Digital Farming & Robotics in Crop Protection 2019

Disease, Insect and Weed Control; Company Profiles and Activities; R&D and Future Pipelines
Contents

Executive Summary .................................................................................................................. 8
1. Introduction ......................................................................................................................... 13
   1.1 Summary ......................................................................................................................... 13
   1.2 Introduction .................................................................................................................... 13
      1.2.1 Scope and objectives ................................................................................................. 13
   1.3 Precision agriculture ....................................................................................................... 14
      1.3.1 Definition .................................................................................................................. 14
      1.3.2 Progress ..................................................................................................................... 15
         1.3.2.1 USA ..................................................................................................................... 15
         1.3.2.2 Europe ................................................................................................................. 16
            1.3.2.3 R&D pipeline ................................................................................................. 17
   1.4 Crop protection ................................................................................................................ 18
   1.5 Networking and information ........................................................................................... 18
      1.5.1 Associations and forums .......................................................................................... 18
      1.5.2 Scientific publications .............................................................................................. 19
      1.5.3 Online magazines ..................................................................................................... 20
   1.6 References and resources ............................................................................................... 20
2. Key enabling technologies ................................................................................................. 21
   2.1 Summary ......................................................................................................................... 21
   2.2 Introduction ..................................................................................................................... 22
   2.3 Navigation ....................................................................................................................... 22
   2.4 Sensing ............................................................................................................................. 23
      2.4.1 Remote sensing ......................................................................................................... 23
      2.4.2 Proximal sensing ....................................................................................................... 23
      2.4.3 Sensors ...................................................................................................................... 23
   2.5 Imaging and mapping ..................................................................................................... 25
   2.6 Big data ............................................................................................................................ 25
   2.7 Artificial intelligence and machine learning ................................................................. 26
   2.8 Internet-of-things ............................................................................................................ 27
3.10 Digital farming and AI specialists ................................................................. 46
  3.10.1 Ag Leader................................................................................................. 46
  3.10.2 Agronow.................................................................................................. 46
  3.10.3 Blue River Technology............................................................................. 46
  3.10.4 Iteris ........................................................................................................ 47
  3.10.5 Farmers Edge.......................................................................................... 47
  3.10.6 Proagrica ................................................................................................ 47
  3.10.7 Quantified Planet .................................................................................. 48
  3.10.8 Raven Industries ................................................................................... 48
  3.10.9 Ripe.io ................................................................................................... 49
  3.10.10 Solinftec ............................................................................................... 49
  3.10.11 Strider .................................................................................................. 50
  3.10.12 Tbit ....................................................................................................... 50
  3.11 References and resources ......................................................................... 51

4. Drones .................................................................................................................. 52
  4.1 Summary ...................................................................................................... 52
  4.2 Introduction .................................................................................................. 52
  4.3 Regulations ................................................................................................. 54
  4.4 Drone spraying ............................................................................................ 55
    4.4.1 Situation in the Far East ....................................................................... 55
    4.4.2 Pesticide application science ............................................................... 56
  4.5 Drone companies ......................................................................................... 56
    4.5.1 AeroVironment .................................................................................... 57
    4.5.2 DroneDeploy ....................................................................................... 57
    4.5.3 ecobotix ................................................................................................ 57
    4.5.4 insensiv ................................................................................................. 58
    4.5.5 Nileworks .............................................................................................. 58
    4.5.6 PerfectFlight ......................................................................................... 58
    4.5.7 PrecisionHawk .................................................................................... 59
    4.5.8 Rantizo .................................................................................................. 59
    4.5.9 XAG ....................................................................................................... 60
    4.5.10 Yamaha ............................................................................................... 60
  4.6 References and resources ........................................................................... 60

5. Ground robots and guidance ........................................................................... 62
  5.1 Summary ...................................................................................................... 62
  5.2 Introduction .................................................................................................. 62
    5.2.1 Key emerging technologies and needs ................................................. 63
    5.2.2 Miniaturisation ..................................................................................... 64
  5.3 Projects and initiatives ................................................................................ 64
    5.3.1 Agri-EPI Centre .................................................................................... 64
    5.3.2 ESMERA project .................................................................................. 64
    5.3.3 Green Patrol project ............................................................................ 65
    5.3.4 RHEA project ....................................................................................... 65
  5.4 Robots and automation companies ............................................................ 66
6. Weed control research and innovation ................................................................. 71
   6.1 Summary ............................................................................................................. 71
   6.2 Introduction ........................................................................................................ 71
   6.3 Detecting weeds ................................................................................................. 72
      6.3.1 Deep learning ............................................................................................ 72
      6.3.2 Chlorophyll fluorescence ........................................................................... 72
   6.4 Pre-emergence weed control ............................................................................ 73
   6.5 Weeds control in cereals, maize and rice crops .............................................. 73
      6.5.1 Deep learning ............................................................................................ 73
      6.5.2 Drone mapping .......................................................................................... 73
      6.5.3 Determining thresholds for control ......................................................... 74
      6.5.4 Distinguishing between crops and weeds ............................................... 74
   6.6 Weed control in broadleaved field crops ...................................................... 74
      6.6.1 Drone mapping .......................................................................................... 74
      6.6.2 Herbicide damage to crops ..................................................................... 75
   6.7 Weed in pasture and turf ................................................................................ 75
      6.7.1 Deep learning ............................................................................................ 75
      6.7.2 Drones and ground robot systems ............................................................ 75
      6.7.3 Auto-guided hoeing .................................................................................. 75
   6.8 Detecting herbicide resistant weeds .............................................................. 76
      6.8.1 Glyphosate resistant weeds .................................................................... 76
      6.8.2 Other herbicide resistant weeds ............................................................. 76
   6.9 Commercial developments ............................................................................ 77
      6.9.1 Agrifac ......................................................................................................... 77
      6.9.2 Amazone .................................................................................................... 77
      6.9.3 Bilberry/Berthoud ..................................................................................... 77
      6.9.4 Bosch ......................................................................................................... 77
      6.9.5 Cambridge Consultants ............................................................................ 77
      6.9.6 Micron ......................................................................................................... 78
      6.9.7 Ubiquitek .................................................................................................. 78
      6.9.8 Trimble ....................................................................................................... 78
      6.9.9 Wageningen University .......................................................................... 79
      6.9.10 Zasso ........................................................................................................ 80
6.10 References and resources ................................................................. 80

7. Disease control research and innovation ........................................... 82
7.1 Summary .......................................................................................... 82
7.2 Introduction ..................................................................................... 82
7.3 Cereals .............................................................................................. 83
  7.3.1 Powdery mildew ......................................................................... 83
  7.3.2 Rusts .......................................................................................... 85
  7.3.3 Mycotoxins ............................................................................... 86
7.4 Other field crops ............................................................................... 87
  7.4.1 Cotton ......................................................................................... 87
  7.4.2 Oilseed rape .............................................................................. 87
  7.4.3 Rice and soybeans .................................................................... 88
  7.4.4 Sugar beet ................................................................................. 88
7.5 Orchards, plantations, vineyards ...................................................... 89
  7.5.1 Spot-spraying systems ............................................................... 90
  7.5.2 Apples ....................................................................................... 90
  7.5.3 Citrus ......................................................................................... 91
  7.5.4 Coffee ....................................................................................... 91
  7.5.5 Olives ....................................................................................... 92
  7.5.6 Sugarcane ................................................................................ 92
  7.5.7 Vines ....................................................................................... 92
7.6 Glasshouse crops ............................................................................... 92
7.7 Ornamentals .................................................................................... 93
7.8 References and resources ................................................................. 93

8. Insect control research and innovation .............................................. 96
8.1 Summary .......................................................................................... 96
8.2 Introduction ..................................................................................... 96
8.3 Field crops ....................................................................................... 97
  8.3.1 General .................................................................................... 97
  8.3.2 Cotton ...................................................................................... 97
  8.3.3 Maize ....................................................................................... 98
  8.3.4 Oilseed rape ............................................................................ 98
  8.3.5 Potatoes ................................................................................... 98
  8.3.6 Rice .......................................................................................... 99
  8.3.7 Soybeans ................................................................................ 99
  8.3.8 Tomatoes ............................................................................... 99
8.4 Orchards and plantations ................................................................. 99
  8.4.1 General .................................................................................... 99
  8.4.2 Citrus ....................................................................................... 100
  8.4.3 Date palm ............................................................................... 100
  8.4.4 Mulberry ............................................................................... 100
8.5 Stored products ............................................................................... 100
8.6 References and resources ................................................................. 101
Appendix 1: Glossary......................................................................................................................... 103
Appendix 2: Abbreviations .............................................................................................................. 107

List of Figures

Figure 1: Subject areas covered in a) more applied and b) more academic publications since 2015 .... 17

List of Tables

Table 1: Towards Agriculture 5.0 ........................................................................................................... 14
Table 2: US uptake of precision agriculture technology services 2017 and forecasts for 2020 ............. 16
Table 3: Acquisitions and investments by BASF (and formerly Bayer) in digital farming....................... 31
Table 4: Collaborations between BASF (and formerly Bayer) on digital farming.................................... 31
Table 5: Acquisitions and investments by Bayer (and formerly by Monsanto) in digital farming............. 34
Table 6: Collaborations between Bayer and other parties on digital farming ........................................... 35
Table 7: Acquisitions and investments by Corteva (formerly Dow and DuPont) in digital farming ........... 37
Table 8: Collaborations between Corteva and other parties on digital farming ....................................... 37
Table 9: Acquisitions and investments by Syngenta in digital farming .................................................... 39
Table 10: Collaborations between Syngenta and other parties on digital farming .................................... 39
Executive Summary

Chapter 1: Introduction

The aim of this report is to provide an overview and update of the ‘software’ and ‘hardware’ aspects of precision agriculture, i.e. ‘digital farming’ and ‘robotics’ (and general automation) being researched, commercialised and used in practice in the crop protection sector.

Precision Agriculture is a management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production.

The next wave of innovation in precision agriculture, which involves technologies such as artificial intelligence, deep learning, drones and other robots has increasing emphasis on crop protection.

In the US, surveys show the rapid uptake of a wide variety of precision agriculture services.

In Europe, potential savings in pesticide use of up to 80% are being emphasised as a key benefit from adopting precision agriculture. In order to realise such benefits, farmers would need to make significant investments in training and equipment. Other issues relate to the ownership and protection of farm data that is shared in digital farming systems; and the public perception of farming becoming more industrialised.

Optimised crop protection requires detailed data on the occurrence and distribution of weeds, pests and diseases at the earliest possible stage of detection.

Information is provided concerning associations and forums devoted to precision agriculture; scientific journals; and online magazines and other websites.

Chapter 2: Key enabling technologies

This chapter provides an introduction to and overview of the wide variety of technologies that enable the current state of development and application of digital farming and robotics in precision agriculture.

Satellite technology, and in particular the deployment of ‘constellations’ of satellites in coordinated orbits, has revolutionised navigation. Although GPS has become the generic term, there are, in fact, several global navigation satellite systems (GNSS).
Remote sensing is the detection and/or identification of an object(s) or landscape without direct contact. Proximal sensing occurs near ground level.

Imaging and spectrometric sensors capture light at various wavelengths (visible, near infra-red, UV, etc). Other sensors include LiDAR and RADAR, which are not impeded by clouds, and chlorophyll fluorescence.

Data acquired by remote sensing can be used to create images and maps. Maps of features changing across a field can indicate aspects of the condition of soil or vegetation that can be used for site-specific management and variable rate application of inputs.

Big Data has been defined as data of greater variety arriving in increasing volumes and with ever-higher velocity, which has potential value if it can be verified.

Artificial intelligence is a branch of computer sciences that enables the development of intelligent machines, thinking and working like humans. For example, speech recognition, problem-solving, learning and planning.

Machine learning and deep learning are routes to artificial intelligence for use in autonomous decision-making machines. Neural networks are often used to recognise underlying relationships or patterns in data sets like images through a process that mimics the way the human brain operates, i.e. by repeatedly clustering and classifying.

The Internet of Things (IoT) connects numerous diverse devices to collect and collate to ultimately guide decision-making.

Blockchain technology aims to achieve database consistency and integrity in the context of a distributed decentralised database. In practice, it allows transparency in complex supply chains to generate trust.

**Chapter 3: Digital farming**

Digital agriculture refers to tools that digitally collect, store, analyse, and share electronic data and/or information along the agricultural value chain. In this report focused on the Crop Protection sector, ‘Digital Farming’, to distinguish the content of this chapter from others, is interpreted as being more concerned with software platforms, connectivity and decision making, etc.

This chapter concentrates on the activities in the digital farming space of the crop protection majors and other agrochemical companies; their specialist collaborators; and other farming companies engaged in activities with some connection to crop protection.

BASF has stated that its strategy includes leveraging digital technologies to drive business growth, promoting innovations across chemicals, artificial intelligence, internet of things, robotics and other emerging technologies. Its digital farming platform Xarvio was acquired from Bayer CropScience in 2018.

Bayer acquired The Climate Corporation subsidiary and its digital farming platform FieldView as part of the acquisition of Monsanto.
Corteva introduced a new digital agriculture platform, *Granular Insights*, to a limited number of customers in spring 2019. The company is expanding its digital farming activities from the US, Canada and Australia to Brazil, with more countries to be added in 2020. The Pioneer seeds business has the *Encirca* platform.

Syngenta’s *AgriEdge Excelsior* programme started over 17 years ago and by 2018 had around 20 million acres (8 million ha) enrolled in the programme in the US and growing at about 25% *per annum*.

The digital farming activities of other crop protection companies including Adama, Amvac, Land O’Lakes, Nufarm, Sumitomo and UPL are noted.

AGCO, CNH Industrial and Deere and Company are leading agricultural machinery companies with digital farming platforms and precision agriculture technologies.

Satellite and imagery companies working in crop protection are profiled along with their latest news.

Digital farming and AI specialist companies are profiled along with their latest news.

**Chapter 4: Drones**

Drones (UAVs) can be used to map and monitor fields through remote sensing and to apply crop protection and other inputs. The value of global drone sales is forecast to be over $12 billion by 2021.

Most drones for agricultural use in Europe and the Americas are medium-sized multi-rotors used for surveillance and analysis. Compared to satellites, they offer lower cost for smaller fields, more flexibility, more reliability in not being impeded by cloud cover, and higher resolution imagery.

Larger drones are now in use, which carry a payload, such as seeds or spray solution. In China, Japan and S. Korea, drones are already widely used for spraying.

An important issue around the adoption of drone technology in agriculture is the drafting of regulations controlling their use *per se* and for crop spraying. The debate on regulations also concerns the authorisation for aerial application of specific crop protection products. Spray drift and risks to bystanders and the environment are at issue; also, who bears responsibility?

The physics of spraying by drone is being investigated. The downdraught air-stream of drone rotors pushes the crop canopy open and facilitates the distribution of spray droplets through the canopy to reach the base of the plant and underside of leaves. This should increase the efficacy of control and reduce spray drift.

There may be potential for low carrier volume electrostatic spraying to be done by drones and there is already some commercial use.

Profiles and activities of a selection of some of the most prominent drone companies operating in agriculture are described.
Chapter 5: Ground robots and guided tillage

This chapter focuses on the technologies being deployed and the progress made by the industry from research to commercialisation of ground robots working in fields. The application of ground robots in crop protection is largely directed towards weed control by mechanical or other physical methods and spraying.

Key emerging technologies in robotics include robot vision and machine learning. Standardisation of data is needed to ease the exchange between devices, software systems and the various stakeholders.

There is a trend towards smaller robots, which could have benefits including the ability to quickly take advantage of windows of favourable weather; to work in soil conditions precluding the use of heavy machinery; and to work continuously in ‘swarms’ in a coordinated way, day and night.

A common approach to ‘training’ robots is by ‘digitising’ numerous crops under different circumstances, or analysing tens of thousands of images representing the targets, e.g. crops and weeds. The information is then automatically analysed by neural networks and then used to programme robots to deal with each plant and each patch of soil according to the ‘deep learning’.

Some collaborative projects are described and prominent companies involved in robotics and automation are profiled.

Chapter 6: Weed control research and innovation

Recent research studies in the field of weed control using precision farming technologies reported in leading journals and other sources are summarised, together with commercial developments in precision weed control.

Deep learning is being used to enable recognition of both the presence and identity of different weeds. ‘Training’ devices to recognise weeds and using artificial intelligence has become the leading means of ultimately enabling precision weed control.

Soil mapping and relating soil properties and their spatial distribution has been researched to enable variable rate pre-emergence herbicide application.

Drone mapping of weed locations and control by ground robots are reported. Using the systems together can increase efficiency.

Auto-guided mechanical weed control using camera imagery has been shown to control weeds more effectively than when done manually, without damaging the crop.

Various methods, including reflectance, thermal imagery and quick enzyme-based diagnostic kits, have been tested with some success to detect weeds resistant to particular herbicide modes of action.

Machines controlling weeds by electrocution are being commercialised.
Chapter 7: Disease control research and innovation

Research publications reported in the field of disease control using precision technologies are summarised.

Early remote detection of disease infection, ideally before symptoms become visible, has been the major target for research. Mapping fields to designate areas of soil-borne infection is another important topic.

Various spectral imaging techniques have given encouraging results in experiments aiming to remotely detect the early signs of powdery mildew infection in wheat.

There has been some success in distinguishing rust infections in wheat from leaf chlorosis caused by nitrogen deficiency. Complications in identifying infections are caused by light reflected from top or undersides of leaves. Chlorophyll fluorescence imaging has shown promise as a tool for early screening for rust resistance in breeding programmes. Easier detection of mycotoxins is another target.

Recent research on other field crops has included: remote monitoring of patchy infected areas of cotton and oilseed rape to map soil-borne disease; early diagnosis of oilseed rape leaf diseases by hyperspectral imaging and multivariate techniques; and monitoring rice and soybean fields for *Rhizoctonia solani* carried over through the rotation; and the identification of leaf diseases of sugar beet by spectral analysis.

Recent research in orchards and plantations has included: early detection of scab infection on apple leaves by spectral reflectance and fluorescence imaging; evaluation of HLB (citrus greening) infected citrus rootstocks using ground penetrating radar; development of a multiband sensor for citrus black spot disease detection; evaluation of satellite imagery to monitor coffee leaf rust; assessing the variability of red stripe disease in Louisiana sugarcane; and prediction of black rot epidemics in vineyards using a weather-driven disease model.

Other research has included investigating various imagery techniques for the diagnosis of diseases in greenhouse crops such as peppers and tomatoes; and in ornamentals.

Chapter 8: Insect control research and innovation

Recent research studies on controlling insects and other pests using precision farming technologies reported in leading journals and other sources are summarised, along with note of other innovations.

Spectral-based remote sensing from satellites and drones has been successfully tested to detect a variety of pests and the damage they cause to field crops, in orchards and other perennial crops, and in stores post-harvest.

Moth populations in tomatoes have been monitored by recording the sound made by moths in traps.

Machine vision systems have been developed to detect invertebrate pests on leaves and fruit in orchards.

Kriging within a geographic information system has been used to model the spatial heterogeneity of fruit flies in citrus.
to improve productivity and profitability (especially as the availability of labour and revenues are squeezed) and to reduce risks and environmental impact.

Borrowing from ICT terminology, ‘Agriculture 4.0’ is a term in vogue useful to overview the advances in technologies being applied to farming – as it progresses towards ‘Agriculture 5.0’ (Table 1).

**Table 1: Towards Agriculture 5.0**

<table>
<thead>
<tr>
<th>Agriculture 1.0</th>
<th>Agriculture 2.0</th>
<th>Agriculture 3.0</th>
<th>Agriculture 4.0</th>
<th>Agriculture 5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoeing weeds</td>
<td>Pesticides</td>
<td>Geo-spatial information</td>
<td>High resolution satellite imagery</td>
<td>Artificial intelligence</td>
</tr>
<tr>
<td>Animal manures</td>
<td>Artificial fertilizers</td>
<td>Local weather forecasts</td>
<td>Internet of Things</td>
<td>Deep learning</td>
</tr>
<tr>
<td>Horse power</td>
<td>Machinery</td>
<td>Soil analysis and prescriptions</td>
<td>Beginning of robotics</td>
<td>Advanced statistics and modelling</td>
</tr>
<tr>
<td>Very high manual labour</td>
<td>High labour inputs</td>
<td>GM crops</td>
<td>Big data</td>
<td>Advanced robotics</td>
</tr>
<tr>
<td>Very high manual labour</td>
<td>High labour inputs</td>
<td>GM crops</td>
<td>Big data</td>
<td>Advanced robotics</td>
</tr>
</tbody>
</table>

Fundamentally, information and communications technology software and hardware are increasingly being applied to farming.

The aim of this report is to provide an overview and update of the ‘software’ and ‘hardware’ aspects of precision agriculture, i.e. ‘digital farming’ and ‘robotics’ (or general automation) being researched, commercialised and used in practice in the crop protection sector.

The chapters following this introductory one cover:

- A review of the technologies enabling the current state of precision agriculture
- The digital farming activities of the leading crop protection companies, their collaborators and other leading specialist companies
- Drones and ground robots
- Progress with precision spray application
- Research into the use of precision farming technologies to control weeds, diseases and insect pests

### 1.3 Precision agriculture

#### 1.3.1 Definition

Precision agriculture utilises information technology through related tools to manage all farm enterprises more accurately and with attention to detail. The International Society of Precision Agriculture adopted the following definition in 2019:
The CropLife/Purdue survey’s 2017 estimates of market penetration (in the areas covered by all of the 209 dealers responding across the US) of the range of precision agriculture technology services and forecasts for 2020 are shown in Table 2. Although impressive increases in adoption were forecast for 2020, crop protection *per se* has a relatively lowly place.

### Table 2: US uptake of precision agriculture technology services 2017 and forecasts for 2020

<table>
<thead>
<tr>
<th>Technology</th>
<th>Dealer market area uptake (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017 Estimate</td>
</tr>
<tr>
<td>Guidance/Autosteer</td>
<td>60</td>
</tr>
<tr>
<td>GIS field mapping</td>
<td>45</td>
</tr>
<tr>
<td>Soil sampling</td>
<td>45</td>
</tr>
<tr>
<td>Variable rate liming</td>
<td>40</td>
</tr>
<tr>
<td>Variable rate fertilizing</td>
<td>38</td>
</tr>
<tr>
<td>Satellite/aerial imagery</td>
<td>19</td>
</tr>
<tr>
<td>Cloud storage of farm data</td>
<td>14</td>
</tr>
<tr>
<td>Farm data management systems</td>
<td>13</td>
</tr>
<tr>
<td>Variable rate seeding</td>
<td>13</td>
</tr>
<tr>
<td>Variable hybrid placement within fields</td>
<td>7</td>
</tr>
<tr>
<td>Drone use</td>
<td>6</td>
</tr>
<tr>
<td>Chlorophyll sensors for N management</td>
<td>3</td>
</tr>
<tr>
<td>Variable rate crop protection</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: CropLife/Purdue 2017 survey of precision agriculture dealers

#### 1.3.2.2 Europe

A study for the EU Parliament (EPRS, 2016) on the potential for precision agriculture focused on possible benefits for reduction in pesticide use. It was estimated that only 25% of EU farms then used technologies with a precision agriculture component. However, adoption across the EU could lead to reductions in pesticide use of up to 80%.

Using online weed detection maps to spray patches of fields could result in reductions in herbicide use in winter cereals of 6 - 81% for broadleaf weed herbicides and 20-79% for graminicides, said the report. The use of various sensors to detect and enable early and localised pest or disease treatment could achieve pesticide savings of 85%. In orchards and vineyards, pesticide use could be reduced by up to 30% and the area sprayed by up to 80%.

In order to realise such benefits, farmers would need to make significant investments in training and equipment, and concerns over possible job losses were noted. Other concerns related to the ownership and protection of farm data that is shared in digital farming systems; and the public perception of farming becoming more industrialised.
1.3.2.3 R&D pipeline

Two sources of information about progress in precision farming technologies were surveyed to provide an overview of areas attracting interest in investing in research and development.

- The International Society of Precision Agriculture (ISPA) holds a biennial conference and papers (not peer reviewed) are published online. These generally cover work that is more applied, and the commercial potential has been recognised.

- *Precision Agriculture* is the leading peer-review publication covering the topic (published by ISPA) and reports earlier-stage work, more academic in nature.

The technical subject areas covered as a proportion of the total (having excluded livestock, general methodology, progress and economic reviews, etc) in the IPSA Conference proceedings for 2016 and 2018, and in *Precision Agriculture* 2015-2019 are displayed in Figure 1. These reveal more interest in crop protection topics in the R&D pipeline.

**Figure 1:** Subject areas covered in a) more applied and b) more academic publications since 2015
BASF’s leading established insecticide active ingredients include alpha-cypermethrin (*Fastac*), a pyrethroid non-systemic insecticide and the recently introduced afidopyropen (trademarked as *Inscalis*), a systemic foliar, seed- and soil-applied insecticide.

### 3.3.2 Digital farming and precision agriculture overview

BASF has stated that its strategy includes leveraging digital technologies to drive business growth, promoting innovations across chemicals, artificial intelligence, internet of things, robotics and other emerging technologies. Since 2013, BASF has been working with companies including Iteris, John Deere, the European Space Agency and Proagrica. An online IT-platform with a variety of tools called *Maglis* was launched 2017, but this was very soon subsumed into *Xarvio*, which was acquired from Bayer CropScience following divestments made in the wake of the latter’s acquisition of Monsanto. Bayer had claimed there were over 250,000 users of the its digital farming technology in more than 60 countries by the end of 2017. Bayer had been working with various partner organisations to develop *Xarvio* and these are included in the tables of acquisitions and collaborations below.

#### Table 3: Acquisitions and investments by BASF (and formerly Bayer) in digital farming

<table>
<thead>
<tr>
<th>Other party</th>
<th>Comments</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayer CropScience</td>
<td>Bayer’s digital farming platform <em>Xarvio</em> acquired following acquisition of Monsanto</td>
<td>Agreed April 2018</td>
</tr>
<tr>
<td>US digital agricultural intelligence company, ZedX (Bellefonte, Pennsylvania)</td>
<td>ZedX focuses on the development of agronomic weather, crop and pest models</td>
<td>Agreed April 2017</td>
</tr>
<tr>
<td>proPlant Gesellschaft für Agrar- und Umweltinformatik (German plant health diagnosis and infection level warning service provider)</td>
<td>Bayer acquired and used as basis of <em>Xarvio</em></td>
<td>Acquired March 2016</td>
</tr>
</tbody>
</table>

Source: Agrow

#### Table 4: Collaborations between BASF (and formerly Bayer) on digital farming

<table>
<thead>
<tr>
<th>Other party</th>
<th>Comments</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planet (US aerospace and data analytics company)</td>
<td>Daily global satellite imaging to develop analytics to power field zone metrics and insights for <em>Xarvio</em>.</td>
<td>Announced December 2018</td>
</tr>
<tr>
<td>VanderSat (Satellite-derived data company, Holland)</td>
<td>High-precision microwave technology to measure soil moisture and surface temperatures in field zones (more consistent and representative than measurements from field sensors)</td>
<td>Announced December 2018</td>
</tr>
<tr>
<td>Proagrica (digital connectivity company)</td>
<td>Development and operation agreement to launch the farm management system interface for <em>Maglis</em> (superseded by <em>Xarvio</em>).</td>
<td>Commenced August 2017</td>
</tr>
<tr>
<td>European Space Agency (ESA)</td>
<td>Use of satellite-derived data and images</td>
<td>Announced Feb 2017</td>
</tr>
<tr>
<td>Yara International (Norwegian agricultural technology supplies company)</td>
<td>Yara granted Bayer access to its mobile imaging technology to determine the nutrient status provide crop nutrition recommendations for <em>Xarvio</em></td>
<td>Agreed January 2017</td>
</tr>
</tbody>
</table>
Bayer CropScience’s leading insecticide active ingredients include several neonicotinoids, such as imidacloprid; pyrethroids like deltamethrin; and the ryanodine receptor modulator flubendiamide.

3.4.2 Digital farming and precision agriculture overview

Bayer CropScience transferred its digital farming platform Xarvio, which it had been developing since 2016, to BASF following the acquisition of Monsanto, which had provided similar services through its subsidiary The Climate Corporation. Bayer had claimed there were over 250,000 users of the Bayer digital farming technology in more than 60 countries by end 2017. Bayer had been working with various partner organisations to develop Xarvio and these are included in the tables of acquisitions and collaborations by BASF earlier in the chapter.

In late 2013, Monsanto acquired the agricultural and climate data company, The Climate Corporation for a price in the region of $930 million. Monsanto integrated the technology into its digital farming platform Fieldscripts.

Bayer’s ForwardFarming initiative started in Europe in 2011 and farms in the US and Latin America have now joined the network. A Forward Farm is an operational farm that uses best practices to deal with everyday farming challenges in a sustainable way. The aim is for these farms to share expertise and achievements with those in the supply chain as well academics, politicians, government officials and consumers. Selected farms demonstrate sustainable practices including the use of precision farming in IPM and the application of new personal protective equipment and systems. The network is pioneering digital farming techniques, such as GPS-informed precision spraying.

The following tables list the acquisitions and investments made and collaborations entered into recently by Bayer CropScience (including Monsanto, prior to the acquisition).

<table>
<thead>
<tr>
<th>Other party</th>
<th>Comments</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>VitalFields (Estonian farm management software company)</td>
<td>VitalFields operates in seven European countries, offering tools for farmers to plan, manage and analyse their field activities, including simplified tracking and reporting of all crop inputs. The system helps ensure compliance with EU environmental standards</td>
<td>November 2016</td>
</tr>
<tr>
<td>Tbit (image analysis start-up, Brazil)</td>
<td>Monsanto invested RS$ 1 million (US$320,000) supplying companies with digital image processing and artificial intelligence to check among other things seed and grain quality</td>
<td>October 2017</td>
</tr>
</tbody>
</table>

Source: Agrow
Table 6: Collaborations between Bayer and other parties on digital farming

<table>
<thead>
<tr>
<th>Other party</th>
<th>Comments</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus Defence</td>
<td>High resolution data of fields from Airbus SPOT 6, SPOT 7 and Pléiades satellites for Climate FieldView service</td>
<td>Commenced April 2019</td>
</tr>
<tr>
<td>Ceres Imaging</td>
<td>Ceres’ high resolution aerial imaging with the Climate FieldView platform. It will allow farmers to access scientifically validated imagery in their FieldView account to enable the detection of water, fertilizer, pest and disease issues weeks before they are visible</td>
<td>Commenced April 2019</td>
</tr>
<tr>
<td>Netafim (precision irrigation) and BGN Technologies (Ben-Gurion University of the Negev, Israel)</td>
<td>Soil research, digital prediction tools and drip technology as a delivery system for Velum Prime (fluopyram) nematicide</td>
<td>Commenced February 2019 for three years</td>
</tr>
<tr>
<td>LB-Track (Precision agriculture, Chile)</td>
<td>Development of methods for the detection of herbicide-resistant weeds based on equipment that makes hyperspectral images</td>
<td>Commenced February 2018 for three years</td>
</tr>
<tr>
<td>Plantar (seed multiplier, Brazil)</td>
<td>Mapping soil on 4,000 ha in Parana allowing diagnosis of soil fertility and more precise recommendations for applying products to crops</td>
<td>Agreed 2017 March</td>
</tr>
</tbody>
</table>

Source: Agrow

3.4.3 Digital solutions: Climate FieldView

Monsanto acquired the agricultural and climate data company The Climate Corporation in 2013 and integrated the technology into its own developing digital farming platform (FieldScripts).

When Bayer acquired Monsanto in 2018, it gained a digital farming business then operating across 24 million ha (60 million acres). At the same time, Bayer sold the digital farming platform it had developed, Xarvio, to BASF.

Climate FieldView was launched in the US in 2015. It enables farmers to collect and visualise field data, analyse and evaluate crop performance, and manage their field variability through customised fertility and seeding plans to optimise yields, maximise efficiency and reduce risk. In 2019, Climate FieldView is a subscription service available in the US, Canada, Brazil and some countries in Europe (France, Germany, Ukraine).

The acquisition of VitalFields, an Estonian farm management software company, which operated in seven European countries, supports the expansion in Europe. VitalFields offers tools for farmers to plan, manage and analyse their field activities, including simplified tracking and reporting of all crop inputs. The system also helps ensure compliance with EU environmental standards. Similarly, the acquisition of Brazilian company Tbit supports the expansion in Latin America.

In India The Climate Corporation is delivering smallholders relevant agronomic information and advice through a pilot launch of its FarmRise Mobile Farm Care app. The company intends to fully launch FarmRise in India in 2019, with further anticipated launches in Asia, Africa and South America.
Table 7: Acquisitions and investments by Corteva (formerly Dow and DuPont) in digital farming

<table>
<thead>
<tr>
<th>Other party</th>
<th>Comments</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular (San Francisco, California), software and analytics</td>
<td>A DuPont deal as a development of the Encirca digital farming platform in US, Canada and Australia</td>
<td>2017</td>
</tr>
<tr>
<td>PrecisionHawk (US) aerial data and drone technology provider</td>
<td>A DuPont Pioneer investment in drone technology</td>
<td>2016</td>
</tr>
</tbody>
</table>

Source: Agrow

Table 8: Collaborations between Corteva and other parties on digital farming

<table>
<thead>
<tr>
<th>Other party</th>
<th>Comments</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embrapa (Brazil)</td>
<td>A four-year deal to collaborate on genomics research to improve crop tolerance to pests and drought. The latest digital tools will be used to support the early detection of disease</td>
<td>May 2019</td>
</tr>
<tr>
<td>DroneDeploy (US)</td>
<td>A global deal to use DroneDeploy’s fleet of over 400 DJI drones across the company’s global seed production and supply chain</td>
<td>March 2019</td>
</tr>
<tr>
<td>Planet US aerospace and data analytics company</td>
<td>A three-year agreement. Granular (Corteva’s US software business) will license and integrate Planet’s daily feed of satellite imagery into its farm management software, starting with its Encirca system</td>
<td>March 2018</td>
</tr>
</tbody>
</table>

Source: Agrow

3.5.3 Digital solutions: Granular Insights

Corteva introduced a new digital agriculture platform, Granular Insights, to a limited number of customers in spring 2019. DuPont had acquired the San Francisco based software and analytics company Granular in 2017. Granular is an independent subsidiary of Corteva.

The Granular platform includes a suite of farm management software products:

- **Granular Business** and **Granular Agronomy** by Encirca
- **AcreValue** farmland real estate analysis tool
- **AgStudio** precision agronomy software for ag retailers

Granular Insights offered scouting in spring 2019 and planned to offer integrated agronomic and financial analysis later in the year. The company is expanding its digital agriculture platform from the US, Canada and Australia to Brazil this year, with more countries to be added in 2020. It foresees a 100 million acre (40 million ha) opportunity for the technology by 2023 and a potential global market of 500 million acres.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosaic (mosaicking)</td>
<td>Process of assembling GIS database files (e.g. images) for adjacent areas into a single file. UAV images, for example, cannot cover a whole field, resulting in the need to take a series of multiple overlapped images. Multiple overlapped images must be accurately orientated and geo-referenced 'ortho-mosaicked' image of the entire field.</td>
</tr>
<tr>
<td>Multifractal analysis</td>
<td>A mathematical technique to improve the understanding of variations in complex systems.</td>
</tr>
<tr>
<td>Multispectral imagery</td>
<td>A technique in which image data is captured across the electromagnetic spectrum. Wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, such as infrared.</td>
</tr>
<tr>
<td>Neural network</td>
<td>A series of algorithms that endeavours to recognize underlying relationships in a set of data through a process that mimics the way the human brain operates.</td>
</tr>
<tr>
<td>Normalised Difference Vegetation Index (NDVI):</td>
<td>There are several vegetation (spectral) indices using spectral imagery. NDVI values range from +1.0 to -1.0. Areas of bare ground usually show very low NDVI values (e.g. 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing or stressed crops may result in moderate NDVI values (e.g. 0.2 - 0.5). High NDVI values (approximately 0.6 - 0.9) correspond to dense vegetation such as crops at advanced vegetative growth stages. There can be errors, in that NDVI is sensitive to underlying soil colour, for example.</td>
</tr>
<tr>
<td>Pixel</td>
<td>A ‘picture element’ - a fundamental unit of data collection. A pixel is represented in a remotely sensed image as a rectangular cell in an array of data values and contains a data value that represents a measurement of some real-world feature.</td>
</tr>
<tr>
<td>Prescription maps</td>
<td>Maps of features, e.g. patches of weeds, used as the basis for decision support systems, which detail variable application rates of herbicide.</td>
</tr>
<tr>
<td>Proximal sensing</td>
<td>Contrasts with remote sensing in that the sensor is close to the target. Applications include soil proximal sensing and crop canopy proximal sensing.</td>
</tr>
<tr>
<td>Real-time kinematic (RTK) GPS navigation</td>
<td>Refers to utilising GPS ‘on-the-move’. A technique used to enhance the precision of GPS data, providing real-time corrections, giving up to centimetre-level accuracy. RTK systems use a single base station receiver and a number of mobile units.</td>
</tr>
<tr>
<td>Remote sensing</td>
<td>Detection and/or identification of an object(s) or landscape without direct contact. Operations may be conducted at various altitudes, e.g. by satellites, aircraft or drones. Common forms include colour and infrared aerial photography, satellite imaging and radar sensing.</td>
</tr>
<tr>
<td>Resolution</td>
<td>In remote sensing, spatial resolution is related to the distance separating adjacent pixels, spectral resolution concerns variation in the range of spectral responses covered by a wavelength band, and temporal resolution means the variation caused by time over the same location. Higher resolution (e.g. images) means that finer details can be discriminated.</td>
</tr>
<tr>
<td>Site-specific management</td>
<td>The thorough assessment of field and crop conditions and the precise application of inputs aiming for the best possible financial return.</td>
</tr>
<tr>
<td>Spectral angle mapping</td>
<td>A spectral classification that uses an algorithm that determines the spectral similarity between two spectra from pixels. It is relatively insensitive to illumination effects, i.e. sunlit and shaded leaves.</td>
</tr>
<tr>
<td>Spectral imaging</td>
<td>See multispectral imaging and hyperspectral imaging.</td>
</tr>
<tr>
<td>Spectroradiometer</td>
<td>A device designed to measure the amount (flux) of electromagnetic radiation of particular frequencies or wavelengths leaving or arriving at points on a surface.</td>
</tr>
</tbody>
</table>