6 Case study 1: sustainable rations for intensive broiler production	266
	7 Case study 2: reducing emissions in pig production	272
	8 Summary and future trends	273
	9 Acknowledgements	274
	10 Where to look for further information	275
	11 References	275
12	Developing decision-support systems for pasture and rangeland management	279
	<i>Callum Eastwood and Brian Dela Rue, DairyNZ, New Zealand</i>	
	1 Introduction	279
	2 Decision-support systems (DSSs) in pasture and rangeland management	280
	3 Decision-making processes of pasture and rangeland farmers	281
	4 Development of effective decision-support tools	284
	5 Case studies of decision-support system (DSS) development in pasture and rangeland management	292
	6 Conclusion and future trends	302
	7 Where to look for further information	303
	8 References	304
	Index	311

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 loF2020 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

Ben Schaap, Wageningen University and Research, The Netherlands and Global Open Data for Agriculture and Nutrition (GODAN), UK; and Suchith Anand and André Laperrière, Global Open Data for Agriculture and Nutrition (GODAN), UK

- 1 Introduction
- 2 Key issues in current availability of data
- 3 Use of data for decision making: case studies
- 4 Current trends
- 5 Conclusions
- 6 Where to look for further information
- 7 References

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).

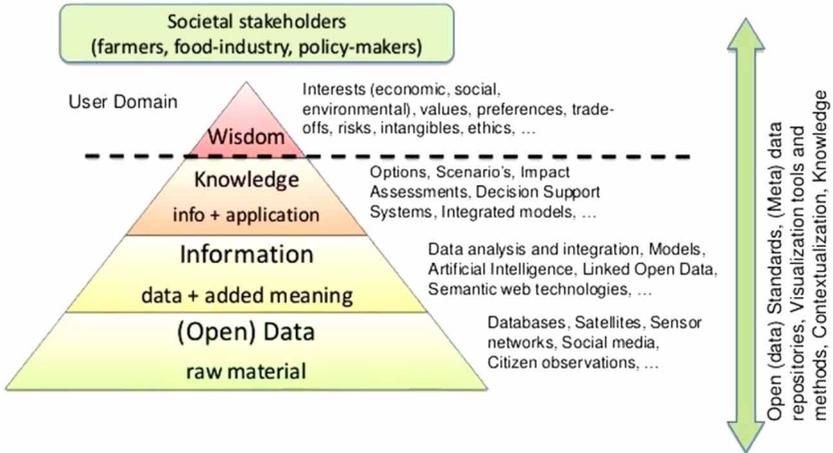


Figure 1 Pyramid of wisdom with open data as raw material. Source: adapted from Janssen et al. (2017).

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

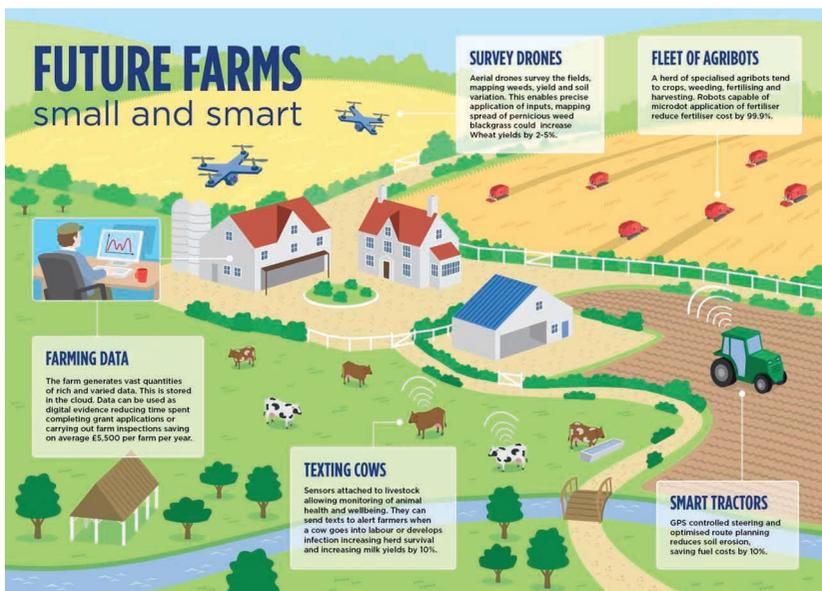


Figure 2 Future farming technologies. Copyright: NESTA. <http://nesta.org/precisionfarming>.

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

Index

- Access inequalities 188
- Accumulated degree days (ADD) 220
- Africa Regional Data Cube (ARDC) 6, 7-8
- AgEagle RX-60 139
- AgMine DSS 98
- Agras MG-1-DJI octocopter 138
- Agricultural decision support tools 118, 119
- Agricultural decision systems 83
- Agricultural Production Systems sIMulator (APSIM) 164, 178
- Agricultural supply chains, data management
 - data management for
 - transparency 244-246
 - decision model approaches 239-241
 - decision situation 238-240
 - decision tools
 - decision tables 241-242
 - multi-criteria decision tools 244
 - SWOT analysis 242-243
 - environmental management 246-249
 - future trends 249-250
 - and information support 250
 - overview 235-237
 - quality management 246-249
- AgriPrediction 146
- AgriSense 110, 112
- AgroDSS 146
- Agro-equipment 39
- AgroPortal 48
- AGROVOC 54
- AHP. *see* Analytical hierarchy process (AHP)
- AICD. *see* Akaike Information Criterion based on the Deviance (AICD)
- AICRIP. *see* All India Coordinated Rice Improvement Project (AICRIP)
- Akaike Information Criterion based on the Deviance (AICD) 145
- Albatross UAV 139
- All India Coordinated Rice Improvement Project (AICRIP) 210
- Analytical hierarchy process (AHP) 244
- Animal welfare 239
- Annotation 48
- ANNs. *see* Artificial neural networks (ANNs)
- API-AGRO 7
- APIs. *see* Application programming interfaces (APIs)
- Application layer 27
- Application programming interfaces (APIs) 23
- App store 23, 24
- APSIM. *see* Agricultural Production Systems sIMulator (APSIM)
- ArcMap software 223
- ARDC. *see* Africa Regional Data Cube (ARDC)
- ARK 42
- Artificial intelligence (AI) advancement
 - AgData DSS tool, western Australian broad acre cropping 109-111
 - agricultural DSS using 96-100
 - core AI technologies
 - artificial neural networks (ANNs) 105-106
 - Bayesian networks (BNs) 106-107
 - data mining process 102-105
 - statistics and other techniques 107-109
 - support vector machine (SVMs) 107
 - data and image acquisition 100-102
 - future trends 116-117
 - GeoSense 110-113
 - overview of 95-96
 - rice-based DSS 113-116
- Artificial neural networks (ANNs) 105-106, 207

- Backdoor malware 73
- Base-temporal CVSS vs. environmental CVSS 81
- Bayesian networks (BNs) 106-107
- Big Data era 37
- Big Data Grapes H2020 project 56
- Biotic variability 145
- BNs. *see* Bayesian networks (BNs)
- Book-and-claim approach 246
- Boundary object 287
- Bovine spongiform encephalopathy (BSE) 246
- Brown plant hoppers (BPH) 208, 221
- BSE. *see* Bovine spongiform encephalopathy (BSE)
- Business process model, variable rate fertilizing 22

- CCT. *see* Collaborative control theory (CCT)
- Cellular networks 27
- Centre of Studies In Resources Engineering (CSRE) 110
- CEOS. *see* Committee on Earth Observation Satellites (CEOS)
- Chain captain 238
- CIA model. *see* Confidentiality, Integrity, and Availability (CIA) model
- CLimate and rEMote sensing Association patteRns Miner (CLEARMiner) 104
- Climate scenarios
 - for different agroclimatic zones 117
 - Maharashtra 116, 118
- Cloud computing 100, 110
- Cnaphalocrocis medinalis* 218
- Collaborative control theory (CCT) 139
- Committee on Earth Observation Satellites (CEOS) 8
- Common Vulnerability Scoring System (CVSS) 61
 - approach 77, 78
 - formula 79
 - score 79-82
- Concept mapping 52
- Confidentiality, Integrity, and Availability (CIA) model 64
- Connectivity layer 26
- CP. *see* Crude protein (CP)
- CPS. *see* Cyber-physical systems (CPS)
- CropGIS 146
- Crop models 142-144
- Crop Pest DSS 212
- Crop Rotation Application 7

- Crop rotations, DSS
 - agronomic models 190-193
 - design principles 194-195
 - be forward looking 196
 - check the market 196
 - focus in 195-196
 - interoperate 196
 - know your user 195
 - make accessible 197
 - optimize 196-197
 - personalize 197
 - safeguard interests 195
 - state and test your assumptions 196
 - ecological theory 189-190
 - encoding farmer decisions 193-194
 - key information challenges 187-189
 - outlook 197
 - overview 185-187
- Crop sensors 141
- Crude protein (CP) 257, 258, 264
- Cryptolocker 72
- Cryptowall 72
- CSRE. *see* Centre of Studies In Resources Engineering (CSRE)
- CVSS. *see* Common Vulnerability Scoring System (CVSS)
- Cyberattack 60, 66, 82
 - consequences estimation 82-83
 - sources, threat profile of 74, 75
 - threats 67
 - vulnerabilities 84
- Cyber-physical systems (CPS) 82, 139

- Data
 - cleaning 103
 - corruption 67
 - curation 54
 - driven agronomy 195
 - driven model 165, 167, 176, 191
 - gaps 187-188
 - infrastructures 6
 - integration 103
 - linking approach 52
 - privacy 64
 - protection 63
 - selection 103
 - transformation 103
- Data access improvement
 - case studies, data use
 - Africa Regional Data Cube 7-8
 - Akkerweb 7
 - current trends 10-12

- Farm-Oriented Open Data in Europe (FOODIE) 10, 12
- GEOGLAM 8, 12
- Geo-Wiki platform 8-9
- Sustainable Technology Adaptation for Mali's Pastoralists (STAMP) 9-10, 12
- data availability, key issues in 4-7
- overview of 3-4
- Data identification and tagging improvement
 - future trends 53-54
 - overview of 37-39
 - plant phenotyping 49
 - Phenotyping Hybrid Information System (PHIS) 50-52
 - structuring the data 38
 - agriculture, ontologies and semantic tagging in 47-49
 - identification 39-44
 - ontologies and semantic web, interoperability with 45-47
- Data management improvement and decision-making
 - future trends 146-147
 - overview of 135-136
 - remote sensing technologies 136-137
 - sensors and sensor networks 140-142
 - statistical and crop simulation models 142-144
 - variability identification, crop production systems 144-146
- Data Management Plans (DMPs) 53, 55
- Data Sciences for Farming Support Systems (DSFS) 147
- Data security advancement
 - cyberattack source psychology 74-76
 - cybersecurity frameworks, PA system vulnerability 77-78
 - modern cyberattack methods 71-74
 - overview of 59-61
 - PA systems, security challenges in assessment 79-82
 - key availability threats 67-68
 - key confidentiality threats 64-66
 - key integrity threats 66-67
 - network characteristics 62-64
 - research pathways 82-83
 - security framework considerations, PA systems
 - access control 70-71
 - detection of 70
 - encryption 71
 - system architecture and legal recourse 68-69
 - old dogs, new tricks 69-70
- Data standards and integration improvement
 - agricultural machinery communication layer 29
 - business process modelling to identify data requirements 19-20
 - harmonized information models 31-32
 - interoperability, replicability and reuse, creating reference architecture for 25-27
 - IoT connectivity layer 26-28
 - IoT service layer 26, 28-29
 - linking platforms and software 22-25
 - overview of 17-19
 - security and privacy 32-33
 - variable rate fertilization 20-21
- DDoS. *see* Distributed denial-of- service (DDoS)
- Decision support systems (DSS) 66, 97, 98, 106, 161, 178, 206, 211, 254, 273, 280, 281, 298, 300
 - architecture of 115
 - general framework of 99
 - graphic user interface of 115
- Degree-day model 211, 220
- Denial-of-service (DoS) attacks 76
- Destructive ransomware 72
- DGC. *see* Digital ground cover (DGC)
- DGCA. *see* Indian Directorate General of Civil Aviation (DGCA)
- DHCD. *see* Distributed host-based collaborative detection (DHCD)
- Digital ground cover (DGC) 101
- Digital image processing 101
- Digital object identifier (DOI) 41
- Digital Single Markets Strategy 11
- Digital Twin 140
- Distributed denial-of- service (DDoS) 73
- Distributed host-based collaborative detection (DHCD) 83
- DJI Matrice 100 138
- DJI MG-1S 138
- DJI T600 Inspire Quadcopter 138
- DMPs. *see* Data Management Plans (DMPs)
- DOI. *see* Digital object identifier (DOI)
- DOI translator 42
- DoS attacks. *see* Denial-of-service attacks
- Downloader 72
- Drones, sensors used on 137
- Dropper 72

- DSFS. *see* Data Sciences for Farming Support Systems (DSFS)
- DSS. *see* Decision support systems (DSS)
- DYMEX modelling package 213
- EBEE SQ-SenseFly 138
- EC. *see* Electrical conductivity (EC)
- Ecological life tables 213
- Edge computing 67
- EISs. *see* Enterprise information systems (EISs)
- Electrical conductivity (EC) 141
- Electronic Product Code (EPC) 32
- EMPHASIS ESFRI 56
- Encoding data 71
- Encrypting ransomware 72
- Enterprise information systems (EISs) 32
- EntomoLOGIC decision tool 215
- EOSC. *see* European Open Science Cloud (EOSC)
- EPC. *see* Electronic Product Code (EPC)
- EPPN H2020 56
- e-readiness 246
- eSagu 207
- EU Code of Conduct 32
- EU General Data Protection Regulation (GDPR) 32
- European IoF2020 project 19
- European Open Science Cloud (EOSC) 11, 12
- Execution method 72
- Expert system 206
- Failure Mode and Effect Analysis (FMEA) 240, 246
- FAIR. *see* Findable, Accessible, Interoperable and Reusable (FAIR)
- FAIR data 11, 12
- FAO. *see* Food and Agriculture Organization of the United Nations (FAO)
- Farm data train visualization 11
- Farm information management systems (FIMS) 66
- Farm management information systems (FMIS) 4, 5
- Farm-Oriented Open Data in Europe (FOODIE) 10, 12
- Fertiliser management, DSS
decision support in action 167-168
direct methods, crop nitrogen requirements 161-162
decisions direct, yield maps 163
traditional approach, soil tests 162-163
future trends 178
indirect methods, crop nitrogen requirements
simulation models 163-165
yield forecasts based on water supply 166-167
yield forecasts using data-driven approaches 165-166
nitrogen fertiliser applications
April forecast 170-171
data-driven approach 168-170
July forecast 171-173
nitrogen requirements
calculation 168-169
nitrogen fertiliser decision-making, soil moisture predictions 173
nitrogen applications 174-175
yield potential map production 173-175
overview 159-161
two approaches comparison 175-178
- FieldServer 110
- FIMS. *see* Farm information management systems (FIMS)
- Findable, Accessible, Interoperable and Reusable (FAIR) 11, 54
- First Person View (FPV) 138
- Flspace 33
B2B collaboration engine 24
platform 23-25
- FIS techniques 107
- FIWARE 23, 34
business ecosystem 25
GEs 23
NGSI 30
NGSIv2 30
- FMEA. *see* Failure Mode and Effect Analysis (FMEA)
- FMIS. *see* Farm management information systems (FMIS)
- Food and Agriculture Organization of the United Nations (FAO) 3
- FOODIE. *see* Farm-Oriented Open Data in Europe (FOODIE)
- Food value chain 235
- FPV. *see* First Person View (FPV)
- French ANR project 56
- Future farming technologies 5
- Fuzz testing 69
- Fuzzy logic techniques 99

- GDPR. *see* EU General Data Protection Regulation (GDPR)
- GENEPEST 214
- Generic enablers (GEs) 23
- Genotype-by-Environment-by-Management interaction (GxExM) modeling 146
- Genotype x environment (GxE) interactions 145
- Geographical information systems (GISs) 97, 209, 210
- Geo-ICT 110
- GeoSense
DSS 98
near/real-time sensory data 114
oriented architecture for 100
- Geo-Wiki 6
- GEPIR. *see* Global Electronic Party Information Registry (GEPIR)
- GEs. *see* Generic enablers (GEs)
- GIAI. *see* Global Individual Asset Identifier (GIAI)
- GISs. *see* Geographical information systems (GISs)
- GIS visualizations 108, 116
- GLN. *see* Global Location Number (GLN)
- Global Electronic Party Information Registry (GEPIR) 31
- Global Individual Asset Identifier (GIAI) 32
- Global Location Number (GLN) 31
- Globally unique identifier (GUID) 40, 41
- Global Open Data for Agriculture and Nutrition (GODAN) 3
- Global positioning systems (GPSs) 108
- Global Returnable Asset Identifier (GRAI) 31
- Global Trade Item Number (GTIN) 31
- GLONASS 67
- Goal programming (GP) models 256, 262-264, 266
- GODAN. *see* Global Open Data for Agriculture and Nutrition (GODAN)
- GP. *see* Goal programming (GP) models
- GPFARM. *see* Great Plains Framework for Agricultural Resource Management (GPFARM)
- GPSs. *see* Global positioning systems (GPSs)
- GRAI. *see* Global Returnable Asset Identifier (GRAI)
- G-Range 298
- Great Plains Framework for Agricultural Resource Management (GPFARM) 298
- GrIDSense 147
- Group on Earth Observations Global Agricultural Monitoring Initiative 8
- GS1 31, 32
- GSMA IoT security 32
- GTIN. *see* Global Trade Item Number (GTIN)
- GUID. *see* Globally unique identifier (GUID)
- GxE interactions. *see* Genotype x environment (GxE) interactions
- GxExM modeling. *see* Genotype-by-Environment-by-Management interaction (GxExM) modeling
- Harmonization 187-188
- HEAPS. *see* HELicoverpa Armigera and Punctigera Simulation (HEAPS)
- HELicoverpa Armigera and Punctigera Simulation (HEAPS) 213
- High-throughput plant phenotyping (HTPP) systems 144, 145
- Honeycomb AgDrone System 138
- HTPP systems. *see* High-throughput plant phenotyping (HTPP) systems
- Hydrometer 63
- Hyperspectral reflectance patterns 209
- ICDTs. *see* Information communication and dissemination technologies (ICDTs)
- ICS. *see* Industrial control systems (ICS)
- ICT. *see* Information and communication technology (ICT)
- IGAD. *see* Interest Group on Agricultural Data (IGAD)
- IGSN. *see* International Geo Sample Number (IGSN)
- IGSN network 43
- IIRR. *see* Indian Institute of Rice Research (IIRR)
- ILCYM. *see* Insect Life Cycle Modeling (ILCYM) software
- Indian Directorate General of Civil Aviation (DGCA) 138
- Indian Institute of Rice Research (IIRR) 207
- Industrial control systems (ICS) 69
- Inference engine 206
- Information and communication technology (ICT) 19, 215
- Information communication and dissemination technologies (ICDTs) 141
- Information management layer 27
- Information overload 187

- Insect Life Cycle Modeling (ILCYM)
software 212
- Integrated GeoSense architecture 114
- Integrated pest management (IPM) 205,
214-215
- Interest Group on Agricultural Data
(IGAD) 55
- Intergovernmental Panel on Climate Change
(IPCC) 265
- International Geo Sample Number
(IGSN) 42
- Internet of Things (IoT) 17, 25, 42, 62, 82,
100
- Intuitive ability 283
- IoF2020 25, 26, 34
reference architecture 26
ensuring re-use and interoperability 25
solution 32
- IoT. *see* Internet of Things (IoT)
- IPCC. *see* Intergovernmental Panel on
Climate Change (IPCC)
- IPM. *see* Integrated pest management (IPM)
- ISBN 40
- ISOBUS 29
- Key performance indicators (KPIs) 293
- k-nearest neighbor approach 103-104
- KPIs. *see* Key performance indicators (KPIs)
- LAI. *see* Leaf area index (LAI)
- Lancaster 5 Precision Hawk 138
- LandPKS. *see* Land-Potential Knowledge
System (LandPKS) app
- Land-Potential Knowledge System (LandPKS)
app 299
- Laser-based light detection and ranging
(LIDAR) 136
- LCA. *see* Life cycle assessment (LCA)
methodology
- LCCC. *see* Lin's concordance correlation
coefficient (LCCC)
- Leaf area index (LAI) 20, 102
- Leaf hoppers (LH) 221
- LIDAR. *see* Laser-based light detection and
ranging (LIDAR)
- Life cycle assessment (LCA)
methodology 256-257
- Life science identifiers (LSIDs) 41
- Linear programming (LP) 254, 257-262,
266, 273
- Linked Open Data (LOD) 47, 53, 54
- Linked Open Data cloud diagram 46
- Lin's concordance correlation coefficient
(LCCC) 165
- Livestock diets in farms
data management, sustainable
diets 264-266
decision support systems, sustainable
diets 264-266
future trends 273-274
goal programming (GP) models
262-264
intensive broiler production, sustainable
rations 266-271
linear programming (LP) models, feed
costs minimization 257-262
mathematical programming
models 255-257
overview 253-254
reducing emissions in pig
production 271-273
- LOD. *see* Linked Open Data (LOD)
- LoRa 28
- LoRaWAN 28
- Low power wide area (LPWA) wireless
technology 28
- LP. *see* Linear programming (LP)
- LPWA. *see* Low power wide area (LPWA)
wireless technology
- LSIDs. *see* Life science identifiers (LSIDs)
- LTE networks 28
- LWM2M 28
- Machine-to-machine (M2M)
communication 140
- Maize calculator 164
- Malicious software 71
- Malware attack, farm systems using third-
party access 64, 65
- MDR. *see* Monitoring, detecting, and
responding (MDR)
- ME. *see* Metabolizable energy (ME)
- Mediation layer 27
- MEMS. *see* Micro-electromechanical systems
(MEMS)
- Metabolizable energy (ME) 257, 258
- Micro-electromechanical systems
(MEMS) 63
- MLPs. *see* Multilayer perceptrons (MLPs)
- MLR. *see* Multinomial logistic regression
(MLR)
- Modeling CPS attacks 83
- Monitoring, detecting, and responding
(MDR) 139

- MQTT 28
 MQTT-SN 28
 MRS. *see* Multispectral remote sensing (MRS)
 Multilayer perceptrons (MLPs) 104
 Multinomial logistic regression (MLR) 209
 Multispectral remote sensing (MRS) 209
- NAAN. *see* Name Assigning Authority Number (NAAN)
 N advice process 20
 NAIP. *see* National Agricultural Innovation Project (NAIP)
 Name Assigning Authority Number (NAAN) 42
 Name Mapping Authority (NMA) 42
 National Agricultural Innovation Project (NAIP) 212
 National-level weather data 5
 NB-IoT 28
 N deficiency 160
 NDVI. *see* Normalized difference vegetation index (NDVI)
 NFC chips 39
 NGSi 30
 NGSi-LD 30
 NIST. *see* U.S. National Institute of Standards and Technology (NIST)
 Nitrogen-use efficiency (NUE) 160, 162
 NMA. *see* Name Mapping Authority (NMA)
 Non-ambiguous URI 50-52
 Normalized difference vegetation index (NDVI) 102, 208
 N^{soil} 169, 170
 NUE. *see* Nitrogen-use efficiency (NUE)
- OADA 6
 Objective function (OF) 258
 OEEV. *see* Ontology of Experimental Events (OEEV)
 OEPO. *see* Ontology for Experimental Phenotypic Objects (OEPO)
 OF. *see* Objective function (OF)
 OGC. *see* Open Geospatial Consortium (OGC)
 OLAP. *see* On-line analytical processing (OLAP)
 OLTP. *see* On-line transactional processing (OLTP)
 OMA LWM2M protocol 29
 ONEM2M 29, 33
 On-line analytical processing (OLAP) 98
 On-line transactional processing (OLTP) 98
- Ontology-driven approach 52
 Ontology engineering 45
 Ontology for Experimental Phenotypic Objects (OEPO) 52
 Ontology of Experimental Events (OEEV) 52
 Open Data Index 5
 Open Geospatial Consortium (OGC) 141
 Operational decision-making theory 193
 OWL. *see* Web Ontology Language (OWL)
- PA. *see* Precision agriculture (PA)
 PARJIB model 164, 165
 Pasture and rangeland management
 - decision-making processes 281-283
 - seasonal decision-making cycles 284, 285
 - decision-support systems
 - development 280-281, 292
 - grazing DSS 293-297
 - for New Zealand dairy systems 292
 - for pasture and rangeland sustainability 298-299
 - responsible innovation, DSSs and smart farming 299-302
 - decision-support tools
 - development 284, 286-288
 - stimulating and inhibiting factors 288-292
 - future trends 302-303
 - overview 279-280
- PCA. *see* Principle component analysis (PCA)
 Pedotransfer functions (PTFs) 173
 PESTMAN 215
 Pest monitoring and management
 - crop pest DSS 218-221
 - future trends 224-225
 - IIRR Geo-Portal 222-223
 - integrated pest management (IPM) 214-215
 - mobile-based AI module, rice pests identification 224
 - mobile rice IPM app 223
 - overview 205-206
 - forecasting 210-214
 - identification 206-208
 - monitoring 208-210
 - rice expert system 215-217
- Pest Prediction Empirical Model Based System (PestPredict) 213-214
 Phenology models 211

- Phenotyping Hybrid Information System (PHIS) 50–52
- PHIS. *see* Phenotyping Hybrid Information System (PHIS)
- Physical device layer 26
- PID. *see* Proportional integral-derivative (PID)
- PLANT 206
- Plant phenomics 49
- Plant soil feedbacks (PSF) 189
- PLC. *see* Programmable logic controls (PLC)
- PNT systems. *see* Positioning, navigation, and timing (PNT) systems
- Positioning, navigation, and timing (PNT) systems 67
- Potential crop yield 161
- Precision agriculture (PA) 59, 60, 135, 160
 - algorithms 67
 - sensor technologies 62
 - system control framework
 - detect infiltration 91–92
 - identify cyber threats 87–88
 - incidence response 92–93
 - protect systems, networks, actuators, and automated devices 89–91
 - recovery activities 92–93
 - technology 17
- Principle component analysis (PCA) 221
- Privacy 32–33, 188
- Process-based models 142
- Programmable logic controls (PLC) 70
- Proportional integral-derivative (PID) 69
- PSF. *see* Plant soil feedbacks (PSF)
- PTFs. *see* Pedotransfer functions (PTFs)
- Pyramid, open data as raw material 4
- Radial basis function (RBF) 104
- Radio frequency identification (RFID) 39, 135
- Rangeland Rummy 299
- Ransomware 72
- RBF. *see* Radial basis function (RBF)
- RBS. *see* Rule-based system (RBS)
- RDA. *see* Research Data Alliance (RDA)
- RDF. *see* Resource Description Framework (RDF)
- Real-time B2B collaboration core 23
- Real-time kinematic (RTK) positioning 67, 68
- Recursive noise removal (RNR) 105
- Remote sensing 209
- Research Data Alliance (RDA) 55
- Research Resource Identifier (RRID) 43
- Resource Description Framework (RDF) 46, 47
- Responsible research and innovation (RRI) 300
- Reusing ontologies 53
- RFC 3986 standard 41
- RFID. *see* Radio frequency identification (RFID)
- RFID chips 42
- RICEPEST 215
- RMSD. *see* Root-mean-square deviation (RMSD)
- RNR. *see* Recursive noise removal (RNR)
- Robotic agriculture 142
- Root-mean-square deviation (RMSD) 165
- RRI. *see* Responsible research and innovation (RRI)
- RRID. *see* Research Resource Identifier (RRID)
- RTK positioning. *see* Real-time kinematic (RTK) positioning
- Rule-based system (RBS) 214
- Rule-of-thumb approach 162, 163
- SAR. *see* Synthetic aperture radar (SAR)
- Satellite data 5
- SCADA/ICS systems 69, 70, 73
- SCADA system. *see* Supervisory control and data acquisition (SCADA) system
- Security and privacy layer 27
- Security architecture development 83
- Segregating data and real-time network architecture 73, 74
- Semantic annotation 48
- Semantic interoperability 45
- Semantic Web 46, 47
- Sensor web enablement (SWE) 141
- SESAR. *see* System for Earth Sample Registration (SESAR)
- Sharpe-Schoolfield-Ikemoto model (SSI) 219
- Short-range communications 27
- SIEM analysis 76
- SigFox 28
- SIMAGRI 146
- Simple Knowledge Organization System (SKOS) 46
- Slack 259
- SLGA. *see* Soil landscapes grid of Australia (SLGA)
- SmartAgriFood 33
- Smart farming 17, 18, 66

- Smart technologies, Australian agriculture 101
- Soft support 242
- Soil
 sample data 6
 sensors 141
 testing 162
- Soil landscapes grid of Australia (SLGA) 173
- SOLO AGCO 139
- SOYBUG 215
- Space-time cube (STC) 168
- SPAE. *see* Sustainable Precision Agriculture and Environment (SPAE)
- SPARQL 46
- Spatial variability 144
- SSI. *see* Sharpe-Schoolfield-Ikemoto model (SSI)
- STAMP. *see* Sustainable Technology Adaptation for Mali's Pastoralists (STAMP)
- Statistical models 143
- STC. *see* Space-time cube (STC)
- SubClassOf plantOrgan 51
- Supervisory control and data acquisition (SCADA) system 64, 69, 70
- Supply-driven design 188
- Support vector machine (SVMs) 107
- Support vector regression (SVR) 104
- Surplus 260
- Sustainable Precision Agriculture and Environment (SPAE) 140
- Sustainable Technology Adaptation for Mali's Pastoralists (STAMP) 9-10, 12
- SVMs. *see* Support vector machine (SVMs)
- SVR. *see* Support vector regression (SVR)
- SWE. *see* Sensor web enablement (SWE)
- SWE standards 145
- Swimlanes 22
- Synthetic aperture radar (SAR) 136
- System for Earth Sample Registration (SESAR) 43
- Tag data standard (TDS) 32
- Temporal variability 145
- Thermal summation model. *see* Degree-day model
- Three-tiered service-oriented architecture 18, 20
- Tier 1 approach 265
- Tier 2 approach 266
- Tier 3 approach 266
- Time Series Tools (TSTools) 146
- Tool isolation 188
- TSTools. *see* Time Series Tools (TSTools)
- UAV. *see* Unmanned aerial vehicle (UAV)
- Uniform resource identifier (URI) 41, 44, 49, 50
- Uniform resource name (URN) 40
- Universally unique identifier (UUID) 40
- Universal Product Code 42
- Unmanned aerial vehicle (UAV) 135, 137
- URI. *see* Uniform resource identifier (URI)
- URN. *see* Uniform resource name (URN)
- U.S. National Institute of Standards and Technology (NIST) 77
- UUID. *see* Universally unique identifier (UUID)
- Validation, DSS 188
- Vandalizers 73
- Variable rate technologies (VRT) 136, 142, 160
- VEGES 207
- Video sensor networks 102
- Viruses 73
- Visualization techniques 108
- VRT. *see* Variable rate technologies (VRT)
- Vulnerability level 71
- WA. *see* Western Australia (WA)
- Web Ontology Language (OWL) 46
- Web service 21
- Western Australia (WA), study site 168
- WFS 30
- Wireless sensor networks (WSNs) 62, 63, 70, 98, 105, 110, 135, 140, 142
- WMS 30
- Worms 73
- WSNs. *see* Wireless sensor networks (WSNs)
- WUE 166
- XRI 42
- Yet Another Time Series Model (YATSM) 146
- Yield maps 163
- Yield Prophet (YP) 164
- Yield sensors 141
- YP. *see* Yield Prophet (YP)