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Grid Soil Sampling and Mapping Soil Phosphorus Distribution for an Extended Period on a Production Agricultural Field

Abhijit Nagchaudhuri (Professor)

Dr. Abhijit Nagchaudhuri is currently a tenured professor in the Department of Engineering and Aviation Sciences at the University of Maryland Eastern Shore(UMES). Dr. Nagchaudhuri received his baccalaureate degree from Jadavpur University (India) with honors in mechanical engineering in 1983. Thereafter, he worked in a multinational industry for a little over three years before joining Tulane University as a graduate student in the fall of 1987. He received a master's degree from Tulane University in 1989 and a doctoral degree from Duke University in 1992. He is a member of the American Society for Mechanical Engineers (ASME), American Society for Engineering Education (ASEE), and, American Society for Agricultural and Biological Engineers (ASABE) and is actively involved in teaching and research in the fields of (i) robotics and mechatronics, (ii) remote sensing and precision agriculture, and,(iii) biofuels and renewable energy

Madhumi Mitra (Professor)

Dr. Mitra is a professor of Environmental Sciences at the University of Maryland Eastern Shore. Her research areas are in Bioenergy; Bioremediation; and Biosorption studies of aquatic plants.

Travis Ford

Charles Raleigh

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Abstract

University of Maryland Eastern Shore (UMES) is a historically black 1890 land grant institution located in the Delmarva Peninsula. Most of the corn and other crops that are grown in and around UMES are used as feed for the immense poultry industry in the region. General practice in the past has been to use poultry litter as fertilizer for the feed crops based on their nitrogen needs. The ingredients of typical poultry litter have phosphorus levels that far exceed what the crop utilizes during its growth cycle if the amount of poultry litter is applied based on the nitrogen requirements of the crops. The continued decline of the water quality in the bays of the Delmarva Peninsula is now being attributed largely due to phosphorus run-offs. Crop and poultry farmers and the integrators form a delicate balance that sustains a large percentage of the local economy and as such state legislators have been slow to enact legislation despite increasing pressure from the environmental groups giving rise to a so-called "wicked problem" in the region.

A spatial map of phosphorus levels from a comprehensive soil test performed a few years ago (2013) on a 0.5-acre grid on a selected UMES agricultural field (Bozman) indicated that the average phosphorus level was extremely high at approximately 192 ppm (parts/million ~mg/kg) even though the use of poultry litter on UMES farms was discontinued at the beginning of the new millennium. This situation is not unique to UMES fields but can be observed in a large number of crop farms in the Delmarva region. Soon after taking office in 2015, Governor Hogan brought together stakeholders from the business, agriculture, and environmental groups to address unresolved issues related to the use of poultry litter as fertilizer and associated economic and environmental concerns. The enactment of the enhanced phosphorus management tool has forbidden the use of poultry litter in all farms in the eastern shore region with high phosphorus content after the enforcement of the legislation.

At UMES precision agricultural practices using grid soil sampling, site-specific application of nitrogen using drone-based prescription maps, yield monitoring with advanced combine harvesters, judicious use of irrigation water, and other smart farming tools are being utilized for environmentally friendly farming practices. The project leaders have not only worked closely with UMES farm personnel but have involved both undergraduate and graduate students in experiential learning and research endeavors integral to the overall effort. The smart farming project team has promoted the use of inorganic nitrogen fertilizer on all university production agricultural fields and has continued with the annual grid soil sampling and mapping efforts on the selected field to document the anticipated gradual decline of phosphorus levels in the corn, soybean, and wheat crop rotation and harvest cycle. Kolb's experiential cycle paradigm has provided a meaningful framework to involve student teams, advance the project goals, and promote educational outcomes for the students in both field and laboratory settings covering all aspects of the overall project. This paper is largely focused on the grid soil sampling efforts that have been undertaken by UMES students over the past several years. Over the years several improvements have been made with the hardware and software tools utilized by the team to improve the efficiency of the labor-intensive grid soil sampling efforts. The team acquired and installed an automated soil sampler on a Utility Task Vehicle (UTV). A web application has been identified and utilized by the team that allows the soil sampling grid to be rapidly developed and utilized by the UTV operator to navigate to the GPS locations and activate the automated soil sampler to significantly improve the logistics and efficiency of this otherwise extremely labor-intensive procedure. The last grid sampling and mapping completed in the 2021 fall indicate that the average phosphorus levels on the field are significantly lower and averages around 92 ppm. The paper will highlight the recent efforts of the project team involving a food science and technology(FDST) doctoral student and several engineering undergraduates utilizing the automated setup described and subsequent compilation and mapping of the soil data using appropriate software tools. The data analysis and visualization tools allowed the students to utilize all the soil sampling data acquired since 2013 and readily understand how the phosphorus levels have gradually but rather slowly diminished and reached acceptable levels over the last couple of years for the particular field.

1.0 Introduction

"Precision Agriculture" has been identified as an efficient approach for coping with the food demands of a growing population in an environmentally friendly manner. Synergies and trade-offs that are essential to driving sustainable practices with due regard to “people, planet, and profit” considerations can be addressed through the appropriate adoption of precision farming technologies. UMES is an 1890 land grant institution and more than 200 acres of farmland are integrated with the 700-plus acre campus. Recently the university has acquired additional 300 plus acres of land contiguous to the campus - a large portion of which will be used for field research and production agriculture. Faculty in the engineering and aviation programs on the campus collaborate with faculty in agriculture and natural sciences programs and work closely with the farm personnel to advance precision agriculture-related efforts on campus. While farm employees are utilizing basic smart agricultural technologies on all production agricultural fields on campus, a specific 50-acre field that is under corn, soybean, and wheat rotation has been earmarked for systematic field trials, and data-driven research and analyses to study the benefits of using advanced precision farming technologies including drone imagery, prescription maps, variable rate sprayers, yield monitors and other intelligent implements. More recently a subsurface drip irrigation system has been installed on a 15-acre portion of this field for conducting field trials for both water and nutrient use efficiency [1-3].

Right from its inception stages the precision agriculture efforts on campus have adopted Kolb’s experiential learning framework [4]. The overall scope of the precision agriculture project is extensive as demonstrated in Figure 1. Grid soil sampling, analysis, and mapping form a significant component of the overall precision agriculture project. It not only helps to visualize the variabilities in production agricultural fields but is also essential for variable rate application of agronomic inputs using geo-located prescription maps. In this paper, the student experiences and results of grid soil sampling efforts that have been undertaken on a specific production field on campus are outlined. In alignment with Kolb’s cycle, the students used *concrete* field and laboratory experiences and used *experiential* knowledge, *reflection*, and *abstract concepts* to improve the grid soil sampling process on campus. The improvements were achieved by integrating contemporary technologies that provided additional avenues for *active experimentation* and learning. The scope of the project allowed the engineering undergraduates to get hands-on exposure to not only the advanced technology integration with grid soil sampling and mapping but

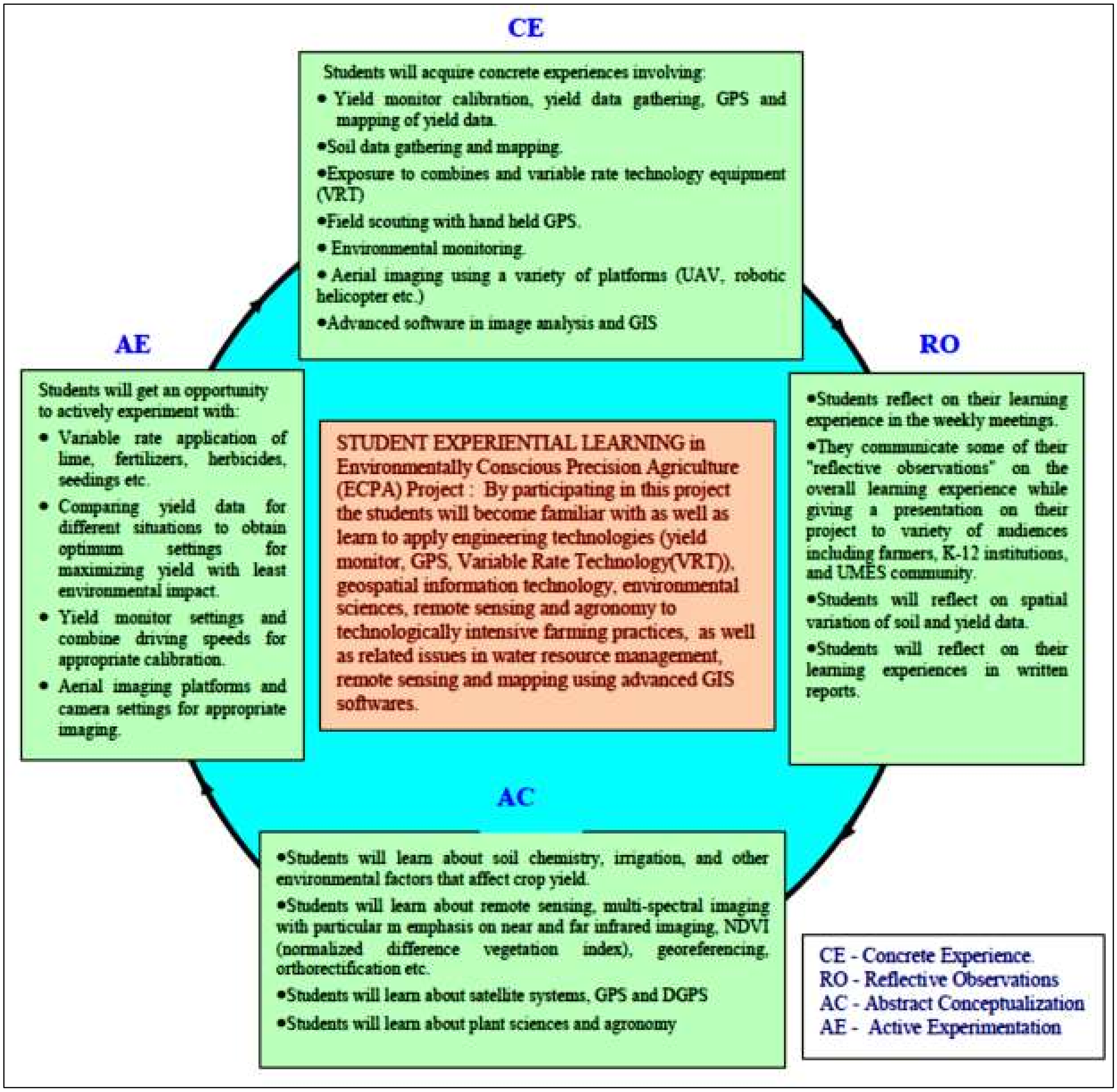

Figure 1: Kolb's Experiential Learning Cycle adapted for the Student Active Learning Endeavors in the Broader Scope of the Precision Agriculture Project

also, other smart farming technologies integral to modern precision agriculture practices. By working in field and laboratory settings with a graduate student outside the engineering program the participating engineering undergraduates learned to appreciate some of the ABET outcomes[5] that were elaborated to them in several course lectures in classroom settings in a more meaningful way. From the engineering educator's perspective of the primary author, the rich learning experiences of the engineering undergraduates during the execution of the project efforts were strongly aligned with the following ABET learning outcomes stated in the new engineering accreditation criteria (EAC): (i) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts (ii) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives (iii) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions, (iv) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. The engineering students worked closely with an FDST graduate student who led the team, and the farming staff on campus; this facilitated the development of their communication skills with audiences outside of the field of engineering, which is also an outcome identified in the ABET EAC criteria [5].

Participating students have indicated to the primary author that they have developed a better appreciation of the complexity of issues surrounding water quality, aquaculture, crop farming, poultry industry, and associated policy decisions for the eastern shore region, as well as the critical challenges confronting the globe as we endeavor to grow food for a rising world population sustainably by participating in the project.

The poultry industry in the Delmarva region has grown rapidly with the proliferation of highly automated poultry farms (CAFOs- Confined Animal Feeding Operations). Most of the corn and other crops that are grown in and around UMES are used as feed for the growing poultry industry in the region. General practice has been to use poultry litter as a nutrient for the crop. Farmers tended to apply poultry manure uniformly based on the nitrogen needs of the crop following nutrient management plans. Such practices have resulted in excessive phosphorus in most eastern shore agricultural fields. Moreover, the excessive poultry litter produced often ends up in the local bays and other water bodies. The continued decline of the water quality in the bays is now being attributed largely due to phosphorus run-offs. Water quality issues in Chesapeake and other coastal bays play a dominant role in the Delmarva region. Crop and poultry farmers and the integrators (Perdue, MountAire, Tyson, etc.) form a delicate balance that sustains a large percentage of the local economy. As mentioned earlier, soon after taking office in 2015, Governor Hogan brought together stakeholders from the business, agriculture, and environmental groups and implemented the enhanced phosphorus management tool that has forbidden the use of poultry litter in all farms in the eastern shore region with high levels of phosphorus.

As mentioned earlier, grid soil sampling and analysis is an integral component of site-specific farming and allows farmers to understand the variability in their fields. In conjunction with other advanced technologies including drone-based aerial imagery, the variable nutrient levels in the soil determined by grid sampling facilitate the development of prescription nutrient application rates that optimize yield and enhance environmental stewardship. This paper will largely focus on the grid soil sampling and data visualization using GIS maps for a specific field on campus to observe the gradual reduction of phosphorus levels after the use of poultry litter as fertilizer was discontinued. In this context improvements in grid sampling efficiency using contemporary technologies integrated with recent experiential learning endeavors by a team of engineering undergraduates and a graduate student in the FDST doctoral program on campus will be advanced.

2.0 Grid Sampling and Data Visualization in 2013

Concerns with nutrient run-offs and deterioration of water quality in the Chesapeake and other coastal bays in the Delmarva Peninsula have persisted for a long time. In the early stages, nutrient management plans for crop agriculture were largely focused on restrictions on nitrogen application. However, the use of poultry litter as fertilizer based on the nitrogen needs of the crop resulted in excessive amounts of phosphorus in the soil that was not required by the crop during its growth cycle. However, the differences in opinion among crop farmers, integrators, water keepers, and other environmental groups delayed any legislative action based on the University of Maryland_Phosphorus management tool [6] for the broader farming community. As a proactive measure, the campus farm manager and Agriculture Research Station director decided to reduce the use of poultry litter as crop fertilizer in the early part of the new millennium, and eventually discontinued its use. As the campus started adopting precision agricultural technologies best practices involving grid soil sampling, remote sensing, and the use of inorganic nitrogen application became the order of the day. In selected fields, variable rate application trials were also undertaken based on grid soil sampling [7, 8].

Representative results for pH, phosphorus, and potassium from a comprehensive grid soil sampling that was performed in 2013 on UMES Bozman field (50 acres) are shown in Figure 2 on spatially interpolated GIS maps. For this effort, a team of engineering, agriculture, and environmental students worked together to traverse the Bozman field with a handheld GPS unit to perform grid soil sampling on a 0.5-acre grid on the 50-acre field. They collected soil cores at an appropriate depth. The samples were delivered to the Delaware State University's Soil Evaluation Laboratory (SEL) for analysis. The GIS maps were put together by the undergraduate students under the supervision of the GIS program manager at the UMES_GIS Lab using the commercially available ArcGIS/ ArcMap software tool based on the soil analysis results. The spatially interpolated data-maps reveal that the soil pH has remained around the desirable level of 6-6.5 that was achieved a few years ago by variable rate lime application. However, the past practice of applying poultry litter on UMES farms based on the nitrogen needs of the crop has resulted in extremely high levels of phosphorus in the field. This situation is not unique to UMES fields but can be observed in a large number of crop farms in the Delmarva region and is considered to be a primary reason for

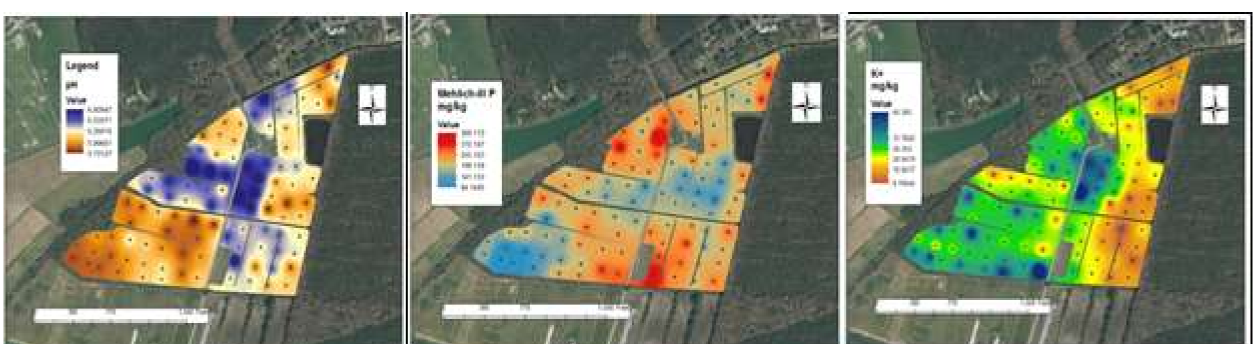

Figure 2: Specimen GIS maps from grid soil sampling and analysis for Bozman field

phosphorus run-offs and degradation of water quality in the coastal bays. After long deliberations with the stakeholders from the business, agriculture, and environmental groups Governor Hogan facilitated the enactment of legislation related to the enhanced phosphorus management tool https://news.maryland.gov/mda/press-release/2015/02/23/.

3.0 Enhancement of Grid Sampling Efficiency Using Autonomous Sampler and Mobile App.

Figure 3. MagicTech Soil Sampler.

A subsurface drip irrigation (SDI) system was installed on a 15-acre portion of the 50-acre field to conduct field trials to optimize nutrient as well as water use efficiency for cereal crops in 2017 as an integral component of a National Institute of Food Agriculture (NIFA) funded research project led by the primary author. The use of poultry litter as fertilizer was discontinued in the field in the early part of the new millennium and inorganic nitrogen has been used as a crop nutrient subsequently. It was decided by the precision agriculture research team that grid soil sampling and analysis will be conducted on this portion of the field annually for informing the team of the nutrient status of the field, as well as, to document how the phosphorus levels decline in the field over time as the cereal crops take up phosphorus from the soil during its growth cycle. A graduate student in the FDST doctoral program on campus incorporated this component as part of his dissertation efforts and worked with the support of engineering undergraduates to execute the logistics of field data collection. Samples were delivered to a commercial soil testing lab for analysis. To improve the efficiency of this labor-intensive process, an autonomous soil sampler (https://magictecllc.com/) was acquired by the project team and students installed it on a UTV (John Deere Gator) made available by the campus farm manager (Figure 3). In 2017, 2018, and 2019 the student teams sampled only the 15-acre SDI portion of the field using a 0.5-acre grid. A GIS map of the portion of the field was used to determine the GPS locations on the center of each grid. In 2021 they sampled the entire 50-acre field using a 1-acre grid. A mobile phone app (https://soiltestpro.com/) was used to autonomously create the grid (Figure 4) and a student driver navigated to the GPS locations at the center of the grid on the UTV under the guidance of the mobile mapper. The use of the mobile app and the autonomous soil sampler significantly improved the efficiency of the grid soil sampling process used by the team in 2021 as compared to the manual process used in 2013. The Soil Test Pro App works in conjunction with several soil testing labs throughout the nation where the samples can be sent for processing and the soil testing data can be directly uploaded to the John Deere Operations Center from these labs as raw geo-located data as well as a GIS map. The project team did not use this capability for the soil samples collected from the field in 2021 but will utilize this capability in the future. Unfortunately, none of the soil labs participating with the company (Soil Test Pro) are located on the eastern shore area near the campus, as such for convenience in 2021 the collected soil samples were delivered to a local lab for analysis. The same lab was also used in 2017, 2018, and 2019 to process the soil samples collected by the students. In this context, it may be worthwhile mentioning that the UMES Agricultural Experiment Station has recently acquired a state-of-the-art combine harvester and a sprayer from John Deere that are cloud-connected. The harvest data and nutrient prescription maps can not only be visualized but can also be downloaded and uploaded to the equipment by way of the John Deere Operations Center (https://www.deere.com/en/technology-products/precision-ag-technology/data-management/operations-center/). The Operations Center provides easy access and a repository of all digital data (including grid soil sampling data) of agricultural fields that have adopted advanced precision technologies and will facilitate big data analytics for optimizing agricultural inputs and productivity in the future.

Figure 4. 2021 Soil Test Locations (Grid generated using Soil Test Pro)

4.0 Results and Discussion

In 2017, 2018, and 2019 soil sampling was done only on the 15-acre portion of the Bozman field on campus where the SDI setup was installed. The soil analysis data reported by the lab was compiled by the students with corresponding location data (GPS– latitude, and longitude) and saved on a spreadsheet. To compare the phosphorus levels with the 2013 data, soil samples were obtained from the entire 50-acre field, using a 1-acre grid (Figure 4) in 2021. As mentioned in 2013 the UMES students had used the popular ArcGIS (ArcMap) software from ESRI (https://www.esri.com/en-us/home) to visualize the variations in the data on a color indexed GIS map. However, the ArcGIS software can only be accessed in the GIS Lab on campus, so the project team decided they would perform the data visualization of mapping of 2021 soil data as well as the soil analysis data from 2017-2019 using the open-source QGIS software (https://qgis.org/en/site/). The QGIS software could be downloaded freely on all the participant's own computing devices and they could easily collaborate using video-conferencing platforms from anywhere without having to access the GIS Lab on campus. This turned out to be both convenient and effective considering the COVID-19 restrictions. Although the open-source QGIS software does not have all the bells and whistles of the commercial ESRI software, however, for the purposes of this project, the students found the software to be very suitable and quite user-friendly. The FDST graduate student who had previously trained on ArcGIS has mentioned that he found QGIS to be more user-friendly than ArcGIS and it was easier to find information on the web to navigate the software efficiently when faced with difficulties. The engineering undergraduates also were able to come up to speed with using the software with the help of the graduate student and information available on the internet.

Although the commercial laboratory that analyzed the soil samples provided data for a variety of soil nutrients relevant to agriculture, for the stated objectives of this project, only the phosphorus data were mapped using QGIS. For ready comparison, soil phosphorus data for 2013 were also mapped using QGIS (Figures 5 and 6). The raw point data inputted in the map at the corresponding GPS locations have been spatially interpolated using inverse distance weighting (IDW) to create

Figure 5: QGIS Map of Phosphorus Levels in the 50-acre Bozman field in 2013

Figure 6: QGIS Map of Phosphorus Levels in the 50-acre Bozman field in 2021

the raster maps shown. It can be readily observed that the phosphorus levels in the field have been reduced substantially throughout the field in particular for the SDI portion of the field (lower-left 15-acres) the reduction is even more pronounced. Upon further reflection, the participating students inferred this is possibly owing to increased productivity due to the availability of irrigation water in the SDI portion of the field. The average phosphorus level in the field reduced from 192 ppm in 2013 to 92 ppm in 2021.

The students also put together spatially interpolated maps for the phosphorus data collected previously in 2017, 2018, and 2019 for the SDI portion of the field (~15-acre) for a more comprehensive report. The 2017 and 2019 maps for phosphorus levels for the SDI portion of the

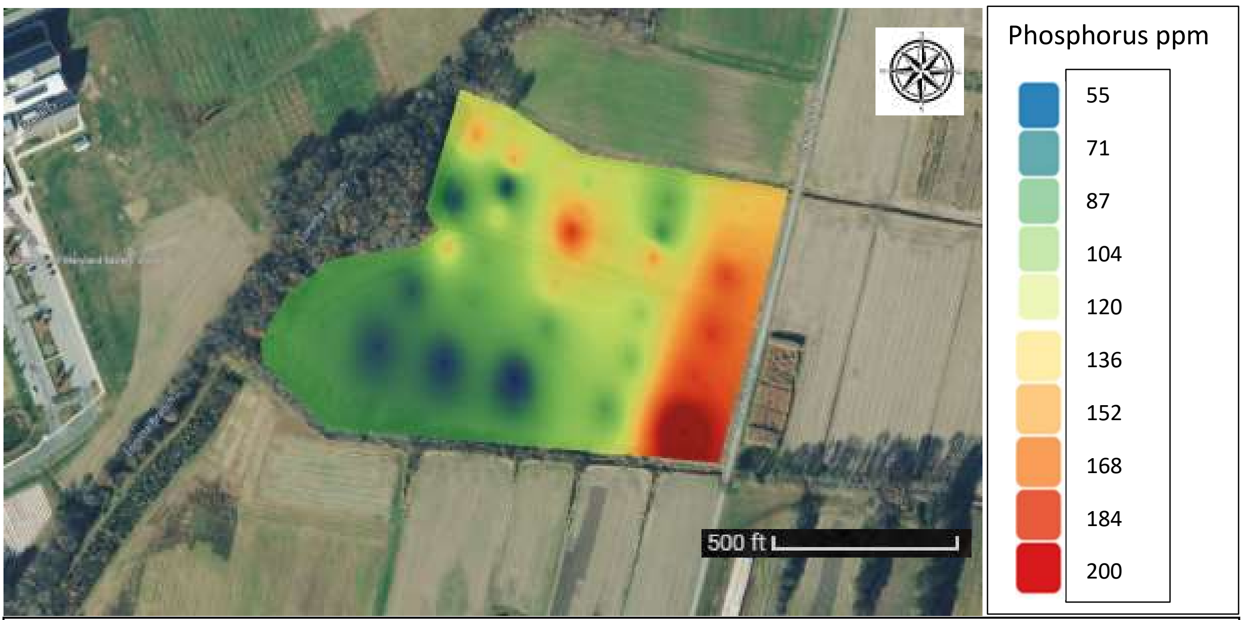

Figure 7: QGIS Map of Phosphorus Levels in the 15-acre SDI Portion of the field in 2017

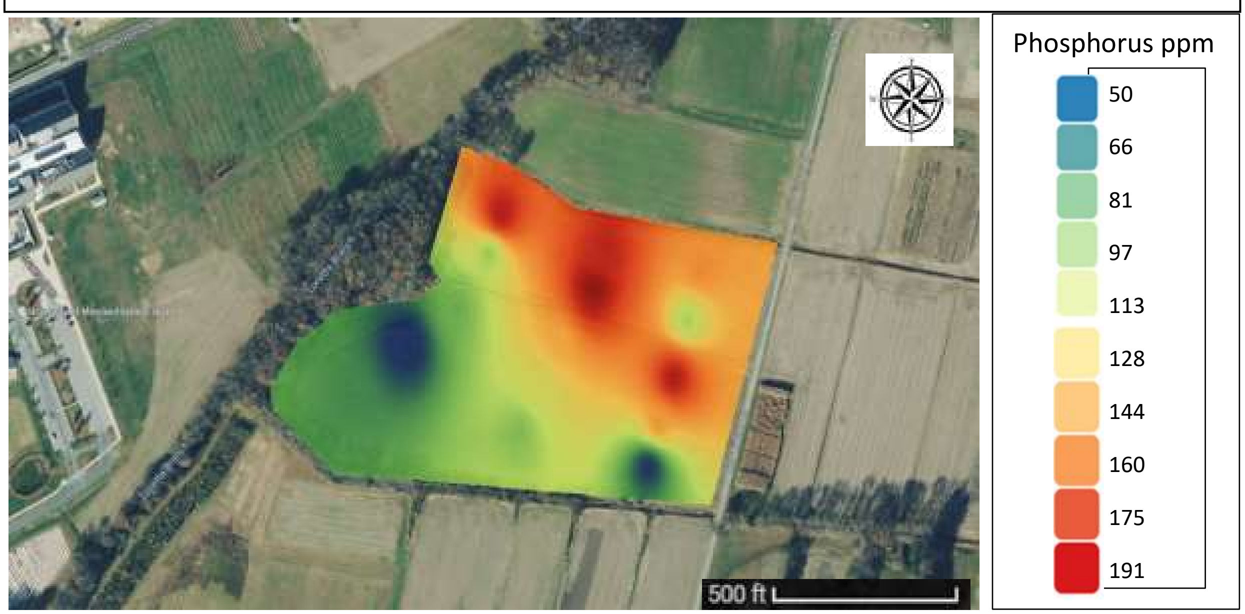

Figure 8: QGIS Map of Phosphorus Levels in the 15-acre SDI Portion of the field in 2019

field are shown in Figures 7 and 8 for ready reference. The gradual decline of phosphorus levels can also be readily observed from these figures.

5.0 Conclusion

Learning can be categorized into developing skills in three broad domains - cognitive, affective, and psychomotor. Higher education typically focuses largely on the cognitive domain following Bloom's taxonomy – knowledge, comprehension, application, analysis, synthesis, and evaluation [9]. ABET outcomes for engineering education integrates developing student abilities in both the affective and cognitive domain. Integrating out-of-classroom active learning experiences for students such as the one described above provides rich learning outcomes that integrate academic, life skills, and civic responsibility outcomes in land grant settings that are difficult to address from within the classroom. Often the artificial silos limit the overall educational experiences for students in some majors. Land grant mission objectives of campuses such as UMES can be creatively integrated with experiential learning field experiences for all majors. The graduate student leading the project has indicated that for the engineering undergraduates it took some time to become comfortable with the demands of the field efforts but they eventually worked well together. The out-of-classroom experiences are not limited to problem-solving from textbooks, structured laboratory studies, or even open-ended design projects that are constrained by compartmentalization of knowledge in academic disciplines, and as such integrate aspects of the real work environment that most students will join after completing their graduation requirements. Overall campus experiences of the students are enhanced by involving them in such efforts although at times non-academic aspects of the fieldwork may appear to be of little educational relevance. For the particular project outlined here, the graduate student who is considering an academic career as one of his career options has indicated the experience provided him with valuable insight through self-reflection on how to effectively work with undergraduates.

In keeping with the Federal Aviation Administration (FAA) guidelines, only faculty and students with UAS pilot's licenses (FAA Part 107) [10] are allowed to fly the aerial imaging drones utilized by the precision agriculture project team. The graduate student involved with the project has acquired a UAS pilot's license and could demonstrate the aerial imaging and post-processing efforts to the undergraduates. Although drone-based aerial imaging efforts were not directly associated with the project undertakings outlined in this paper, it has piqued the interest of the undergraduates and they have indicated they will start making preparations for the FAA pilot's license test in the not too distant future.

The undergraduates have also reflected on how to improve the design of the automated soil probe. The preliminary exposure to QGIS has also motivated the undergraduates to continue to develop geospatial mapping and analytics expertise using this open-ended software. The participating undergraduates have realized the wide applications of GIS in various sectors in the real world and an additional skill they may include to enhance in their resumes.

6.0 Acknowledgment

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