Integrating GIS into farm operations at the Homer C. Thompson Research Farm in Freeville, New York

by

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To my parents. You may not always understand what I do, but you are always there to support me anyways.

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List of Abbreviations

AHP	Analytic Hierarchy Process
CPU	Computer Processing Unit
D2M	Drone2Map
FAA	Federal Aviation Administration
GIS	Geographic information system
GSP	Ground Station Pro
SSI	Spatial Sciences Institute
USC	University of Southern California
UAV	Unmanned Aerial Vehicle
VWC	Vegetation Water Content

Abstract

Over time, the methods and technologies by which we produce and harvest our food have advanced. Large corporations are quick to adopt new technologies and processes, but smaller farms can struggle to see the value in pursuing advanced technologies for farm management. Development of a streamlined protocol for introducing geospatial technology at the individual farm level can help prioritize operations, and help develop long-term operational plans. While the benefits of integrating GIS software and tools are apparent to corporate farm managers, or agricultural economists, they are not always as apparent or easily accessible to small farmers. Using the research farm in Freeville as a case study, a developmental framework for other farmers at Cornell University and around Tompkins County for small-scale geospatial data integration will develop. With a focus on easy-to-obtain datasets, the procedures outlined on this paper will articulate in a way that non-geospatial data users can understand and build upon. This paper will examine the possible benefits of implementing GIS technology in small farming communities of like that of the Homer C. Thompson Research Farm and discuss how it can improve the visualization and management of small farms. While the overall impact of introducing geospatial technology at the small farm level is not quantifiable in this paper, understanding what data is available, and its impact on farm operations, can be beneficial in the long-term planning and management of small farms.

Chapter 1 Introduction

Considering its central location within New York, and its proximity to surrounding rural communities, Homer C. Thompson Research Farm was an ideal site for a small-scale implementation of geospatial technology. Demonstrating to famers in the region, that GIS technology is a worthwhile and meaningful investment. By developing these management solutions using farm data, farmers can benefit from this change and its effects on their operations. In a similar fashion, neighboring communities have examined farm data from a non-geographical standpoint to provide better insight into their agricultural impact area. In a 2014 report published by the towns of Homer, Preble, Scott, and the Agriculture and Farmland Protection Plan Steering Committee, the quality of the soil in neighboring Cortland County is considered ideal for farming (Table 1) (Brock, et al 2014). The table uses the term "prime farmland", which is defined by the National Soils Survey Handbook as land that has the best chemical and physical characteristics for producing crops. The soil quality and moisture to yield a large number of crops, dependable water supply, and adaptability to environmental changes. Developed with spatial understanding of the area, the farmland protection plan implements both data analytics and geographic data. While the use of the study was to develop a planning and environmental platform, the use of geospatial data gives the reader spatial context of the area of focus. In a similar way, using geographic data like soil taxonomy, location of aquifers, and the development of site specific farm data at Homer C. Thompson Research Farm can, and should, be developed giving the farmer and researchers a greater chance for success in understanding and implementing geospatial data practices.

Development of tools from native data, not only teaches farmers of these benefits, but it lays the groundwork and progression into precision agriculture and high-level analytical processes available with GIS. Without the fundamental understanding of geospatial technologies, the next evolution of integration may not be beneficial and truly understood. Small-scale implantation, like that of this project, gives context and proof of concept.

Table 1 Prime Farmland in Cortland County

	HOMER	PREBLE	SCOTT
PRIME FARMLAND	6,120	5,132	2,247
FARMLAND OF STATEWIDE IMPORTANCE	16,053	6, 393	7,739
TOTAL FARMLAND	22,173	11,252	9,786

1.1 Spatial Potential

Understanding how to utilize the spatial potential of farmland will help alleviate negative environmental impacts and improve local ecology. Farmers who understand the spatial diversity of their land will be better equipped to manage local variations in soil properties and topography. Introducing geospatial applications with high-level precision farming concepts provides insight in to organic and ecological data and its relationship with the farm. Attributes like weather changes, soil health, pesticide application and tilling schedules have the ability to integrate into day-to-day farm operations. Simple tabular data that, once compiled, can be stored at the individual plot level, helping track operational and biological changes throughout the farm. The research farm covers 260 acres of land, with farm data spanning back to 1962. Also available are rudimentary maps showing the development of the farm, and a secondary data store of pesticide applications. Incorporating even a fraction of this data will give researchers, campus planners, and farm manages spatial context to planning future operations. Figure 1 shows the study area at Thompson Research Farm. The research farm plot sits on the edge of Freeville, NY, with much of the surrounding area also occupied by farmland. While these operations are functional in their present state, digitization of these records also develops a strategy for data sharing and partnership with other branches of the university. Connections with the researchers begin during the planning phases, but it can be difficult to provide information for past projects on specific plots, all without compromising the data integrity of the records. Having the tools and the support to maintain a system of control over who has access to these records builds, and develop a secure platform for the Thompson Research Farm. For a total farm management plan, farm managers currently rely on printed maps with post-it notes to show research plans and Microsoft Excel to track chemical application. These maps and data are geographically sound, but provide no accessible system of record from year to year, and no backup exists in case of a disaster or accident resulting in destruction of the data storage. Development of an initial geospatial farming application will kick start the process of farm data being continually stored in a location that curates a more complete history of the property; allowing farm managers and researchers in future years to have a cohesive idea of plans and agricultural schedules previously used on a specific plot. The passing of institutional legacy data can also be stored in this elementary platform. As Cornell prepares for members of their workforce to retire, the retention of institutional knowledge is rapidly becoming an issue. If only one person fully understands how operations are to occur, their departure creates a gap in service. By adding even a fraction of that knowledge to this platform, processes and fundamentals can remain intact.

Figure 1. Homer C. Thompson Research Farm

1.2 Local Data

As the population continues to grow, both farmers and scientists will be more likely to adopt new technology that will create an increased food supply on the same acreage of land, while still preserving local ecology, and keeping costs down. Being proactive rather than reactive will give farmers in Tompkins County the economic advantage that many of their counterparts do not have; allowing them to pursue new opportunities for increased production of products at their farm, through technology, new techniques in farming, or operational changes.

The movement of geospatial technology is developing a workflow for small-scale implementation and allowing local governments to share data that they maintain with new industries and people. Tompkins County provides geospatial services ranging from a tax parcel locator, to providing information on the county's agricultural land values. Knowing this data is available for use and query may help farmers, both at Cornell and in other parts of the county, look at their farm as more than a singular entity. Instead as a living, breathing geospatial platform, that can continue to develop with the right tools and education. Sourcing data locally when possible also helps develop relationship and the potential for other geospatial projects.

While geospatial data can provide a new direction for economic growth in central New York, the widespread implementation of GIS technology for farm management has not occurred Thompson Research Farm. Using data from Tompkins County, Cornell University, and information provided by the research farm, this paper examines the difficulties in agricultural data, and documentation of implementing geospatial data. Implementation workflow and documentation will provide the research farm the opportunity to utilize the wider Cornell University geospatial data network. This framework provides basis for any future expansion of the project to other Cornell-owned research farms.

Chapter 2 Background and Literature Review

The approach of introducing GIS and GPS technology into the agricultural industry is not a new concept. Over the last 20 years, increased use of technology in all industries has helped develop a major shift in practice and the technological use of application in the agricultural industry. As the use of geospatial technology in agriculture continues to grow and migrate into day-to-day operations, agricultural groups have begun to understand the importance and value of learning and implementing these new systems.

2.1 Precision Farming

With its large mountain ranges, natural feature, and limited room for growth, many of the successful geospatial transitions in industries focus their attention in Europe. The unique terrain of much of the continent is creating ideal use cases for the use of GIS and GPS technologies in agriculture. That is not to say that precision agriculture is not happening elsewhere in the world, but research in England and Hungary present the best research-based examples for this paper. Precision farming is already in use in United States industrial farming, but those use cases are large-scale operations that are far beyond the scope of this project. Most of the major agricultural operations in the United States use tools and technology developed by manufactures with the intended use being precision farming practices. The scope and research supplements of the project focus on small-scale agricultural implementation of precision farming and the development of tools for initial data integration.

2.1.1 Geographic Challenges

In Hungary, researchers worked to introduce proper GIS systems and platforms to a population with little to no technology experience. In this case, the work focused on determining the best system and process for introducing precision farming (Pecze et al, 2001); Defined by the Pecze as '…a way of farming which takes into account the in-field variability, a technology where the application-seeding, nutrient replacement, spraying, etc. has taken place to act on the local circumstances of a given field". Using environmental sustainability as building blocks, Pecze developed worked to show justifications on the introduction of geospatial technology in agricultural practices. Developing from that foundation, Pecze also states that the introduction of GIS into these practices will help to maintain a level of sustainable practices. With elevation challenges and limited cycling in the ecological health of plots, the use of precision farming can help alleviate the over use of plots and farm systems. Precision control of fertilization locations and amounts helps monitor the potential impact on the surrounding areas, while saving money from excess use of product. Using these practices, Pecze was able to demonstrate a small-scale theoretical application of precision farming, and its benefits. Using field data from 1999 and 2000, Pecze was able to demonstrate the use in both fertilizer application and increase in yield. Figure two shows histograms of his results, as well as yield geography. That concept, and understanding its value, create increased value for all those involved. While this project is similar to the overall goal of this paper, it demonstrates the possibilities of precision farming and the benefits farmers can expect to see, even with theoretical data. With these concepts in mind, other attempts at having systematic planning and cultivation processes for the masses have occurred.

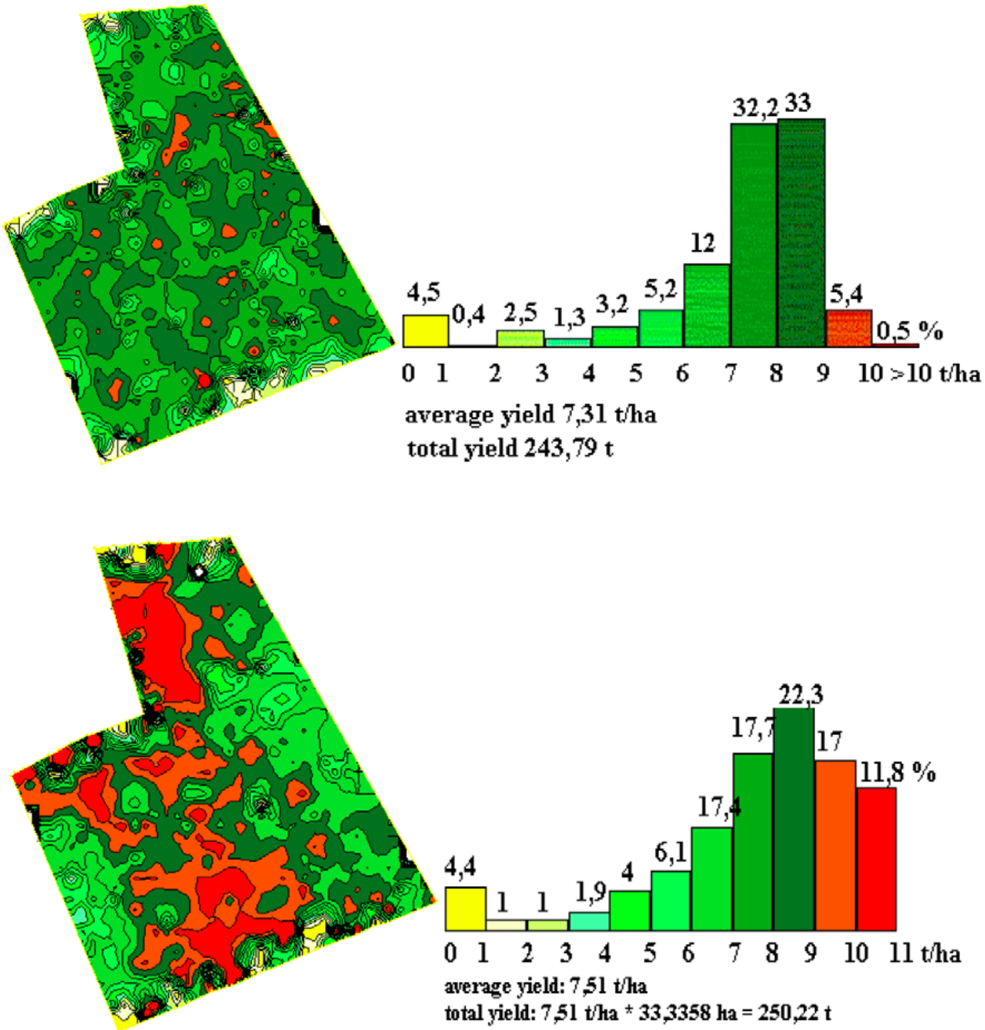


Figure 2. Yield map (RDS, 1999 and 2000), the histogram shows the distribution of the yield categories.

(Pecze et al, 2001)

2.1.2 Meeting Increasing Demands

Researchers in the Netherlands developed a geo-spatial arable field optimization service (GAOS). The main functionality of GAOS was to develop the geometry needed to integrate into the agricultural software; In the case of farms, this means field boundaries, and natural features. The assisted layout pattern of fields adopted by farmers, developed over the course of a three-year study during which farmers saw a four percent increase in income (Bruin et al, 2014). Twenty-three of the twenty-six participants were willing to invest in a full system. A major drawback to the study was the level of understanding needed by farmers to use the new software. Like any software, time and knowledge play a factor in the usability and effectiveness of the platform; however, with guidance, most participants became engaged in using the field optimization service.

Both Bruin and Pecze show the application precision farming and the usefulness of the technology in agriculture. Each displaying the continuation the agricultural and technology implementation, but working toward a simpler process for non-uses to understand. In order for GIS to become even more of a universal standard in agriculture, action must occur. With a focus less on the technical application of the product, and instead, present the product in an easy-to-understand manner. By utilizing commonly understood analogies, simple ways of displaying data or modeling the user interface off a product that is familiar, farmers can continue to develop a better understanding of the geospatial products.

2.2 Land Sustainability

As ecosystems change with the ebb and flow of nature, and the global population continues to grow, food stability and agriculture efficiency are assuming a greater importance, which require additional functionality: how do we produce more agricultural goods, like dairy and grains, without sacrificing sustainable practices? Urbanization continues to be an ever-increasing problem, specifically in areas with a growing population density. The conversion of agricultural land to housing or urban landscapes challenges this question, and forces farmers to examine their practices with a new outlook and system impact. The loss of local food sources requires the community to outsource, putting a strain on an outside agricultural communities and increase in energy transportation resources to bring those products to the consumer. The use of geospatial technology to monitor these conditions continues to increase as the data associated becomes more accessible to those who need it.

2.2.1 Using Technology to Make Decisions

While high-density urbanization is not an immediate threat to our study area, other studies focusing on geospatial technology and agriculture are addressing the issue. Both agricultural development and urbanization growth have key factors that affect long term planning of any area. As land availability decreases, and land value increases, industries have looked to capitalize on any available resources. Using concept developed in the 1970's by Thomas Saaty, the Analytic Hierarchy Process (AHP), researchers in Shri Lanka have been able to determine well-trusted and widely used decision-making theory regarding space management (Weerakoon, 2014). Using application-based decision-making provides evidence for major projects, and help integrate all aspects of an areas needs within the calculation. AHP's major value is the using the Pair-Wise comparison matrix to value judgements. This procedure is by which combined criteria arrive at an evaluation and the same criteria allows evaluations to occur and actions taken. Weerakoon used this platform determine the best location for specific types of farming, and expansion of urban development from major cities. These statistical and geographic based analyses also used natural features like rivers, lakes, and coastline as variables in the final analysis. From these conclusions, Weerakoon was able to develop a map that demonstrates these findings and sets the stage for future geographical analytics based on this initial mapping of the area. Figure 3 demonstrates Weerakoons final map. Integrating a process of statistical decision making into site-specific agriculture practices and planning can allow decisions to rank in a hierarchy and help develop a better understanding which fields needed the most attention, and taking into consideration other factors of a farm: field output, employees on staff or the overall health of the land.

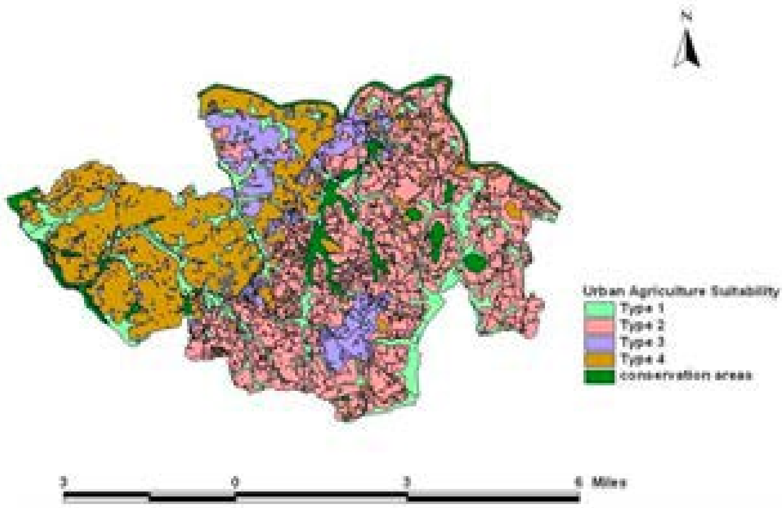


Figure 3. FINAL SUITABILITY MAP (Weerakoon, 2014)

2.2.2 Soil Health

The health of the soil is one of many overall contributing factors to the success of a farm, as well as at Thompson Research Farm. Development of a proper soil taxonomy can aid in determining best potential plots for research project, or areas of a farm that require additional attention and supplemental materials. While the quantifiable variables of a soil are something that researchers in the United Kingdom see, researchers have used soil data and geotagged social media phots to verify the positive correlation of proximity to water sources and the decreased amount of carbon soil (Casalegno 2014). In in the United Kingdom, inland soil’s decreased carbon content is be directly related to the higher number of farms inland, with the decreased number near the coast. Agricultural data developed from the United Kingdom’s ward census data and used to calculate an overall measure of agricultural production by summing the gross margins for all major crops/livestock. This data was displayed using £/hectare, resampled at

1meter resolution, and displayed at one km sample level (Casalegno, 2014). Using soil carbon data at one km^2 resolution, and the agricultural data, Casalegno was able to develop a high-level view of the ecologically valuable land in the UK. Figure 4 demonstrates the areas of data collected for the study. Once this baseline data was developed, social media data provided geographic locations to show the cultural impact on these areas, and their influence on social media. While unconventional, this study demonstrates the human perception of plant health and the visual impact imagery has on understanding an areas overall health. The concepts used and the environmental relationship will create deeper dimension into this study. Viewed in conjunction with soil taxonomy mapping, and its relation to irrigation issues, soil health is a major area of study to consider when developing any geospatial data for agricultural application. Since our study area is in the United States, rather than needing to produce carbon soil samples and soil salinity tests, we can use data gathered by the National Cooperative Soil Survey. Not developed on a singular project basis, this data relies on the collection of qualified individuals who then report this data and samples back to the United States Department of Agriculture (USDA). Those reports add to their data download portal for use. Soil taxonomy is a specialized field of study, and although the data could be a variable in this project, the application of the data at a singular location or area could warranted as a separate project to be conducted allowing proper focus on the data to occur.

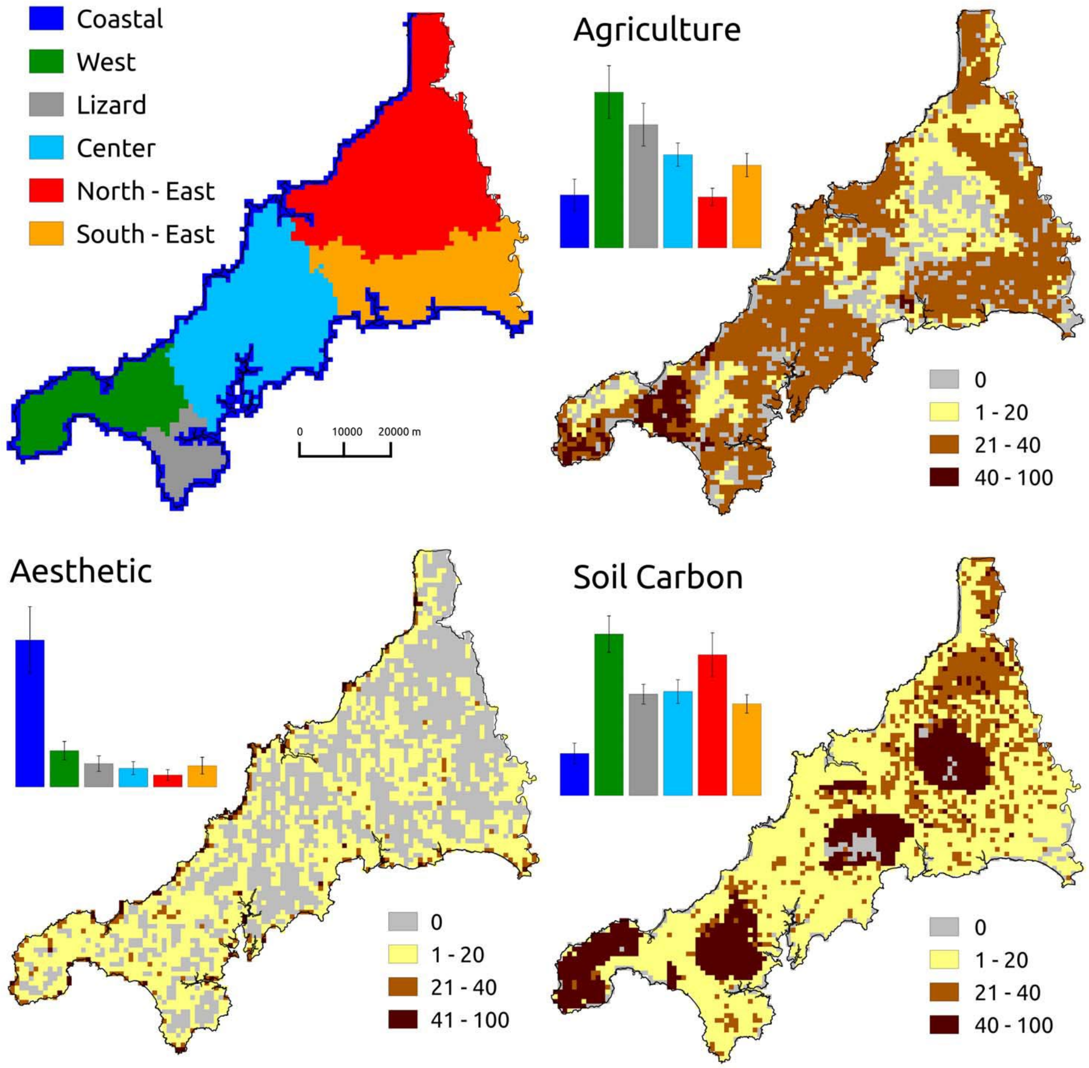


Figure 4. Geographical zonation of Cornwall (upper left), the distribution of agriculture, aesthetics and soil carbon (other maps; variation scaled from 0–100), and the mean value of each ecosystem service within each geographical zone (histograms). (Casalegno, 2014)

2.2.3 Using LANDSAT Data in agriculture

Since LANDSAT first launched in 1972, earth observational imagery has changed the way we view aspects of the earth's surface, and how it changes. These new technological insights highlight the opportunities to monitor and analyze these developments. Through multispectral imaging urbanization expansion, loss of natural land and vegetation health monitoring can occur through scheduled LANDSAT data analysis. The timing and quality of data collections can however be the major limiting factor in data collection and analysis. Clean up of atmospheric anomalies can be difficult to process, and the proper analysis of data can be tricky depending on the processing type. Using LANDSAT data, researchers at the University of Wisconsin- Madison developed a workflow for analyzing the Vegetation Water Content (VWC) in corn and soybean plantings. Based on the Normalized Vegetation Density Index (NVDI), Jackson was able to equate the potential reflective properties of vegetation (Jackson, 2004); However, NVDI calculations are variable and do not always produce constantly accurate results. Using a plot of land labeled SMEX02, Jackson developed collection dates and data needs to utilize LANDSAT data bands five and seven to develop a more accurate VWC value. Processed data collections developed new calculations for more accurate VWC values and represent a lower margin of error in the overall calculations. Figure 5 represents the findings from Jacksons LANDSAT data collections.

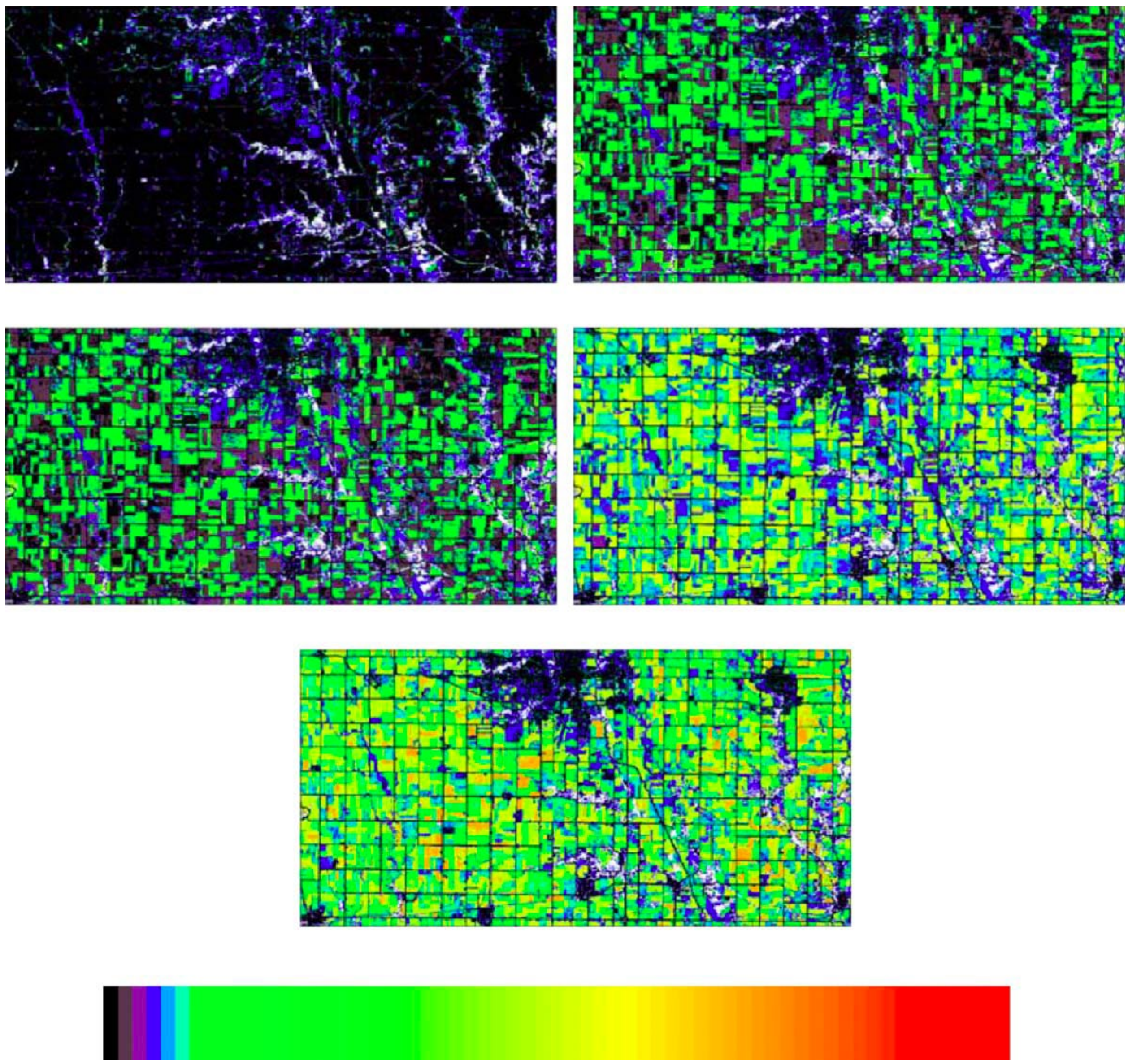


Figure 5. Vegetation water content images derived from the Landsat data during SMEX02. The region is approximately 18 by 36 km and the city of Ames, IA (Jackson, 2004)

Jackson's research demonstrates the application of LANDSAT spectral images and determining the health of specific areas, and developing a collection schedule based on the satellites and the variables associated with using the data. While this project was developed to show the relationship between VWC and NDVI calculations, and deriving them from the LANDSAT data, the project can be used as a proof of concept for demonstrating the hurdles that can be encountered when using data collected by a third party, on a differential collection schedule.

2.3 Our Use Case

Much of the success of this study relies on the understanding and cooperation of farmers to participate in the study. Understanding the Thompson Research Farm is not only critical for this study, but allows the basis of this papers discussion to reflect the data and natural environment at the farm. People will not develop homes where they cannot grow food, this concept has exceptions but the idea of connectivity and the relationships of the surrounding population is a key element (Hart,1998). Communication between different parts of the agricultural process are critical in developing a cohesive geographic platform and process. In a report developed by the Towns Homer, Preble, & Scott Agriculture and Farmland Protection Plan Steering Committee, this relationship developed into a more succinct pattern. Towns in Cortland County developed a farmland protection plan, with the major focus being local environmental conservation, and the understating of local zoning laws. The intended use of this study was not only to enact environmental restrictions on certain areas of the county, but also to give local planning originations proper background information when developing their efforts. Participation by these communities demonstrates local support for the protection of agriculture and its economic as well as economic impact on the area. Communities in and around the agricultural industry will continue to learn about the impact of farms in the economic and ecological environments of the area. These areas will develop an understanding of how geospatial technology can give them the tools to make better decisions, and provide tools and data to garner better results from efforts.

Chapter 3 Methodology

Chapter 3 describes the framework of this thesis, including the data used and any processes developed. Section 3.1 proper data implementation and the implications of data integration. Section 3.2 describes other data used, focusing on data that needs to be collected and created for this project. Section 3.3 explains the methods used to process the data, and examining the transition from ArcGIS Desktop to ArcGIS Online.

3.1 Introduction

Proper implementation of a precision farming application relies on the development of data sets. With the digitization and integration of current data records, farmers at the Thomson Research Farm have the capability to plan long-term operations for the farm, and better advise researchers on specific aspects of the farm. While data in this process can be simple, the visualization in geographic context provides a new level of precision not currently in place at the farm. With no geographic visibility, farmers must rely on institutional awareness to address issues and concerns within the farm. With an aging employee basis, overlapping education and farm operations needed to be stored in an understandable format. By introducing of geographic data to this institutional knowledge transfer, data development and retention will streamline. While some of the data is currently available through Tompkins County GIS, and Cornell University Planning Office, much of these decisions on data were farm specific and development occurred specifically for this paper.

3.2 Research Design

Building a small-scale geospatial, data integration does not have to be a complicated process.

Designs as simple as one geographic feature on a map with simple data are in essence a geographic information system. For the integration at the Homer C. Thompson Research Farm, the simplicity of such a system was the building blocks for various reasons. One: the users of said system do not have any formal geospatial training. This projects intention was for non-GIS users to have the capabilities to access geospatial data, without having to take formal training. Two: current staffing standards and data stewardship at Cornell University does not have a dedicated employee to develop and maintain research-based agricultural management data. As such, consideration of designing any data integration, the longevity and maintenance of the system need, are included in technical plans. While the goal of every geospatial professional is to build a first-class product in any field, consideration of the maintenance beyond initial build was a factor in system design. In his research at Cornell University, Frank Popowitch also designed a system that, on initial build was a fully functional integration and with the proper maintenance could live beyond the scope of his project. Using Cornell University Police as his case study, he designed a geospatial platform that would allow for out-of-office map consumption by Emergency First Responders, and Environmental Health & Safety staff (Popowitch, 2010). While the project development occurred using off-the-shelf data platforms, after the tenure of the project no steps occurred to continue building out his suggested platform. This was mainly because no appointment of a data steward ever occurred to support the projects goals and inter-disciplinary geospatial development. Three: the data used in this project is only a preliminary amount of the total data available for integration in an agricultural application. Forty more years of tabular data are available for additional digitization from the farm, and other supplemental geographical data is available to develop a system with more depth and complexity.

Simplicity and using out-of-the-box products was used an intentional way to help promote the ease of use and ease of maintenance of the system after completion. The Environmental Systems Research Institute's (Esri) movement in the last 10 years to server based data storage, and widespread development of cloud based data services. Rather than developing a product that is only consumable on ArcGIS desktop, the move to a server-based application allows internet based geospatial data services to be included. Web based applications allow for more users, both traditional GIS professionals and non-users, to have steady access to data, regardless if they have a desktop version of the software installed on whatever computer they were using. ArcGIS Online allowed for web mapping applications to embedded into other web systems, allowing more people to use web-based maps in new ways. This move away from traditional desktop-based systems gives new flexibility to the platform. This project developed a web based mapping application to serve as a data hub for the Homer C. Thompson Research Farm, allowing for better geographic visualization and relationships between year-to-year farm plot data. From the data from the farm's legacy storage, and simple geographic features, a small-scale geospatial application emerges.

3.2 Data Descriptions

For this paper, the gathering of baseline information about the Thompson research farm played a critical role. With the addition of legacy information about the farm, currently stored in paper format, a robust geospatial platform adds to farm operations.

3.2.1 Tompkins County Data

Through the Tompkins County GIS Portal, users are able to view and select data that is of interest to them, and download the files in a format such as .JPEG, or GeoTIFF. For this paper, Tompkins County has provided parcels, found through the portal in shapefile format, for use in any web applications developed as a part of this study. Data is available using the Tompkins County GIS Open Data portal. Operated by the Tompkins County GIS office, this portal allowed anyone to view or download different types of geospatial data that is publically available. Property boundaries and addresses are among the most useful for this project. Figure 6 shows the available data when searching the address data portal from the website. Other available data includes transportation, natural resources and county planning data. All data in the portal is queryable, and includes viewed using charts and graphs.

The access to local data at a simple location allows this project to exist outside the parameters mentioned in this paper. If a farmer not part of the Cornell University agricultural system wanted to set up a similar platform, the opportunity to gather similar data sources is available to them through this portal. For this project, data directly from the Tompkins County GIS office is available as a part of the data sharing between offices. These parcels not only provide spatial context to the property, but also can identify any adjacent land owned by the Thompson Research Farm, and be potentially utilized in the future. Long term planning and analytics will not be a part of this project, but the potential with the data at hand is of note.

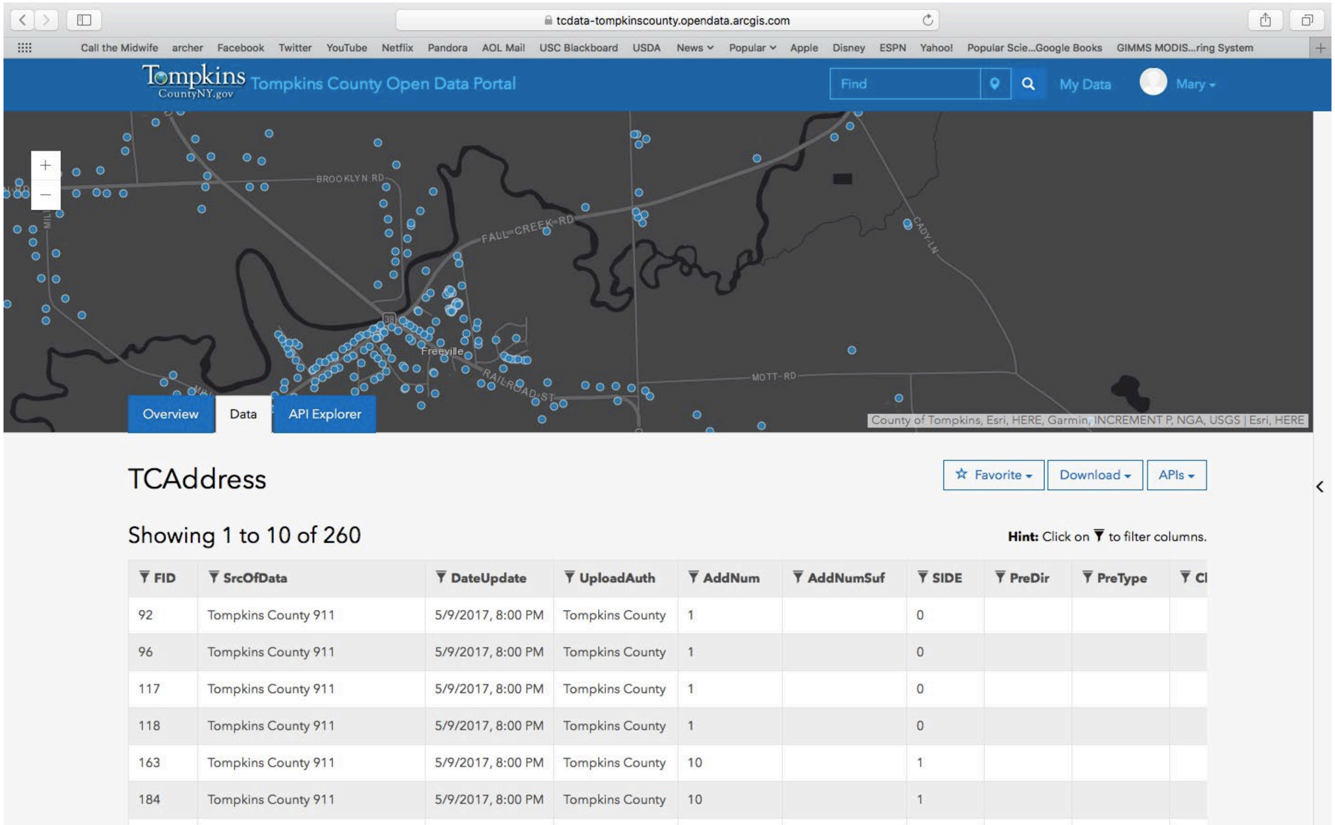


Figure 6. Tompkins County GIS Open Data Portal focusing on address data available in Freeville, NY

3.2.2 Thompson Research Farm Data

At the time of this paper, the Research Farm did not have any digital platform storage of their data. Farm records from the fifty plus years of record keeping resided in filing cabinets in the main farm building at the research facility. Sorted by year, these records were available when a farm manager needs access to them; however, when an outside source requests data, documents require manual scanning onto the computer. The data in the document had no dynamic capabilities and did not represent the full capabilities of the data. Each year the data packets restructure based on research needs, and any additional farming done by staff. In its current state, the data did not reflective of all the research done over the farms history, and it was not possible to develop a comprehensive history of any specific plot at the research farm. Each plot contained a unique alphanumeric identifier maintained from to year, and could be used to track a specific plots history. This value joins the tabular data to plots created from overhead images of the farm. Collected bi-annually, Soil pH, phosphorus, and potassium values supplement the records in correspondence of the years they are available. Fertilization type, amount used, and any additional applications are collected, but depending on the intended use of the plot, this data varies between parcels. General research plots may see more than one traditional application of fertilizer depending on the research conducted, while organic plots will receive compost to help deliver the same properties. Plots left to fallow do not always receive fertilizer applications, and may be missing this data from the records. In addition, records show cover crop and research crop plantings, with the latter sometimes excluded depending on the plot designation. Additionally, the research groups tend to the plot, so there is a gap in information coming to the farm management office. Record of any tilling or maintenance done to the plot will also reside in these records.

Also available from the farm records are basic maps showing the general plot placement from year to year. These maps did not have any geographic accuracy, but play a critical role in development of an accurate geographic representation. Using UAV images, these placements allow modifications, creating a more comprehensive geographic history of the farm. Even in the four years of data used in this study, these maps were critical in understanding how certain plots interacted or were completely combined, only to reemerge a year to two down the road when the plots are separated again.

Table 3 shows an example section of the first 10 rows of the farm data after entering plot information into Microsoft Excel.

Table 2. Excerpt from plot records after they have be added to Excel

PLOT_ ID	PROJECT	CROPS_GROWN	TOTAL_ AREA	SQ_FT	ACRES	PH	P	K
A1	NEWSS	Multi Crop for Herbicide ID	38,850	38850	.89	5.7	16	175
A2	M.MAZOUREK	MISC SQUASH	23,600	23600	.54	6.7	31	385
N1A	M.MAZOUREK	CUCURBITS WATERMELON	20640	20640	.47	5.9	31	250
N1	M.MAZOUREK	MISC CURCUBITS	74000	74000	1.7	6.3	37	2880
N2	R. BELLMDERS	BEANS SNAP AND DRY PEAS	75420	75420	1.73	6.2	39	360
N3	R. BELLMDERS	POTATO	73260	73260	1.68	6.2	38	335
N4	BELLMDERS/ GALLOW	N/A STONEPICKED	N/A	70920	1.63	6.4	49	410
N5	BELLMDERS	N/A	N/A	74000	1.7	6.0	41	390
N6	BELLMDERS	WINTER SQUASH PUMPKINS	N/A	102000	2.34	6.4	50	405
N7	R. BELLMDERS	SWEETCORN 5. 200 FT	56000	121250	2.78	6.6	40	355
N7N	FALLOW	CLOVER	N/A	63560	1.47	6.7	30	290
N8	FALLOW	RED CLOVER	N/A	86520	1.99	6.6	6	175
N9	A. RANGARAJON	SWEETCORN	N/A	150000	3.44	6.6	33	280
N10	FARM	RYE CLOVER	N/A	61800	1.42	6.8	8	2010
S1	O. HOEKENG	TOMATO CUCURBITS CRUCIFERS SNAPBEANS	43600	43600	1.0	6.7	5.2	235
S2	FARM/ANN R.	ESTABLISH COVER FOR 2011 SEASON	N/A	45000	1.03	6.9	65	255
S3	K. PERRY	POTATO	47200	47200	1.09	6.2	45	355
S4	R. BELLMDERS	STRAWBERRIES CRUCIFERS	N/A	56200	1.29	5.7	40	410
S5	R. BELLMDERS	CAB. EGGPLANT PEPPERS TOMATOES	50968	50968	1.17	6.2	44	340

For this paper four years of the data, 2010 – 2013, were migrated to Excel and integrated as part of this project. This interval determines the best length of time needed to digitize the data, as well as understand its usefulness.

3.3.3 Unmanned Aerial Vehicle Data Collection

For an additional layer of detail and visualization, this project used an Unmanned Aerial Vehicle (UAV). Cornell University Facilities and Campus Services (FCS) owns and operates a DJI Inspire 2 UAV, and has worked with the Thompson Research Farm in the past, as a facility for UAV flight practice and data collection. For this project, FCS allowed the use of the UAV. Using the UAV, this project will collect overhead images to process into topology, three cm accurate GeoTIFF files, and aid in the digitization of individual farm parcels. While not a critical aspect of this project, overhead aerial images in Google Maps, Esri, were not adequate for determining plot edges. Figures 7 and 8 represent images in Google Maps and Esri respectively. The lack of clarity in these images did not give enough spatial context to be useful. Beyond the initial data integration, these 3rd part images are not useful in any additional analytics. RGB data is capable of multi spectral analytics but it not always the intention.

Figure 7. Google Aerial Image quality

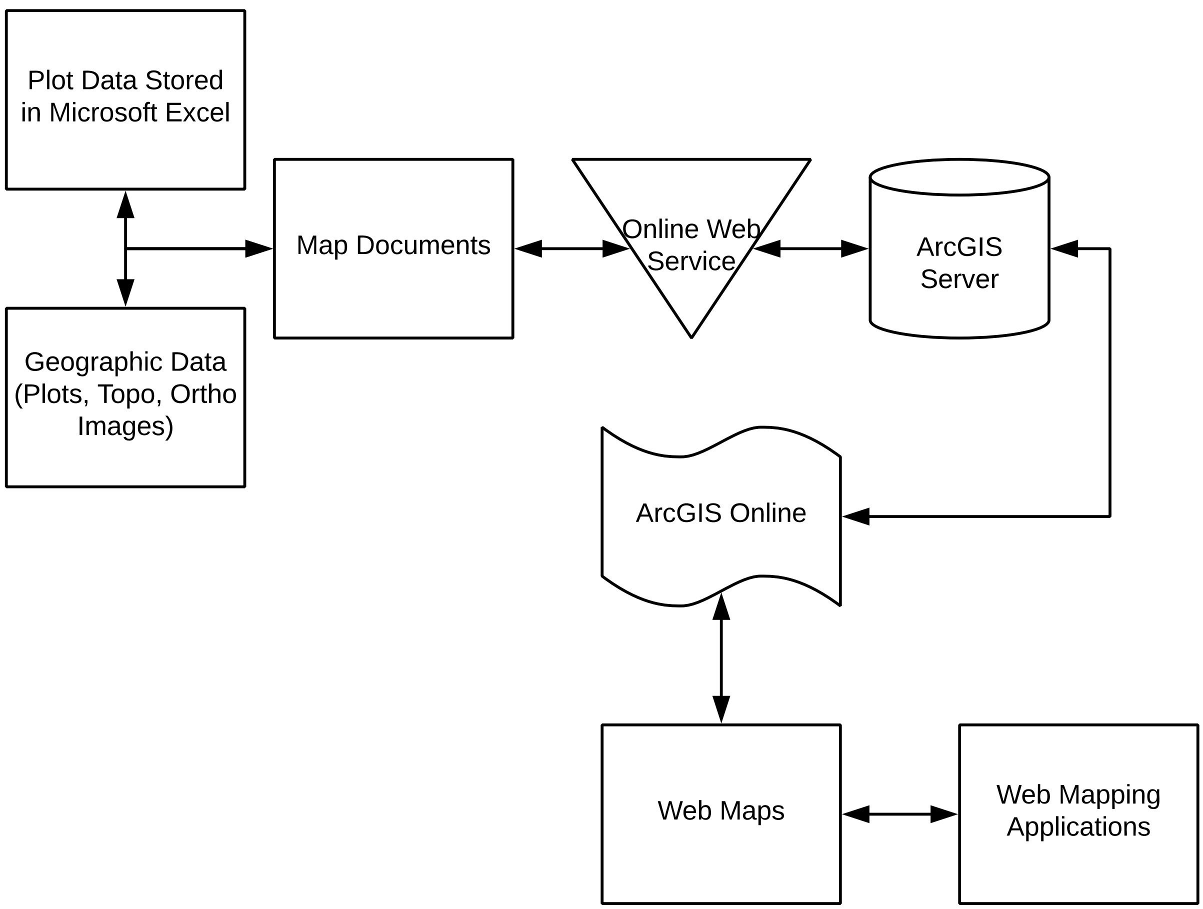
Figure 8. Esri Aerial Image Quality

Scheduled image collection was determined on weather allowances, with batches of data collected on the same day to introduce a degree of consistency between the images. The first section of images dates July 2018 were a proof of concept for the data collection timeline. The remaining collection occurred over two days in August 2018. Weather patterns were the major contributing factor to data collection schedules. Quadcopter flights can occur in a variety of weather patterns. Aerodynamics of quadcopter flight favor stable heavy air mass, allowing the UAV to move easily in the sky, and the pilot to have better control over the device. These stable air patterns have a high humidity content, giving the quadcopter propellers better lift in the air, with low wind from the air mass being slow moving. Overcast days with the cloud cover lowering reflections from water, plants and building in any images collected. Overhead images taken on a sunny day will still be useable, but there is a risk of distortion from shadows, especially around buildings and any large objects. This will be especially obvious after processing, and proper match points fail to generate. Using Drone2Map (D2M), an ArcGIS companion software, overlapping images generated new compiled images. The D2M platform uses geo-located images from UAV cameras to develop 2D and 3D products. The user has the ability to select specific parameters for a data processing query, based on their needs and the speed of the processing. For this project, the parameters selected that allowed singular orthomosaic file generation, while simultaneously processing topographic data files. These processing options can be detailed in their nature, or as basic as selecting a checkbox before processing. This 'behind the curtain' processing that Drone2Map provides allows for a dedicated software to only process aerial imagery, while not requiring manual match point selection by the user. Figure 10 shows the processing options when setting up an orthomosaic project. Once completed, the orthomosaic images served as a basis for new plot boundary data, generated form the yearly plot maps. The orthomosaic verified these locations as well as provided any visual clues to plots modifications or combinations in years past. These plots were then assigned plot identification based on the alphanumeric tags used in the plot records. Plots then have the ability to join with the tabular data and brought online.

3.4 Data Processing

Data required to develop a program management system fell into three phases: Foundational, Data Creation, and Data Compilation. Foundational data consisted of files useable in their original format and currently accessible by anyone with an internet connection. Data Creation and Compilation focused on the data needs for this specific project at the Thomson Research Farm. Creation of data focused on collectable datasets like aerial images and topography from UAV technology, and field boundaries gathered from the aerial excursion. Data compilation is the digitization of historical planning records that are currently in use at the research farm. This will allow the planning of farm operations to consider historical elements. This data was stored on a secure ArcGIS Enterprise Server developed by the Cornell University Planning Office for use by units across campus. Chart 3 demonstrates the relationship between Cornell's server data storage, and the link to ArcGIS Online. Using all of these data sources, an ArcGIS Online web application can give the farmers insight and a geographic visual of plans.

Table 3. Cornell's Server relationship and its connection to ArcGIS Online.



3.5 ArcGIS Online Web Map

Developed as the next online iteration of ArcGIS Desktop, ArcGIS Online provided a platform for geospatial data to develop into new online maps or mapping applications that look and feel like a traditional webpage. Not to be confused with ArcGIS Portal, ArcGIS Online provided a secure web environment for groups to store, manage their online mapping, and associated applications. For this project, Cornell University hosted the final location of the server side data, as well as hosted the online locations for the application build-out. Using Cornell University's preexisting accounts helped promote the longevity of this project after its completion, as well as remove the need to migrate the data off the USC ArcGIS platforms after this project was finished.

After data compilation from UAV images and farm documents, and subsequently developed into each study years' respective maps, datasets were prepared for online processing. Data uploaded to the web must follow specific parameters set by ArcMap. The user runs the risk of the data not processing to the web if these specific parameters are not completed. All data uploaded to the web must have basic metadata, allowing for better tracking and management of data files once uploaded to the web. It is possible to bypass some of these processing steps, but it may produce errors with data down the line. Using the Cornell ArcGIS Server as an administrator, all data aspects of this project reside at the server level as package files, keeping the symbology and relationship between data maintained. The advantage to using ArcGIS server, rather than uploading the data directly to the web provides an added layer of security to this project. Besides having server based authentication, data on the server has the ability to integrate into ArcGIS Portal. Similar to ArcGIS Online, ArcGIS Portal allows the Cornell Central IT group to set up login parameters based on Cornell University Net ID accounts, restricting access only to those who receive permission. At the completion of this project, those are not necessary steps, but designing the system with such flexibility will allow for the option later on if it as needed.

Once verification occurred and uploaded to the server was complete, data was then available from ArcGIS Online. It is possible to add data directly to the map and modify based on your needs, but for this project, the REST location of the data within the server provided the best connection. Figure 9 shows the selection of adding data from the server in the ArcGIS Online environment. Adding data this way, kept the processing load of the online map down, and allows for faster maps with higher data content. This was especially helpful with the aerial images, adding a significant processing load to any maps they reside in. With the map data added, and maps for each year compiled, the web mapping application was then developed. ArcGIS Online provided many choices for web mapping applications based on the need of the project and the data. For this project, the Story Map Basic provided the proper environment to develop a tabular web mapping application. These map designs allowed for multiple maps and data sets at the same location, emulating a webpage developed in a traditional platform. Each tabbed section represents the years included in this study, and populated with the appropriate web map. Setting up a tabular platform also allowed the project room to develop and grow as it continues, with minimal effort and the same web address. Each web map is queryable and can display the tabular data joined from the plot identification files in the attribute section. Look and feel, controls (or widgets) were customizable through a development wizard that requires no programming skills, and allows for real time updating of the application. Once completed the application has have a stable web address, and can be embedded into any website for further use across the web. Additional data easily merges into the platform as needed, developing a central hub for any data or analytics preformed on the project, or future endeavors.

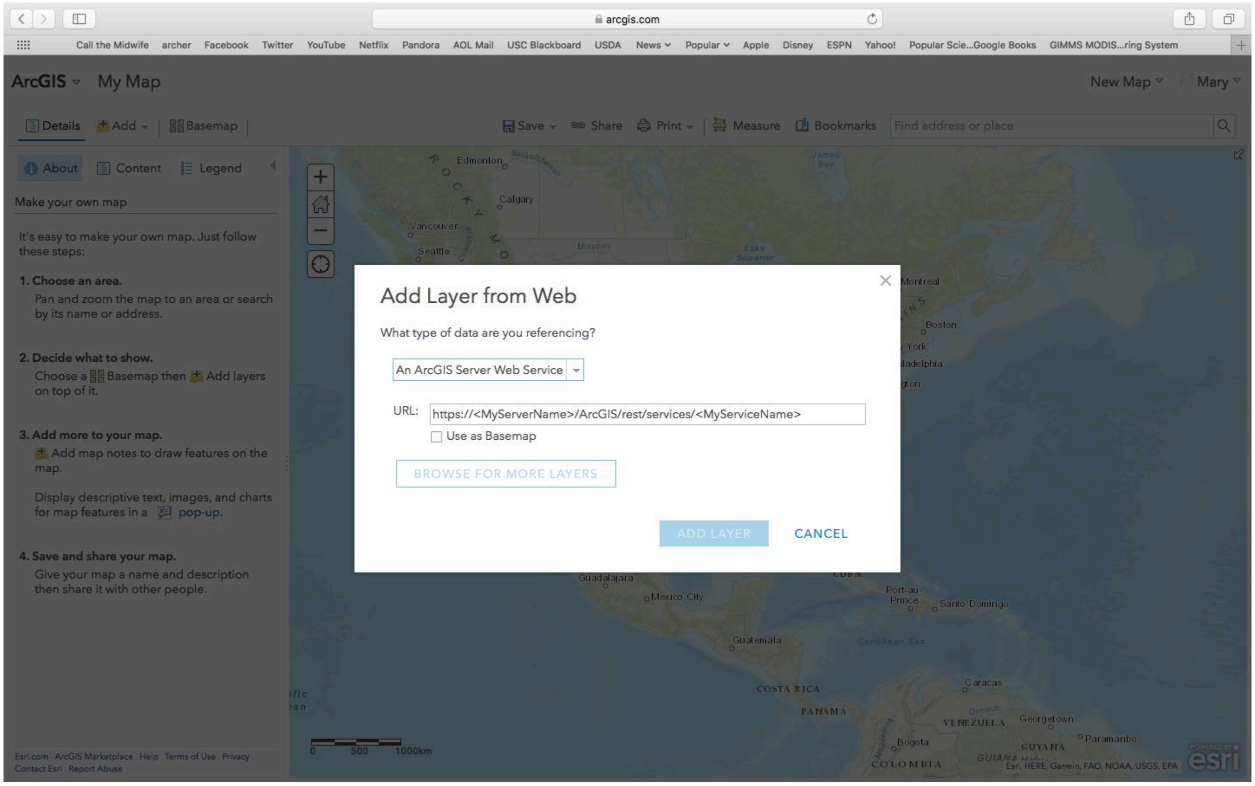


Figure 9. Adding data to ArcGIS Online from a REST service

Chapter 4 Results

When beginning the research for this project, a major concern of the project was the procurement and adequate data to develop a geospatial database for agricultural data. During a previous iteration of this project, attempted was made to develop a countywide agricultural database for Cortland County. With data provided by the county, a preliminary data listing was established; however, without specific agricultural information, the database was not functional for in its intended use. The project ultimately was not successful due to the lack of data resources, and the vast scope of the project.

4.1 Adequate data

During a practice flight with the Cornell Facilities UAV team, the farm managers at the Homer C. Thompson Research farm discussed the opportunities that UAV technology would bring to an agricultural operation, especially one tied to research projects. At these initial discussions, the farm managers acknowledged that the farm had been keeping records since the 1960's with all of the data following similar standards. Each plot assignment generated with a unique alphanumeric value, maintained from year to year. In the case of multiple plots merging, or disintegrating, new ID names are added or removed as needed and recorded in that year's data packet. Also recorded in each plot's record is soil health, crops, cover crop, and any notes pertaining to the maintenance or history of that growth season. Consistency of information was a key factor when examining the plot data. Plow dates and research crop listings did not always have complete records, and some information was complicated to decipher. That is not to say the data itself was complicated, but the handwritten notes sometimes became crammed or jumbled based on the authors handwriting. Deciphering these data sets required time and patience to ensure each notes formatting matched to create a cohesive tabular dataset. Each tab in the file is represented a year, to keep the records separate and viewable by year, but also to create a cohesive map when joined to the plot polygons later on.

In the initial phases of this project, the intention was to integrate as much data as possible. With over fifty years of data to select from, this quickly became a non-viable angle for this project. After reaching this first conclusion, a brief consideration of working with ten years of data came up. At the time, the feeling was that this would be a summative amount of history, and display the conceptual aspect of this project.

Involvement of the mangers of the Thompson Research Farm was an essential part of this project. Receiving insight on farm operations, answering questions about records, and providing history for the farm not contained in the documentation were all beneficial to the project. One of the major insights garnered from conversations is the amount of data that was actually contained within each plot document. When beginning this project, the project understanding was that data input would be a major area of work. The lift to convert the entire farm to a digital platform would take beyond this projects scope and time limitations, but most alarming was level of detail that was contained within the records. During the data management phase of this project, the decision to use only four years of records became the best option; this adequately displays the functions of the system, and provides a benchmark timeline for work that the rest of the records can potentially take.

Each plot record contained the following data: plow dates, fertilization treatments, crop and cover crop plantings, and any miscellaneous operations that took place during the year. Many of the plots contained the minimum data fields, providing enough to fill in each of the fields, but not diving into depth on that year's operations. Other plots contained little to no information. The plot grew just fallow that year, or did not receive much attention. Fallow refers to the practice of tilling a plot of land, but leaving it unsown in order to allow the soil to restore its fertility. In the case of the Thompson Research Farm, this was typically clover or rye left to grow to its own accord. Plots with the most information were difficult to input as the large amounts of records would not properly display in pop-up views later on in the project, and when viewing the data in an excel document. Much of this additional information was recommendations on planting settings, comments about farm employees or volunteers that were involved, and while relevant to the farm history, is not applicable to the application of this project. These 'non-essential' items became omissions from the data input, as their presence was inconsistent and not critical to understanding the rest of the plot record. The miscellaneous history of the plot did contain comments on the health and history of the plot. These included information on flooding, changes to crop planting, or notes on tilling and harvest schedules.

Also included in each packet of plot data, are maps designed from Google images and tools in Adobe Acrobat. Serving as inspiration and a basis for plot placement, these rudimentary maps provided a benchmark for this project. Determining the usefulness of paper maps and documents in their original state, and using the basis of precision farming fundamentals, these records act as the foundation of the farms history, and as such played a pivotal role in this project.

4.2 Aerial Images

The use of UAV technology is becoming increasingly common in agricultural practices. The ability to access the center of a densely planted field to examine plant growth without disturbing the outlying rows. LANDSAT data from the USGS, near infrared cameras and overhead images all can play a role in examining the overall health of a plot. Using LADNSAT bands two or three, farmer could run an unsupervised or supervised classification with band two data to determine specific amounts of vegetation or examine chlorophyll production to monitor the health of plants with band three. LANDSAT data schedule, determined by the USGS, focuses on a path delineated on the satellites orbit around the sun. Data collection is frequent, but there is no control over when the data schedules; therefore, it is possible for every images collected during a planting season to contain cloud cover that does not allow for the analysis of vegetation.

For the development of a geospatial platform at the Thomson Research Farm, only technology allowing overhead RGB images was available to use data collection. While this data is able to utilize similar data component, the result is not as accurate as a LANDSAT dataset. Figure 10 shows an RGB image, classified in an unsupervised format. Cornell University Facility and Campus Services owns and operates the Inspire 2 quadcopter, capable of thirty minutes of flight time, four hundred foot data capture and up to 4k video quality. During initial planning discussions of this project, farm managers that up to date aerial images would provide up to date field boundaries, show the growth of the farm, and help better understand the history seen in the visual aspects of the landscape.

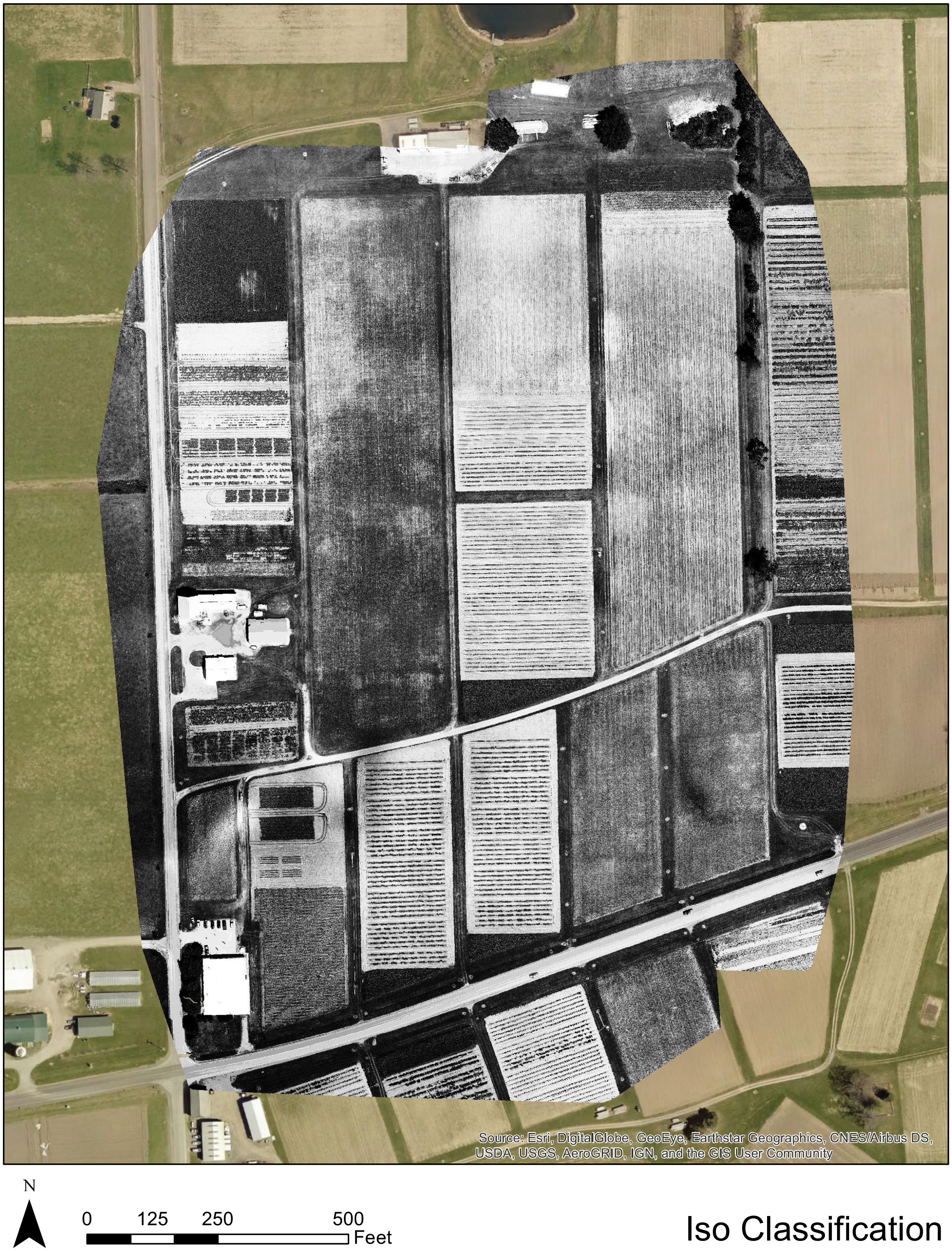


Figure 10. Unsupervised Classification of an RGB image.

To prepare for the initial data collection, the project explored the option of automating the UAV into order to collect consistent images, and develop a standard of flight specifics, repeatable as needed. Because the entire farm is two hundred and sixty acres, flying to take the images occurred in phases. The farm's geography and naming conventions allowed the creations of five sections: Certified Organic, Freeville Plots Farm, Entomology Plots, and Terwilliger Plots. Figure 11 displays these sections in relation to the total farm area. Collected in July 2018, the first set of images of East Farm are the partial result of testing maneuvers with the Cornell UAV team. Using the DJI Ground Station Pro (GSP) App, a six-acre test pass at three hundred eighty seven feet generating a resolution of three cm images became the optimal flight settings. Generating seventy-four images, this first pass was a success. By separating the automated flights, any technical difficulties were resolved, and farm section collection at a sufficient rate.

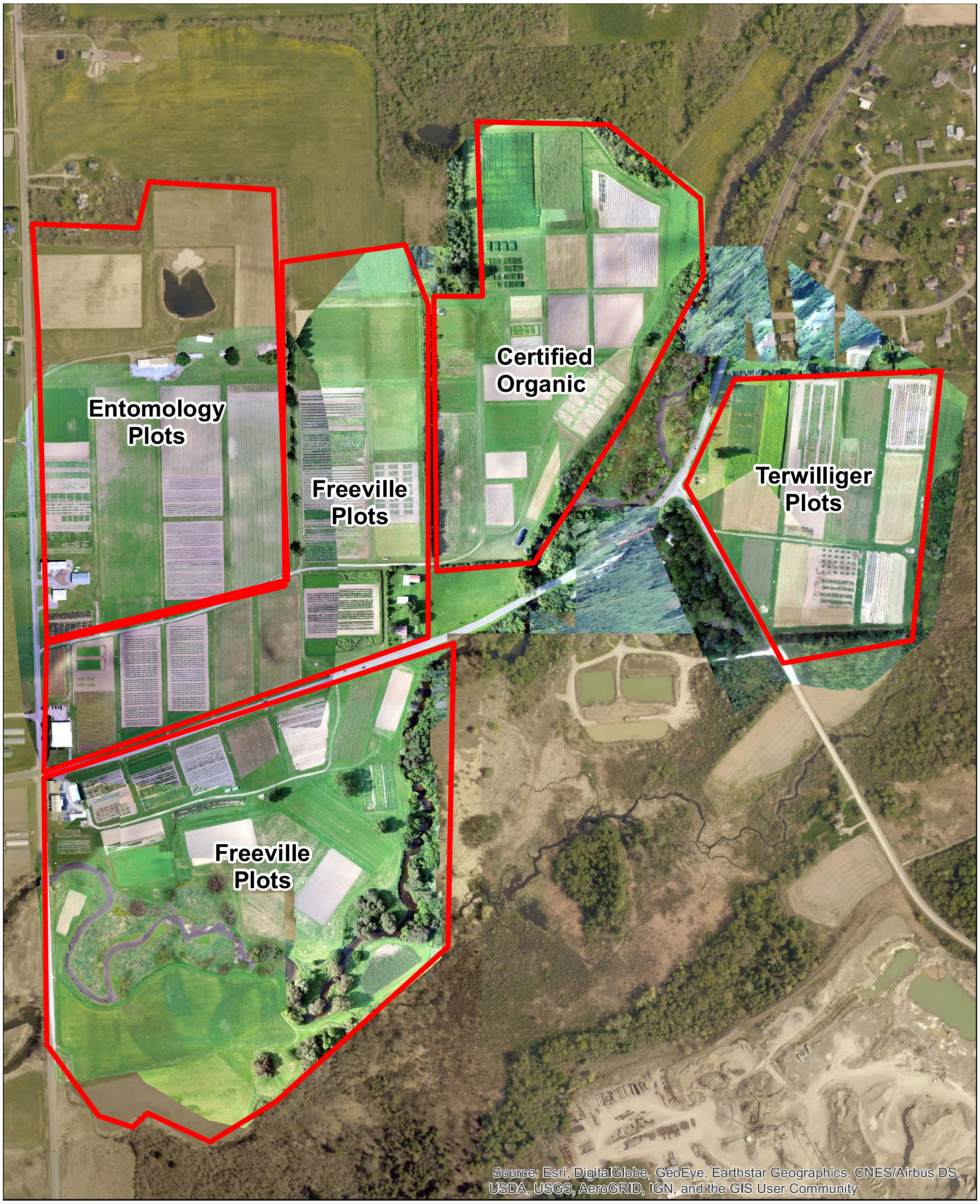


Figure 11. Thompson Research Farm Sections

One of the difficulties of UAV flight planning is determining the weather at the time of data collection. Like airplanes, UAV have ideal conditions and physical limits in the air. In ideal conditions, low wind speed, high humidity, and partly cloudy skies produce the best circumstances for flight, and overhead images. The cloud cover reduces glair on the overhead images, producing images with flat surfaces, and low shadows. These low shadow images are best for digitizing data from images, as it is possible to take photos on a sunnier day, but images taken are only ideal for 'glamor shots'. Meaning, ones used for promotional material for a location, rather than analysis or record. During the mission planning, date selection occurred to generate a workflow, but with the unpredictability of weather, any day selected might not be the best candidates for data collection. The Federal Aviation Administration (FAA) acts as not only the authoritative power for commercial and hobbyist UAV pilots, but also provides up to date weather and barometric readings for local airports. These readings helped arrive on a decision before driving to the flight location, if conditions were ideal enough to consider flying. Under the Part 107 regulation, this project was responsible for the flight planning, aircraft safety, and proper support staff for any flight. The project also retained the responsibility to check the FAA for weather warnings and any notices handed out by region.

After successful data collection, imagery processing began using ArcGIS Drone2Map (D2M). D2M allows the georeferenced images to be matched based on location and create a cohesive ortho image. Processing for the flights happened separately, again to allow for any technical difficulties. Once completed and quality checked for continuity, combined images form a single file. Having this background image allows for creation of accurate field polygons to be and analysis of farm management.

4.3 Combining Data and Maps

Besides gathering and maintain plot records, each year of records contains a simple map of the farm to provide a visual aid for navigation and planning. These maps range from hand drawn sketches, to documents developed in Adobe Acrobat with hand written notes. While effective for short term planning, these maps provided context and history to the farm, as well as the impact of certain research projects from year to year. As a part of this project, digitized plot records migrated to Excel, and it was necessary to bring in the plotting structure as well. Chart 4 represents a section of this data as shown in Microsoft Excel. From year to year, plot structure is subject to change; whether the change occurs due to a natural occurrence that forced the farm to shift, increased research demands, or the planned rotation of plot structure. After completion of the overhead flights and reconciliation of the imagery collected, polygon development occurred. First, using these new images, the polygons boundaries were developed to reflect the current state of the plot structure. Within the feature class, fields are added for plot ID and usage for the year included in the study. When completed, these polygons will represent a high-level view of the farms history, but did not have to contain any of the plot specific records. Record delineation from year to year became a part of the red with a simple Y/N variable, to reduce the amount of data stored within the file.

Table 4. Excerpt from the plot records from Microsoft Excel

PLOT_ID	PROJECT	CROPS_GROWN	TOTAL_AREA	SQ_FT	ACRES	PH	P	K
S6	J. CIOVANNONI	TOMATOS	N/A	43125	.99	6.3	38	215
S6A	FALLOW	N/A	N/A	1750	.04	3.6	25	285
S7	G. BERGSTRON/CHRISTINE LAYTON	SWITCHGRASS	N/A	24970	.57	6.4	63	80
S8	FALLOW	N/A	N/A	29140	.67	6.3	31	250
S9	M.MAZOUREK/M. GLOS	CUCKS SQUASH	N/A	9250	.21	6.0	39	285
S10	BELLINDER	MUSTARDS COVER CROP	N/A	29400	.67	5.7	38	315
S11	M. MAZOUREK	WATERMELON	N/A	31490	.72	6.3	48	335
S12	FARM	SWEETCORN	N/A	44000	1.01	6.3	31	160
S13	FALLOW	N/A	N/A	41760	.96	6.6	53	125
S14	FALLOW	RYE CLOVER	N/A	67500	1.55	6.5	40	135
S14A	FARM	CUCURBITS PUMPKINS	N/A	22750	.52	6.5	40	135
S15	FALLOW	N/A	N/A	66600	1.53	6.3	32	215
S16	M. HOFFMAN/J. GARDNER	CURCUBITS	10850	10850	.25	6.4	26	80
S17	NEWSS	MISC. W/ GRASS SEEDING	N/A	N/A	6	N/A	N/A	N/A
S18	NEWSS	MISC. W/ GRASS SEEDING	N/A	N/A	6	N/A	N/A	N/A
S19	NEWSS	MISC. W/ GRASS SEEDING	N/A	N/A	6	N/A	N/A	N/A
S20	NEWSS	MISC. W/ GRASS SEEDING	N/A	N/A	6	N/A	N/A	N/A
S21	R. BELLMDERS	BASIL CARROTS SPINACH RADISH	N/A	45600	1.04	7.0	80	95

Once the existing polygons resided in ArcMap, and before assigning Plot ID values, the project returned to the original maps in the plot documents. The suggestion came to the project to scan the original map documents, georeference them based on the overhead images, and use them to complete any maps. While this could work in theory, the original maps documents are extremely simple, with some containing little to no geographic reference points. These original maps do however provide context to plot naming conventions and help in verifying the locations and total number of plots year-to-year. Using these documents, the project verified plot location based off the new ortho images, and added the proper plot id. Before joining to the digitized plot data, the naming conventions between plots and plot records needed to be verified. This verification ensured no plot lacked data, and helped clean up the data to better match is geographic counterparts.

Once the polygons received a proper plot identification, and the location was verified using the original documentations, the file was finally ready to join to the new excel file. To prepare for upload to ArcGIS Online, each year of data displayed independently within an ArcMap document. Figures 12 and 13 show the geographic differences between data used in 2010, versus data used in 2013. First added to the map document, was the polygon feature class. Using the 'joins and relates' feature, each year of the Excel sheet was joined to the polygons layer dependent on what year the map was being built for. Because of the possibility of there being more data in the yearly packet, than plots on the farm, the data set was verified before the join took place, and the records were kept intact; meaning, if a plot id in the excel sheet didn't match to a specific polygon, the information still remains the attribute table of the polygon layer. Once the data verified, and joined to the excel document, the polygons layer was symbolized based on that year's usage. Using the usage category stored natively in the plot polygons, data symbolization allowed only plots used in that year to appear, giving a brief high-level overview of the farm for that specific year. Using the 'Used_YYYY' field, the symbology of the map can determined simply using the Y and N characters in the field. Once properly symbolized by year usage, the data is ready to upload to ArcGIS Online. It is possible to develop a symbology based on usage, or specific crops used in a year, but for the baseline implementation of this project, a simple usage map will meet the needs of the project.

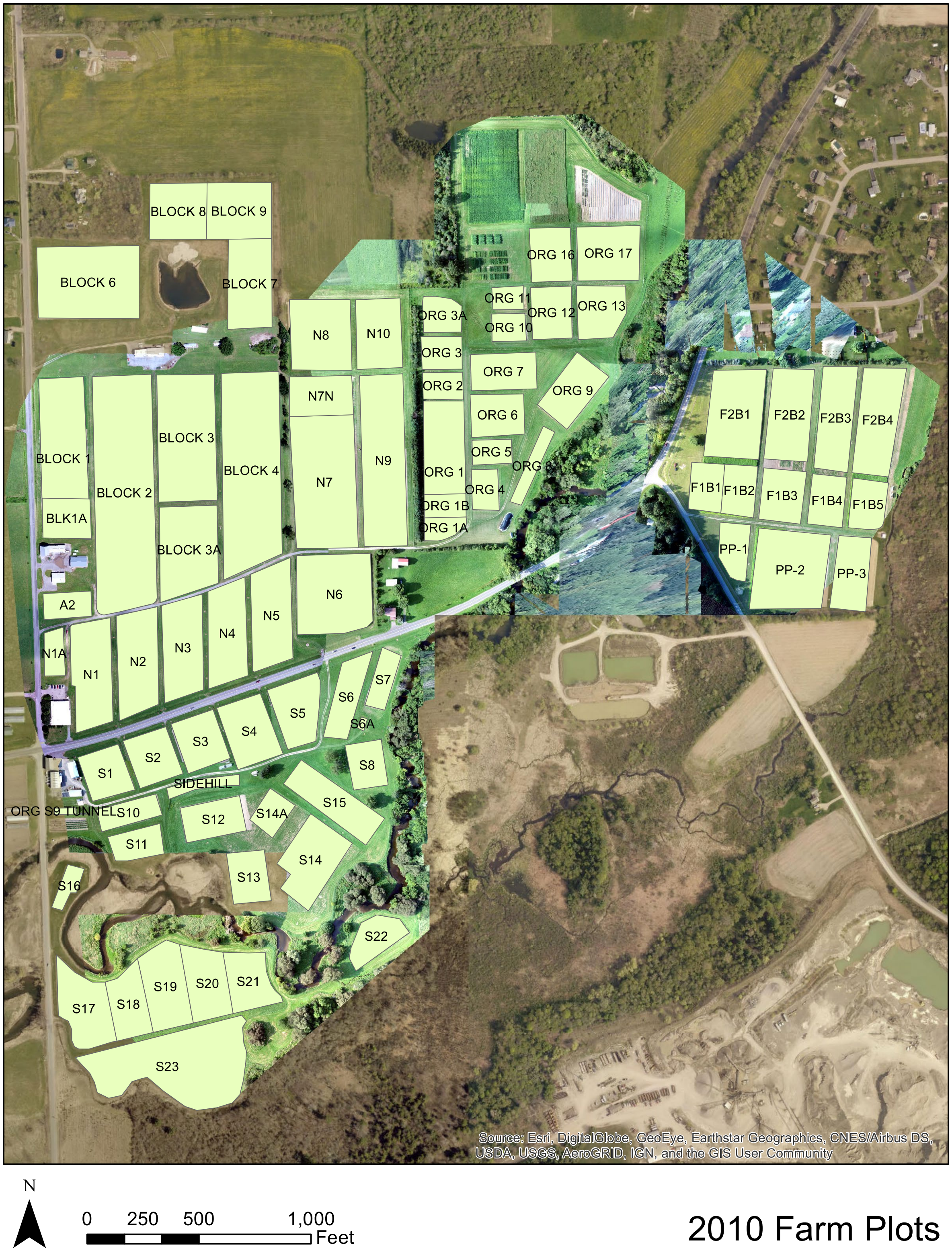


Figure 12. 2010 Thompson Farm Plots

Figure 13. 2013 Thompson Farm Plots

4.4 Online Application

Development of proper data and geographic features are a major part of this project, and if the users fell in to the traditional ‘power user’ group of ArcGIS users, then maybe the project could have potentially stopped here. However, users were not fully equipped with the knowledge of GIS, but rather have simple technology skills that allow them to access the needed data in a geospatial platform. The existence of applications such as ArcGIS Online, ArcGIS Portal, and ArcGIS Collector do just that. For the purposes of this project, ArcGIS Online allowed for public access to the maps and data published as part of the project. In addition, Cornell University staff will have the accessibility to update and maintain the data after the completion of this project.

Because Cornell used both ArcGIS Online and ArcGIS Portal in their data services, these applications would best meet the needs of the end users, Thompson Research Farm and its researchers. ArcGIS Portal configuration accepts only users cleared by Cornell staff, and have proper privileges through Duo Two-Factor Authentication. The University central IT staff configure this login system and as such, the process to gain access to the data is more complicated. Access to ArcGIS Online is a more streamlined process. Having the correct login and password for specific account, users are able to access data, create new maps, and develop web applications. The other approach from ArcGIS Online is the use of public maps. Maps without the need for any login or security.

At the start of this project farm managers discussed access and security of this data. Who should have the ability to access these maps and data? For the purposes of this project, and the limited amount of data used, it was determined to build out the initial proof of concept in a public environment. This way all players have access to the information and can have input on the final design of the web application. After the completion of the project, if the project is continued, there is a possibility of moving to ArcGIS Portal to have stricter access to the full breadth of data available.

With the data fully prepared, and the platform chosen, datasets could upload to the web. Starting from a map document for each specific year, the polygons layer and the aerial imagery could upload to the Cornell University ArcGIS Online account. Not only did this allow data management to carry out, but it also gives me access from an administrative account, and associates the data with the university. Initially, the data resides in the Cornell University ArcGIS Server to retain security standards. When the web map development begins, the REST link to this feature can connect the two applications. This workflow also allowed data utilization in the Cornell University ArcGIS Portal when applicable, keeping the data links open for other analysis. Publishing the data required the data service to have a name, a brief summary of the data to be included, as well as at least one descriptive tag. Adding each of these ensures the data had some metadata attached, and is queryable in ArcGIS Online. Analyzing the data was required before it its published allows for the correction of any errors. The most common are those previously mentioned, as well as the addition of feature templates. Templates are a simple remedy of starting and stopping and edit session within the map document, and reanalyzing the data.

Once published to the ArcGIS Online platform, a data service could populate a web map. Once added to the web map, any edits to the symbology occur. For this project, four separate web maps for each year of data examined were developed. Sharing settings of any new map received an assignment to full public access for the duration of the project. Using the 2010 data as a starting template, the web map became the basis for the web application. Using the Story Map

Series template, the web map emulates a similar style to the excel sheet. Each year could be contained within its own tabular section, with easy navigation between panes. The web maps created for the different years of focus become their own tabs within the application, simply by adding them to the section when prompted by the site. Configurable application tools were an available added to allow additional capabilities. Printing, measurement, query, and location assistant were all applicable add-ons to this project, and others were available under the settings toolbar. Customization of these tools gave the user a streamlined experience. Once the web app contained the web maps, and the additional features configured, the application could save and published for viewing. Because the ArcGIS Online environment could be considered a 'what you see is what you get' development environment, the final version of the web mapping application functioned as a standalone site, or can be easily embedded into a site. This is in contrast to a full-blown write up in a programming application. That is not to say that it was impossible with the tools provided be Esri, but for the simplicity of this application, using a tool that provides the necessary links internally was beneficial. Once the web mapping application was live to the public, the first phase of integration of small scale GIS at the Thompson Research Farm was complete. The final web maps location is at http://bit.ly/2E9Ntrk .

Chapter 5 Discussion and Conclusions

Bringing the Thompson Research Farm to a preliminary geospatial data integration acted as the first phase of full geospatial data integration at the farm. Because this study only covered a small portion of the data available for integration with the plot polygons, the entire project of geospatial data integration can continue. Adding any number of the remaining years to the database will continue to bring geographical context to the history of the farm, and develop a wider breadth of data available for analysis.

5.1 Next Steps

Based on the time spent on this project, digitizing four years of data takes roughly four weeks of steady work, if the individual works at least three hours a day on the data input. If a crew of student workers or other staff received the task of digitizing data, it is not to say that the remainder could migrate to a digital platform within a month's time. This allows for steady data input, quality control, and verification of naming conventions within each year's data packets. A suggestion by a colleague at Cornell that scanning the accompanying paper documents may be a potential solution for data input time. Rather than substitute all data entry with these documents, specific plot scans would attach to the polygons. This feature within ArcMap products allows non-geographical and tabular data to be associated and stored within the same database. Scanning each plot record and associating the data would take more time, and each year's files would have to be distinguished when adding them to a data association. Because the feature allows for many data types to be stored, images could also be a potential addition to the geographic dataset. Images of specific areas of the farm may provide context to some of the data contained in the set, but if the intention is to focus on the entire history of the farm, this may quickly become too much data, with too wide of a chronological period to be accurately contained in ArcMap. Development of a file based photo structure may be of more use, and allow project specific images to remain together.

One area of data that is included as apiece of the initial data to expand upon is the addition of soil data to any geographic analysis. Contained in each plots records are the phosphorus, potassium and pH of the plot, but no specific data is included as to where the collection took place. Figures 14 and 15 show soil data for pH and potassium levels in 2010. This data collection occurs on a biennial basis. Development of a more comprehensive view into the soil taxonomy of the farm is a possible data creation. The USDA has developed soil polygons to represent the soil taxonomy across the United States, but these studies only update with submission of new findings. Rather than relying on low-level soil data, the research farm could embark on a full-scale soil identification project, developing its own soil polygons based on their data and the USDA data. Such a project would add continued depth to the farm, as well as develop a granular history of the farm, and show the relationship between certain research projects and their impact on the surrounding soil.

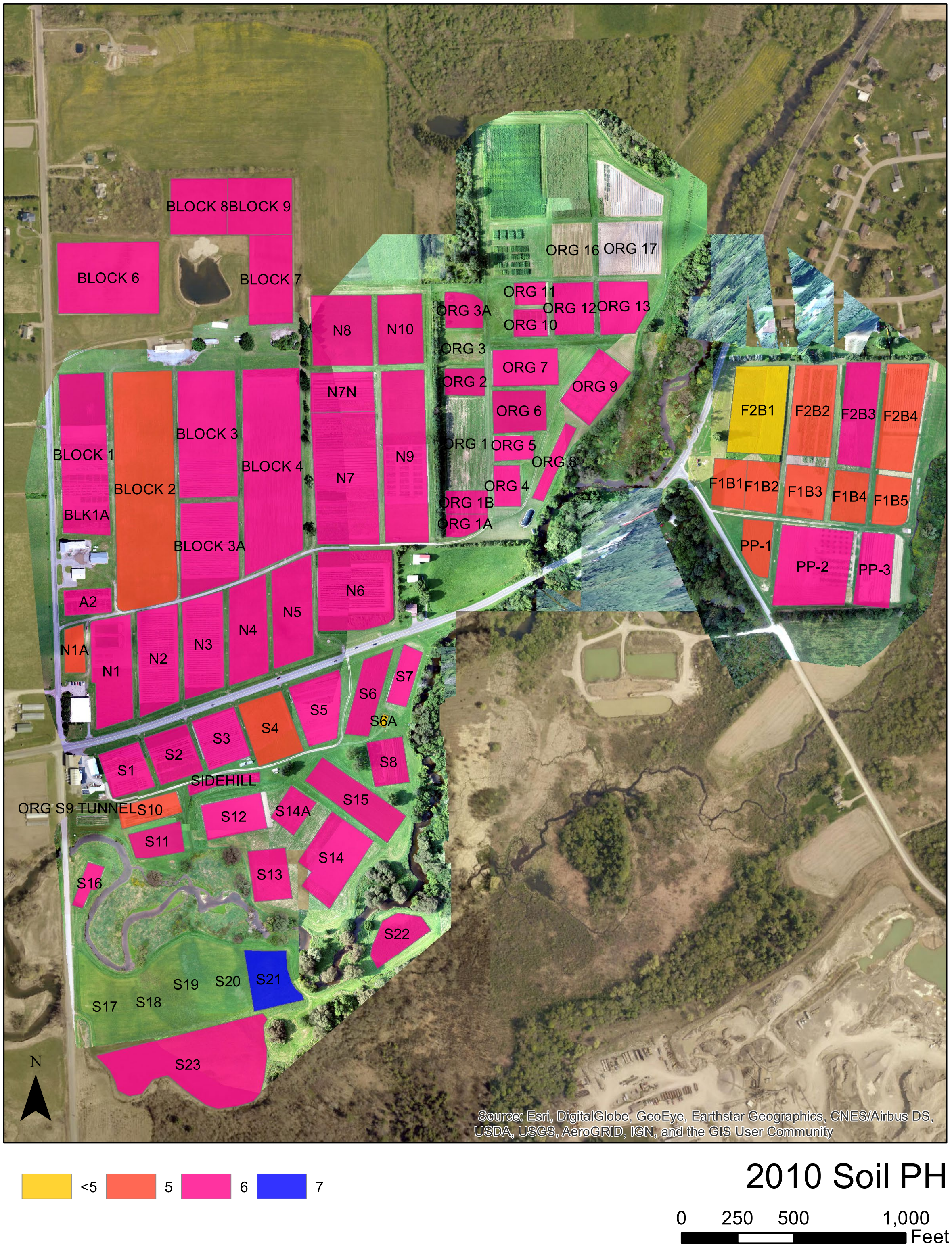


Figure 14. 2010 Soil pH

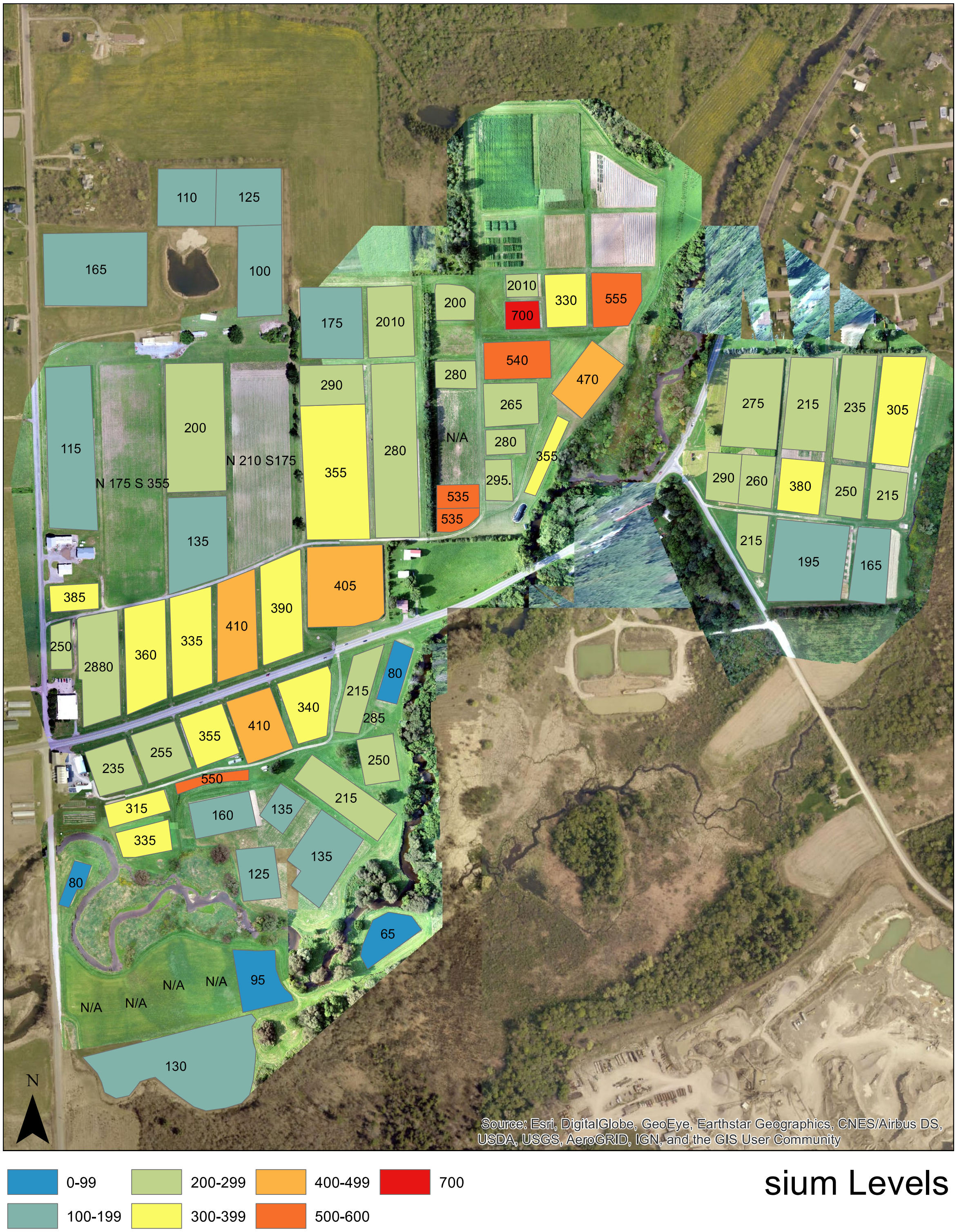


Figure 15. 2010 Soil Potassium Levels

Supervised and unsupervised classification of aerial images area additional areas of research as this project progresses forward. While the traditional idea of image classification is synonymous with LANDSAT data, it is possible to establish a classification grid though RBG spectral images taken from everyday cameras. Using the 'Iso Cluster Unsupervised Classification' tool in the Spatial Analyst extension, ortho images can be classified based on pixel value, generating a total sum of specific pixel values once calculated. These classifications and calculations allow researchers to see the estimated total of vegetation in a given area. This addition to research on plant growth charts, and giving granular identification of incremental growth if a schedule of image collection can be set. While this is possible to do in single plots, the wide scale classification also allows for large sections of farm, or whole farm, classification to process with a single data analysis.

5.2 Lessons Learned

5.2.1 Data Entry

While a simple project, this paper still laden with hurdles. Initially, this project set out to be a full-scale precision farming program. Helping farmers understand the benefits, cost savings, and technological advances of the move to precision farming, and developing a platform for the move was the fundamental outcomes during the projects infancy. Quickly that became a non-realistic achievement during the projects parameters. Determining how to scale this project down to an integration rather than a migration seemed to be the only logical path. Reaching the conclusion that with too large of a project, the result can quickly run out of control. First, the initial plan of integrating all data sources was not feasible for the limitations of this project.

Even after scaling the data entry down to ten years, the result remained too large of a task. Four years of data resulted as the best option. The spread of four years demonstrates the capabilities of the software, and gives a viewpoint of long-term planning.

5.2.2 Aerial Images and Processing

While aerial images are valuable to this project and the processing of ortho imagery is a major step in bringing the images together. Due to the size of the farm, the data collection occurred in phases as explained in the previous chapter. Because of this separation of data, the processing of images into ortho mosaic layers processed in batches. While a conclusive product of the farm, the result was a set of files that do not quite match in their image coloring, and the overlapping sections are not concrete. What could be an interesting and informational overview of the farm is choppy in certain places, drawing focus away from the data contained within. To try to remedy this issue, the project attempted to run a batch process of all the images collected during the individual flights. To reduce runtime on the processing, I removed the variable of Drone2Map processing 3D products, and instead focused only on processing the singular ortho mosaic. The weight of the image processing was not possible for the PC that I was running on. The computer-processing unit (CPU) was not able handle the stress of processing such a heavy load. If this project continues, the processing of images would need to run on a computer with a higher CPU power, or a level off acceptable error will need to be established.

Another technological hurdle of this project was the technical difficulty of connection between the DJI GPS application and the standard vision system app DJI Go4. During the first attempt of flight procedures, there were no issues with either application. After establishing connection, the flight path loaded properly and the waypoints added to the path. Seventy-four images collected without incident. Returning to the farm on a different day to continue to collection, both apps opened to begin flight preparations, loaded the flight path in to the GSP app, and set up the UAV to fly. After take-off, standard procedure is to switch from the GO4 App, to the loaded GSP app, and relinquish control so to the automated flight could take place. After switchching over to the GSP app, the connected previously seen before takeoff was gone. The aircraft lost connection to the app. In an attempt to remedy the situation, I switched back to the GO4 app, only to realize the application disconnected there as well. This resulted in no visual communication with the UAV. Operational controls with the remote controller remained intact, but the ability to see the forward vision system, and camera did not exist. At the point, I scrubbed the mission in the field. Using manual maneuvers, the UAV landed safely and dismantled for proper technology inspection after I returned from the field. A full inspection and update verified the UAV was in full working order. It was not clear, and remains unclear, as to why this error occurred. As a solution to this issue, all flights continued at the same parameters as the automated flight, but the flight pattern became difficult to stick with. While navigation in a grid-like pattern is possibly with a UAV, automation is much more precise and generates a consistent product, instead of a wobbly grid of flight passes. This error also causes gaps in the imagery. While it may seem like the entire section of farm received coverage during a flight, it is not fully possible to know what was collected and what was not until the images processed.

This projects intention was to introduce the principals and concepts of geospatial technology into the farm management practices at the Homer C. Thomson Research Farm. Because there was no system of record in place beyond these paper maps, integration of this project has shown deficits in the current system. It its current practice, there is no dedicated steward for this and any farm specific data within the University. If this project, in its intention, is meant to be a stepping stone for geospatial technology and precision farming at the Thompson Research Farm, or any Cornell-run farm, a system of data management and records keeping needs to be set in place to maintain data quality across the University. Currently, the university data stewards focus solely on campus planning, transportation, utility and real estate data. Individual colleges within the university do not have any data stewardship programs. Single farm agricultural data is stored and maintained by the individual farms, but if a system is set in place that focuses on brining farm management data to a head, a single managing body should be set up to maintain the relationship between legacy farm data, and geographical data that can be of use to both researchers and farm managers.

5.3 Future Projects

Beyond the Homer C. Thompson Research Farm, Cornell manages five research farms, with an additional three hundred twenty five acres in the immediate vicinity of campus that compromise another eleven small farms. Each of these farms contains their own unique set of farm legacy data, and unique geographic features. Figures 16 and 17 represent current maps of Musgrave Research Farm, and the Willsboro Farms respectively. If it is determined a success, and ran until its complete integration, this project can be a template for the rest of Cornell-owned agricultural assets to move to a similar system. Even with limited data, the relationship between institutional knowledge and geography shows a different perspective to staff and researchers looking to develop a better understand the area they are working in. It is, however, completely feasible that this project will only be completed to a certain extent at the Thompson Research

Farm, and never be integrated at any other agricultural location. The reality of projects such as these remains that after the project finishes from a research perspective nothing happens. Waived are all other expectations and projections of other projects due to interest changes. It is my hope that the value and knowledge that comes from even a small-scale integration inspires others at Cornell to look into the data behind the large agricultural network, and develop a better understanding of geographic and data relationships.

5.4 Conclusions

While small-scale implementation was not my original intention for this project, the opportunities and results far outweigh any hurdles experienced. With the data uploaded to ArcGIS Online, farmers at the Homer C. Thompson Research Farm now have the opportunity to test and discuss the value of geospatial integration with researchers and other staff on the farm. This data will continue to live on the Cornell ArcGIS Server, and modified as the project progresses beyond the scope of this paper.

Figure 16. Cornell Musgrave Farm

Figure 17. Cornell Wilsboro Farm

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