Topics in Agricultural Entomology XIII

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Topics in agricultural entomology - XIII

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Dados Internacionais de Catalogação na Publicação (CIP)

T674 Topics in agricultural entomology - XIII / Joacir do Nascimento, Claudiane Martins da Rocha, Daniel Dalvan do Nascimento, et al. – Ponta Grossa - PR: Atena, 2022.

Outros organizadores
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Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-65-258-0544-3
DOI: https://doi.org/10.22533/at.ed.443220109

1. Agricultura. I. Nascimento, Joacir do (Organizador). II. Rocha, Claudiane Martins da (Organizadora). III. Nascimento, Daniel Dalvan do (Organizador). IV. Título.

CDD 338.1

Elaborado por Bibliotecária Janaina Ramos – CRB-8/9166

Atena Editora
Ponta Grossa – Paraná – Brasil
Telefone: +55 (42) 3323-5493
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The authors are grateful to the São Paulo Research Foundation (FAPESP) for the grant 2022/04343-9

PREFACE

The Graduate Program in Agronomy (Agricultural Entomology) at the UNESP Faculty of Agricultural and Veterinary Sciences in Jaboticabal has always been characterized by its focus on Integrated Pest Management (IPM). Since its foundation, the program has graduated 287 students with a master's degree and 148 Ph.D. students. They are now active in various areas of the public or private sector and contribute to agriculture's economic and environmental sustainability.

This e-book entitled "Topics in Agricultural Entomology - XIII" was made possible through the immense effort of the Organizing Committee, formed by MSc and Ph.D. students from all research areas of our Graduate Program. In its 14 chapters, readers will find information on the most diverse areas of IPM, with a richness of information on both the fundamental and applied aspects of IPM.

As coordinator of the 2022 edition of the Winter Workshop on Agricultural Entomology, it is my pleasure to provide event attendees with an e-book of excellent content, demonstrating the importance of our research to society.

Prof. Ricardo Antônio Polanczyk

FCAV/UNESP

PPG Entomologia Agrícola Coordinator

SUMÁRIO

CAPÍTULO 11

CHALLENGES OF DIGITAL AGRICULTURE IN PEST MANAGEMENT

David Luciano Rosalen

1 I INTRODUCTION

This chapter aims to provide a basic reference for consultation encompassing Digital Agriculture within the scope of Agricultural Entomology. In item 2, the Concept of Digital Agriculture is shown since the historical evolution of agriculture and the emergence of the so-called Industry 4.0, as well as its respective disruptive technologies.

In item 3, basic concepts of GNSS (Global Navigation Satellite System) Positioning, Remote Sensing, and Geographic Information Science, together with their applications in the context of Agricultural Entomology, are shown. Finally, item 4 discusses some challenges relating the three mentioned geotechnologies with Agricultural Entomology.

2 I DIGITAL AGRICULTURE CONCEPT

Agricultural labor productivity can be measured as cereal equivalent per worker per year. This factor increased highly over the evolution of agricultural technology, increasing by 10 times at the time of agricultural mechanization in the between-war period, and 100 times in the late twentieth century after the Green Revolution (Mazoyer; Roudart, 2008).

This technological evolution, according to Feldens (2018), went through the following stages:

1. Modern agriculture, before 1900 (use of hand tools and animal traction);
2. Mechanized agriculture, after 1920 (mechanization);
3. Green Revolution, after 1960 (intensive use of mechanization, inputs, and breeding);
4. Digital revolution, after 1990 (beginning of automation and digitization of agriculture).

Massruhá et al. (2020) also divided technological evolution into four stages, but differently:

1. Agriculture 1.0, 1900-1950 (Animal Traction), characterized using animal traction, family and subsistence farming, with the sale of surpluses;
2. Agriculture 2.0, 1950-1990 (Green Revolution), characterized by monocropping, monodisciplinary activities, synthetic inputs use, and adaptive research;
3. Agriculture 3.0, 1990-2015 (Integrated Systems), characterized

by integrated crops, multidisciplinary activities, higher efficiency, and systemic research;

4. Agriculture 4.0, 2015 - present days (biologically-based Agriculture), characterized by complex systems, transdisciplinary activities, biological inputs, and complex research.

Stages 3.0 and 4.0 break with the Agriculture-2.0 paradigm (Green Revolution), which is characterized by monocropping, monodisciplinary vision, intensive use of synthetic inputs, and adaptive agricultural research. Notably, the questioning of the Green Revolution principles is not new, with its starting point being the publication of the book "Silent Spring" in 1962, by Rachel Carson. In this work, the serious environmental effects of the large-scale use of agrochemicals are presented. For more details, consult Rachel Carson's original work (Carson, 2010) and the work of Bonzi (2013), which analyzes the impact of that book's publication.

It is also important to analyze the origin of the term 4.0. According to Pereira and Simonetto (2018), this terminology originated in Germany in 2011, from a government project, Industry 4.0, which would be the Fourth Industrial Revolution and is characterized by:

1. Internet of Things (IoT);
2. Cloud computing (CC);
3. Cognitive Computing (CoC);
4. Cyber-physical System (CPS).

IoT is the ability to connect all sorts of devices (machines, gadgets, cell phones, cars, among others) to the internet and make them smart, considering autonomy and privacy issues (Ali; Ali; Badawy, 2015).

On the other hand, CC is not only data storage but also data processing in large providers with high hardware capacity as described in Madhavaiah and Bashir (2012). The CC service is monopolized by the so-called "Big Techs": Microsoft (Microsoft Azure), Google (Google Cloud Platform), and Amazon (Amazon Web Services - AWS). Besides these, there are also IBM Cloud, Oracle Cloud, CloudStigma, GoDaddy, VMware Center Server, DigitalOcean, and Hyve.

Within the remote sensing scope, image processing can be cited as a CC example. This tool has undergone a major revolution, with any user being allowed to process several images using state-of-the-art algorithms. Formerly, such high-level processing was restricted to companies and/or research institutions that owned advanced and expensive hardware and software resources. If on one side cloud processing has led to greater democratization and ease, on the other side, the dependence on a good internet connection and the fact that few companies have an information monopoly on the Internet, as shown by Öhman and Aggarwal (2020). In this context, the wireless field (Wi-Fi) connection in Brazilian rural areas is often poor, leading to the search for local solutions to circumvent such a problem, e.g., LoRaWAN (Low Power WAN; Protocol for IoT), as described by Silva et al. (2017).

CoC is a multidisciplinary field and its main goal is to develop computational models for decision-making based on neurobiological brain processes, Cognitive Sciences, and Psychology (Gutierrez-Garcia; Lopez-Neri, 2015). Big Data Analytics and Artificial Intelligence (Machine Learning and Deep Learning) techniques are part of the CoC (Pereira; Simonetto, 2018).

CPS consist of a coordinated combination of computational and physical resources, such as collision avoidance systems in autonomous navigation (NSF, 2008). In this way, physical entities (robots or other devices) are controlled by computational elements.

Huang et al. (2020) developed an agricultural CPS consisting of an intelligent robotic vehicle controlled by neural networks, with crop growth and pest and disease detection models in its decision-making mechanism.

Within the above context, Agriculture 4.0 should cover technologies that also characterize Industry 4.0. However, according to Fonseca et al. (2020), the concept of Agriculture 4.0 is broader as it encompasses agricultural production systems, inputs used, and applied research modality. Thus, it goes beyond the simple use of technologies; in this approach, Agriculture 4.0 would be a new paradigm in agricultural production.

Another important point to be discussed is the terminology “Precision Agriculture”, “Smart Agriculture” and “Digital Agriculture”. The definition of Precision Agriculture by the International Society of Precision Agriculture (ISPA) is given below:

> Precision Agriculture is a management strategy that gathers, processes and analyzes 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. (ISPA, 2022, np).

The “Smart” concept emerged in the last decade (2010-2020), within the scientific and industrial communities, which fostered the so-called “Smart Vision”. In this case, “smart” means integrated, intelligent, fast, as well as technologically, economically, politically, and culturally sustainable (doing more with less, improving the quality of life for all).

This new vision integrated disciplines in the problem-solving process (Castrignanò et al., 2020). Therefore, Smart Agriculture (Smart Agriculture or Smart Farm) proposes, from disruptive technologies such as the IoT, intelligent solutions to various agricultural problems. Intelligent Agriculture can therefore be understood as a step beyond Precision Agriculture, as this would initially be restricted to local actions using geotechnologies, such as GNSS Positioning, Remote Sensing, and Geographic Information Science. Therefore, Intelligent Agriculture would be a milestone for a new stage of Precision Agriculture.

In this context, Precision Agriculture can be divided into three steps. The first (1990-2000) consists of using GNSS technology to map soil physicochemical properties and automation processes for Variable Rate Application (VRA). The second (2000-2010) comprises the progress of autonomous navigation of agricultural machinery and the increase in VRA use, besides the beginning of the use of low-altitude aerophotogrammetry (drones). The third (from 2010 onwards) encompasses the adoption of Smart vision and Industry 4.0 technologies. Therefore, "Digital Agriculture" may be referred to as the junction of Precision Agriculture and Intelligent Agriculture.

The Food and Agriculture Organization of the United Nations (FAO) states that the process of digitizing agriculture would be the "Digital Agricultural Revolution," and this would not be limited to the concept of Precision Agriculture, even in its third stage. The concept of Digital Agriculture by FAO indicates that the digitalization process is not limited only to the agricultural production process itself (as in Precision Agriculture), but also to the entire agri-food value chain: Pre-production, Production, and Post-production, including agricultural research in pre-production. Such a concept is also adopted by Fonseca et al. (2020).

Precision Agriculture is also called "Site-Specific Management - SSM". It must adjust the use of inputs as a function of the spatial and temporal variability of production factors within a given area, hence locally customized. Accordingly, Precision Agriculture is partly analogous to Industry 4.0 since this, as indicated by Lasi et al. (2014), allows industrial products to be customized according to customer preferences, without losing mass production advantages.

3 I GEOTECHNOLOGIES AND AGRICULTURAL ENTOMOLOGY

As seen in the previous item, Digital Agriculture involves the use of GNSS positioning, Remote Sensing, and Geographic Information Science, as well as Industry 4.0-related technologies. This item presents some concepts and applications that make use of these technologies in the scope of Agricultural Entomology.

3.1 GNSS Positioning

GNSS positioning has revolutionized Geodesy and Surveying, as it allows georeferenced data collection on the earth's surface, in any geographic position and 24 hours a day. It also allows three-dimensional mapping, both statically and kinematics, the latter being unprecedented in terms of topographic surveys in general.

According to Monico (2004), the GNSS system encompasses three segments: Space (satellite constellation), Control (satellite tracking and control stations), and User (receivers used in field surveys). The GNSS system also includes global and local systems. Global systems allow navigation and mapping in any terrestrial location, while locals serve as a complement to global systems in specific geographic regions.

Examples of global systems are NAVSTAR-GPS (United States), GLONASS (Russia), BEIDOU (China), and Galileo (European Union). As complementary local systems and their respective regions of operation, there are Wide Area Augmentation – WAAS (North America), European Geostationary Navigation Overlay System - EGNOS (Europe), System for Differential Corrections and Monitoring – SDCM (Russia), Multifunctional Transport Satellite-based Augmentation System - MSAS (Japan), Quasi-Zenith Satellite System - QZSS (Japan), and GPS Aided Geo Augmented Navigation System - GAGAN (India).

Regarding application in Agricultural Entomology, GNSS positioning can be used in georeferencing of pest sampling in the field for Integrated Pest Management - IPM. This georeferencing can be done through smartphones, using general mapping applications, such as GeoMapp (Figure 1), developed by UNESP (Rosalen; Monteiro, 2021), or other specific to Agricultural Entomology.

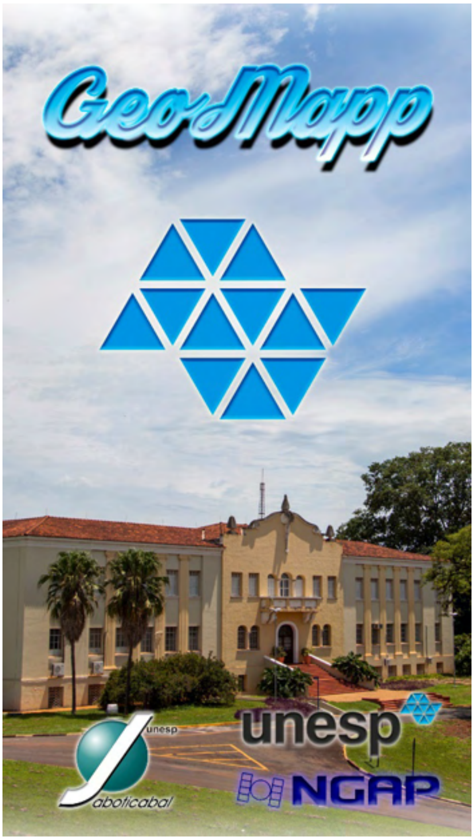

Figure 1 – GeoMapp splash screen (Source: Monteiro [2021]).

FAW Monitoring and Early Warning System (FAMEWS), for example, is aimed at sampling *Spodoptera frugiperda* (Lepidoptera: Noctuidae). This application was developed by FAO for Android system v.5 or higher and allows data collection on *S. frugiperda* at a local, national, and global levels, identifying priority areas and promoting early warning mechanisms for all interested parties. Another interesting app is OsBeeHives, which is aimed at inspecting beehives in beekeeping activities. This application, using the IoT concept, allows monitoring of hives remotely. Moreover, Cubero et al. (2020) used GNSS positioning as a field robot navigation feature intended for pest detection in horticulture.

3.2 Remote sensing

The American Society for Photogrammetry and Remote Sensing (ASPRS) defines Remote Sensing as “techniques used to collect and process object information without direct physical contact” (ASPRS, 2022, np).

Remote Sensing collects data at different levels on which platforms and their respective sensors are located. There are orbital levels used by satellites, aerial used by manned or unmanned aircraft, and terrestrial used by agricultural machinery and/or static platforms. The aerial level can be divided into aerial and low-altitude aerial, the latter being used by Remotely Piloted Aircraft (RPA), the so-called drones. The terrestrial level, also called Proximal, can be divided into terrestrial (field) and laboratory (bench).

Apart from data collection levels, there are sensors with different characteristics. Optical sensors, for example, are passive sensors and may have one or more spectral resolutions, which can record different spectral bands. Sensors with few non-continuous and relatively wide spectral bands (e.g., 4 to 10) are called multispectral. On the other hand, sensors with several bands (e.g., more than 40), narrow and continuous, are called hyperspectral sensors.

Active sensors, unlike optical sensors, have their energy; therefore, they do not require sunlight for data collection. Some active sensors record bands in the visible spectrum (Light Detection and Ranging - LIDAR) or the microwave spectrum (Radio Detecting and Ranging - RADAR). More details about the different sensor types used in Remote Sensing can be found in Barros et al. (2021).

Studies on the relationship of Low Altitude Aerophotogrammetry and Proximal Remote Sensing with Agricultural Entomology have increased significantly in recent years. For example, Pinto et al. (2020) studied Hyperspectral Proximal Remote Sensing and gas exchange parameters to characterize the responses of peanut (*Arachis hypogaea*) plant leaves to herbivory by *Stegasta bosqueella* (Lepidoptera: Gelechiidae) and *Spodoptera cosmioides* (Lepidoptera: Noctuidae), two main pests in this crop. The authors observed that the spectral range from 777.42 to 1,000 nm can be used to classify *S. bosqueella* and *S. cosmioides* lesions and that these pests should be considered individually in sampling programs for IPM purposes.

Concerning Remote Sensing with optical sensors, Feng et al. (2022) evaluated *S. frugiperda* infestation in corn (*Zea mays* L.) through image processing using Convolutional Neural Network (CNN), in particular: ResNeSt50, ResNet50, EfficientNet, and RegNet. Images were captured by an RGB sensor embedded in RPA. Results indicated the following hit rates: 98.77%, 97.59%, 97.89%, and 98.07% for evaluated networks, respectively.

An important point to be highlighted in optical sensor data processing is the use of different vegetation indices, with the Normalized Difference Vegetation Index (NDVI) being one of the best known and used. There are structural and biochemical indices; in Barros et al. (2021), a brief list of some of these indices can be found, as well as in Bagheri (2020).

In terms of active sensors, Song et al. (2020) used a continuous wave LIDAR system

(Continuous Wave - CW) to monitor insects and verified that insect abundance varies with time of day and weather conditions. They could also identify insect species, analyze wing beat frequencies, and ultraviolet light attraction. The authors used LIDAR to evaluate flying insect populations, as its sensors can be used on vegetation canopy rather than directly on insects to evaluate their behavior.

Most phytosanitary problems trigger plant defense mechanisms, changing and/or reducing vegetative growth, and hence decreasing biomass, leaf area index, or other canopy parameters. Accordingly, detection of canopy changes by active sensors can reveal the occurrence of plant-health problems such as pest infestation (Barros et al., 2021).

Undoubtedly, both passive and active sensors can be embedded in orbital, air, and ground platforms. In this sense, Iost Filho et al. (2020) reviewed the literature extensively on Low Altitude Aerial Photogrammetry applied to MIP.

3.3 Geographic Information Science

Geographic Information System (GIS) and Geographic Information Science (GISc) concepts must be distinguished. For ASPRS, GIS is "an information system capable of encoding, storing, transforming, analyzing, and displaying geospatial information" (ASPRS, 2022, np). On the other hand, GISc, as conceptualized by Prof. Michel F. Goodchild (Goodchild, 1992), is a set of fundamental research questions, which GIS can solve. Such issues can be enumerated as data capture, measurement, and storage; spatial analysis; spatial data modeling and theories; data structures; algorithms and processes; data display; analytical tools; in addition to ethical, institutional, and managerial issues. Despite being more related to Engineering issues than Science itself, Artificial Intelligence and Expert Systems could be added (Goodchild, 2010). Therefore, GIS, as a computational tool, answers the questions "what?" and "where?" are phenomena that occur in geographic space, whereas GISc will add the questions "how?" or "why?" they occur.

GISc has been widely applied in spatial distribution studies on pest infestations. For instance, Arends et al. (2022) characterized spatiotemporally injuries caused by *Helicoverpa zea* (Lepidoptera: Noctuidae) in corn (*Zea mays* L.), which is fundamental for Bt technology crops (transgenic plants).

4 I FINAL CONSIDERATIONS

Industry 4.0, Precision Agriculture, Smart Agriculture, and Digital Agriculture concepts shall be clearly defined. For Precision Agriculture, the concept established by ISPA is recommended, while for Digital Agriculture the FAO concept, both discussed in item

2 of this chapter.

Regarding item 3, in terms of GNSS positioning, the challenge of Digital Agriculture, in the context of Agricultural Entomology, is developing applications to map pest infestation, to be integrated into IPM programs. Another point is designing lightweight and versatile insect tracking systems integrated with GNSS technology. Lastly, integrating GNSS positioning with applications for pest monitoring through smart traps.

There is still a wide range of research to be conducted on Remote Sensing, from developing specific sensors for monitoring and early detection of pest infestations to specific research that could support such development. Furthermore, image processing techniques involving both evaluation and development of vegetation indices and Convolutional Neural Networks should be developed to detect injuries and infestations.

A challenge to be met in Geographic Information Science is its use in pest spatial distribution studies and respective mathematical modeling of pest behavioral dynamics under field situations. Finally, Machine and Deep Learning algorithms must be developed in R and Python. Furthermore, QGIS open-source plugins applied to Agricultural Entomology are a wide and fascinating field to be explored.

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Atena Editora
Ano 2022