Analysis of Soil Tests: Nutrients and Soil Properties to Help Farmers Improve Management Practices

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Abstract

Soil nutrients and properties are the foundation of plant growth and our health. The basis of our soil starts with its texture. Soil texture impacts infiltration rate and cation exchange capacity; which in turn affects water and nutrient availability in plants. Analysis of soil nutrients and properties is imperative for effectively managing adequate soil levels and helping prevent excessive amounts of fertilizer applications. While research studies were conducted to analyze specific nutrients, these studies do not provide farmers the importance of certain nutrients and soil testing on specific farmland parcels. This research study identified soil texture for three parcels of farmland in Dewitt County, Illinois, described soil sampling methodology used, and trends of periodic testing results. Analysis of the soil testing results was compared to recommended optimal soil test values. Key nutrients that were analyzed were phosphorus, potassium, and calcium, as well as pH and organic matter content. Management practices were also assessed. Most test results identified nutrients within the optimum values. Where there were slight variations, effective management of fertilizer applications were applied. Variable rate technology was used to spread fertilizers specifically to field locations in need. Management practices, including crop rotation, were used and based on soil test results, farmers were able to maintain a critical balance of adequate soil nutrients. Further, based on pH soil test results, farmers applied a liming program to regain optimal pH levels for annual crop production. While the organic matter content on one of the three parcels had declined below the Illinois average level, the other two parcels remained within the average range. Maintaining soil nutrient levels through periodic and consistent soil testing is paramount to help farmers more efficiently use limited resources for protecting the soil quality for future generations.

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Introduction

Soil properties and nutrients are the foundation of plant growth and provide agronomic resources for a healthy environment that animals and humans alike rely on to effectively survive. Soil is a critical element that carries food nutrients for plant growth (Van Walt, 2015). Farmers must be aware that periodic soil testing is an extremely important component in nutrient management and provides critical information to help soybean, corn, and other agricultural crop production. Soil testing can also help farmers prevent unnecessary nutrient applications if their soil is already sufficient in that specific nutrient (Noble Research Institute, 2002). Consistent soil nutrient monitoring is essential to, not only maximize crop production, but to identify plant nutrient deficiencies and to reduce runoff contamination from excess fertilizer applications. Farms release large amounts of agrochemicals, organic matter, sediments and saline drainage into water bodies (Mateo-Sagasta, 2017). This pollution puts our aquatic ecosystems and human health at risk. (Mateo-Sagasta, 2017). As such, soil testing is vital to prevent factors that can negatively impact the health of our soil and groundwater quality.

Literature Review

There are many research studies and articles that demonstrate the importance of soil and nutrient monitoring. Assessing soil is critical to help identify the soil's content. Key factors in assessing soil include its texture, nutrient concentration, and properties. Specifically, soil nutrients include phosphorus, potassium, and calcium, as well as soil properties pH and organic matter, that can be evaluated by soil tests. Other key factors effecting soil health are management practices, such as crop rotation, tillage and fertilizer methods. Soil sampling and testing general practices are also key factors that can influence soil test results.

Factor 1: Soil Texture

The basis of the soil starts with its texture and structure. Soil texture is the foundation and provides the ability to carry and store nutrients. Soil textures are a combination of clay, silt, and sand, as reflected in the United States Department of Agriculture Figure 1.

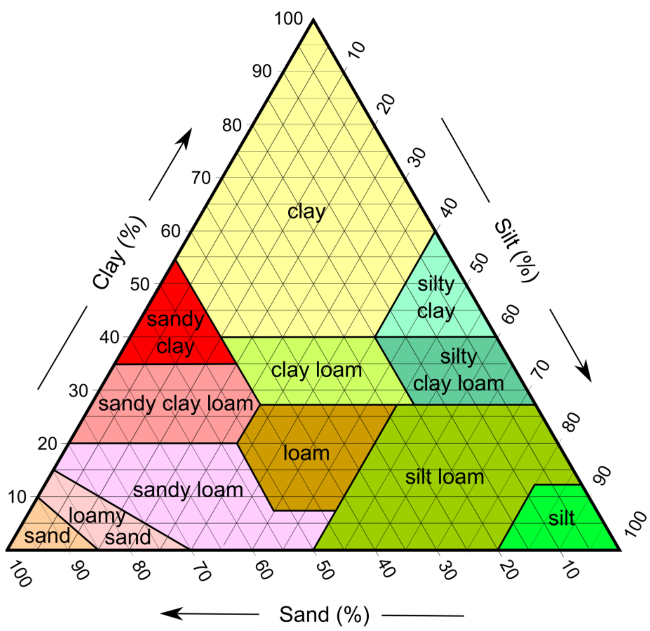


Figure 1. Soil Texture Triangle (Beasley, 2019).

There are multiple factors that determine soil formation, structure, and texture including parent material, climate, and type of crops grown over time (Earle, 2015). The texture of soil is the basic information needed to understand soil nutrient levels and apply proper management practices. Soil texture and structure greatly impact infiltration rates, which in turn affects nutrient availability, e.g., nitrate and sulfate, to plants (Mitchell, 2019).

According to the Natural Resource Conservation Center, soil texture (percent of sand, silt, and clay) is a fundamental component that affects infiltration (USDA, 2012). As such, water moves more rapidly through the soil when the soil contains larger pores of sandy soil compared to small pores of clay soil, particularly if the clay is not well structured or compacted (USDA, 2012). In studies where the soil has a low infiltration rate, it has been shown to impact the amount and type of nutrients within the soil. For example, if rainfall exceeds the soil's infiltration capacity, runoff moves down slope. Runoff carries away nutrients reducing soil productivity (USDA, 2012). Therefore, crops grown in soils with low infiltration rates have less nutrient and soil organisms available which contributes to weak root function and overall decreased crop growth (USDA, 2012).

Factor 2: Soil Nutrients - Phosphorus, Potassium and Calcium

Along with soil texture and structure, nutrients within the soil are critical components for healthy crop yields. Providing plants with the right amount of nutrients at the right time is the key to successful production. Assessing nutrient levels, such as phosphorus, potassium, and calcium is critical to help identify the soil's content.

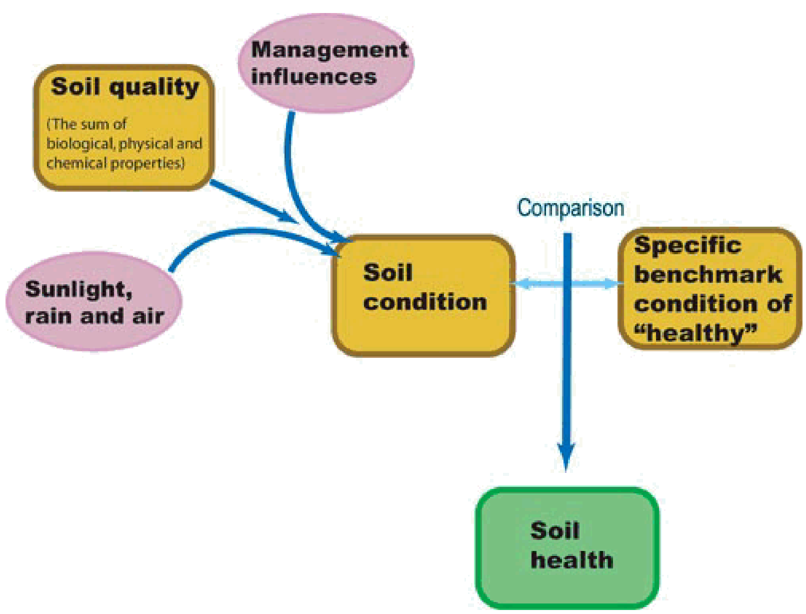


Figure 2. Diagram showing how soil health is compared to benchmark conditions (Victoria Resources Online, 2019).

Nutrient values are compared to a benchmark that is determined adequate. Each nutrient has a healthy benchmark or optimum value for productive growth. Plant growth and development depend on nutrient concentrations available in the soil. Nutrient deficiencies may decrease plant productivity and reduce crop yield (Morgan, 2013). A critical element that must be available for proper plant growth is phosphorus. Phosphorus is needed throughout the plants' life but is essential in the early phases of plant growth because it aids with the "energy transfer within the plant throughout the growing season" (Nair, 2018). Phosphorus is an important nutrient to monitor because it is an immobile nutrient. This means it has a relatively short range of movement in the soil (Bayer Group, 2016). If phosphorus concentrations are insufficient, soybean and corn crops will not grow well, nor have the ability to endure certain stresses (Bayer Group, 2016). When soils are found to be deficient in phosphorus, the addition of phosphorus fertilizers can considerably help promote plant growth (Nair, 2018). However, it is critical that farmers do not apply an amount of phosphorus that exceeds the crops' need. If so, excess phosphorus from the soil may accumulate in nearby lakes, ponds, and streams through erosion or tile drainage, possibly leading to fish kills or algal blooms (Nair, 2018). Consequently, soil tests completed on a regular basis can help farmers observe and adapt the amount of phosphorus applied (Nair, 2018).

Another key nutrient that needs to be found within the soil for proper plant growth is potassium (K). Potassium affects many physiological functions during plant growth including water regulation, transportation of carbohydrates, and photosynthesis (Nair, 2018). Potassium is a key nutrient to be monitored because it is one of 12 nutrients essential for corn growth and development. (Bayer Group, 2016). Further, plants with insufficient K, potentially experience stress from drought (Bayer Group, 2016). When there are sufficient levels of potassium available for plant uptake, the crops will be better equipped to fight off diseases, maintain a higher drought tolerance, resulting in better crop growth and quality (Nair, 2018).

Phosphorus and potassium are two extremely important elements that must maintain adequate levels within the soil to ensure healthy soil and enhanced crop yields. According to the Illinois Agronomy handbook, soil testing is a valuable guide for fertilizer applications of potassium, lime, and phosphorus because soil tests describe the lands' fertility (Fernández, 2012). The state of Illinois contains low, medium, and high supplying regions of phosphorus based on the parent material (Fernández, 2012). DeWitt County is located in the medium supplying power region, where the parent material consisted of greater than three feet of loess deposited over glacial till (Fernández, 2012). The majority of DeWitt farmlands contained poor drainage, therefore many years ago drainage tiles were installed on most farms, including the three parcels under this study, which allow for higher yield production (Nunnery, 2020). According to the University of Illinois Agronomy handbook, for farmers within the medium phosphorus supplying regions, the levels of available phosphorus should be at least 40 pounds per acre to obtain optimal yields for corn and soybeans (Fernández, 2012).

The amount of phosphorus that should be applied to maintain available P in the soil is based on the soil test results. If the range of available P is from 45 to 65 pounds per acre, the amount of P that should be applied is only to replenish the estimated amount removed by the crops (Fernandez, 2012). If the fertilizer is under applied, the current crops' production may not be reduced but the following crops' yield maybe negatively impacted because adequate concentrations may not be sustained in the soil (Fernandez, 2012). The most common phosphorus fertilizer sources used are diammonium phosphate (DAP) and monoammonium phosphate (MAP) (Nunnery, 2020). The key difference between MAP and DAP is the quantity of nitrogen and phosphorus in the fertilizer and the chemical reaction that occurs in the soil when it is first applied (Fernandez, 2012). However, the differences between MAP and DAP diminish within a few months and either source does not display a greater agronomic advantage over the other (Fernandez, 2012). Based on interviews, in Virginia, diammonium phosphate seems to be the preferred source while, in Dewitt County monoammonium phosphate is more commonly used (Jones, 2020). According to Mr. Nunnery, Dewitt County Farm Bureau Board of Directors member and drainage district commissioner, and several farmers in Dewitt County, the reason MAP is more commonly used on DeWitt County farms is because MAP source is easier to make and is more available to them than DAP (Nunnery, 2020). DAP also contains higher amounts of nitrogen and farmers who are using variable rate technology like to use fertilizer products with lower nitrogen content to help reduce over application (Marvel, 2020).

Calcium (Ca) is another important nutrient to monitor because it positively influences soil properties (Rehm, 2008). This is because calcium enhances the soil structure which will increase water infiltration and provides a more conducive soil environment for plant root growth and soil microbial activity (Rehm, 2008). Additionally, calcium is considered to be an immobile nutrient in plants, meaning it will not flow from old to younger leaves, and composes a critical component of the cell walls known as calcium pectate (Rehm, 2008). Therefore, without the necessary concentration of calcium within the soil, crop production would be hindered and plants may collapse (Rehm, 2008).

Factor 3: Soil Properties - pH and Organic Matter Content

Soil pH is an extremely important component of soil quality and health. Soil pH is a measure of the alkalinity and acidity within the soil (Fernandez, 2012). Soil acidity can be an issue in Illinois due to the acidity generated by crop removal and acid remaining in the soil from nitrogen fertilizers (Fernandez, 2012). The ideal pH for agronomic crop systems such as corn and soybean production, should be at minimum a pH of 6 and maintain a pH of 6.5 (Fernández, 2012). According to USDA, the maximum yield for corn and soybean crop can be obtained at a pH of 6.8 (Table 1) (USDA, 2019). If the soil pH becomes too acidic or too alkaline, it will impact and reduce the soil nutrients that are available to the plants, therefore hindering crop production. While, phosphorus and potassium are measured in pounds per acre, soil pH is displayed as pH units (Fernández, 2012).

When soil pH is outside the optimal range, less nutrients are available to plants, potentially causing deficiencies (Pariera-Dinkins, 2013). To illustrate, a farmer in Illinois did not lime his fields for many years and as a result had relatively low yields. When he had his soil tested, his pH levels were low but the fields contained extremely high P and K levels. Since his pH was so low (pH around 3.9-4.0), the P and K was not available for the plants to utilize. In order for P and K to be available for the plants, it must be in the proper pH range of 6.0-7.5. When his grandson took over the farm, he implemented a liming practice. As a result, the soil pH went up and the nutrients became available to the plants. When the soil was tested after the liming practice, pH levels were higher, P and K levels were lower (proper range) and available for plant uptake, and crop yields increased (Ingram, 2020).

Table 1. Table displaying the optimum pH level for maximum production of several agronomic crops (USDA, 2019).

Crop	Soil pH				
	4.7	5	5.7	6.8	7.5
	Relative Yield (100 is the best, 0 is the worst)				
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Soybeans	65	79	80	100	93

Soil organic matter is an important component when determining soil quality and productivity. The higher organic matter content within the soil, the healthier the soil and the greater possibility of maximal yields. This is because when the plant material and other organic matter is being decomposed, nutrients such as potassium and phosphorus are released into the soil, enhancing the soil fertility and providing more nutrients for plant uptake (Fenton, 2008). Additionally, the organic matter contributes to the soil structure, which increases the infiltration rate and decreases the amount of nutrients lost to runoff (Fenton, 2008). The optimum range of soil organic matter for most agricultural soils is 3-6% (Fenton, 2008). However, the state of Illinois contains a much larger range of organic matter content due to the different soil texture and conditions throughout Illinois. For example, while soils in southern Illinois are older and have lower organic matter content as well as lower cation exchange capacity, central Illinois organic matter has a mean value of slightly above 3% (Farmaha 2012).

Soil organic matter is important to monitor because the decomposition of the organic materials impact the soil's properties and health (Bot, 2005). The decomposition affects the soils' structure, infiltration rate, and availability of nutrients (Bot, 2005). Also, the greater amount of organic matter the soil possesses, the higher the cation exchange capacity (Fenton, 2008). When the soil contains a higher cation exchange capacity, there are more negatively charged surfaces on the soil particles which cations can adsorb. This leads to a greater amount of nutrients being retained in the soil for crop production.

Factor 4: Management Practices: Crop Rotation, Tillage, and Fertilizer Methods

Crop rotation is a common management technique to help maintain adequate soil quality. Crop rotation has been conducted on the parcels in Dewitt County to help maintain soil health. The study by Sasal (2010), stated that these crop sequences such as corn, soybean rotations, can impact the amount, quality, and longevity of crop residues and enhance the distribution of the root systems, which help improve soil structure (Sasal, 2010). Therefore, the practice of crop rotation impacts the infiltration rate and soil moisture content (Sasal, 2010). It is important to note which type of crop was grown on the soil where soil quality is being monitored or if that field area had been fallow for the season. A study completed in Iowa about the importance of crop rotation found that three to four-year crop rotations resulted in, higher yields and reduced herbicide and fertilizer use (Mulik, 2017). According to the study, “corn yields per acre were 2 to 4 percent higher, and soybean yields 10 to 17 percent higher, in the three- and four-year rotations compared with the two-year corn-soybean rotation” (Mulik, 2017). Crop rotation practices should be employed when the farmer grows a high nitrogen consuming crop, such as corn, with soybeans, a lower nitrogen consuming (University of Nebraska Plant and Soil Sciences, 2019). This will not only reduce nitrogen fertilizer applications, but also provide other benefits such as decreased pest and weed levels and increased disease tolerance (University of Nebraska Plant and Soil Sciences, 2019).

The article by Sasal (2010) stated other possible types of management practices that are important considerations to maintain adequate soil nutrients. For example, the tillage systems used on the land can impact soil content and quality (Sasal, 2010). Tilled soil loses more nutrients through runoff compared to fields that do not practice tillage, this is because untilled soils contain more crop residues, aiding in organic matter content and increased soil structure leading to better infiltration (Sasal, 2010).

Another management practice to consider is fertilizer application methods. Fertilizer applications of phosphorus and potassium have been implemented on the Dewitt county parcels for the past several years to aid in maintenance and increasing nutrient levels. Illinois farms use broadcast, banded, variable rate spread technology methods, among others. The broadcast method is widely used in Illinois as well as other states. This method broadcasts the fertilizer over the land and then it is generally mixed into the soil using a disk or plow to aid in maintaining soil P and K nutrient levels (Fernández, 2012). Banding application is used and is considered to be a more efficient method in comparison to broadcasting, but it is also a more labor-intensive application method, so many farmers choose broadcasting (Jones, 2020). Another type of fertilizer application method is the variable rate application method. This method uses special equipment such as GPS, GIS, and variable rate technology (VRT) to apply the fertilizer in appropriate amounts in specific locations on the fields based on the soil test results (Ingram, 2020). This method has been implemented and was developed to use fertilizer more efficiently by applying it to selected soil locations that need increased amounts, thereby potentially reducing fertilizer costs to the farmer and the amount of excess fertilizer that may leach or run off polluting the nearby water systems (Schaefer, 2007). The variable rate fertilizer application method has been used on all three farmland parcels in Dewitt County, used in this study. Timing of fertilizer application is also an important component; in most Dewitt County farmlands the fertilizer is applied in the fall. Farmers in Dewitt County state the reasons they apply the fertilizer in the fall is mainly due to time, there is generally more time available in the fall for them to apply their fertilizer rather than during the spring planting season, and the other reason is because the soil is less likely to be compacted (Nunnery, 2020). Fertilizer applications have been completed on the parcels under this study, twice every four years, and have been applied prior to the corn crop and the soybean crop is the residual feeder.

Factor 5: Soil Sampling and Testing General Practices

The number of soil samples per acre collected for soil testing is chosen by the farmer, but should be based on multiple factors such as costs, the parcel's size, and fertilizer application method. The more samples that are collected, the more information can be gained; however, at a higher price. The most common mistake is taking too few samples to represent a field adequately (Fernández, 2012). When too few samples are collected for a specific field, it may lead to undependable soil test results which will impact costs for fertilizers and possible yield return (Fernández, 2012). The fertilizer application method should also be taken into consideration when selecting the number of soil samples per field. There are very few farmers in Dewitt County, Illinois who collect soil samples manually. Most soil sample collection is completed by the soil lab workers who use special machinery when collecting soil samples in the field. With the use of this technology, when analyzing each soil sample, the farmer can variable rate spread the fertilizer throughout his field. For example, if soil sample 1 location had high P and soil sample location 14 had low P, the farmer can use this information and input into his fertilization spreader technology so when he applies the fertilizer more P is released at location 14 than at location 1 (Ingram, 2020). If farmers do not utilize the variable rate spread fertilizer application process, farmers can determine the average of all soil sample locations analyzed and apply average field rates over the entire field (Ingram, 2020). Both, the Illinois Agronomy Handbook and soil testing labs, such as Ingram's soil lab, suggested that the most economical and efficient sampling ratio would be a 2.5-acre grid, one soil sample for every 2.5 acres (Ingram, 2020). Ultimately, the decision on sampling ratio is up to the farmer.

It is recommended that soil sampling be conducted at a minimum every 4 years (Fernández, 2012). However, some farmers have their soil tested every 2 years to ensure that their soil nutrients are maintaining certain levels. Farmers who use ammonium sulfate (which will lower the pH) will test their soil every two years to help maintain a proper liming program (Ingram, 2020). Soil sample collection should always be done at the same time of year. The University of Illinois Agronomy Handbook states that the best seasons to collect soil samples is either late summer or the fall because potassium tests are more reliable at that time (Fernandez, 2012). Potassium is cyclic, containing higher concentrations in January and February and lower concentrations in late summer (Fernández, 2012). This is possibly due to the fact that potassium is more available when the soil contains a higher moisture content. However, many Illinois farmers complete their soil sample collection in the spring time for two main reasons: 1) there is more consistency in soil moisture and 2) when samples are collected in the spring it provides ample time for the samples to be processed and results analyzed before the fall, so the farmers have time to determine and order the amount of fertilizer desired before the fall (Ingram, 2020). If soil samples are collected in the fall, it creates a very rushed process and the samples may not be able to be analyzed in enough time before the farmer must buy his/her fertilizer (Ingram, 2020).

Purpose of the Study

While many research studies have been conducted to analyze specific nutrients and observe agricultural and environmental factors, these studies do not provide farmers an understanding of the importance of certain nutrients and soil testing on specific farmland parcels in Dewitt County, Illinois. This research study identified soil texture for three parcels of farmland, totaling 240 acres and described soil sampling methodology used and trends of periodic testing results from 2006 through 2019 on selected parcels of land. An analysis of the soil testing process and soil sample nutrient results obtained highlighted the potential differences in the soil quality and compared nutrient concentrations to recommended optimal soil values for crop production. Key nutrients that were analyzed included phosphorus, potassium, and calcium, as well as soil properties, pH and organic matter content. Information obtained from conducting this research study will help local farmers understand adjustments made based on soil test results, the importance of soil nutrient monitoring, and provide insight on management practices.

Objectives and Hypothesis

The research objectives are: 1) determine soil testing methodology, the number of samples collected, the frequency, and fertilizer applications for the three parcels of land in Dewitt County, Illinois; 2) identify soil texture and analyze soil results for nutrient concentrations, as well as organic matter and pH and compare these results to optimum values; and 3) determine if management practices employed influenced the variation of soil nutrients and properties to maintain adequate levels of soil quality. This study addressed the following hypothesis: Monitoring and analyzing soil test data of key nutrients and properties helps farmers implement and understand management practices to maintain adequate soil productivity.

Methodology and Design

The research method for this study is a mix of the qualitative and quantitative research. The study will use quantitative soil testing data from farmland in Waynesville, Illinois in conjunction with interviews with the Dewitt County Farm Bureau officials, farmers, and a soil lab that analyzed previous tests to gain an understanding of the soil testing processes and factors that may influence the soil's nutrients. The study will utilize different field plots where soil samples have been extracted and tested to review levels of nutrients and properties reported. Certain factors were considered when analyzing the soil test results including, relationships between soil nutrients (numerical data) found overtime, crop management strategies, such as crop rotation and tillage practices, and fertilizer method applied. This soil nutrient analysis was conducted from January 2020 through May 2020. Specifically, for each plot, soil texture was identified as one or a combination of the following textural classes: silt, sand, and clay. The soil texture was described specific to the three Illinois parcels, each located in DeWitt County, IL, their locations have been mapped as Section T20N R1 S8(30-acre plot and 120-acre plot) and Section T20N R1E S17 (90-acre plot) to provide its texture, and potential infiltration rate through soil's pores that may affect nutrient levels.

A review and analysis of soil test results conducted every 4 years on each parcel since 2006 (totaling 222 soil samples) was performed. The parcels, number of samples drawn, years tested, nutrients, and time tested, as well as the crop grown on the tested parcels are located in Table 2. These soil tests, covering three different fields totaling 240 acres, had soil samples extracted and tested to determine certain levels of nutrients and properties. The parcels of land include a 30-acre, 90-acre, and a 120-acre field.

Table 2. The parcels, years tested, nutrients and properties, number of samples drawn, time tested, as well as the crop grown on the tested parcels.

Parcel size and number	Years tested	Nutrients tested	Number of samples collected per soil test	Total number of samples over the years tested	Time of year tested	Crop grown
T20N R1E S8 120-acre plot	2006, 2010, 2014, 2018	P, K, pH, Organic Matter, Ca (except 2006)	30	120	Spring	Soybean
T20N R1 S8 30-acre plot	2011, 2015, 2019	P, K, pH, Organic Matter, Ca	10	30	Spring	Soybean
T20N R1E S17 90-acre plot	2011, 2015, 2019	P, K, pH, Organic Matter, Ca	24	72	Spring	Soybean

When analyzing data for quantitative research studies, there are several key components that must be reviewed. One of these important steps is to review all soil test results and observe if any tests resulted in an abnormal or outlying number. Evaluations of past soil test results were performed and a review of soil test notes, where available, to identify environmental factors applicable to that test, as well as, interviews with soil lab experts were conducted to understand any conditions that may have limited the accuracies in past years' test results. After observing all outlying numbers, the next step in analyzing data collected was to use the descriptive data analysis method. This data analysis method allows the researcher to summarize separate variables and determine patterns (Bhatia, 2018). By doing so, visual charts were developed to illustrate the variations in the soil test results on each field plot. Each field plot has its own graph displaying the different levels of tested nutrients observed from each soil test over time. This aided in characterizing the different soil plots and numerical data collected. For example, pH results were analyzed to see if they are around the proper level for optimum plant growth. Visual presentations of the pH levels obtained from the test results were developed. From these results, we were able to see if appropriate adjustments were made to the pH to reach the optimal level for crop growth. Other nutrients from the soil test results will note if a nutrient is low, medium, or high (Pariera Dinkins, 2013). Similar to the pH, results of each soil nutrient and property were analyzed. A descriptive analysis of the soil tests was conducted on each field plot completed and correlations were drawn between certain test results and the management practices.

Some limitations that may have occurred during the study include: (1) certain variations in testing methods over the years may alter soil test results; (2) equipment used may vary and it is important to understand the limitations of soil measurement instruments and; (3) difference between lab soil results may exist, and as such standardized soil selection methods and protocols on laboratory analysis should be followed. An additional component that farmers must take into consideration is who is in charge of the soil testing lab where samples are sent. About 50 years ago soil testing labs in Illinois were run by banks, the soil labs were in the bank's basement and farmers realized that they did not like the banks testing their soil because the bank knew how much money the farmers had, as the saying goes "the farmers were jumping from the frying pan into the fire" so, then fertilizer dealers began to open up labs (Ingram, 2020). However, this was not a good option for farmers either because if the fertilizer company tests their soil samples, they may recommend higher amounts of fertilizer be bought (Ingram, 2020). Therefore, it is an important consideration that the soil testing lab used to analyze the farmers' soil samples is a farmer based, independently owned company, or a land grant university, to ensure the best outcome for the farmer.

Results and Discussion

Soil Testing Methods

Farmers in DeWitt County use soil testing centers to collect and analyze soil samples. The fields that this study analyzed had their soil samples collected and processed by Ingram's Soil Testing Center, Sullivan Illinois, with the exception of 2006 which the soil samples were collected and analyzed by Van Horn Company in Warrensburg, IL. Ingram's Soil Testing Center covers a large geographic area, over 300,000 acres of land ranging from Southern Illinois up to the Wisconsin border, Missouri, and Indiana. They provide soil tests for farmers, gardeners, and home yards. The soil testing process used by Ingram's Soil Testing Center for the three parcels of land analyzed in this study were:

1) Crews travel to the fields and collect soil samples using automatic probes. The most common tool used for soil sampling is a stainless-steel probe which will obtain a "continuous soil core with minimal disturbance to the soil" (USDA-NRCS, 2007). It is also very important to note that brass or galvanized equipment could contaminate the samples and should not be used (USDA-NRCS, 2007). The automatic probes obtain 7 cores (each core length is 6 ¾ inch). The fertilizer is usually limited to the top portion of the soil (core length of 6-7 inches) and it is also where the soil contains the most root activity to this depth (USDA-NRCS, 2007). These soil samples (0-6 inches) are used to test potassium, phosphorus, pH, and organic matter (USDA-NRCS, 2007). The automatic probe obtains 7 cores at one time from one sample location then the crew moves on to the

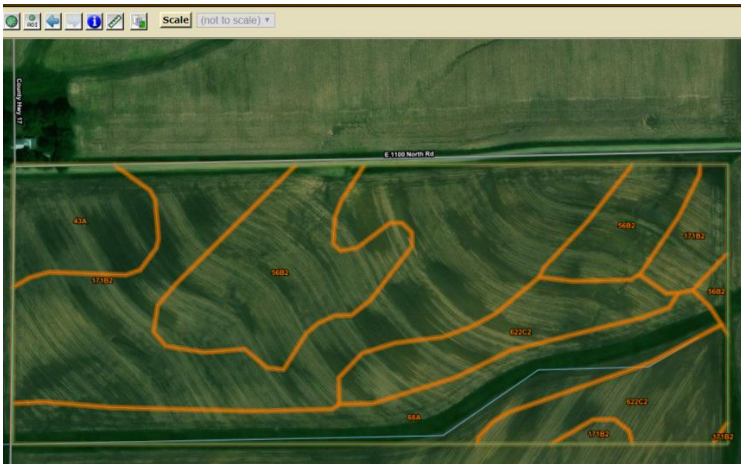
next sample location. The lab only needs one cup of soil from each sample location but, obtains 7 cores worth of soil to ensure they have enough.

2) Soil samples are brought into the lab and are sorted and assigned lab identification numbers.
3) The samples must be dried so, they are placed in the drying room. The length of time the samples must stay in the drying room depends on how much moisture they contain. If they were collected after a rain event and are quite wet it will take about two days to dry the samples, but if they were fairly dry when collected they may just need to be in the drying room overnight. It is critical that the drying room does not exceed 80 degrees Fahrenheit. If the drying room's temperature reaches above 80 degrees Fahrenheit, it will destroy the organic matter content within the soil samples. Once soil samples are dried, there is not a limit to the time in which they must be processed. If the samples are dry, covered, and do not become contaminated, they can be analyzed years later.
4) After the soil is dried, it is transferred to the grinding room. The soil is ground and must pass through a US No.10 (2mm) sieve to move on to the dipping room.
5) The dipping room is where the soil is laid on tables and 1 gram of soil is added into an Erlenmeyer flask that contains 10mL of Mehlich-3 extract. The extract and soil solution is shaken for 5 minutes and then placed into a filter. The solution is then checked for clarity, and continues to the lab processing room. For pH tests, 5 grams of soil must be used.
6) The Erlenmeyer flasks and pH cups are taken to the labs to be processed (Ingram, 2020).

In a soil testing center, once soil samples are sent to the lab there are two main types of phosphorus tests that may be used by the center, Mehlich-3 test or the Bray P_1 test. These tests demonstrate the available phosphorus in the soil (Fernández, 2012). The Bray P_1 test has been used in Illinois since the 1940s, the Mehlich-3 test was developed later but is capable of analyzing P, K, and Ca and the phosphorus concentration results from each of these tests are very similar (Fernández, 2012). Ingram's soil testing center utilizes the Mehlich-3 test, unless specifically asked to complete the Bray P_1 test. This is because the Mehlich-3 test is simpler for them to obtain all the different nutrient readings. When using the Mehlich-3 test the workers only dip the 1 gram of soil sample into the 10mL of Mehlich-3 extract one time and it will extract every nutrient and micronutrient in one dipping, then the solution is shaken for 5 minutes, filtered, and checked for clarity before it is placed into the ICP machine (Ingram, 2020). The ICP machine analyzes the nutrient levels and within in one minute will print out a report (Ingram, 2020). While, with the Bray P_1 test, they must dip the soil sample for each nutrient separately, this utilizes more equipment, labor, and time (Ingram, 2020). The soil properties of organic matter and pH tests are conducted separately from the nutrient tests. To determine the percentage of organic matter, it is chemically extracted using 1 gram of soil, mixed with 10mL of potassium dichromate, then 20mL of sulfuric acid is added, let sit for 10 minutes and add 100mL of tap water. This solution must sit for 1 hour and then filtered and compared to the organic matter color meter to determine the organic matter percentage. To determine the pH, 10mL of the soil must be mixed with 10mL of water and set for 20 minutes, then it can be read on the pH meter (Ingram, 2020).

Soil Texture

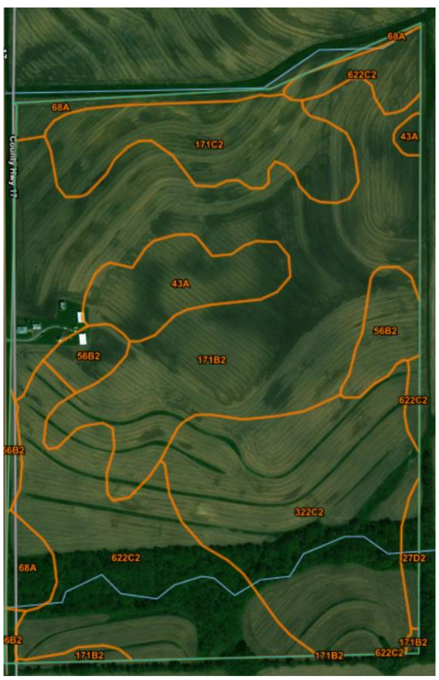
It is known that Illinois contains some of the best and most fertile soil in the world for crop production, "minerals deposited by glaciers and subsequent prairie growth for thousands of years have blessed Illinois with some of the world's most fertile topsoil" (CST, 2019). Especially farmland north of Interstate 70, such as land in Dewitt County, is considered some of the best soil for corn and soybean production (Ingram, 2020). Many soil textures in northern and central Illinois can be considered Mollisol soils. These soils are productive because of their thick, dark A horizon, “this fertile surface horizon, known as a mollic epipedon, results from long term addition of organic materials” (University of Idaho, 2020). Furthermore, the soil texture that was found to be the majority within all three farm land parcels analyzed was Catlin Silt Loam (171B2). The Caitlin soil type is considered a prairie soil (Mollisol) with high organic matter content (Roy, 1991). According to the USDA soil series, Caitlin Silt loam soil has a very dark brown Ap horizon that is moderately well drained and contains a fine granular structure (USDA Soil Series, 2020). Due to this soil texture’s highly fertile top horizon, contains moderately well drainage, and fine granular structure, its porosity and infiltration rates are good and contain good concentrations of soil nutrients as long as proper management practices have been employed. Maps of each parcel of land displaying that Catlin Silt Loam (171B2) is the most abundant soil texture (Figures 3, 4, and 5). However, about 10 acres in the lower right portion of the 120-acre parcel is composed of Russel Silt loam. Russel Silt loam contains a weak granular structure and moderate to slow permeability (USDA Soil Series, 2020). Throughout the soil test analysis, the lower right portion of the 120-acre parcel contained lower nutrient concentrations and soil property values than the majority of the 120-acre parcel that contained a greater amount of Caitlin Silt Loam.



Typical profile

Ap - 0 to 8 inches: silt loam
Bt - 8 to 43 inches: silty clay loam
2BC - 43 to 47 inches: clay loam
2C - 47 to 60 inches: clay loam

Figure 3. Image of T20N R1E 8S (30-acre field) that is composed of 41.6 % of soil texture 171B2—Catlin silt loam. The typical profile for this texture of soil is shown above (USDA Web Soil Survey, 2020).



Typical profile

Ap - 0 to 8 inches: silt loam
Bt - 8 to 43 inches: silty clay loam
2BC - 43 to 47 inches: clay loam
2C - 47 to 60 inches: clay loam

Figure 4. Image of T20N R1E 8S (120-acre field). The majority soil texture within this field is also 171B2—Catlin silt loam. The typical profile for this type of soil is shown above (USDA Web Soil Survey, 2020).

Typical profile

Ap - 0 to 8 inches: silt loam
Bt - 8 to 43 inches: silty clay loam
2BC - 43 to 47 inches: clay loam
2C - 47 to 60 inches: clay loam

Figure 5. Image of T20N R1E 17S (90-acre field). The majority soil texture within this field is also 171B2—Catlin silt loam (USDA Web Soil Survey, 2020). This parcel contains rows of trees and a pond that was intended for soil and water conservation.

Soil Test Results and Management Practices

The majority of the years the soil has been tested; nutrient and property levels were within adequate range with a few exceptions. Soil test results are provided in Tables 3, 4, and 5, organized by parcel and test year.

Table 3. T20N R1E S8 30-acre parcel: Soil tests results for the 30-acre parcel collected in 2011, 2015, and 2019

Year	Organic Matter (%)	P (lbs/ac)	K (lbs/ac)	pH	Ca (lbs/ac)	Crop Type
2011	2.5	51	333	6.2	4156	Soybean
2015	2.5	62	371	6.7	4511	Soybean
2019	2.6	58	402	6.4	5665	Soybean

Table 4. T20N R1E S17 90-acre parcel: Soil tests results for the 90-acre parcel collected in 2011, 2015, and 2019

Year	Organic Matter (%)	P (lbs/ac)	K (lbs/ac)	pH	Ca (lbs/ac)	Crop Type
2011	2.6	43	346	5.7	4118	Soybean
2015	2.5	65	383	7.1	4946	Soybean
2019	2.6	72	406	6.8	6268	Soybean

Table 5. T20N R1E S8 120-acre parcel: Soil tests results for the 120-acre parcel collected in 2006, 2010, 2014, and 2018

Year	Organic Matter (%)	P (lbs/ac)	K (lbs/ac)	pH	Ca (lbs/ac)	Crop Type
2006	2.7	31	274	6.1	No Data	Soybean
2010	2.8	52	370	6.2	4305	Soybean
2014	2.5	50	398	6.6	4705	Soybean
2018	2.0	53	379	6.6	4768	Soybean

Phosphorus and Potassium

Based on the analysis of soil test results for all years and land parcels, the phosphorus levels were consistent with the recommended P levels for optimum yields with exception of two of the parcels in different years. In 2006 on 120-acre parcel, T20N R1E S8, the phosphorus concentration was below the recommended 40 lbs. P/acre at 31 lbs. P/acre and in 2019 on the 90-acre parcel, T20N R1E S17, the phosphorus level was above the 65lbs. P/acre recommendation at 72 lbs. P/acre. The year 2006 contains some of the lower end nutrient concentrations. The

2006 samples were collected and analyzed by a different company and the testing methodology could have used a different extraction method which may have resulted in different test results as compared to tests completed in the following years. Based on the low P levels in 2006, fertilizer applications were applied on the 120-acre parcel, resulting in raising the phosphorus levels to the proper range in the following years; 2010-52lbs, 2014-50lbs, 2018-53lbs. As shown in Table 4, in 2019 on the 90-acre plot, the phosphorus level was found to be 72lbs P/acre, which is slightly higher than the recommended value of 65 lbs P/acre (Fernández, 2012). In the fall of 2017, a phosphorus application was completed on the 90-acre plot, applying an average rate of 165 lbs. P/acre, but containing a variable rate, applying more in locations where the soil test results were lower in phosphorus. As such, the phosphorus concentration results in the 2019 soil test was possibly due to an excessive amount of fertilizer applied in 2017 and/or less P being removed and utilized by the corn and soybean crops than anticipated. However, with this information from the 2019 soil test results, the 2019 fall fertilizer application contained a reduced amount of phosphorus, applying 129 pounds per acre versus the 165lbs rate that was applied in 2017. Figures 6, 7, and 8 display the change of Phosphorus levels within the three different parcels over time.

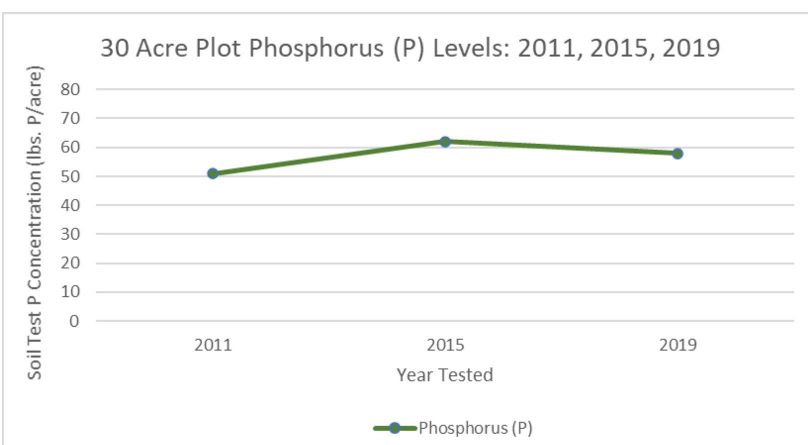


Figure 6. Soil test Phosphorus results for the 30-acre parcel in 2011, 2015, and 2019.

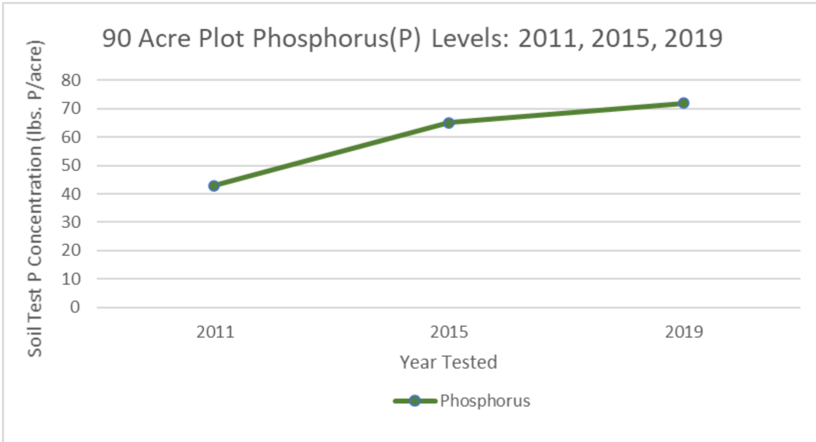


Figure 7. Soil test Phosphorus results for the 90-acre parcel in 2011, 2015, and 2019.

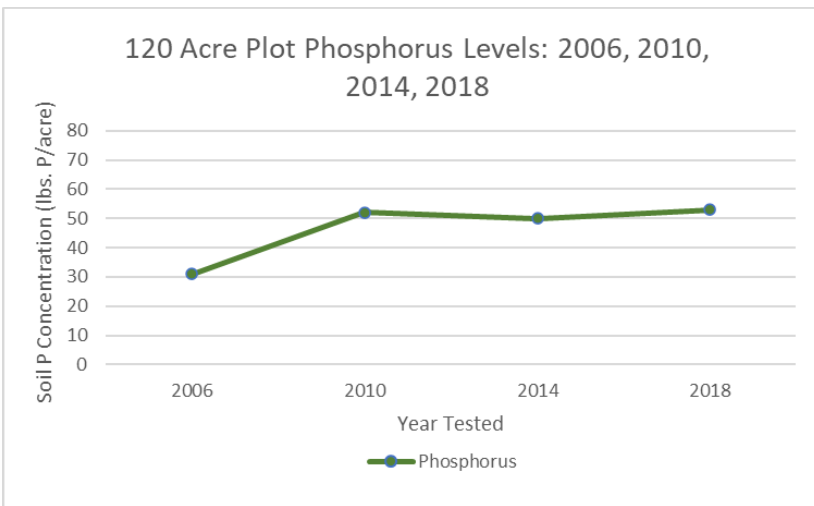


Figure 8. Soil test Phosphorus results for the 120-acre parcel in 2006, 2010, 2014, and 2018.

Potassium

Like the phosphorus supplying regions in Illinois, there are regions for potassium. These regions are divided into low and high potassium supplying regions (Fernández, 2012). Dewitt County is located in the high potassium supplying region. Similar to phosphorus, potassium loss in the soil is mainly through soil erosion and crop harvest/removal (Fernández, 2012). Therefore, it is suggested that soil potassium levels should be about 300 pounds per acre for corn and soybeans to ensure that there is enough available potassium within the soil to attain maximum yield potential (Fernández, 2012). When the potassium levels are from 300-400 pounds, the amount of potassium fertilizer applied should replace the amount that the crop grown is anticipated to remove (Fernández, 2012). If the potassium fertilizer is applied under or over this rate, the next crop yield may not be hindered, but the following crop yields will be impacted (Fernández, 2012).

Potassium concentrations of the three parcels of land were within the recommended potassium levels for all soil test years with the exception of the 120-acre parcel in 2006, similar to 2006 data for phosphorus. As stated above a key consideration was the company that collected and analyzed the 2006 data may have had a different testing methodology, and used a different extraction method. Subsequent years, the 120-acre parcel contained potassium levels that were in the higher range of the recommended values; 2010-370lbs, 2014-398lbs, 2018-379lbs. In 2011, the potassium level on the 30-acre plot was still in the proper range, but on the lower end. Therefore, if potassium fertilizer application was not appropriately conducted, within the next several crop harvests and removal of potassium from the soil would result in potassium levels lower than the recommended range (below 300 lbs per acre). However, potassium fertilizer was applied to 22 of 30 acres using variable rate technology and as a result the potassium levels on the 30-acre parcel in 2015 and 2019 increased within the soil, allowing potassium to be available and optimal for plant uptake. Additionally, the 2019 soil test results displayed that the 90-acre plot contained a potassium level of 406 lbs per acre, which is on the relatively high end of the recommended value. Therefore, the potassium application that took place in the fall of 2019 used the variable rate technology to only spread potassium where it was needed on the field based on the specific soil sample result and location (Table 6 and Image 1). This method ultimately helped keep potassium levels under control, saved the farmer money on fertilizer, and reduced the possibility of excess nutrients leaching and reducing water quality.

Table 6. 2019 Nutrient results for specific sample locations on the 90-acre plot. Samples 2, 3, and 10 contained lower levels of K than other locations on the field which did not need an addition of potassium. As such, with VRT potassium fertilizer was only applied on the 90-acre field in the area of sample locations 2, 3 and 10 as seen in Image 1.

Sample Number	K (lbs/ac)
1	366
2	338
3	369
4	366
5	481
6	446
7	421
8	406
9	374
10	323

Image 1. 2019, 90-acre plot potassium application in burgundy covering soil sample locations 2, 3, and 10 that contained lower K levels than the other parts of the field.

Certain factors were assessed to determine why the sample locations of 2 and 10 had lower values and needed to have more potassium fertilizer applied. One reasoning could be the soil texture. However, the soil texture throughout that specific area of sample locations 2 and 10 on the 90-acre plot was consistently Caitlin Silt loam with a fine granular structure. As such, the soil texture would not be a likely factor that would cause a need for potassium fertilizer to only be applied at those locations. Another factor considered was the previous potassium fertilizer application in the fall of 2017. In 2017, potassium fertilizer was applied, but did not cover sample location 2. In 2017 soil test results, sample location 2 contained 351 lbs. K/acre. This concentration is still within range of the recommended 300-400 K lbs/acre. However, when it is within that range, it is recommended that the amount of K applied be enough to replace what the crop will remove. As such, when sample location 2 contained a concentration of 351 lbs. K/acre, the 2017 K application should have also applied a maintenance amount, but, it did not receive the needed application (Image 2). Therefore, in 2019, the K concentration at sample location 2 decreased further. As for sample location 10, according to the soil test results of 2017 it contained 230 lbs K/acre, which is below the recommended minimum concentration. Therefore, in 2017 K fertilizer was applied to location 10 and it did increase to 323 lbs. K/acre in 2019. However, that concentration value is still on the lower end. Therefore, in 2019, sample locations 2 and 10 contained the lowest K concentrations on the 90-acre parcel compared to other sample locations and will need an application of potassium fertilizer to increase concentration values.

The 120-acre parcel throughout the years, contained consistent K concentrations, however, the lower right portion of the parcel that contains Russel Silt loam soil texture compared to the rest of the parcel that contains Caitlin Silt loam, expressed relatively lower nutrient concentrations than the rest of the parcel. The values in the lower right portion of the 120-acre field can be expressed through sample locations 1 and 2 (Table 7). As such, based on the soil test results, the lower right portion of the 120-acre parcel receives potassium fertilizer applications every two years to increase potassium levels.

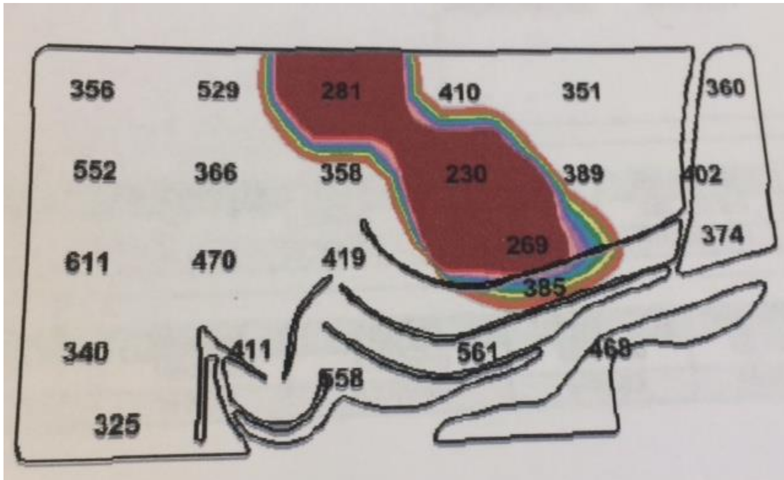


Image 2. 2017, 90-acre plot potassium application in burgundy, covering low K concentration sample locations, including location 10. However, location 2 did not receive a K fertilizer application and it should have received a maintenance application amount to replace what would have been removed from crop harvest.

Table 7. 120-acre parcel sample locations 1 and 2, located in lower right portion of parcel containing a different soil texture of Russel Silt loam (weak granular structure) displaying lower nutrient values in comparison to the rest of the parcel's average (Table 5).

Sample Number	K (lbs. /acre)	P (lbs./acre)	pH
2010			
1	321	39	5.5
2	316	41	6.0
2014			
1	340	75	6.1
2	350	46	6.3
2018			
1	331	66	6.1
2	330	54	6.2

Figure 9, 10, and 11 display the change of potassium levels within the three different parcels over time.

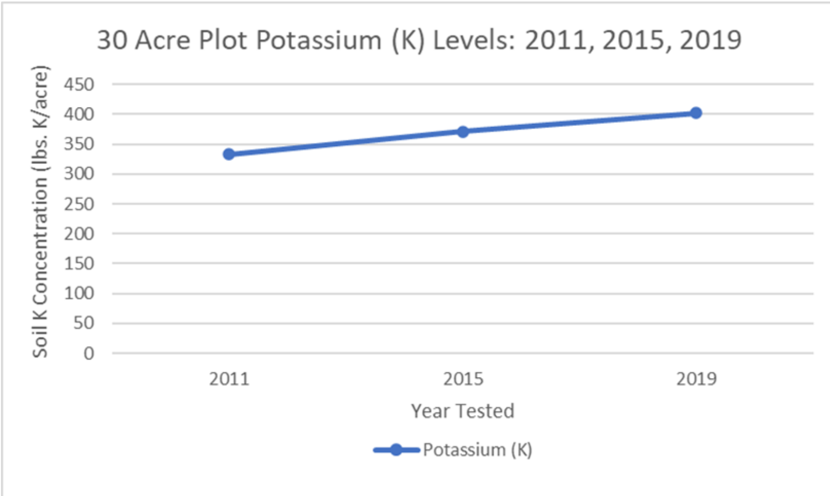


Figure 9. Soil test Potassium results for the 30-acre parcel in 2011, 2015, and 2019.

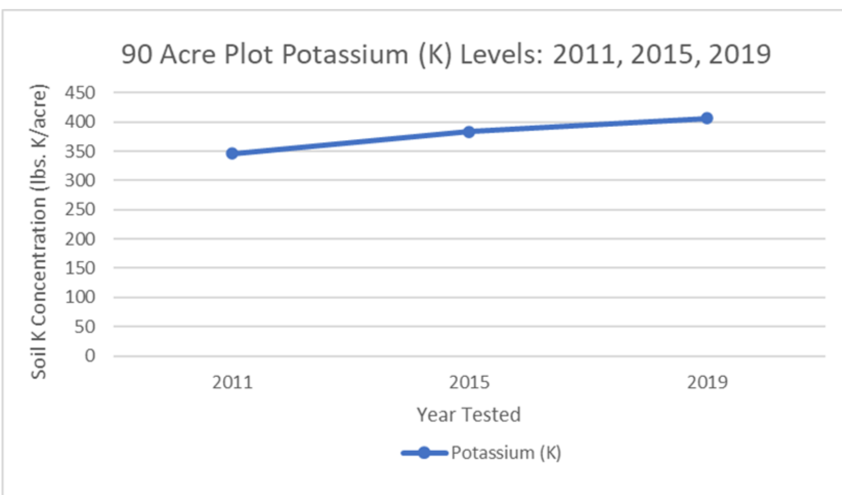


Figure 10. Soil test Potassium results for the 90-acre parcel in 2011, 2015, and 2019.

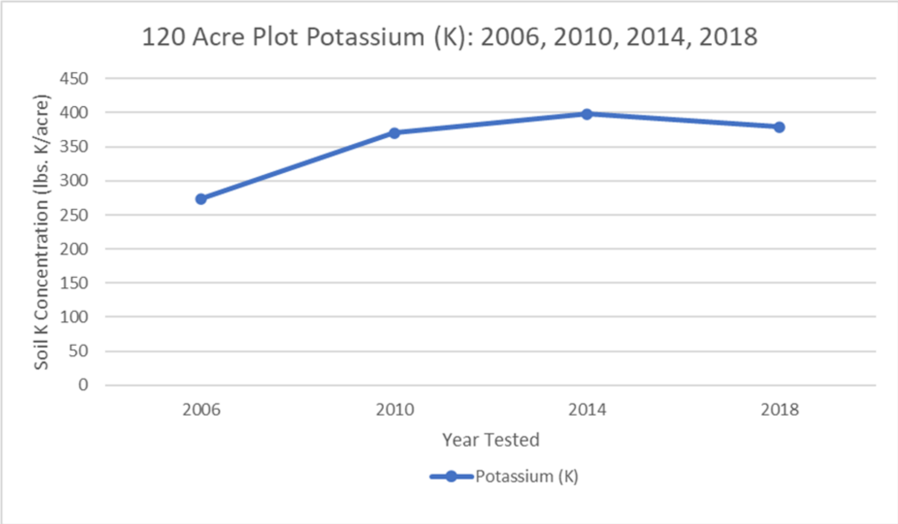


Figure 11. Soil test Potassium results for the 120-acre parcel in 2006, 2010, 2014, and 2018.

pH

The three parcels of land contained adequate pH levels throughout the time period analyzed. However, one year was on the lower end and needed to be addressed. In 2011, the 90-acre plot contained a pH of 5.7, slightly lower than the recommended 6.0 pH level. As such, in order to slightly raise the pH level, the farmers added a liming program to this parcel of land and the following soil test in 2015, the pH level was 7.1 (slightly higher than needed). As such, the farmers did not apply their liming program and subsequently in 2019 the pH was at an optimal level of 6.8. (USDA, 2019)

Figures 12, 13, and 14 display the change of pH levels within the three different parcels over time.

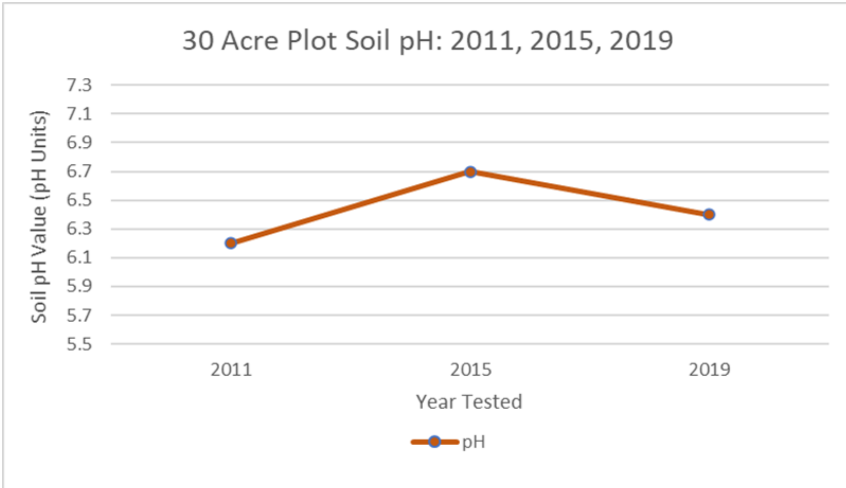


Figure 12. Soil test pH results for the 30-acre parcel in 2011, 2015, and 2019.

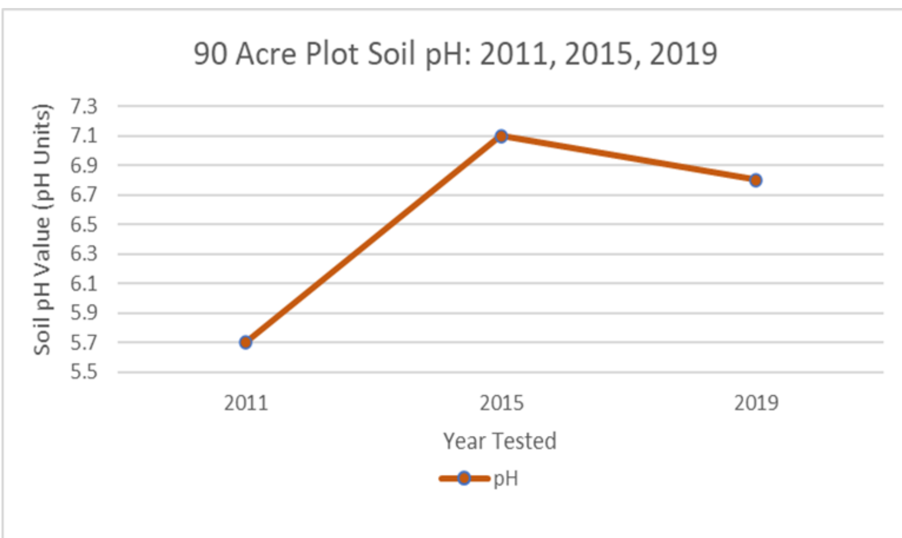


Figure 13. Soil test pH results for the 90-acre parcel in 2011, 2015, and 2019.

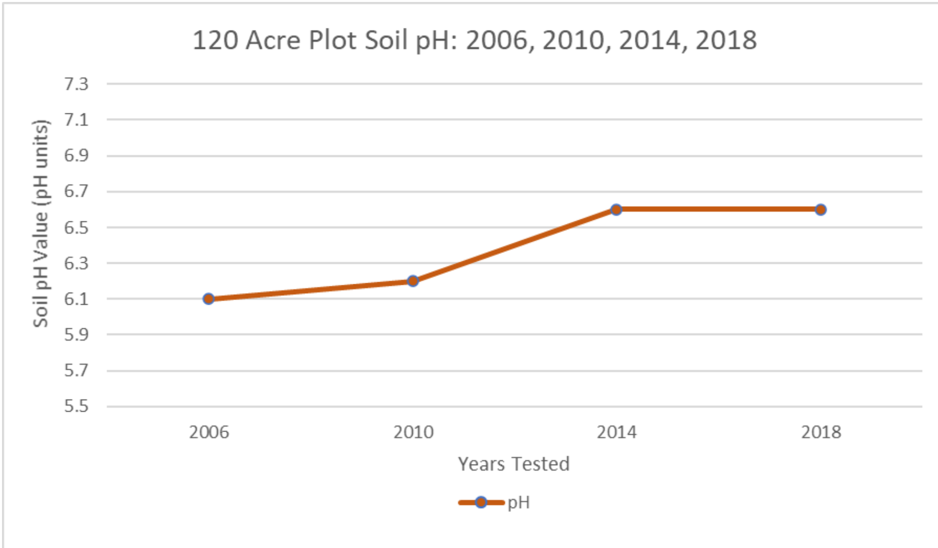


Figure 14. Soil test pH results for the 120-acre parcel in 2006, 2010, 2014, and 2018.

<u>Organic Matter</u>

Based on the soil test results, the organic matter content of these farm parcels have been in close range to the organic matter mean value of Illinois. The only year and parcel that contained a lower organic matter content than previous years was in 2018 on the 120-acre plot which was 2.0% while the previous year it was 2.5%. According, to Ingram soil testing lab that is an extremely slight change in percentage and could have been due to the soil samples containing plant material that was on top of the soil, such as a corn stalk that became ground into the soil samples (Ingram, 2020). This could have resulted in a slightly higher percentage of organic matter content (Ingram, 2020). While the parcels' soil organic matter content are in fairly good range, this is in part due to the use of crop rotation. Some farmers use additional management practices such as implementation and use of cover crops, to help maintain and improve soil organic matter to ensure productive soil for years to come. Additionally, tillage practices can impact organic matter. The farmers for the three parcels do not implement the use of cover crops or no-till practices. The farmers noted that another nearby parcel has used no-till for the last 40 years and has increased organic matter by about 1% (Marvel, 2020). As such, the farmer for the three parcels of land under this study has managed to maintain mostly adequate levels of organic matter by using the management technique of crop rotation. Figures 15, 16, and 17 display the organic matter content within the three different parcels over time.

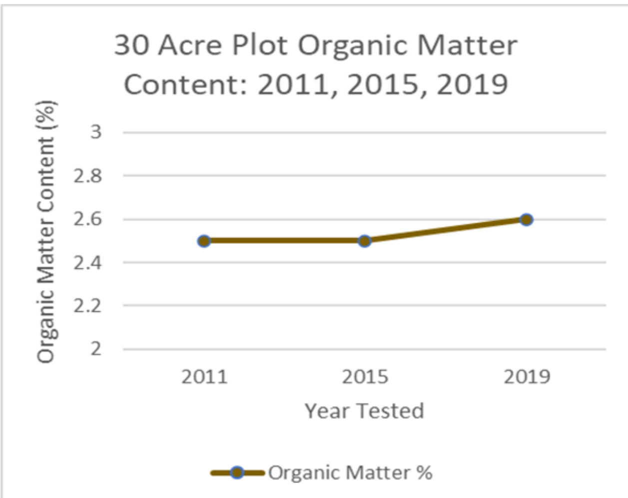


Figure 15. Soil test organic matter content results for the 30-acre parcel in 2011, 2015, and 2019.

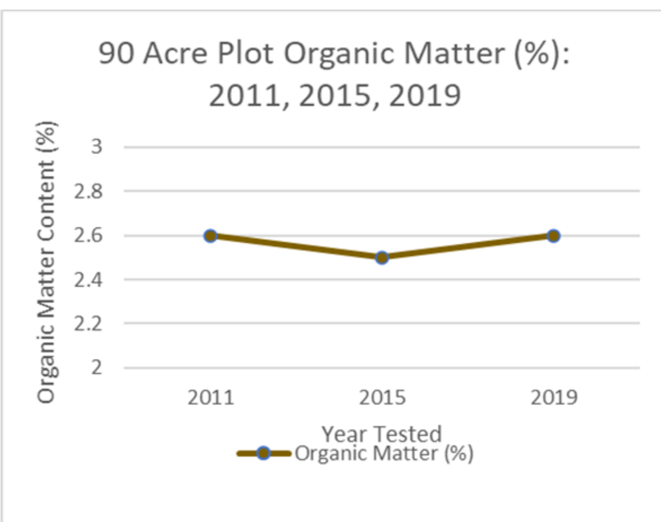


Figure 16. Soil test organic matter content results for the 90-acre parcel in 2011, 2015, and 2019.

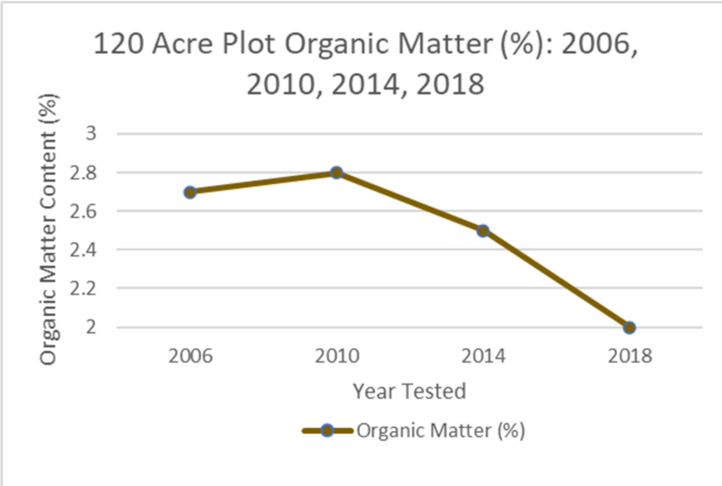


Figure 17. Soil test organic matter content results for the 120-acre parcel in 2006, 2010, 2014, and 2018.

<u>Calcium</u>

Given central Illinois' soil texture, there is currently an abundant supply of Calcium (Farmaha, 2012). In accordance with the general Illinois soil texture, all three parcels of farmland, every year tested contained an ample amount of calcium, with a range of 4,156 to 6,268 lbs per acre. When proper pH levels are maintained, calcium deficiency is not common but if pH becomes too low resulting in acidic soils calcium deficiencies may appear (Fernández, 2012). As such, throughout the years on these three parcels, liming programs and monitoring of the pH levels have helped increase the levels and amount of plant available calcium in the soil (Marvel, 2020). The soil calcium nutrient levels should be continued to be tested and monitored and it is recommended that silt loam soils contain at least 800 pounds per acre of calcium to ensure productive soil (Fernández, 2012).

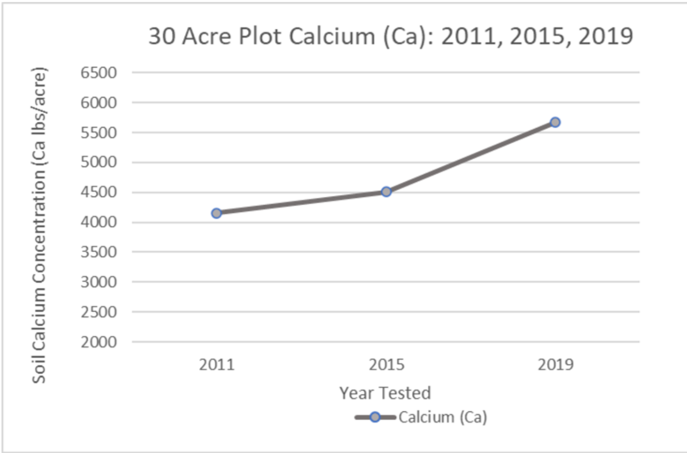


Figure 18. Soil test Calcium results for the 30-acre parcel in 2011, 2015, and 2019.

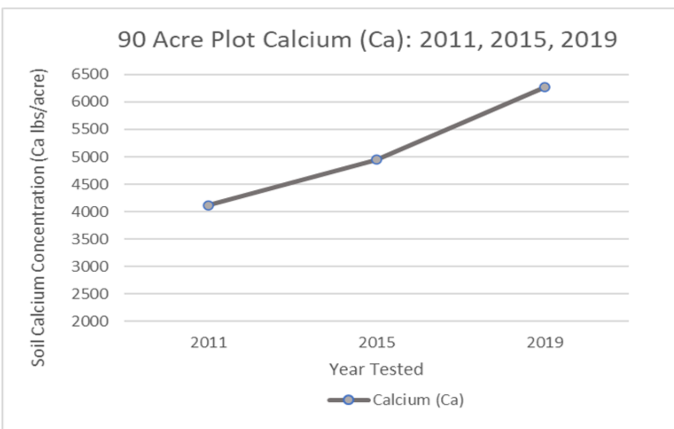


Figure 19. Soil test Calcium results for the 90-acre parcel in 2011, 2015, and 2019.

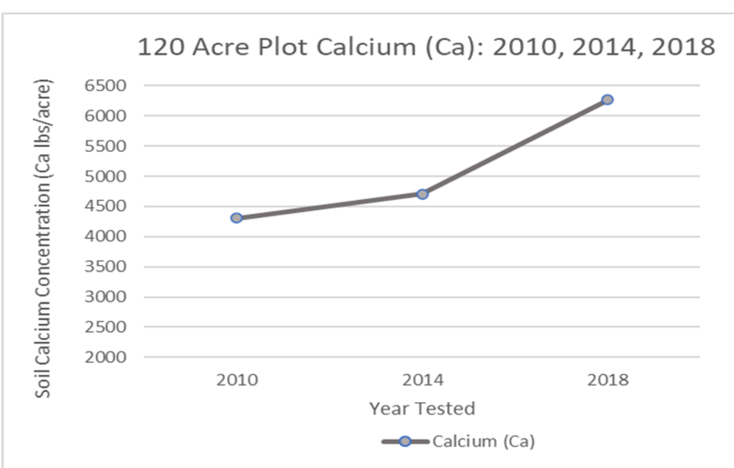


Figure 20. Soil test Calcium results for the 120-acre parcel in 2010, 2014 and 2018.

Conclusion

In summary, the analysis of soil test results is a vital tool for the farmer, helping highlight and guide nutrient levels to effectively maintain optimal soil values for crop production. While the nutrients phosphorus, potassium, and calcium have unique considerations, given the soil texture, management practices provide farmers additional ways to help maintain soil values. Most test results identified nutrients within the optimum values. Where there were slight variations, effective management of fertilizer application was applied. Variable rate technology to spread nutrients specifically to field locations in need, reduced the possibility of excess nutrient runoff and erosion. Additionally, based on pH soil test values, farmers applied a liming program to regain optimal pH levels for annual crop production. Organic matter content has remained within adequate levels for two out of the three parcels. Since 2010, organic matter content on the 120-acre parcel has declined and is below the Illinois average level. Current management practice of crop rotation is employed to improve soil productivity. If the organic matter content continues the downward trend, additional management practices may be implemented to increase O.M. content such as cover crops or altered tillage practices. As such, the soil analysis results provide the farmers insight on how to manage soil properties and have aided the farmer to more efficiently use limited resources for increased soil productivity.

Acronyms and Key Terms

CEC: Cation Exchange Capacity- a numerical value that demonstrates the degree of attraction between the soil and plant nutrients and other elements due to the negatively charged components on soil organic matter that retain positively charged elements such as potassium and calcium (Fernandez, 2012).

GPS and GIS: Global Position Systems and Geographical Information Systems. These technological systems are used during the soil testing process and fertilizer applications to ensure soil samples are obtained from the exact locations as previous soil tests conducted and in conjunction with variable rate technology. They are also used to ensure that fertilizer is applied onto the corresponding farmland that demonstrated low levels of a particular nutrient.

Mehlich-3 and Bray P_1 tests: Two different soil test methods that quantify the amount of available phosphorus within the soil sample.

SOM: Soil Organic Matter- A portion of the soil that contains decaying plant and animal materials that enhance soil fertility and structure (Fenton, 2008).

VRT: Variable Rate Technology- A technological system that is used by farmers to help them utilize and apply fertilizer in a more effective and efficient manner (Fernandez, 2012).

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