Women in Engineering and Science

Takoi Khemais Hamrita *Editor*

Women in Precision Agriculture

Technological breakthroughs, Challenges and Aspirations for a Prosperous and Sustainable Future

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To the loving memory of my father Khemais Hamrita who was my role model, cheerleader, anchor, and guide, and who instilled in me a hunger for knowledge and a burning desire to make a difference
To my mother Jamila Dardour who taught me the meaning of hard work, selflessness, and patience
To you Ayman for helping me grow and persevere in ways I never thought possible

Preface

I write this book preface during the COVID-19 crisis, while social distancing in my home. To me, this crisis has revealed a number of invaluable lessons to the world. The two lessons most important to the context of this book are: (1) science and technology are vital to our collective future, and (2) problems of the future can't be solved in isolation, we must work together. As the founder of the Global Women in STEM Leadership Summit, I have the privilege to interact with some of the most brilliant women in STEM (Science, Technology, Engineering, Math). Through these interactions and through the summit programs, I have learned that we are far from achieving equity in STEM. We, women in STEM, are still severely underrepresented and our efforts are to a great extent marginalized. This is not only detrimental to our well-being as women, but it is also detrimental to the advancement and preservation of our collective future as a humankind.

This book is a small contribution towards promoting the efforts of women in my technical field, precision agriculture. Precision agriculture is the application of technology to study, assess, and control the agricultural process and its inputs/outputs. To me, this field is a natural fit for women. Our land, our environment, and natural resources are stressed to the max. New solutions to steer us in a more positive and sustainable direction are becoming more vital every day. In my conversations with all the women I meet through the summit, one thing has become increasingly clear: women are driven by the common good, they like pursuing passions, and they care about their communities, the environment, animals, etc. Precision agriculture is inherently designed to optimize the use of natural resources and reduce waste, and to contribute to our well-being and that of the environment and the animals within it. A natural fit.

As you will see through the pages of this book, the passion and care of the contributing women authors are evident in every chapter. The chapters present cutting-edge research in almost every area of precision agriculture. I am particularly pleased that our book is unique in addressing both land and animal agriculture. I'm also delighted that the women authors represent various geographic areas around the world, and many disciplines and career paths and stages. I hope you will find this book not only informative and helpful in your own precision agriculture journey but also inspiring. We, women in STEM, are a vital intellectual, emotional, and spiritual resource for vital new global paradigms such as precision agriculture. Our collective future as a species depends on women in STEM being represented, being seen, and being heard!

Athens, GA, USA Takoi Khemais Hamrita

Acknowledgments

This book wouldn't have come into existence were it not for Jill Tietjen's invitation to contribute to her Women in Engineering and Science book series. Thank you Jill for including me in your very special series and for being an amazing role model. I would also like to thank Springer for their invitation to create this book and for all the support they have given me. In particular, special thanks to Mary James, Hemalatha Velarasu, Zoe Kennedy, Brian Halm, and Mario Gabriele for their assistance with the book.

I am very grateful to the many women authors who have contributed to this book. They represent various geographic areas, and many disciplines and career paths and stages. I'm indebted to them for the huge time and effort they invested to produce high quality relevant content.

I would also like to thank my undergraduate research assistants Kaelyn Deal, Selyna Gant, Haley Selsor, Taylor Ogle, and Amanda Yi for their assistance with all aspects of putting this book together. In particular, I'm grateful for the thorough literature searches they conducted and the quality of references they produced.

I'm fortunate to have created the Global Women in STEM Leadership Summit. This community of very successful women and men has opened my eyes to the difficulties and inequities women in STEM face, and hence has fueled my interest in highlighting, advancing, elevating, and promoting women in STEM fields. I am very grateful to this powerful community.

Last but not least I would like to thank my personal tribe. I am fortunate to have a very loving family who believes in me and supports all my professional endeavors and pursuits. I am forever indebted to my late father Khemais Hamrita who dedicated so much of his wisdom, time, and energy to supporting, encouraging, and elevating me. I am able to empower others because he empowered me.

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Chapter 1
Precision Agriculture: An Overview of the Field and Women's Contributions to It

Takoi Khemais Hamrita, Kaelyn Deal, Selyna Gant, and Haley Selsor

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1.1 Introduction

By 2050, the world's population will exceed 9 billion people (Pandey 2018). According to some projections, to feed the world's population, the agricultural sector must increase production by 70% (Yun et al. 2017). This urgent need for

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increased productivity, coupled with the need for reduced cost, more optimal use of resources, and reduced impact on our environment, has made it imperative to create and adopt new ways of farming. Many industries around the world are stepping up to meet the expected demand and supply. In agriculture, many researchers have turned to technology to aid food production.

Historically, agriculture has not benefited from systems thinking nor the tools and technologies that have been developed to control and optimize systems in other industries, such as manufacturing automation, process control, and aerospace. In these types of systems, in order to control and optimize performance, the outputs along with other important system variables are monitored, and their measurements are used to determine the inputs that would produce the desired performance. Precision agriculture is about viewing and treating the agricultural process as a system and incorporating information available from all its parts to improve its performance. In order to do so, new methods, tools, processes, and technologies had to be developed to enable the observation and measurement of important variables (Phadikar et al. 2012), facilitate the study and assessment of these variables to extract relevant information and knowledge (Castle et al. 2015), and use this knowledge to control the agricultural process and its inputs/outputs (Shobha et al. 2008). The goal is to create farming practices that respond precisely to the spatially and temporally varying needs of land and livestock, therefore optimizing yield while reducing cost and environmental impact. In other words, precision agriculture is about listening to the needs of the land, the animals, the environment, the farmers, and the consumers and doing what it takes to respond to these needs. It's about being holistic and tuning in to all parts of the system to make optimal management decisions.

Precision agriculture is a complex research and development field that lies at the interface of various disciplines and technological advances. Precision agriculture began to develop in the twentieth century with the help of researchers. As research started to release results, visionaries and scientists continued this trend and created precision agriculture (Srinivasan 2006). The trends arising in the research and development of precision agriculture include data mining, machine learning, Big Data, Small Data, data analytics, geographic information systems (GIS), Global Positioning System (GPS) and GPS auto guidance equipment, unmanned aerial vehicles (UAVs), Internet of Things (IoT), remote sensing, smart sensor networks, variable rate technology, nanotechnology, and robotics.

This book is a compilation of contributions, breakthroughs, and impactful research done by leading female researchers and scholars from various fields and from around the world toward making precision agriculture a reality. Tables 1.1a and 1.1b show the diverse technical, career paths and stages, and geographic backgrounds of the authors of this book. Tables 1.2a and 1.2b show examples of patents by leading women researchers in precision agriculture. Additionally, women authors or coauthors of research referenced in this chapter are highlighted. All these women are creating new technological advances that are revolutionizing agriculture and providing innovative solutions to some of today's most challenging global food problems, paving the way for a smarter, more precise, more efficient, and more profitable agriculture for the twenty-first century. The chapters in this book present a holistic view of the field, highlighting relevant technologies, decision-making strategies, practices, applications, economics, opportunities, and challenges for both land and livestock applications. This is the only known book focused on advances in precision agriculture for both land and livestock, led by women researchers and scholars, hence providing a unique woman's perspective in a field primarily dominated by men.

Table 1.1a Author and coauthor contributors to Chaps. 1, 2, 3, 4, and 5

Author name	Title and affiliation	Country
Chapter 1: Precision Agriculture: An Overview of the Field and Women's Contributions to It		
Takoi Hamrita	Professor and Inaugural Chair of the School of Electrical and Computer Engineering at the University of Georgia (UGA)	United States
Kaelyn Deal Selyna Gant Haley Selsor	Undergraduate Research Assistant University of Georgia	United States
Chapter 2: Sensing Technologies and Automation for Precision Agriculture		
Man Zhang	College of Information and Electrical Engineering, China Agricultural University	China
Ning Wang	Professor at Oklahoma State University, Department of Biosystems and Agricultural Engineering	United States
Liping Chen	Beijing Research Center of Intelligent Equipment for Agriculture, Beijing Academy of Agriculture and Forestry Sciences	China
Chapter 3: Perspectives to Increase the Precision of Soil Fertility Management on Farms		
Joann Whalen	Professor at McGill University and Adjunct Professor at Gansu Agriculture University	Canada
Chapter 4: Toward Improved Nitrogen Fertilization with Precision Farming Based on Sensor and Satellite Technologies		
Heide Spiegel	Senior Scientist at Agency for Health and Food Safety (AGES) and Department for Soil Health and Plant Nutrition	Austria
Taru Sandén	Postdoctoral Researcher, Department for Soil Health and Plant Nutrition at AGES	Austria
Laura Essl	Dipl.-Ing., Institute of Geomatics at the University of Natural Resources and Life Sciences	Austria
Francesco Vuolo	Senior Scientist, Institute of Geomatics, University of Natural Resources and Life Sciences	Austria
Chapter 5: Precision Weed Management		
Sharon Clay	Distinguished Professor, Plant Science Department at South Dakota State University	United States
Anita Dille	Professor in Weed Ecology and Assistant Head for Teaching in the Agronomy Department at Kansas State University	United States

Table 1.1b Author and coauthor contributors to Chaps. 6, 7, 8, 9, and 10

Author name	Title and affiliation	Country
Chapter 6: Precision Irrigation: An IoT-Enabled Wireless Sensor Network for Smart Irrigation System		
Sabrine Khriji	Research Assistant at the Chemnitz University of Technology and University of Sfax	Germany, Tunisia
Dhouha El Houssaini	Research Assistant at the Chemnitz University of Technology and University of Sfax	Germany, Tunisia
Ines Kammoun	Professor at the National Engineering School of Sfax	Tunisia
Olfa Kanoun	Professor at the Chemnitz University of Technology	Germany
Chapter 7: Women Farmer-Breeder Partnerships in Plant Breeding, Seed, and Food Innovations: Experiences from Tigray, Northern Ethiopia		
Fetien Abay Abera	Vice President for Research and Community Services at Mekelle University	Ethiopia
Chapter 8: Synthesis of a Research Program in Precision Poultry Environmental Control Using Biotelemetry		
Takoi Hamrita	Professor and Inaugural Chair of the School of Electrical and Computer Engineering at the University of Georgia	United States
Taylor Ogle Amanda Yi	Undergraduate Research Assistant University of Georgia	United States
Chapter 9: Advancement in Livestock Farming through Emerging New Technologies		
Jarissa Maselyne	Researcher at Flanders Research Institute for Agriculture, Fisheries, and Food (ILVO)	Belgium
Chapter 10: The Impact of Challenges and Advances of Bush Internet Connectivity for Women in Agriculture in Queensland, Australia		
Rachel Hay	Social Scientist and Lecturer in Marketing at James Cook University	Australia

1.2 Precision Agriculture in Crop Production: Enabling Technologies and Applications

Precision agriculture makes use of the understanding of variability within land and crops to implement spatially and temporally variable application of agrochemicals. As one analyst suggests, a way to view farming is as a branch of matrix algebra that juggles the variable inputs to a farm and the required analysis to understand the quantity those inputs are needed at (Technology Quarterly 2016). In addition to informing agricultural input decisions, precision agriculture can suggest to the farmers the right crop based on their site-specific parameters (Pudumalar et al. 2017). Being able to measure variability within a field and apply inputs accordingly requires a number of enabling technologies.

Table 1.2a A sample of US female patent holders in precision agriculture

Name	Title and affiliation	Patent #	Patent title
Takoi Hamrita et al.	Professor at the University of Georgia	6525276	Crop yield monitoring system
Sarah L. Schinckel et al.	Manager at Deere and Company	10150483	Settings manager – distributed management of equipment and display settings via centralized software application
Margaux M. Price et al.	Manager at Deere and Company	10150483	Settings manager – distributed management of equipment and display settings via centralized software application
Kimberly A. Salant et al.	CEO and Co-owner of Sentek Systems	9945828	Airborne multispectral imaging system with integrated navigation sensors and automatic image stitching
Lori J. Wiles et al.	Quantitative Agricultural Scientist at Colorado State University	9563852	Pest occurrence risk assessment and prediction in neighboring fields, crops, and soils using crowdsourced occurrence data
Shelley Haveman Wolff et al.	Principal Investigator, Microbiology at Luca Technologies	20140154727	Geobacter strains that use alternate organic compounds, methods of making, and methods of use thereof
Zarath Morgan Summers et al.	Researcher at University of Massachusetts Amherst	20140154727	Geobacter strains that use alternate organic compounds, methods of making, and methods of use thereof
Lynn David Jensen et al.	Title and affiliation unknown	US6701857B1	Depth control device for planting implement
Chloe Romier	Global Product Manager at GEOSYS SAS	9972058	Method for correcting the time delay in measuring agricultural yield
Cherish Bauer-Reich et al.	Assistant Professor of Engineering at NDSU Research Foundation	9964532	Biodegradable soil sensor, system, and method
Emily Rowan et al.	Title unknown, affiliated with Climate Corporation	US10028451B2	Identifying management zones in agricultural fields and generating planting plans for the zones

1.2.1 The Global Positioning System (GPS)

A cornerstone technology for precision agriculture is the Global Positioning System (GPS). The GPS, along with new sensor technology, has enabled the development of various types of maps that allow farmers to visualize their land, crops, and management in unprecedented ways (Yousefi and Razdari 2015). With this variability information, and visualization of their land, farmers can better manage their resources. The satellite-based GPS system was first created in the 1970s by the US

Table 1.2b A sample of European and Australian female patent holders in precision agriculture

Name	Title and affiliation	Patent #	Patent title
Montserrat Jurado Exposito et al.	Tenure Scientist at Consejo Superior de Investigaciones Cientificas CSIC	ES2245250A1, WO2005122755A1	Procedure for the discrimination of soil uses and the quantification of vegetable cover through teledetection with air photography
Francisca Lopez Granados et al.	Research Scientist, Laboratory Head at Consejo Superior de Investigaciones Cientificas CSIC	ES2245250A1, WO2005122755A1	Procedure for the discrimination of soil uses and the quantification of vegetable cover through teledetection with air photography
Nadia Shakoor et al.	Title and affiliation unknown	WO2018049189	Integrated field phenotyping and management platform for crop development and precision agriculture
Pramila Mullan et al.	Principal Director at Accenture	US9792557B2, AU2017228695B2	Precision agriculture system

Department of Defense. In the 1990s, agricultural engineers combined this technology with various yield sensing and data processing technologies to create crop yield maps. In the late 1990s, the US farmers began to use yield mapping technology to "see" bigger variations within their fields than they had ever imagined. Today, GPS receivers are common on farm equipment. Producers use GPS information to control and guide farm equipment and to map and monitor their farms. Without GPS as a reliable and affordable tool, it would have been hard for precision agriculture to become a viable and popular solution (National Museum of American History 2018).

1.2.2 Geographic Information Systems (GIS) (https://www.esri.com/en-us/what-is-gis/overview)

A geographic information system (GIS) is a framework for gathering, managing, and analyzing information. GIS integrates and organizes many types and layers of information using maps and 3D scenes. With this unique capability, GIS reveals deeper insights, patterns, connections, and relationships in the data, helping users make smarter decisions. Organizations around the world use GIS to make maps that communicate, analyze, and share information to solve complex problems.

Early applications of GIS in agriculture date back to the 1970s (Mulla and Khosla 2016). GIS technology is an integral part of PA as it is instrumental in creating maps that reflect variability within soil, crops, and yield across a field. These maps serve as the basis for making and executing optimal management decisions.

1.2.3 New Sensing Technologies Are the Backbone of Precision Agriculture

As it is the case for any type of system, being able to measure outputs of the system as well as other important variables is a prerequisite for controlling the system and obtaining the desired outcomes. For the application of precision agriculture in crop production, it is important to be able to measure properties of the soil and the crops, as well as the output or the yield as it is commonly referred to, in order to gain understanding of the spatial and temporal variability within fields. Some experts like Shannon Ferrell and her associates suggest that we are witnessing an information revolution in the agricultural sector as sensor technology and data analytics from other industries are now being applied to agricultural applications (Coble et al. 2018). According to Takoi Hamrita and colleagues, the need for these sensors stems from the necessity of real-time control in order to have high-quality agricultural production (Hamrita et al. 1996, 2000). Sensors also address labor shortages and meet regulatory constraints on safety and environmental responsibility (Hamrita et al. 1996, 2000). Availability of sensors and sensor data has driven a number of agricultural innovations such as variable rate technology, crop-specific yield monitors, UAVs, and GPS Guidance Systems (Castle et al. 2015). "Information became a new crop of the 21st century, making farmers more efficient and sustainable but increasingly technologically dependent" (National Museum of American History 2018). Precision agriculture would not be what it is today were it not for two key technological advances: remote sensing and wireless smart sensor networks.

In Chap. 2 of this book, Ning Wang (Oklahoma State University, USA), Man Zhang (China Agricultural University, China), and Liping Chen (Beijing Academy of Agriculture and Forestry Sciences, China) provide a detailed discussion of different sensor technologies geared toward sensing soil, root, and crop properties. The authors also discuss the various types of platforms that are used to meet sensing requirements of different PA applications including in-field sensor networks, ground mobile platforms, manned and unmanned aerial vehicles, and satellites. The chapter also gives two detailed examples of the use of sensing technologies in PA, namely, the use of wireless sensor networks for real-time soil property monitoring, and the use of a ground-based phenotyping platform to evaluate peanut canopy architecture.

Remote Sensing

Farmers gather remotely sensed information by using planes, UAVs, and low earth orbital satellites passing over their land (Technology Quarterly 2016). Airborne instruments attached to planes can measure plant coverage and make distinctions between weeds and crops. This distinction allows autonomous machinery to remove weeds without damaging or mistakenly removing valuable crops. Small satellites use multispectral imagery that observes plant absorption of varying wavelengths emitted by the sun (Technology Quarterly 2016). Recent technological developments in aerospace engineering have led to Low-Altitude Remote Sensing systems. These systems allow aerial images to be taken at low altitudes using unmanned aerial systems (UAS) (Zhang and Kovacs 2012), also referred to as unmanned aerial vehicles (UAV). An unmanned low-altitude imaging system is more accessible and affordable to producers than the more expensive manned aerial imaging systems or satellite imagery. In Zhang and Kovacs (2012), the authors provide a review of recent studies in the application of UAS imagery for PA. The authors analyze and discuss results of these studies and limitations of UAS in agriculture. Topics discussed include remote sensing, small UAS and environmental studies, limitations of UAS, platforms and cameras, UAS image processing, issues with aviation regulations, future application of UAS in PA, advancements in UAS, methods of data extraction from UAS imagery, and attracting farmer interest. Ana Isabel de Castro, Francisca López-Granados, Maggi Kelly, and colleagues indicate that UAVs can supplement small satellites with ultrahigh spatial resolution data to distinguish weeds from crops and finely tune site-specific weed management (Gómez-Candón et al. 2013; Peña et al. 2013), as well as detect spatial variability in yield using smart yield detection technology (Vellidis et al. 2001). UAVs have the potential to be used on all farms in the world (Zhang and Kovacs 2012) and are proving to be versatile in unexpected ways. For example, In Japan, UAVs are used for more than imaging as they are used to scare birds, spray areas, protect against theft, aid in the creation of fields' maps, and monitoring the evenness of germination and analysis of all the necessary nutrients to plant's availability over large areas (Yun et al. 2017).

Wireless Smart Sensor Networks

Recent innovations have made it possible for sensors to be smaller and cheaper and to be made with computer components according to Loredana Lunadei and colleagues (Ruiz-Garcia et al. 2009). Advances in wireless communication and digital circuits have made it possible to build wireless smart sensor networks. These sensors are called smart sensors as they are capable of wireless communication with each other and with other parts of the system, data processing, and computing (Hamrita et al. 2005). In the past decade, wireless sensors have been subject to continuous innovation, allowing them to complete increasingly complex tasks (Ivanov et al. 2015). Smart sensors are multidisciplinary, monitoring yield, inputs, and interactions between machines and crops. They integrate with other innovative technology such as autonomous machinery and have been widely accepted by farmers. The role of wireless sensor networks in agriculture has become vital as part of the precision farming initiative according to Kriti Bhargava and colleagues (Ivanov et al. 2015). Wireless communication platforms are developing to mitigate the need for wiring harnesses and maintenance and increase mobility. They allow sensor applications in remote or dangerous locations to be monitored. Additionally, wireless networks can take advantage of and utilize cellular phones, radios, and Global Positioning Systems. Sensor networks can be combined with data mining techniques to map behavioral patterns for different crops. Tatiana Gualotuna and colleagues suggest that their data can be used to create the most effective and productive management plan for specific crops (Rodríguez et al. 2017). In Ruiz-Garcia et al. (2009), Loredana Lunadei and her colleagues provide a review of wireless sensor technologies and communication systems such as wireless sensor networks (WSN) and radio frequency identification, and the application of these technologies in agriculture is discussed. These applications include fire detection, climate monitoring, crop canopy influence, climate influence, farm machinery, pest control, viticulture, irrigation, greenhouses, livestock, and cold chain monitoring and traceability. Future trends are also discussed.

Sensor Applications

Soil Sampling

Soil sampling to study its properties is not new. In the 1970s, groups of soil scientists studied the spatial variability of soil moisture and hydraulic properties and its use to improve the precision of soil mapping (Mulla and Khosla 2016). In the 1980s, building on these studies, research was done to map phosphorus levels in soil, and software was developed to automatically classify and map soil fertility sampling data into fertilizer management zones. This was the first combined use of geostatistics and GIS for precision farming (Mulla and Khosla 2016). This was also most likely the first real application of PA (Srinivasan 2006).

Several sensing technologies have been developed since to sense various properties of the soil. In Adamchuk et al. (1999), the authors discussed the development of an automated soil sampling system that extracts soil at a designated depth and measures the pH every 8 s. This allows farmers to insightfully administer fertilizers to adjust the pH of specific parcels of land instead of the whole field, conserving resources and minimizing costs. In Kühn et al. (2008) Sylvia Koszinski and colleagues explore the viability of using the spatial variability of electrical conductivity in soil as a digital soil mapping tool. This method proved to offer a more detailed and lower level look at soil properties rather than traditional geological maps.

Applying PA techniques to soil fertility management will optimize agricultural production while protecting the environment. In Chap. 3 of this book, Joann Whalen (McGill University, Canada) discusses soil fertility and evaluation methods of soil nutrient status to aid in the selection of the right source and amount of fertilizer, and the best time and place to add fertilizers so the nutrients will be used efficiently by the crop. Joann makes the case for how technological advances, such as low-cost sensors, make it possible to apply nutrient-rich fertilizers to crops in smaller doses and with greater precision at the field scale, therefore avoiding nutrient losses from agroecosystems to surrounding environments. In Chap. 2 of this book, the authors discuss the use of wireless sensor networks for real-time soil property monitoring.

Weed Control

Precision weed management consists of optimizing inputs to reduce weed presence and improve crop yields. In Gómez-Candón et al. (2013), UAVs coupled with ground control points produced ultrahigh spatial resolution to locate weeds in their early phenological stages throughout a wheat field. The primary objective that this study supported is the creation of broad-leaved and grassweed maps in wheat crops for early site-specific weed management. In Peña et al. (2013), using UAVs, a six-band spectral camera, and object-based image analysis (OBIA), weed maps were made at the early phenological stage of both the crops and weeds themselves. The study aimed at creating highly detailed weed maps for early site-specific weed management to support Europe's recently passed legislation for more sustainable practices with pesticides.

In Chap. 5 of this book, Sharon Clay (South Dakota State University) and J. Anita Dille (Kansas State University) present a very thought-provoking discussion of site-specific weed management. In particular, they highlight opportunities for precision weed management, methods to collect and process information needed to implement precision management, current knowledge available on the topic, and challenges and recommendations for success. They indicate that no matter the method, understanding which weeds are present, location, density, and the appropriate control and timing are critical for success. They also argue that in the future, agronomists will need to have knowledge and skills beyond traditional weed science to include an understanding of state-of-the-art topics such as robotics as well as big data management and processing.

Nitrogen Fertilization

Nitrogen is a crucial nutrient for crops. Precision farming aims at adjusting nitrogen fertilization according to the needs of the plants while minimizing waste in the environment. In Haboudane et al. (2002), Louise Dextraze and colleagues predict the chlorophyll content of plants using remote sensing and hyperspectral imaging. This predictive tool aids in quantifying the amount of nitrogen dosage needed by plants to prevent excess nitrogen from running off into irrigation networks and waterways. In a study led by Jana Havránková, an analysis of passive and active ground-based remote sensing systems for canopy nitrogen management was conducted in winter wheat. The study revealed that both passive and active sensors uncovered nitrogen content of plants particularly well at the early growth stages, and succeeded in reducing the UK's nitrogen application by 15 kg/ha and in Slovakia by 1.5 kg/ha. Additionally, the UK reduced its residual nitrogen content in the soil by 52% (Havránková et al. 2007).

In Chap. 4 of this book, Heide Spiegel and Taru Sandén (Austrian Agency for Health and Food Safety, Austria), and Laura Essl and Francesco Vuolo (Institute of Geomatics, University of Natural Resources and Life Sciences, Austria) describe a study aimed at evaluating sensor and satellite technologies using field data collected under optimal conditions at different stages of nitrogen fertilization. Their work involved close cooperation between remote sensing experts, soil scientists, agronomists and practitioners, and their findings yielded productivity maps that serve as a basis for nitrogen fertilization maps for use by commonly applied farm machinery.

Irrigation Control

One of the greatest agricultural inputs is water and irrigation. Agricultural production requires a large amount of fresh water. As a result, agriculture must compete with other industries for potable water. Add in climate change, rainfall variation, and decreasing water tables, and there arises an obvious need for monitoring and optimizing water usage. Water management offers an effective solution to satisfy the world's growing demand for water (Dalezios et al. 2017). Irrigation systems can become more efficient with sensor networks, data science, and variable rate technology. Precision irrigation has great promise to improve the efficiency of water use. The importance of water availability estimation, agriculture water needs, and the necessity for monitoring drought conditions are essential to successful PA (Dalezios et al. 2017). Several studies in the literature have dealt with precision irrigation.

Gago et al. (2015) discusses how PA can be used for water stress management using unmanned aerial vehicles (UAVs) to monitor crop fields with high spatial and temporal resolution. It is suggested that these vehicles use thermal imagery to measure the difference between canopy and air temperatures or to measure chlorophyll fluorescence. The information gathered provides insight into water stress variability in a field and can also determine which crops are optimal for breeding purposes by measuring yield and stress tolerance. In a study led by Monica Diez, Cristina Moclan and colleagues (Díez et al. 2014), satellite imaging was used to monitor high-density cornfields and soya crop plots in northern Texas with the goal of making irrigation practices more efficient and effective. The study focused on high-frequency passes (every 2 days) over the test site in order to generate the best irrigation recommendations. The approach was considered successful by reducing irrigation costs and improving crop productivity (Díez et al. 2014). In Dalezios et al. (2019), the authors used Earth Observation data to measure water availability in fields in a drought-susceptible area in Greece. By monitoring water uptake of crops, rainfall, and drought potential, farmers can better manage their field and productivity.

In Chap. 6 of this book, Sabrine Khriji (Technische Universität, Germany, and University of Sfax, Tunisia), Dhouha El Houssaini (Technische Universität, Germany, and Technopark of Sousse, Tunisia), Ines Kammoun (National School of Engineers of Sfax, Tunisia), and Olfa Kanoun (Technische Universität, Germany) present a real-time IoT-based smart irrigation system. A number of wireless sensor nodes are used to monitor both soil moisture and temperature. Sensed data is transmitted to the gateway through the Queuing Telemetry Transport communication protocol. A Web interface and mobile application are provided to users to control the level of water in the soil in real time. Users can take immediate action to open or close the water pump through the mobile application.

Sensors in Harvesting

Sensors have also been developed to study the effects of harvesting and transportation processes on crops. For example, niche sensors needed for characterizing harvesting impact on soft-skinned berries and other sensitive crops are being developed by Takoi Hamrita and colleagues to improve upon the harvesting process and yield better products (Yu et al. 2011a, b). These sensors are vital for future understanding of the relationship between sensitive crops and machinery (Yu et al. 2011a, b).

Yield Mapping

Yield mapping is one of the most widely adopted PA technologies. Several studies in the literature discuss yield mapping and highlight the fact that it is a gateway technology to future adoptions of other complementary precision agricultural technologies. Yield maps reveal critical information about the status of the soil and the crops, therefore uncovering problem areas and providing insight into what areas need more resources or attention to increase their yield or productivity. For instance, in Aguilar-Rivera et al. (2018), the authors discussed yield monitoring of sugar crop fields in Mexico. Productivity or yield was measured with GPS and remote sensing technologies to show which land was highly productive and which needed improvement. Through yield mapping, land suitability was divided into three different levels, and to increase yield in less suitable areas, "agroecological management practices" were recommended for those areas. In another study of a peanut yield monitor developed at the University of Georgia (Vellidis et al. 2001), a yield map generated by the yield monitor uncovered problem locations such as a parasitic nematode infestations of peanuts and major yield variability. With the problem location known, more efficient and effective solutions could be applied saving both time and money. An important issue for yield monitors is to factor in and compensate for combine dynamics when interpreting yield data. It is recommended that to ensure accuracy with yield results, a yield reconstructive algorithm that takes into account combine dynamics should be developed. With proper installation, calibration, and operation of yield monitors, sufficient accuracy can be achieved in yield measurements to make site-specific decisions (Arslan and Colvin 2002).

1.2.4 Data Mining and Precision Agriculture

The use of numerous smart sensors, networks, and machines geared toward data collection has led the agricultural process to increasingly resemble a factory that produces mass data stemming from strict monitoring and control of a farm (Technology Quarterly 2016). Data harvested from PA can be used to maximize profits for a farmer. In a study led by Yan Ma, she and her colleagues found that remote sensing data in particular has grown to be termed Big Data because of the sheer volume and the rate at which data is received for analysis (Ma et al. 2014). Data management paired with data analytics can allow site-specific fertilization for crops or tracking a specific beef cut from producer to consumer (Coble et al. 2018).

In order for precision technology to advance and become widely adopted, expansive databases with information regarding spatial variation within fields are needed. Data mining has become the common term for analysis to glean insightful conclusions and new information from available data. There are many methodologies to "mine" this data including machine learning, spike and slab regression analysis, time series analysis (Coble et al. 2018), relevance vector machines (Elarab et al. 2015), and variograms (Cameron and Hunter 2002; Kerry et al. 2010). These methods can be used in weather forecasting, crop yield prediction and selection, irrigation systems, crop disease prediction, and agricultural policy and trade (Coble et al. 2018). For example, to sift through multispectral and thermal infrared spatial imagery captured by a UAV, a relevance vector machine was used in Elarab et al. (2015) coupled with cross validation and backward elimination. The information gleaned from this data mining effort estimated chlorophyll concentrations and is used in other instances to predict future chlorophyll concentrations (Elarab et al. 2015; Haboudane et al. 2002). Another example of data mining involving the use of variograms to provide indications of the scale of variation within soil and crops is described in Cameron and Hunter (2002) and Kerry et al. (2010). From mining data in these manners, farmers get a better understanding of how many soil samples are needed to fully characterize a plot of land (Kerry et al. 2010). In Rodríguez et al. (2017), a wireless sensor network was developed and used to collect data for a rose greenhouse. This paper discussed data mining techniques to discover behavioral patterns of environmental conditions in the greenhouse.

Managing and processing big data still presents many challenges. In Skouby (2017), Danielle Skouby discusses the challenges and opportunities of Big Data being applied in agriculture and applied economics. Topics that are discussed include policy and legal implications, asymmetric information implications, sustainability, and traceability. In Ma et al. (2014), Yan Ma indicates that the technology receiving Big Data is not designed for quick and large amounts of data and data processing which reveals a gap of opportunity for technology to advance to meet data analytics level of development.

1.2.5 Robots and Variable Rate Technology

Variable rate technology allows inputs, such as water, fertilizer, and pesticides, to be analyzed by remote sensors and then altered by variable rate applicators in order to reduce waste and increase efficiency (Important tools to succeed in precision farming 2018). The success of variable rate technology depends on multiple factors including GPS, consumer perception, accuracy of the technology, yield mapping, and the perceived benefits by the farmer (O'Shaughnessy et al. 2019). In a study