Precision Agriculture (PA) techniques for smallholder farmers in the US: status and potential opportunities.

Rajveer Dhillon*, Qianna Moncur, Cadance Lowell, Sakthi Kumaran, Alcinda Folck, Deng Cao
*Corresponding author – rdhillon@centralstate.edu
Central State University
1400 Brush Row Rd, Wilberforce, Ohio, USA

Abstract

Smallholder farmers play an important role in ensuring world food security. More than one-third of global food is produced by smallholder farming systems. Besides food security, small-scale farming also provides numerous other direct and indirect environmental, social, cultural, and economic benefits by improving crop diversification, job security, and self-sufficiency. Smallholder farmers in U.S. play an important role as well. Most farms in the U.S. are small family farms, and they operate almost half of U.S. farmland, while generating 21 % of production (USDA 2021). Success and upliftment of smallholder farming systems will play a key role in feeding the predicted 9 billion earth's population by 2050. However, small-scale agriculture faces several challenges including reduced farm income, lack of technology, poor access to information and capital, market and certification barriers, and labor shortage. These challenges are further exacerbated by climate change, population increase, water scarcity, and soil degradation. Agriculture has seen a lot of technological advancements in the last few decades. This substantial transformation in agriculture was led by advancements in precision agriculture (PA) technologies like Global Navigation Satellite System (GNSS), auto-steering, crop and soil sensors, rate control technologies of crop inputs, and yield mapping. PA Precision Agricultural technologies have proven their worth by making farm operations automated, more efficient, and sustainable. However, PA has not always been an economically viable option for small or medium farm operations. The objective of this paper is to review the status and potential opportunities offered by advanced agriculture technologies and PA techniques that can benefit smallholder farmers in U.S.

Keywords: Smallholder farming, precision agriculture, robotics, Internet-of-Things (IoT), automation, Artificial Intelligence (AI), drones.

1. Introduction

According to United States Department of Agriculture (USDA), more than 90 percent of farms in the U.S. are classified as small, with a gross cash farm income of $250,000, or less. Undoubtedly, smallholder farmers play a very important role for world food security. More than one-third of global food is produced by smallholder farming systems from 24% of gross agricultural land (Lowder et al. 2016). Most of these small farming systems are the primary source for food in developing countries (Ricciardi

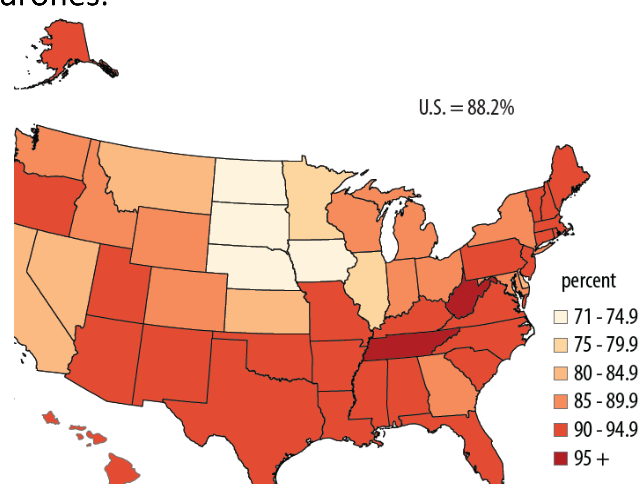

Fig. 1: Small family farms as percent of total farms by state in U.S. Source: USDA NASS 2012 Census of Agriculture.

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et al. 2018). Similar scenarios can be found in the developed countries as well. According to the 2012 census of agriculture from United States Department of Agriculture (USDA), small family farms in U.S. operated 48% of all farmlands, accounted for 20% of agriculture sales, but only earned 5% of the country's net farm income (USDA 2017). As shown in Fig. 1, more than 90% of total farms fall in the category of small farms in many of the states in the U.S. Success and upliftment of smallholder farming systems will play a key role to feed a predicted 9 billion earth's population by 2050. Small-scale farming throughout the world provides numerous direct and indirect environmental, social, cultural, and economic benefits by improving crop diversification, job security, and self-sufficiency. However, small-scale agriculture is facing several challenges like lower income, lack of technology, poor access to information, market and certification barriers, and labor shortage (Jouzi et al. 2017). In addition, these challenges are exacerbated by climate change, population increase, water scarcity, and soil degradation.

Agriculture, specifically large-scale agriculture, has seen a lot of technological advancements in the last few decades. This substantial transformation in agriculture was led by advancements in precision agriculture (PA) technologies like GNSS, auto-steering, crop and soil sensors, rate control technologies of crop inputs, and yield mapping (Schimmelpfennig & Ebel 2011).Precision Agricultural (PA) technologies have proven their worth in many ways, for example: (a) by making farm operations automated, more efficient, and sustainable; (b) by enhancing agriculture profitability and productivity; and (c) by providing environmental benefits with reduced use of chemicals and natural resources. Precision farming adopters from U.S. Midwestern states have reported that even though there is room for improvement, these technologies already help them in many ways (Batte & Arnholt 2003). However, PA has not always been economically viable option for small or medium farm operations (Mondal & Basu 2009). The aim of this article is to review the status and potential opportunities offered by advanced agriculture technologies and PA techniques that may benefit small scale farms for higher efficiency and profitability.

2. Potential ag-tech opportunities for smallholder farmers

Advanced PA technologies have yielded higher efficiency, profitability, and sustainability for agriculture. However, most of these proven technologies developed in the last few decades might not be suitable for small-scale farms. For example, a sprayer with wide swath equipped with RTK GPS and variable rate control technology is very useful for higher efficiency to minimize skips and doubles in large scale farming, but it is not the right fit economically or practically for a small farm. On the other hand, some of the advanced technologies can be very useful for small farms if these are developed and applied in a specific way. This section lists some common and emerging farm technologies, reviews the status, and discusses potential opportunities on how these technologies may be suitable for small-scale farming systems.

2.1. Unmanned Aerial Vehicles (UAVs)

Drones or UAVs are becoming mainstream technology on a modern farm. According to market research report by IndustryARC, the market for agricultural drones is forecast to reach $5.89 billion by 2026. There is no doubt that drones provide invaluable data by remotely sensing of crops for nutrient management, biotic or abiotic stress detection, and for other aspects of farm management. There are several uses of UAVs in agriculture based on size, payload, and type of sensors mounted on the UAV. Drones offer an effective approach to efficient agricultural management that helps farmers, and service providers to quickly gain insights into their crops or assets. These provide solutions like scouting and crop monitoring for weed pressure, seed emergence, field conditions, and detecting irrigation system defects (Tripicchio et al. 2015). Sophisticated sensors mounted on UAVs also are used for obtaining high-resolution data for gaining insights about soil properties, in-season crop nitrogen management, and early disease detection (Malveaux et al. 2014). Many companies provide service for drone-based applications for farmers, which allow farmers to obtain the imagery and information extracted from the images without investing on in-house drone hardware, training, remote pilot license and image processing software. As prices decrease for drone technology, drones may be used for small scale operations as well (Ehsani 2011). Studies show successful implementation of drone technology and satellite imagery for small scale farms. For example, a study was conducted in central Malawi to evaluate what spatial resolutions are most effective for relating multispectral images with crop status. Single and multiple linear regressions were tested for spatial resolutions ranging from 7 cm to 20 m using a small unmanned aerial system (sUAS) and satellite imagery. Results suggest that imagery with spatial resolutions nearer the maize plant scale (i.e., 14–27 cm) are most effective for relating spectral signals with crop health on smallholder farms (Peter et al. 2020).

Short battery life has been the biggest challenge for agriculture drones. This limitation makes a compelling case to use drones for small scale operations. For small scale operations that have multiple crops in a small area, drones have potential to offer variable rate application of chemicals, and fertilizers. However, there is need for on-farm studies to validate the effectiveness and efficacy of using of UAVs for dry, liquid or seed product applications. In fact, drones are becoming a popular option for chemical application in some Asian countries where average farm size is relatively small (Zhang et al 2020). There is opportunity for small-scale farmers to be part of agricultural cooperatives to get access to otherwise costly drone-based applications for agriculture. For example, imagery services provided by drones for weed and other crop stress detection might not be a feasible option for individual growers. However, this might be practical and suitable for small scale operations as a part of a bigger group of farmers.

2.2. Smart sensors and IoT

Sensors are not at all new to agriculture industry. Data obtained using sensors from soil, crop, machine, and environment plays key role for implementation of PA techniques on the farm. Agriculture sensors are becoming smarter and more robust. Handheld, tractor or implement mounted, drone mounted, weather stations, under the soil sensors, on-the-go soil and crop sensors are some usual places and methods to acquire valuable data for PA implementation. Improvement in wireless technologies like LoRa (Long Range), Bluetooth, and cellular services coverage on farms allows wireless networks and smart sensors to continuously send data to cloud services. This continuous flow of data combined with cloud computing made it possible for the agriculture industry to bring various internet of things (IoT) solutions to market. These data can be processed and accessed in real time mobile phone applications which allows growers to make wise decisions and keep track of farm and market activities at their fingertips. Technologies like smart sensors, and IoT are much needed for small scale specialty growers and urban agriculture growers (Gyeltshen et al. 2018). Lots of time and labor are required for record keeping to run small scale specialty crop farm operations. Inexpensive sensors and IoT solutions in combination with mobile apps can be very helpful to develop affordable and easy to use solutions to ensure high quality data collection and record-keeping throughout the growing season.

Greenhouse, hydroponics, and aquaponic systems claim to be more efficient and sustainable ways to produce food by using less inputs (water, pesticides, fertilizers). Adoption of these systems is on the rise in many urban centers as it is taken up by small and first-time growers (Han et al. 2018). PA addresses food security in many areas and is a desirable choice for many small-scale and beginning farmers. The major challenge is to ensure profitability for small scale specialty crop growers and urban agriculture operations. Smallholder growers manually record, monitor, and control lot of variables to run their operations on organic farms, family farms, greenhouses, hydroponics, or aquaponics systems (Lundqvist 2000). Affordable and reliable smart sensors and IoT solutions can be very useful for successfully and profitably running small scale farm operations by delivering data driven decision making, and automation.

2.3. Robotics and artificial intelligence (AI)

Data driven, and AI-based digital agriculture has potential to make agriculture more efficient and profitable (Torero 2021). It can provide radical solutions to challenges in agricultural production systems not just by automating data acquisition and processing, but also by automating complex, repetitive and labor-intensive agricultural operations like weed management, pest management, disease management, crop scouting, fruit picking, and harvest automation (Marinoudi et al. 2019). Agricultural robots are considered the most important solution to solving the prolonged issue of labor shortage in different agricultural communities around the world. Labor shortage in agriculture is common problem faced by both large-scale and small-scale operations. Robotic platforms are also going to play a crucial role in meeting ever increasing global demand for food. Almost all the major agriculture equipment manufacturing companies are investing to deliver autonomous solutions to the market as early as possible. For example, Raven Industries, recently acquired by CNH Industrial has launched fully autonomous platform branded as OMNiPOWER which is capable of interchanging implements for handling spraying or spreader operations suited for large scale row crop production fields.

Smaller sized robotic platforms compared to traditional tractors and implements bring great opportunities for using these technologies for specialty crops and smallholder grower operations. One major challenge is that the cost of robotic systems equipped with AI solutions is often not affordable for smallholder farmers. To reach a wide range of farmers, especially smallholder farmers and new farmers, agricultural robots need to be cost effective, simple with an easy user interface, and must be suitable to perform field operations in various types of field conditions and terrains. Another challenge is that current robotic and AI based PA solutions have also been divided into different sub-systems including robot, drone, tractor, and various other mechanical equipment. Little effort has been made to integrate these sub-systems to make one affordable and coherently integrated system. These sub-systems need to be integrated in a way that ensures affordability and convenience to the end-user.

2.4. Yield monitoring and food traceability

Smallholder farmers often have minimal margins, and most farm operations are handled manually with lots of labor hours. Ampatzidis et al. (2016) developed and evaluated a cloud-based Harvest Management Information System (HMIS) for orchard crops that provides real-time access to harvest data, yield maps, payroll and labor productivity records, and real-time decision making and fruit handling logistics. This type of specialty crop harvest management system can be very useful for many specialty crop types for other farm operations. Automation of bookkeeping, scheduling, and managing farm operations, and yield monitoring in one central cloud-based app not only makes small-scale farming efficient and profitable, and it can also provide key data driven decision making statistics. These apps and online portals need to be customizable by the farmer based on the crop type, and farm size. These systems have very important role in the food traceability, which is value added to small-scale farm operations. Consumers demand for more information about the source of the food they consume. Based on food safety regulations and consumer awareness, most fresh produce retail and grocery stores have started to require food traceability. This plays a crucial role for taking quick action in case of food recalls. Because food contamination can occur at any point in the food supply chain, and foodborne disease outbreaks can cost the industry health and monetary losses worth billions of dollars. Low-cost GPS receivers, RFID, and QR code methods can be used to gather harvest data from the small manual operations. This data becomes the key asset and a starting point for the farm-to-fork supply chain transparency and food traceability.

2.5. Irrigation automation

Irrigation automation (IA) or Precision Irrigation emerged as the most promising technique for farmers in irrigated agriculture in arid and semi-arid regions where water is scarce. Techniques like development of irrigation management zones, variable rate irrigation, and plant water stress sensing received a lot of attention from researchers and growers. There is no doubt that demand for automated irrigation systems that integrate irrigation requirements, soil moisture sensing, rainfall data, and IoT technology is on the rise in arid and semi-arid regions irrespective of the farm size (Lichtenberg et al. 2015). On the other hand, agriculture in temperate and continental climates usually has a lot of non-irrigated acreage. Considering the traditional row crops in Midwestern U.S., only 47% and 64% of total harvested soybean and corn crops, respectively, were under irrigation in 2013 (USDA 2013). These numbers are on the rise recently and it should be noted that irrigation plays critical role for small-scale specialty crop farming, even in Midwestern U.S.

There is a big opportunity for IA for small-scale operations as well. Most of the work on small-scale specialty crop farming operations is done manually. Weeding and harvesting are most labor-intensive operations, and it is quite expensive and complex to automate these operations. To save the labor costs, small scale specialty crop operations will certainly benefit from IA based on soil moisture sensing. This information can be combined with soil type, field slope, and rainfall data to implement automated irrigation control setup. Future climate change effects in humid subtropical regions are predicting possible negative effects on maize yields. Most of the agriculture is rain dependent in these areas, therefore this demands better preparation and adoption strategies (Hernandez-Ochoa & Asseng 2018). Specialty crop production with IA systems can also play important role in crop diversification for these climates. Because unpredictable water supplies for specialty and high value crops can be a critical risk, this is one of the primary reasons that hinders crop diversification in humid climates.

2.6. Use of smartphones for agricultural applications

Cellphones and smart mobile phones are becoming the most important tools of communication for farmers for accessing agricultural related information. The rapid growth of smartphone technology and the introduction of mobile-enabled information services provide ways to improve information dissemination to the knowledge intensive agriculture sector (Masimba et al. 2019). Smartphones are also helping farmers in sharing their experience, data, and information by providing easy access to internet and mobile applications. A survey was conducted to examine factors affecting the likelihood of Kenyan farmers' adoption of mobile services specifically related to agriculture and livestock information, buying, and selling products, and alerts about agricultural or livestock activities. According to the survey of 577 farming households, 98% of respondents own a mobile phone. Approximately 25% use it to access information about agriculture and livestock, 23% access information about buying and selling products, and 18% receive alerts. (Krell et al. 2021). Smartphones can play key role for business to enter the rural markets which are lagging to get access to advanced agricultural techniques.

Smartphones not only provide the easy access to weather information, and market information; In addition, smartphones also remove the technological barrier and provide easy to use applications for operating hardware, accessing sensor data, real time IoT solutions and cloud services, and farm management applications with affordable prices. These applications and websites can help smallholder farmers in communication, access to information, tracking expenses and yield, managing farms, and eventually that can lead to better decision making, increase in productivity and profitability.

3. Conclusions

Small-scale farms play a key role for producing fresh produce in U.S. and small-scale farming is the primary source of food production in many developing countries. Advanced agricultural technologies have been mostly out of the financial reach from smallholder farmers. This article discusses the importance of small-scale farming, lists agricultural technologies relevant to small-scale farming, and provides potential opportunities on how these technologies can be useful for small-scale farming. In conclusion, UAV technology have shown promise and have potential to be used for liquid and dry product application which can be huge for small-scale farms. Irrigation automation for small farms can help to increase productivity and it also solves the challenge of labor shortage for many other manual operations in small-scale farms. Robotic solutions can solve the labor issue for small-scale farms; however, cost remains a major barrier for robotics to be a viable solution for smallholder farmers. Combination of smart sensors, IoT solutions, and smartphone applications has huge potential for small scale farmers for data driven decision making, automation, bookkeeping, yield tracking, food traceability, and cloud-based applications for managing farm operations.

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