Wayne Fredericks, co-author of this article, has been farming fields in Mitchell County, IA near Osage since the mid-1970s. Using his experiences as a backdrop, this article focuses on what actually happens in the soil along the journey of change in corn and soybean systems. Photo by Joseph L. Murphy/Iowa Soybean Association.

Changes in Soils and Crops along a Transformational Journey

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Some questions most often asked by producers are, "What is changing in my soil when I adopt a management practice? How can I detect that change? and What does it mean for my yields?" These questions reveal our uncertainty in how we quantify changes in the soil and how we view the soil. More importantly, they give insight into what is important to producers for their operations. The current attention on soil health has revealed that we don't completely understand how soil changes and what is required to determine what is changed in our soils. The focus of this article will be on what actually happens in the soil along the journey of change in corn and soybean systems in the upper Midwest. Earn 1.5 CEUs in Soil & Water Management by taking the quiz for the article at https://bit.ly/3rjoV5C. View all CEUs at https://web.sciencesocieties.org/Learning-Center/Courses.

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There are a couple of backdrops to this journey to help with the context. First, in his book, *40 Chances*, Howard G. Buffett describes in Story 21 that we must focus on the soil if we want yields to increase. We have forgotten about the critical role that soil plays in agricultural production and especially in weather resilience, and the recent efforts on soil health have bought this back into focus. The second is a recent report by Bruno Basso and his colleagues (2019) at Michigan State who identified zones within a field that could be characterized as high-yielding stable zones, low-yielding stable zones, and unstable zones. They have expanded this research to demonstrate how soil and weather are interacting to affect crop yields each growing season. We have used this information to help untangle a very complex puzzle of changes in corn and soybean production across the upper Midwest.

Location and History of Change

The fields are in Mitchell County, IA near Osage and have been farmed by Wayne since the mid-1970s. In the fall of 1991, an early fall freeze with snow prevented the typical fall tillage operations after corn production. This led to a decision to use a John Deere 750 drill to no-till-plant soybeans for the 1992 cropping season. There was no impact on yields, and there was no looking back by reverting to tillage for soybean production. The success of no-till soybean caused another shift in 2002; after attending various seminars and talking to producers in Minnesota about strip-till corn, Wayne decided to shift from conventional tillage in the spring of 2002 to strip tillage. This has been used on corn production since that time.

Throughout this time, nitrogen fertilizer rates have followed MRTN (Maximum Return to Nitrogen) recommendations running from 130 to 150 lb/ac, and P and K have been determined by soil tests and adjusted over time with a decrease in the amount of P and K added each year. An additional change in production occurred in 2012 with experiments on cover crops, and by 2017, rye cover crops were used on all the corn and soybean acres on the farm. Currently, soybeans are directly seeded into the standing rye cover crop, and strip-till corn is planted directly into the green crop. Planting green allows for timely operations in the spring to take advantage of the entire growing season for crops. Emergence of the crops is often ahead of the conventionally tilled fields because of the ability to plant earlier and not having the wait for the soil to dry before being able to traffic across the field.

Available Data

The authors of this article share a common interest about soil health and farming operations. This created a dialog about the value of changing soil and climate resilience and the effect of changing tillage practices on crop yields. We often appear on the same programs to discuss trends in agriculture, and after one of those meetings where Wayne was talking about his systems, Jerry asked if he would be willing to share his data, so we could do a detailed analysis of the changes in soil, yields, and resource use efficiency. Wayne thought that this type of detailed analysis would be valuable and provided Jerry with yield monitor data from 10 fields from 2003–2018 along with field descriptions, weather data, and soil organic matter samples from 1984 through 2015. We also collected the Mitchell County corn and soybean yield data from USDA-NASS summaries for each year along with county weather data and used the NRCS soils data to identify soil types within each field.

For each field, the yield monitor data were screened to remove any obvious problems within the field and the end rows. Yield monitor data were then segregated by soil type within the field and maintained as a separate file for each field. This was done for each dominant soil for each field, and for these soils, we computed the mean, median, skewness, and kurtosis along with frequency distribution of the yields. This was done for the entire field as well. We computed water use efficiency for each field as a product of the yield divided by the seasonal rainfall to estimate yield per unit of water received during the growing season with the goal of determining if the changes in the soil were helping improve resource use efficiency.

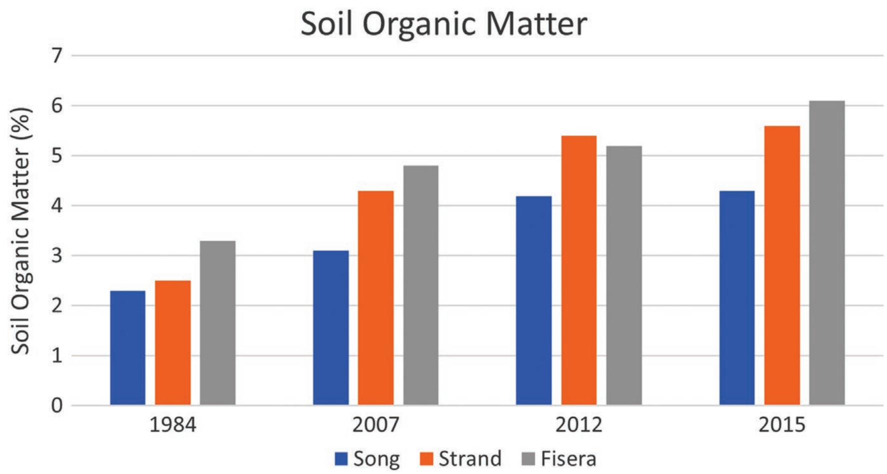

Figure 1. Increase in soil organic matter across three fields on Fredericks farm across time.

Changes in Soil Organic Matter

Producers often look at soil organic matter as the primary indicator of change in their soils with a change in tillage practices. Samples were collected at nine locations across each of three fields in 1984 to evaluate whether herbicide rates needed to be adjusted. These fields had tillage changes over the years and demonstrated an increase in soil organic matter through 2015. Two of the fields were rented and sold in 2017 with a change in operators, and data are no longer available. During this period of tillage changes, there was a steady increase in organic matter across these fields as shown in Figure 1. There were differences among the fields in the initial organic matter levels; however, all three fields increased over time with a doubling over the 30-year period.

The reduction in tillage intensity between the early sampling (1984) and the first sampling (2007) after tillage practice change showed a large increase in soil organic matter, and there has been a continual increase over time with the continued reduction in tillage intensity. There are soil organic matter measurements on all the fields that Wayne farms, and the general observation is that all fields show an increase over time; however, the rate of change among fields varies over time with a few fields showing only small changes in soil organic matter; however, these fields have seen changes in field uniformity.

With the current interest in using agricultural soils to capture carbon, these data demonstrate the potential across the upper Midwest. The increase over time reveals that changes can occur and continue to accrue over time. Across all the fields, there is an increase in the soil organic matter content because of changing tillage practices; however, there was considerable variation in the soil organic matter values among years due to sampling variation within fields. This is similar to our observations that revealed a positive carbon balance in the first year after switching from conventional tillage to no-till (Dold et al., 2019). For the producer, the value of the increased carbon for production should be the primary question asked about the impact of any change in practice, e.g., tillage, cover crops, or crop rotations.

Changes within the Fields

We often look at the whole field in terms of yield but don't evaluate the changes occurring in different soils within field boundaries. When we separated the yield monitor data by soil type within the field and begun to analyze the changes over time, there were some interesting patterns that began to emerge. This is best illustrated in these two examples shown below for two common soil types in Mitchell County (Figures 2 and 3). We are only showing the beginning of the observation period for corn and the last year with corn for these two soils. In both soils, there were two evident changes. First, over time, the skewness of the distribution changed, so the low-yielding parts began to decrease; and second, the tightness around the mean increased.

Changing the skewness of the distribution represents an elimination of the low-yielding areas within each soil. From the beginning of the observation period until the last observation, the low-yielding parts of the soil diminished. These reductions in low yields would increase the overall yield within that soil along with increasing the profitability because there is a better return on inputs. However, the frequency distribution reveals that these are not extremely large areas within a soil type, so we don't see a large increase in the overall yield.

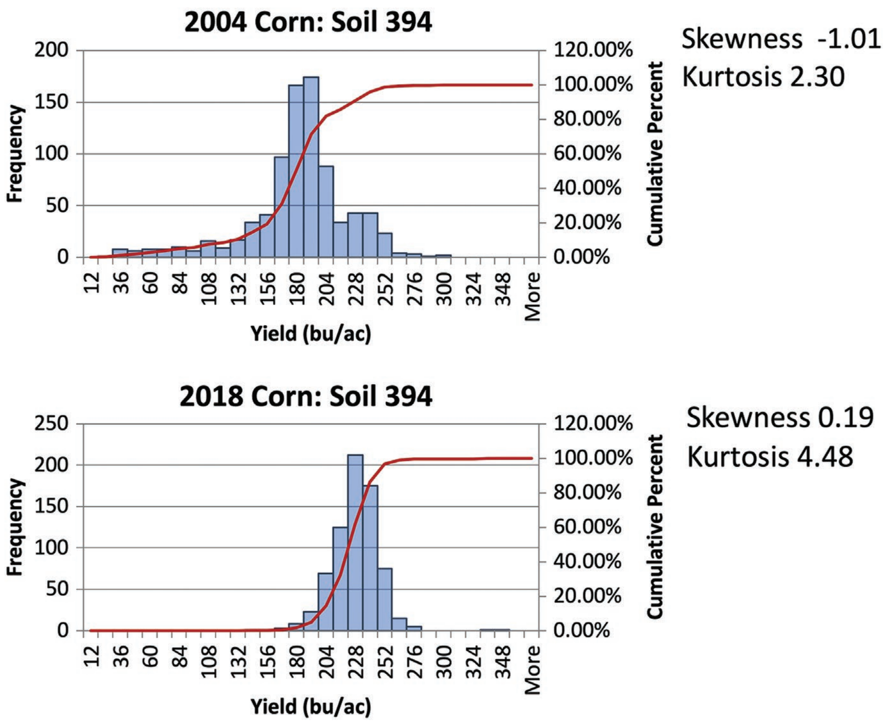

Figure 2. Yield distribution changes from 2004 to 2018 for corn grown on the Ostrander loam soil in Mitchell County, IA.

Another important feature in these changes is the kurtosis, or the tightness of the distribution around the mean. These also changed over time, showing that the yields became more uniform within a soil type. The less variation around the mean shows the field is becoming more uniform within a given soil type. Yields continue to increase over time, and decreasing the variation around the mean indicates continual improvement in production efficiency in the use of the inputs.

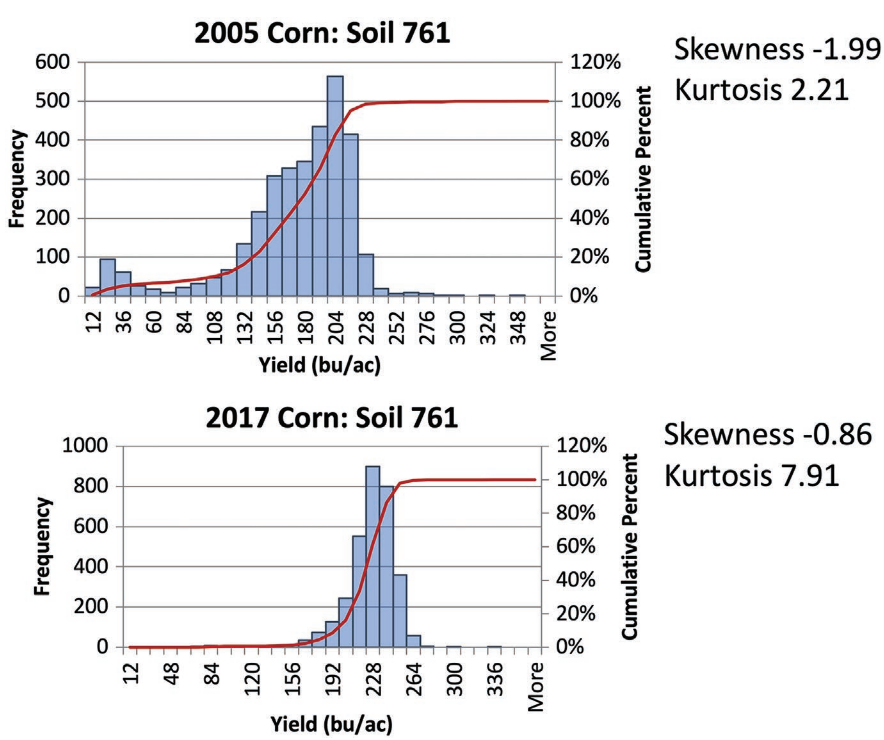

Figure 3. Yield distribution changes from 2005 to 2017 for corn grown on the Franklin silt loam soil in Mitchell County, IA.

For all the different soils within the 10 fields, we observed the same pattern of change over time: the skewness decreased, and the kurtosis increased as the yield distribution changed. These were gradual changes with the skewness and kurtosis showing the largest changes in the last six to eight years of the observation sequence. These changes reflect the changes in the soil properties over these 18 years and the value of examining yield monitor data within the field boundaries to determine the amount of change in a field with a change in management.

Observations during harvest from the 2020 and 2021 growing seasons have shown the uniformity in fields continues to increase with areas in the fields where low yields were often observed and evident in the yield monitor maps. There is still variability within fields; however, the amount of variation continues to decrease. As we have shared this information with different audiences, there have been several producers who have indicated that they have observed that uniformity in their fields have increased over time with the use of no-till or strip till and even more when they added cover crops. They have seen these changes through analysis of the yield monitor data by comparing across years or through aerial pictures taken of the fields in the grain-filling period. Providing this type of analysis to producers would help them understand how their management decisions are changing profitability within a field.

Changes in Water and Nitrogen Use Efficiency

The question is often asked about the impact of increasing soil organic matter on water-holding capacity. Using Mitchell County yield data for corn and soybeans from 1980 to 2020, we evaluated the yield response to precipitation patterns for each year. What we found was low-yielding years were negatively correlated with above-normal April and May rainfall. Excessive soil water in the spring often delays planting, causes stress in the low-lying parts of the field, or drowns out corn and soybean crops in the poorly drained areas. Extending this analysis to the Corn Belt showed the same relationship. However, above-normal precipitation in July–August was positively correlated with grain yields. This relationship is to be expected because the grain-filling period is the highest crop water use period, and any additional rainfall pays dividends in increased crop yields.

The continual improvement in Wayne's fields didn't show these same relationships in the past five years. There are two factors that contribute to this change. First, there is improved soil structure that allows for traffic on the fields after rains in the spring. Second, planting corn and soybean is done by "planting green," and the cover crop increases the trafficability of the field. This allows for timely planting in the spring and the capability to take advantage of the longer growing season while

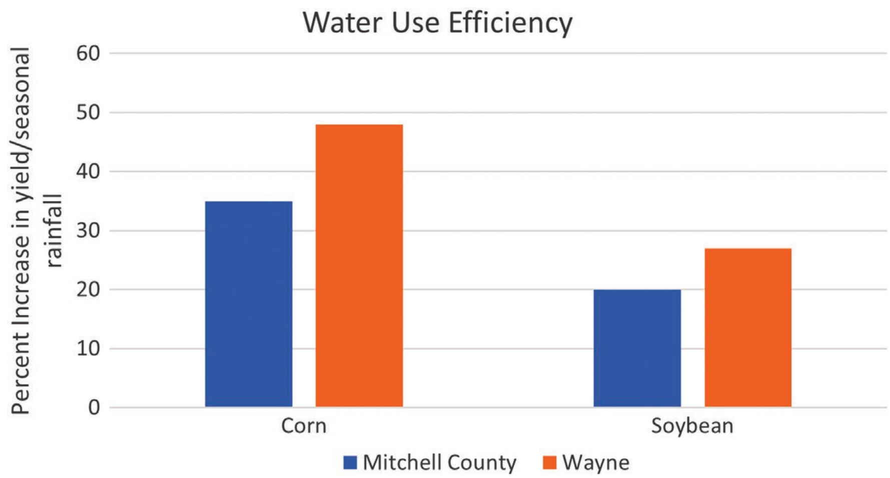

Figure 4. Increase in water use efficiency in corn or soybean grain yield relative to seasonal rainfall for Mitchell County and Frederick fields.

conventionally tilled fields have delays in planting to wait for the soil to dry.

One metric that we examined with these data was the change in water use efficiency by looking at the grain yield relative to the seasonal rainfall. There was an increase in the water use efficiency over time. A portion of this change is to be expected because we have continued to increase grain yields due to technology faster than the rainfall has increased. When we evaluate the change in water use efficiency for Mitchell County from 2002 through 2020, we find there was a greater increase in efficiency of crop water use from Wayne's fields compared with the county for both corn and soybeans as shown in Figure 4.

Other farms that have adopted no-till or strip-till and cover crops have shown a similar increase in efficiency in the use of seasonal rainfall compared with the county levels. This provides a way to account for the technology increases in water use efficiency to document the effect of enhancing the soils' ability to infiltrate and store soil water. Across all the corn fields on Wayne's farm in 2020, the water use efficiency was 9.95 bu/inch of seasonal rainfall. Observations on the water dynamics with reduced tillage and cover crops reveal there are three positive changes in the water balance. First, the presence of the crop residue protects the soil surface from the direct impact of raindrop energy and maintains the infiltrate rate of water into the soil; second, crop residue reduces the water evaporation rate from the soil surface, making more water available for crop use; and third, the presence of crop residue creates a favorable microclimate near the soil surface for crop roots to grow and be able to take advantage of small rainfall events.

Nitrogen use efficiency has improved over time as evidenced by the data shown in Figure 5. These results show that as the soil has changed, there is a benefit to corn production because there is less N required to produce a bushel of corn. The trend line over the course of this observation period shows a significant reduction in the N requirement to produce a bushel of corn. Three production years, 2012, 2013, and 2014, show the largest deviation from this trend for a variety of reasons. Rainfall was deficient in 2012 during the growing season. In 2013, planting was delayed or prevented in the region because of excessive rainfall in the spring and

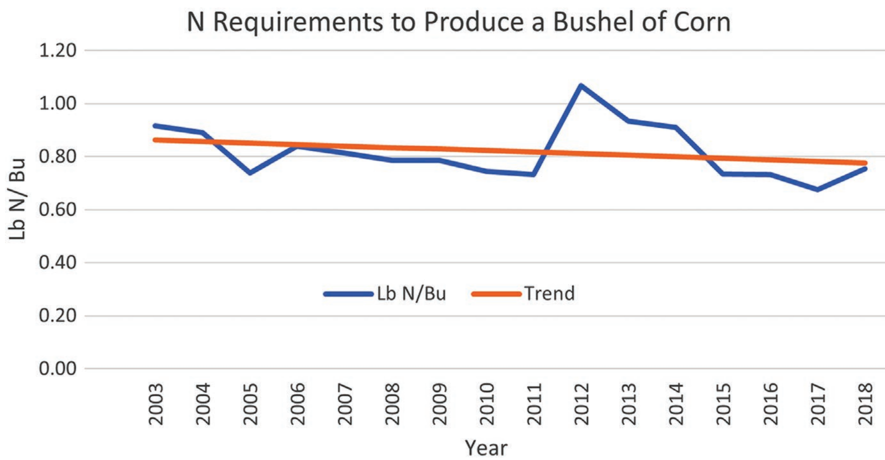

Figure 5. **Nitrogen utilization per bushel of corn produced on all fields on Fredericks farm from 2003–2018.**

only 6 inches of rainfall during July to September, and in 2014, there was adequate rainfall throughout the season with no apparent explanation for the reduced yields other than possible after effects of 2013. County yields were also low in these years as well. Efficient nitrogen management will impact water quality because there is less available to leave the field. Improvements in the water use efficiency have increased the corn yield to take advantage of the N applied to the crop and further enhance water quality. Examining nitrogen use efficiency in this way is another metric producers could examine from their production data to determine whether the changes they are making are having an impact on resource use efficiency. Soil tests have shown it is possible to decrease P and K rates across the fields, leading to a savings in fertilizer costs.

Impacts on Producers

Profitability and efficiency of production are linked, and producers are asking more and more questions about their farming systems. We haven't captured the full potential of yield monitor data collected each harvest season by examining these data over a series of years. The rich data set Wayne provided from his fields to follow the impact of reducing tillage intensity in both corn and soybean crops revealed there were changes in his soils and yield distributions. The increase in organic matter across fields showed that reducing tillage had a positive impact on soil carbon. Although not every field responded in the same magnitude, all fields showed a positive increase in soil organic matter. More meaningful to producers, in our opinion, is the reduction in the yield variation for both crops within soil types within a field. There was a continual reduction in the low-yielding areas as the soils improved over time and a tightening of the yield distribution about the mean, which showed that there was increasing uniformity within each soil type. Producers are interested in increasing their resilience to weather variation, and these data show that corn and soybeans are better able to utilize the rainfall during the growing season to produce grain.

Although soil organic matter response varied among fields, the change in the yield distribution characteristics were the same with the low-yielding areas increasing in productivity, suggesting that the ability of the soil to capture and make more soil water available to the crop enhanced production. This increases the profitability of the field. Producers need to see where in their fields there is not a return on investment of inputs.

Producers have yield monitor data or field-level yields along with their input data of nutrients and rainfall. Our challenge should be to help them use these data resources to evaluate any change in their management practices. Helping producers enhance their soil resource and capture the maximum return on the investment of natural resources, e.g., water, or purchased inputs, e.g., fertilizers, should be the primary goal of our education and consulting efforts. Our goal is to demonstrate ways we could look at fields for their yield and water use efficiency response to changes in tillage and cover crop management. The addition of cover crops into these fields has further improved field uniformity and decreased the impact of variable rainfall during the growing season. This is a journey in which we have seen multiple benefits, and in evaluating the data with these methods, we now understand the impact of changes in management over time.

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1. **Which of the following is NOT a soil classification coined by Bruno Basso and his colleagues at Michigan State?**
   a. High-yielding stable zones.
   b. Low-yielding stable zones.
   c. Low-yielding unstable zones.
   d. Unstable zones.

2. **Wayne, a producer in Mitchell County, IA, found that switching to no-till planting of soybeans had no impact on his soybean yields.**
   a. True. **b.** False.

3. **Which of the following was NOT a change in production that Wayne tried since adopting no-till soybean in 1992?**
   a. Cover crops.
   b. Direct seeding corn into rye.
   c. Decreasing P and K amounts added each year.
   d. Planting later.

4. **For Wayne's fields, resource use efficiency was determined as a product of seasonal rainfall divided by yield to estimate yield per unit of water.**
   a. True. **b.** False.

5. **According to Figure 1, which field in the Fredericks farm had the highest soil organic matter percentage in 2012?**
   a. Song. **b.** Strand. **c.** Fisera. **d.** Fredericks.

6. **Though some of the fields showed only small increases in organic matter over time, they have also seen improvements in field uniformity.**
   a. True. **b.** False.

7. **Over time, low-yielding areas within fields ______, which ______ profitability.**
   a. increased, increased. **c.** decreased, increased.
   b. increased, decreased. **d.** decreased, decreased.

8. **By looking at kurtosis (the tightness of the distribution around the mean), the team determined that.**
   a. the field is becoming more uniform within a given soil type.
   b. yields became more uniform within a given soil type.
   c. production efficiency in the use of inputs improved.
   d. All of the above.

9. **For all of the different soils in Wayne's fields over the 18-year data set, the team observed the same pattern of change. Which of the following was NOT true of that pattern?**
   a. Skewness decreased as yield distribution changed.
   b. Kurtosis increased as yield distribution changed.
   c. The largest changes in skewness and kurtosis occurred in the first six to eight years of observation.
   d. Skewness and kurtosis, overall, changed gradually.

10. **According to Figure 2, the most frequent yield for corn grown on Ostrander loam soil in 2018 was about ______ bu/ac higher than in 2004.**
    a. 10 **b.** 40 **c.** 70 **d.** 100

11. **Using Mitchell County yield data from 1980 to 2020, the team found that ______-yielding years were negatively correlated with ______-average rainfall in April and May.**
    a. high, above. **c.** low, above.
    b. high, below. **d.** low, below.

12. **For corn fields on Wayne's farm in 2020, his water use efficiency was ______ bu/inch of seasonal rainfall.**
    a. 5.75 **b.** 7.75 **c.** 8.90 **d.** 9.95

13. **Which of the following is NOT a factor that helped Wayne's crops increase water use efficiency compared with Mitchell County?**
    a. Presence of crop residue.
    b. Increasing N inputs.
    c. Implementing cover crops.
    d. Using no-till or strip till.

14. **According to Figure 5, N requirements to produce a bushel of corn were ______ lb N/bu in 2003 to ______ in 2018 across all fields on Fredericks farm, showing a downward trend over time.**
    a. 0.90, 0.75 **c.** 0.65, 0.75
    b. 1.05, 0.65 **d.** 0.90, 1.05

15. **Overall, the long-term changes in management demonstrate that improving soil structure, implementing cover crops, and reducing tillage resulted in increased profitability on Wayne's farm.**
    a. True. **b.** False.