Summer 2021

Establishing Regenerative Pasture Systems Using Management Intensive Grazing in the Ozarks

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ESTABLISHING REGENERATIVE PASTURE SYSTEMS USING MANAGEMENT INTENSIVE GRAZING IN THE OZARKS

A Master's Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Plant Science

By

Shelbi Mundy

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Agriculture

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ABSTRACT

Soil carbon and soil health are important topics relating to how climate change is impacting agriculture, and how agriculture can in turn impact climate change. The agriculture industry, particularly beef production, has a large opportunity to use conservation agriculture techniques, such as rotational grazing, to offset some of the industry's impact on carbon emissions, erosion, water pollution, and other environmental issues. This study is the beginning of a long-term project exploring regenerative pasture systems in the Ozarks. The project takes place in a rotational grazing system with 12 paddocks. The objectives of this study are to characterize soil types by paddock and establish baseline values for important soil properties and species distribution and collect GIS data to develop maps to make management decisions. Baseline soil tests were done as well as plant species counts throughout the duration of the study. Data was compiled into map forms using Arcmap.

Key words: rotational grazing, soil health, soil carbon, regenerative agriculture, carbon sequestration, plant species, native warm season grasses, grazing

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ACKNOWLEDGEMENTS

Graduate school is not something you can attempt to complete on your very own. It takes a village for every student and I am so lucky to be surrounded by such an amazing village of my own. First, I would like to thank Dr. Will McClain. Graduate school was a decision I made with absolute zero plan of what to study, who to study under, how to pay for it, or even if I would want to complete it. I figured I would try it for a semester and if I didn't like it, I would quit and settle for just having my Bachelors. Dr. McClain knew this and the second there was an opportunity available he called me, and my journey began. He has given me complete intellectual freedom in designing my project and encouraged my independence in creating a graduate plan that was important to me since day one. I am beyond lucky that he saw something in me, and I could never thank him enough for that. I would also like to thank Dr. Bledsoe, whom I barely knew when I started this journey but now, I can say she has been a rock of sorts the last couple of years. She is the "mom" of my village and I have come to depend on her calming presence and assuring demeanor. She has also been a tremendous help in completing my lab work for my project. Dr. Dogwiler…you are an actual saint. When half of the agriculture department just decided we wanted to learn GIS in the fall of 2019, and it was an actual nightmare, you handled it with patience and kindness that I had not seen in a professor before. You always drop everything to help me (and anyone who needs it) no matter how busy you are. My GIS certificate is without a doubt the most valuable thing I will be leaving graduate school with. I can't thank you enough for helping me every step of the way even when it was not your responsibility to do so. I don't think I would have fallen in love with GIS the way I did if my first experience with it wasn't with you. Of course, I couldn't have gotten through grad school without the help of my peers. A huge thank you to Anna Dietrich, Austin Livingston, and Robby Moody. These students pulled hundreds of soil samples with me. 8-hour days in the rain, heat and even once, snow. These were not easy days that they did not have to do but they wanted to help me, and I couldn't appreciate enough. A special thank you to Austin Livingston. He has helped me not only with every single day of field work, lab work, thesis writing, and many classes we have shared. I have thoroughly enjoyed bonding with you over our addiction to Taco Bell. Thank you also to Mary Books, Kara Powelson, and Macie Clark.

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INTRODUCTION

The study of carbon sequestration in soils and the concept of soil health are new areas of research in agricultural science. Many questions regarding carbon processes in the soil and the role of soil health have not been answered, along with sorting through many emerging methodologies regarding both. Additionally, baseline data is hard to obtain given not only the differing soil types throughout the world, but also the different land uses, vegetation cover, and climatic conditions. (Olson et al., 2014).

Sequestration of soil organic carbon (SOC) is of important political and scientific regard because of the potential to help the agriculture industry mitigate CO_2 emissions. It is imperative to improve the fertility and health of our soils while continuing to support a growing population with food, fiber, and other agricultural products. To do this, we must better understand key soil processes and environmental services that soil provides and identify key drivers that connect soil health and carbon sequestration. Soil is the largest terrestrial pool of carbon, containing 2334 Gt of organic carbon. With agricultural lands occupying a large portion of the United States alone, the US has a large opportunity to use conservation agricultural practices to reduce the industry's carbon footprint. Poorly managed agricultural lands negatively impact climate change in a variety of ways, including increasing erosion, loss of ecosystem services, release of greenhouse gas emissions, and reduction of soil microorganism diversity (Lefèvre et al., 2017).

As mentioned above, it is difficult to know how to measure soil health, identify parameters, and interpret data collected over a long period of time, as studies conducted on different land uses, and in different climates often produce different results. Many times, the information can be contradicting. (McSherry and Ritchie, 2013). There is little data on how long

the effects of carbon sequestration last. Further, as beef production in the United States is a large industry, with large effects on climate, movement towards cow-calf pairs and grass grazed beef has become popular, but there are still techniques such as rotational grazing to make this industry more sustainable and aid in mitigating climate change.

Soil and Greenhouse Gases- The Potential

There is more carbon stored in the soil than that of the atmosphere and vegetation combined, about 2334 Gt. (Lefèvre et al., 2017) Although this number is large, it is not stagnant. Carbon is constantly entering and leaving the soil. Carbon entrance into the soil can happen via plant litter, or root exudates. When microbial organisms mineralize these carbon inputs from plants, gases such as CO_2 and CH_4 are produced and released into the atmosphere. This means that soil can be a source of greenhouse gases and contribute to global warming. (Brady and Weil, 2008). This is a very simple explanation of the carbon cycle, which happens with or without anthropogenic changes to the environment.

As the population grows, we must rely on large scale agriculture to support the world. This has led to a large release of another greenhouse gas, N_2O, which is largely released from highly disturbed agricultural soil and livestock facilities. This may make soil processes sound like a very bad thing, which, a lot of this is truly out of our control, but there are management practices that can help keep more carbon in the soil. This is called soil carbon sequestration, a poorly understood process that has tremendous potential to mitigate climate change. The more carbon in the soil, the lesser amount of carbon in the atmosphere.

It is thought that most soils throughout the world are depleted in carbon, therefore there is more potential for these soils to capture carbon, although these soils may have trouble doing so

naturally. That is why the potential for increasing carbon inputs and increasing management practices that protect existing soil carbon is so great. (Kane, 2015). A change of 10% increase in the soil carbon pool would equal 30 years of human derived emissions, while small increases in the rates of oxidation of soil carbon due to rising global temperatures could increase atmospheric CO_2. (Kirschbaum, 2000).

The Knowns and Unknowns of Carbon Sequestration

As mentioned previously, carbon sequestration in soil is a poorly understood process because there are so many factors taking part in the process, along with so many different soils of the world, and multiple key processes within the soil, (chemical, biological, and physical). There are several factors that we know influence soil carbon indefinitely, although we may not know the extent of each. Climatic conditions and temperature influence soil carbon by changing net primary production, the type of organic material inputs into the soil, and microbial activity, which all influence carbon fluxes (Stockman et al., 2013). Generally, it is believed that soil carbon stocks will decrease as mean annual temperature increases by increasing rates of decomposition (Groenigan et al., 2014). On the other hand, it is also believed that soil carbon could increase slightly because of accelerated net primary production from increased CO_2 levels. There is debate in the agricultural sciences about the temperature sensitivity of different factions and different pools of organic matter mineralization.

Land use change also has a significant effect on soil carbon. It is known that changing cropland to either pasture, or permanent forest has the highest gains for soil carbon, although changing any land to crop or monoculture will result in loss of carbon (Jangrid et al., 2018). It is also known that timing of organic matter inputs, as well as type (based on plant species

community), can influence soil carbon. It is thought that plant species diversity can increase soil carbon. Each plant species contributes to soil carbon by influencing microbial activity and nutrient cycling, which in turn influences the quality and amount of carbon inputs into the soil Plants that fix nitrogen and plants that have mycorrhizal interactions enhance nutrient uptake and therefore also can influence carbon sequestration. These associations are easier to demonstrate and study in artificial rather than natural studies (Stockman et al., 2013).

There is also debate on how root exudates and root functions influence carbon sequestration. According to Rasse et al., (2005), root carbon seems to be better stabilized compared to shoot carbon due to greater chemical resistance of root tissues, as well as protection of root carbon by root exudates. Another reason for this is that root hairs are thought to place root carbon in very small micro-pores and aggregates. Scientists who do not agree argue that root exudates negatively affect soil carbon because of rhizosphere priming effects, which means that rates of soil organic matter decomposition increase in the presence of root exudates (Stockman et al., 2013). Before soil organic matter can be soil organic carbon, but there is still debate within the community about the influence of abiotic factors versus microbial processes on the decomposition of organic matter (Jangrid et al., 2018). More research needs to be done on this before we can fully understand this influence on soil carbon.

Soil Health Parameters

Soil health is a concept of soil science that describes soil as “living” and takes into consideration biological, physical, and chemical characteristics of the soil system. Since soil health is a concept that encompasses so many aspects and processes of the ecosystem, scientists have worked hard to estimate parameters that can best describe the health of a soil system.

Indicators are used to correlate to important soil functions, i.e., decomposing organic matter, cycling water and nutrients, soil gas emissions, plant species diversity, and microbial density are to name a few (Franzluebbers, 2016). These indicators also have key characteristics. They must be 1) be easily measured, 2) detect changes in soil function, 3) integrate soil physical, chemical and biological characteristics and processes, 4) be accessible to many and be applicable in field conditions, and 5) be sensitive to changes in management and climate. (Franzluebbers, 2016).

Franzluebbers suggests these indicators to analyze changes in soil health, soil organic carbon and total nitrogen, water stable aggregation, flush of CO_2 after rewetting dry soil, microbial substrate, inorganic nitrogen, extractable phosphorous, and soil pH. Soil organic carbon and total nitrogen can tell us how well the soil can sequester greenhouse gases, buffer the soil for nutrient extremes, and support healthy and diverse microbial populations. Water stable aggregation can tell us how capable the soil is of resisting wind and water erosion. Flush of CO_2 helps us make assumptions about the microbial community, which connects to the soil's ability to decompose organic matter and carryout ecosystem services. The process of rewetting dry soil and measuring the flush of CO2 can also help us understand how soils behave after rainfall in terms of gas release (Franzluebbers et al., 2000). Microbial substrate can help us analyze the soils' ability to provide a diverse habitat for microorganisms and what kind of microorganisms the soil supports. Inorganic nitrogen, extractable phosphorus and soil pH tell us how well the soil can provide nutrients and promote the microbial community the system needs. (Franzluebbers, 2016) Many of these parameters can be linked to the factors that influence carbon sequestration.

Rotational Grazing on the Environment, and Soil Carbon

According to the Food and Agriculture Organization of the United Nations, global livestock production accounts for 14.5% greenhouse gas emissions, with the United Sates being a leader in production, providing 19% of world production (Stanley et al., 2018). Systems like feedlots can negatively impact the environment by causing erosion, compacting the soil, causing nutrient runoff and nutrient overload into the ecosystem and polluting rivers, and have numerous health concerns for the cattle. Grazing cattle is more beneficial for the environment, but there are still implications associated to grazing cattle without proper management. Cattle left to graze freely can cause significant damage to plant growth, plant species communities, and can impact productivity (Ball et al., 2015). Cattle will also frequent areas for shade and water, and hay in the winter, leading to erosion and more nutrient overload and runoff and compaction. (Stanley et al., 2018).

In a review by Abdalla (Abdalla et al., 2018), it is explained that it is not just the act of grazing that effects soil health and carbon, but the intensity of the grazing, the animals that are being grazed, and the climate. This review found that when all data was pooled together and not separated by climate, high grazing intensity was associated with low soil organic carbon. When all data was separated, they found that the effect rotational grazing had was dependent on the climate of the region. For the 'dry/wet climate", characterized by dry soils and high temperature and evapotranspiration, grazing intensity had negative effect at all levels but low grazing intensity. At low grazing intensity, soil carbon increased by 5.8%.

In the moist/cool climates, all grazing led to decreases in soil carbon. This is because the cool temperatures and lack of oxygen limit microbial activity, as well as change the community's fungal-bacterial composition. In moist/warm climates, all grazing led to increased carbon due to

high microbial carbon due to warm temperatures which led to faster decomposition of plant litter. In dry/cool climates, low to medium grazing intensity was found to sequester more carbon but very little data was present for high grazing intensity. They explain that in C4 dominated grasslands increased soil carbon was associated with higher grazing intensity because C4 plants have more resources to react to loss of leaves due to grazing, such as rhizomes. Higher grazing intensity decreased soil carbon for C3 and mixed C3-C4 grasslands. It is also known that late successional grassland species, due to the mixture of C4 species and legumes, can sequester more than 200% more carbon than monoculture agriculture (Yang et al., 2019).

In a 12-year study in Georgia by Franzluebbers and Stuedemann (2009), researchers were interested in the distribution of soil carbon and total nitrogen within a soil profile and hypothesized that at least a decade of data would be needed to distinguish changes in the ecosystem. A few goals of the study were to determine the rates of change in soil carbon and total soil nitrogen with depth increments throughout the soil profile, sampling at 0, 5, and 12 years of pasture management; as well as quantify the potential spatial redistribution of soil carbon and total soil nitrogen influenced by cattle behavior within the pasture. They compared the effects of unharvest pasture, low grazing pressure, high grazing pressure, and hayed pasture.

A few highlights of their findings were that grazing led to significant increases in total nitrogen and soil carbon in the top 15 cm of soil compared to ungrazed pasture. Carbon was also increased in the unharvested pasture compared to hayed pasture. Haying forage yearly had the lowest levels of carbon and nitrogen compared to grazed and ungrazed areas. With high grazing pressure, soil carbon and nitrogen were heavily increased in shaded areas due to cattle defecation and urine and avoiding eating in these areas. Grazing pressure influenced soil carbon at the end of the 12-year study, with low grazing pressure ending at 21.6 kg-1, and high grazing pressure

ending at 19.9 kg-1, but significant accumulation was only observed in the top 15 cm of the soil profile for all areas. (Franzlubbers and Stuedmann, 2009).

The Role of Pasture

Understanding SOC sequestration and total soil nitrogen (TSN) estimates are needed to improve our knowledge of management practices on soil health and carbon cycling related to greenhouse gas emissions (Franzleubbers and Stuedmann, 2009).

Pastures are identified as an important land use in the Unites States, capable of storing large amounts of SOC and TSN compared to other agricultural land uses (Franzluebbers, 2010). In a pasture setting, there can be varying soil types and plant populations, making for an exceptionally dynamic ecosystem compared to a monoculture or even an untouched ecosystem. Apart from soil type and plant populations, there is also interaction between the soil fauna (microorganisms), the grazing animals, and even humans (Kallenbach, 2015). These factors can change in response to different environmental stressors, be they biotic or abiotic, which correlates with the chemical, physical, and biological properties of soil. These multi-faceted ecosystem features can make evaluating a multitude of measurements difficult. “Quantifying any particular aspect of pasture productivity is also a dynamic proposition with “snap shots in time”, as perhaps the best phrase to characterize many measurements” (Kallenbach, 2015).

Rotational grazing involves the movement of cattle from different pasture areas on a day-to-day basis. Rotational grazing ensures an even distribution of manure across the ecosystem, reduces erosion and nutrient overload in high traffic areas, and prevents overgrazing, leading to better forage quality and plant species composition (Ball et al., 2015). Upwards of 95% of uncultivated grasslands are grazed by cattle, and grazing may be an important factor in

controlling carbon storage based on species composition and grazing intensity (McSherry and Ritchie, 2013).

As mentioned above, there are many unknowns regarding research and data on soil carbon sequestration and soil health. We know some factors that indefinitely influence soil organic carbon, but maybe we do not know how they influence, or the extent to which they influence. Examples of these include climatic conditions, temperature, CO_2 levels in the atmosphere, land use change, organic matter inputs and timing of inputs, plant species diversity and composition, microbial community, soil depth, (Stockman et al., 2013), root exudates (Rasse et al., 2005) and even what parameters to measure and how to interpret these parameters, to make sense of it all regarding the carbon cycle in soil. Another gap in the research is soil type. No studies have been explored in Missouri on the influence of soil type of carbon sequestration.

The objective of this study was to begin documenting long term changes in soil health parameters and plant species composition, impacted by rotational grazing management. As changes in soil health parameters and species diversity occur over several years this project will be able to provide insight to producers on the benefits of rotational grazing and how management decisions affect soil health parameters and species diversity.

MATERIALS AND METHODS

Site Description and History

The Little Sac Grazing Demonstration site is owned by Springfield City Utilities, leased by The Watershed Committee of the Ozarks and is managed in partnership with USDA/NRCS, Greene County Soil and Water Conservation District, and Missouri State University (Fig. 1). The location of the site is S-16, T-30N, R-21W; -93.241106, 37.319646, near Fellows Lake, between Springfield and Fair Grove, MO with an elevation of 382 meters (m) to 323 m above sea level (Fig. 2). The land area is divided by a creek running east to west, separating the grazing area into a north and south set of paddocks. The north area has five paddocks, ranging from 0.72 hectares (ha) to 1.33 ha in size. The south area has six paddocks ranging from 0.52 ha to 1.21 ha in size and both areas combined equal 10.72 ha. Each set of paddocks has a central watering system for livestock and is separated with a single strand of high tensile electric fence (Fig. 2).

This area has eight different soil types and a varied plant species composition between the north and south paddocks. This allows us to examine a wide range of trends regarding the site in response to grazing management over time. There has not been any previous research done on the site, but the site has been cleared to better suit a grazing system (Fig. 1 and 3). The soil types present in the grazing system include: 46000 Humansville silt loam, zero to two percent slopes, frequently flooded, 70009 Goss gravelly silt loam, eight to fifteen percent slopes, 70124 Goss-Gasconade complex, three to fifty percent slopes, 70139 Parsons-Sacville complex, one to three percent slopes, 75376 Cedargap gravelly silt loam, zero to two percent slopes, frequently flooded, 75380 Dapue silt loam, zero to two percent slopes, occasionally flooded, 76383

Cedargap silt loam, zero to two percent slopes, frequently flooded, and 76758 Secesh-Cedargap complex, zero to two percent slopes, frequently flooded (Fig. 4).

In 2018, Cedar saplings were pushed into piles and burned, and the site has been spot treated with Rodeo herbicide. The burn piles were still evident on the site for the first year of the study. The grazing system was designed and installed in 1994 by USDA/NRCS, Greene County Soil and Water Conservation District. In June of 1998, Big Bluestem and Indiangrass were drilled into paddocks six, seven, eight, and nine. In 2000, the Watershed Committee of the Ozarks developed a riparian buffer around the creek spanning 15.24 m with mixed woodlands species. Riparian buffers are imperative to best management practices for cattle systems as they promote healthy waterways (Ball, et al, 2015). In 2018, the system was revived by the Watershed Committee of the Ozarks and single strand of high tensile electric fence was utilized to divide paddocks. Paddocks 8 and 9 were combined altering the original design of the system. The system is under a grazing contract with a livestock producer who lives adjacent to the site. There are 10-13 cow-calf pairs utilizing the system during a grazing season and they are on a one to two-day rotation. In May of 2020, paddocks 11 and 12 on the south side of the system were cut for hay.

Field Sampling Methods

Weather data, including the precipitation and minimum and maximum temperatures of the duration of the study, as well as the 30-year average, were collected from the NOAA weather station in Springfield, Missouri. Plant species counts were taken using the line intercept method (Cook and Stubbendieck, 1986; Blevins et. al., 2018), observations were taken at every 0.305 m within a 15.24 m transect. Five replicate transects were randomly taken per paddock, providing

250 plant species observations per paddock. Plant species transects were conducted three times throughout the duration of the study; October 2019, June 2020 and October 2020 to monitor seasonal changes in vegetation.

Soil samples were initially taken to obtain baseline soil nutrient data in August of 2019. One composite soil sample was taken from each paddock, comprised of about 10-15 cores, to a depth of 10-15 cm. Individual cores were randomly sampled across each paddock. These samples were used to determine pHs, Calcium (Ca), Magnesium (Mg), Potassium (K), Bray I Phosphorus (P), and Bray II P. A separate set of soil samples was obtained in December 2019 through January 2020 for future assessment of several soil health parameters. These samples were taken by paddock and by soil type within each paddock. For each soil type, three m^2 sampling sites were randomly chosen within a paddock. At each sampling site, soil moisture was taken using a Campbell Scientific HydroSense II Moisture Meter (Campbell Scientific, Logan, Utah, USA) and GPS coordinates were also recorded. Soil Temperature was taken at each sampling site using an Innoquest Inc. Spot-On Temp-34 temperature probe (Innoquest Inc., Woodstock, Illinois, USA). Each sample is comprised of a total of 15 cores pulled within each m^2 sampling site. Each core was segmented by depth: 0-2.5 cm, 2.5-5.0 cm, and 5.0-7.5 cm, and composited with cores from the sampling site (Franzluebbers, 2016).

Soil Sample Preparation

Composite soil samples from paddocks were air-dried, ground using a Gilson Company Inc. Soil Grinder (110 V/60 Hz) (Gilson Company Inc Lewis Center, Ohio USA), and analyzed for pHs, Ca, Mg, K, Bray I and II P. Soil samples collected from each soil type and separated into depths (0.0-2.5 cm, 2.5-5.0 cm, and 5.0-7.5 cm) were air-dried, thoroughly picked through

to remove roots, rocks and plant material, ground with a standard mortar and pestle, then sieved using a No. 18, 100 mm sieve. These samples will be used to compare future samples for changes in carbon and nitrogen.

Soil pHs was found using 0.01 M $CaCl_2$ solution and Neutralizable Acidity using the New Woodruff Buffer method as outlined in Nathan et al. (2012) were measured by an OHAUS ST300 pH meter (HOGENTOGLER & CO. INC., Columbia, Maryland, USA). Calcium, Magnesium and Potassium were determined using the Ammonium Acetate Extraction method (Nathan et al. 2012) using an Atomic Absorption/ Flame Emission Spectrophotometry (Agilent Technology, 200 Series AA, Santa Clarita, California, USA). The analytical wavelengths were set at 766.5 nm (K), 285.2 nm (Mg), and 422.7 nm (Ca). All samples were diluted 1:20 using 0.105% lanthanum (La) from La_2O_3. Standard solutions were made using a background 1% HNO_3 and 0.105% La. Standards were 1.00, 2.00, 3.00 and 4.00 ppm for Ca, 0.25, 0.50, 1.00, 1.50, and 2.00 ppm for Mg, and 0.25, 0.50, 1.00, and 2.00 ppm for K (Murphy and Riley, 1962) Bray I P (Denning, 1998; Nathan et al., 2012), was measured using 0.5 gram soil samples and 5 mL of Bray I solution, 0.03 N NH_4F in 0.025 N HCI, and were vortexed twice within 5 minutes and centrifuged (ThermoFisher Scientific, Megafuge™ 8 Small Benchtop Centrifuge Series, Waltham, Massachusetts, USA) for 5 minutes. One mL of the supernatant added to 4 mL of working solution, vortexed, and developed for 20 minutes. A standard absorbance curve was developed using solutions of 0.00, 0.50, 1.00, 2.50, and 5.00 ppm P in Bray I extract background. Standard and samples were measured using a GENESYSTM 30 Visible Spectrophotometer (ThermoFischer Scientific, Waltham, Massachusetts, USA) at 660 nm Bray II was determined as stated above using a 0.1 N HCl + 0.003 N NH_4F extractant and standard background (Nathan et al. 2012).

For total carbon and total nitrogen, 100 mg samples were weighed into small tin cups and folded using the equipment that accompanied the Flash Smart Elemental Analyzer (Thermo Fischer Scientific, FlashSmart NC SOIL, Waltham, Massachusetts, USA). Samples were stored in plastic trays for future analysis.

Drone Flight and ArcMap Methods

A DJI Phantom 4 Pro sUAS (DJI Nanshan District, Shenzhen, China) was used to obtain imagery of the site utilizing the 20 megapixels integrated camera. The camera utilizes a global shutter which captures the entire scene within the photo simultaneously (Hostens, et al., 2019). The base mission was flown at an altitude of 75 meters above ground level. This altitude yielded a 2.1 cm/pixel ground sampling distance. The flight path was N-S Orthogonal, with the camera angle also being orthogonal. Side-to-side and front-back overlap of photos was at 80%. The sUAS traveled at a speed of 7.5 m/s. The flight length was 10,169 m and covered an area of 15.94 ha. Course angle was at 90° and the margin was at 30 m. The camera's shutter interval was determined based on the photo overlap and sUAS airspeed. Ground control points (GCP's) were used for this flight. The acquired imagery was processed in Agisoft Metashape following the workflow in Noble and Matthews (USGS, 2017) with some slight modifications. Image alignment was completed with an accuracy setting of "highest" with key point limit of 60,000 and tie point limit of 0. After alignment a least squares bundle adjustment, which is referred to as "camera optimization" in Metashape, was run to correct for camera lens distortions. As specified in Noble and Matthews (USGS, 2017) the parameters f, cx, cy, k1, k2, k3, p1 and p2 used for this bundle adjustment. (Hostens, et al 2019). The gradual selection procedure described in the Noble and Matthews (USGS, 2017) workflow was used to eliminate erroneous and noisy data

from the sparse point cloud. Data collected was processed by Dr. Toby Dogwiler. Maps were created using Arcmap 10.8.1. Plant species maps were created using dot density symbology. Extractable nutrients Ca, Mg, and K and Bray I and Bray II P were created using proportional dot symbology. pHs were created using graduated color symbology. The base data used for these maps is an orthophoto from the drone flight over the site on June 2020 (Fig. 3).

RESULTS AND DISCUSSION

Environmental Conditions

For precipitation, monthly totals were above average for 2019 and 2020 for January through June (Fig. 5). For both years, May had exceptionally elevated precipitation. For 2019, only August, September, October, and December dramatically deviated from the 30-year average (Fig. 5). For 2020, as mentioned above, January through May precipitation levels were either at or above the 30-year average, while for the remaining 6 months of 2020, the Ozarks suffered a drought, apart from October, which was above the 30-year average (Fig. 5). For 2019 temperatures, every month of the year was well above the 30-year average for maximum temperature, while every month except September was below the 30-year average for minimum temperature (Fig. 6). For 2020 temperatures, every month's maximum temperature was above the 30-year average and every month's minimum temperature was below the 30-year average (Fig. 7).

Plant Species Transects

The Watershed Committee of the Ozarks was interested in the effects grazing management would have on changes in plant species diversity. Initial visual assessments of the site pointed to a system that was predominately tall fescue (*Festuca arundinacea*) with a slightly higher number of other species on the south paddocks (Fig. 8). Early discussions with the Watershed Committee of the Ozarks provided some insight as native warm season grasses had been introduced south of the creek in the late 1990's. The interest in the impact of rotational

grazing management on changes in the plant population led to seasonal species transects to monitor the species composition of the site.

The Little Sac Grazing Demonstration is considered a cool-season or C3 system, Tall Fescue is the dominate species in all but the southernmost paddocks (Fig. 8). In the fall of 2019, the highest percentage of tall fescue was in the northern paddocks at 94% and lowest were the southernmost paddocks at 59% (Fig. 8). Paddocks 8-10 had the highest concentration of warm season C4 grasses at 15-20% in fall of 2019. This was anticipated as the warm season C4 grass species were introduced in these paddocks in the late 1990's and still dominate the area. Another trend illustrated by the map (Fig. 8), was the number of paddocks with bare ground percentages as high as 15% in fall of 2019.

In the spring of 2020 cooler temperatures and wetter periods slowed the early growth of tall fescue in all paddocks (Fig. 9). However, these environmental conditions produced an increase in the number of legumes present in the transects across all paddocks with the highest concentrations 37%, occurring in the northern most paddocks (Fig. 9). Another trend was evident in the number of species that emerged around the old burn piles and in areas of compaction due to renovating the site with heavy equipment. Species like yellow woodsorrel (*Oxalis stricta*) were found near the old burn piles throughout the site. In poorly drained areas, yellow nutsedge (*Cyperus esculentus*) was observed many times throughout the north paddocks in spring 2020 (Fig. 9). There was also a higher occurrence of native warm season grasses in the southern paddocks with ~30% increase over the previous fall (Fig. 8).

In the fall of 2020, the highest percentage of tall fescue was in the northern paddocks at 94% and lowest were the southernmost paddocks at 29- 41% (Fig. 10). Paddocks 8-10 had the highest concentration of warm season grasses at ~50% and the lowest of tall fescue at 29% in fall

of 2020. Southwest Missouri was suffering a drought during this time so a slight increase in tall fescue and native warm season grasses could be expected as both are drought tolerant (Fig. 10). The increases in native warm season grasses was apparent moving across the southern paddocks even during the short amount of time these observations were recorded.

As mentioned previously, native warm season grasses have been introduced in a few of the southern paddocks. Native warm season species benefit from the regenerative results of prescribed burning, which has been planned by the Watershed Committee of the Ozarks since the sites inception, however, due to legal liabilities has not yet occurred. This could greatly improve the already well-established stands of native warm season grasses in paddocks 8-10. All the other south paddocks could greatly benefit from introducing more native warm season grasses, as the area is suited to them. The soils on the south side of the system could support native species very well due to being deeper, and less rocky than the north side of the system. It should also be noted that the number of grazing livestock could be increased in order to better manage competition and help spread the native warm season grasses.

Soil Nutrient Analysis

Composite soil samples for paddocks showed soil pHs ranged from 5.41 in the southernmost paddock to 6.35 on the north side of the system. (Fig. 11). Soil Bray I P by paddock ranged from 23 to 51 lbs/acre, while Bray II P ranged from 15 to 48 lbs/acre, with two paddocks from the south side being extremely low in Bray II P (Fig. 12 and 13). Soil Ca ranged from 2486 to 5835 lbs/acre, with three paddocks from the northern side having much higher concentrations of Ca than the rest of the system (Fig. 14). Soil Mg in all paddocks ranged from 156 to 637 lbs/acre (Fig. 15). Like Ca the higher concentrations of Mg were found on the

northern paddocks compared to the southern paddocks. Soil K ranged from 275 to 500 lbs/acre across paddocks (Fig. 16). Unlike other soil nutrients, soil K was highest in one paddock on each side of the system. It is possible that these paddocks have had slightly higher grazing intensity or had hay fed on them in the past, which could explain the higher soil K values.

The northern paddocks had a generally higher pH than the southern half of the system (Fig. 11). The northern paddocks also had a more uniform Tall Fescue-White clover grassland species mix that many producers strive for in the Ozarks (Fig. 8, 9 and 10). Cool season perennial grasses require a minimum pH of 5.8 for optimum production (Ball et al., 2015), which suits tall fescue allowing it to dominate the northern paddocks. Legumes require a higher pH than most grasses (Ball et al., 2015). The northern paddocks 1, 2, and 3 had the highest pH and higher numbers of legumes in their species composition compared to some of the more diverse paddocks (Fig. 11). The northern paddocks also exhibited higher concentrations of plant available nutrients compared to the southern paddocks in the system (Fig. 12-16). The lone exception was paddock 2 that had levels of Bray I P and K that were comparable to the southern paddocks (Fig. 16). This is likely due to a large area in paddock 2 that remained wet throughout the year. Wet soils that are often low in oxygen, limit plants from taking up significant amounts of Mg, regardless of Mg levels in the soil (Ball et al., 2015). This could also explain the lower soil K values in that paddock as K is easily leached in wet soils.

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Figure 1. Historical photo of the property Springfield, Missouri. Photo courtesy of The Watershed Committee of the Ozarks.

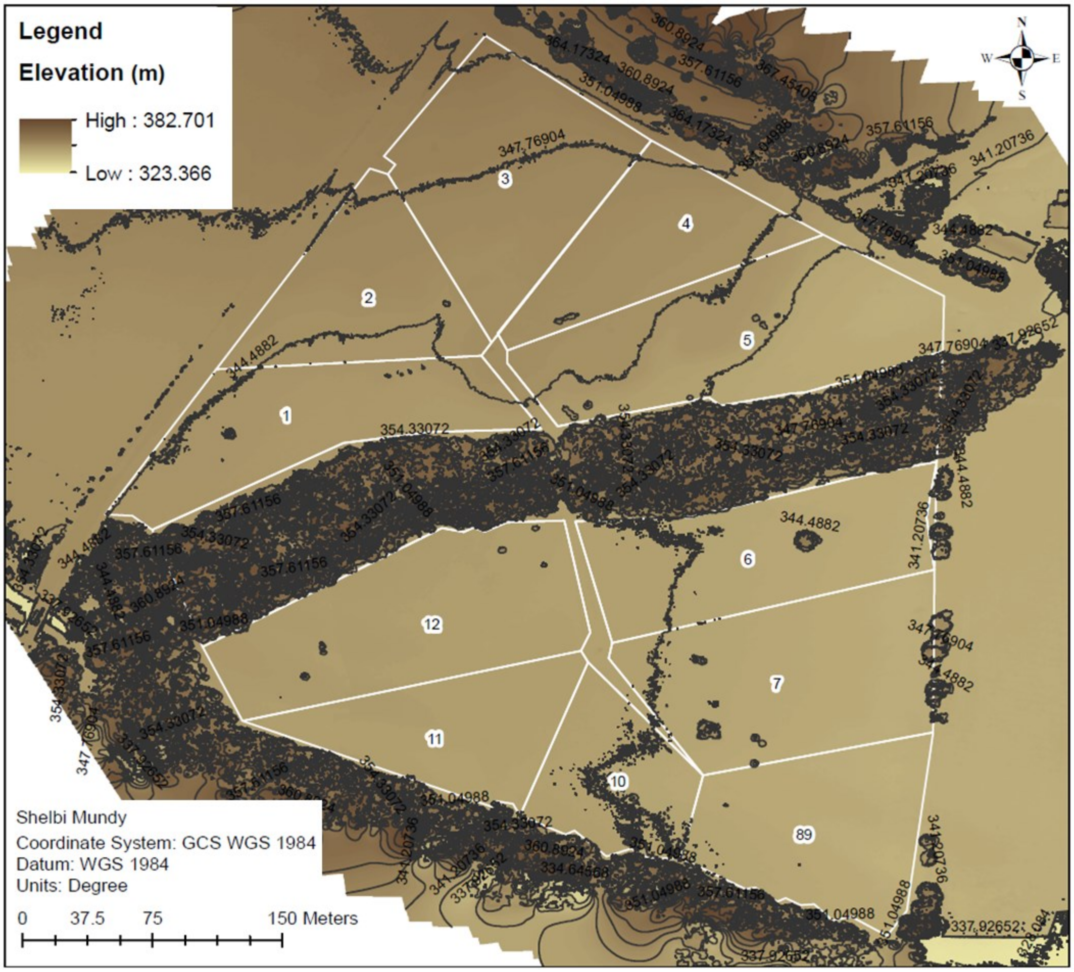

Figure 2. Elevation and paddock layout for the little sac grazing system.

Figure 3. Aerial Image from drone flight June 2020, Springfield, Missouri.

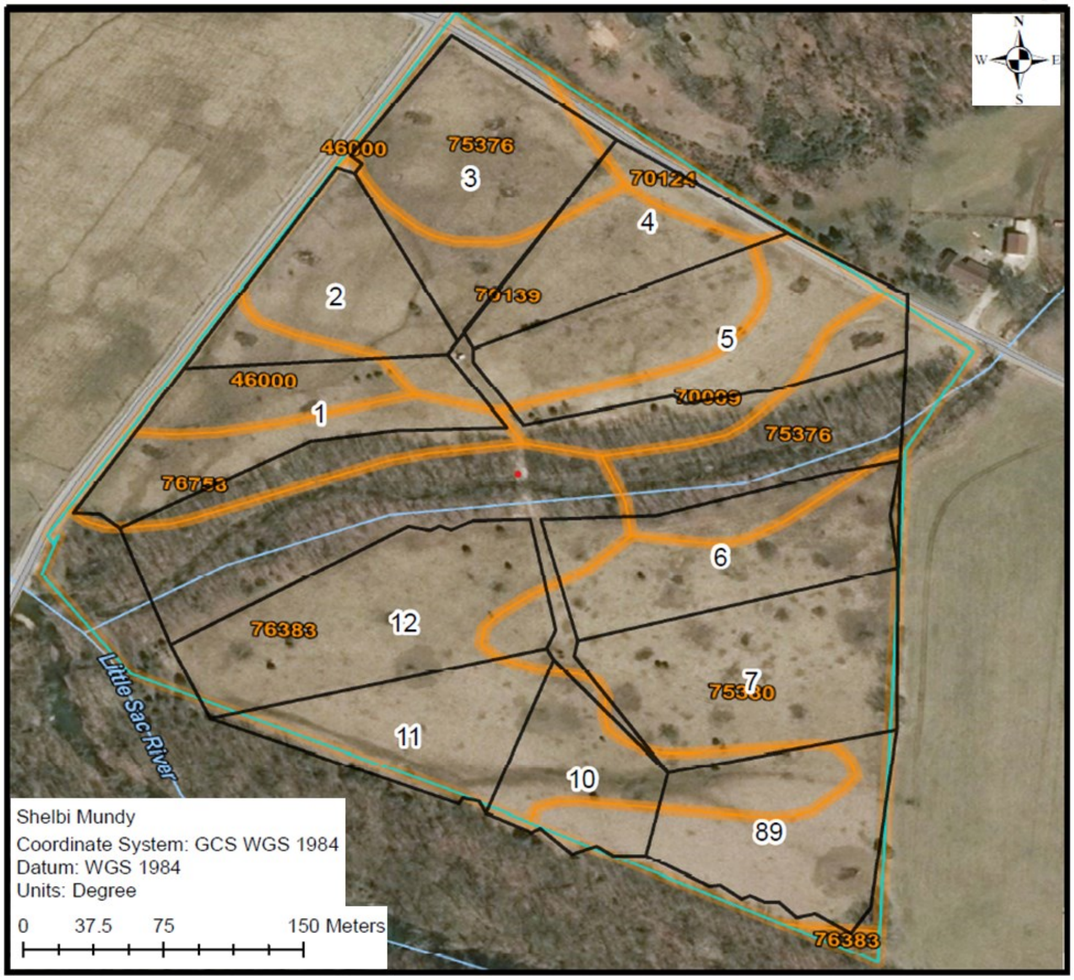

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Figure 4. Soil type and paddock layout for the little sac grazing system.

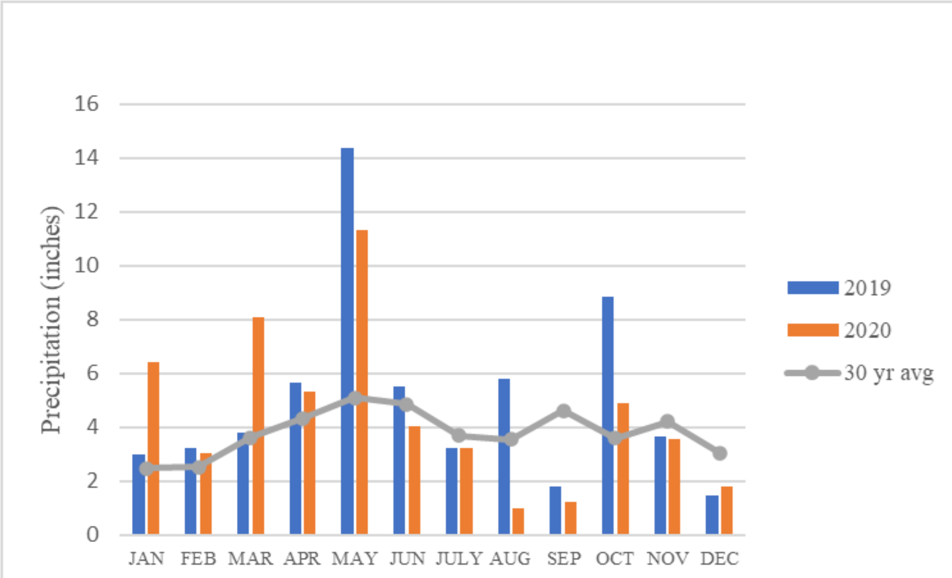

Figure 5. Monthly precipitation totals for the 2019 and 2020, and the 30-year monthly precipitation average for Springfield, Missouri.

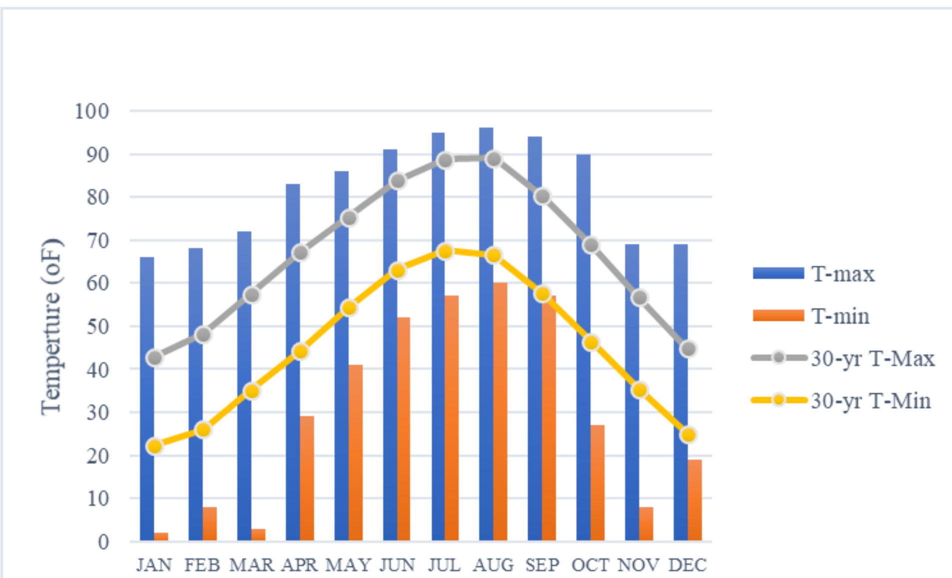

Figure 6. Monthly minimum and maximum temperatures for 2019, and the 30-year monthly minimum and maximum temperature average for Springfield, Missouri.

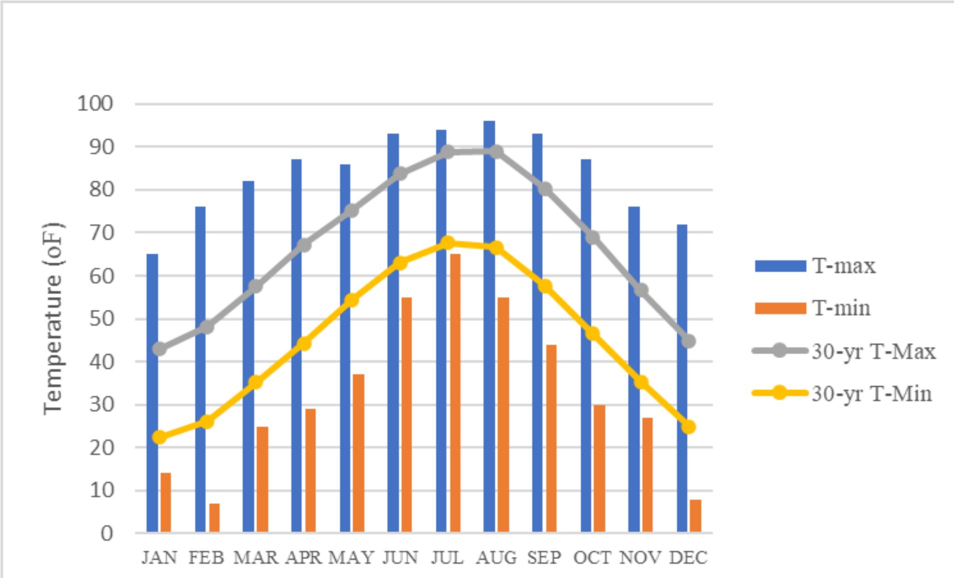

Figure 7. Monthly minimum and maximum temperatures for 2020, and the 30-year monthly minimum and maximum temperature average for Springfield, Missouri.

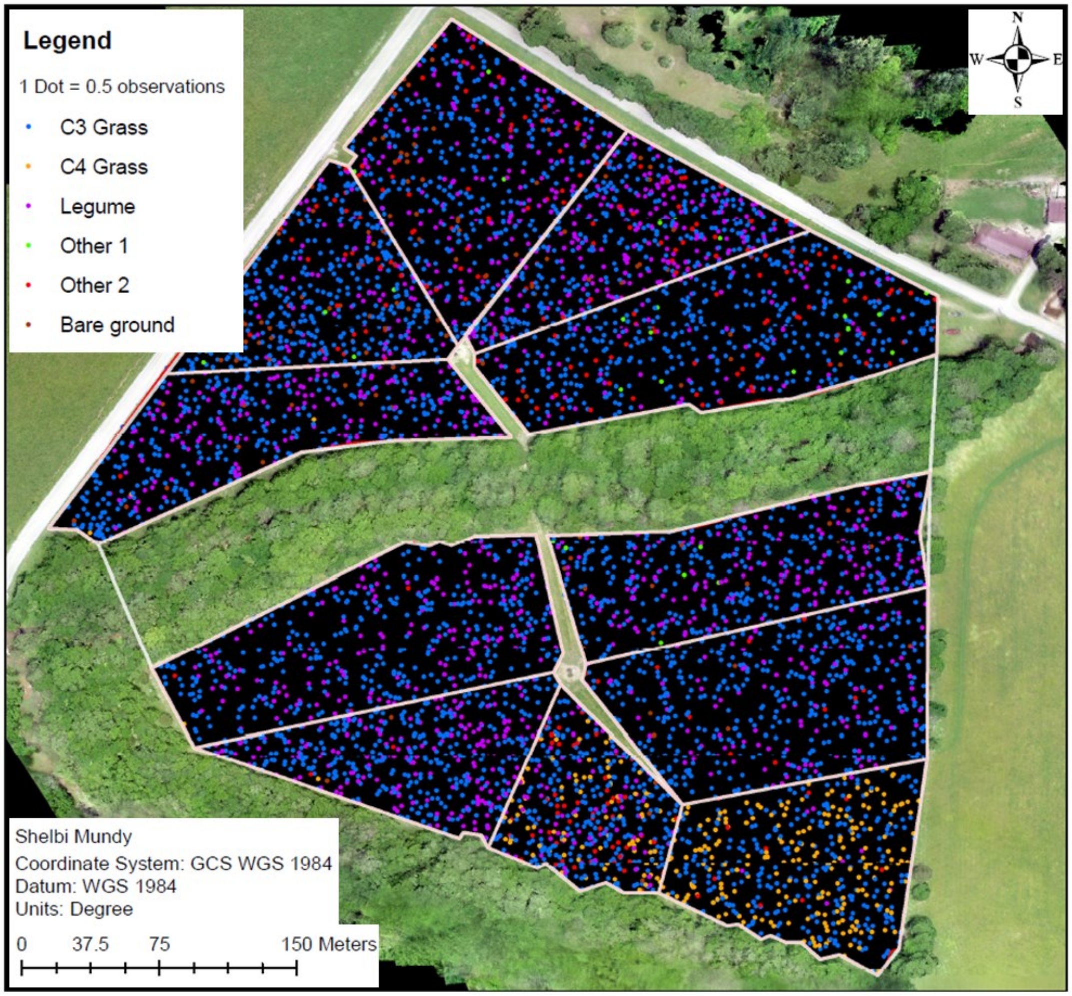

Figure 8. Plant species transects for Fall 2019. ArcMap dot density symbology to illustrate plant species observations by paddock.

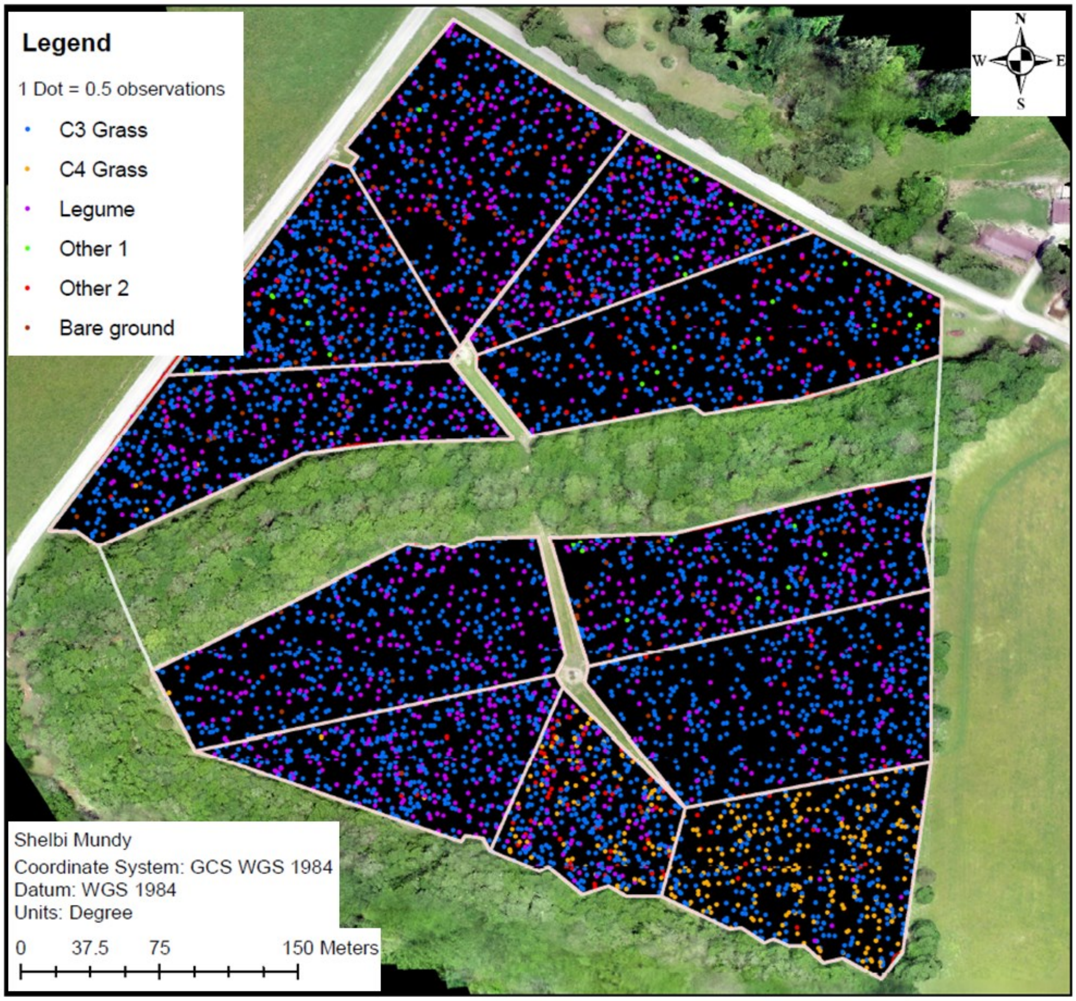

Figure 9. Plant species transects for Spring 2020. ArcMap dot density symbology to illustrate plant species observations by paddock.

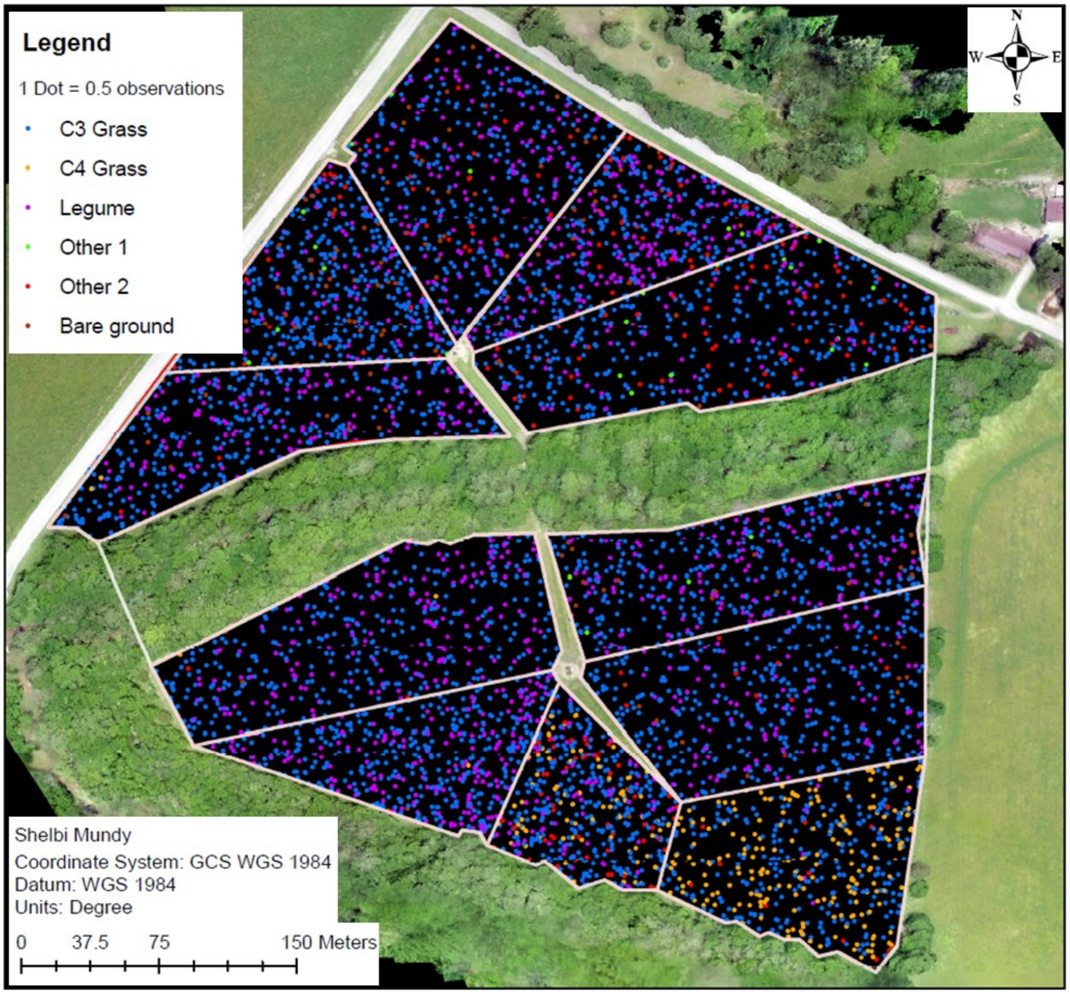

Figure 10. Plant species transects for Fall 2020. ArcMap dot density symbology to illustrate plant species observations by paddock.

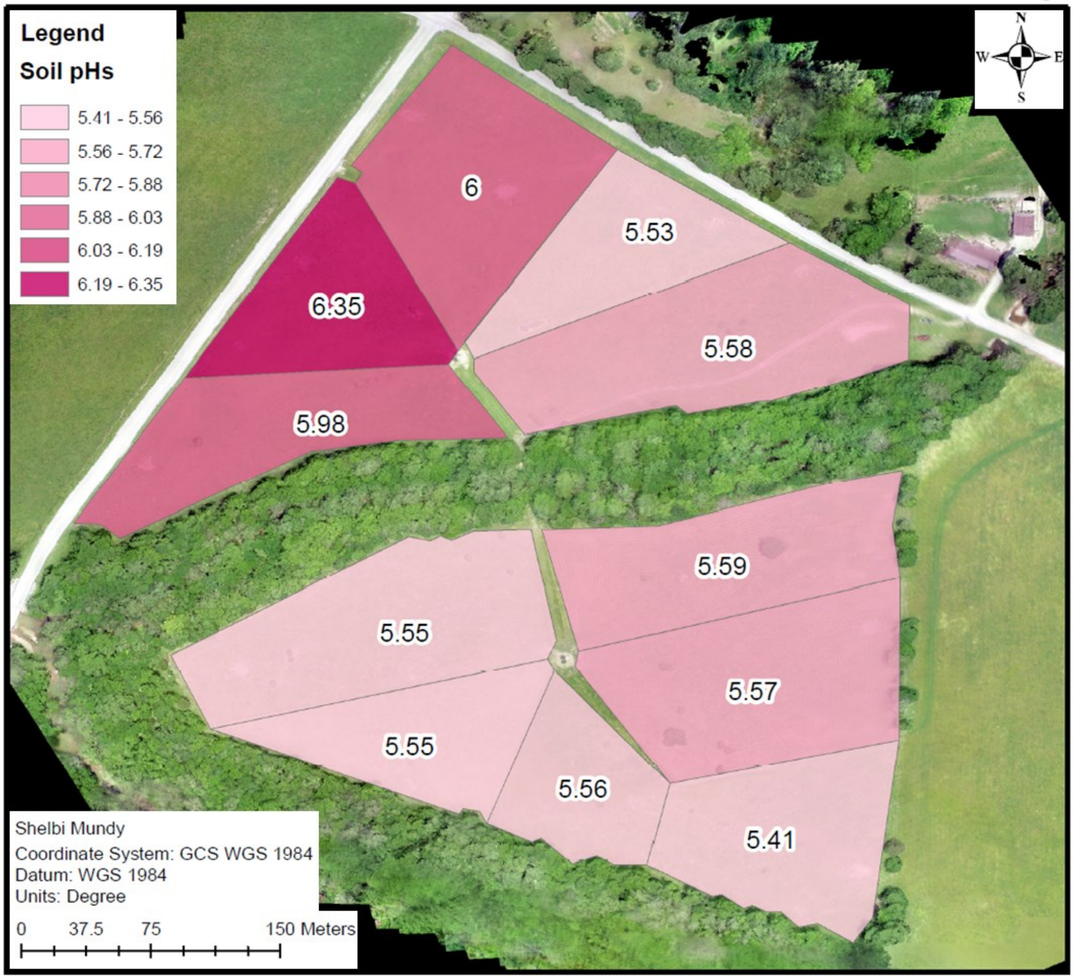

Figure 11. Soil pHs values by paddock. ArcMap graduated color symbology.

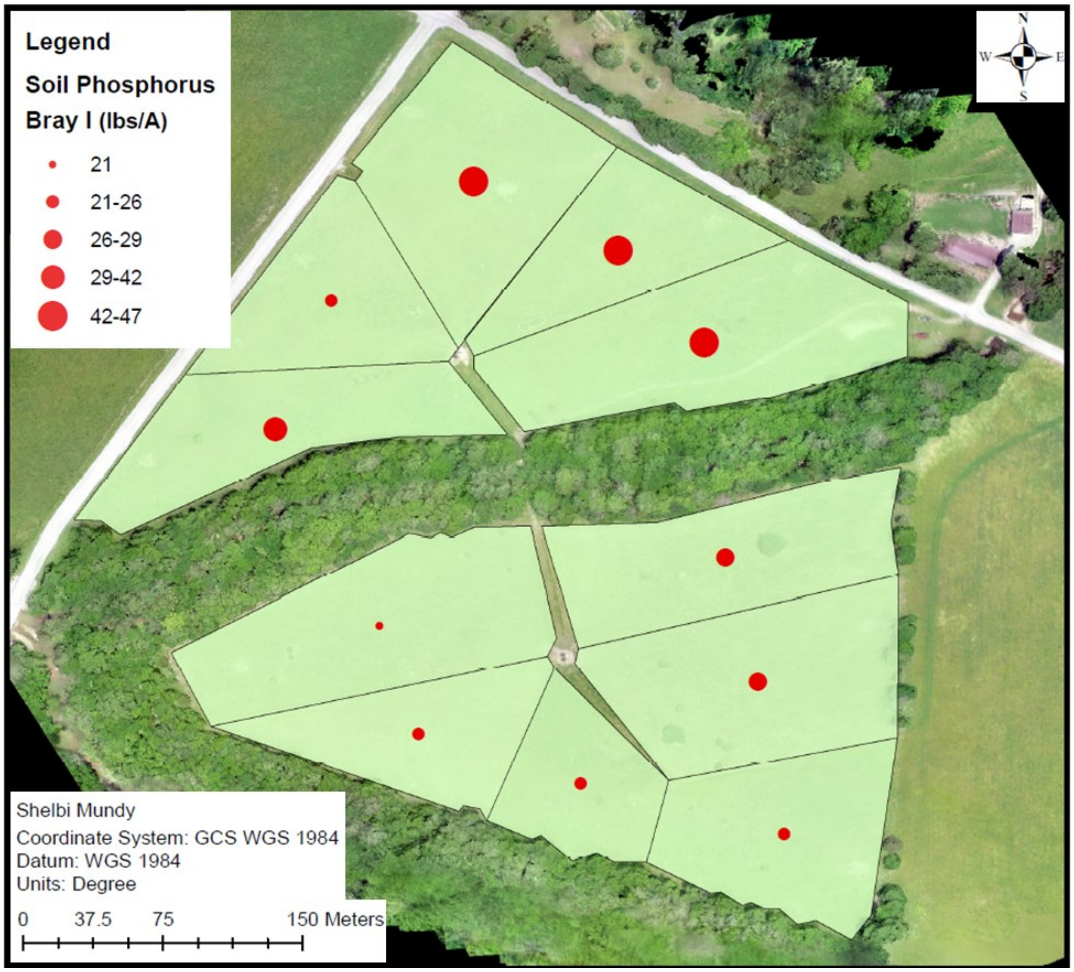

Figure 12. Soil Bray I Phosphorus values by paddock. ArcMap proportional dot symbology

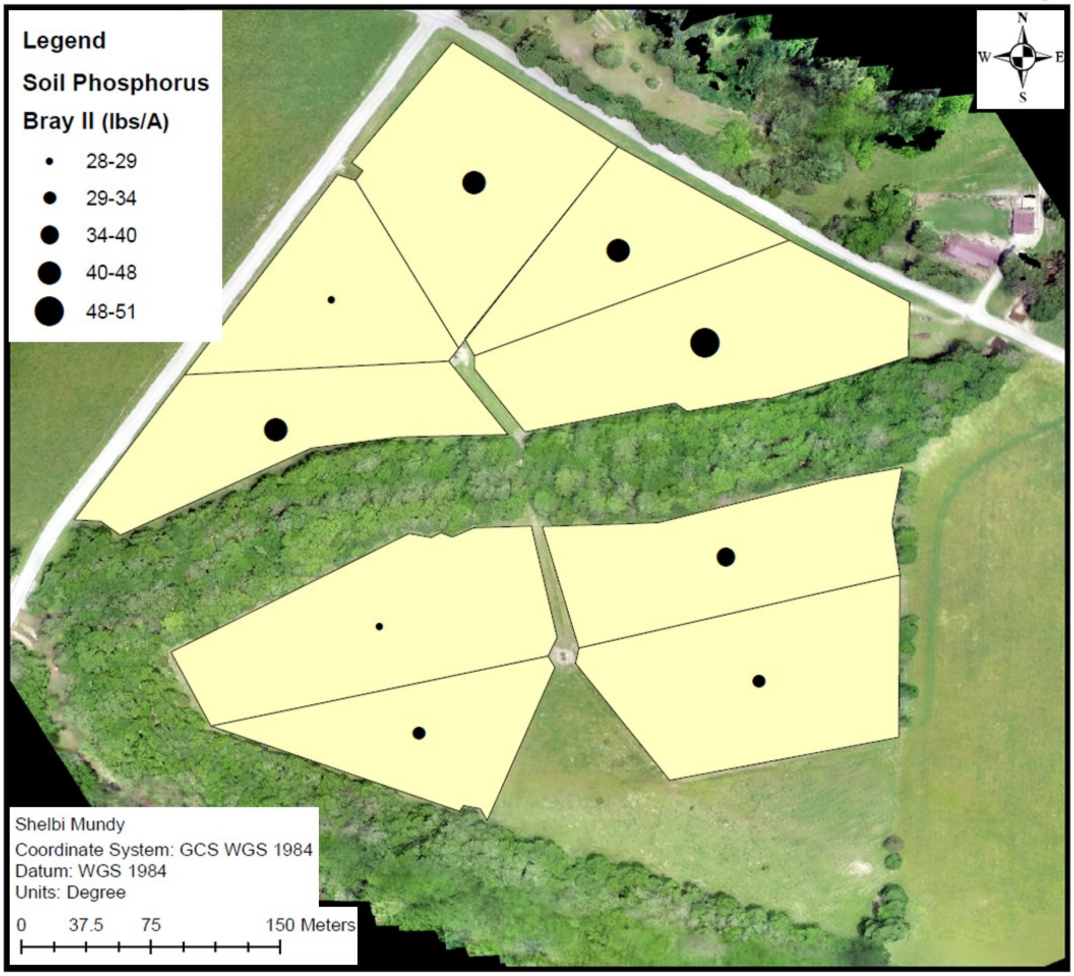

Figure 13. Soil Bray II Phosphorus values by paddock. ArcMap proportional dot symbology

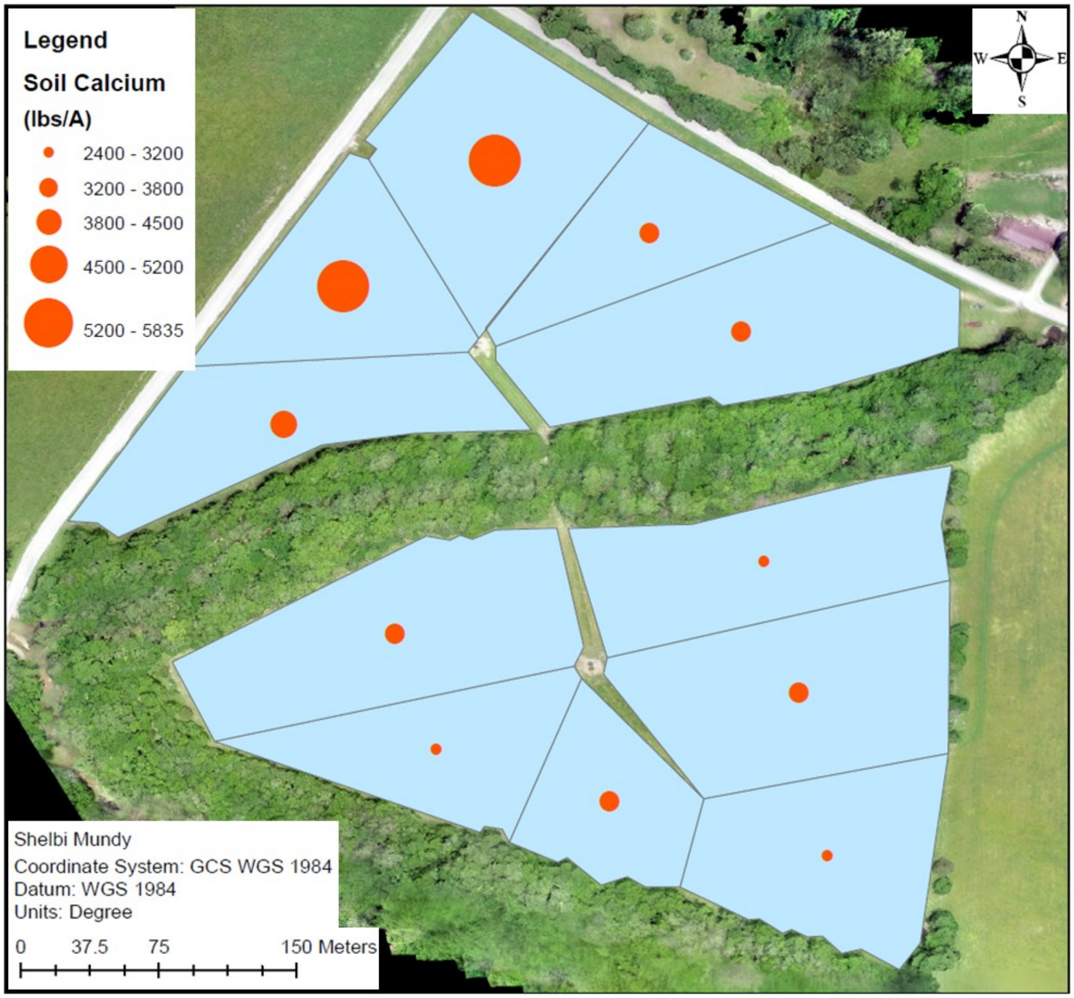

Figure 14. Soil Calcium values by paddock. ArcMap proportional dot symbology

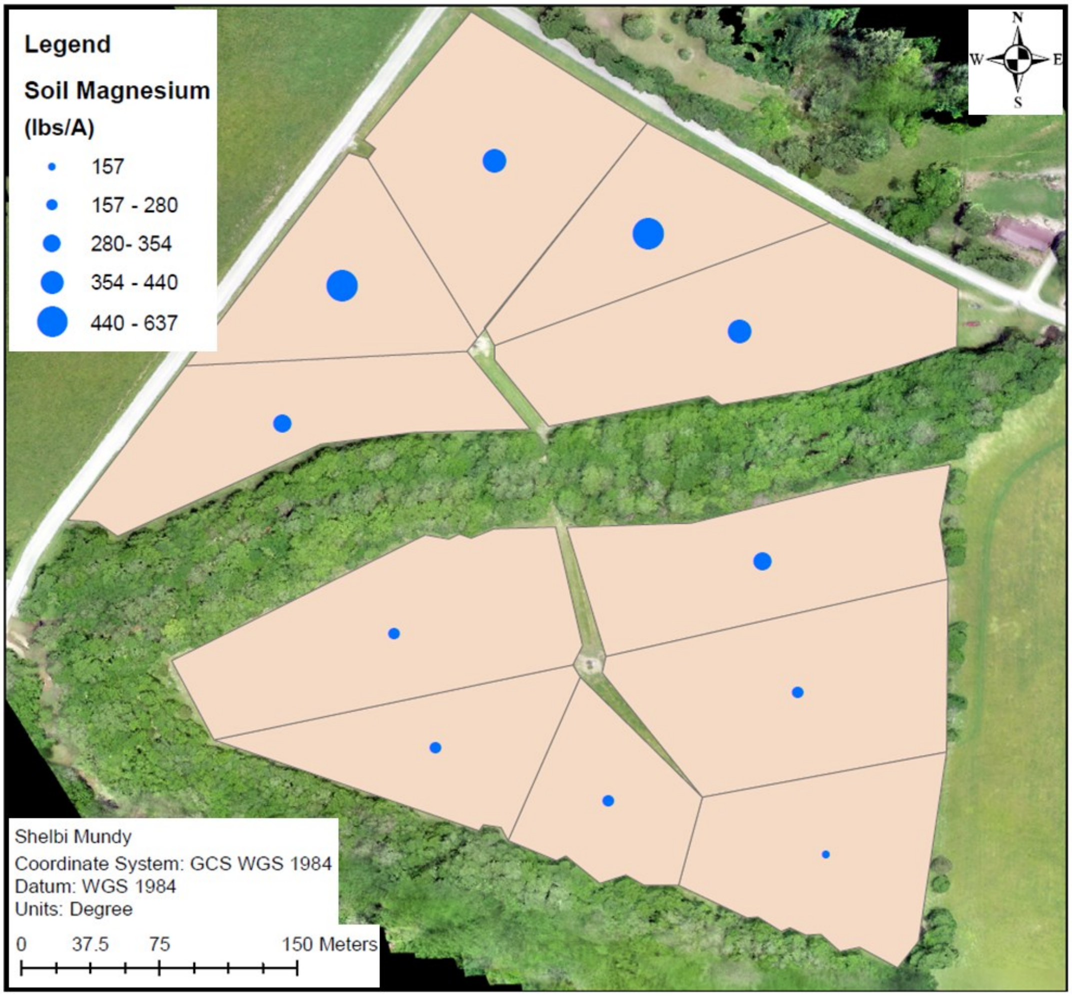

Figure 15. Soil Magnesium values by paddock. ArcMap proportional dot symbology

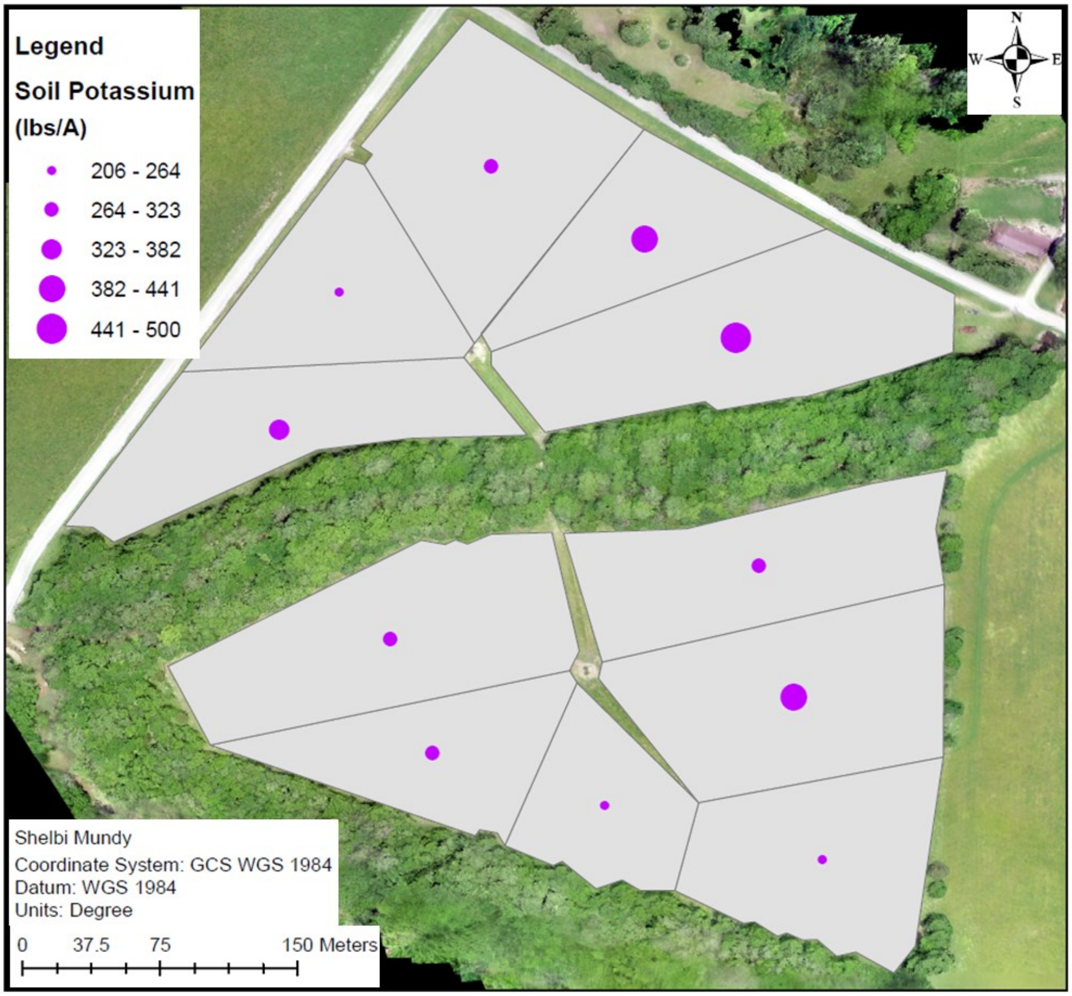

Figure 16. Soil Potassium values by paddock. ArcMap proportional dot symbology