DIGITAL AGRICULTURE IN NEW YORK STATE

Report and Recommendations

Cornell University
College of Agriculture and Life Sciences

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Acknowledgements

Principal Investigators:

Harold van Es, Professor, Cornell University, School of Integrative Plant Science

Joshua Woodard, Assistant Professor, Cornell University, Dyson School of Applied Economics and Management

Contributors:

Michael Glos and Aaron Ristow, Cornell University, School of Integrative Plant Science

Leslie Verteramo Chiu and Tridib Dutta, Cornell University, Dyson School of Applied Economics and Management

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Cover design: Jenn Thomas-Murphy, Extension Support Specialist, Cornell University, School of Integrative Plant Science

Contact:

Aaron Ristow
1001 Bradfield Hall
Ithaca, New York 14853
ajr229@cornell.edu

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Commission and Project Scope

This report was commissioned by the New York State Commission on Rural Resources, through legislation introduced by Senator Catharine Young and Assemblyman Bill Magee with the following mandate:

"to direct the Commissioner of Agriculture and Markets to issue a report assessing the use and development of precision agriculture in the state with recommendations pertaining to rural broadband accessibility, use, and support for the farmers, as well as cost savings and higher crop yield."

The report of the commissioner shall include, but not be limited to:

a. definitions of precision agriculture and site-specific farming;

b. statistics of use by farmers in the state;

c. statistics of crop yields with the use of precision agriculture as compared to traditional methods;

d. statistics of rural broadband availability, with particular emphasis on agricultural land;

e. availability of suitable global positioning services;

f. environmental impacts of precision agriculture;

g. cost analyses of the use of precision agriculture, including start-up costs and affordability;

h. recommendations regarding technology support including, but not limited to, technological delivery and broadband access to remote and underrepresented geographic areas;

i. recommendations for regulatory review pertaining to precision agriculture and the encouragement for the use thereof;

j. addressing barriers to the implementation of precision agriculture systems in the state;

and

k. recommendations related to farmer privacy and the sharing of electronic information.

This document provides the New York Commissioner of Agriculture and Markets with a report that meets these directives.

Note: This report primarily uses the term Digital Agriculture in place of Precision Agriculture. The former is a newer and broader concept that involves the large-scale integration of digital technologies, analytics and communication into agricultural activities. The conventional term Precision Agriculture refers to more limited applications of Digital Agriculture as they relate to optimizing inputs in field environments.

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Executive Summary

A New Era for Agriculture

Like other economic activities, agriculture is increasingly affected by the digital revolution. **Digital Agriculture** refers to the employment of computational and information technologies to improve the profitability and sustainability of agriculture. It is a new direction for Precision Agriculture, a more established concept that is broadly defined as **"the use of advanced technologies to precisely match agricultural inputs with needs"**, and which has primarily been aimed at crop production, historically. Digital Agriculture (DA) offers new opportunities through the ubiquitous availability of highly interconnected and data-intensive computational technologies as part of the so-called Fourth Industrial Revolution. Digital Agriculture applies to all crop and livestock systems, in that it reflects a shift from generalized management of farm resources towards highly optimized, individualized, real-time, hyperconnected and data-driven management. The desired outcomes of leveraging Digital Agriculture are more profitable and sustainable production systems.

Mandate

In 2015, the New York State Legislature directed the Commissioner of Agriculture and Markets to "issue a report assessing the use and development of precision agriculture in the state with recommendations pertaining to rural broadband accessibility, use and support for the farmer, as well as cost savings and higher crop yield." This document details the technologies, opportunities, barriers and recommendations around 'Digital Agriculture', a preferred term over the conventional tem 'Precision Agriculture' for the purposes of this report. As part of the mandate, agricultural producers were engaged to assess adoption of new agricultural technologies and to help identify challenges and develop recommendations to advance Digital Agriculture in New York.

Understanding Digital Agriculture

Digital Agriculture leverages the smart use of data and generally involves the processes of data creation and analysis, decision making, and implementation through management interventions. These processes are becoming increasingly computational, data-intensive, real-time, and precise. Digital Agriculture is enabled by the high-performance computing and communication abilities of the Cloud, hyperconnectivity through mobile technologies, and the widespread availability of data.

New York farmers are adopting advanced technologies, but their complexity makes it difficult to discern farmer benefits, especially for non-traditional sectors like specialty crops. It is also becoming increasingly difficult for farmers to manage, interpret, and make use of their data on their own due to the volume and complexity of the data, as well as privacy concerns. Control of farm data and access needed to make new discoveries are increasingly controlled by corporate entities with less opportunity for public-sector research or extension for communal benefits. There is a compelling need to support Digital Agriculture adoption through investments in infrastructure, knowledge, e-communication, education, and business development.

Digital Agriculture Technologies

The technologies that enable Digital Agriculture are multiple and varied, and are inclusive of conventional precision agriculture tools as well as computational and sensing tools that are yet to be developed. Production efficiencies can be gained from the integration of data associated with multiple technologies (which currently are mostly considered independently), and from the real-time transfer of data/information between field equipment, barn, office, and the Cloud. Inadequate data analytics and telematics (the long-distance transfer of digital information) are currently constraining the potential benefits from these technologies. The main enabling DA tools that exist today include cross cutting technologies such as sensors and controllers and computational decision tools. Field-based activities are also enabled by technologies such as geo-locationing, communication (cellular, broadband, and others), geographical information systems (GIS), yield monitors, precision soil sampling, proximal and remote sensing, unmanned aerial vehicles, variable rate technologies and auto-steer, guidance, and robotics. Livestock-specific technologies include radio frequency identification, automatic milking systems and electronic feeding systems, among many others.

Assessing Needs for Digital Agriculture in New York

To understand the status of digital and precision agriculture in New York, several activities were performed:

(i) a workshop with farmers and agribusinesses,

(ii) a statewide farmer survey,

(iii) a literature analysis, and

(iv) a study on current and evolving trends in Digital Agriculture.

The statewide survey targeted farmers throughout the state across all farming sectors and was conducted in collaboration with several NY farmer organizations, with 388 responses received. The survey assessed farmers' current and expected use and adoption of precision agriculture technologies, barriers and opportunities, and perceptions of benefits. Adoption rates in New York State remain well below those in leading agricultural states, particularly for non-livestock operations. The results of the survey analysis suggest several interventions for improving digital agriculture adoption, including better availability of data storage and analytics, better access to high speed broadband and mobile communications, more education to illustrate the benefits and use of these technologies, and more research to facilitate use of existing data and equipment.

A recurring theme of both the workshop and the survey was the large current analytics and data management gap relative to the capabilities of modern-day equipment. 34% of respondents indicated insufficient technical support, while 51% reported that they are uncertain on how to implement new technologies in a profitable manner. Producers reported the #1 priority to be extension and education (24%), research and development (20%), infrastructure (20%), and business development (18%). Access (or lack thereof) to high speed internet was found to be a highly significant factor affecting benefits of DA technology.

Opportunities and Challenges for Digital Agriculture

Connectivity limits the effective employment of DA technologies in many rural areas of the state, and was found to be statistically related to the probability of adopting DA technologies. Generally, needs exist around (i) expanding broadband access for the entire state, (ii) improving cellular coverage and data transmission speeds for proper uploading and downloading of data, (iii) establishing low-power wide area networks that offer opportunities for the use of sensor technology and equipment communication through the so-called "Internet of Things", and (iv) universal access to RTK technology in the state's rural areas.

Concerns with data tend to focus around (i) security and privacy, (ii) the use of such data by companies to advance their own rather than public interests, and (iii) farmer ability to employ their own data to improve management and profitability.

In order to advance Digital Agriculture in New York, educational issues need to be addressed at multiple levels related to (i) farmer knowledge on the use and economics of DA technologies, data management, and emerging technology applications, (ii) training of professional service providers and educators, and (iii) undergraduate and graduate training for the next generation professionals at universities and colleges.

For research, opportunities and concerns center around (i) farm data availability for analytics, (ii) an inadequate researcher corps at universities in promising areas of DA, (iii) opportunities for highly innovative research initiatives and the development of new management recommendations, while current research cycles are long and slow in the context of rapidly-evolving technologies, and (iv) better partnerships between the research-extension community and private sector agriculture and technology companies.

Recommendations for Digital Agriculture in New York

By seizing opportunities and overcoming barriers, New York's technology companies, farmers and public institutions can help lead its agricultural industry into the digital age, while foregoing these opportunities will negatively impact the industry's national and global competitiveness. Given that agriculture forms the backbone of the Upstate economy and employment profile, the state should leverage Digital Agriculture technologies through significant investments, specifically in the following:

Connectivity

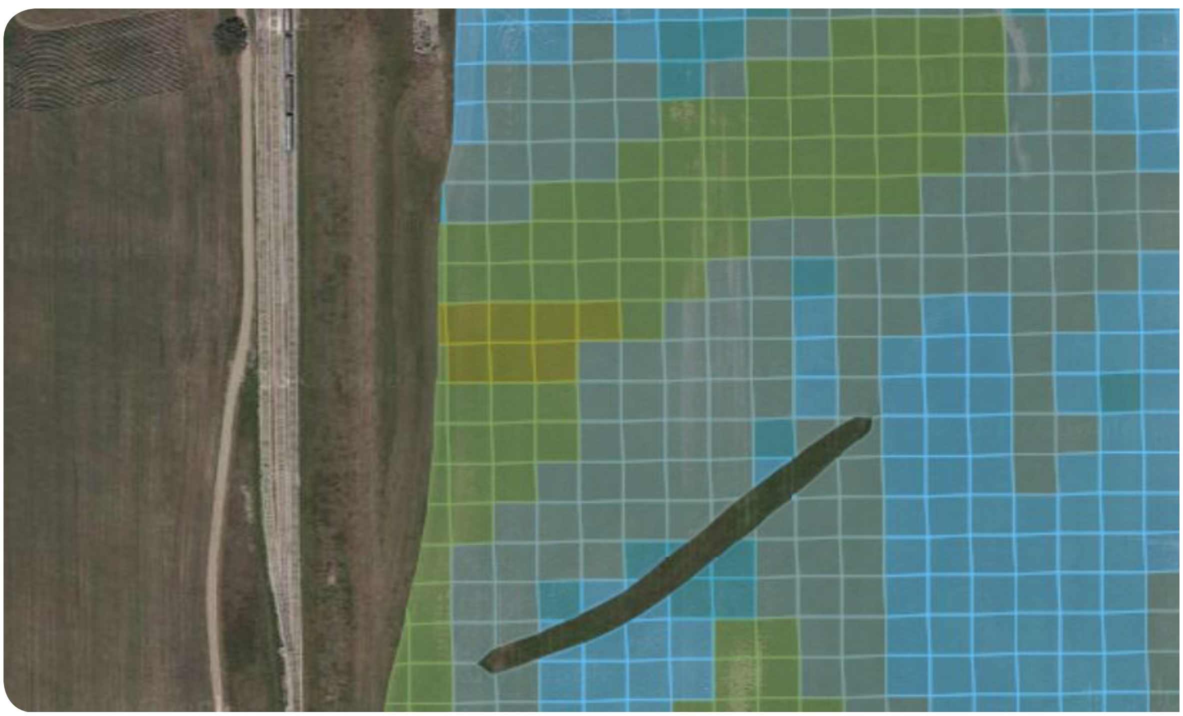
- Expand broadband access to all rural areas in the state. We acknowledge that this effort is already underway with the New York Broadband program; currently 25% of all crop acres in the state fall in Census Blocks deemed to be underserved or unserved. Phase II of the NYS Broadband Program proposes virtually 100% coverage (100 Mbps) by 2018.
- Promote the expansion of next generation cellular technology in rural areas to connect mobile farm equipment with the internet, and enable high levels of data acquisition and transfer.
- Explore opportunities offered by low-cost LPWAN networks to facilitate the Internet of Things (multiple farm tools and sensors having internet connectivity).

Data, Education and Research

- Establish an **Institute for Digital Agriculture** (IDA) at Cornell University focused on research, education, data management, and business development. It would enhance the recently developed DA initiative at the University, serve as a focal point for DA activities, attract talented researchers and educators, facilitate robust and innovative research efforts, and collaborate with New York-based agricultural and technology enterprises, leading to employment and workforce development.
- Establish within IDA a public-sector data center infrastructure that allows for the secure collection, curation, and analysis of data from New York farms, with appropriate consent, privacy and security considerations. The data will be stored for farmer use and benefit and also become available for aggregate and anonymized analytics and the development of a new generation of management recommendations. IDA should also support and engage with initiatives that address concerns about data privacy, security, and ownership for New York agricultural data.
- Within IDA, allocate funding to support highly-innovative research efforts in Digital Agriculture, while also enhancing on-farm research through existing programs (NYFVI, IPM, etc).
- Develop an educational program within IDA working with agribusinesses, consultants, Extension, and SUNY institutions to advance Digital Agriculture adoption in the state.
- Initiate a faculty hiring effort at Cornell University and SUNY agricultural and technology institutions to increase research, education and extension capacities in DA. This would build a cadre of specialists with high skill levels in data analytics and precision technologies in different agricultural disciplines who could effectively engage with other technology disciplines, notably engineering and computer science.
- Consider guidelines that proactively addresses privacy, availability, regulatory and equity issues around agricultural data.
- Link research and education with entrepreneurship and venture development programs at the university and state level.

Part I

Introduction to Digital Agriculture



Definitions

Like other economic activities, agriculture is increasingly affected by the digital revolution. **Digital Agriculture refers to the employment of computational and information technologies to improve the profitability and sustainability of agriculture.** It is a new direction for Precision Agriculture (PA), a more established concept that is broadly defined as "the use of advanced technologies to precisely match agricultural inputs with needs", which has primarily been aimed at crop production. Digital Agriculture (DA) offers new opportunities through the ubiquitous availability of highly interconnected and data-intensive computational technologies as part of the so-called Fourth Industrial Revolution, which is characterized by "a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres" (Dr. Klaus Schwab at the 2016 World Economic Forum).

Table 1. Enabling Technologies for Digital Agriculture

Type of Technology
Cross-Cutting
- Computational Decision Tools and Data
- The Cloud
- Sensors
- Digital Communication Tools
Field
- Geo-locationing (GPS, DGPS, RTK)
- Communications (Cellular, Broadband, LPWAN)
- Geographic Information Systems (GIS)
- Yield Monitors
- Precision Soil Sampling
- Sensing (Proximal and Remote)
- UAVs/UASs
- Auto-steering and Guidance
- Variable Rate Technology
- On-board Computers
Livestock-Focused
- Radio Frequency Identification (RFID)
- Automatic Milking and Feeding Systems
- Livestock Software Models

Digital Agriculture applies to all crop and livestock systems, and reflects a shift from generalized management of farm resources towards highly optimized, individualized, real-time, hyperconnected and data-driven management. The desired outcomes of leveraging Digital Agriculture are more profitable and sustainable production systems.

PA concepts were developed in the 1990's and initially referred to the application of technologies that allowed for site-specific (spatial) management in a field-scale crop production context (Table 1). Other generic definitions refer to PA as "that kind of agriculture that increases the number of (correct) decisions per unit area of land per unit time with associated net benefits" (McBratney et al., 2005), and "the application of geospatial techniques and sensors to identify variations within a field and the solution to smooth the difference using diverse strategies" (Zhang and Kovacs, 2012). Such definitions focused mostly on spatial management in crop production environments, while the concept of **Digital Agriculture** is a next step with large-scale integration of digital technologies, analytics, and communication into a broad range of agricultural activities.

The precision agriculture era was ushered in with the advent of some key technologies. Global Positioning Systems (GPS) made it possible for agricultural innovators to develop methods to geo-reference spatially variable field conditions. Geographic Information Systems (GIS) allowed for the management of georeferenced field data for the purpose of analyzing them and making site- specific management decisions. Real breakthroughs came when yield monitors and variable-rate applicator equipment for fertilizer were developed. Since those early years, PA hardware, software, and associated technologies have blossomed and led to innovations such as sub-inch (centimeter) accuracy tractor auto-steering, sensor based variable rate input application, field equipment connected to the Cloud and highly computational decision tools.

Although precision agriculture origins are based with field crop production, most other agricultural sectors are also benefiting from new technologies. In the case of livestock and dairy management, electronic identifiers are commonly used (mandatory in some countries) to enable better control and information on individual animal productivity and to trace back possible disease spreads. In dairy, milking robots reduce the need for unskilled labor, and can also conduct milk analysis in real-time which generates valuable information on productivity and health. Other applications involve motion detectors (pedometers) as well as rumination monitors. Precision feeding systems for swine and dairy cattle can aid in the formulation and evaluation of feeding programs with more accuracy and efficiency. Stable monitoring systems--which use cameras, microphones and even sensors for temperature and humidity—are likewise useful agricultural informatics tools. In horticulture and viticulture, precision auto-steer and variable rate technologies (VRT) are becoming more common along with the use of UAV's/UASs for high-resolution remote sensing that allows for tree/vine-specific management. Controlled-environment production systems (greenhouses, hydroponics, etc.) are also rapidly expanding, and modern systems often use digital sensing and control systems to optimize the growing environment and reduce labor needs.

DA also facilitates management on large and small-scale operations that focus on high-value products (e.g., wine, fruit, local meat) where product quality can be optimized through intensive monitoring of production units. DA has allowed for increased production efficiencies, but benefits are variable across the industry. This is in part the result of poor employment of the data for management decisions due to inadequate data analytics and communication which often leaves farmers unable to fully capitalize on the DA/PA technologies.

Data in Agriculture

Data use in agriculture can often be divided into four processes:

1. data creation
2. data analysis
3. management decisions
4. implementation.

For crop production, data creation examples include crop yield data from a combine harvester yield monitor, soil data from detailed soil sampling or sensors, or field imagery from aerial vehicles or satellites (Fig. 1). Data from various sources need to be transferable among different platforms in order to create layers of georeferenced data layers for the same field. This uniformity in data interoperability is a key factor for DA adoption and higher value-added.

The field data can then be analyzed by the producer directly or in conjunction with scientists or professional agronomists to make field recommendations. The transfer of field data may require equipment interconnectedness, and the Cloud is increasingly used for storage and transfer of farmer field data. Soil and weather data, for instance, can be employed to recommend appropriate varieties, and fertilizer and irrigation amounts for specific areas of a field at given times. Also, pesticide recommendations can be made from remote sensing imagery collected by UAVs, planes, or satellites. The value of the field data is optimized when all the data layers are available to the right parties.

Once field data are analyzed and specific recommendations on agricultural inputs have been made, a management strategy can be implemented to optimize inputs for different management zones. These may include, for example, variable fertilizer and pesticide application, use of different varieties, and variable rate seeding.

Variable-rate technologies with GPS enabled equipment are available that allow the farmers to implement these management strategies. Prescriptions typically involve transfer of data as digital maps to the application equipment, which then implements the precision recommendations. In some cases, like the use of canopy sensors for nitrogen application, the four-steps are integrated into an "on-the-go" process where these components are all implemented within a sub-second time scale.

Similar processes are used in animal-based systems where data from the field and barn are analyzed to make decisions on feed quality; feed storage and inventory control; ration formulation, mixing and delivery to animals' feed intake and refusals; production of meat, milk and manure and nutrients; culling; health interventions, etc.

In general, inadequate **data analytics** and **telematics** (the long-distance transfer of digital information) are constraining potential adoption and benefits of these technologies. Production efficiencies are likely gained from the integration of multiple data sources that are now mostly considered independently, and from the real-time transfer of data/information between field equipment, office (farmer or consultant), and the Cloud, although some vendors have come forward to fill some of these gaps.

Enabling Technologies for Digital Agriculture

For the purpose of this discussion, we consider three types of technologies that enable digital agriculture (Table 1, page 2): (i) Cross-cutting technologies that apply to all industry sectors, (ii) field-focused technologies that are primarily used in crop production, and (iii) animal-specific technologies.

Cross-Cutting Technologies

Computational Decision Tools and Data

An expanding range of models and apps on stationary and mobile computer platforms (data centers, desk and laptops, tablets and smartphones, and purpose-built devices) have come online in recent years to aid a wide range of decision making from field prescription maps, dynamic nutrient and feed recommendations, image-based analyses, animal and herd performance, report writing; maintaining and graphing information, etc. Data may be derived from the farm (e.g., crop yield, milk production, greenhouse temperature), or externally (e.g., weather, market prices). With some exceptions, there is currently a disparity between science-based data analytics and many of the online products offered on the market.

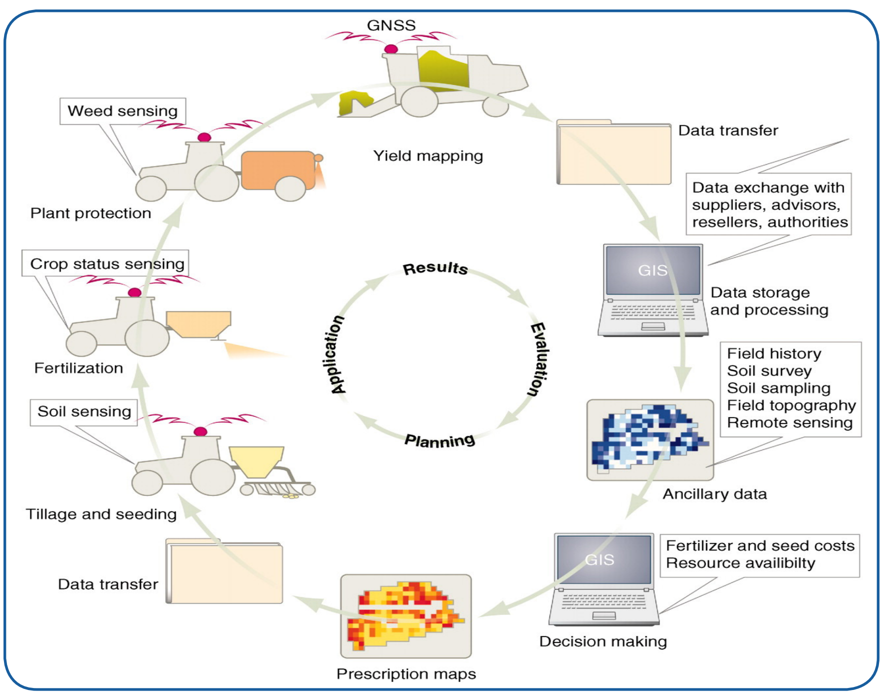


Figure 1. DA information flow in crop production (from Gebbers and Adamchuk, 2010).

The agricultural sector is following the lead of other industries and businesses by engaging the increased computing power in mobile phones, tablets, and other handheld devices (Fig. 2). While traditionally software has helped farmers streamline their business activities, the current trend is towards utilizing the vast amounts of data that are being generated, and integrating them with local weather data and other production parameters to make better decisions. New software helps meet this challenge. Many of the programs are portable, with components accessible through mobile apps on computers used in the cab of a tractor, barn, or greenhouse. Since farmers and consultants work mostly in the field, outside traditional office environments, they can benefit disproportionally from mobile computation and communication.

There are many types and varieties of precision farming and decision making software available for sale in the agricultural business market. Most offer a way for a farmer or consultant to organize and manage their farming data. This would include soil sample results, aerial imagery, planting information, input applications and yield results. The software can help make sense of the data, for example:

- discover yield influencers;
- reveal management and crop productivity zones;
- create recommendations based on soil information, harvest data, zone maps or previous input applications;
- interpret imagery from satellite, airplane or UAVs for data analysis and prescription maps;
- determine optimum individualized animal feeding, health interventions, and harvesting

The Cloud

'The Cloud' is a generic term that refers to the collection of large data centers that are connected by the internet, which allow for greater integration and analytics of data, and facilitates more secure data storage, and real-time communication. The Cloud is also a generic term referring to modern highly available, redundant, secure, reliable, and low cost commodity servers, and the general trend toward using the internet to store and process data (as opposed to local computing and storage). Cloud computing provides a framework for on-demand computing and storage resources, and can connect mobile and immobile equipment on farms, and can be scaled and parallelized without the need to maintain physical infrastructure. The Cloud therefore increasingly serves as a central processing point for all computational and data matters in Digital Agriculture.

Sensors

Sensors are devices that can continuously or intermittently measure the physical, chemical, or biological status of agricultural resources, including temperature, weight, chemical concentration, electromagnetic radiation (e.g., light intensity), water content, presence of objects, mass flow, movement, etc. They are becoming less expensive through mass production, and increasingly accessible through wireless communication. Sensors are often directly linked to control devices to optimize production environments including nitrogen application, irrigation, or barn/greenhouse fans.

Figure 2. Mobile devices like tablets allow for in-field data access.

Communication

Cellular/Mobile Broadband: A dependable strong cellular (mobile) connection is necessary for many DA technologies, notably in field environments. This would include many of the technologies like auto-steer and precision/input application that rely on RTK (page 7), and in turn rely on internet data transfer via a cellular connection. Cell service is dependent on the network of cell towers throughout the state which is maintained by private communication companies. Each has their own network, and state coverage varies depending by network. Cell communication is also the primary mode for information transfer to field-based workers to receive updates and communicate with managers or central data sources (Fig. 3). Cellular availability is discussed in Part III of this report.

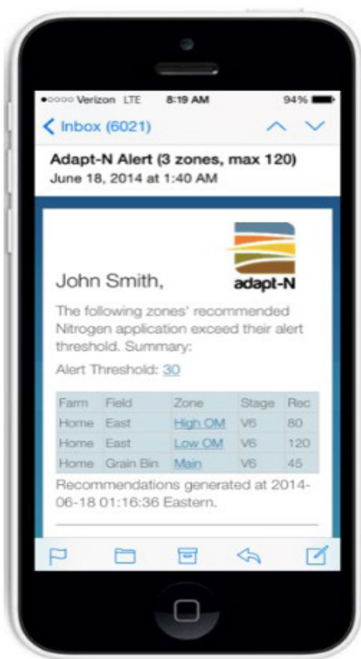


Figure 3. Nitrogen recommendation report on a mobile device.

Broadband (High Speed Internet). Digital agriculture produces a large amount of data that needs to be shared, transferred, uploaded, and downloaded from and between many locations. One example is aerial imagery that is downloaded from the provider to a consultant and analyzed, or a variable rate prescription that is uploaded to the Cloud to be downloaded by the farmer or custom applicator. In this case, a combination of mobile internet and wired internet may be used. Broadband is available from private providers typically via cable, phone line, or satellite dish. The definition of broadband was updated in 2015 by the Federal Communications Commission (FCC) to include speeds of at least 25 megabits per second (Mbps) for downloads and 3 Mbps for uploads (Federal Communications Commission, 2015). Speeds less than this can be very limiting for the efficient use and adoption of DA, and connectivity has been found to be a barrier to the full utilization of current precision agriculture technologies (Mark and Griffin, 2016). Current 4G cellular only allows download speeds of 10 Mbps and upload speeds of 2-5 Mbps (and is more expensive), meaning wired connections with higher speeds are likely necessary for certain applications. Yield and image data specifically may require higher speeds. It is noted that most precision agriculture data that are created on the farm typically need to be uploaded to the Cloud, rather than downloaded, and upload speeds are usually substantially slower than download speeds (Shearer, 2014). Broadband availability in New York is discussed in Part III of this report.

Low Power Wide Area Networks (LPWAN) show great promise for agriculture in certain applications. LPWAN (such as LoRa®) does not allow for high speed data transfer, like Cellular, WiFi or Bluetooth, but may be beneficial in applications where latency of data transfer in not an issue. This technology also has a much longer range capability compared to WiFi or Bluetooth, and a single gateway or base station can cover up to hundreds of square miles. "LPWAN offers multi-year battery lifetime and is designed for sensors and applications that need to send small amounts of data over long distances a few times per hour from varying environments" (Technical Marketing Workgroup 1.0. 2015). Emerging uses in agriculture include livestock, soil and crop monitoring in real time. For example, a wireless bolus can be placed in a cow that communicates via Bluetooth with an ear-tag, which is then communicated through a LPWAN to transmit the heath measurements of the cow. Similarly, crops can be monitored with sensors for soil moisture and nutrient levels that can communicate with an access point 10-50 miles away (http://www.link-labs.com/iot-agriculture/).

Field Technologies

Geo-locationing

Global Positioning System (GPS) is a "U.S.-owned utility that provides users with positioning, navigation, and timing (PNT) services." (http://www.gps.gov/systems/gps/). This network of satellites is maintained and operated by the US Air Force. Use of GPS is free and publicly available. Originally intended for military applications by the US Department of Defense, it was made available for civilian use in the 1980s. As a pivotal technology for precision agriculture, standard GPS provides location information within a field with accuracy of about 10 feet. Technologies that rely on GPS need a receiver to utilize GPS-enabled devices. It allows for mapping of spatial variability of yield using yield monitors, moisture levels, etc., on a given field with sufficient accuracy to identify the general spatial profile of the field, and facilitate input optimization. Standard GPS is not necessarily sufficiently accurate for precision placement, auto-steer, or guidance technologies (see below).

Global Navigation Satellite System (GNSS) refers to all the satellite positioning systems, not just GPS. Tractor-mounted satellite receivers commonly are able to utilize other satellite systems including GLONASS (Russia), Galileo (EU), and Compass (China).

GPS Differential Correction refers to (usually private) subscription-based satellite correction services that allow for improved accuracy. These utilize a network of GNSS (including GPS) reference stations around the world to compute GNSS satellite orbit and clock corrections. The corrections are broadcast via geostationary satellites, typically with no dependence on a cellular network, base station, or RTK network, although in some cases the correction can be received over the internet via a cellular connection. GPS corrections can be as accurate as 1-2 inches and are acceptable for most PA applications requiring a high degree of accuracy.

Real Time Kinematic Technology (RTK) enhances the accuracy of GPS to the sub-inch level. RTK relies on a base station on the farm, third-party based stations like the national CORS system, or privately owned networks. A private subscription may be needed and each tractor requires a receiver to communicate with the base station, either by radio antennae (repeaters may be necessary) or over the internet via cellular service. Activities like auto-steer and guided precision planting, cultivating, controlled traffic, spraying, land leveling, and strip tillage require this level of accuracy to be effective.

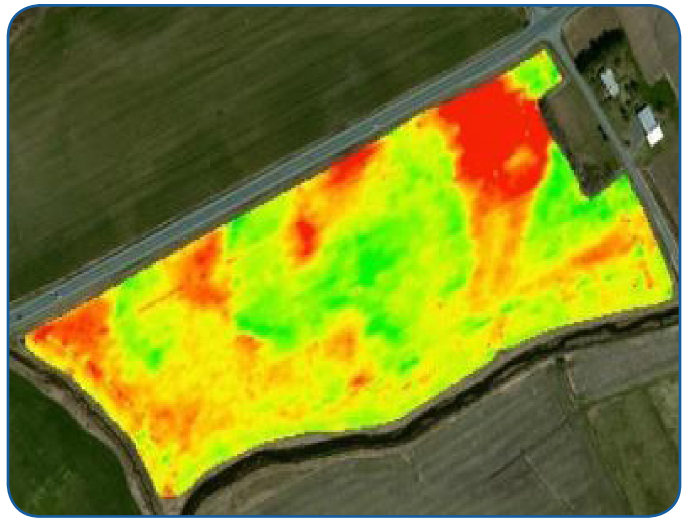


Figure 4. Example of a corn yield map.

Geographical Information Systems (GIS)

GIS can capture, store, edit, manipulate and analyze various types of spatial or geographical information. GIS can be applied to digital/precision agriculture to display site-specific information within a field and help make management prescriptions such as fertilizer usage and crop protection. GIS can incorporate, process and display digital information from other DA technologies like remote sensing images, soil and yield maps, etc. (Lou et al., 2013; Ryu et al., 2011). Although different formats are possible, in DA these are generally displayed as rasters, or pixel values. Due to specialized functionality needs, GIS use in agriculture typically involves industry-tailored software (e.g., SST, Agrian, Mapshots, etc.) rather than generic platforms like ArcGIS or open-source QGIS. In recent years, GIS technology has incrementally moved towards integrated Cloud-based platforms that facilitate direct links with other software through Application Programming Interfaces (APIs). For example, crop nitrogen decision tools have been integrated into GIS platforms while maintaining independent operability.

Yield Monitoring

Crop yield monitors are devices that can electronically record crop yield during short time intervals as the harvester operates. It involves sensors that measure biomass flow or weight that are connected to an on-board computer. Yield monitors were initially developed for grain harvesting, but have recently also been developed for forage and horticultural crops. They are best coupled with a GPS system to record yield with other spatial information within a field. Resulting yield maps can be displayed and used in GIS systems or farm data management software (Fig. 4). Yield maps help farmers quantify crop performance and identify low and high performing areas of fields, which can be used for future management decisions. For example, low yields in certain sections can help identify soil fertility, drainage or compaction problems, and profitability maps can be generated to identify loss-making field areas. In general, high-resolution yield data are widely available due to the standardization of yield monitors on modern harvesters, but the data are often not effectively analyzed.

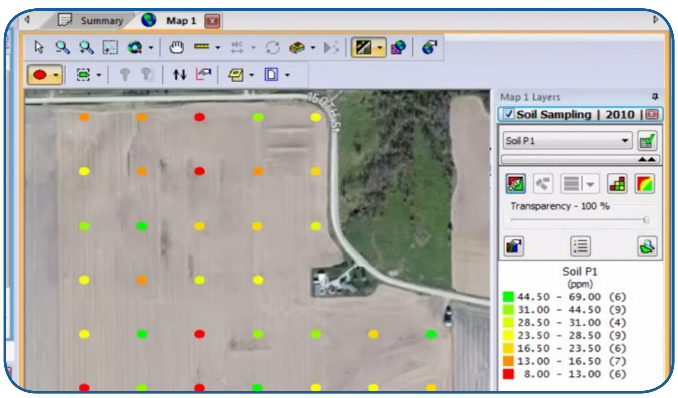


Figure 5. Example of grid-based soil sampling in a field and the distribution of a nutrient level.

Precision Soil Sampling

Grid soil sampling involves testing and analysis of soil samples from several locations in a field to determine the presence of crop nutrients, PH, and other relevant soil characteristics. A traditional soil sampling scheme may use one or two samples per field, while for precision agriculture the grid sampling resolution may be down to every 1 to 2.5 acres, or based on yield zones, soil maps, or remote sensing patterns. Soil sampling results can be entered into GIS software to generate maps and prescriptions for variable rate input applications, especially fertilizer and lime (Fig. 5).

Figure 6. Proximal sensing equipment that continuously measures electrical conductivity, reflectance spectroscopy and soil pH.

Proximal Sensing

Proximal sensing uses instruments operating close to, or in contact with, soil or plant material (Bramley, 2009; Bramley and Trengove, 2013), while concurrently recording GPS data. Many different types of proximal sensors are available that can suit a wide range of techniques to monitor soil and plant properties. Among them, are Electromagnetic Induction (EMI), apparent electrical conductivity (ECa), and visible near-infrared reflectance spectroscopy (VNIRS; Fig. 6). They can be used as surrogate measurements to infer other soil properties and their spatial distribution in an agricultural field, notably clay and organic matter, and soil moisture content in deep layers. Proximal sensing equipment does not generate images (like digital cameras), but when used with GPS can generate raster maps (Fig. 7).

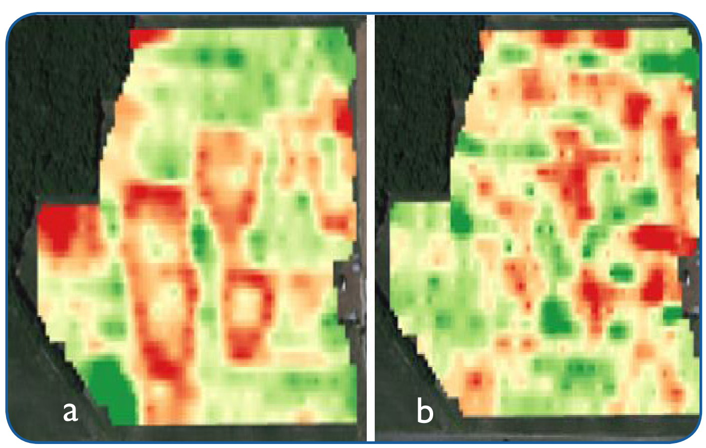


Figure 7. Example of maps of apparent electrical conductivity for 0-18 inches depth (a), and 950 nm (NIR) reflectance at 4 inches depth (b).

Figure 8. Proximal canopy sensors used with on-the-go variable nitrogen application. *Source: cornandsoybeandigest.com*.

Proximal crop sensing typically involves the measurement of light reflectance from crop canopies (Visible-NIR) to determine the health of a crop (Fig. 8) using either passive or active (with light source) sensing. Using ratios of light reflectance at certain wavelengths allows for the estimation of indices (e.g., normalized difference vegetation index, or NDVI) that estimate crop biomass or nitrogen status; this information can be used in on-the-go systems that control in-season nitrogen or herbicide application.

Remote Sensing

Remote sensing is a technology based on the interaction of electromagnetic radiation with soil and plant material. Unlike proximal sensors, this involves the use of advanced digital cameras that generate images involving numerous pixels. Remote sensing devices can be classified by the platform of the sensor, including satellite, standard aircraft, and unmanned aerial vehicles/systems (UAV's, UAS's; discussed separately). Applications of remote sensing in agriculture usually focus on identifying and collecting images from either bare soil (providing patterns of soil moisture, organic matter content, etc.) or from crop canopies (estimating crop health/biomass, nutrient deficiencies, pest or weather damage, crop management errors, etc.) using reflectance information in the visible and near-infrared bands (Fig. 9).

Satellite remote sensing information is continuously collected and typically sold through wholesalers to farmers and consultants. Primarily, remotely sensed data are challenged with both the timeliness of the data and the variable atmospheric conditions that interfere with measurement (especially on cloudy days). Aircraft and UAV imaging is typically done on-demand or by subscription by a service provider. Mulla (2013) reviewed the application of remote sensing in precision agriculture in the past twenty-five years and pointed out some key advances and remaining knowledge gaps.

The *spatial* resolution of images is dependent on the observation platform and impacts the level of detailed information that can identify physical traits in crops such as size, relative distance, proximity patterns, height, width and diameter of plants (Fig. 10). In agriculture, the spatial resolution impacts the utility of the images depending on the level of spatial management intensity. For example, grape vines and fruit trees may be managed individually, while field crop plants are typically managed in zones, not as single plants.

The *spectral* resolution of remote sensing images affects the quality of the information and thereby its utility to the user. Typical VNIRs images from satellite or aircraft involve 3-to-6 bands (wavelengths), which allow for identification of general crop health and field patterns (esp, with NDVI). Each spectral region provides unique information about the plant.

Figure 9. False-color images (red indicates healthy vegetation) from satellite (a) and aircraft (b) platforms, showing different levels of resolution..

For example, reflectance at visible wavelengths (RGB) provides information on leaf pigmentation while reflectance at the infrared wavelength is indicative of the physiological conditions of the plant (Huang et al., 2007). Although the spectral signatures can also detect the color of leaves (related to nutrient concentrations), disease patterns, and moisture levels, the development of precise prescription maps remains somewhat challenging due to the effects of variable light and atmospheric conditions.

New developments in commercial remote sensing include *hyperspectral* imaging, where reflectance data are collected from up to 2000 wavelength bands (e.g., Corning Inc's SHARK platform). This higher spectral resolution promises images that contain reflectance patterns associated with a larger number of soil or plant-related properties. For example, Bravo et al. (2003) investigated the application of visible-NIR hyperspectral imaging for the early detection of yellow rust disease in winter wheat.

Unmanned Aerial Vehicles (UAV)

Unmanned Aerial Vehicles (UAV, commonly referred to as drones) are small aircraft flown without an onboard pilot. They can be remote controlled from the ground, or autonomously controlled by onboard computers with a pre-planned or algorithmically determined flight path. UAVs were initially developed for defense applications, but recently have begun to serve more commercial applications such as agriculture, filmmaking, and construction. The Association of Unmanned Vehicle Systems International (AUSVI) estimates that in the United States, by the year 2025, the number of UAV units sold will be about 160,000, that the use of UAVs will have an economic impact of $82 billion, and that they will create about 100,000 jobs. Some predict that the agricultural sector will be one of the biggest benefactors (Jenkins and Vasigh, 2013).

There are two kinds of commercial UAVs available in the market - fixed-wing (small aircraft) and rotary wing (small helicopters). Rotary-wing UAVs are highly manoeuvrable and can stay in flight for a shorter period of time (typically less than 0.5 hours). They are therefore more conducive to smaller fields or spot-specific areas. The fixed-wing UAVs are designed for longer flight and are better suitable for mapping larger areas, including multiple fields.

UAVs are not necessarily a technological breakthrough for agriculture, as they basically provide the same information as satellite and aircraft images, but their lower cost, and low-altitude, higher resolution images allow for greater utility, and real-time management.

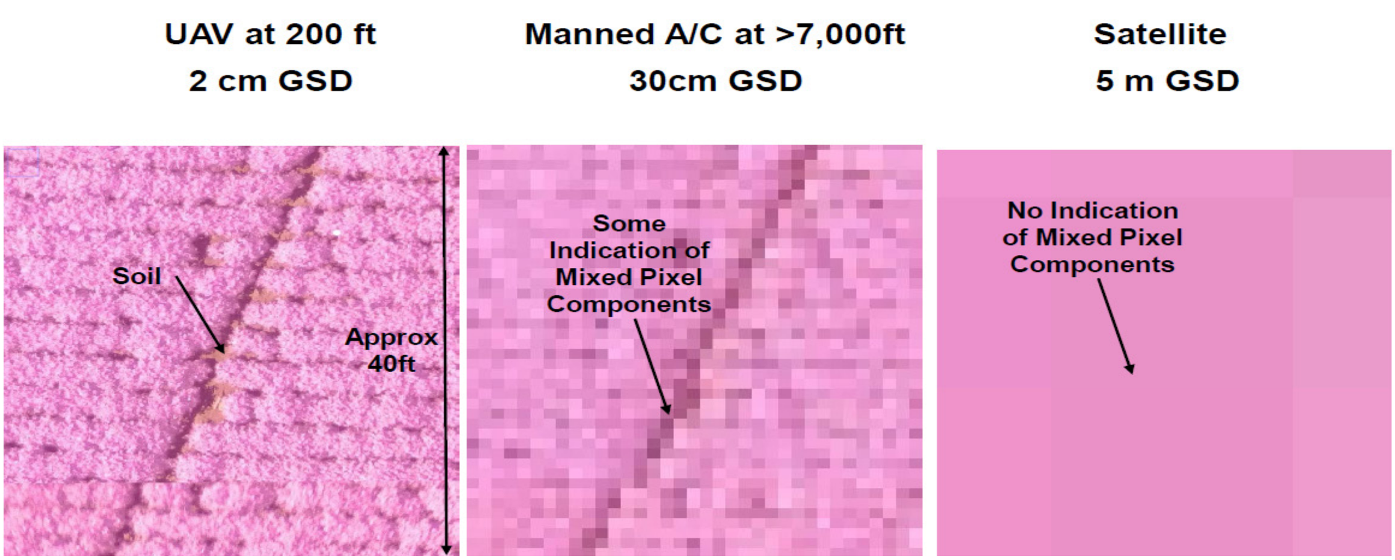


Figure 10. Spatial resolution associated with different remote sensing platforms.

UAVs are suitable for field scouting, mapping and (bulk)-or spot spraying. For example, UAVs are being used in research to detect diseases in citrus and avocado in Florida (Aldrich, 2016). UAVs can be used in spot-spraying as well, although they have limited carrying capacity.

UAVs low-altitude and high resolution photography of an individual plant eliminates the 'de-mixing problem' with satellites or high-altitude aircraft imagery, where colors of crops, weeds and soils (which have different light reflectance properties) need to be separated from a single pixel. The livestock industry is also benefitting from UAVs, where they can be used to monitor stock at night, look for animals in trouble and check water levels on the farm.

Currently, there are several companies that offer UAV services for farming, including HoneyComb, Agribotix, AgEagle Aerial Systems, Hoverfly, Best Farming Drones, among others. Most UAVs have limited flight time. For example, the Enduro UAV has 25 minutes of flight time and can cover 160 acres of land, while AgEagle RAPID can run 40 minutes and cover 180 acres.

Use of UAV's for commercial purposes is governed by FAA regulations. Federal, state, and local regulations are likely to continue to evolve as UAV's become more prevalent due to new uses and lower cost. Recent changes in the regulations as reflected in part 107 require the following (Penhorwood, 2016; www.faa.gov/uas):

- UAV's must weigh less than 55 pounds, fly no more than 100 miles per hour and stay within 400 feet of the ground.
- They must remain in sight of the operator, and flights must be during daylight hours.
- The operator must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate.
- The UAV cannot fly over people that are not participating in the UAV flight

While these most recent regulations have fewer restrictions than previous ones, requirements such as keeping the UAV in line of sight make using them in agriculture difficult in large fields, or in variable terrain, and prevents remote dispatching. Waivers to some of the restrictions may be available and may make the use of UAV's in agriculture less restrictive.

Figure 11. Prototype field robot. *Source:* *rowbot.com*.

Auto-Steering and Guidance

Auto-steering relies on high-precision GPS technology to self-drive agricultural equipment with high degrees of precision, while reducing operator fatigue and providing the ability to work in low light or nighttime conditions. RTK or high-level GPS differential correction is needed so that accuracy is in the 1-2 inch range (Brown, 2013). At the end of each row the operator turns the tractor around and then auto steer is re-enabled relative to the last pass, eliminating variation between rows. A digital record is created showing exactly where the crop rows are planted so subsequent field operations like spraying, fertilizing, or weed cultivation can follow the same route. Auto-steering also reduces operator fatigue.

This technology is also generating new advancements in self-driving field equipment, including small and large robots that can be employed at any time for any duration. For example, small autonomous tractors and sprayers are being developed to precision-apply crop inputs with the use of sensors (Fig. 11).

Section Control

Section (or point-row, or swath) control is available on implements that apply inputs like seed, fertilizer, or pesticides. A GPS map of the field is loaded into the planter software and

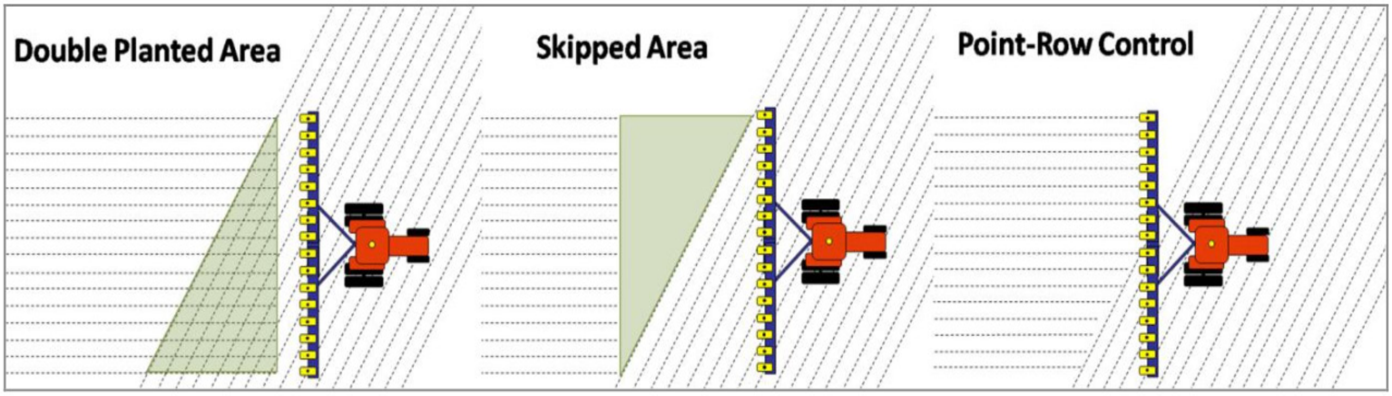


Figure 12. Section control can improve input efficiencies by reducing overlap. *Source:* farmershotline.com.

automatic row shutoffs are done when intersecting an already-planted row or when planting a field section that is not square (Fig. 12). The planting file can then be used in conjunction with a GPS enabled sprayer or fertilizer implement so the input is put exactly where it is intended (especially useful for banding). Like the planter, the sprayer automatically turns off parts of a boom or individual nozzles before they overlap already-applied areas (Hopkins, 2015). This can translate into significant savings in input use and unnecessary application of chemicals, especially on irregularly shaped fields.

Variable Rate Technology (VRT)

Variable rate technology/application (VRT or VRA) refers to the application of crop inputs specific to locations or zones in a field, as opposed to uniform amounts (Andrade-Sanchez and Heun, 2010). Mostly, this involves different rates of fertilizer or lime, but can also involve seed or pesticides. VRT is divided into two types, map-based and sensor-based, depending on whether the usage of a material is decided before or during the application (on-the-go). The former method requires a GPS device while the latter is done instantaneously based on sensor data, without a GPS receiver (although it may be used to develop an as-applied map).

Map-based VRT adjusts the material rate based on a "prescription" map developed from previous field based data collection including soil sampling or sensors, foliage testing, yield data, remote sensing, or model simulation results (Fig. 13). Sensor-based VRT requires no map or positioning system (Fig. 8). A crop characteristic is continuously collected by the sensors (see Proximal Sensors, page 8), a control system calculates the input rate, and the data are transferred to the controller which delivers the optimal level of input to the right location, typically within less than a second.

VRT, in principle, helps farmers increase return on investment (ROI) by applying the optimal amount of inputs to specific locations, and focusing inputs to zones that have most profitable economic value. Redundant application is avoidable, and high-performing zones can create more profit compared to low profitable zones when the same amount of material is applied.

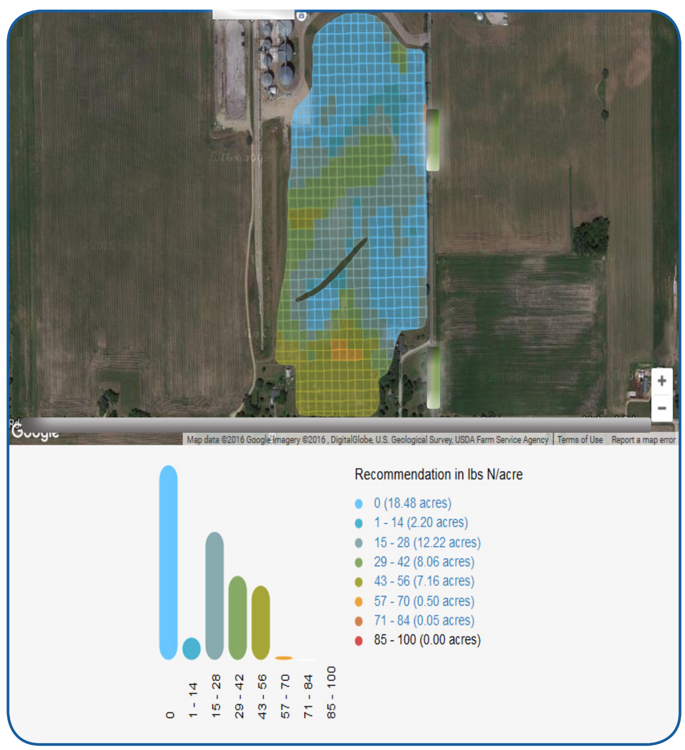


Figure 13. Variable rate nitrogen application prescription map (courtesy of Adapt-N).

On-Board Computers and Navigation

In addition to controlling seeding and fertilizer application, onboard computers also help in route planning, vehicle control, navigation and obstacle detection, all taking place in real-time. *Path planning* adapts in real-time as the harvest combine moves, and relies on the navigation system identifying the grain cart's position, orientation and velocity. When tandem-driving with the combine for off-load, it also relies on high-speed communications between the vehicles to exchange position information. The path planner must continuously consider vehicle position and the drivable area map, as well as the vehicle's physical capabilities. Vehicle control also takes place in real-time, ensuring that the vehicle follows the planned path. Onboard computers synchronize throttle, brake and steering to achieve the desired/planned path.

Livestock-Focused Technologies

Radio Frequency Identification (RFID)

RFID's tags are commonly used for tracking cattle, small ruminants, and swine (MSU, 2007). The ID's allow for identification and individualized management of animals, even though they may be part of a herd. An ear tag embedded with a microchips can be read by a handheld or hard-mounted reader to identify the individual animal (Fig. 14). They can monitor animals, including weight and temperature, and can be used in conjunction with a sorting facility to separate animals into different feeding groups, or to identify animals that are ready for slaughter. RFID's are also a necessary component of precision feeding systems and robotic milking.

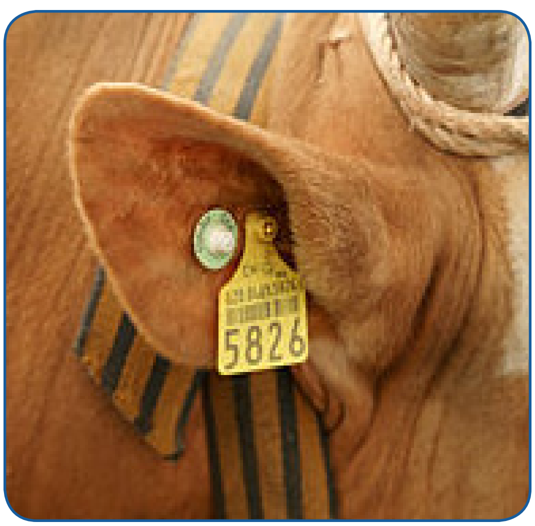


Figure 14. Ear tag with RFID technology.
Source: Wikipedia.

Figure 15. Automated (robotic) milking system.
Source: modernfarmer.com

Automated Milking Systems

Automated milking systems (AMS, also called robotic milking, Fig. 15) allow cows to be milked by a robotic unit rather than a human worker. They can be used in a traditional batch milking system or voluntary system where the cow goes to the AMS when she wants to be milked. Each cow is equipped with an RFID that is scanned by the robotic milker. The system typically cleans the udder, milks, and disinfects. Specifications of systems vary, but may also detect heat, health problems (mastitis and ketosis), and even photograph body condition. Exhaustive data are kept for each cow, including milk production, allowing a farmer to make better management decisions tailored to individual cows. Due to its multiple benefits (labor savings and individualized cow management), robotic milking systems are expected to see rapid adoption in the next years.

Electronic Feeding Systems

Electronic feeding systems individually manage an animal's feeding needs and measure body conditions. It can automatically mark the animal that needs breeding (or culling) and separate it from the herd. (http://bit.ly/2d6n0ue).

As with AMS, the system relies on an RFID ear tag. Extensive data collection and analysis can lead to better management. The RFID tag is read each time the animal enters the feeding area. For each individual, the feeder gives it an amount of feed based on whether it has already eaten and how much feed the individual animal is supposed to receive. Daily feed amounts are pre-programmed for each animal based on its body condition and point in gestation. There are also "feeding robots" that can automatically mix the feed and then deliver it to the animals.

Livestock Software Models

Livestock production software allows a farmer or consultant to manage an operation and make sense of collected data. Examples include report writing functions; maintaining and graphing information per animal, including test data and individual production curves, and aggregating and graphing by group or herd; tracking health features and treatments; producing vet lists and analyzing disease re-occurrences; interfacing with various testing services; analyzing reproductive data; etc.

Precision feeding models in dairy systems can evaluate diets and animal performance in different production situations, using science-based principles of rumen function, microbial growth, feed digestion and passage, and physiological state (Tylutki et al., 2007). By accounting for farm-specific animal, feed, and environmental characteristics, more accurate prediction of dietary nutrient requirements for maintenance, growth and milk production of cattle and nutrient excretion in diverse production situations is possible. Such software is used by both nutritional consultants and feed companies, and can help optimize use of farm-specific feeds, decrease the need for purchased supplements, optimize herd size, predict the manure nutrients that will have to be managed, and improve the annual return over feed cost.

Controlled-Environment Systems

Controlled environment production systems like greenhouses, controlled atmospheric storage, and indoor hydroponic systems deal with high-value crops and are well adapted to automation and digital technologies. Modern systems include sensor-based data acquisition and control systems that allow for continuous optimization of the growing environment, in some cases throughout the year.

Livestock Software Modeling

Agricultural Modeling and Training Systems (AMTS), L.L.C.

Caroline Rasmussen, Tom Tylutki and Vajesh Durbal lead AMTS (agmodelsystems.com), whose products are used across the entire U.S. and in 28 countries worldwide. AMTS is a global company based in Central New York, offering expertise and tools for ruminant (cattle, sheep, etc.) nutrition and management.

With a license from Cornell University, AMTS uses the Cornell Net Carbohydrate and Protein System module (CNCPS) that enables efficient use of feed inputs for better growth and production, and reduced environmental loss.

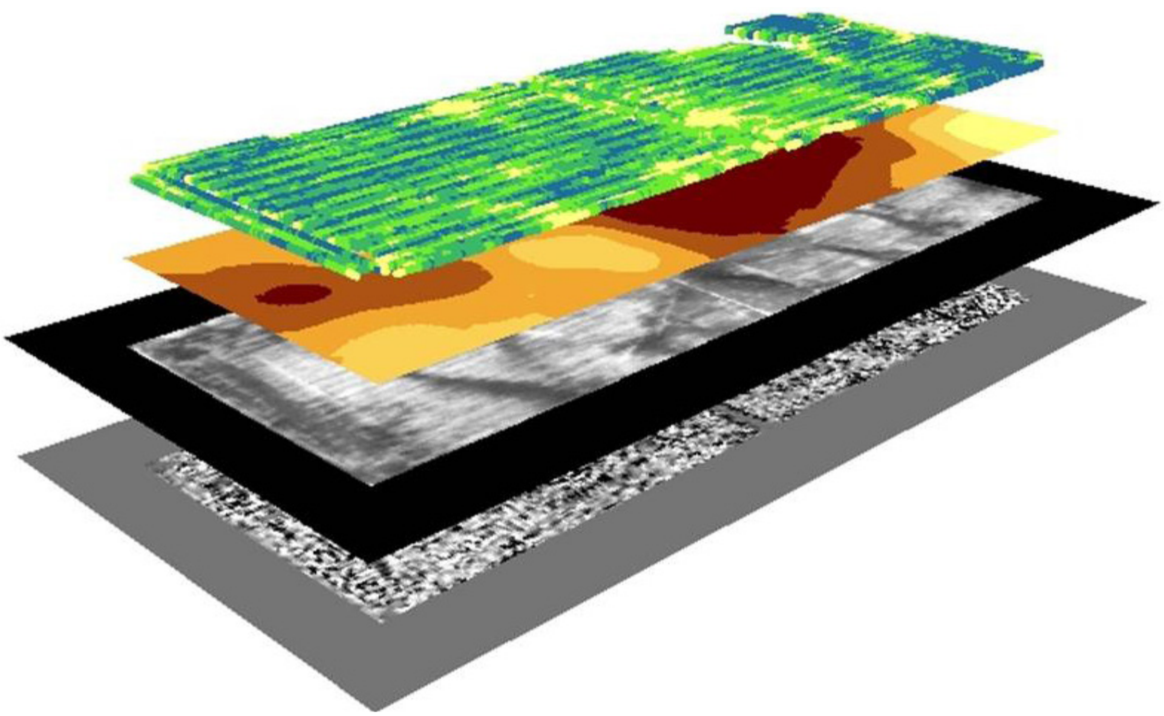
"If New York wants to make a big difference, small communities are a good place to start"

The sophisticated CNCPS model has been used to research and implement Precision Agriculture and is the standard for ruminant nutrition worldwide. More recently, AMTS has integrated cloud-based systems to deliver rations to robotic feeders. Data need to be shared between AMTS and the farmer, as well as directly with equipment like mixer wagons, making access to broadband indispensable.

With this technology, farms can be more responsive to ever-changing animal nutritional needs while minimizing waste and nutrient losses from over feeding.

Part II

Digital Agriculture Adoption:
Factors and Surveys



Digital Agriculture Adoption

Adoption Factors

The use of digital agriculture can provide benefits in four main areas: (i) increased production, (ii) reduced production costs, (iii) environmental gains, and (iv) improved employment.

Increased Production

DA has the ability to help farmers increase profitability through higher revenues, i.e. higher crop yield or quality, animal production, etc. Profitability may also be increased by altering investments away from unprofitable units (field zones, animals, etc.), as defined by DA-related data analysis. Schimmelpfennig and Ebel (2011) found that nationally corn and soybean yields were significantly higher for yield monitor adopters than for non-adopters and that they had lower per-acre fuel expenses. Those adopting GPS mapping and variable-rate fertilizing had higher yields and lower per-acre fuel expenses.

Based on New York studies, Cox et al. (2004) found that the purchase of a yield monitor is justified for farms over 200 acres even if solely used for hybrid selection. However, Katsvairo et al., (2003) and Magri et al. (2005) did not find yield benefits from site-specific placement of different corn hybrids on Central New York fields. Work on New York farms has also repeatedly shown limited potential for varying corn seeding rates (e.g., Cox and Sandsted, 2016).

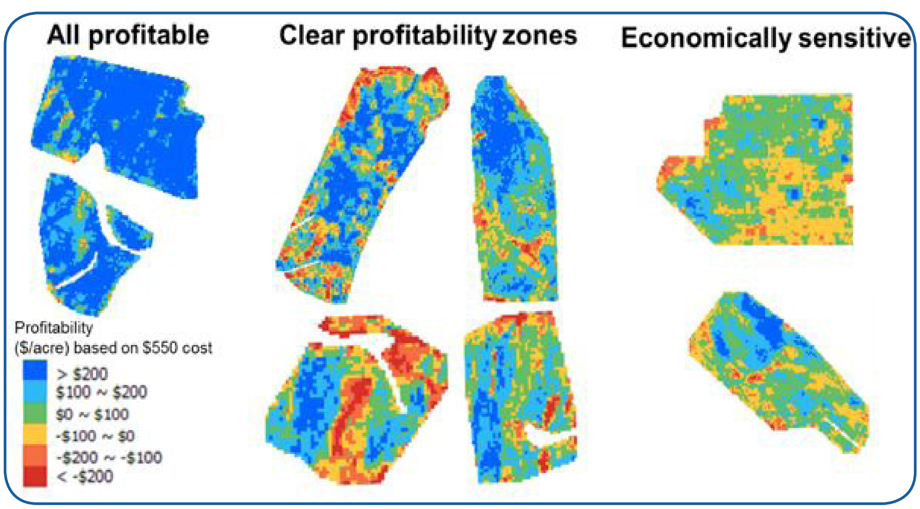


Figure 16. Maps of profitability zones (revenues-inputs) based on multi-year corn yield monitor data. Red and orange areas are not profitable and are better converted to alternate uses (Kinoshita, 2016).

Varying nitrogen rates on can be profitable by accounting for both seasonal weather effects and field variability (Sogbedji et al., 2001; Kahabka et al., 2004; van Es et al., 2005). Corn production profitability in New York was increased with the Adapt-N nitrogen management software, which incorporates real-time weather data (Sela et al., 2016). Magri et al. (2005) concluded that aerial VNIRS images correlated well with organic matter patterns in fields in Central New York, but not with soil fertility or pH patterns and were therefore of limited use for site-specific nutrient management. However, grid-based soil sampling was effective for establishing fertility zones and allowed for more efficient P, K, and lime management.

Kinoshita (2016) performed analyses on multi-year corn and soybean yield maps (Fig. 16) in Maryland and found three types of profit variability in fields: (i) all areas consistently profitable, (ii) clear and consistent profit zones (from highly profitable to highly-unprofitable), independent of prices, and (iii) zones with profitability that is highly dependent on input and grain prices. Especially in case (ii) overall field profitability could be enhanced by taking unprofitable zones out of production, e.g., by converting them to buffer strips.

Little information is available on a promising aspect of the adoption of DA: improved product quality and associated higher prices with specialty products. More individualized and timely management of high-value crops like grapes through sensing and computational technologies offers opportunities to better detect or predict disease incidence (e.g., the Cornell Late Blight decision tool: http://newa.cornell.edu/index.php?page=potato-late-blight-dss), optimize management of individual plants, target spraying and harvest schedules, etc. This offers the potential for higher quality products and associated price premiums, which is currently still largely un-researched from an economic perspective. Measurement of canopy density and light infiltration can also lead to better pruning decisions in wine grapes and apples, and more accurate spray application adjusted for canopy density.

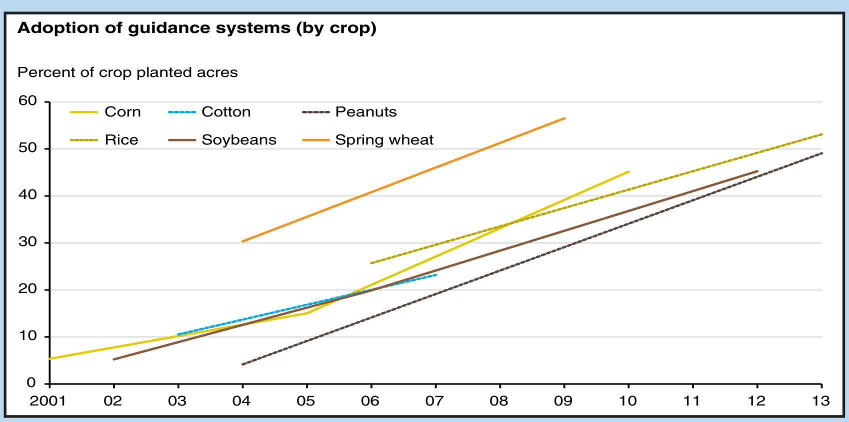
Reduced Production Costs

Digital agriculture technologies can also offer return on investment by reducing input costs. Variable-rate application can lower input costs as it reduces application of unnecessary fertilizer, lime, pesticides or other inputs that would have been used while applying inputs at uniform rates over the entire field. Several studies have found that the use of DA technologies have resulted in a reduction of inputs to a field resulting in greater economic benefit for the farmers. Tian et al. (1999) found a reduction of 42% in herbicide usage for corn in the US. Clay et al. (1998) also concluded that a reduction in herbicide usage provided savings of $33/ac for soybeans in South Dakota. Silva et al. (2011) collected regional survey data in Brazil in which 67% of companies that adopted PA technologies reported improved sugarcane quality, 78% reported higher yield, and 71% reported lower production costs. Sela et al. (2016) found from 5 years of on-farm trials in New York that profits from corn production can be improved by an average of $26/ac using the Adapt-N software, compared to conventional grower practice. Similarly, Sela et al. (2017) found higher profits of $35/ac from the use of this tool compared to a conventional N Calculator for corn production.

Other DA technologies may also provide clear production benefits. Section control results in savings in seed, fertilizer, and pesticides, especially with irregular field shapes. In an analysis of three differently-shaped fields, Schockley et al. (2012) determined an average reduction in overlap for fertilizer use of 9%, and planter and seed costs of 6%. Auto-steer and guidance technology can improve production efficiencies through optimization of plant spacing, precision placement of crop inputs, and reduced crop damage from common operator mistakes (e.g., accidentally driving over crops, or spilling grain from a combine harvester on the ground because the grain wagon is not properly aligned). In addition, auto-steer and guidance technologies can reduce operator fatigue and thereby enhance overall worker productivity, and also allow for workday extension into night hours. In fact, a recent USDA study found that GPS mapping had the largest estimated impact on profits of DA technologies, leading to increased operating profits of around 3% (Schimmelpfenning, 2016).

U.S. Adoption of Guidance Systems (by crop)

The USDA recently announced that about half of all planted acres for several major crops use guidance systems (see figure below). According to the USDA, "Guidance systems use global positioning systems (GPS) coordinates to automatically steer farm equipment like combines, tractors, and self-propelled sprayers. Guidance systems help reduce operator fatigue and pinpoint precise field locations, within a few inches. Freed from steering, operators can access timely coordinates from a screen, monitor other equipment systems more closely, and correct problems more quickly. Guidance systems also reduce costs by improving the precision of sprays and the seeding of field crop rows. Between 2010 and 2013, these systems were adopted on 45 to 55 percent of planted acres for several major crops, including rice, peanuts, and corn. Once adopted for a particular crop, the use of guidance systems tends to be rapidly adopted by other crop farmers. The ease-of-use and functionality of these systems has also increased along with adoption rates". This chart appears in the ERS report Farm Profits and Adoption of Precision Agriculture, released October 18, 2016.



Similarly, automation in animal agriculture, especially automated milking systems, can reduce labor needs on farms, which is often a challenge to managers. Other benefits are higher product consistency, increased milking frequency, perceived lower stress environment for animals (from elective milking and feeding), and more efficient herd management.

Reduced Environmental Impacts

DA technologies are not only associated with reductions in production cost and increased revenue, but often have significant environmental benefits. Bongiovanni and Lowenberg-DeBoer (2004) found that environmental benefits from precision application comes from more targeted and specified use of inputs so that farmers could cut excessive applications and reduce production losses due to various factors such as nutrient imbalances, weed escapes, insect damage, etc. Sela et al. (2016) found that, based on 5 years of on-farm trials using Adapt-N in New York, environmental nitrogen losses were reduced by 39% through the use of precision management software, compared to conventional grower practice. Similarly, Sela et al. (2017) found reductions in environmental losses from the use of Adapt-N compared to a static, conventional N Calculator for corn production. Regional survey data collected by Silva et al. (2011) found that 73% of farmers replied that precision agriculture helps minimize environmental impacts . Takacs et al. (2013) estimated that Hungarian precision agriculture users could reduce their environmental burden by 30%, depending on farm size and farming intensity, while increasing income due to the reduction in input costs.

Another opportunity comes from the reduction in pesticide usage by only applying chemicals where they are needed through the use of VRT. Thakur et al. (1998) concluded that such reduction from herbicides applications can help preserve water quality for corn and soybean growers in MN. Nordmeyer et al. (1997) examined data from German farmers and found that herbicide use decreased by 47-80% for cereal production in Germany, while Johnson et al. (1997) and Oriade et al. (1996) found a reduction in herbicide usage for corn, and soybean growers in the US and Denmark, respectively, lead to improved environmental outcomes for those who adopted VRT technologies. Insecticide usage could be decreased by 30-40% and as a result, insects became less resistant to insecticides (Midgarden et al., 1997; and Weisz et al., 1996).

Indirect Benefits

New knowledge: DA technologies can have indirect economic and environmental benefits by enhancing user learning and providing more actionable information on farms. For example, yield maps may show localized problems with field drainage or compaction that can be remediated. They may also be used to reallocate resources in a field or a farm based on crop profitability (Fig. 16, page 16). Farmers have been shown to improve nitrogen application timing after reviewing precision management software results that show high losses from untimely fertilizer or manure applications. On livestock farms, intensive individual animal monitoring and management can offer insights into overall herd management, field activities (feed sourcing, etc.) and capital investments. For example, by integrating milk culture analysis and historical treatment data into the DairyComp software, 60% reductions in mastitis treatments could be achieved (Steve Eicker, Valley Agricultural Software, pers. comm.).

On-farm research: Much of the equipment that facilitates efficiencies in farming also allows for on-farm experimentation. VRT technology, for example, allows entire fields to become experiments for fertilizer response, pesticide efficacy, seeding rate, or variety response by entering prescription maps of different product rates into applicators, and using yield monitors to measure yield response. Similarly, automated milking and feeding systems allow for experimentation that optimize animal management. This opens up new research paradigms that facilitate (i) more extensive experimentation and (ii) more farm-specific tailoring of management.

Climate change adaptation: The use of data-driven management is inherently more adaptive than conventional approaches, and thereby facilitates better adjustment to changes in the production environment. Notably, this enables the agricultural industry to better adapt to the impacts of climate change, to which it is disproportionately exposed. For example, weather-driven nitrogen software allows growers to seasonally adapt their fertilizer rates to account for weather conditions, and moreover, reduce the greenhouse gas impact of nitrous oxide that contributes to climate change dynamics. Similarly, animal management can be better adapted based on heat or cold stresses, crop insect pressure can be predicted with weather modules and automated greenhouse environments can allow for continuous optimization of growing conditions.

Local food: Enhanced growing conditions offer opportunities for more local food production and employment. Notably, automated controlled environment agriculture offers year-round fresh produce for retail and restaurants that can be sold at high price premiums (e.g., http://aerofarms.com/).

Record keeping: The use of DA technology and associated analytical and record keeping software can be used to meet local, state, and federal environmental regulations (see Part III).

Employment Opportunities

Increased adoption of Digital Agriculture offers favorable impacts on rural employment in New York, with different impacts on worker and professionally-skilled jobs in agriculture. We see three main areas of impact:

1. **Automation, self-guidance, and robotics** (esp. automated milking systems) reduce the need for low-skilled labor. Despite decreasing jobs this may be regarded as a positive outcome, because such occupations are generally difficult to fill and retain, and often necessitate the employment of migrant laborers who require special accommodations. Also, such automation reduces the stress on farmers by lowering fatigue (e.g., with auto-steer and guidance field equipment) or unfavorable working hours (e.g., early or late milking). This will make agriculture more attractive to the next-generation farmers and increase employment in high skill jobs.

Production Benefits

Torrey Farms

Travis Torrey is a 12th generation farmer on his local family farm based in Elba, NY. They farm over 12,000 acres across 5 counties in Western New York and control all aspects in the growing and selling of their produce, from seed to shelf (torreyfarms.com).

Torrey farms first started using auto-steer with RTK on their planters in 2006. Later, they experimented with variable rate seeding with their new system. By using auto-steer they have minimized driver fatigue from long days on the tractor. By using variable rate planting, they noticed savings from planting expensive onions seeds.

"The biggest issue we faced initially was connectivity"

Connectivity was an initial concern for the farm. Over time, however, software and data transfer has gotten faster. With the digital data they are concerned with transferring and sharing information without knowing who will have access to it and how it will be used. They are also still challenged with a lack of support to train their people and fix problems with software and data when they arise.

"Issues with technologies can't be fixed with a hammer"

2. **Attractive professional jobs** will be created in areas of data management, farm consulting, and technology support as farmers will increasingly outsource such work to skilled professionals. This will enhance job opportunities in rural New York, especially for recent college graduates. Jobs that utilize cutting edge technology are more likely to attract people to agriculture and keep the next generation of professionals engaged with the industry.

3. Employment opportunities will be generated when New York **builds a technology industry around agriculture.** This can range from start-ups that commercialize new technologies (e.g., Agronomic Technology Corporation, http://www.adapt-n.com/) to large established technology companies (e.g., Corning, Inc., https://www.corning.com/worldwide/en/products/advanced-optics/product-materials/spectral-sensing/hyperspectral-imaging-systems.html and IBM http://www.research.ibm.com/articles/precision_agriculture.shtml) that have recently shown a pivot towards agriculture. Also, controlled environment enterprises have been shown to enhance employment opportunities and business education in economically disadvantaged areas (e.g., repurposed industrial buildings http://aerofarms.com/our-farms/).

Questionable Benefits

Digital agriculture technologies promise great opportunities for improved production and sustainability, and the scientific literature often supports those benefits. However, some DA products are marketed that have not shown evidence of benefits, or have been overstated. There is often inadequate independent evaluation and the promised benefits often cannot be assumed for several reasons:

- **Unrealistic comparisons:** DA technologies may be advanced based on perfect implementation and unrealistic expectations of input data that do not represent real-farm scenarios, resulting in an overstatement of benefits. This includes problems with self-calibration: The research results may state benefits of the technology based on calibration in a specific testing environment (e.g., a research farm), when in many cases independent validation (different locations and years) is lacking and therefore the benefits are lower. A recent study in Pennsylvania (Schmidt et al., 2009), for example, found good calibration for a crop nitrogen sensor based on research experiments that did not hold up for a larger region in different growing seasons.

- **False precision:** Technology is promoted as functioning at very high levels of specificity (e.g., 50x50 feet grids if fields) that may not be justified by the underlying data.

- **Reverse Technology Flow:** Technologies may be promoted based on the availability of conventional technologies that are not necessarily proven to function in the DA context. For example, site-specific variety placement in fields may be promoted without much evidence that such variable crop genetics indeed consistently perform better.

- **Technology or time challenges:** DA adoption may be hampered by implementation challenges for the user. This has become less problematic with the advance of more "plug-and-play" technologies, better integration of hardwares and softwares on the farm, and standardization of data protocols. However, in reality a multitude of collected data often remains un-analyzed and therefore not gainfully utilized for the business.

- **Outdated conclusions:** Due to the rapid advancements in DA technology and analytics, past research conclusions may have become outdated and possibly superseded by new technological advances.

Overall, the benefits of digital agriculture technologies vary and are not always discernible to the end user. Most farmer decisions related to technology adoption are therefore strongly influenced by commercial marketing efforts that may or may not, for the above reasons, represent true benefits. The current research and education infrastructure in New York is inadequately equipped to provide farmers with solid advice in these matters.

Digital Agriculture Investment and Entry Points

Investment in DA technologies may be considered from different perspectives, depending on the type of business and owner interests. For a farm enterprise, three different types of technology investments can be identified:

1. **Capital investments** that promote efficiencies (computer hardware/software; robotic milking systems; auto-steering and guidance; VRT equipment; sensors; RTK GPS, etc.). These typically involve the purchase of equipment that can be installed and employed without much farm customization.

2. **Service investments** that provide actionable information (remote sensing; cloud-based nutrient models; feeding models; etc.). These are investments that are offered by external companies or consultants, typically on a per-unit (acre, animal, year) cost basis. Such investments may provide immediate benefits to the operation, and generally do not require high up-front investments.

3. **Farm knowledge and human capital investments** involves the development of actionable knowledge for a specific farm, herd, or field location (optimum variety and seeding rates, site and time-specific fertilizer and pesticide application, field workability, optimized animal feeding system, etc.). These investments involve the collection of data (often from investments discussed under 1 and 2) that are then analyzed to generate specific recommendations. For example, gridded soil information, combined with multi-year yield maps and satellite images may be used to generate zones for fertility management or planting densities for a specific field. In some cases, these investments involve several years of data collection or experimentation, e.g., to evaluate the performance of different crop varieties. These investments often involve advanced data analytics and require training and education for farm staff as well as consultants and agriservice personnel.

The same considerations exist for service providers, including custom applicators and consultants. Custom applicators are generally the first adopters of equipment-based DA technologies and consultants often invest in software for data management.

Cost Analyses, Including Start-up Costs and Affordability

The economics of using digital agriculture technology is complicated and not thoroughly researched, which is likely one reason for skepticism about the technology. Much of the research on profitability has focused on straightforward equipment investments, like auto-steer, yield monitors, VRT, and section control. Smith et. al (2013) found guidance systems cost from \$2,000 to \$40,000 in capital costs and achieved 5% input savings. Section control costs \$250 per row and achieved 4.3% savings on input costs. Their analysis showed "that investing in these technologies is not scale-neutral. However, as input costs increase and/or the investment costs for DA tools decrease, these technologies will have shorter payback periods and will likely be beneficial to smaller operations." An online profit calculator for guidance and section control from Kansas State University is available at http://www.agmanager.info/guidance-section-control-profit-calculator.

Computational nitrogen management tools can save farmers \$30-\$39 per acre (Sela et al., 2017). Schimmelpfennig and Ebel (2016) determined average production cost savings for several DA technologies and showed that the effect on profitability depended on the farm size. These savings included: yield mapping (\$25.01 per acre), GPS with soil mapping (\$13.45 per acre), guidance (\$14.98 per acre), VRT with yield map (\$21.87 per acre), and VRT with soil map (\$20.56 per acre). We postulate that the benefits of DA in some cases are predictable (e.g., auto-steer, section control, or automated milking), but for other technologies are highly dependent on the availability of actionable knowledge about the production environment.

In all, the economics of DA adoption is an elusive concept and very dependent on the farm production environment. However, agriculture follows other industry sectors in that the benefits from adoption of digital technologies are the primary source of increased production efficiencies. In a global economic environment, New York agriculture's competiveness is strongly tied to its ability to innovate in these key aspects of the production system. Therefore, the question is not whether NY farmers will adopt digital technologies (they likely will) but how this adoption process can be supported in an environment that allows them to fully capitalize on the production efficiency gains.

Adoption Potential for Different Agricultural Sectors

Field Crops: Precision agriculture has its origins in field crops, and crop farms have been the earliest adopters both nationally and statewide, with much of the innovation geared towards these production systems. New York has generally lagged behind national trends in precision agriculture adoption and the new opportunities offered by DA are dependent on adoption hurdles being lowered, notably (i) better adaptation of technologies to NY-specific conditions (forage crops, variable fields, high-value crops, etc.), (ii) improved agribusiness and service industries (trained personnel, equipment availability, etc.), (iii) improved education, (iv) improved research support and knowledge generation, and (v) improved communication infrastructure.

Livestock: Dairy farms have been early DA adopters and swine and poultry farms are also increasingly employing these technologies. The livestock sector has traditionally not been considered with precision agriculture, but continues to invest heavily into digital technologies. Many animal farms are integrated with crop production to produce feed for their animals and are likely to use DA in both parts of their operations.

Horticulture: Many of the DA tools used for field crops are also relevant to horticultural crops. Technologies like auto-steer, precision planting, and VRT can be effectively employed for high value crops like vegetables and fruits (Pullano, 2014). Since the crop input costs are generally high, DA technologies can potentially have a large impact in horticulture. With smaller fields (orchards/vineyards), UAVs with high-resolution remote sensing appear suitable for crop monitoring to facilitate intensive per-plant management, develop maps for the use of VRT application of pesticides and nutrients, and optimize harvest chronology, among others. They could detect insect or disease outbreaks earlier, allowing treatments to be implemented and crops saved. Precision planting combined with auto-steer allows better precision weed cultivation and reduced damage to the crop. Sensing technologies like "Trimble Weedseeker" enable a farmer to reduce pesticide usage by only spraying where weeds exist. Yield monitors have also recently become available for grapes.

Controlled environment agriculture is also increasingly becoming automated with sensors, controllers and robots being readily implemented in greenhouse, growth chambers and nurseries.

Spatial vineyard management. Mobile sensors are used to collect and integrate spatial data on field characteristics. These data can be used to inform management, including variable-rate inputs. Photo courtesy of Terry Bates.

Adoption on Organic Farms

Organic farms in New York are diverse in scale and production and, like conventional farms, there is not a one-size-fits-all application of digital agriculture technologies. Many of the same technologies that help a conventional farm would also help a similar-sized organic farm. Large organic farms may be able to financially justify and utilize features such as auto-steer, precision feeding systems, robotic milking, VRT, and yield monitors while smaller ones may not, as is the case with many other technologies.

DA technologies that could be especially relevant to organic farmers including:

- **Precision planting technology** that assures more uniform crop stands (density and depth). Uniform crop germination and stands are critical for weed control. Uneven stands are more likely to have weed escapes (due to uneven canopy closure) and crops of different heights are difficult to cultivate without injuring either the smaller or larger plants, depending on timing. Also, organic farmers don't use chemical seed treatments so anything that assures a more uniform stand is beneficial.

- **Tractor guidance systems like auto-steer** could make rows straighter and guarantee uniform distances between rows, making mechanical weed cultivation easier. Guidance systems used during cultivation reduce the number of damaged plants and improve cultivation overall. Controlled traffic is also better for soil health - especially important and valued on organic farms (Zanen and Koopmans, 2008).

- **DA software** could be highly useful to organic farmers as it can be used to track much of the production information needed for organic certification on a site specific basis. Software can also help with environmental or food safety compliance concerning the use of animal manures.

- **Accurate site specific weather data** can be critical to properly managing activities like nutrient application, planting, cultivation, and harvesting. While these activities are not unique to organic farms, they rely more on cultural techniques (versus synthetic inputs) for management. A conventional farmer may have a long window for when a chemical like glyphosate can be applied to a GMO crop, but the window for mechanical cultivation can be very narrow.

Organic products currently have considerable price premiums, and organic inputs are more expensive than conventional inputs. So the optimal use of organic seed, fertilizers, and organic pest treatments could be even more important, and the payback for DA investment on organic farms could be faster than on conventional farms.

Organic farms are generally more diverse (multi crop rotations, more farming enterprises) so technologies that can be used across multiple activities are more likely to be financially justifiable. Organic farmers of all scales may be concerned about digital agriculture removing them from being as engaged in how their crops and animals are grown, but precision organic farming may rely as much on the farmer's observations as the use of GPS and other precision technologies (Martens, 2003).

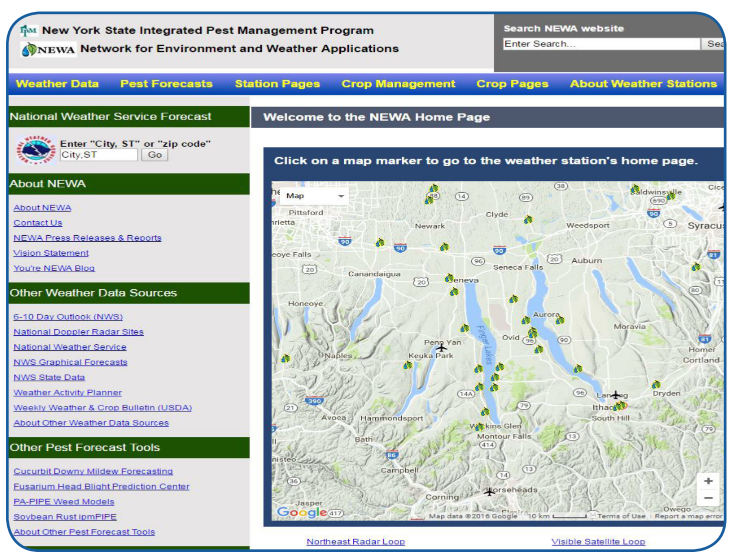
Digital agriculture technologies can have a large impact in horticulture.

DA Adoption on Large and Small Farms

Based on the NY Precision Agriculture survey, previous research (Cox et al., 2004) and how farms adapt new technologies, larger farms can more readily justify and implement new technologies that are capital intensive (like yield monitors, auto-steer, GPS, new GPS-ready equipment, etc.). Through ROI calculations they can often determine whether the equipment will justify its expense through tangible benefits like yield increases or reduced inputs. Environmental or labor benefits may be harder to quantify, but can factor into decisions to adopt, or not. Smaller farms are less likely to justify capital intensive technologies, and also commonly use older equipment that would not necessarily be compatible with technologies like yield monitors, auto-steer and VRT. Lack of financial resources may also be a major hindrance to technology adoption (Pierpaoli et al., 2013). As Schockley et.al, (2011) pointed out, the annual cost of an RTK enabled auto steering system is approximately $5000, and previous users of precision technology are generally more price sensitive (Marra et al., 2010). Norton and Swinton (2000) also found similar evidence that agricultural capital abundance is positively related to precision agriculture adoption.

But not all DA technologies are capital intensive and some are more scale neutral. Site specific weather and pest/disease prediction models are often freely available or on a per-acre cost basis, and offer farmers highly-localized information in support of pest and nutrient management. These include the Network for Environment and Weather Data (NEWA-http://newa.cornell.edu/, Cucurbit Downy Mildew Forecasting network (http://cdm.ipmpipe.org/), and the Potato Late Blight Decision Support System (http://newa.cornell.edu/index.php?page=potato-late-blight-dss). Nitrogen management tools like Adapt-N (Adapt-N.com) are priced on a per-acre basis. Farm management software like Agsquared (http://www.agsquared.com/en/about) is scaled for small operations to help organize and utilize the data that are collected. Other Cloud-based software (e.g., Farmer Business Network, https://www.farmersbusinessnetwork.com/) charge fixed rates but offer reasonable pricing packages.

Small farms may not have enough acreage in any one crop to justify purchasing capital intensive technologies but crop consultants and custom applicators are more likely to invest. For example, a consultant can be hired to do remote sensing (aerial, satellite, and/or UAV) and georeferenced soil sampling data could be used to create a lime application prescription map for a custom applicator. Much can be learned from other parts of the world where the adoption of DA is encouraged across all scales of farming. The European Union Ag community studied the issue of scale with respect to adoption of precision agriculture (EIP-AGRI, 2015) and concluded: "For small farms and farms with limited revenues, it will be especially difficult to clearly demonstrate the return on investment in Precision Farming. The benefit of current Precision Farming systems to the farmer is not always clear as investments required and actual reduction of inputs may not always be readily known. Some cost-benefit tools do exist but they are designed for specific scenarios, climatic conditions, and cropping systems. Also, the information needed to calculate the economic benefits may be lacking. Other gains, such as social, and some environmental benefits, are difficult to quantify and probably mostly underestimated. More work is needed on assessing situations, areas, field sizes and conditions where Precision Farming would be profitable. Farmers with small fields and/or a small number of animals may question whether yield, soil mapping or individual animal data would add any useful new information for their management. Many smaller farms would consider that precision farming technologies used by larger farms would not be applicable to them. In summary, most farmers need a clear quantification of the potential benefits of Precision Farming before adoption is considered."



Site specific weather and pest/disease prediction models, like the Network for Environment and Weather Data (NEWA) are often freely available to the public.
Source: http://newa.cornell.edu/

Digital/Precision Agriculture Surveys

We collected data from several sources to gain a better understanding of DA/PA adoption and use in New York:

- Survey data on precision agriculture use obtained from the Agricultural Resource Management Survey (ARMS)of the USDA;
- An extensive on-line farm level survey conducted in 2015 as part of this project;
- In-person interviews in 2015 with over 60 people in western NY about precision agriculture use and adoption;
- A statewide workshop in December 2015 with farmers, technology companies, researchers, extension, professionals and agribusiness companies.

USDA- Agricultural Resource Management Survey (ARMS)

The USDA Economic Research Service (USDA-ERS) each year conducts a national survey of over 30,000 farms that includes information on production practices and costs for major commodities. The Agricultural Resource Management Survey (ARMS) includes questions about the use of precision agriculture technologies, although not publicly available at the farm level. The publicly available data consist of state and national averages. For this reason, we cannot estimate differences in production from farmers who use DA technologies and those who do not.

ARMS uses several variables that identify precision agriculture practices. These include: use of yield monitor, soil mapping of properties based on soil tests and electrical conductivity, aerial or satellite imaging, variable rate technology (VRT) for different products (fertilizer, seeds, pesticide), and auto-steering systems. ARMS survey data on precision agriculture include seven years: 1997, 1998, 1999, 2000, 2001, 2005, and 2010. The 1997 survey, although it measures DA practices, is limited to yield monitors and the creation of yield maps from such data. The 1998 survey includes soil mapping and VRT use. The 2001 survey includes auto-steering, and the last two surveys, 2005 and 2010, also include specifications on use of the yield monitoring data (to monitor crop moisture, to conduct experiments, to document yields, and other uses), soil mapping, and VRT uses (for nitrogen, phosphorus, and potash application; seeding; and pesticide application). Because of the widespread use of precision agriculture technology in recent years, the surveys of 2005 and 2010 contain the most information, especially considering that some states do not have data recorded until 2000.

The amount of acreage under any precision agriculture technology use, defined in its broadest sense, has been increasing since 1997 (Fig. 17). According to the most recent (2010) survey, 72.5% of total planted corn acres in the US are managed under some type of PA technology, an increase from just under half (49.4%) in 2005.

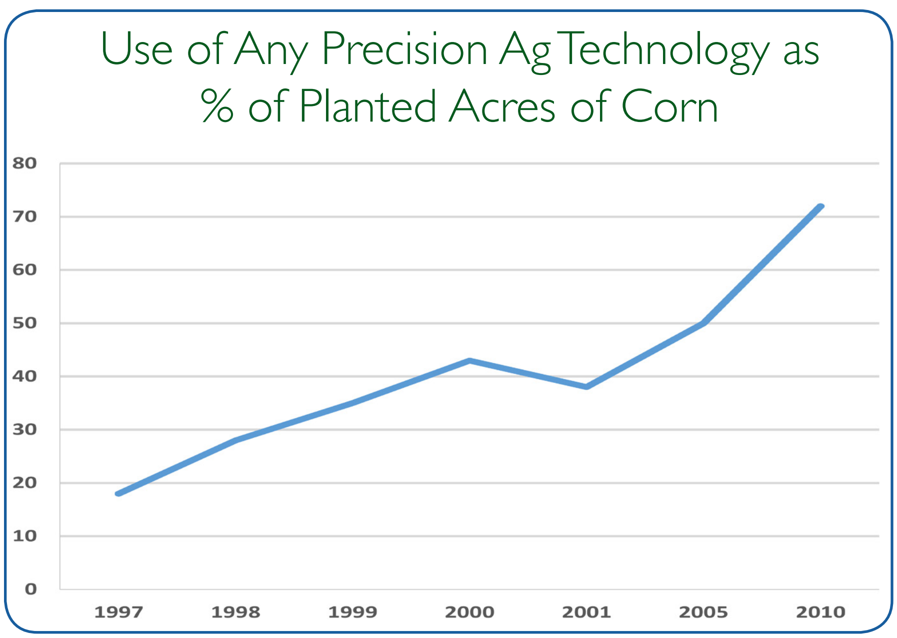


Figure 17. Percentage of planted acres of corn under precision agriculture (national). *Source: USDA-ERS.*

Table 2. Percentage of corn and soybean acres using precision agriculture in the United States (2010; 2012).

	Corn (2010)	Soybean (2012)
Planted Acres	81,740 (ac)	73,527 (ac)
Precision Agriculture Used	72.5	73.4
Yield Monitor Used	61.4	62.9
Yield Map Created	33.9	20.3[2]
Yield Monitor Information Uses: Monitor Crop Moisture	51.7	33.9[2]
Yield Monitor Information Uses: Conduct Experiment	20.4	12.5[2]
Yield Monitor Information Uses: Document Yield	28.0	18.5[2]
Yield Monitor Information Uses: Other Uses	23.2	13.8[2]
Soil Properties Map Based On: Soil Test	12.0	6.6[3]
GPS Device Used to Create Soil Properties Map	22.3	19.4
Soil Properties Map Based On: Electrical Conductivity	1.2*	1.2*/3
Soil Properties Map Based On: Other	3.6	2.5[3]
Aerial or Satellite Image Made	5.9	1.0[3]
VRT Used for Any Purpose	22.5	21.8
VRT Used for Any Fertilizing	19.3	5.0[2]
VRT Used for Nitrogen Application	10.0	1.2[2]
VRT Used for Phosphorus Application	15.1	2.9[2]
VRT Used for Potash Application	13.8	3.8[2]
VRT Used for Other Application	7.0	3.2[2]
VRT Used for Seeding	7.2	1.7[2]
VRT Used for Pesticide Application	5.0	2.8[2]
Guidance or Auto-steering System Used	45.2	45.3

* Statistically unreliable due to low sample size

1. Data from year 2005
2. Data from year 2006
3. Data from year 2002

Table 3. Precision agriculture technology use for corn (State level, year 2010) in Percent of Total Acres.

System Used	NY	IL	IN	IA	PA	OH
Precision Agriculture Used	36.6*	76.5	83.7	81.7	13.7*	78.2
VRT Used for Any Purpose	12.5*	35.3	23.5	19.7	5.8*	36.4
Guidance or Auto Steering	16.0*	53.4	56.5	37.2	NA	59.5

* Statistically unreliable due to low sample size.

Precision agriculture technology use as a percentage of total acres for corn (2010) and soybeans (2012) at the national level are shown in Table 2 to the left. Farmers commonly rotate between corn and soybeans, helping explain why the usage is similar in both. For instance, the percentage of precision agriculture use for corn in 2010 was 72%, while that of soybean in 2012 was 73%. Larger farms are also more likely to use DA. Yield monitors are the most commonly adopted precision agriculture technology, and are considered as entry level technology for grain crop producers. In 2010, over 60% of all planted US corn or soybean acreage used yield monitors, more than double from 2001. Use of VRT is around 22%, and guidance or auto-steering use is around 45% in 2012.

Use of precision agriculture technologies in NY State was compared to nearby Pennsylvania and high productivity Corn Belt states (Illinois, Indiana, Ohio and Iowa; Table 3), showing that the latter have much higher levels of precision agriculture technology participation (at least twice) than New York and Pennsylvania.

Nevertheless, the results from USDA-ARMS survey fail to provide a clear picture on the current use of PA technologies in NYS. Most of the data are not reliable, are outdated, or do not capture sufficient information on NYS. Lack of reliable data on PA adoption is not the case for the Corn Belt states. In order to fill in the gap of missing data for NYS, we conducted a survey on agricultural producers across the State in the next section.

Precision Agriculture Survey of New York State Growers

In order to better understand the characteristics of DA technology use in NYS, we conducted an online survey of agricultural producers in the state. The survey participants included producers of livestock, dairy, grains, vegetables, grapes, and other fruits. Some questions related to DA adoption were similar to those from the ARMS data, while most others were unique to this survey. A draft of the survey instrument was circulated to multiple groups for review and dissemination. The survey included items to better understand barriers and challenges to DA adoption in NYS, the perception of producers regarding benefits, adoption patterns of different technologies, and several other related aspects. It consisted of 54 multiple choice questions, which took approximately 15 minutes to complete. The online survey was distributed to agricultural producers with operations in NYS through email lists from different producer associations, including the Corn and Soybean Growers Association, New York Farm Bureau, Northeast Dairy Producers Association, and Farm Credit. In this section we discuss the highlights of the survey, while the complete results are listed in Appendix I-A. *Note that in the survey we used the more familiar term 'precision agriculture' (PA) rather than 'digital agriculture' (DA).*

Overview of Survey Respondents

The survey was taken by 338 producers, however, only 182, or 53.84%, completed it. 168 out of the 182 respondents are NYS residents (92.3%). Female respondents account for 27.5% (50) of the sample.

The respondents have operations in 39 counties of NY State. Yates, Orange and Chautauqua counties had the most respondents with 11, 10 and 7 producers respectively. Most farmers are above 50 years old (Table 4). About 20% of the sample are younger than 40 years old, and 32% are older than 60 years.

Table 4. Age distribution of the NYS Precision Agriculture Survey.

Age	Frequency	Percent
< 30	6	3.3
31-40	30	16.5
41-50	26	14.3
51-60	60	33.0
61-70	49	26.9
> 70	11	6.0

n = 182

The number of farming years has a somewhat different distribution than the age distribution of farmers. Farming experience has a bimodal distribution, with the two modes at both extremes of the distribution. The percentage of farmers with 10 of less farming years is 31%, while that of more than 30 farming years is 35% (Table 5). 10% of farmers have between 20 and 30 farming years.

Most producers in our sample have a 4-year college degree of higher (64%, Table 6). 18% have either a master's degree or an associate's degree, and 17% have a high school degree of lower.

Table 5. Number of farming years

Number of Farming Years	Frequency	Percent
10 or less	56	31.1
11-20	41	22.8
21-30	19	10.6
More than 30	64	35.6

n = 180

Table 6. Education level distribution

Maximum Education Level	Frequency	Percent
Less than High School	2	1.1
High School	29	15.9
2-year College (Associates)	34	18.7
4-year College (B.A., B.S.)	77	42.3
Master's	34	18.7
Ph.D.	3	1.7
Professional Degree (MD, JD, Vet)	3	1.7

n = 182

Farm size is very variable. 21% of the sample have 10 of fewer acres, 25% between 11 and 50 acres, 23% between 51 and 200 acres and 29% above 200 acres. The average number of acres farmed is 416, with minimum and maximum acres of 0.5 and 12,000 respectively.

Producers' gross sales are classified into three groups: less than $250,000; between $250,000 and $1,000,000; and more than $1,000,000 in annual sales. Most of producers (67%) have gross sales of less than $250,000 (Table 7). Only 12% have sales above a million USD. Certified organic produce is grown by 11% of the sample, and 22% of producers grow GMO crops.

From the 54 respondents that use irrigation, 52 stated the number of irrigated acres. From those, the average number of irrigated acres is 72, with minimum and maximum values of 0.25 and 1000, respectively. On average they irrigate about 51% of their total farmed acres. This represents 14.6% of irrigated acres from the total sample.

Table 7. Gross sales

Gross Sales	Number	Percent
Less than 250 k	123	67.6
250k- 1 Million	37	20.3
More than 1 million	22	12.1

n = 182

A survey of agricultural producers was conducted in order to better understand the characteristics of DA technology use in New York State

On average, farmers hired 4.6 full time equivalent employees. With a minimum and maximum of 0 and 46, respectively (Table 8). The number of hired labor increases for larger acres in production. The farm operations with the fewest acres are also those that have the highest percentage of irrigated acres, i.e, operations with 10 of fewer acres have on average 35% of their area under any type of irrigation. However, they tend to be in the lowest sales group (less than $250,000), therefore presumably mostly involving smaller farms that produce high-value crops like fresh produce. As expected, operations with largest acreage have the highest gross sales, but the smallest rate of irrigated acres, presumably mostly involving grain and forage crops.

Table 8. Farm data by number of acres farmed.

Acres Farmed	Number of Full Time Equivalent Workers (not including respondent)	Percentage of acres with irrigation	Gross Sales Group (See Table 7)
10 or fewer	0.47	34.9	1.0
11-50	2.8	9.9	1.1
51-200	2.6	11.8	1.3
201-500	7.6	9.7	1.9
More than 500	13.7	2.2	2.4

n = 182. Standard deviation in parenthesis.

Current Precision Agriculture Adoption Rates in New York State

Table 9 presents results of those that use PA as a source of information for different technologies and different producer groups. Remote sensing imagery was the most widely adopted PA information source by all farmers in the sample, with 39.56% indicating that they used some form of imagery produced by satellites, planes, or UAVs. About 23% of corn and soybean producers reported using yield monitors without GPS, while 35% reported using yield monitors with GPS and yield maps. Yield monitors are typically regarded as an introductory precision agriculture technology for grain producers. Yield monitor use was much lower (10-15%) among other types of producers. About 20% of producers indicated using soil maps, with the highest use among grape producers (32%). Very few producers use soil moisture sensors (10%) with the highest use among grape producers (16%). Very few (about 5%) reported using unmanned aerial platforms (UAV) for scouting, with the most frequent being among corn and soybean producers (10 %).

Table 9. Precision agriculture technology use as an information source (percentage of sample).

Information Source	*All Sample (n=182)*	*Dairy and Livestock Producers (n=60)*	*Corn and Soy Producers (n=38)*	*Juice and Wine Grape Producers (n=55)*	*Other Fresh Fruits and Veg. Producers (n=53)*	*Other Crop Producers (n=39)*
Yield monitor without GPS	11.5	8.3	23.7	14.5	13.2	7.7
Yield monitor with GPS.	9.3	13.3	34.2	9.1	5.7	10.3
Images and photographs produced by satellites, planes, or unmanned aerial vehicles (UAV).	39.6	31.7	31.6	47.3	37.7	35.9
Yield Maps.	14.3	13.3	36.8	12.7	11.3	18.0
Soil maps created by grid soil tests or electrical conductivity measurements with GPS.	22.5	15.0	18.4	32.7	22.6	23.1
Soil moisture sensors	10.4	6.7	2.6	16.4	11.3	5.1
UAV for scouting crop health	4.4	5.0	10.5	3.6	5.7	0.0

Note: Producer groups are not mutually exclusive. The dairy producer category includes those that produce crops, and some in the corn and soybean producer category include dairy and other livestock producers.

Producers were also surveyed on the use of variable rate technologies (VRT) and other DA technology use, including soil mapping, precision feeding, and auto-steer (Table 10). About 34% of corn and soybean producers reported using auto-steer, while only 10% of other crop producers do. About a third of producers report using soil mapping based on soil tests (47% for corn/soybean producers, 40% grape, and 41% other crop), but far fewer (8%) use soil maps derived from electrical conductivity data. Around 18% of corn/soybean producers reported adoption of some form of precision nitrogen management, although those rates are much lower among all other groups (less than 5%). VRT use was fairly low, with about 10% of the sample reporting using some form of this technology. However, about 29% of corn/soybean growers reported VRT use for either fertilizer or pesticide application, but only 10% reported use of VRT seeding. Very few producers reported using crop sensors (less than 5% of all producers, and less than 8% of corn producers). Among dairies, only 15% reported using precision feed mixers.

Table 10. Variable rate and other precision technology use (percentage of sample)

Variable Input Applicators	*All Sample (n=182)*	*Dairy and Livestock Producers (n=60)*	*Corn and Soy Producers (n=38)*	*Juice and Wine Grape Producer (n=55)*	*Other Fresh Fruits and Veg. Producers (n=53)*	*Other Crop Producers (n=39)*
Variable rate chemical (fertilizer/ pesticide) applicators with GPS.	10.4	6.7	29.0	10.9	5.7	2.6
Variable seeding rate and precision planter/ drill with GPS.	3.9	1.7	10.5	3.6	1.9	0
Precision nitrogen (N) management software (Adapt-N, Encirca, Climate Pro, etc.)	4.4	3.3	18.4	0.0	3.8	2.6
Auto steer technology	9.3	10.0	34.2	3.6	5.7	10.3
Crop sensors (Greenseekers, OptRx, CropSpec, Crop Circle, etc.)	4.4	1.7	7.9	5.5	3.8	2.6
Soil mapping using soil tests	35.2	23.3	47.4	41.8	28.3	41.0
Soil mapping using electrical conductivity tests	8.2	1.7	15.8	14.6	3.8	5.1
Precision feed mixer	6.6	15.0	21.1	0.0	1.9	5.1

Note: Producer groups are not mutually exclusive. The dairy producer category includes those that produce crops, and some in the Corn and Soybean producer category include dairy and other livestock producers.

Table 11. Percent technology use of dairy/livestock farmers by type.

Technology	*Dairy Producers Only (n=16)*	*Livestock Producers Only (n=44)*	*Both Dairy and Livestock Producers (n=60)*
Automatic monitoring for animal heath	31.3	4.5	11.7
Rumination monitoring	6.3	4.5	5.0
Ultrasound or blood testing for pregnancy confirmation	43.8	20.5	26.7
Computerized decision making tools with monitoring (feed, yields, etc.)	43.8	9.1	18.3
Electronic livestock identifiers	37.5	2.3	11.7
Automatic (robotic) milking systems	25.0	0.0	6.7

Livestock and Dairy Specific Precision Agriculture Adoption

Table 11 presents results on technologies used in dairy and livestock production operations. These producers were asked about the use of six technologies, although some of those are specific to dairy operations. We would note that despite sending the survey instrument to thousands of dairy farmers, only 16 responded. So these results are likely not representative. The dairy farmers in our survey also tended to be associated with larger dairy farms.

Among dairy producers, 31% use automatic monitoring for animal health, in contrast to only 4% of livestock producers. 43% of dairy producers reported using ultrasound or blood testing for pregnancy, and computerized tools for feed or yield measurement. 25% of the sample reported using automated robotic milking systems. The least reported precision technology was rumination monitoring, with only 5% of both types of producers adopting it. About 69% of dairy producers track individual cow milk production, and 56% of them track individual cow milk quality. 56% of dairy producers use outside consultants with herd management, and 38% of dairy producers use electronic identification devices, but only 5% of other livestock producers. About 31% of dairy producers used precision feeding software, but none of the other livestock producers reported using such software.

Table 12. Motivations for PA technology adoption (percentage of sample).

Motivations for PA Technology Adoption	*All Sample (n=182)*	*Dairy and Livestock Producers (n=60)*	*Corn and Soy Producers (n=38)*	*Juice and Wine Grape Producer (n=55)*	*Other Fresh Fruits and Veg. Producers (n=53)*
Higher profits	60.4	61.7	81.6	65.5	56.6
Reduced environmental impacts	47.3	46.7	60.5	54.5	49.1
To address labor shortage	36.3	38.3	39.5	43.6	41.5
To be at the cutting edge	16.5	21.7	23.7	16.4	13.2
Personal time savings	48.9	53.3	57.9	41.8	49.1
I like data-based management	23.6	25.0	26.3	21.8	20.8
Other	6.0	5.0	0.0	1.8	5.7

Note: More than one reason can be selected. Percentages may not sum to 100.

Motivations for Adoption

The motivations for adopting PA technologies were varied, but somewhat consistent across producer groups (Table 12). About 60% indicated they were motivated by higher profits, while nearly 50% surveyed indicated that the motivation was to reduce environmental impacts. About half of farmers were interested in time savings that were potentially afforded by DA adoption. About a quarter cited it was because they like data based management, and about 36% reported motivations stemming from labor shortages.

Precision Agriculture, Broadband/ Cellular Connectivity and Information Tools

The use of precision agriculture technologies relies heavily on communication infrastructure. We would note that since our survey was conducted online, those with internet at their farm were more likely to participate, so the connectivity results maybe be biased (we report analysis of broadband availability using GIS data from the New York Broadband Office in Section III).

See Tables 13 and 14 on the following page. Around 80% of the sample reported having access to high speed internet on their farms. About 69% reported having access to reliable cellular. Despite this, only 10% of farmers reported having any equipment that was mobile enabled to send data from the field, although this is higher for corn, soybean, and other row crop producers (30%). Likewise, RTK and DGPS adoption on these farms is quite low, with only around 15%, although this is closer to 40% for dairy and row crop producers (including corn and soybeans). About one-third of producers reported using one or more of Cornell University's agricultural management tools, with apple and grape producers having the most frequent use (71% and 58%). Most producers (63% total, and 81% of corn and soybean producers) reported using mobile technologies (smart phone or tablet) for farm management.

Adopting New Technologies

T&S Crop Service

Seth Sheehan and T&S Crop Service offer full retail services of liquid fertilizer, crop protection and seed. They have a custom application business that covers approximately 60,000 acres across New York State.

T&S Crop Service first put swath control and auto boom on their sprayers 10 years ago. Their 5 self-propelled sprayers now have those technologies plus auto steer and wireless data transfer. Auto steer and swath control nearly eliminated overlap and skips that used to occur from human fatigue or inaccuracy of foam markers.

"Auto steer and swath control nearly eliminated overlap and skips that occurs from human fatigue"

Wireless data transfer in the sprayers allows them to upload and download files while in the field. Fortunately, they have had very few issue with cell signals in their coverage area.

In-field use of the technology is not a problem but it is challenging to manage the volumes of data that come back from the sprayers. New opportunities exist to offer services to farmers and consultants to help manage the data and write prescriptions.

Table 13. Percentage of producers with access and use of the following technologies (part 1).

Technology Infrastructure	Total Sample (n=182)	Dairy producers (n=16)	Livestock Producers (n=44)	Dairy and Livestock Producers (n=60)	Corn and Soybean Producers (n=38)	Other Row Crop Producers (n=18)
Do you have access to high speed internet on your farm?	80.8	81.3	81.8	81.7	89.5	94.4
Do you have good / reliable high speed cellular data service on your farm?	69.2	75.0	61.4	65.0	86.8	83.3
Do you use high-precision GPS on your farm (RTK or DGPS)?	13.7	37.5	6.8	15.0	39.5	38.9
Do you use mobile technologies (smartphones, tablets, etc.) for farm management?	63.2	43.8	63.6	58.3	81.6	83.3
Is any of your farm equipment mobile enabled (can communicate and send/receive data from the field)?	9.3	12.5	9.1	10.0	28.9	33.3
Do you use any of Cornell University's agricultural management tools (e.g., NEWA, fire blight forecasting model, Cornell IPM's scout, Adapt N)	35.7	18.8	18.2	18.3	34.2	38.9

Table 14. Percentage of producers with access and use of the following technologies (part II).

Technology Infrastructure	Juice and Wine Grape Producer (n=55)	Apple Producers (n=14)	Other Fresh Fruits and Veg. Producers (n=53)	Other Crop Producers (n=39)
Do you have access to high speed internet on your farm?	87.3	78.6	83.0	87.2
Do you have good / reliable high speed cellular data service on your farm?	81.8	50.0	71.7	66.7
Do you use high-precision GPS on your farm (RTK or DGPS)?	10.9	14.3	9.4	15.4
Do you use mobile technologies (smartphones, tablets, etc.) for farm management?	61.8	64.3	66.0	74.4
Is any of your farm equipment mobile enabled (can communicate and send/receive data from the field)?	7.3	14.3	11.3	10.3
Do you use any of Cornell University's agricultural management tools (e.g., NEWA, fire blight forecasting model, Cornell IPM's scout, Adapt N)	58.2	71.4	35.9	33.3

Note: Producer groups are not mutually exclusive.

Only 5.5% of the sample reported using any cloud-based farm management software. Not all reported platforms were, however, actually farm management software (some were simply file backups). For those that did report use of these technologies, the following were reported: AgraScout, NEWA, Precision Planting, Climate Apex, Carbonite, Agri Data, Agfinity/SMS (AgLeader), AgSquared, Farm Produce Manager, Farm Logs, and My John Deere. Most of the software was used for weather forecasting and for estimating crop and harvest timelines.

Of those producers reporting using some form of DA technology, we asked who was conducting most of the information processing (Table 15). About 58% of producers reported they were processing the information themselves or an employee, followed by a consultant (5%).

Sources of Technical Information

Attending workshops and other technical instructions was reported as an important channel for learning about DA technologies (Table 16). Almost half attended workshops and other technical instructions 1 to 5 times in the last three years. 26% of our sample attended 6 to 10 times, higher for corn and soybean producers.

Table 17 identifies the sources of technical information. About 80% of respondents use university extension as a primary source of technical information, followed by internet (67%) and fellow producers (64%). Corn and soybean producers are more likely to hire independent technical consultants (34% versus 16% for the sample). Juice and wine grape producers show less interest in independent consultants, with only 11% of our sample reporting their experience in consulting. Dairy and livestock producers are more likely to seek help from government professionals (15%) compared to the average (9%).

Table 15. If using PA technologies, who does most of the information processing, as a percentage of PA users?

	All PA Users
Self	49.5
Employee	8.6
Consultant	5.4
Other operator	2.2
Service company	9.7

n = 93

Attending workshops and other technical instruction is an important opportunity for learning.

Table 16. Percentage of sample that attended technical workshops in the last three years.

Number of workshops and other technical instructions in the past three years	*All Sample (n=181)*	*Dairy and Livestock Producers (n=60)*	*Corn and Soy Producers (n=38)*	*Juice and Wine Grape Producer (n=55)*	*Other Fresh Fruits and Veg. Producers (n=52)*
0	9.9	13.3	5.3	1.8	7.7
1-5	47.5	43.3	36.8	47.3	44.2
6-10	26.0	26.7	34.2	29.1	30.8
More than 10	16.6	16.7	23.7	21.8	17.3

Table 17. Source of technical information, as a percentage of sample.

Source of Technical Information	*All Sample (n=182)*	*Dairy and Livestock Producers (n=60)*	*Corn and Soy Producers (n=38)*	*Juice and Wine Grape Producer (n=55)*	*Other Fresh Fruits and Veg. Producers (n=53)*	*Other Crop Producers (n=39)*
University Extension	79.9	78.3	76.3	81.8	69.8	79.5
Independent consultant	16.5	15.0	34.2	10.9	18.9	25.6
Seed/ fertilizer/ chemical/ equipment dealer	43.4	35.0	71.1	50.9	43.4	41.0
Government professionals	8.8	15.0	7.9	7.3	1.9	10.3
Northeast Organic Farming Association (NOFA)	14.8	21.7	10.5	5.5	34.0	7.7
Fellow producers	63.7	56.7	60.5	65.5	67.9	64.1
Family/ friends	35.7	35.0	36.8	32.7	35.8	23.1
Trade magazines	46.2	51.7	63.2	34.5	43.4	48.7
Other	6.6	10.0	2.6	3.6	3.8	7.7
Internet	67.0	71.7	76.3	56.4	79.2	76.9
Nutritionist	8.2	18.3	23.7	0.0	3.8	5.1
Veterinarian	20.3	46.7	31.6	5.5	13.2	20.5

Note: Producer groups are not mutually exclusive.

Priorities, Opportunities and Challenges

Several barriers were noted to adoption of precision agriculture technologies (Table 18). About half of producers indicated that they were uncertain on how to implement these technologies in a profitable manner. Among other prevalent reasons cited were that technologies were deemed to be too expensive (58%), too expensive to replace manual labor (29%), insufficient technical support (34%), connectivity (broadband/mobile, 24%), and concerns about unproven technologies (18%).

In an effort to better understand specific technology adoption barriers, producers were asked about primary reasons for not adopting certain technologies (among non-adopters), including whether it was "Too Expensive/ Cannot Obtain Financing", "Skeptical of Benefits", "Cannot get Technical Support", and "Other" (Table 19). Regarding remote sensing products (e.g., satellite images) 25.6% reported that it was too expensive, while 23.4% indicated that they were skeptical of benefits. Almost half indicated some other reason. Similar numbers were revealed for yields maps, yield monitors, VRT, RTK, GPS, and auto-steer.

RTK connection allows for variable rate, precision N application. *Source: Adapt-N.com*

Table 18. Barriers for PA technology adoption in NYS, as percentage of sample.

What Do You Think are the Barriers for Adoption of PA Technologies	*All Sample (n=182)*
Insufficient research	15.4
Insufficient technical support	34.1
Insufficient equipment availability from local dealerships	22.0
Insufficient connectivity (broadband, mobile)	24.7
Concerns about unproven technology for NY	18.1
Too expensive	58.2
Technology too expensive to replace manual labor	29.1
Uncertain how to implement the technologies in a profitable manner	51.6
Other	17.6

Table 19. Primary reasons for not using PA technologies, as percentage of responses.

PA Technology	Too Expensive/ Cannot get financing	Skeptical of Benefits	Cannot get Technical Support	Other	Number of Responses
Images produced by satellites, planes or drones	25.6	23.4	10.2	46.7	137
Yield Maps created by GPS	28.3	19.7	4.6	51.3	152
Yield Monitors	28.7	17.2	2.5	54.1	157
Soil maps created by soil tests	25.0	14.5	10.5	53.2	124
Soil maps created by electrical conductivity tests	24.7	22.1	9.1	49.4	154
Variable rate applicator (seeds, fertilizer, chemicals)	30.0	20.0	4.7	51.3	150
Auto steering system	31.8	16.9	1.4	54.1	148
Soil moisture sensors	21.7	22.4	4.0	54.6	152
DGPS subscription	25.9	15.6	1.4	59.9	147
Data analysis software subscription	26.7	18.7	1.3	55.3	150
RTK GPS subscription	27.2	16.3	1.4	57.1	147
Electronic livestock identifiers	17.1	15.8	2.7	67.8	146
Precision feed mixers	19.7	12.7	0.7	70.4	142

Note: More than one reason can be selected. Percentages may not sum to 100.

Future and Forecasted Adoption

We also elicited producer (by operation type) forecasts of which technologies they expected to start using in the next 5 years, if not already using them (Table 20). Soil maps created by soil tests had modest expected future adoption rates, with about 21% and 25% of corn and soybean producers and grape producers reporting they expected to adopt these technologies in the next 5 years. Slightly higher numbers were found for VRT, crop sensors, precision nitrogen management technologies, and remote sensing imagery (about 25-40% depending on group/technology). 45% of corn and soybean producers expect more use of images produced by satellites, planes or drones. Variable rate chemical applicators and precision nitrogen management software also have a bright future, with 34% of corn and soybean producers showing an interest. Only 14.8% of producers expected to start using data analysis software subscriptions (about 10% of dairy, 13% of corn/soy, and 17% of fresh fruit and vegetable producers), however this presumably excludes those needed for precision nitrogen management or other VRT technologies. Only 6.7% of dairy and livestock producers (who were not already) expected to begin adopting livestock management machinery. Overall, adoption rates for these precision agriculture technologies would lead to at least a doubling or tripling of use relative to current adoption rates, although most would still be at less than 100% adoption.

Table 20. Precision Agriculture technologies expected to use in the next five years, as percentage of sample.

	All Sample (n=182)	*Dairy and Livestock Producers (n=60)*	*Corn and Soy Producers (n=38)*	*Juice and Wine Grape Producer (n=55)*	*Other Fresh Fruits and Veg. Producers (n=53)*
Yield monitor without GPS	3.8	1.7	2.6	7.3	3.8
Yield monitor with GPS	9.3	5.0	13.2	14.5	3.8
Yield maps	17.0	8.3	10.5	25.5	13.2
Images produced by satellite, planes, or drones	31.3	30.0	44.7	30.9	37.7
Soil maps created by grid soil test with GPS	18.7	18.3	21.1	25.5	17.0
Soil maps created by electrical conductivity measurements with GPS	8.8	10.0	13.2	7.3	11.3
Variable rate chemical applicators with GPS	19.8	20.0	34.2	25.5	13.2
Variable seeding rate and precision planter with GPS	8.8	15.0	28.9	5.5	7.5
Auto-steering system with RTK GPS	6.0	10.0	18.4	0.0	9.4
Precision nitrogen management software	13.7	15.0	34.2	20.0	9.4
Crop sensors	15.4	13.3	28.9	16.4	24.5
Data analysis software subscription	14.8	10.0	13.2	12.7	17.0
Livestock management machinery	3.8	6.7	2.6	0.0	3.8

Table 21. If New York State were to invest in PA in NY, what areas should receive priority? (as a percentage of respondents).

Priority Areas	*Percentage of Sample*
Research and development	24.0
Business development (loans, etc.)	17.8
Extension, education, and workforce training (cooperative extension)	24.8
Infrastructure (mobile broadband, RTK GPS access, etc.)	20.2
Other	13.2

n = 129

Producers were also polled on their opinions regarding what they thought the State of New York should prioritize for investment in precision agriculture (Table 21). They indicated greater need for Research and Development (24%) and Extension/Education (24%), followed by about 20% who indicated that communications infrastructure should be the priority investment area. About 17% indicated business development such as loans, and about 13% indicated “Other”.

In terms of whether producers were favorable toward future developments in PA in the state, only about 7% indicated disagreement, whereas 54% indicated agreement or strong agreement with the statement “I believe that precision agriculture has a bright future in NY State” (Table 22). Most producers also agree that precision agriculture has good business and employment opportunities in NY State. Almost 74% agreed that the use of precision agriculture technologies brings environmental benefits and efficiencies. However, only 22% agree that new college graduates have a good understanding of precision agriculture technologies.

Producer Perceptions of Risk and Relationship with Precision Agriculture Adoption

Table 23 reports the level of agreement to various statements about perceptions of farm risk. In the statements, technologies refer to new varieties, precision agriculture practices, etc., while management practices refer to crop rotation, tillage practices, forward contracts, and insurance. The purpose of these questions is to identify what factors play a role in adoption of DA for farms.

Most respondents state that they follow business, financial, and technology news (69%). Also, 80% agree that their farm operation is very vulnerable to weather and other production risks. Many, 44%, are willing to take risks with new production technologies that are not tested on other farms, 30% disagree with this statement, and 25% are neutral about it. With regards to whether they believe DA technologies provide a mechanism to allow them to better cope with weather risk, about 40% are neutral, 43% agree or agree strongly, and 17% disagree.

Table 22. Agreement to statements on PA technologies in NYS (as percentage of sample)..

Statement	*strongly disagree or disagree*	*neutral*	*agree or strongly agree*
I believe that precision agriculture has a bright future in NY State (n=178).	7.3	38.2	54.5
I believe that there are good business and employment opportunities related to precision agriculture in NY (n=176).	8.5	33.0	58.5
I believe the use of precision agriculture technologies brings environmental benefits and efficiency (n=177).	4.0	21.5	74.3
I believe new college graduates have a good understanding of precision agriculture technologies (n=176).	10.8	66.5	22.7

Table 23. Risk perceptions and PA technologies (percent of sample).

Statement	*strongly disagree or disagree*	*neutral*	*agree or strongly agree*
I pay close attention to business, financial, and technology news (n=178).	10.1	20.8	69.1
My farm operation is very vulnerable to weather and other production risks (n=181).	9.4	10.5	80.1
I am willing to take risks with new technologies before I see good results in other farms (n=179).	30.2	25.7	44.1
I am willing to take risks with new management practices before I see good results in other farms (n=178).	16.3	27.5	56.2
I believe precision agriculture technologies will allow me to better cope with weather and climate related risks (n=178).	17.4	39.9	42.7

About 38% of producers indicated agreement with the statement "I undertook a major expansion recently or am in the process of one", while 21% were neutral, and 40% did not agree (Table 24). 40% of producers think uncertainties regarding availability of farm labor prevented them from expansion, while 32% disagree.

Most producers (74%) reported their debt to asset ratio as lower than 30% (Table 25). Only 5% of producers indicated a debt to asset ratio greater than 60%.

Explaining Precision Agriculture Adoption: Econometric Model

In order to better understand the factors affecting producer adoption of PA technologies in our sample, linear probability models were estimated using the sample survey data. The dependent variable, PAUse, is a dichotomous variable that indicates whether the producer uses any PA technologies as defined in the survey. As explanatory variables we include demographic and economic variables, risk preference measures, and indicators of infrastructure access that supports PA (Table 26). Under the linear probability model, the coefficients to be estimated represent probabilities of adopting a precision agriculture

Table 24. Business risks and uncertainties (percent of sample).

Statement	*strongly disagree or disagree*	*neutral*	*agree or strongly agree*
I undertook a major expansion recently or am in the process of one (n=175).	40.0	21.7	38.3
I have canceled or significantly scaled back a major expansion recently (n=176).	59.1	29.6	11.4
Uncertainties regarding tax and regulatory policies have prevented me from expanding or investing recently (n=176).	39.8	28.4	31.8
Uncertainties regarding availability of farm labor have prevented me from expanding or investing recently (n=178).	32.6	27.0	40.5
Uncertainties regarding price volatility have prevented me from expanding or investing recently (n=176).	27.8	40.9	31.3
Climate change poses a great threat to my farm operation (n=175).	34.3	28.6	37.1
Borrowing constraints have /would put my farm operation in financial jeopardy (n=173).	39.3	31.8	28.9

Table 25. Debt to Asset Ratio.

Value	*Percentage of Sample*
0-30%	73.5
30-60%	21.2
Greater than 60%	5.3

n = 151

technology, as defined in the model, given a one unit change in the explanatory variable. In the case of dummy variables, it measures the change in probability of adoption when the condition is true. For categorical variables, it measures the change in probability when the explanatory variable increases by one unit (see Appendix I-A).

We ran two linear probability regressions (Table 27), one where the dependent variable refers to whether the producer uses any of the PA technologies used for information gathering (such as yield monitors with and without GPS, images produced by satellites, planes, or UAV, yield maps, soil maps with GPS, soil moisture sensors, and using UAVs for scouting crop health), and the other if the producer uses any PA technologies, which includes information PA and variable rate applicators, and other technologies. About 60% of our sample reported using some type of information technologies, while 69% of the sample reported using some type of any PA technology regardless of the type.

Younger producers are more likely to adopt PA, although this is only statistically significant for information-based PA. Education level and gross sales are positively related to PA use, indicating that those farms that are larger and operated by those with more education are more likely to adopt. Presumably, people with more education are more likely to be able to access the resources required to learn and use new complex technologies, and larger farms are afforded economies of scale that put them in a better position to pursue these investments.

Related to risk preferences of producers, being risk averse is not statistically significant in explaining PA adoption. However, being loss averse is negatively related to PA adoption and is significant. That is, people who stated that they care more about potential losses than gains are about 13% less likely to use any PA technologies than those who are less loss averse. Having a high discount factor (which reflects information about "how fast" the producer wants to be repaid on an investment) is positively related to the probability of adopting PA technology.

Attending technical seminars and workshops was also associated with an increase in the probability of PA technology adoption. Having access to cellular data services was also found to be statistically and economically related to PA adoption, with producers being 13% more likely to adopt some form of PA if they have high speed cellular access.

Conclusions of the New York Statewide Survey

Precision agriculture technologies allow for improved management of inputs and farm assets, potentially improving the profits of producers and environmental outcomes. Although the benefits of using these technologies are many, not all producers are actively adopting them to improve their operations. Factors related to infrastructure (e.g., reliable cellular data access), research and development, technical information, and relevant extension resources were all cited as important factors. The results from the econometric analysis of

Table 26. Explanatory variable definition

Variable	Statement
ProdRisk	My farm operation is very vulnerable to weather and other production risks.
RiskAverse	I'd prefer a project yielding $100,000 profit for sure rather than a project that has a 50% chance of yielding $150,000 and a 50% chance of yielding $50,000 profit.
HiDiscRate	I usually only invest in new technologies that will pay off quickly (a couple of years)
LossAverse	I am more concerned with possible losses than gains.

Table 27. Linear probability model regressions on precision agriculture use.

	Information PA	Any PA
Female	-0.138*	-0.110
AgeG	-0.0574*	-0.0444
EduG	0.0398	0.0464*
Sales	0.0819	0.146***
ProdRisk	0.122	0.106
RiskAverse	0.0347	0.0329
LossAverse	-0.193**	-0.132*
HiDiscRate	0.182**	0.216***
DairyLivestockP	-0.0195	0.0051
CornSoybeanP	-0.117	-0.107
GrapeAllP	0.0740	0.0275
ApplesP	-0.146	-0.239*
OtherFreshVegP	0.0260	-0.0804
AttendSeminars	0.0703	0.0808**
CelularDataAccess	0.0943	0.136*
Constant	0.250	0.107
Observations	181	181
R^2	0.185	0.245

* p<0.10, ** p<0.05, *** p<0.01

the survey suggest ways to improve DA adoption. For instance, better internet data access, more workshops and communication to illustrate the benefits of DA technologies and how they work (and related R&D) may increase producers' willingness to adopt these technologies. These results suggest that government programs that invest in public R&D and education, and data and communications infrastructure, and provide better information on benefits and technical support are paramount in capturing the full benefits for New York agriculture.

Digital/Precision Agriculture Adoption and Trends in Western New York

In 2015, Cornell Cooperative Extension of Genesee County and the Northwestern New York Dairy, Livestock and Field Crops Team commissioned Mr. Kevin Kreher to conduct a qualitative survey of Western New York farmers to evaluate precision agriculture technology, and a possible role of Cornell Cooperative Extension. More than 60 individuals representing 140,000 acres of cropland were interviewed for this report, encompassing the perspectives of growers, consultants, industry experts, dealers, and equipment manufacturers. Advanced farms were specifically targeted for the interviews, therefore the data collected are not a random sample of farms across the region. One finding among this group was that the average farmer age shows no distinct correlation with technology adoption on a farm. The following text is a summarized version of opinions of the surveyed farmers and agricultural business professionals (full report is in Appendix I-B).

Equipment using GPS-enabled auto-steer, planters, sidedressers and sprayers is common on many larger farms in Western New York and the potential agronomic and economic benefits are being realized. Monitoring equipment to capture yield at harvest is also common on combines, although less so for choppers and fruit and vegetable machinery. The benefits of capturing yield data will be more apparent over time as it will allow for an understanding of variability in a field while making management decisions or modeling crops. A lot of data are currently collected and therefore a growing need exists for qualified support services. Many individuals in the survey wanted local community colleges or other educational institutions to offer courses related to digital agriculture.

A majority of the surveyed farmers agreed on the potential economic returns and benefits found when using auto-steer or GPS steering enabled equipment. They experience savings from a range of efficiency improvements, not just decreased input costs. In a planting operation, additional technology can be used to control several planting variables such as down force, population, singulation, and more. The ability to easily adjust these parameters, paired with row clutches or shutoffs also provides a majority of adopters with noticeable economic returns. Many reported that tiling operations using current software and GPS guidance became more than three times as efficient when compared to the previously used manual systems.

Variable rate application is one of the most prevalent ways farmers are using the data they generate. Utilizing collected data, software, and variable rate equipment, farms can turn soil health management and other input applications into a maintenance program for their fields, although these benefits may take years to pay off. For many inputs, especially nitrogen, economic returns will be most prevalent when the application is properly timed, as opposed to properly positioned. It is projected that increased adoption of variable rate application, and more precise soil, weather, and yield data will have a much greater impact on bottom lines in western NY than other agricultural areas in the US with less variability in soil type, geography, and climate.

As scouting data increase in both quantity and quality using both traditional methods and unmanned aerial systems, tracking of pests, diseases, weeds, and nutritional deficiencies can be coupled with precise and preemptive spraying and prevention practices. This will require increased connectivity between machinery and farmers' computers and between farms and other farms or consultants, all of which will require reliable internet connections, software training, and attention to data privacy.

As the precision of the data recorded for fields increases through more accurate yield, soil, elevation, nutrient, pH, and precipitation maps, digital agriculture technologies can be used to leverage greater economic returns. An example is advanced planters, capable of switching seed variety, varying down force, population, or fertilizer rate dependent on soil type or other variables, which will produce more consistent yields across variable fields. Soil nutrient and plant modeling software, coupled with weather data, and supplemented by aerial surveying methods, location aware scouting, and tissue sampling will make nutrient adjustments as close to automatic as possible. Fruits and vegetables will likely follow field crops when it comes to increased data collection and higher precision of data as more operations are mechanized at cost effective price points.

Cost Saving Technology

M.K. Phelps Farm Inc.

The Phelps Farm is located in Chaffee, NY on about 500 acres - 50 acres of potatoes, 50 acres of peas, and the remaining in corn.

The farm first started using DA technology over a decade ago with auto-steering and RTK. They have also used grid soil sampling and conductivity mapping in the field.

They initially adopted auto-steer for potato production. They produce high quality "B" size red potatoes. They had good support in the beginning to help them adapt to the new technologies although they admit to a large learning curve.

"We have been fortunate to have excellent dealer support which has been crucial to adopting new technologies"

Planting with auto-steer removes the "guess" from the guess rows, makes their hilling more accurate and leads to fewer sunscalded green potatoes and more precision during harvest.

The cost of the equipment was justified by the increase in marketable potatoes. They now use auto-steer with their corn and pea planting as well, enabling them to work in conditions that allow for timely planting. Reduced operator fatigue is also a huge benefit to their farm.

Figure 18. Lightning talks on digital agriculture initiatives and technologies in New York State are available on-line.

New York State Precision Agriculture Summit

A New York State Precision Agriculture Summit was held on December 15, 2015 at the New York State Agricultural Experiment Station in Geneva, NY. In all, 51 invitees from the New York agricultural community were in attendance, representing higher education, research, agricultural service businesses, farmers, technology companies, and government (Appendix II-A; Fig. 18). The meeting started with lightning sessions involving presentations on various initiatives and technologies currently available in New York, also including a preliminary analysis of the statewide precision agriculture survey.

A web site was created and the lightning talks were posted online: https://fieldcrops.cals.cornell.edu/extension-outreach/meeting-and-training-archives/2015-precision-agriculture-workshop; https://vimeopro.com/user9954358/2015-precision-agriculture-workshop.

In addition, abstracts of all the presentations along with their PowerPoints are available online (abstracts are also printed in Appendix II-A):

https://fieldcrops.cals.cornell.edu/extension-outreach/meeting-and-training-archives/2015-precision-agriculture-workshop/precision-ag-workshop-presentation-files

Breakout group discussions were held around the following topics:

- Areas of Opportunity for Precision Ag in NY
- Future Enabling Technologies and Innovation
- Business Development
- Impediments and Regulatory Issues
- Research and Education Needs

Key comments and overlapping themes included:

- Need for fast, widely available, reliable cellular data and rural broadband access.
- Need for economic feasibility and benefits analyses, demonstrating value of technologies
- Need for research and education
- Need for data management infrastructure, creating and standardizing data privacy and management policies, and a framework to govern storage, access and accountability of data
- Need for an institute to provide leadership, research, education, and promotion of business development

Summary notes of the workshop are included in Appendix II-B. Information on research, education, and business efforts are also discussed in Section IV.

Precision Agriculture Decision Making Program at the 2016 New York State Farm Show

A half-day program dedicated to Precision Agriculture was held in February 2016 as part of the New York Farm Show in Syracuse, organized by the New York Farm Viability Institute in collaboration with Cornell University. Over 40 farmers and ag-professionals attended the informative sessions with topics on precision agriculture technologies, economics, research, and results from the statewide Precision Agricultural Survey. The event concluded with a panel of three growers on their experiences with precision agriculture technologies. The event was filmed and the presentations is available online: https://vimeopro.com/user9954358/2016-precision-ag-decision-making-program . A descriptive abstract is available in Appendix II-C.

Part III

Communication, Data Management and Regulations for Digital Agriculture

Communication for Digital Agriculture in New York State

This section discusses the availability and needs around the use of digital communication in agricultural areas of the state.

GPS

The GPS network of satellites is maintained and operated by the US Air Force. It is low precision but very robust and functioning close to 100% of the time. While GPS is broadly available throughout the entire state, obstructions like forests or dense hedge rows may prevent a reliable signal within 45' of the trees (Bruce Wright, Cobleskill Univ., pers. comm.). Areas of the state with hills and valleys may also lack a reliable signal.

RTK

Utilization of RTK has the potential to give farmers the needed precision for many of their farm operations, but this may be a challenge for some parts of NYS. RTK is utilized by receiving satellite corrections via a public or private RTK network or a single base station. Communication with the networks is done over the internet or via a cellular network, while communication with an individual base station is done by radio signals or cellular connection.

Public Networks: The Continuously Operating Reference Station (CORS) network is available throughout the country. (CORS) is coordinated by the National Oceanic and Atmospheric Administration (NOAA), and the network of base stations is commonly maintained by states. As part of CORS, the New York Department of Transportation (NYSDOT) maintains a network of RTK base stations across the state called the NYSNet (New York State Spatial Reference Network). Use of the network is free and connection to NYSNet is by cellular service. Based on their coverage map, most of the state is within 20 miles of a base station, and some within 30 miles (Fig. 19). The correction is less accurate farther away from a base station in the network. Still, many areas within network coverage may not be accessible because of a lack of cellular signal. NYSNet is also not reliably functional. Some stations are off line for extended periods of time and a farmer relying on the network for DA technologies could find the correction signal unavailable when they need it (http://cors.dot.ny.gov/spiderweb/frmIndex.aspx and https://twitter.com/nysnet).

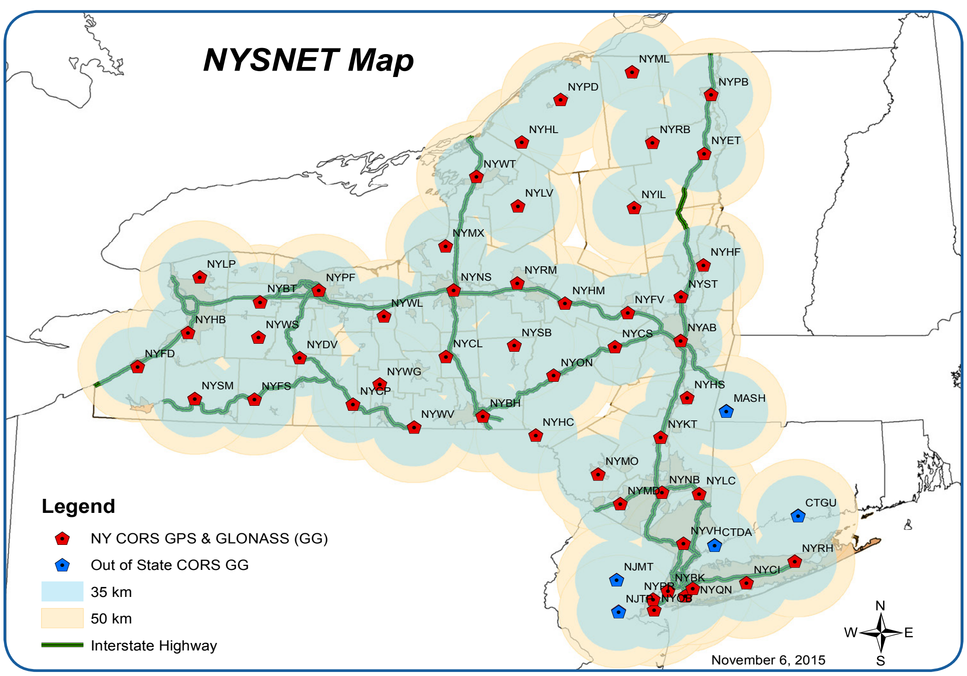
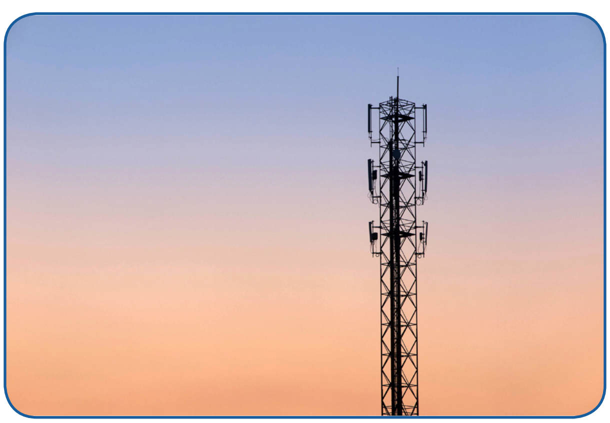


Figure 19. NYSNet coverage map (https://www.dot.ny.gov/divisions/engineering/design/design-services/land-survey/repository/NYSNET%20RTN%20Map.pdf)

Subscription Networks: Services like Trimble VRS Now and MyWay RTK are privately maintained RTK networks that don't require private base stations, but rely on cellular connections. MyWay RTK has coverage in Western NY (between Rochester and Buffalo) through five stations, but not in other areas of the state. Trimble VRS Now is not yet available in NY.

Private Base Stations: A strong cellular data signal is necessary to access private or public RTK networks and there are many places throughout the state with poor cellular service. Currently there are no privately maintained RTK networks that are available by subscription in NY, but some dealers have formed informal networks with their customers . Farmers can erect their own farm based station to provide RTK service for their farm operations as an alternative option to the NYSNet. These can also be shared by farmers and serve as a common local network. Base stations are accessed by either radio or cellular connections and can use a repeater for increased range. Radio transmission can be a limiting factor because of obstructions like forests or hills, but have the advantage of being possible in areas without cellular service. Radio transmissions can reach a distance of about 12 miles by line-of-site, possibly with another 12 miles in one direction with a repeater. However, many will be much less than 12 miles because of obstructions. Cellular communication can provide increased range, but the cellular network must be accessible.



Strong signals are necessary to access networks and allow for rapid data transfer.

Private base stations also need to be maintained to continue working correctly. Lack of a dependable cellular network could prevent the use of RTK even if there is a local RTK base station or network. Many farmers are moving away from RTK to subscription based satellite corrections citing inconsistent cell service, private tower maintenance, and an undependable public RTK network (Bruce Wright, pers. comm). It is also anticipated that corporate RTK networks (Trimble and MyWay RTK) will expand in the state.

Satellite Correction

Private subscription-based satellite correction services remove most of the errors inherit with GPS. A network of GNSS reference stations around the world is used to compute GNSS satellite orbit and clock corrections. The corrections are broadcast via geostationary satellites and are independent of cellular networks, base stations, or RTK networks. Although satellite correction (1.5 inch) has lower accuracy potential than RTK (<1 inch), this level of accuracy is often acceptable for most DA applications.

Companies such as Agleader, Trimble, Terrastar, Starfire, Veripos, and, Omnistar all provide correction services. Each usually provides a range of options with different levels of accuracy and prices, which farmers adapt to their needs. The companies built multiple redundancies into their systems with one company (Starfire) claiming "99.99% uptime." (https://www.navcomtech.com/navcom_en_US/products/equipment/cadastral_and_boundary/starfire/starfire.page).

Like uncorrected GPS, topography including hills, hedgerows, and variations in terrain have the ability to affect access to the correction signals. Currently, in most areas of the state satellite correction is a better option than RTK, although it limits the use of certain high-precision applications.

Cellular Network

A dependable strong cellular connection is necessary for many DA applications, including technologies like auto-steer and precision seed/input application that rely on RTK and in turn rely on the internet via a cellular connection. Cell service is dependent on the network of cell towers throughout the state that is maintained by private companies, and state coverage varies. Cellular coverage maps are available from the major providers in the state (Verizon, AT&T, Sprint, and T-Mobile). While they are generally accurate on a macro scale there are still "dead spots" that don't show up on the coverage maps, in addition to areas known for absent coverage.

Other DA services are also increasingly relying on internet data coming directly into equipment cabs (and vice versa), which are also becoming mobile offices. This includes farmers or custom applicators receiving variable rate prescriptions directly to their equipment and those who may wish to load yield and application data into the Cloud directly from their equipment. Without proper connectivity farmers are more likely to rely on manual data transfer that may not happen until the end of the season so "opportunities to adjust management practices are missed, significantly affecting farm profitability, productivity, and environmental impact…real-time communication between farm equipment and online servers is not possible… and leads to geospatial data not being sufficiently backed-up in a timely manner, therefore increasing the risk of this valuable data being lost or destroyed" (Mark and Griffin, 2016). Advertised download speeds of 5-15 Mbps and uploads speeds of 2-5 Mbps are not high enough for cellular service to be considered broadband (Federal Communication Commission, 2015), which would be necessary for dynamically uploading and downloading many DA data files.

Broadband

While most of the mobile hardware relies on accessing the internet via a mobile cellular data connection, much of the processing of the data happens in the office and relies on a dependable high speed internet connection. This is usually a hard-wired or wireless broadband connection but can also be a wireless

Connectivity

Western New York Crop Management Association

WNYCMA (wnycma.com) is a grower owned cooperative providing soil sampling, crop nutrition recommendations, CAFO planning and other services to 551 member farms.

They use GIS, satellite imagery and in-field observations to inventory field information. The data are used to develop crop nutrition and pest management plans. Prescriptions can be installed directly onto tractors allowing the vehicle to automatically vary the rates of material applied.

"Modern software requires fast internet connections with 100% uptime that is not available in all the areas we serve"

Their clients are purchasing new software and equipment but are not always clear on how to use and benefit from the technology. There are other challenges such as different brands being able to exchange information with each other and slow or unreliable connectivity preventing real-time data transfer and decision making.

Avery DeGolyer, crop consultant and data manager for WNYCMA, sees the need for rapid, responsive, field-based research for various field conditions. "Research and development is crucial for equipment and methods specific to the Northeast" he said.

cellular connection depending on what is available and their speed. If mobile cellular connections are poor or non-existent, data tend to be manually transferred from field equipment or barns to the central farm computer where all data uploading, downloading, and processing is done.

According to USDA-NASS national data (USDA NASS, 2015) 73 % of farms have computer access and 43% utilize computers for farm use. Similarly, in New York State, 73 % of farms have computer access and 42% utilize them for farm use. Internet connectivity has increased nationally with 70% of the farms having internet access in 2015 through DSL (30%), wireless (29%), or satellite (21%). Again, the statistics are mostly similar for New York State: 72% have internet access with the most common connection method being cable (25%), wireless (24%), DSL (22%), and satellite (18%). Satellite and wireless internet access have increased in recent years, while DSL has seen the biggest decline. In New York State, cable has increased substantially, although this is not the case nationally.

It is important to note that statistics from USDA-NASS only provide information on internet access, not broadband. This is relevant because speeds may not be high enough for efficient data uploading and downloading. Broadband maps show that high speeds are still largely limited to areas of high populations (Fig. 20).

New York State Broadband Expansion

New York State is committing significant resources to expand broadband throughout the state. The goal is to have 100Mbps service throughout the entire state by 2018 with the most remote areas having at least 25Mbps (http://nysbroadband.ny.gov/sites/default/files/broadband_press_release.080316.pdf).

The state has allocated $500 million to this goal through grant programs as part of the "New NY Broadband Program." Phase I grants have already been allocated, and Phase II grant proposals are currently being requested. One final request for proposals will ensure that all parts of the state are adequately covered. In addition to state resources, funds have also been requested by NYS from the Federal Connect America Program (CAP). For those areas that did not fall under the Phase II expansion areas, as a condition of the merger approval between Time Warner and Charter, the NYS Public Service Commission required increased broadband speeds for 2 million customers (mostly in rural areas) to 100 Mbps by 2018 and required Time Warner to expand broadband availability to 145,000 households, which is roughly all of the remaining underserved households in NYS (Fig. 21, NYS Broadband Office, per. comm.) There are a total of 8.1 million "housing units" in NYS.

To obtain estimates of the percent of crops grown in Census blocks where households are currently underserved or unserved, we obtained Cropland Data Layer files from USDA for 2015, and combined them with the NYS Broadband availability maps to calculate the percent of crop acres falling in areas without appropriate service (Fig. 22 and Table 28 a and b). About 22.4% of corn acreage

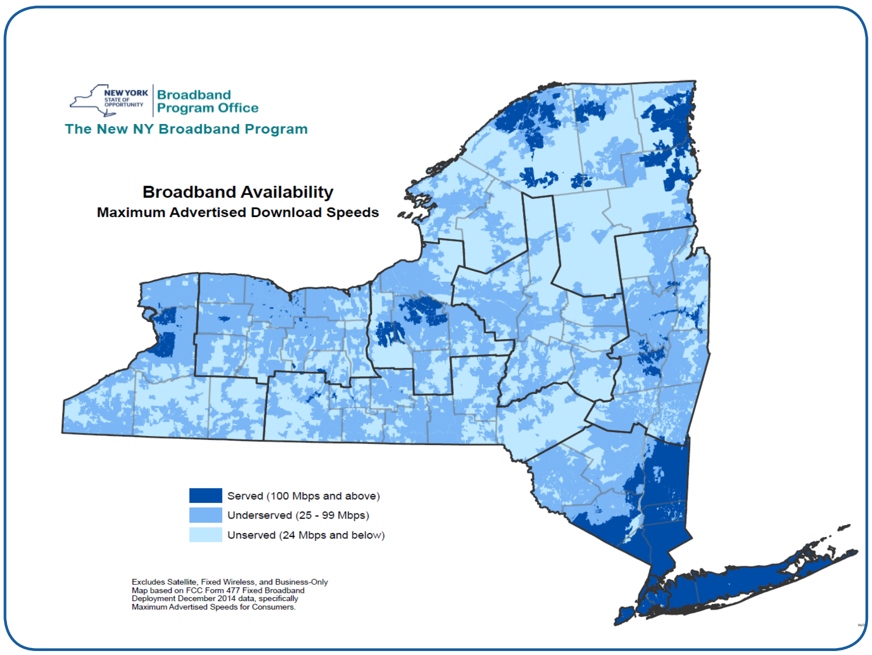


Figure 20. Broadband Availability (Underserved and Unserved) as of December, 2014 (Source: Map Image Published by New York Broadband Office). Unserved Census Block - An area where broadband service is not available from a wireline or wireless facilities-based provider at advertised speeds equal to or higher than 25Mbps (download). Underserved Census Block - An area where broadband service is not available from a wireline or wireless facilities-based provider at advertised speeds equal to or higher than 100 Mbps (download)

falls in a Census Block that is currently un/underserved in NYS, although this varies significantly by county (Table 28 a and b). Even a top corn producing county like Cayuga still shows 43% insufficient broadband coverage (Fig. 22).

Similar numbers were found for other crops, such as soybeans (18.1%), Wheat (15.1%), Alfalfa (24.2%), as well as total crop numbers in the state (25.7%). Onions had a much higher underserved ratio, with about half of all onion acres falling in Census blocks that are not properly served. Notably, both apples (9.5% un/underserved) and grapes (8.0% un/underserved) had much higher rates of broadband access, though some counties such as Dutchess and Lewis had very high rates of underservice.

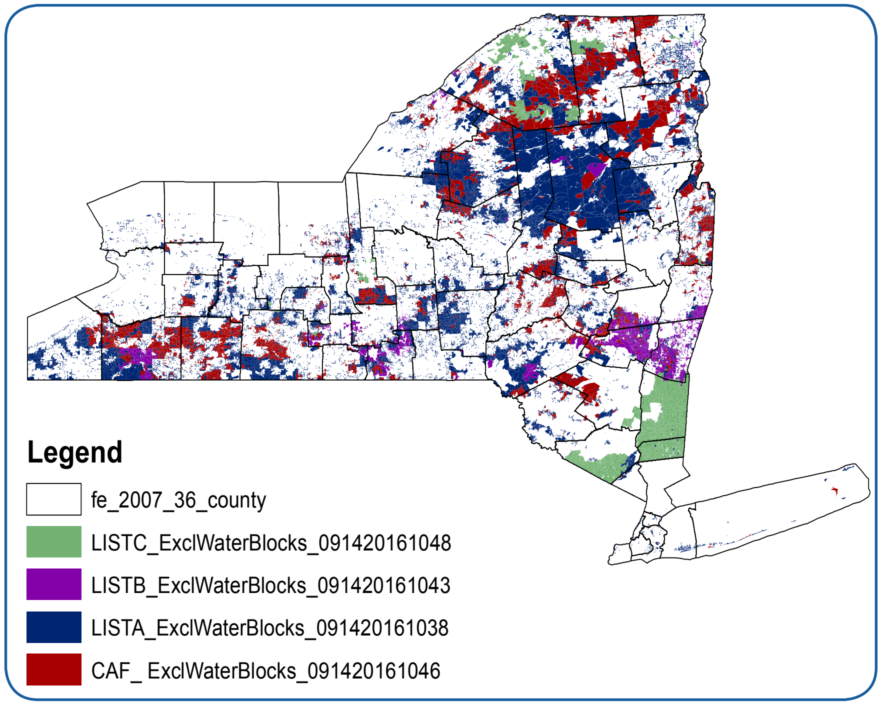


Figure 21. Phase II Broadband expansion areas, as of September 2016, including Unserved (list A), Underserved (list B), Additional Service Areas (list C), and CAF. These include essentially all remaining uncovered broadband households in NYS, and are slated to be completed by 2018.

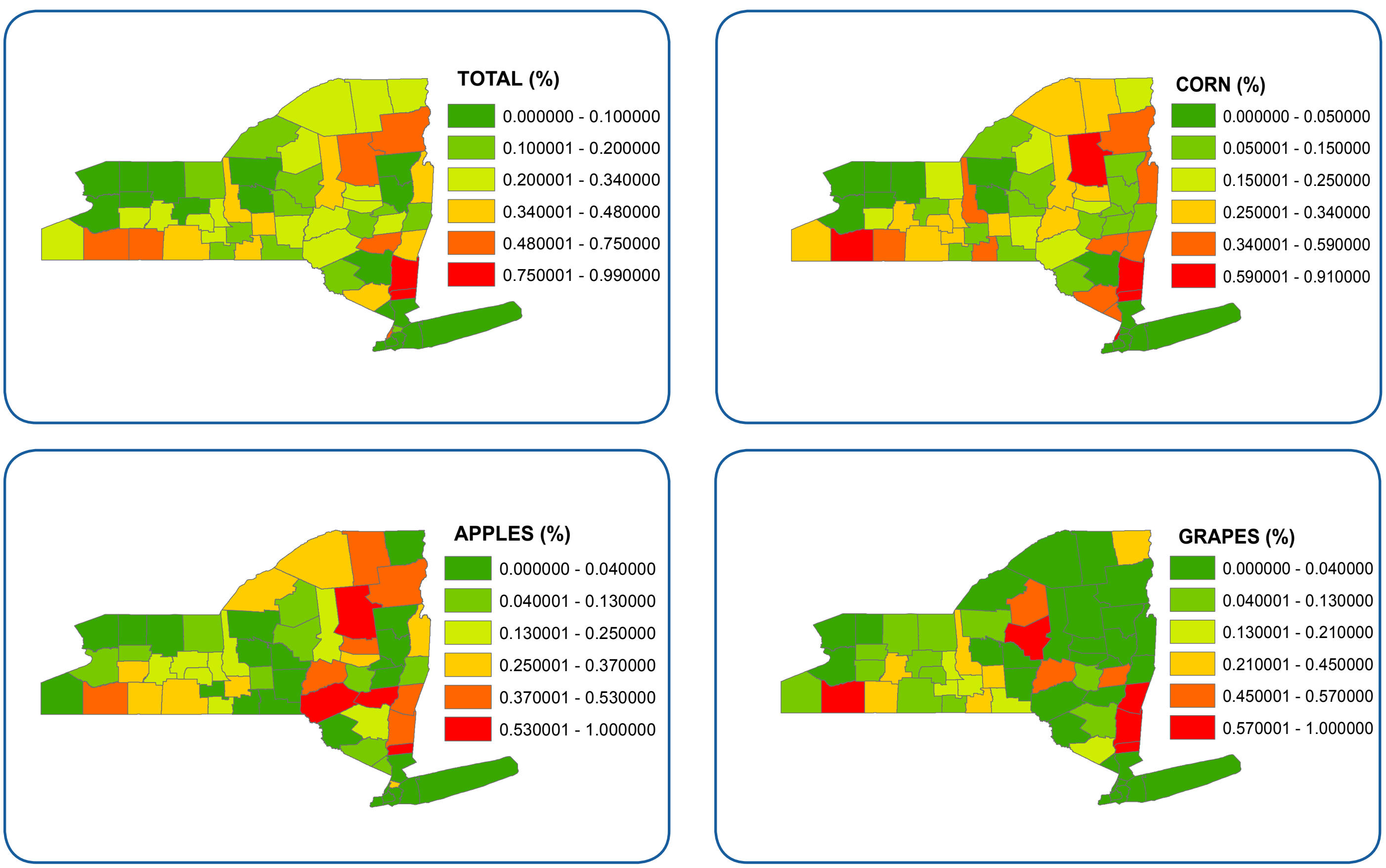


Figure 22. Percent of Crop Acreage with Insufficient Broadband Service Area, by County: Total, Corn, Apples, and Grapes.

Table 28a. Percent of cropland with insufficient broadband coverage by county and crop (all combined Phase II areas).

	Corn	Soybeans	Winter Wheat	Oats	Alfalfa	Other Hay	Dry Beans	Potatoes	Onions	Peas	Apples	Grapes	All Crops
New York State	**22**	**18**	**15**	**28**	**24**	**32**	**15**	**13**	**52**	**15**	**9**	**8**	**26**
Albany	13	4	50	0	15	33	100				1	50	29
Allegany	50	42	57	61	62	58	49	37	13	36	37	45	56
Broome	13	15	15	14	13	18	20		0	0		20	16
Cattaraugus	66	66	53	75	57	69	68	34	80	64	50	88	67
Cayuga	43	38	38	31	46	44	38	3	97	27	24	44	42
Chautauqua	30	27	21	29	28	35	18	15		22	3	6	29
Chemung	13	18	25	35	14	25	12	100	0	23	25	11	20
Chenango	18	15	21	19	22	28	8	0	0		0	0	24
Clinton	21	5	56	69	31	46					3	42	29
Columbia	42	53	38	63	44	45	0	25			53	82	45
Cortland	28	26	30	43	34	46	18	17	25	41	12	38	38
Delaware	19	22	7	13	22	28	12		0		80		27
Dutchess	91	97	84	74	81	79		44			44	82	82
Erie	4	5	5	1	3	3	3	2	0	1	9	4	3
Essex	58	51	20	35	59	64					53		61
Franklin	30	19	26	28	30	38	25	100	83		44		34
Fulton	30	43	73	80	48	25	0		0		40	0	27
Genesee	4	5	4	6	5	5	3	3	12	4	6	5	5
Greene	48	3	33	8	63	66	0	100			84	0	63
Herkimer	32	30	18	48	35	39	13		25		20		37
Jefferson	13	14	11	11	14	24	10		33		31	0	20
Lewis	20	21	32	25	20	35	21				13	57	28
Livingston	28	25	28	38	30	26	38	17	12	46	23	33	28
Madison	14	9	15	18	16	20	10	0	0		2	0	16

NOTE: Insufficient is defined as either falling in an Unserved, Underserved, Connect American Fund (CAF) Eligible, and Additional Service Eligible (full and partial) as classified by the New York Broadband Office, which generally encompass all households with less than 100 Mbps coverage. These four classifications collectively constitute the New York Broadband Program Phase II Expansion areas. These include all areas of the State with remaining insufficient coverage areas, with the exception of those that fall under the Time Warner/Charter Merger Coverage areas which are subject to the Public Service Commission conditions requiring those providers build out at least 145,000 (~100% coverage) new addresses and upgrade 2 million customers to 100 Mbps speeds. The expected coverage in the State by households is forecasted to be virtually 100% with 100 Mbps coverage or better by 2018 after the completion of Phase II. See more information at https://www.nysbroadband.ny.gov/.

Table 28b. Percent of cropland with insufficient broadband coverage by county and crop (all combined Phase II areas).

	Corn	Soybeans	Winter Wheat	Oats	Alfalfa	Other Hay	Dry Beans	Potatoes	Onions	Peas	Apples	Grapes	All Crops
New York State	**22**	**18**	**15**	**28**	**24**	**32**	**15**	**13**	**52**	**15**	**9**	**8**	**26**
Monroe	5	3	2	3	6	1	1	0	0	0	1	8	4
Montgomery	25	25	21	30	30	27	25	0	0		34		26
Niagara	4	5	4	2	5	5	5	18	5	3	4	4	4
Oneida	13	9	13	12	13	24	7	0	0		6	75	16
Onondaga	4	3	2	2	6	5	5	0	4	0	1	4	4
Ontario	7	7	5	12	7	7	17	53	6	11	15	8	7
Orange	43	52	16	9	44	35	0	0	71		6	21	39
Orleans	3	2	1	3	2	1	0	33	49	1	1	4	3
Oswego	3	5	5	3	3	6	8	0	9		2	10	5
Otsego	28	32	28	33	34	32	16		50		40	50	32
Rensselaer	15	14	6	8	14	13		0			5		14
Saratoga	9	10	6	3	11	9					1		9
Schenectady	9	5	0	0	16	20					3		19
Schoharie	10	11	2	22	15	19	8	0			7	11	17
Schuyler	29	31	28	45	28	34	71	100		53	2	18	31
Seneca	26	21	29	27	22	27	27	28	91	38	19	17	24
St. Lawrence	33	27	35	49	30	35	31	30	0		31		33
Steuben	33	36	24	41	33	48	25	36	74	32	27	10	41
Suffolk	0	1	0		0	1		0			0	0	0
Sullivan	10	8	0	8	8	13			0		0		13
Tioga	40	31	38	32	36	55	20	80		38	0	42	48
Tompkins	15	15	26	20	13	16	12	0	26	43	26	14	15
Ulster	2	3	33	0	3	9	0	9			16	13	10
Washington	44	36	37	61	45	39		0			29		43
Wayne	17	21	14	11	15	14	16	18	6	11	8	6	16
Wyoming	24	22	33	18	23	22	25	18	25	21	29	6	24
Yates	34	28	24	41	34	29	37	99	100	64	21	12	31

NOTE: Insufficient is defined as either falling in an Unserved, Underserved, Connect American Fund (CAF) Eligible, and Additional Service Eligible (full and partial) as classified by the New York Broadband Office, which generally encompass all households with less than 100 Mbps coverage. These four classifications collectively constitute the New York Broadband Program Phase II Expansion areas. These include all areas of the State with remaining insufficient coverage areas, with the exception of those that fall under the Time Warner/Charter Merger Coverage areas which are subject to the Public Service Commission conditions requiring those providers build out at least 145,000 (~100% coverage) new addresses and upgrade 2 million customers to 100 Mbps speeds. The expected coverage in the State by households is forecasted to be virtually 100% with 100 Mbps coverage or better by 2018 after the completion of Phase II. See more information at https://www.nysbroadband.ny.gov/.

Data Privacy and Availability

As farmers adopt precision agriculture technologies they accumulate large amounts of data in the form of yield files, as-applied maps, aerial imagery, nutrient applications, milking, animal health records, etc. They are increasingly concerned about data privacy and ownership issues, while the legal issues around agricultural data are unresolved at this time with the increased use of Cloud-based services and storage. Agricultural data are no longer confined to on-farm computers or equipment. Data may be shared with equipment dealers, service providers, consultants, researchers, custom applicators, and even other farms. Increasingly data are accumulated by large integrated "Big Ag" companies which are currently heavily investing in digital technologies.

Nebraska farmers were surveyed in 2015 about precision agriculture usage and data privacy, which was summarized as follows (Castle et al., 2015; http://agecon.unl.edu/cornhusker-economics/2015/precision-agriculture-usage-and-big-agriculture-data): "Survey respondents were comfortable sharing their data with trusted partners, such as university researchers or educators (45%), relatives (39%), and local cooperatives (39%). But more respondents trusted their data with "no one" (23%) than with equipment dealers (18%), equipment manufacturers (17%), or neighbors (13%)." There is a clear concern about sharing data, yet to get the most from the data it will be critical to have a way to aggregate and share data in a way that respects farmers' data privacy. Growers at the NY Precision Agriculture Workshop also expressed concerns about their data including how dealers and regulators could use their data if they had access to it (Appendix II-B).

Farm data are not protected in current statutes (copyright, patent, trademark, or explicitly protected personal health or financial data). If data are kept in Cloud based software, is the software provider allowed to use it for its own purposes? In the survey of Nebraska farmers 100% of the respondents indicated that they believe that the data belongs to the farmer despite the fact that DA equipment or services often come with producer agreements that gives access or ownership of the data to other parties.

Most DA companies attempt to address this issue with grower contracts (e.g., Adapt-N's Grower Bill of Rights; http://www.adapt-n.com/terms/grower-bill-of-rights/). To respond to these needs more generally, a program has been established by a non-profit organization called Ag Data Transparent, supported by Farm Bureau and several grower organizations (http://www.fb.org/agdatatransparent/). It aims to function as an industry watchdog by offering certification on issues like data ownership, privacy, aggregation, sharing, transparency, consistency, portability, anonymization, and opt-outs through the newly-established Privacy and Security Principles for Farm Data program (http://www.fb.org/tmp/uploads/PrivacyAndSecurityPrinciplesForFarmData.pdf). Companies can receive certification by responding to ten questions and meeting certain criteria, allowing them to use a logo on marketing materials (Fig. 23).

Figure 23. Ag Data Transparent logo.

A remaining concern is that, based on current trends, the vast majority of farm data will be stored and controlled by large equipment or seed/chemical companies, which in turn are rapidly consolidating.

They would mostly employ the data for their own commercial purposes. This will constrain future public research efforts as these data would not be available for analytics and the development of next-generation agricultural management guidelines. I.e., it would make the public-sector research infrastructure a minor player and unable to offer independent analysis and guidance on sustainable management practices. Since farmers appear to trust university researchers and consider DA research and education a high priority (based on the Nebraska and New York surveys), it is recommended that a public data infrastructure is built that allows farms to make their data available for storage, archiving, and analysis. In addition, we recommend that the universities invest in research capabilities to address these Big Data needs.

Regulations

New Technologies:

Solutions to environmental degradation can be assisted by digital agriculture technologies. However, most regulations, standards and cost-share programs are based on research or policies developed prior to the availability of digital management technologies. The enforcement agents, service providers, and policy advisors mostly rely on outdated standards, and new technologies that offer superior outcomes are often not incorporated.

For example, Concentrated Animal Feeding Operations (CAFO) permits require a nutrient management plan that meets the USDA Natural Resources Conservation Service (NRCS) NY 590 Conservation Practice Standard, which is also required for cost sharing. Currently the New York standard requires farms to follow conventional, static university guidelines for proper timing, rate, source, and placement of fertilizer applications. However, some DA technologies have been shown to offer superior economic and environmental outcomes (Sela et al., 2017; http://blogs.cornell.edu/whatscroppingup/2016/05/24/use-of-adapt-n-results-in-better-agronomic-and-environment-outcomes-than-the-corn-n-calculator/), but adoption into the NRCS 590 is lagging. The regulatory community therefore needs to adapt to the more complex digital farming environment.

Innovation and Regulation

Agronomic Tech Corporation and Adapt-N

Steven Sibulkin, Greg Levow and Holly Trytten founded Agronomic Technology Corporation (ATC), which is based in New York. Their services span across 95% of corn production acres of the United States.

ATC owns a license from Cornell University to Adapt-N, a decision tool providing dynamic nitrogen (N) recommendations for corn (Adapt-N.com). The tool combines field-specific inputs with near real-time weather data to improve the precision of N application, thereby improving profits and minimizing environmental impacts.

"A more flexible and adaptable regulatory approach is critical"

A more flexible and adaptable approach to new digital farming technologies, like Adapt-N, is critical in facilitating more rapid farmer adoption and the associated production and environmental gains.

In this context, Adapt-N is the first (and currently only) DA decision tool approved by the NutrientStar Program (nutrientstar.org).

Like with data privacy, third parties are trying to address these needs and are developing programs to assess the sustainability credentials of decision tools. For example, the NutrientStar program (nutrientstar.org) was initiated by the Environmental Defense Fund with a mission to identify fertilizer management products and decision support tools that effectively address air and water quality concerns through rigorous scientific assessment. This is used in supply-chain management initiatives in which food companies and retailers aim to achieve sustainability objectives like greenhouse gas reductions and water quality enhancements.

Records

Automated digital record keeping offers additional opportunities for regulatory compliance when farmers use collected data to document that operations are in compliance with legal guidelines. Examples include:

- Digital as-applied records from fertilizer, manure and pesticide applicators can document that application rates, placement, timing and minimum setbacks were followed in adherence to nutrient management plans or pesticide labels.
- Documented yield, weed, insect or disease data can offer rationale for fertilizer or pesticide applications.
- Animal records can document animal treatment standards (e.g., minimum days in outdoor environment), justify the use of health interventions, and facilitate product source tracking.

When considering DA in the context of regulatory issues, consideration needs to be given to addressing the needs of technology innovators (which is currently inadequate) vis-a-vis potential adverse effects on producers on the other side of the "digital divide". Also, the State of New York may consider guidelines that directly addresses issues around data privacy and availability.

Part IV

Research, Education and Technology Development

Digital Agriculture Research

Research related to digital and precision agriculture is primarily conducted by faculty and extension staff at Cornell University, SUNY Cobleskill and SUNY Morrisville. Work began in the late 1990's as yield monitors emerged on grain farms and continues today as many of these technologies have become standard on new machinery. Leading research interests at the time of this report include the following (see Appendix II-A for details):

- Using real-time weather adjusted models to improve the use of chemical thinners in apple orchards.
- Determining new sites for vineyards based on multiple GIS layers of site-specific information including climate, geography, and soil characteristics. For existing vineyards, researchers are developing new ways to use data-driven variable rate management.
- Developing precision sprayers for orchards that sense the presence, height and width of the crop and can turn nozzles on and off to improve pesticides use efficiency.
- Improving speed of the breeding process through the use of UAV's and field sensors for rapid phenotyping.
- Assessing the accuracy and precision of forage yield monitors, assessing how best to use plant and soil sampling in relation to precision agriculture, developing algorithms for on-the-go sensor-based nitrogen management, and the use of field management zones for yield and resource allocation.
- Researching corn and soybean variety selection and variable rate seeding models adapted to the soil and climatic conditions of New York State.
- Further developing and assessing the effectiveness of the Adapt-N software tool for managing nitrogen in on-farm trials, using yield monitor data to better manage fields for profitability and developing new on-farm research methods.
- Development of an 'Ag-Analytics' data platform by agricultural economists to create a comprehensive open source data warehouse available for research efforts.
- Developing the 'ValuAg' network, an online directory and exchange service for the food industry with the goal of reducing waste from field to fork.
- Developing the Broadband Rural Agriculture Cloud (BRAC) to act as a clearing house for agriculture and farm information. The project will include developing a wireless broadband mesh network connecting the SUNY Cobleskill campus with their 150- acre research farm and training students in the skills to analyze farm data.
- Funding multiple DA related projects through the New York Farm Viability Institute (NYFVI) as well as coordinating DA education and outreach in the state, including a precision grape pruning/thinning and precision apple fertilization irrigation and pruning.

Using real-time, in-field monitoring.

Digital Agriculture Education

Some coursework related to digital agriculture is offered, but is still sparse at colleges throughout the state:

- SUNY-Alfred teaches one undergraduate course on PA that "covers the acquisition and analysis of geographically referenced data for the management of crop production systems."
- SUNY-Cobleskill has integrated PA into several classes including Agricultural Power Machinery and Intro to Sustainable Agriculture.
- SUNY-Morrisville has an introductory course on computer applications in precision farming.
- Cornell University doesn't have any courses specifically dedicated to Digital or Precision Agriculture, but there are several courses that teach component technologies including GIS, GPS, resource inventory (mapping remote sensing, etc.), spatial analysis, high-throughput phenotyping in plant breeding, and also a soil-crop management class that includes lectures and labs on Digital Agriculture.

This highlights the need for further educational coordination and broadening of opportunities for future growers, interested students and entrepreneurs in the state through the state's university system.

Service Providers and Technology Companies

There are growing numbers of businesses providing support for digital agriculture, as well as innovative companies developing technologies for use around the world. Leading NY-based services for DA technologies at the time of this report include (see Appendix II-A for companies and detailed descriptions):

- Tractor and equipment dealers are integrating DA/PA technologies into farm tools, in addition to providing support to help adopt technologies.
- Agricultural consultants are providing services that collect site-specific data such as soil and EC sampling and then translating that information into field-specific prescriptions.
- Companies are offering services such as aerial imagery to provide actionable information to farmers and consultants.
- Custom applicators are adopting GPS-enabled VRT equipment to utilize prescriptions for field applications.

Several industry leaders and pioneers in DA are based in New York (see also Appendix II-A), notably:

- Agricultural Modeling and Training Systems, LLC (Cortland, NY). A global company offering software tools for ruminant nutrition (licensed from Cornell University)
- Agronomic Technology Corporation. A company offering Cloud-based crop nitrogen management software (Adapt-N, licensed from Cornell University)
- Valley Agricultural Software. A company offering software and hardware solutions for the dairy industry. Although formally based in California, it has New York roots.
- Voss Vertical (Syracuse, NY). A startup company developing fixed wing UAVs.
- Ursa Space Systems (Ithaca, NY). A startup company developing low cost satellite imagery applications, including for agriculture.
- Corning, Inc. (Corning, NY). A global leader in glass products that has developed an aerial hyperspectral imaging platform.
- IBM (Armonk, NY). A leading global technology company in computation, big-data applications, and weather products. Its Watson unit is the world leader in artificial intelligence.

Part V

Challenges, Opportunities and Recommendations

Education, Research and Data

Challenges and Opportunities

Based on our analysis, we concluded that, in order to advance DA in New York, educational issues need to be addressed at multiple levels:

- The majority of NY farmers believe they are inadequately trained on the use of DA technologies and have insufficient knowledge to make economic decisions on DA adoption
- Digital Agriculture will inevitably create a "digital divide" in the New York farming community, unless programs address the needs of underserved constituents.
- Machinery dealerships need more employees trained and staffed in DA technologies, and most consulting service providers are inadequately trained to support effective farmer adoption.
- Cornell Cooperative Extension has limited staff expertise and educational programs related to DA, and in many cases cannot effectively meet the needs of innovative farms.
- Recent college graduates generally have received insufficient training in digital technologies, data management and analytics, and their applications in agriculture
- More faculty are needed at Cornell University and SUNY agricultural colleges that have knowledge and skills to prepare undergraduate and graduate students for professions in DA.

For research and data:

- Concerns exist about farm data in terms of (i) security and privacy, and (ii) use of such data by companies to advance their own interests. This will become more significant as real-time interconnectivity of equipment with centralized data storage will become more prevalent with the advance of the "Internet of Things".
- Farm data will offer a "treasure trove" for analytics, but researchers generally do not have access to farm-derived DA data for use in advanced analysis and the development of new management practices.
- Farmers would like to better employ their data, but are constrained in their abilities to take advantage of analytics to improve management and profitability, which is exacerbated by the "digital divide" and lack of university involvement.
- DA and publicly-available data products (e.g., Google Earth Engine) offer opportunities for new research paradigms to develop the next-generation management recommendations (e.g., related to nutrients, pesticides, harvesting, feeding). But due to limited funding and a small researcher community, NY-based DA research is inadequate. Moreover, certain promising areas of DA research and graduate training are not addressed at all.
- Current research cycles are too long and funding programs too conservative for innovative research on rapidly-evolving technologies.
- The present research-extension paradigm is not well adapted to partnerships with private sector agriculture and technology companies.

Recommendations

New York's agricultural sector and technology companies have good potential to leverage Digital Agriculture technologies, but foregoing these opportunities would negatively impact the industry's competiveness. Given that agriculture forms the backbone of the Upstate economy and employment profile, we therefore recommended a significant state investment in Digital Agriculture, and specifically to

- Build on recent DA initiatives at Cornell University and establish an **Institute for Digital Agriculture (IDA)** focused on research, education, data management, and business development. It would serve as a focal point and international leader for DA activities, attract talented researchers and educators, facilitate robust and innovative research efforts, and collaborative work with engineering and computer science disciplines, as well as with New York-based agricultural and technology companies.

- Establish within IDA a **public-sector data center infrastructure** that allows for the collection, curation, and analysis of data from New York farms, with appropriate consent, privacy and security considerations. The data would be available for aggregate and anonymized analytics and the development of a new generation of management recommendations. IDA should also support and engage with initiatives that address concerns about data privacy, security, and ownership for New York agricultural data.
- Within the IDA, allocate dedicated funding to support highly-innovative (and potentially commercialized) research efforts in Digital Agriculture, while also enhancing funding for on-farm research through existing programs (NYFVI, IPM, etc).
- Develop an educational (academic and extension) program within IDA working with agribusinesses, consultants, Extension, and SUNY institutions to advance Digital Agriculture in the state.
- Initiate a coordinated faculty hiring effort at Cornell University and SUNY agricultural institutions to increase research, education and extension capacities in DA. These positions would build a cadre of subject matter specialists with high skill levels in data analytics and precision technologies in different agricultural disciplines.
- Consider guidelines that proactively addresses privacy, availability, regulatory and equity issues around agricultural data.
- Link research and education with entrepreneurship and venture development programs at the university and state level.

Connectivity Infrastructure

Challenges and Opportunities

In New York,

- The current state of connectivity limits the effective employment of DA technologies in many rural areas of the state, although recent plans by the State of New York call for expanding broadband access and are already underway.
- Inadequate cellular coverage and data transmission speeds for uploading and downloading of data will continue to be a problem without additional investments and innovative solutions to improve mobile connectivity.
- New low-power wide area networks (LPWAN) offer opportunities for the use of sensor technology and equipment communications through the so-called "Internet of Things", but are currently non-existent in rural NY.
- Universal access to RTK technology in the state's rural areas will facilitate advances in the use of precision-guided, auto-steered and autonomous self-driving equipment in agriculture, as well as the ability to collect highly localized data for analytical purposes. Adoption of RTK technology could potentially be significantly enhanced through a more coordinated effort and investments by the state.

Recommendations

Due to the multifaceted nature of NY agriculture and the emphasis on high-value products, the state will greatly benefit from investments in connectivity. It is recommended to

1. Expand broadband access to all rural areas in the state (as currently planned); this is already underway.
2. Promote the expansion of next generation cellular technology in rural areas to connect mobile farm equipment with the internet, and enable high levels of data acquisition and transfer.
3. Explore opportunities offered by low-cost LPWAN networks to facilitate multiple farm tools and sensors having internet connectivity.

Expanding broadband access to rural areas is critical.

Business Development

Challenges and Opportunities

Five different types of New York-based businesses can benefit from Digital Agriculure, each with different needs:

- **Farms,** which need support from other businesses as well as public sector services (especially education and research)
- **Consulting companies** that work directly with farms who engage with data collection, management and analysis for improved farm management. These companies would gain from support in technology education and analytics.
- **Dealerships** that sell DA-enabled equipment and provide associated support services. These companies would benefit from education of farmers to help them make adoption decisions, and research-based management recommendations to promote DA use.
- **New enterprises** that offer new DA technologies or services and would benefit from research and education connections, and business networks.
- **Established technology companies** that are developing and offering DA services. These would benefit from research connections and business networks.

Recommendations

Through the institute for Digital Agriculture and other state initiatives,

- Better link research and education with entrepreneurship and venture development programs at the university and state level.
- Better link technology companies with the research and education community.

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Appendix I

New York Farmers and Professionals Surveys

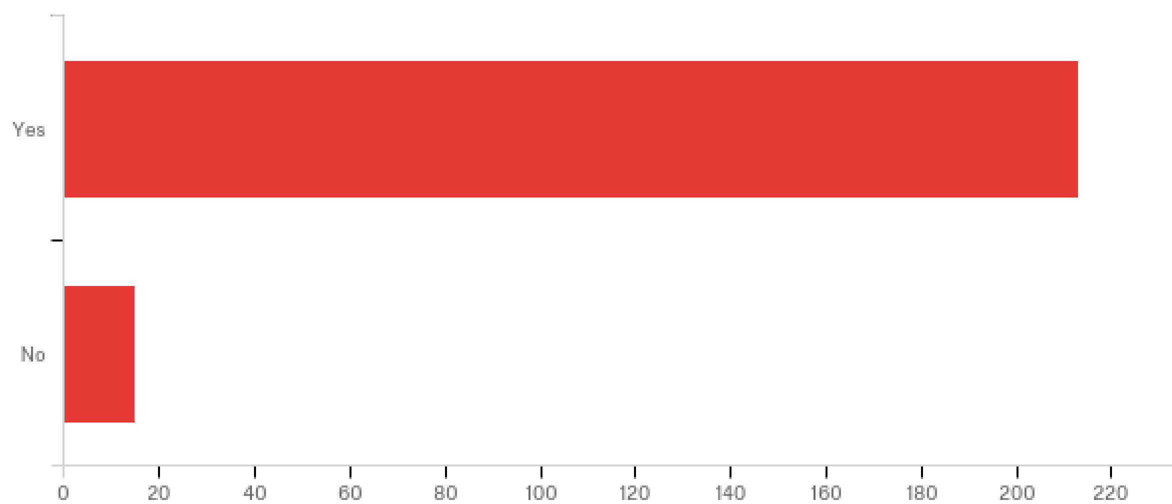
A. Comprehensive On-line Survey

B. Western New York Survey

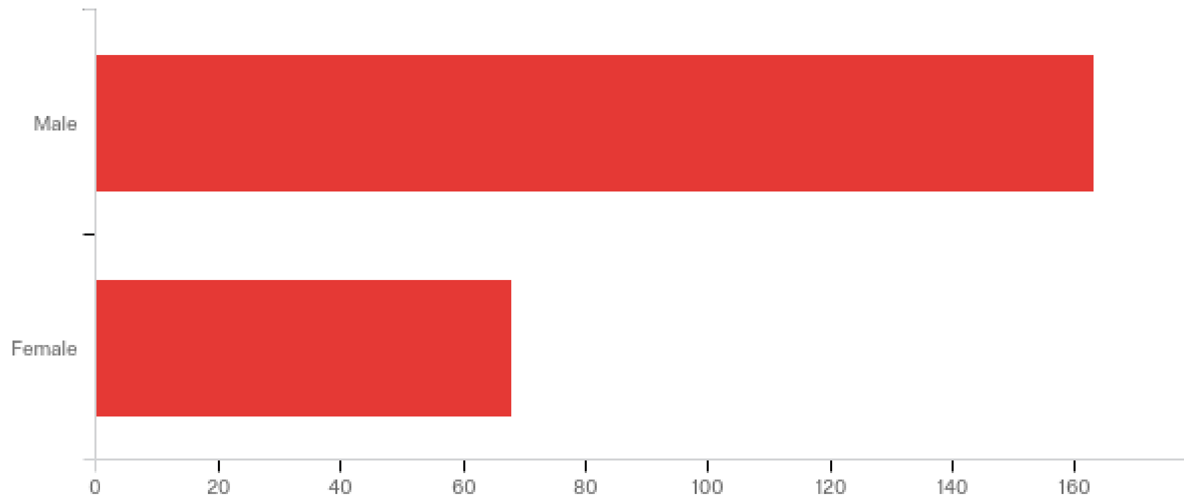
Appendix–NYS Precision Agriculture Supplemental Survey Results

Are you a resident of New York State?

Answer	%	Count
Yes	93.42%	213
No	6.58%	15
Total	100%	228

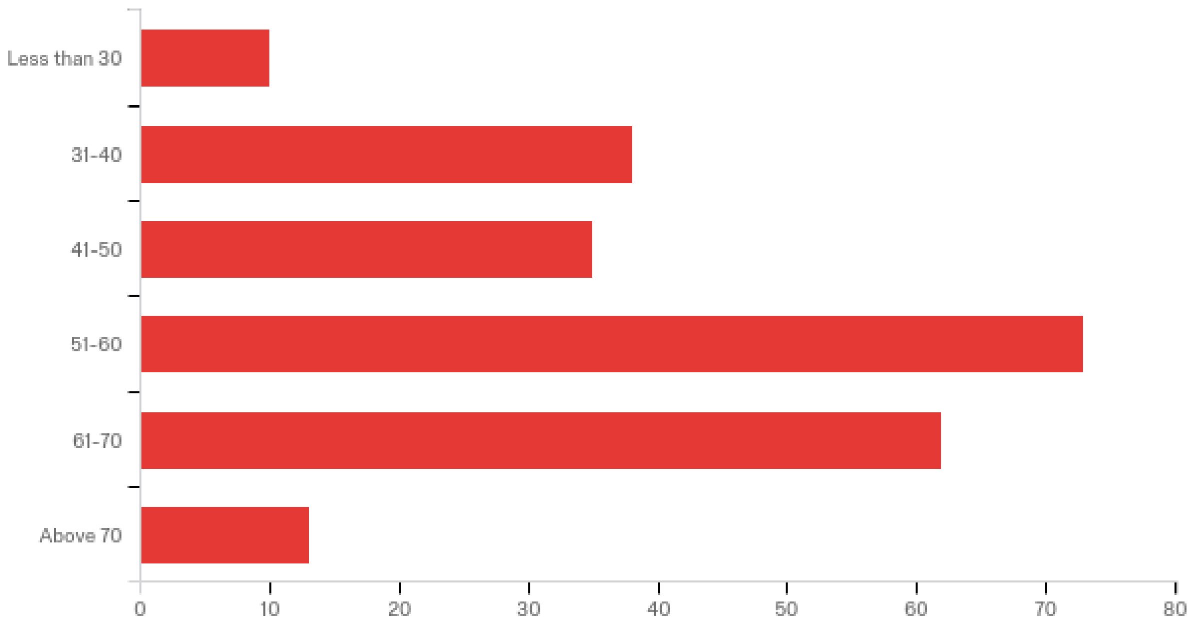


What is your gender?



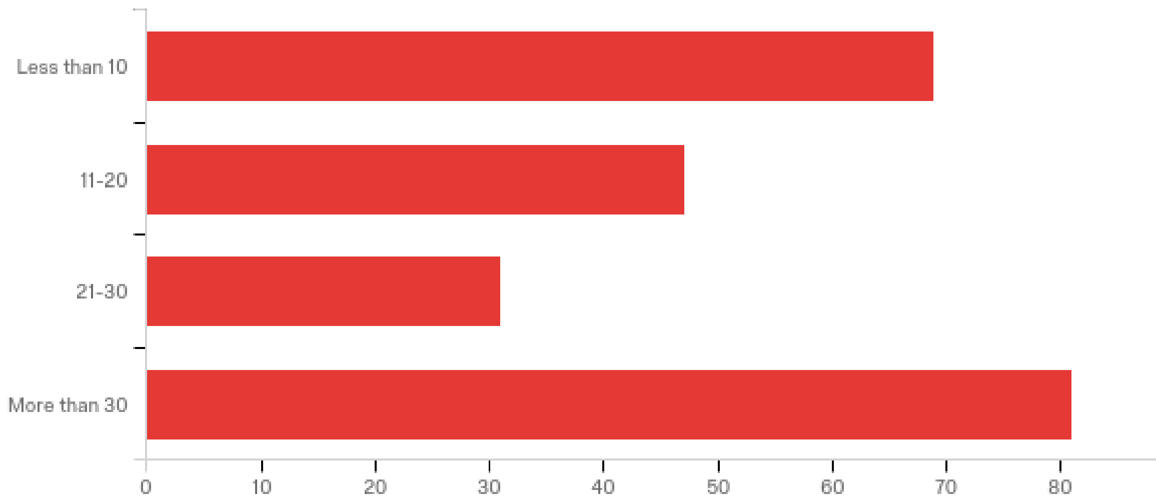
Answer	%	Count
Male	70.56%	163
Female	29.44%	68
Total	100%	231

What is your age?



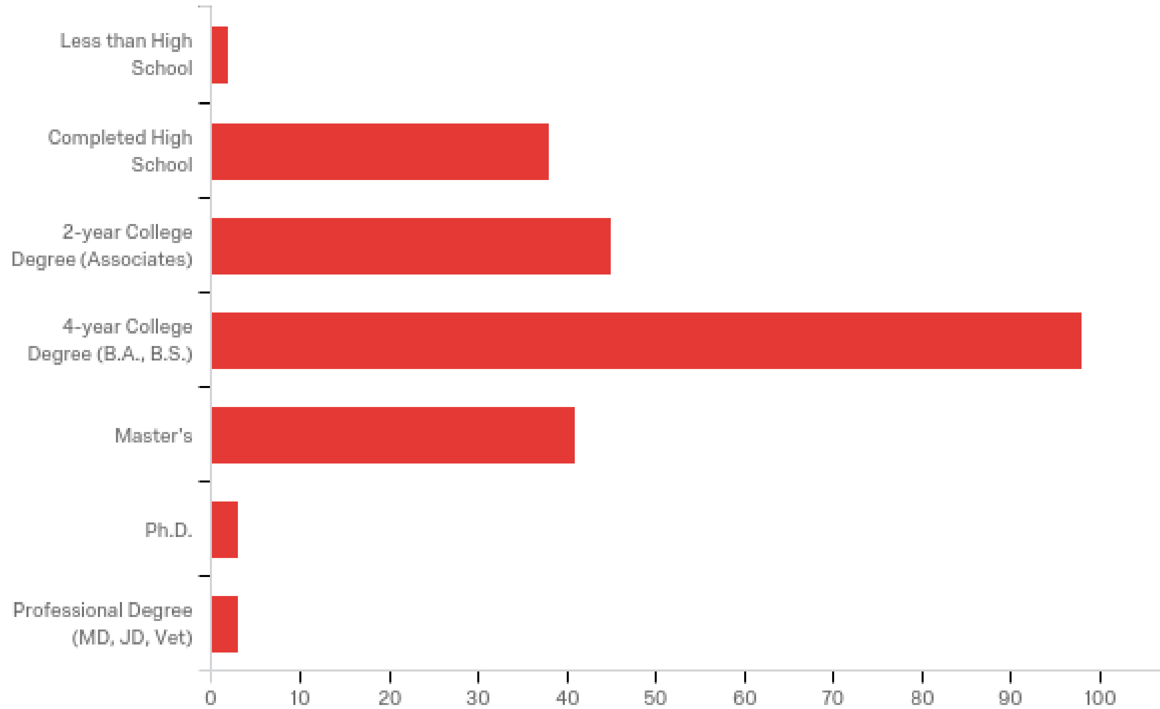
Answer	%	Count
Less than 30	4.33%	10
31-40	16.45%	38
41-50	15.15%	35
51-60	31.60%	73
61-70	26.84%	62
Above 70	5.63%	13
Total	100%	231

How long, in years, have you been farming?



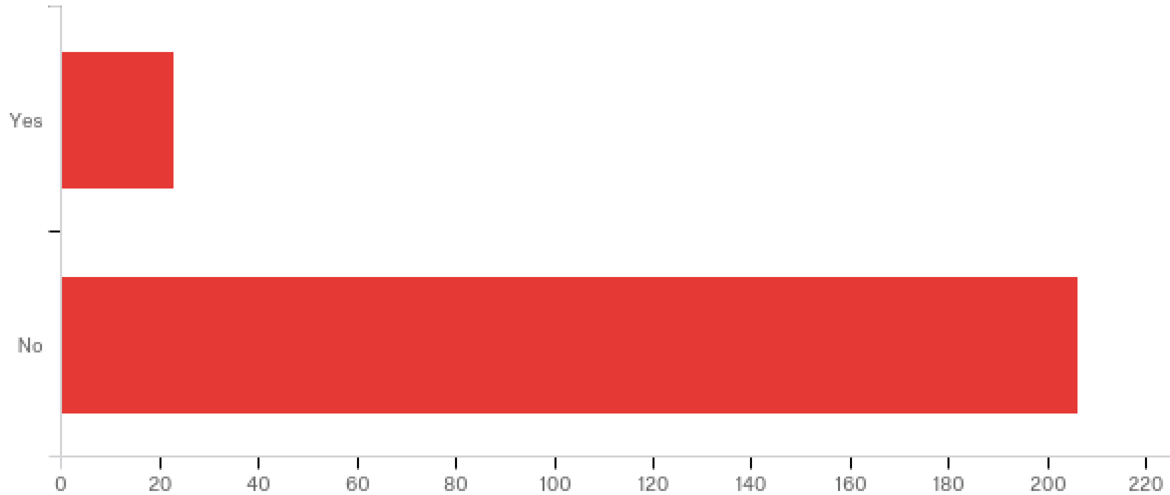
Answer	%	Count
Less than 10	30.26%	69
11-20	20.61%	47
21-30	13.60%	31
More than 30	35.53%	81
Total	100%	228

What is your highest education level?



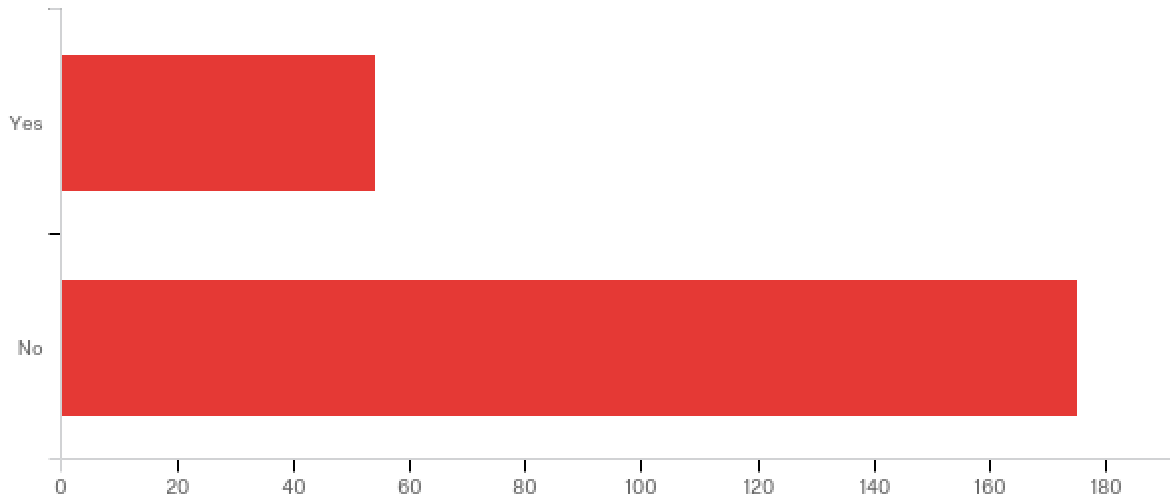
Answer	%	Count
Less than High School	0.87%	2
Completed High School	16.52%	38
2-year College Degree (Associates)	19.57%	45
4-year College Degree (B.A., B.S.)	42.61%	98
Master's	17.83%	41
Ph.D.	1.30%	3
Professional Degree (MD, JD, Vet)	1.30%	3
Total	100%	230

Do you produce certified organic?



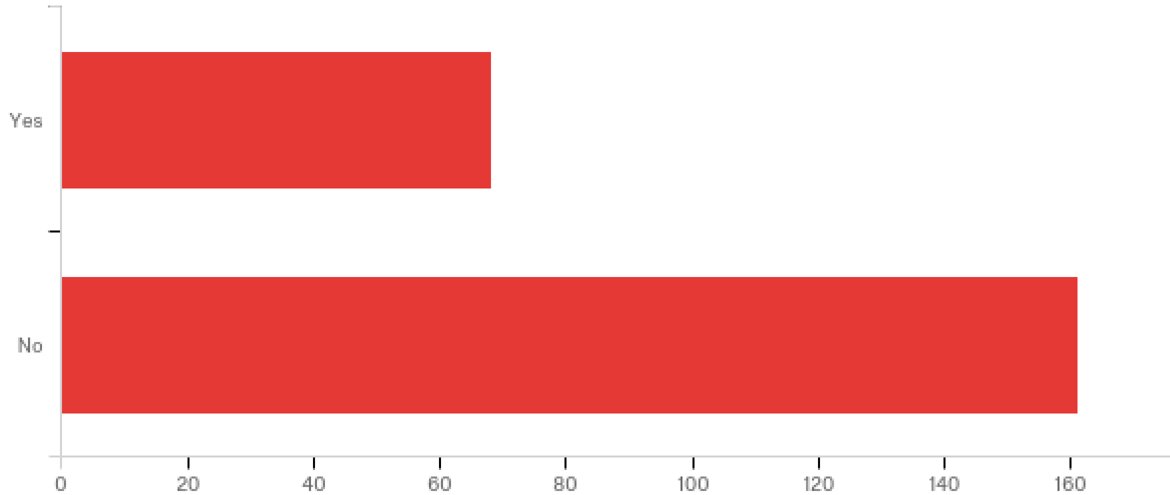
Answer	%	Count
Yes	10.04%	23
No	89.96%	206
Total	100%	229

Do you grow GMO crops (Bt, herbicide resistant, etc.)?



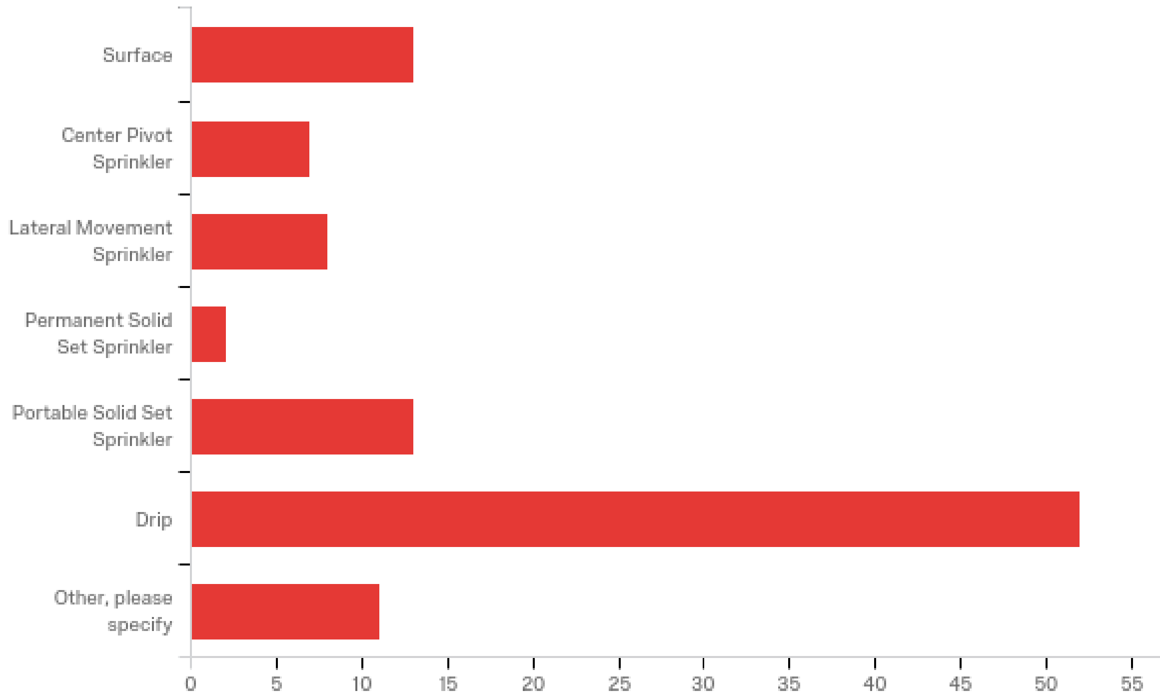
Answer	%	Count
Yes	23.58%	54
No	76.42%	175
Total	100%	229

Do you have irrigation on your farm?



Answer	%	Count
Yes	29.69%	68
No	70.31%	161
Total	100%	229

What type of irrigation technology do you use? Select all that apply.



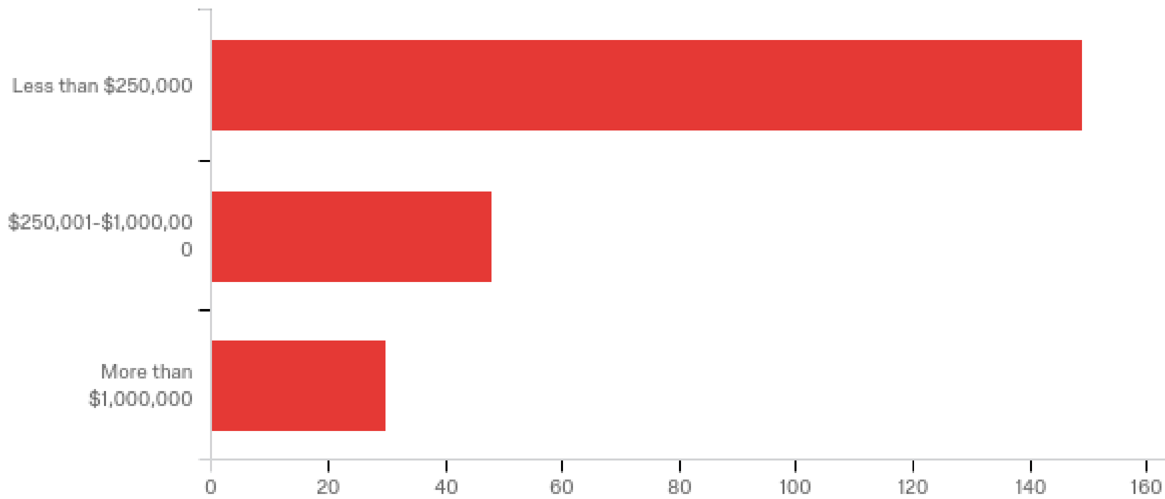
Answer	%	Count
Surface	19.40%	13
Center Pivot Sprinkler	10.45%	7
Lateral Movement Sprinkler	11.94%	8
Permanent Solid Set Sprinkler	2.99%	2
Portable Solid Set Sprinkler	19.40%	13
Drip	77.61%	52
Other, please specify	16.42%	11
Total	100%	67

Other, please specify

Other, please specify
Hard hose traveler
Reel
Irrigation Reel

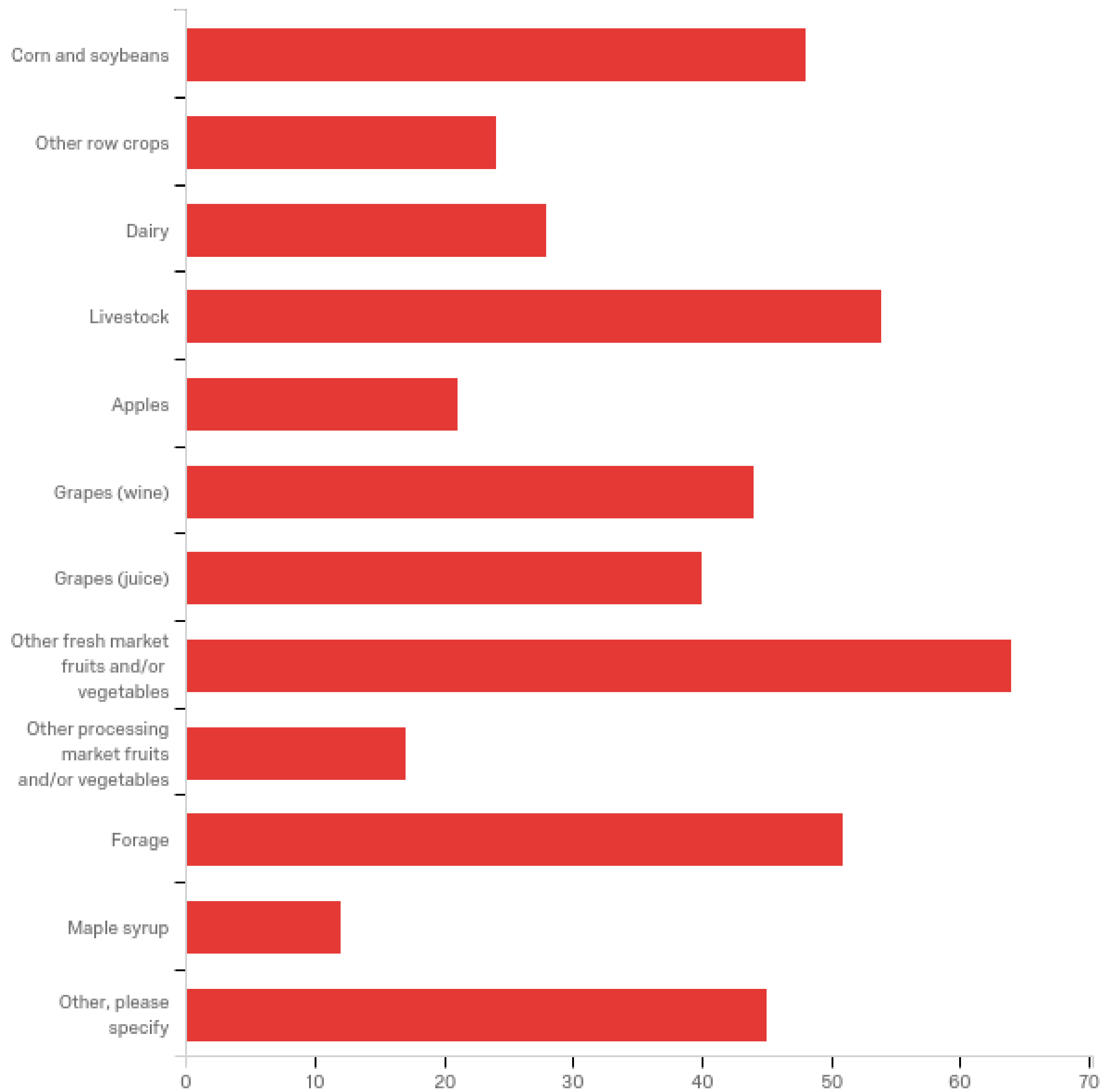
Big Gun
Hose Reel
water gun
Well spike
hard hose traveler
Portable Reel rain (gun)
underground
traveler rain wheels

Approximately, what are your annual gross sales from farming operations?



Answer	%	Count
Less than $250,000	65.64%	149
$250,001-$1,000,000	21.15%	48
More than $1,000,000	13.22%	30
Total	100%	227

What products do you produce in your farm (only those that generate significant revenue, for the past three years)? Select all that apply.



Answer	%	Count
Corn and soybeans	21.43%	48
Other row crops	10.71%	24
Dairy	12.50%	28
Livestock	24.11%	54
Apples	9.38%	21

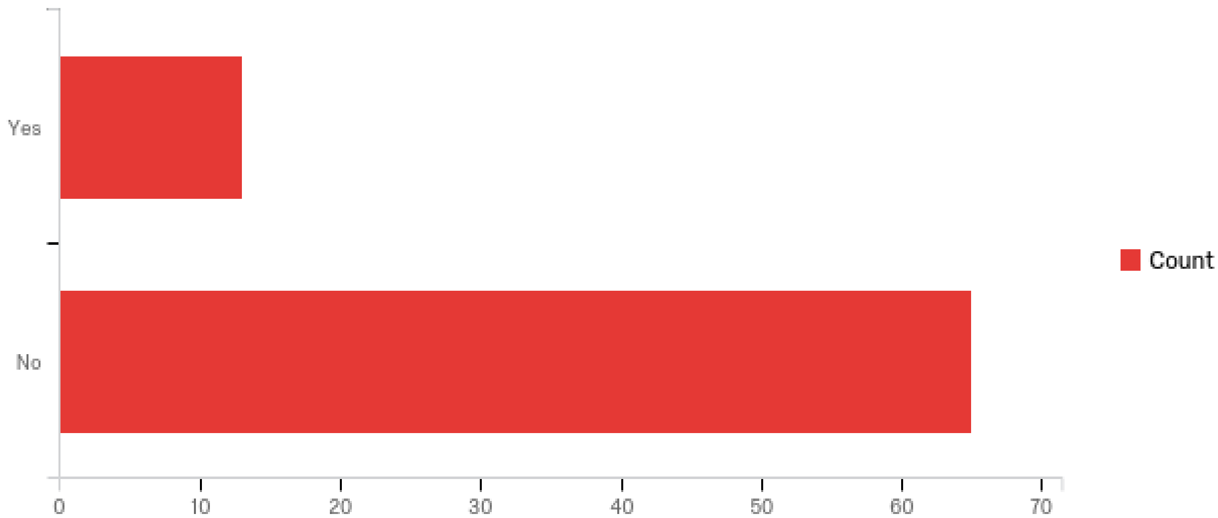
Grapes (wine)	19.64%	44
Grapes (juice)	17.86%	40
Other fresh market fruits and/or vegetables	28.57%	64
Other processing market fruits and/or vegetables	7.59%	17
Forage	22.77%	51
Maple syrup	5.36%	12
Other, please specify	20.09%	45
Total	100%	224

Other, please specify

Other, please specify
Wheat
nursery stocl
Cherries
Christmas Trees
strawberries,caneberries, hydroponic tomatoes
hay
turfgrass sod
Honey
Grapes for Fresh Markets
broilers and eggs
Thoroughbred brood mare operation
Hops
hops
eggs
hay
did not farm for last 3 years due to storm damage to barns
corn and hay
Bees/Honey

sod
Wheat, oats
establishing a tree nut orchard (hazelnuts) and shitakee mushrooms
eggs
wool roning yarn
Tomato, cucumber, okra
mushrooms
None provide "significant" income. Baled Hay is
poultry and eggs
mohair, cashmere, alpaca fiber and finished goods
honey
Dry hay
Flowers
Hay
HONNEY
Hay
timber
Hops
Hay sales
Equine
greenhouse
Grapevines
wheat
Custom Harvest Forage, Grapes and Hay
cash small grain, wheat
Christmas trees
hay

Do you use any of the following technologies? If not sure about the question answer NO.

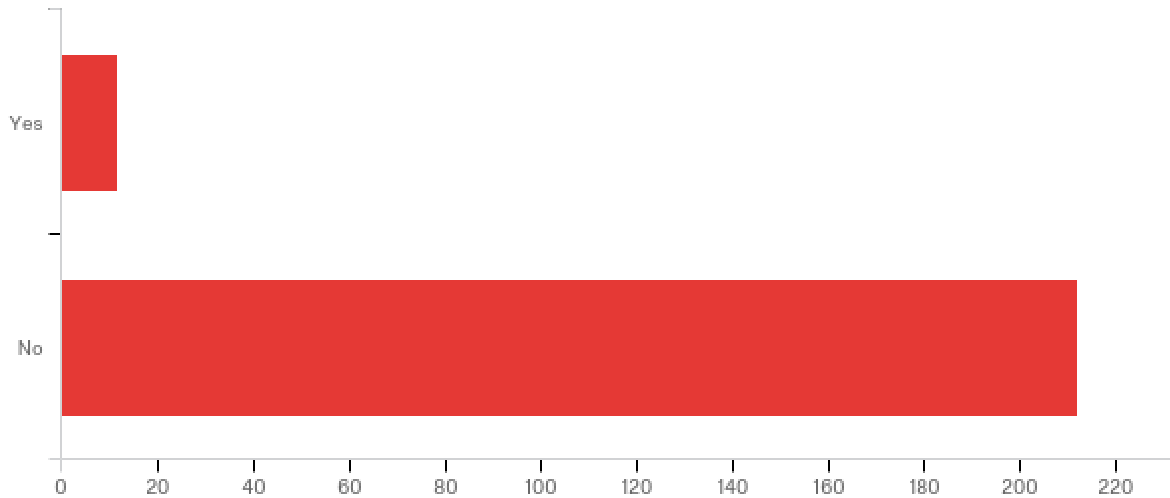


Question	Yes		No		Total
Electronic livestock identifiers	16.67%	13	83.33%	65	78
Automatic monitoring for animal heath	15.58%	12	84.42%	65	77
Rumination monitoring	3.95%	3	96.05%	73	76
Ultrasound or blood testing for pregnancy confirmation	33.77%	26	66.23%	51	77
Computerized decision making tools with monitoring (feed, yields, etc)	23.08%	18	76.92%	60	78
Automatic (robotic) milking systems	8.97%	7	91.03%	71	78

Technology Infrastructure: Please respond to each question. If not sure about the question answer NO. GPS is a satellite based technology that locates and maps specific points on earth. DGPS and RTK GPS are high precision GPS that relies on ground stations. These stations could be public or private, in which case the user can access through a subscription fee.

Question	Yes		No		Total
Do you have access to high speed internet on your farm?	79.11%	178	20.89%	47	225
Do you have good / reliable high speed cellular data service on your farm?	67.86%	152	32.14%	72	224
Do you use high-precision GPS on your farm (RTK or DGPS)?	16.44%	37	83.56%	188	225
Do you use mobile technologies (smartphones, tablets, etc.) for farm management?	64.44%	145	35.56%	80	225
Is any of your farm equipment mobile enabled (can communicate and send/receive data from the field)?	9.82%	22	90.18%	202	224
Do you use any of Cornell University's agricultural management tools (e.g., NEWA, fire blight forecasting model, Cornell IPM's scout, Adapt N)	35.14%	78	64.86%	144	222

Do you use any cloud based farm management software and analytics services (accessed through the Web) actively to manage your farm (e.g., Granular, Agri-Data, Climate Corp, etc.)?

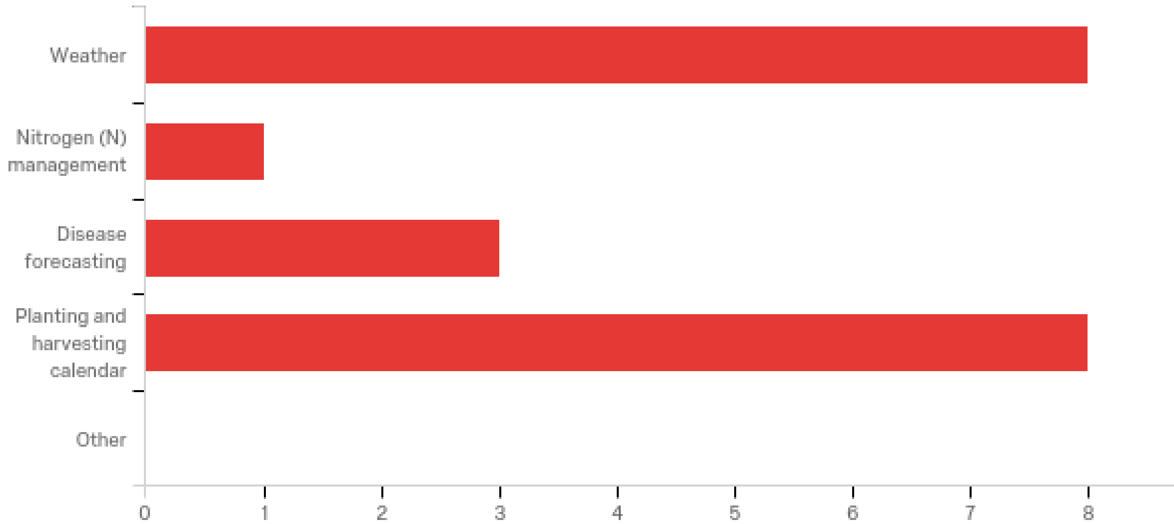


Answer	%	Count
Yes	5.36%	12
No	94.64%	212
Total	100%	224

What cloud based farm management software and analytics services do you use? Please list them all.

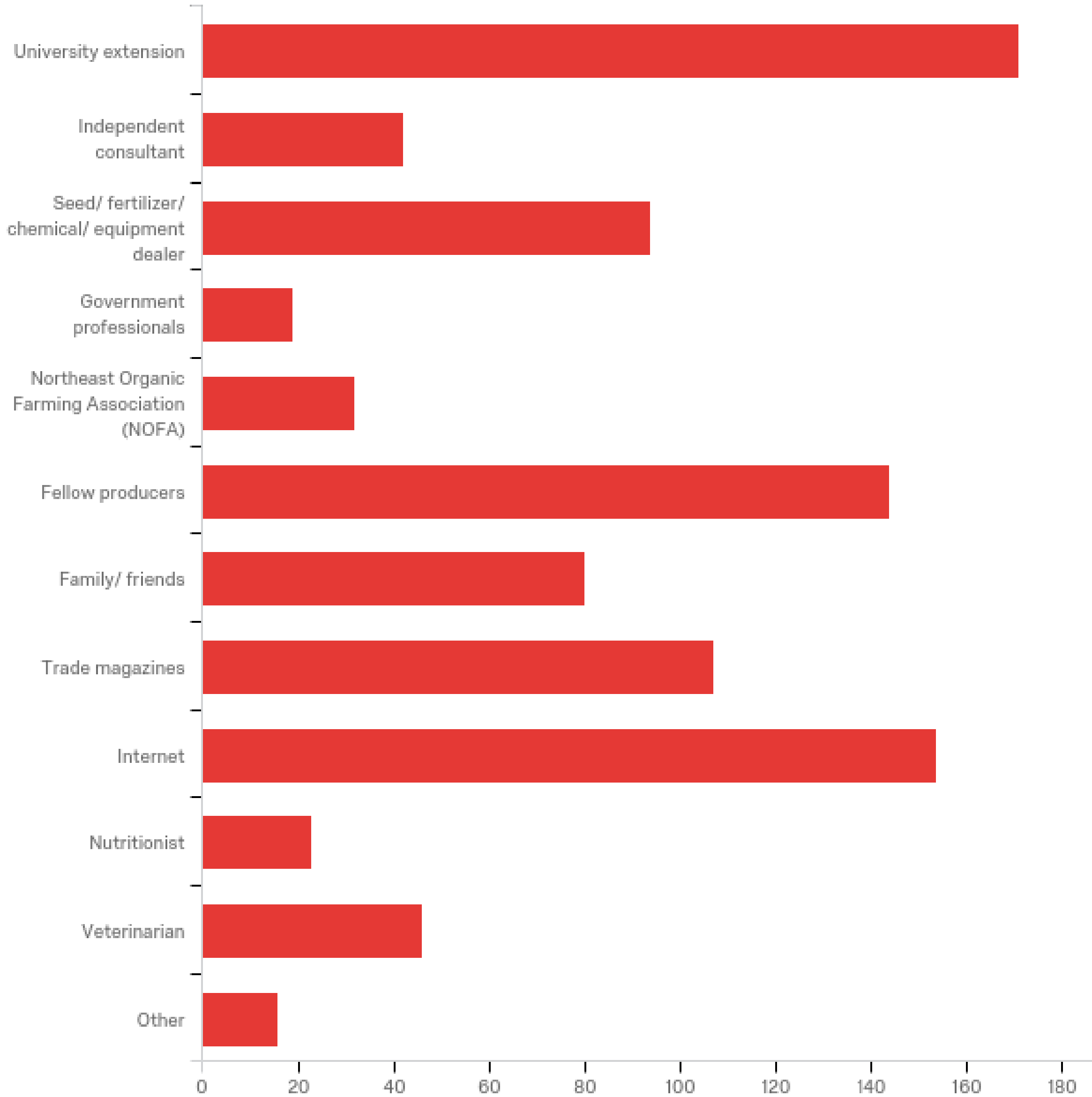
What cloud based farm management software and analytics services do you use...
Ag Squared Farm Produce Manager
Farm logs, my John deere
Farm Produce Manager, Agsquared
AgSquared
AgSquared
Agfinity/SMS (AgLeader), currently looking into Granular but haven't committed
Agri Data
Carbonite
AgraScout, NEWA
Precision planting /climate Apex

If so, what type of information do you access through the cloud? Select all that apply.



Answer	%	Count
Weather	72.73%	8
Nitrogen (N) management	9.09%	1
Disease forecasting	27.27%	3
Planting and harvesting calendar	72.73%	8
Other	0.00%	0
Total	100%	11

What are your primary sources of technical information on farm practices? Select multiple if appropriate.

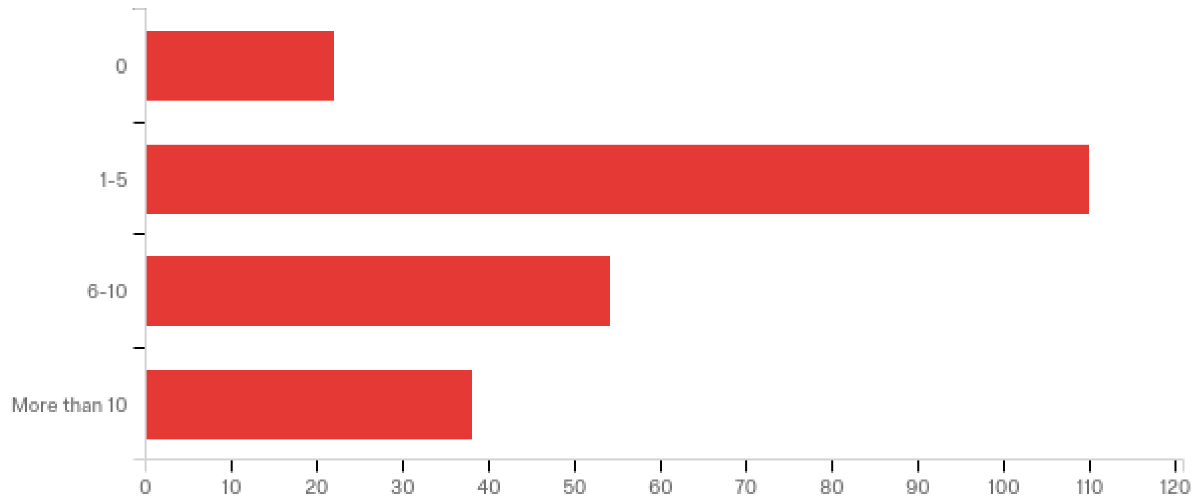


Answer	%	Count
University extension	76.00%	171
Independent consultant	18.67%	42
Seed/ fertilizer/ chemical/ equipment dealer	41.78%	94
Government professionals	8.44%	19
Northeast Organic Farming Association (NOFA)	14.22%	32

Fellow producers	64.00%	144
Family/ friends	35.56%	80
Trade magazines	47.56%	107
Internet	68.44%	154
Nutritionist	10.22%	23
Veterinarian	20.44%	46
Other	7.11%	16
Total	100%	225

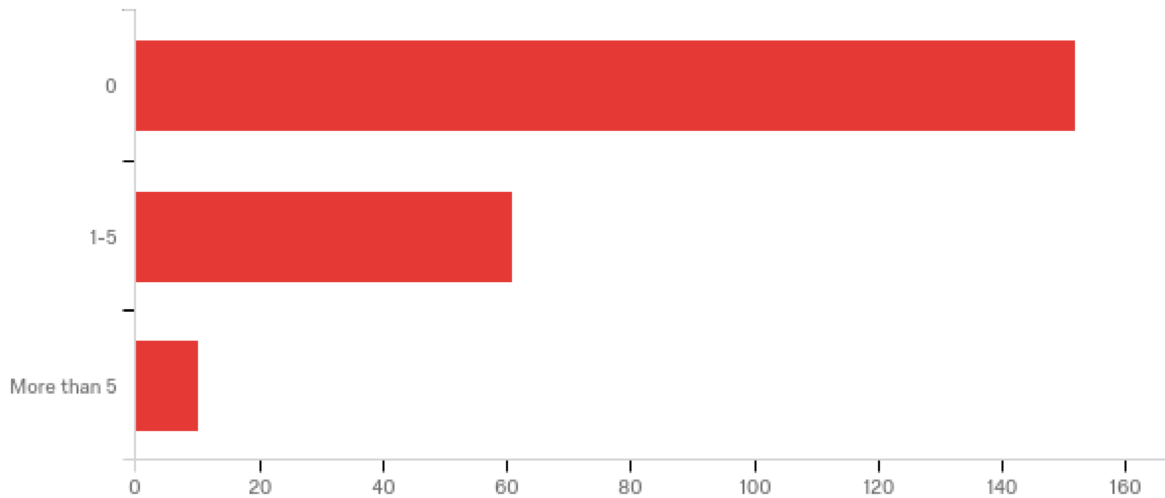
Other
Trade Org
Cornell Sheep & Goat Symposium
Personal skills from previous occupation
Fairly even blend of all ones listed
books , conferences
colleagues at Nut grower association meetings and nursery owners
RFD TV
books
Equi-Analytical Labs
Uihlein Maple Research Center
International Tree Fruit Association
books
over 30 years of personal experience

Approximately how many times have you attended workshops, talks, seminars, or any other form of agricultural technical instruction in the past three years?



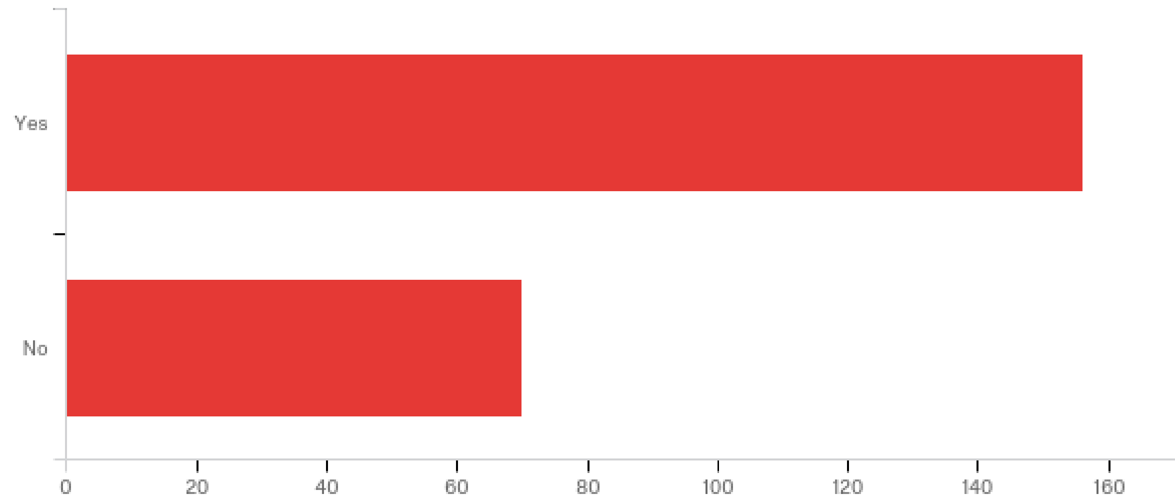
Answer	%	Count
0	9.82%	22
1-5	49.11%	110
6-10	24.11%	54
More than 10	16.96%	38
Total	100%	224

Approximately how many times have you hired technicians or professional consultants in the last three years in order to manage your operation?



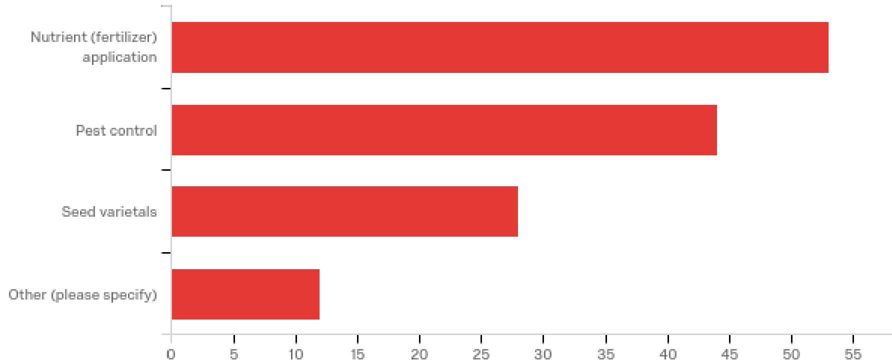
Answer	%	Count
0	68.16%	152
1-5	27.35%	61
More than 5	4.48%	10
Total	100%	223

Have you received technical instruction from Cornell Cooperative Extension? This includes local county office, regional or statewide team such as the Eastern NY Horticulture team, regional CCE teams, Cornell PRO-DAIRY, or IPM program.



Answer	%	Count
Yes	69.03%	156
No	30.97%	70
Total	100%	226

What type of recommendations did you get from the technician /consultant in the past (for crop production only)? Select all that apply.



Answer	%	Count
Nutrient (fertilizer) application	76.81%	53
Pest control	63.77%	44
Seed varietals	40.58%	28
Other (please specify)	17.39%	12
Total	100%	69

Other (please specify)

Other (please specify)
planting recommendations
Application of lime, drainage recommendations, application of manure
No crop production
Seeding rates
d o not use consultant
Veterinarian
Soil testing, pasture utilization
parasite management, silvioculture, pasture health
Horse management
aerial photos of orchards to diagnose problems
Instruction on use of late blight forecasting

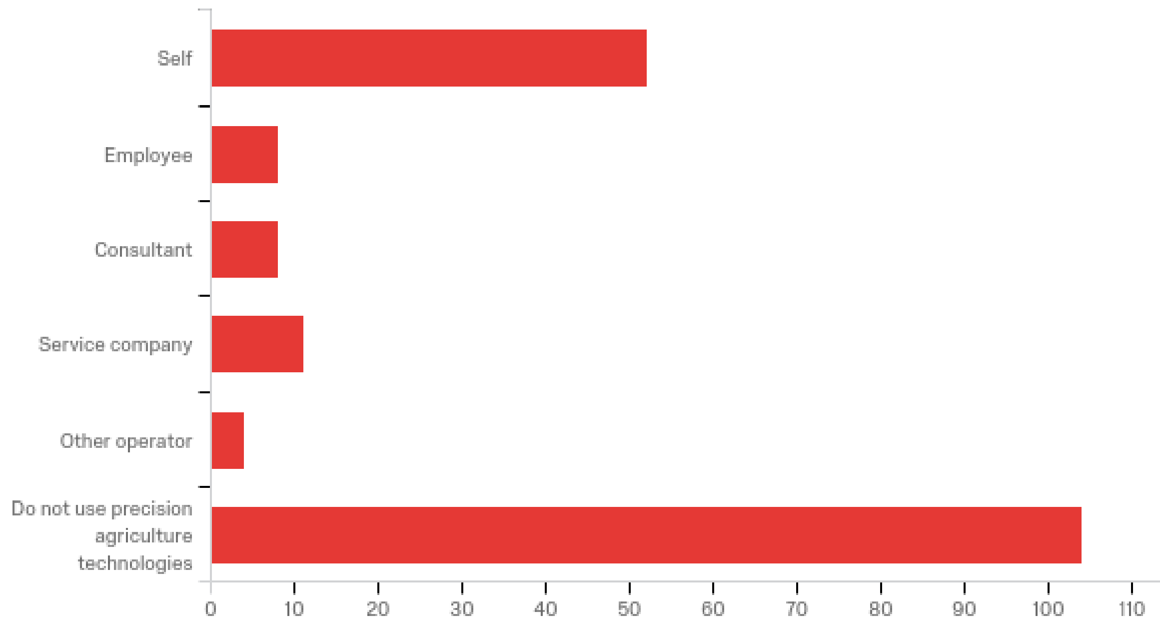
Do you actively use any of the following information sources? Please indicate whether used for information gathering only, or also for management decisions (e.g., variable rate inputs).

Question	Yes, information only		Yes, information and management		No		Total
Yield monitor without GPS	6.76%	14	5.31%	11	87.92%	182	207
Yield monitor with GPS.	3.35%	7	5.26%	11	91.39%	191	209
Yield Maps.	6.28%	13	7.73%	16	85.99%	178	207
Images and photographs produced by satellites, planes, or unmanned aerial vehicles (UAV). These images can help define soil regions and monitor crop status and health.	23.33%	49	17.14%	36	59.52%	125	210
Soil maps created by grid soil tests or electrical conductivity measurements with GPS.	11.00%	23	14.35%	30	74.64%	156	209
Soil moisture sensors	5.29%	11	4.81%	10	89.90%	187	208
UAV for scouting crop health	2.43%	5	2.43%	5	95.15%	196	206

Do you actively use any of the following variable input applicators and precision agriculture technologies? Please indicate whether you used it yourself or used it through a service provider.

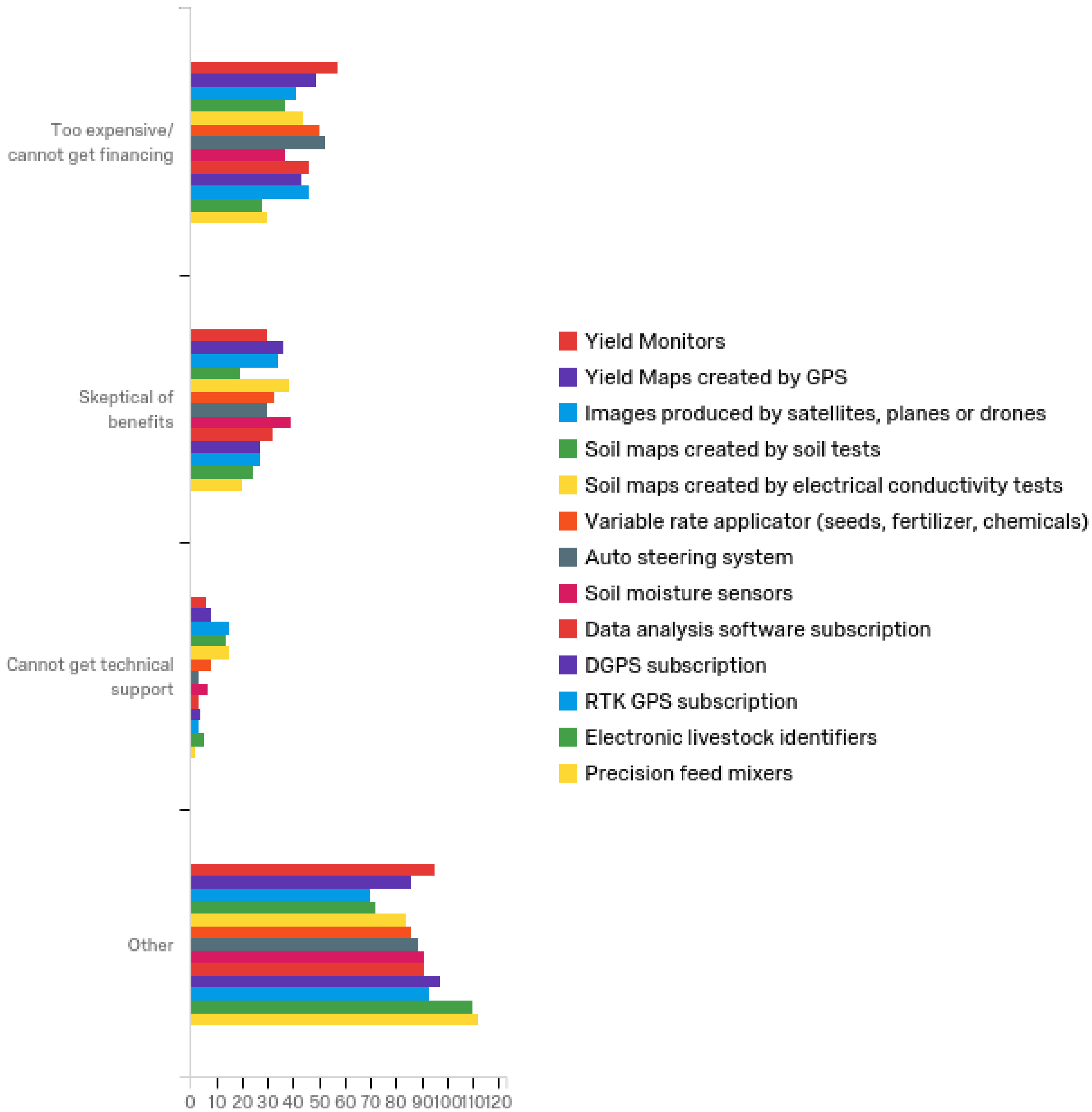
Question	Yes, used it yourself		Yes, used it through a service provider		No		Total
Variable rate chemical (fertilizer/ pesticide) applicators with GPS.	5.71%	12	4.29%	9	90.00%	189	210
Variable seeding rate and precision planter/ drill with GPS.	3.37%	7	0.00%	0	96.63%	201	208
Auto steer technology	8.61%	18	0.48%	1	90.91%	190	209
Precision nitrogen (N) management software (Adapt-N, Encirca, Climate Pro, etc.)	1.43%	3	2.86%	6	95.71%	201	210
Crop sensors (Greenseekers, OptRx, CropSpec, Crop Circle, etc.)	3.33%	7	0.95%	2	95.71%	201	210
Soil mapping using soil tests	17.62%	37	16.67%	35	65.71%	138	210
Soil mapping using electrical conductivity tests	3.33%	7	5.24%	11	91.43%	192	210
Precision feed mixer	5.24%	11	0.48%	1	94.29%	198	210

If using precision agriculture technologies, who does most of the information processing?



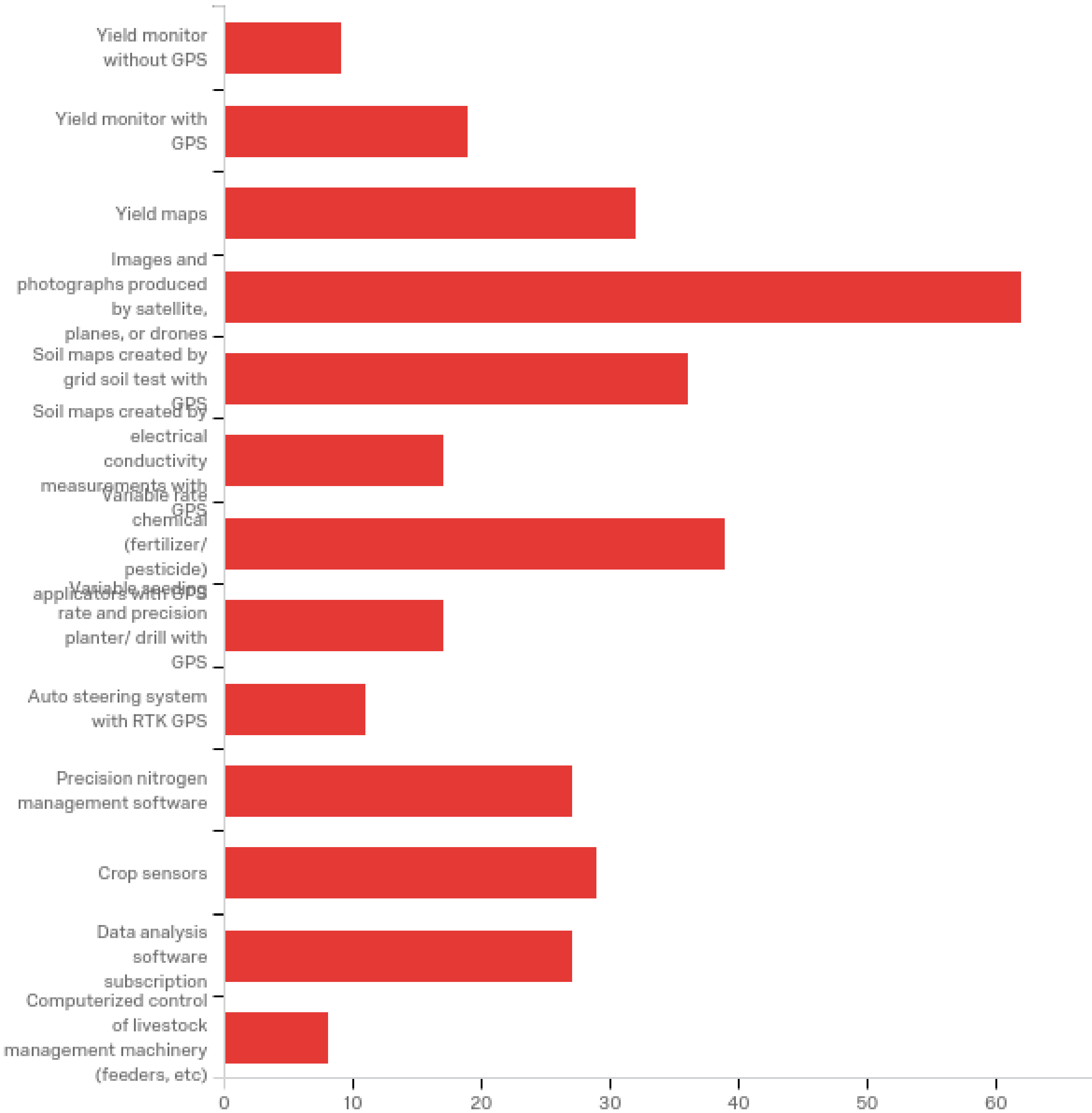
Answer	%	Count
Self	29.55%	52
Employee	4.55%	8
Consultant	4.55%	8
Service company	6.25%	11
Other operator	2.27%	4
Do not use precision agriculture technologies	59.09%	104
Total	100%	176

For precision agriculture technologies that you do NOT use, please select all the reasons that apply.



Question	Too expensive/ cannot get financing		Skeptical of benefits		Cannot get technical support		Other		Total
Yield Monitors	31.32%	57	16.48%	30	3.30%	6	52.20%	95	182
Yield Maps created by GPS	28.32%	49	20.81%	36	4.62%	8	49.71%	86	173
Images produced by satellites, planes or drones	26.97%	41	22.37%	34	9.87%	15	46.05%	70	152
Soil maps created by soil tests	26.81%	37	13.77%	19	10.14%	14	52.17%	72	138
Soil maps created by electrical conductivity tests	25.58%	44	22.09%	38	8.72%	15	48.84%	84	172
Variable rate applicator (seeds, fertilizer, chemicals)	29.76%	50	19.64%	33	4.76%	8	51.19%	86	168
Auto steering system	30.95%	52	17.86%	30	1.79%	3	52.98%	89	168
Soil moisture sensors	21.76%	37	22.94%	39	4.12%	7	53.53%	91	170
Data analysis software subscription	27.22%	46	18.93%	32	1.78%	3	53.85%	91	169
DGPS subscription	25.90%	43	16.27%	27	2.41%	4	58.43%	97	166
RTK GPS subscription	27.88%	46	16.36%	27	1.82%	3	56.36%	93	165
Electronic livestock identifiers	17.39%	28	14.91%	24	3.11%	5	68.32%	110	161
Precision feed mixers	18.87%	30	12.58%	20	1.26%	2	70.44%	112	159

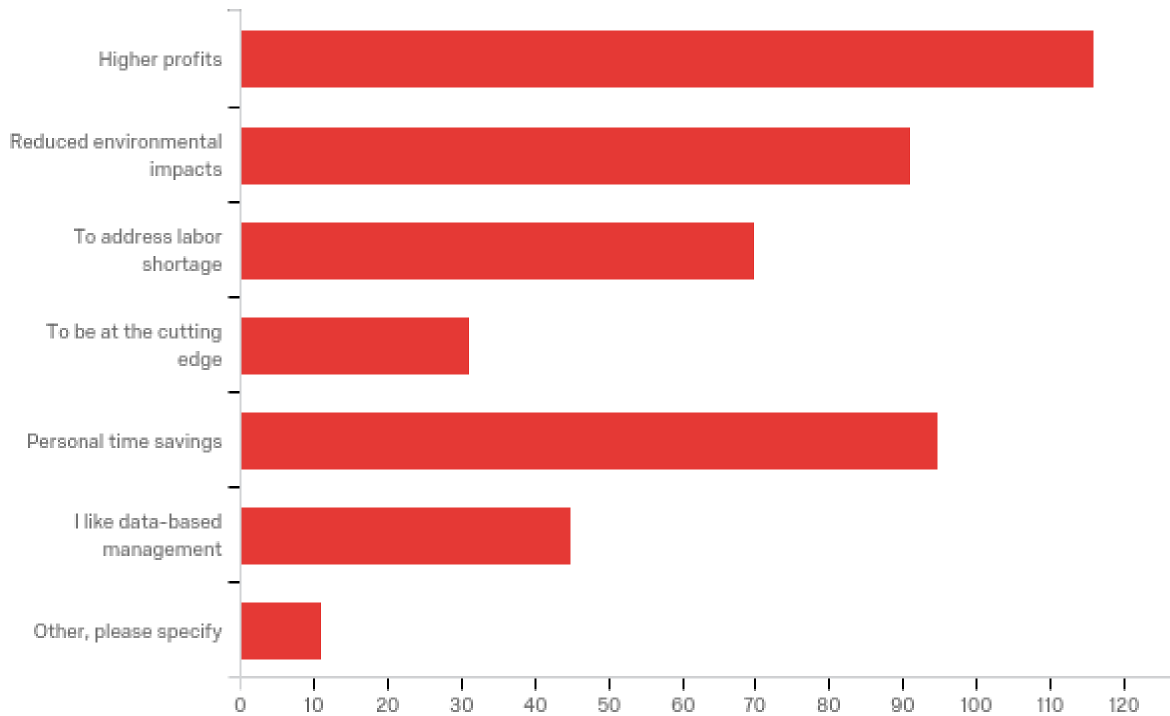
Of the following precision agriculture technologies, which do you expect to start using in the next 5 years?



Of the following precision agriculture technologies, which do you expect to start using in the next 5 years?

Answer	%	Count
Yield monitor without GPS	7.76%	9
Yield monitor with GPS	16.38%	19
Yield maps	27.59%	32
Images and photographs produced by satellite, planes, or drones	53.45%	62
Soil maps created by grid soil test with GPS	31.03%	36
Soil maps created by electrical conductivity measurements with GPS	14.66%	17
Variable rate chemical (fertilizer/ pesticide) applicators with GPS	33.62%	39
Variable seeding rate and precision planter/ drill with GPS	14.66%	17
Auto steering system with RTK GPS	9.48%	11
Precision nitrogen management software	23.28%	27
Crop sensors	25.00%	29
Data analysis software subscription	23.28%	27
Computerized control of livestock management machinery (feeders, etc)	6.90%	8
Total	100%	116

What would be your primary motivations for adopting precision agriculture technologies? Select all that apply.

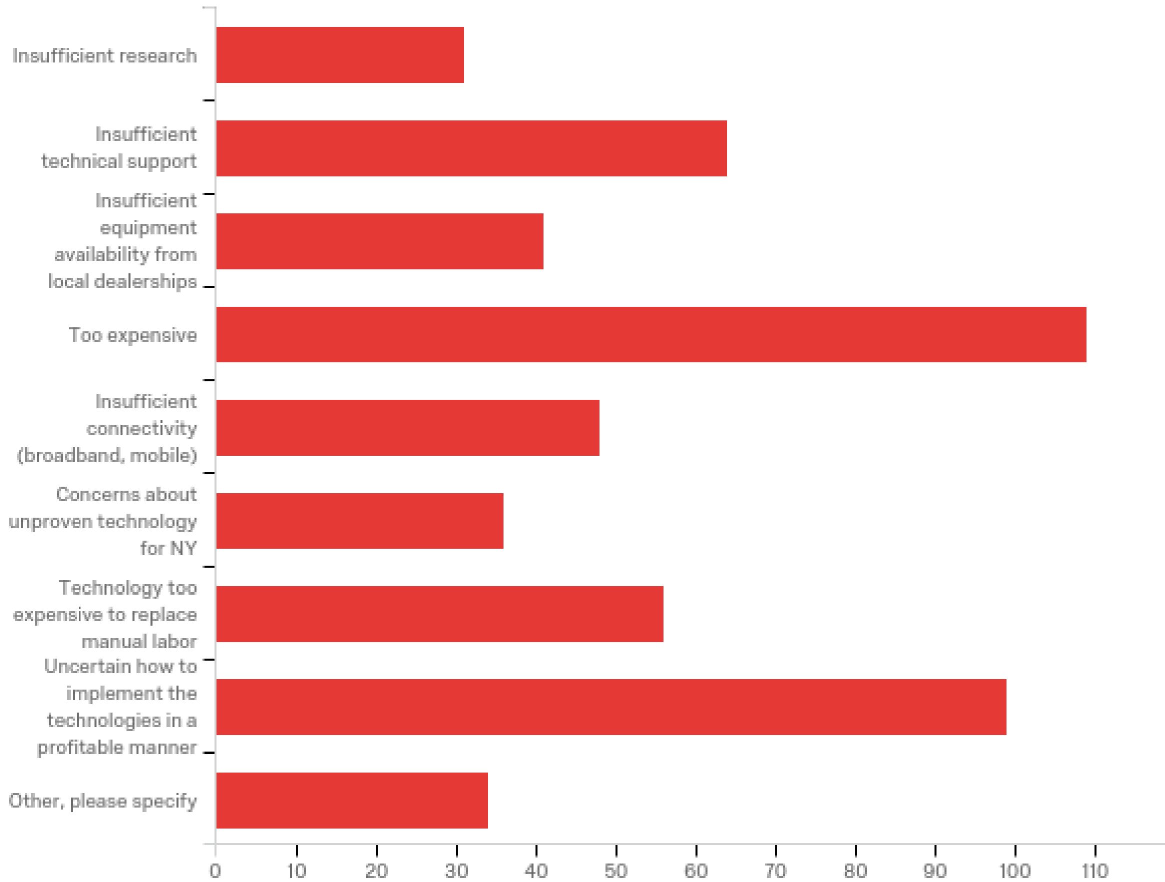


Answer	%	Count
Higher profits	71.17%	116
Reduced environmental impacts	55.83%	91
To address labor shortage	42.94%	70
To be at the cutting edge	19.02%	31
Personal time savings	58.28%	95
I like data-based management	27.61%	45
Other, please specify	6.75%	11
Total	100%	163

Other, please specify
improve crop management
We have permanent cropping sections divided into beds separated by grass lanes. We would like to use GPS to get our sections and beds straight and always in the same location.
higher yield

improve quality/yield
not interested,
Effeciency
The operation is an orchard. I would like to maintain a patient log for each tree. Need user friendly software other then excel.
Training on it
Increase in production/land holding
livestock health
LOAD CELLS UNDER BEE HIVES TO CHECK WEIGHT AND HEALTH LINKED TO A CENTRAL SIGHT

What do you believe are major barriers to the adoption of precision agriculture technologies in NY? Select all that apply.



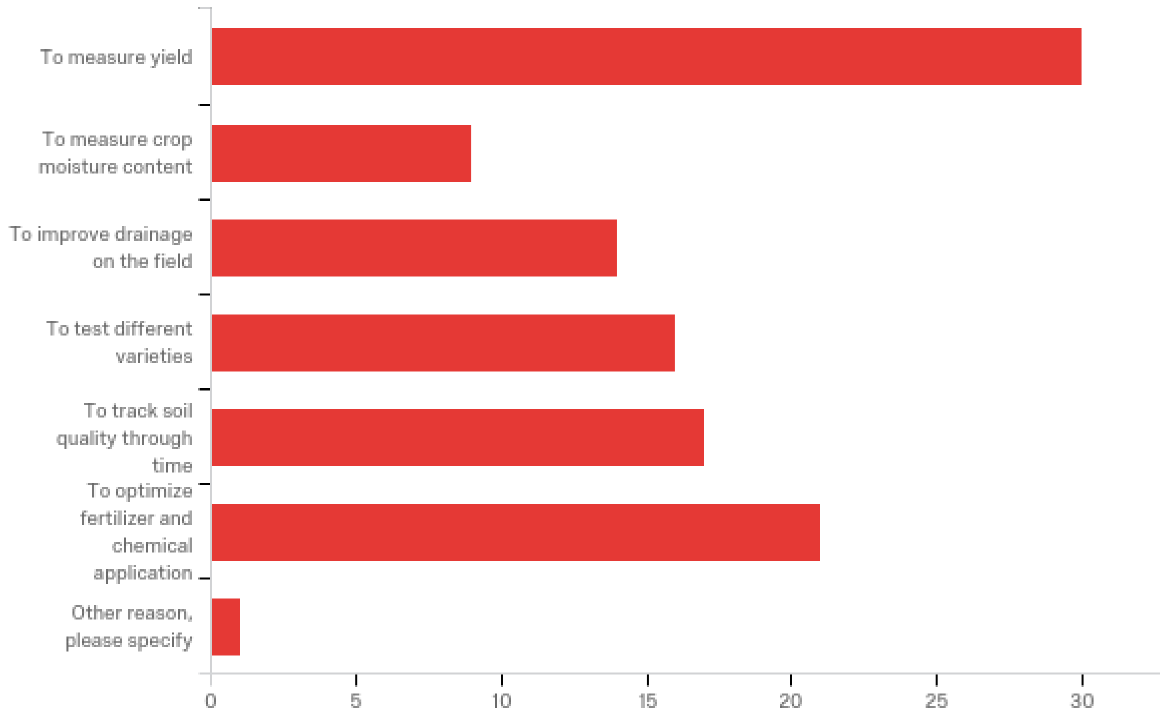
Answer	%	Count
Insufficient research	17.03%	31
Insufficient technical support	35.16%	64
Insufficient equipment availability from local dealerships	22.53%	41
Too expensive	59.89%	109
Insufficient connectivity (broadband, mobile)	26.37%	48
Concerns about unproven technology for NY	19.78%	36
Technology too expensive to replace manual labor	30.77%	56
Uncertain how to implement the technologies in a profitable manner	54.40%	99
Other, please specify	18.68%	34
Total	100%	182

Other, please specify

Other, please specify
Reliability
Average field size is too small
Sometimes doesn't apply to our farm model
More complicated
Nobody wants to change
My own internalized computer is much better.
Not sure if it's financially feasible on a very small scale.
Insufficient software availability
do no fit with our mode and scale of production
is mostly not appropriate scale for diversified vegetable grower
just don't see it at my scale
due to size of fields some applications would not work
not interested
soil too rocky
Concerns about how data held by outside company will be used.
This stuff is not appropriate for my scale. I have never even considered such things! I'm only proceeding with this survey because I'm curious...and so you'll be reminded that micro-scale producers are part of the mix in NY.
need an introduction as to how my operation could benefit.
Operation too small.
Unknown
to small an operation to warrant
Unecessary due to small scale of operation
Too small of s business to use
Not applicable to my crop
fields are too small to add value from this technology
UN WILLINGN BROADBAND PROVIDER TO WORK WITH FARMS THAT ARE ABLE TO INSTALL THERE OWN BROAD BAND AND TO COSTLTY
No need for them at this time and scale of farm
Lack of tech advancements for Equine operations

Not now available to vineyards
too much technology. I am a farmer, not a computer expert
Does not fit my farming needs
Most of these technologies do not appear geared toward grape growing
trying to convincce the older generations it is usefull
lack of awareness
Not sure it's beneficial to our operation

Please state the reasons for using yield monitor data. Select all that apply.

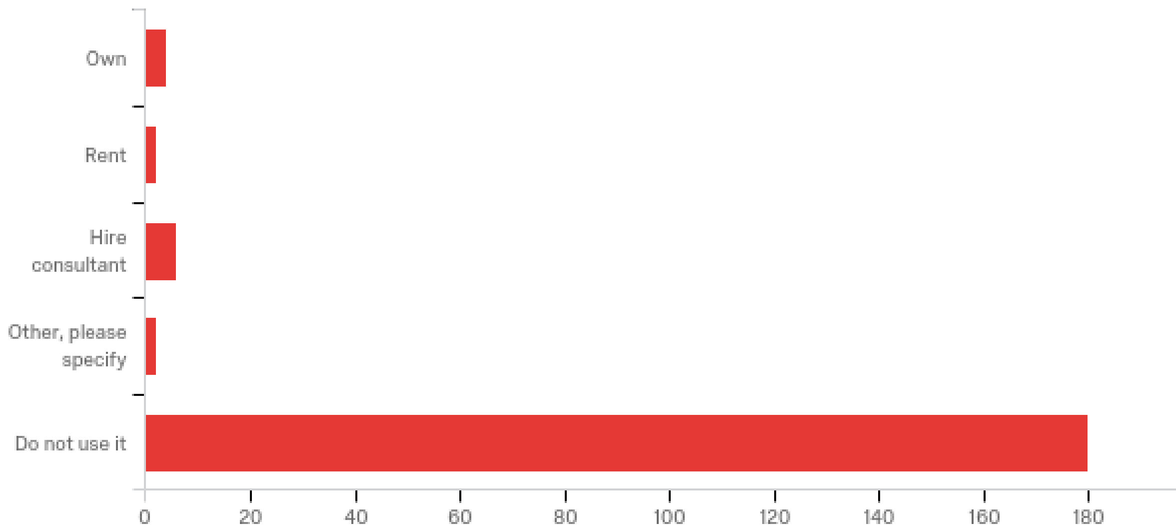


Answer	%	Count
To measure yield	85.71%	30
To measure crop moisture content	25.71%	9
To improve drainage on the field	40.00%	14
To test different varieties	45.71%	16
To track soil quality through time	48.57%	17
To optimize fertilizer and chemical application	60.00%	21
Other reason, please specify	2.86%	1
Total	100%	35

Other reason, please specify

Other reason, please specify
To test different management practices

Do you own, rent, or hire a consultant to utilize a UAV for scouting crop health?

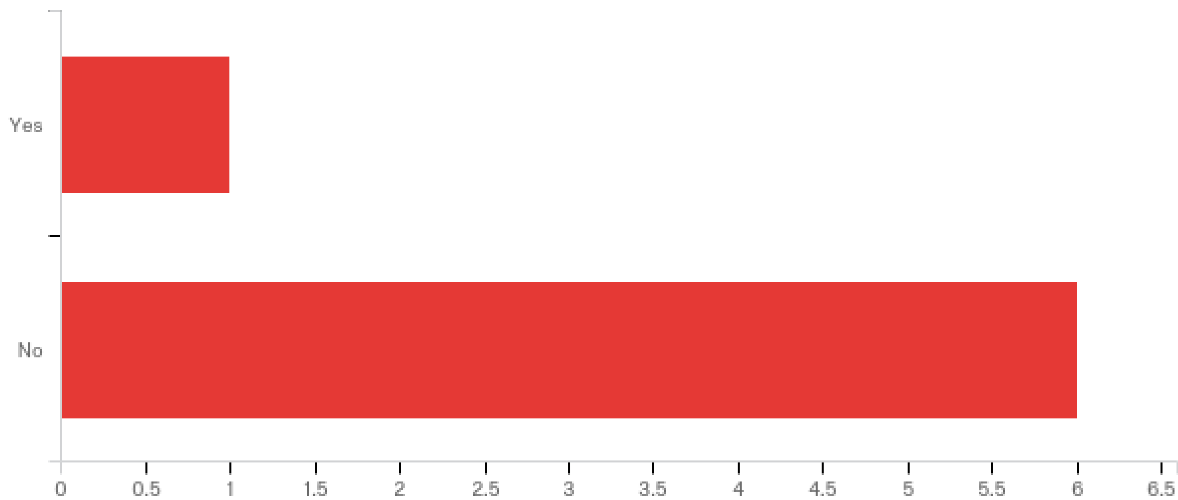


Answer	%	Count
Own	2.06%	4
Rent	1.03%	2
Hire consultant	3.09%	6
Other, please specify	1.03%	2
Do not use it	92.78%	180
Total	100%	194

Other, please specify

Other, please specify
co-operative
have my own plane

Do you own a soil electrical conductivity test machine?

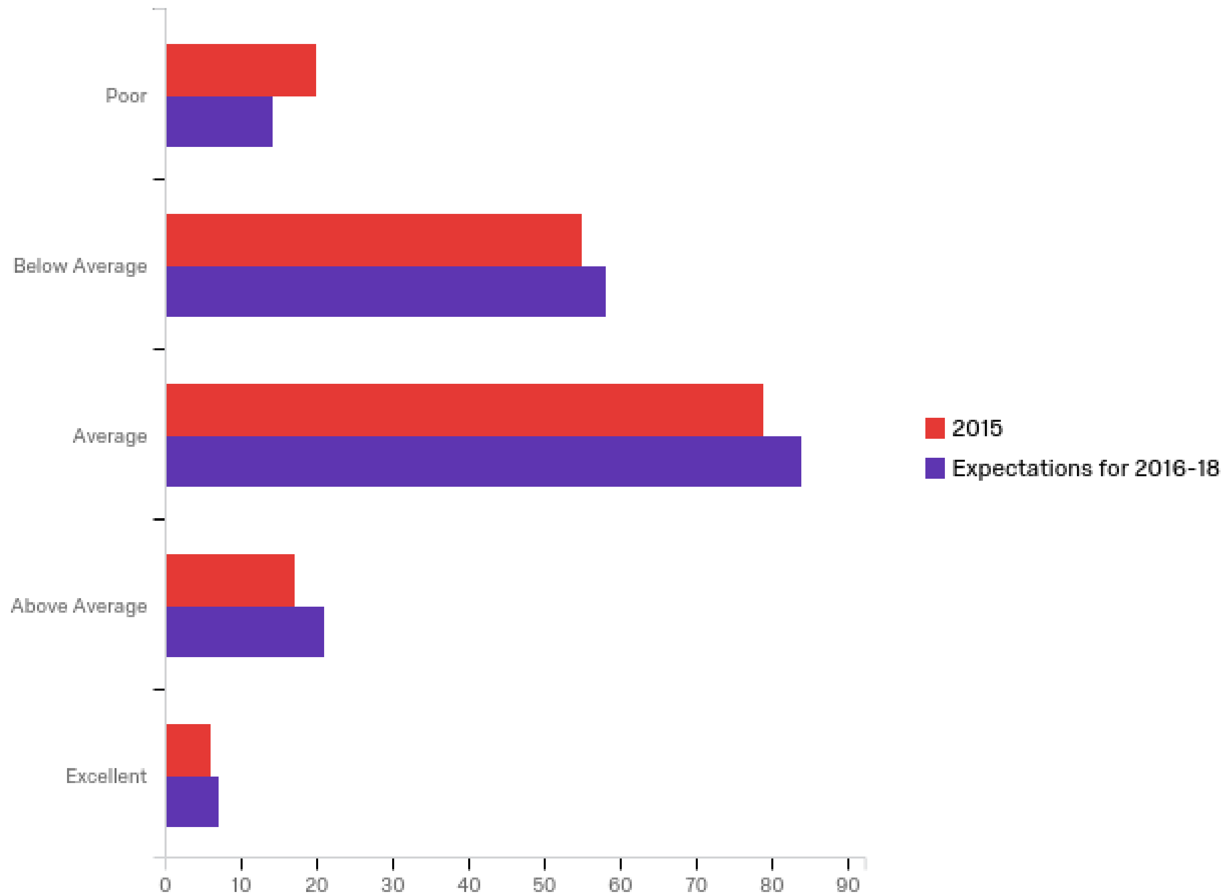


Answer	%	Count
Yes	14.29%	1
No	85.71%	6
Total	100%	7

Do you use any of the following technologies?

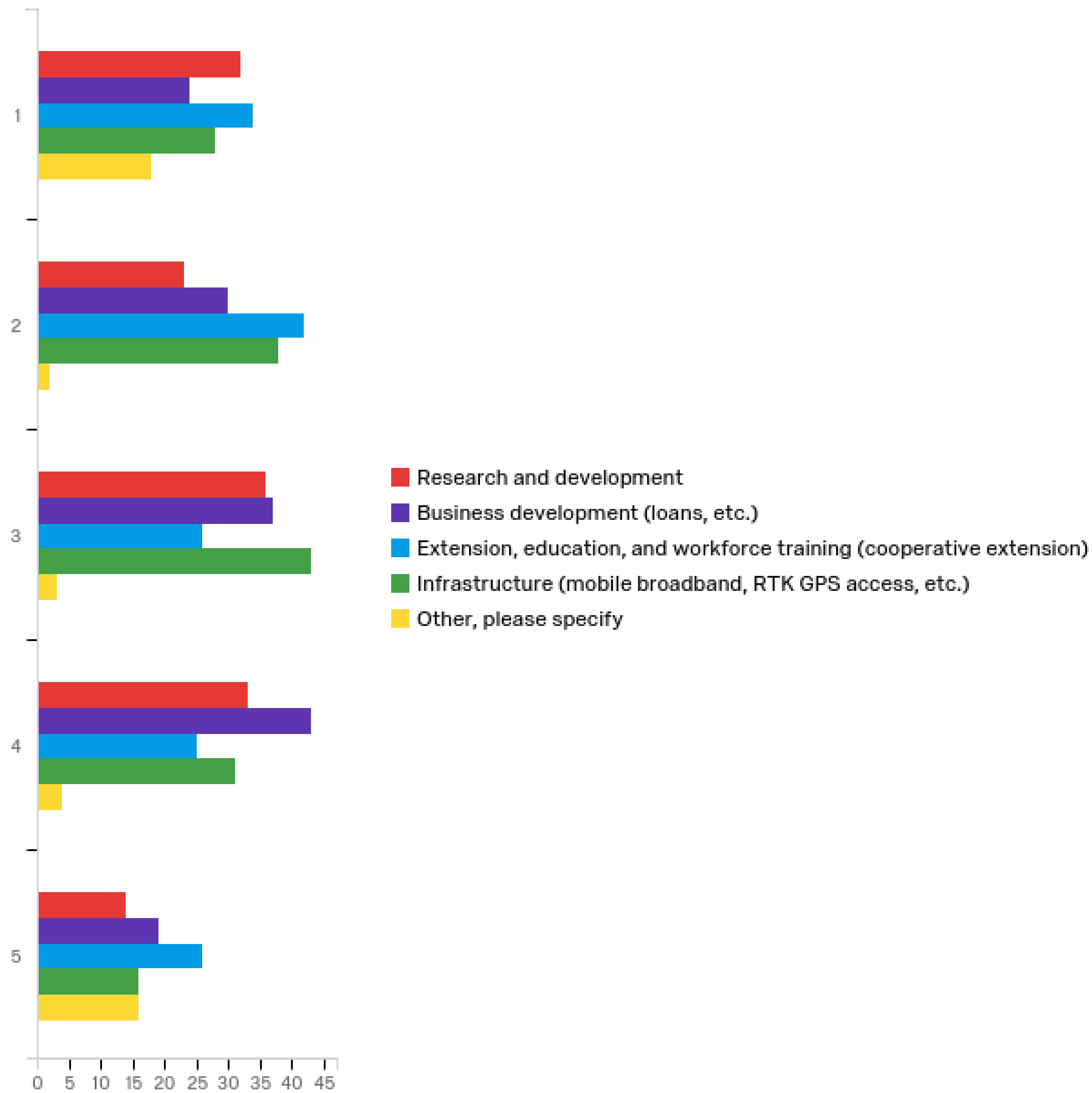
Question	Yes		No		Total
Integrated dairy herd management software for production, health and reproduction	16.92%	11	83.08%	54	65
Mobile devices (tablets, smartphones, etc) to access and record animal information	38.81%	26	61.19%	41	67
Do you track and use individual cow milk production (quantity)?	21.54%	14	78.46%	51	65
Do you track and use individual cow milk quality?	18.46%	12	81.54%	53	65
Outside consultant with herd management	21.21%	14	78.79%	52	66
Electronic animal identification device	15.15%	10	84.85%	56	66
Precision feeding software	10.61%	7	89.39%	59	66

In general, how would you rate the overall business climate for farmers in your area in the following years?



Question	Poor		Below Average		Average		Above Average		Excellent		Total
2015	11.30%	20	31.07%	55	44.63%	79	9.60%	17	3.39%	6	177
Expectations for 2016-18	7.61%	14	31.52%	58	45.65%	84	11.41%	21	3.80%	7	184

If the State of New York were to invest in precision agriculture in New York, what areas should receive priority? Please rank the priorities.



Question	1		2		3		4		5		Total
Research and development	23.19%	32	16.67%	23	26.09%	36	23.91%	33	10.14%	14	138
Business development (loans, etc.)	15.69%	24	19.61%	30	24.18%	37	28.10%	43	12.42%	19	153
Extension, education, and workforce training (cooperative extension)	22.22%	34	27.45%	42	16.99%	26	16.34%	25	16.99%	26	153
Infrastructure (mobile broadband, RTK GPS access, etc.)	17.95%	28	24.36%	38	27.56%	43	19.87%	31	10.26%	16	156
Other, please specify	41.86%	18	4.65%	2	6.98%	3	9.30%	4	37.21%	16	43

Other, please specify

Other, please specify
Lower taxes
improve weather data & use
adapt to all crops
cooperative use equipment
Small Ruminants
How to actually implement profitably
high speed internet in rural areas a must
no opinion
making it applicable at small scale
Open Source and widely accepted data formats so that we don't have to rely on proprietary technologies
I have no idea, so maybe education!
I wanted to inventory plantings using GPS and produce a map with tree ID numbers to correspond to patient log for each tree, Looked into this and cost was through the roof
Program for small farmers to utilize it together.
disagree with government's hand in agriculture. bad enough ags are strong armed by monsanto. longitudinally speaking, these technologies will only take more power away from farmers under the guise of ease when in reality it's spying on the farmer and his land. i don't see how these technologies help smaller operations.
broad species applicability
WITHOUT BROADBAND NOTHING WORKS
High speed internet access
I rated "5" as highest priority. Not sure what scale was
parity for farmers
Unsure
labor reducing technologies
COST

Please indicate your level of agreement with each statement.

Question	Strongly Disagree		Disagree		Neither Agree nor Disagree		Agree		Strongly Agree		Total
I believe that precision agriculture has a bright future in New York State.	2.14%	4	5.35%	10	36.90%	69	41.71%	78	13.90%	26	187
I believe that there are good business and employment opportunities related to precision agriculture in New York.	1.62%	3	6.49%	12	32.97%	61	46.49%	86	12.43%	23	185
I believe the use of precision agriculture technologies brings environmental benefits and efficiency.	1.61%	3	2.15%	4	20.43%	38	50.54%	94	25.27%	47	186
I believe new college graduates have a good understanding of precision agriculture technologies.	1.62%	3	9.73%	18	66.49%	123	16.22%	30	5.95%	11	185

Please indicate your level of agreement with each statement.

Question	Strongly Disagree		Disagree		Neither Agree nor Disagree		Agree		Strongly Agree		Total
My farm operation is very vulnerable to weather and other production risks.	2.11%	4	7.89%	15	10.00%	19	35.79%	68	44.21%	84	190
I pay close attention to business, financial, and technology news.	1.07%	2	9.09%	17	21.93%	41	49.73%	93	18.18%	34	187
I am willing to take risks with new technologies before I see good results in other farms. (Technologies refer to new seeds, precision agriculture practices, etc.)	6.91%	13	22.87%	43	24.47%	46	37.23%	70	8.51%	16	188
I am willing to take risks with new management practices before I see good results in other farms. (Management practices refer to crop rotation, tillage practices, forward contracts, insurance.)	2.67%	5	12.83%	24	26.74%	50	44.92%	84	12.83%	24	187
I believe precision agriculture technologies will allow me to better cope with weather and climate related risks.	4.81%	9	12.30%	23	39.04%	73	31.55%	59	12.30%	23	187

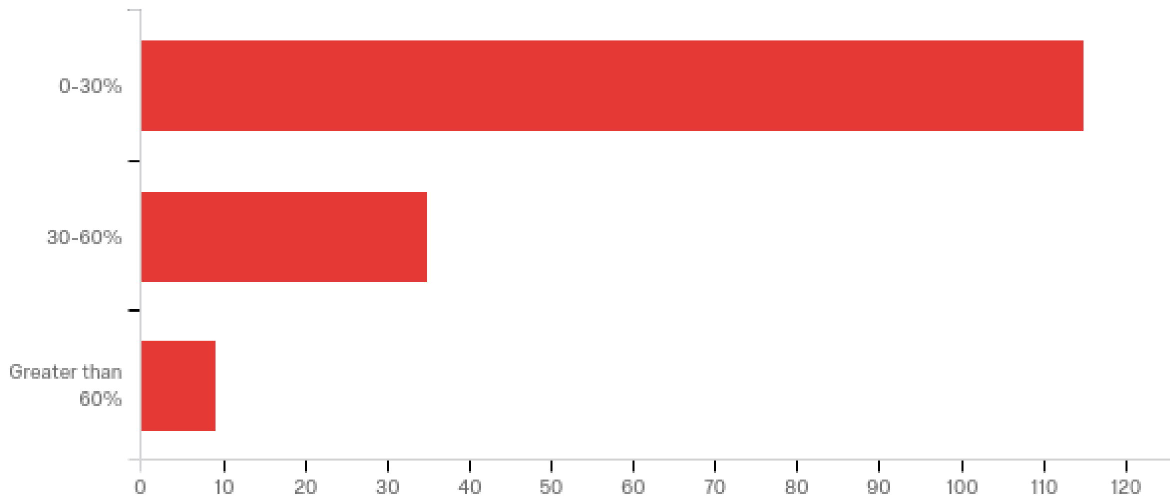
Please indicate your level of agreement with each statement.

Question	Strongly Disagree		Disagree		Neither Agree nor Disagree		Agree		Strongly Agree		Total
When considering new investments or ventures, I am more concerned with possible losses than gains.	1.61%	3	19.89%	37	25.27%	47	46.24%	86	6.99%	13	186
I'd prefer a project yielding $100,000 profit for sure rather than a project that has a 50% chance of yielding $150,000 and a 50% chance of yielding $50,000 profit.	1.67%	3	10.00%	18	33.89%	61	41.67%	75	12.78%	23	180
I usually only invest in new technologies that will pay off quickly (a couple of years).	2.17%	4	19.57%	36	36.96%	68	34.78%	64	6.52%	12	184
I usually adopt new technologies/products/practices before my neighbors do---.	0.54%	1	11.41%	21	41.30%	76	36.96%	68	9.78%	18	184

Please indicate your level of agreement with each statement.

Question	Strongly Disagree		Disagree		Neither Agree nor Disagree		Agree		Strongly Agree		Total
I undertook a major expansion recently or am in the process of one.	12.02%	22	27.32%	50	21.86%	40	30.60%	56	8.20%	15	183
I have canceled or significantly scaled back a major expansion recently.	17.93%	33	40.76%	75	29.89%	55	10.33%	19	1.09%	2	184
Uncertainties regarding tax and regulatory policies have prevented me from expanding or investing recently.	8.15%	15	30.43%	56	28.26%	52	22.83%	42	10.33%	19	184
Uncertainties regarding availability of farm labor have prevented me from expanding or investing recently.	3.76%	7	28.49%	53	26.88%	50	28.49%	53	12.37%	23	186
Uncertainties regarding price volatility have prevented me from expanding or investing recently.	2.72%	5	24.46%	45	39.67%	73	21.74%	40	11.41%	21	184
Climate change poses a great threat to my farm operation.	9.84%	18	24.59%	45	28.42%	52	27.32%	50	9.84%	18	183
Borrowing constraints have /would put my farm operation in financial jeopardy.	10.50%	19	28.18%	51	32.04%	58	20.44%	37	8.84%	16	181

What is your current Debt to Asset ratio (approximate)? This is total debts over total assets.



Answer	%	Count
0-30%	72.33%	115
30-60%	22.01%	35
Greater than 60%	5.66%	9
Total	100%	159

Please indicate your level of agreement with each statement.

Question	Strongly Disagree		Disagree		Neither Agree nor Disagree		Agree		Strongly Agree		Total
I manage risk by using options/futures/forward contracting.	21.93%	41	32.62%	61	33.16%	62	10.70%	20	1.60%	3	187
I manage risk by using Federal Crop Insurance and/or Dairy Margin Protection Program.	22.04%	41	26.88%	50	19.89%	37	23.12%	43	8.06%	15	186
I manage risk by using livestock gross margin-dairy insurance.	28.65%	49	35.09%	60	33.33%	57	2.34%	4	0.58%	1	171
I followed through with my marketing plan this year.	3.33%	6	5.56%	10	31.67%	57	55.00%	99	4.44%	8	180
I followed through with all planned investments I planned to make for this year.	2.70%	5	12.43%	23	29.19%	54	49.73%	92	5.95%	11	185

Precision Agriculture Adoption and Trends in Western New York

Survey and report by Kevin Kreher (kmk279@cornell.edu)

This work was commissioned by Cornell Cooperative Extension of Genesee County and the NWNY Dairy, Livestock and Field Crops Team to determine how many growers are using technology, gauge how it is working for them, and discover how Cornell Cooperative Extension might help farmers working with these technologies. More than 60 people were interviewed for this report, encompassing the perspectives of growers, consultants, industry experts, dealers, and equipment manufacturers. The growers portion of this survey represented almost 140 thousand acres of cropland in the region.

An important point to remember when reading this report is that advanced farms were specifically targeted for the interviews, and the data collected should not be considered a random sample of farms across the region. A key finding among this group was that the average age of a farmer shows no distinct correlation with the amount of technology adopted on a farm. The most important factor was a farmer's willingness to educate themselves on new ideas, regardless of age.

Western New York (WNY) is uniquely positioned in the world of agriculture with abundant natural resources spread across an incredibly variable landscape. It is this variability in geography, soil type, and climate that provides WNY with a competitive advantage for finding a return on investment from precision technologies.

This report contains the following:

- A brief overview of the history of technology adoption in WNY.
- An evaluation of current adoption and trends in the region regarding technology use.
- An exploration of problems and solutions that have emerged with the technology, including a discussion of economic payback for existing and upcoming technology.
- An outlook on technologies role in the future of agriculture in the region.

History of Technology in WNY

Equipment manufacturers started exploring technologies such as GPS steering and yield monitoring in the early to mid-1990s. In WNY, barring some early adopters, the majority of those surveyed started tinkering with these technologies in the mid to late 2000s with initial forays into planter mapping, autosteering sprayers, and yield recording combines. Depending on the chosen technology this either proved to be instantly economical, or further increased skepticism about the economic benefit. As technology progressed closer to where it is at presently, more growers began to see that the benefits outweighed the detracting factors. Ease of use increased, compatibility increased, and data management and transfer became simplified. This streamlining allowed for the technology to be used as a tool to assist farming instead of being seen as an entirely new undertaking that few had time for. Although there are still problems that were repeatedly brought up by numerous parties, the rate of adoption overall has significantly increased and looks to continue to do so. In part this is due to the awareness that WNY stands to benefit tremendously from precision technology.

Current Technology in WNY

An evaluation of more than 30 farms provided a clear picture of what an adaptive conventional[1] grower in WNY is using on his or her farm. A majority of farms have embraced technology generally known as autosteer, where a Global Positioning System (GPS) guides the tractor straight down a row. Use of autosteer is common when a grower would like to synchronize a planter to plant directly in a strip-tilled zone or perform a similar task. Having a GPS enabled planter also allows for more precise planting operations that can respect field boundaries and planter path intersections. The most common technology used on a planter during planting is row shutoffs or clutches that would turn off rows as they intersect already planted rows or pass over field boundaries in unevenly shaped fields.

Further along in the growing season, many farms are using GPS enabled equipment to side-dress and spray. This can be complemented by precision data gathered previously including yield, soil maps, and precipitation and crop models to adjust rate in subsections of fields, although this is much less common currently in WNY.

A majority of combine harvesters in WNY have yield monitoring capabilities, while fewer choppers have monitoring capabilities, and almost no fruit and vegetable harvesting machinery has yield monitoring. This seems to be changing as accuracy increases, and newer equipment comes standard with the capabilities. Yield mapping at a precise, subfield level is a useful feedback for determining whether or not certain actions performed are providing a measurable benefit.

Furthermore, yield data collected over a span of time will become more valuable (capturing wet years, dry years, etc.) as it allows for an understanding of the variability in a field while making management decisions or modeling crops. Not many combines currently utilize autosteer, but those that do benefit from the possibility to share paths between equipment, give or take, including tillage, planting, side-dressing, spraying, harvesting, and even baling.

All of the above discussion circles around equipment generating data, and a majority of this data is underutilized when comparing the average farm to front-runners using the data and technology. This is no fault of the farmers. This is a reality of being in a region where soil and weather variability makes understanding differences in fields over a landscape as complicated and time consuming as understanding a field at a precise subfield level. Fortunately, it also means that those who invest in precision technologies will be able to see a greater return economically. In the following section the most prevalent data uses found in the survey will be shared along with an economic analysis.

Economics, Problems, and Solutions

A majority of farmers surveyed agreed on the potential economic returns and benefits found when using autosteer or GPS steering enabled equipment. Accurate positioning of an implement during passes prevented overlap on all equipment, which, depending on the size of the equipment, field, and the job being performed, could provide significant savings. Savings would come from a range of efficiency improvements, not just decreased input costs, but fuel savings, more work being done in the same amount of time, decreased operator fatigue, and increased operator attentiveness to the task being performed. An example of this last point would be a planting operation where the operator was able to notice a broken disk as soon as it happened because they were watching behind them, saving significant time and lost money from a skip. One interesting caveat is that a mix of equipment that is GPS guided and not GPS guided working together in a field is likely to be just as inefficient as having all the equipment without GPS. This is because the GPS operated machine would have to be driven manually to pick up the correct edge from the other manually driven machines. A number of experienced equipment operators brought the idea up that an all or nothing approach might be best for equipment in groups.

In a planting operation, additional technology can be used to control several planting variables such as down force, population, singulation, and more. The ability to easily adjust these parameters, paired with row clutches or shutoffs also provided a majority of adopters with noticeable economic returns. Shutting off the planter as it overlapped with already planted rows or passed over field boundaries provided savings on seeds, allowed for the most efficient population at all locations instead of doubling at overlaps, and increased ease of record keeping (planting variables, varieties, dates). Similar technology being used on sprayers and fertilizing equipment can provide some of the same benefits.

Tiling operations deserve a brief mention, as many reported that tiling operations using current software and GPS guidance became more than three times as efficient when compared to the previously used highly manual systems.

Throughout the course of the survey, many farmers expect significant savings and returns to come from the previously mentioned technologies. Something that the community should stay aware of is that the above technologies are just the tip of the precision agriculture iceberg. Looking at the amount of data being generated that is already under-utilized, and forecasting the amount of data to be collected in the future by more and more technology shows that there are near endless improvements coming in the future. Utilizing this data and maximizing the benefit will be an exercise in creativity for farmers, and will require outside of the box thinking, as technology is providing whole new solutions to what previously has been seen as set in stone limiting factors. A helpful practice might be to sit down and brainstorm with an agronomist or consultant to see what types of problems can be spotted or solutions can be generated using the data that is collected.

Variable rate application of is one of the most prevalent ways farmers are trying to use the data they generate and collect. Utilizing collected data, software, and variable rate capable equipment, farms can turn soil health management and other input applications into a maintenance program for their fields. Farms that do use variable rate technology have reported success with a wide array of different variable rate applied inputs, and depending on the soil and conditions, variable rate application of most inputs shouldn't be ruled out until thoroughly researched or tested. One thing to keep in mind is that variable rate only affects the spatial positioning of nutrients and not the positioning in time of the application. The case may be that varying the rate of some input be it seed or fertilizer over an entire field does not immediately show a boost in yield, or even save on input costs for a particular year. But because of the long-term impact proper application rates will have on soil health, the returns may become recognizable from a field over the long term. Another thing to keep in mind is that for many inputs, especially nitrogen, economic returns will be most prevalent when the application is properly timed, as opposed to properly positioned. In WNY increased adoption of variable rate application, more precise soil, weather, and yield data will havea much greater impact on bottom lines than agriculturally active areas with less variability in soil type, geography, and climate.

A final issue that was repeated over and over was the need for qualified service and support for all of the above-mentioned agricultural technology. Machinery dealerships all expressed a desire for more employees that had relevant training or technical experience. Almost everyone surveyed including farmers, dealers, consultants, and business owners expressed the growing need for anyone working in agriculture to have an expanded understanding of computers, GPS, data management, and emerging technology applications. Some already existing solutions to these needs are dealership offered classes or review sessions, but many thought that local community colleges or other educational bodies could provide noticeable benefits to the community by either introducing courses related to agricultural technology or offering night classes to educate the local workforce.

Future of Technology in WNY

The future of agricultural technology is difficult to predict as both the hardware and software is rapidly evolving, and each advancement could have an unpredictably large or small impact. What some farmers might not be using for a couple of years, other early adopters will be using next season. What is likely to be common place in the immediate future is that variable rate applications will become the norm, with the spreading or spraying of inputs seen as maintenance programs for keeping the soil health up to par and eliminating variation within a field. As scouting data increases in both quantity and quality using both traditional methods and unmanned aerial systems, tracking of pests, diseases, weeds, and nutritional deficiencies can be coupled with precise and preemptive spraying and prevention practices. This will require increased connectivity between machinery and farmers computers and between farms and other farms or consultants, all of which will require reliable internet connections, new software training, and farmers paying careful attention to data privacy.

As the precision of the data recorded for fields increases via more accurate yield, soil, elevation, nutrient levels, pH, and precipitation maps, precision agriculture technologies can be used to leverage even greater economic returns. An example is advanced planters, capable of switching seed variety, vary down force, population, or fertilizer rate dependent on variables such as soil type or others will produce more consistent yields across inconsistent fields. Soil nutrient and plant modeling software, coupled with weather data, and supplemented by aerial surveying methods, location aware scouting, and tissue sampling, will make nutrient adjustments as close to automatic as possible. Fruits and vegetables will likely follow field crops when it comes to increased data collection and increased precision of that data as more and more operations are mechanized at cost effective price points.

A final note about the future of agriculture shows a bright outlook for WNY. Many young people who were previously uninterested in coming back to family farms have had their interested piqued by the rapid and exciting evolution of agricultural technologies, ensuring a healthy future for farming in New York State and WNY.

[1] Conventional meaning not organic production. Utilizing genetically engineered seeds, sprays, and seed coatings to maximize efficiency.

Appendix II

Precision Agriculture Workshops

A. Abstracts of Precision Agriculture Workshop Presentations

B. Summary Notes of Precision Agriculture Workshop Discussions

C. Precision Agriculture Workshop Decision Making for a Profitable Future

New York State Precision Ag Workshop

New York State Agricultural Experiment Station
Jordan Hall Auditorium
630 West North Street
Geneva, New York, 14456

Abstracts

New York Farm Viability Institute
David Grusenmeyer
Executive Director

NYFVI has funded several precision agriculture projects over the past several years. As NYFVI has become more involved in the precision agriculture arena it is apparent that there is significant interest among farmers, consultants, businesses, federal agencies, as well as Cornell, SUNY Cobleskill, and SUNY Morrisville researchers and educators. It is also equally apparent that there is a significant need for communication and awareness regarding who is doing what and who has what resources and interests.

The whole precision agriculture arena has a web of components and needs that require a wide range of skill sets and resources, and will need the expertise of the entire industry, not just any one organization or individual. A few examples that come quickly to mind – assisting farmers with precision agriculture research interests, designing large scale field research experiments, implementing and managing experiments on farms, data collection, data analysis and interpretation, formulating recommendations, developing individual field prescriptions, integrating prescriptions into farm management systems, helping farmers understand and utilize the technology, producing students with the necessary knowledge and skills, and creating precision agriculture internship opportunities on farms and in agribusinesses. NYFVI has already started efforts to help facilitate communication and coordination between these various industry facets.

Precision Agriculture Applications
Alan N. Lakso
Horticulture Section, Cornell University

Apple Crop Model Supporting Precision Thinning and Crop Control (Lakso, Robinson, DeGaetano, Eggleston) – A dynamic simulation model of the carbohydrate status of the apple tree was found to integrate the effects of daily weather variations on the physiology of the tree. This in turn estimates the sensitivity of the tree to chemical thinners used to control the crop level and quality of the orchard, a critical but notoriously inconsistent practice. Growers can use this real-time information to make precision adjustments for greatly improved consistency, profitability and sustainability. This Cornell Apple Carbohydrate Model is programmed online to provide growers precise guidance both in time and over geographical variations.

An Inexpensive Microtensiometer for Monitoring of Soil and Plant Water Status (Stroock, Lakso, VanEs and Santiago) – New York has extremely variable soils and extremely variable weather leading great variation in soil and plant water stress in time and over space. Monitoring such variation effectively in soils is not feasible now due to the expense of such instruments, and monitoring the internal status of plants is not currently feasible. We have used nanotechnology to develop an electronic microsensor (about 5 x 5 mm) to monitor continuously the water stress of soils and woody plants as part of inexpensive probes. The sensors work over large ranges of stress and are currently being integrated into small, rugged probes with data-logging or wireless capabilities.

An Online GIS System for Basic Vineyard Site Evaluation in New York (Lakso, Martinson, Institute for Application of Geospatial Technology, Auburn) - The rapidly growing wine industry in NY is looking for excellent sites for vineyards as the best quality grape varieties are very sensitive to temperatures, especially cold. Except for Long Island, there are very limited number of such sites. To help prospective growers gather critical basic data on climate, geography, and soil characteristics of sites in NY State, we have developed a GIS-based web site to allow user to navigate locations and obtain over 12 layers of critical information for vineyards in only a few minutes. Launched in 2009, usage has grown over the years.

Precision fruit spraying in New York

Andrew Landers and Tomas Palleja Cabre
NYSAES, Cornell University

Precision spraying allows fruit growers to apply pesticides only to the target canopy or fruit; to apply the correct quantity according to canopy volume, density, growth stage; and to apply products in an economic and environmentally sound manner. At Cornell University we have conducted research into methods of adjusting both liquid spray and airflow according to the dimensions of the crop canopy. In both cases this adjustment was made using information provided by a multiple array of ultrasonic sensors mounted on a vertical mast that scans canopy vegetation. The sensors send signals to a control board that in turn selects the correct number of nozzle blocks or manifolds that can then emit spray according to the canopy. The same sensors and controller is able to position the actuator of an adjustable air louvre, or the speed of rotation of a fan, thus adjusting airflow according to crop volume.

Knowing how much spray has been applied to fruit crops is important for traceability and farm management. We have developed two systems of monitoring spray application and sprayer location based upon rtkGPS and RFID cards; both systems have proven useful in monitoring spray use.

ValuAg Network Co-operative

Jim Dutcher
SUNY Cobleskill

The ValuAg Network is the farm to fork online directory and exchange services for everyone in the food industry. Our mission is to serve everyone, small-to-large in the food chain, from farm to fork, by providing a comprehensive smart network of information, products, and services to farmers, suppliers, distributers, processors, wholesalers, retailers, restaurants, and consumers. We are the local, national, and world online exchange, resource and link into buying and selling food products. ValuAg services will be designed to give especially the small-to-medium ag/farm food produces access to resources and services and allow them to compete as if a larger ag/farm/food producer or organization. Because food security is real and the climate changing around production economics, along with the global demand affecting supply and monoculture putting mass failure at risk, ValuAg will assist with online services pertaining to sustainable practices, increasing yields, and increasing demand while decreasing costly and wasteful energy and water consumption, as well as optimizing any pesticide, fungicide, and fertilizer use. Our services will help reduce the 15-30% crop waste at the farm AND the additional 40% wasted along the entire supply chain. ValuAg will also help in the increasing of demand for local growers/buyers and reach the over 100 million consumers and businesses that are within a day's drive via our online marketplace and exchange. The ValuAg Network Internet business startup will kick-start in 2016 where over the five year period grossing $63 million while projected to employ over 300+ high tech workers (computer programmers, mobile application developers, database experts, and ag/farm/food research & science experts) in the Southern Tier and upstate NY regions.

Precision Vineyard Management:
Collecting and Interpreting Spatial Data for Variable Vineyard Management

Terence Bates, Stephen Nuske, James Taylor, S. Kaan Kurtural, Timothy Weigle, Julian Alston
Horticulture Section, Cornell University

Grape growers of all sizes and market segments across the U.S. are challenged to remain economically competitive while reducing management and environmental inputs required for production. The potential for data-driven spatial vineyard management to improve production, economic, and environmental efficiency is significant but the adoption of precision agriculture techniques has been low because tools for sensing, processing, and integrating complex soil, canopy, and crop interactions for effective variable rate management do not exist in perennial cropping systems. In a newly funded SCRI project, we propose to use mobile sensors to collect and integrate spatial data on vineyard soil, canopy, and crop characteristics; validate and transform the data into useful management information; develop and test data-driven variable-rate vine management; create end-user Internet based tools for semi-automated spatial data processing and management; model and measure the economic benefits from adoption across a range of vineyard types and conditions; and develop outreach materials to facilitate well-informed adoption decisions. The goal of this project is to improve vineyard productivity, fruit quality, profitability and sustainability through an innovative, science-driven, and approachable precision viticulture platform for all sectors of the U.S. grape industry.

Precision Agriculture through the Eye of a Plant Breeder

Michael Gore
Plant Breeding and Genetics Section, Cornell University

The application of high-throughput plant phenotyping (HTPP) to continuously study plant populations under relevant growing conditions creates the possibility to more efficiently dissect the genetic basis of and select for dynamic traits such as daily biomass yield. Towards this end, mobile, HTPP systems that deploy sets of sensors to simultaneously measure canopy temperature, reflectance, and geometry and record climatic factors have been developed or are in the process of being developed for field-based applications in plant breeding and crop management. As a complement, small unmanned aircraft system (UAS) co-robots that work side-by-side with growers are being developed to assess levels of crop disease, in order to breed for resistance, to monitor crops for potential losses and to predict, track and respond to epidemics for national and global food security. In addition, user-friendly mobile apps that converge novel advances in image processing and machine vision for field based, HTPP and crop management are being built and deployed in breeder networks for cassava and wheat.

Cornell SPEAR Program

Quirine Ketterings
Department of Animal Science, Cornell University

The mission of the Cornell Nutrient Management Spear Program is to assess current knowledge, identify research and educational needs, conduct applied, field and laboratory-based research, facilitate technology and knowledge transfer, and aid in the on-farm implementation of *strategies for field crop nutrient management*, including timely application of organic and inorganic nutrient sources to improve profitability and *competitiveness of New York State farms* while *protecting the environment*. Precision agriculture technology plays an important role. Our current work focuses on assessment of accuracy and precision of forage yield monitoring equipment, assessment of field spatial variability and its implications for plant and soil sampling as tools for nutrient management, development of a New York algorithm for sensor-based on-the-go nitrogen management, evaluation of use of field management zones for yield and resource allocation and responsiveness of crops, and we are exploring options for use of unmanned aerial systems for more time efficient and effective decision making at the field level.

Automated Integrated Weed Management:
Challenges and Opportunities

Stephen L. Young
Soil and Crop Sciences Section, Cornell University

During the past decade, it has become possible to conduct on-farm, real-time assessments of crops and pests, such as weeds. Robot technology promises to reduce the amount of labor needed to effectively assess and control weeds. As a consequence, true integrated weed management (IWM), which takes into account all relevant spatial and temporal scales, is within reach. However, even with advanced technology, several challenges remain. In terms of technology, occlusion of weeds by the crop and harsh environments present a challenge. In terms of socio-economics, growers are concerned that technology is replacing the human element of managing agriculture cropping systems. Finally, in terms of science, improved cross-disciplinary collaboration is needed between biologists, who know the most about agricultural systems, and engineers, who develop mechanical and automated solutions, in order to make the advances that are necessary to address critical global food needs and protection of the natural resource base. It will take not only technology, but also a roadmap for overcoming these challenges and move IWM to a level that makes it more applicable, widely adopted, and truly integrated. Within the past 10 years, I have conducted research, published papers, submitted grants, and written an entire book on the topic of automation and weed control. My most recent activities are through the Northeastern IPM Center's Signature Program in Advanced Production Systems, which includes robotics, UAVs and sensor and computer technologies, and collaborating with colleagues in other disciplines to layout a roadmap for the development and adoption of automated integrated weed management.

Adapt-N and Field Profitability Analysis

Harold van Es
Soil and Crop Sciences Section, Cornell University

Adapt-N is a cloud-based computational tool that combines soil, crop and management information with near-real-time weather data to estimate optimum N application rates for corn. It functions at the field, zone or full VRT level, and has recently been licensed and commercialized. Using 115 on-farm strip trials in Iowa and New York we demonstrated that the tool increases grower profits by $27 per acre while reducing environmental losses by 38%. Multi-N-rate trials in IN, OH, WI, and NY showed that Adapt-N closely estimates the Economic Optimum N Rate, and performs better than traditional static methods.

We also developed methodology to evaluate site-specific profitability from yield monitor data and found that fields can be classified into "economically sensitive", "clear profitability", and "all profitable" depending on the field specific characteristics. On many fields, unprofitable zones can be identified for alternative management. We also used EC and NIR sensors (Veris Opti-Mapper) to identify yield zones in fields, and found EC measurements to be more valuable.

Using NDVI Images to Optimize Vineyard Sampling Protocols

Jim Meyers and Justine Vanden Heuvel
Horticulture Section, Cornell University

Using a previously developed sampling optimization model combined with a heuristic optimization algorithm, we determined the most efficient sampling protocols for a vineyard block to accurately capture canopy variability as expressed by NDVI images. Required sample size was reduced by up to 69% and distance traveled was reduced by over 90% compared to random sampling.

Precision Ag Research Project: Optimizing Variable Rate Seeding in NYS
Savanna Crossman
Corn and Soybean Growers Association

This project was initiated in 2013 by a group of growers who recognized the need for a variable rate seeding model that was adapted to the soil and climatic conditions of New York State. Participating growers across the State have been planting field scale research plots and collecting high resolution soils data on ½ acre grids since that time. In 2015 the project partnered with Cornell to sponsor a graduate student to analyze the data and create the model. For each field, the model will create a planting prescription that selects hybrid categories and population rates given certain soil properties/conditions. As the model evolves, the project hopes to add more data layers such as precision weather and UAS layers. The project is always looking to add new participants in order to build the dataset.

Fertility Management Utilizing Electrical Conductivity Mapping
Joe Dunn
Helena Chemical Co.

- Fertility inputs are a major cost of crop production
- 2 goals with fertility management
  -Properly evaluate current soil fertility
  -Provide an appropriate recommendation that satisfies crop need (Right rate, Right place are top priority)
- Electrical conductivity (EC) mapping is a BMP that supports the goals of fertility management
- EC data is collected using Veris machine
- EC data is strongly correlated with soil textures (sand, silt and clay).
- Geo referenced EC data is used to create management zones based on soil texture
- Soil sampling strategies are applied based on EC zones (texture)
- EC sampling is an improved method of sampling because it reduces the tendency to mix soil textures into a single sample resulting in possible improper recommendations
- Why sample by management zones based on soil texture:
  - Provides optimum lime and fertilizer recommendations based on the soil characteristics associated with each zone (CEC, buffer capacity, water and nutrient holding capacity)
  - Provides optimum placement of lime and fertilizer applications based on the soil characteristics found in each zone
- 10 plus years of experience using electrical conductivity mapping to make lime and fertilizer recommendations
- Applications of lime and fertilizer can be made based on EC zones with confidence that crop inputs will be optimized
- Additionally, electrical conductivity "zones" are a good platform to support other agronomic decisions such as seeding rates, nematode management and yield evaluations.

Science based solutions for Sustainable Agriculture
Caroline Rasmussen
Agricultural Modeling and Training Systems LLC

Agricultural Modeling and Training Systems (AMTS) is a global company based in Cortland, NY, offering expertise and tools for ruminant nutrition and management. AMTS licenses the Cornell Net Carbohydrate and Protein System (CNCPS) from Cornell University.

CNCPS is a sophisticated model developed to predict requirements, feed utilization, animal performance, and nutrient excretion for dairy cattle, beef cattle and other ruminants using accumulated knowledge about feed composition, digestion, and metabolism in supplying nutrients to meet maintenance, growth and lactation requirements. Model inputs include air temperature, wind speed and how many steps the cows take. The model can balance for individual amino acids and the chain length of carbohydrates. Using this model our clients are able to use optimization algorithms to maximize animal production and farm income while minimizing potential pollutants such as excess nutrients in manure. The CNCPS model has been used to implement and research Precision Agriculture since 1998. The AMTS implementation of CNCPS quantifies and allows optimization of diets subject to nitrogen and phosphorus excretion and methane and total carbon losses.

AMTS software is used in 26 countries and is available in 7 languages. AMTS also provides technical consulting, workshops and webinars concerning ruminant nutrition and management. Recently AMTS has added products that allow integration of the ration formulation tools with feed mill and manufacturing software. This integration increases animal feed industry efficiency and safety by eliminating redundant data entry and errors. We are continuing to increase the integration of our products to data collection and remote control of feeding at the farm level.

AMTS products increase livestock efficiency. Animal diets formulated using our products maximize milk, meat and fiber production while minimizing cost and nutrient excretion. AMTS products are based on the latest science are highly accurate, have a user friendly interface and excellent company support.

Agricultural Consulting Services Inc.

Jack van Almelo
Manager

Agricultural Consulting Services Inc. (ACS) is an independent crop and environmental compliance consulting company that prides itself on adapting its crop management services to each farm's situation. Today ACS creates subfield breakouts using EC soil mapping, grid sampling, and relative yield maps, and provides variable rate seeding and fertility recommendations. Along with traditional GIS referenced soil sampling ACS offers high density subfield sampling with the Falcon Automated Sampler. ACS also works with adaptive nitrogen management including the use of optical sensors and the Adapt-N Model.

Pathogen-driven Antibiotic Treatment Decisions

Michael Capel, Daryl Nydam, Paul Virkler, Steve Eicker
Valley Agriculture Software

Mastitis accounts for the vast majority of antibiotics used on most dairy farms. As a general rule, mastitis is caused by bacteria infecting the mammary gland. Not all mastitis cases will benefit from being treated with antibiotics. In some cases, the bacteria is no longer there; in others, the damage is already done, so treatment has no effect; and in some cases, antibiotic treatment is necessary, but a 24-48 hour delay in starting treatment does not affect the outcome.

A milk culture can identify what pathogens are involved. It currently takes 24 hours for the bacteria to grow in culture. Pathogen data allow selective treating of cows. A pilot study showed a 60% reduction in antibiotic use for mastitis, significant economic savings, and no change in outcomes. The system is being implemented on additional dairy farms.

Ursa Space Systems Inc.
Derek Edinger
Satellite Manager

Ursa Space Systems Inc. (Ursa) is a geospatial services company located in Ithaca NY. Ursa has a unique spacecraft design with a low cost, synthetic aperture radar (SAR) which provides rich data products at day, night, and in all-weather conditions and a scalable cloud architecture to cost effectively serve a wide variety of markets. This technology and service can support precision agricultural needs by providing crop area, type, height, moisture content, and change in crop features (emergence, tasseling, etc.) in all weather conditions.

Ag Leader Technology
Travis Green
Territory Manager

Twenty years ago the field of precision agriculture was relatively unknown, and Ag Leader Technology was a brand new company in diligent pursuit of making a name for itself. What has evolved over such a short period of time is truly remarkable. Today, Ag Leader is the leading name in precision agriculture and has grown to over 300 employees across the globe in North America, Europe, South America and Australia. Ag Leader has experienced significant growth from its beginnings as a yield monitor company, and now offers a growing array of planting, application, harvest, water management, and software solutions for all brands of equipment.

Corning Hyperspectral Imaging Technologies for Precision Agriculture
Xavier Lafosse
Commercial Technology Director – Advanced Optics

Corning Incorporated has a long history of innovations in optical materials, components and complex optical systems. Over the past decade Corning Advanced Optics division has developed both multispectral and hyperspectral imaging systems. Corning's high-performance hyperspectral imaging and remote sensing solutions, spanning from the visible to the infrared, combine the lowest size, weight and power (SWaP) in the industry with uncompromising performance. This enables deployment for challenging applications in limited payload and/or size constrained environments. After a successful product introduction into the Aerospace and Defense sector, Corning is currently extending its product offering into industrial markets, including the precision agriculture market. Our imaging solutions enable agriculture field surveys at various altitudes and spatial resolutions, thanks to dedicated equipment and software specifically optimized for satellites, manned aircraft, or unmanned aerial vehicles (UAVs, drones). Similar hyperspectral systems are also commercialized to enable the development and validation of innovative agricultural applications in the laboratory, prior to or in conjunction with field deployment. The rich spectral content of this imaging technology, combined with accurate georegistration, will enable a wide range of applications to address the challenges of modern agriculture, from crop yield improvement to the reduction of environmental impact related to water, pesticide, and fertilizer consumptions. While spectral imaging technologies are just emerging in precision agriculture, the overall supply chain remains fragmented and partially connected. Successful implementation of these imaging technologies will rely on our ability to develop strategic partnerships between agronomic consultants, imagery solution providers, custom application developers, academic research, and farm owners and operators.

Aerial Inventory, LLC
Peter Hyland
Owner/Chief Financial Officer

A Remote Sensing and Aerial Data Collection company. Specializing in Multi-Spectral imagery and UAS technology to work with NY Ag Producers. Use GIS to analyze and guide the day-to-day, crop-to-crop, season-to-season growing needs of your farm.

Every flight is fully customized to your farm, and your needs. Data is kept confidential and never given to a third-party. Although we sprouted in the Finger Lakes Region, we are willing to grow into other parts of NY. Optimally set up for 100+ acre operations. Per acre pricing. 100% Legal and insured.

Better data = Better growing decisions, One flight at a time.

Voss Vertical
Steve Welles
Chief Financial Officer

Safe and reliable vertical takeoff and landing aircraft are a dream that has eluded aircraft designers since the 1960s.We have finally realized that dream...

Our elegantly simple design delivers the range and speed of an airplane with the capability to take off and land anywhere, without compromising control, safety, or reliability at any point during the flight.

The aerodynamics have been carefully optimized to compliment the onboard flight controllers, enabling seamless transition between hovering and forward-flight modes. This allows our aircraft to fly beautifully at any speed.

Ag-Analytics Data Platform
Joshua Woodard
Dyson School of Applied Economics and Management, Cornell University

The increased availability of high resolution data and computing power has spurred enormous interest in "Big Data". While analysts typically source data from a wide variety of agencies, even within the United States Department of Agriculture there does not exist a comprehensive data warehouse with which researchers can interact. This leads to massive duplication in efforts, inefficient data sourcing, and great potential for error. The purpose of this talk is to provide a brief overview of this state of affairs within the community. An overview of a prototype warehouse is also provided, and thoughts on future directions.

The following is a summary of discussion notes from the NYS Precision Agriculture Summit held in Geneva, NY on December 15th, 2015

PRIORITIZATION

- Fast, widely available, reliable cellular data and rural broadband is vital
- Economic risks and benefits analysis, demonstrating value of technologies
- Need for further research and education.
- Data privacy and management and regulatory framework to govern storing, access and accountability of data.
- Need of some sort of institute to provide leadership, research, training

SUMMARY NOTES

GROUP ONE – Areas of Opportunity

- Economic feasibility for using digital technology is important for adoption
- Integration/application of the tools is critical
- Partnerships between NYS stakeholders (farms, extension, funders, researchers, ag industry reps, equipment reps, etc.)
- Research and education: there are gaps between technology precision and knowledge in how to prescribe it. There also needs to be training for people to know how to use this tech across the state
- Regulatory compliance and reporting
- What is the value for crop insurance, need to gather information together that is useful for that purpose

GROUP TWO –Future Enabling technologies and innovation

- Overcoming challenging physical landscape of New York State for cellular service
- Big Data –integrated and tied together. Need storage beyond a thumb-drive and personal computer. Big Data will be too large
- Network –cellular and rural broadband needs to be invested in to support accessing and transferring large amounts of data quickly and reliably.
- Big Data – Develop policies for legal privacy protection, ownership and use of data. Who will own data and how will it be shared in a legal framework? Will farmers be compensated for generating this data and allowing access to it?
- API's data standards – being able to cross-communicate the data from many digital tools on one farm and between Ag service providers and farms.
- AI – deep learning and analytics, need some sort of increased investment in order to be beneficial.
- Target funding to further develop technologies currently working while also supporting new innovation.

GROUP THREE –Business Development

- Producers and Ag service providers care about use of private information, how will data be used: most important stakeholders fear that private data can be used against them
- Internet connectivity, reliability and speed is crucial. Cellular data access is very important
- Prec. Ag. Should also offer solutions for *small farmers*
- Farmers need *education* on how to start in on precision ag. From several different sources including dealers, researchers, extension, Ag service providers, and other producers. There needs to be state funding to support this effort early on.
- Tax breaks in NY are good for new business, but for current businesses?
- Big data is a concern (privacy, ownership) and managing all of the data is challenging for producers and those who support them (dealers, extension, consultants)
- Farmers need to understand economic benefits ***–need to emphasis case studies for this. Funding is needed to support further research on economic feasibility along with outreach effort to disseminate results.

GROUP FOUR –Impediments and Regulatory Issues

- Size of farms and field size within a farm in NY makes using DA more challenging vs. the Midwestern states for which a lot of this technology was developed.
- Accessibility and reliability of cellular and wireless connection
- Who owns the data and who has access to it? Legal framework needs to be developed.
- Age of farmers and willingness to adopt and adapt/ need to educate farmers
- High cost of getting in –will it pay off? Is it worth investing in? Hard to get a loan to purchase this type of equipment. Low/no resale value on used (outdated) tech equipment.
- Speed and unreliability of tech change in software and hardware –constant upgrades is confusing to user and pose a risk when upgrades crash.
- Tech companies need to produce equipment with wireless capabilities built in.
- The legalities around drone use: FAA licensing
- Concerns around government surveillance
- Risk of finding environmental problems!
- What is the intent of the regulation? To punish or help?
- Need to engage farmers/producers/getting them involved in the process
- Conflicting messages about what is out there and how useful it is to a particular farm. Need to fund research on the ground to validate, incentivize, and inform DA technological development as well as creating a meaningful regulatory framework.

GROUP FIVE –Research and Education Needs

Research:

- There needs to be more credibility in regards to the research/ more research trials
  For example - developing prescriptions that vary the amount of seeds planted in a given area. More research is needed on the optimal rates for various field conditions.
- Promote public/private partnerships between Univ. and private institutions
- A lot of funding in N management, but little investment in IPM or IWM
- Yield data from monitors is questionable. Need reliable yield data to work with

Education:

- Need educated people in tech changes, need for agronomists: integrate data into a meaningful recommendation
- Replacement of workers: still need research to improve that
- Cornell doesn't have Ag. Engineering focus
- Partnership of Cornell research, private, extension to help the precision ag. movement

February 25th 2016 Precision Ag Program

NY Farm Equipment Show

Precision Agriculture: Decision Making for a Profitable Future

2:30 Registration & Refreshments

2:50 Welcome & Introductions – Dave Grusenmeyer

3:00 Precision Ag – The Basics, the Opportunities, the Industry Trends – Harold Van Es

3:20 Hardware and Software – Capabilities and options through the seasons.

- Transforming Yield Data to Management Decisions – Jim Begley
- Planting and Crop Care – Mark Ochs
- Harvest Technology - Tools to Optimize Your Production – Erick Haas

4:00 Entry Point Precision Agriculture Technology: Benefits and Costs for Decision Making –

John Hanchar & Erick Haas

4:20 Optimizing Variable Rate Seeding Technology in NYS – Savanna Crossman

4:40 Summary of the Survey on the Future of Precision Agriculture in New York State – Aaron Ristow

4:50 Grower Panel – Three growers with significant precision ag technology experience.
Bruce Wright, moderator

- Ag Leader – Travis Torrey, Torrey Farms
- John Deere – Dan Shirley, North Harbor Dairy
- Trimble – Joe Brightly, Brightly Farms

5:20 Summary Comments – Dave Grusenmeyer

5:30 Door prize drawings and Adjourn

For interested Certified Crop Advisors, this program has been approved for 2.5 continuing education units.

Session Descriptions

Introductory and Summary Comments –

Dave Grusenmeyer, Executive Director, New York Farm Viability Institute

In addition to assisting in the precision agriculture efforts of others, NYFVI is providing the organization and leadership for this and other precision agriculture research and education efforts in New York.

Precision Ag – The Basics, the Opportunities, the Industry Trends

Harold Van Es – Cornell University, School of Integrative Plant Sciences, Soil and Crop Sciences Section

In this presentation, I will discuss the basic concepts supporting precision management of crop inputs in field crop and horticultural systems, as well as the enabling technologies. I will highlight the areas of greatest opportunity, and the new technologies that will enhance precision management. We will also discuss industry trends and how they may meet the needs of New York agriculture.

Entry Point Precision Agriculture Technology: Benefits and Costs for Decision Making –

John Hanchar, Cornell University, NW Dairy & Field Crops Team

Erick Haas, Cazenovia Equipment Company, Integrated Solutions Specialist

Erick Haas will provide an overview of auto steer technology, including what is involved, and important points to consider. John Hanchar will review their work to estimate expected economic and financial impacts associated with auto steer, applying partial budgeting and capital investment analysis.

Hardware and Software – Capabilities and options through the seasons

Transforming Yield Data to Management Decisions – Jim Begley, Ag Leader

Evaluating the data collected over the growing season (planting, soil testing, yield, application, Feed Quality from JD Harvest Lab) and how we interpret these in a desktop software setting to provide real information from which the grower can either streamline record keeping for FSA/Crop Insurance or understand what practices are making a profit on their farm.

Planting and Crop Care – Mark Ochs, Ochs Consulting, LLC

Harvest Technology - Tools to Optimize Your Production – Erick Haas, Cazenovia Equipment Company, Integrated Solutions Specialist

In this discussion of Harvest, we will cover the various tools and technology available to document harvest. I will show the value of yield maps/data and how they can integrate to improve the efficiency of your farm operation.

Optimizing Variable Rate Seeding Technology in NYS –

Savanna Crossman, New York Corn & Soybean Growers Association, Precision Agriculture Research Coordinator

Multiple years of data collection and research have led to the creation and testing of a variable rate seeding model customized to the conditions of New York State. Thanks to the statistical analysis by Cornell Professor, Dr. Michael Gore, and PhD student, Margaret Krause, the Precision Ag Project is gearing up to test this model on select fields in 2016. The model examines how yield is affected by several data types including; seeding rate, hybrid, topographical information, NRCS soil survey maps, and precision soil sampling data. Once released, the model can be used by growers to customize variable rate seeding prescriptions based on field specific properties.

Summary of the Survey on the Future of Precision Agriculture in New York State –

Joshua Woodard, Assistant Professor, Cornell University, Dyson School of Applied Economics and Management

New York State policymakers have a strong interest in assessing the use and development of precision agriculture and rural broadband deployment throughout the State. This presentation will summarize the results of a survey in which farmers were asked their perspectives related to the adoption of precision agriculture in NY, including promising technologies, barriers to adoption, cost perspective, labor concerns, and educational and infrastructure needs.

Grower Panel – Questions to be addressed: – Moderator, Bruce Wright, SUNY Cobleskill

- When did you make the decision to invest in GPS Technology?
- What type of GPS signal did you start working with and what applications were you doing?
- What things were easy to understand?
- What things were hard to understand?
- How do you transfer your data from the GPS receiver to your office computer?
- Have you had any problems with file extensions being rejected?
- What is one thing you wish worked better?
- What data are you using now that you were not aware before using a GPS receiver and monitor?


Cornell University
College of Agriculture and Life Sciences