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SOIL QUALITY IN WEST TENNESSEE: CASE STUDY AT THE MILAN EXPERIMENT STATION

Source: Deerwood Farm. 1998. The crop below is emerging from the soil through the existing cover (right), and without the protective cover crop of last year's stubble (left). Available at http://www.deerwood.mb.ca/dswma1.html (verified 1 March 2000).

Prepared for

Dr. Mike Mullen, Committee Chair, and

Dr. Tom Ammons and Dr. Gary Lessman, Committee Members

By

Angela Nevils

2 May 2000

COLLEGE SCHOLARS PROJECT APPROVAL

Angela Nevils
Scholar

Dr. Michael D. Mullen
Mentor

Soil Quality in West Tennessee: Case Study at the Milan Experiment Station
Project Title and Completion Date

COMMITTEE MEMBERS' SIGNATURES
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SOIL QUALITY IN WEST TENNESSEE: CASE STUDY AT THE MILAN EXPERIMENT STATION

Prepared for

Dr. Mike Mullen, Committee Chair, and

Dr. Tom Ammons and Dr. Gary Lessman, Committee Members

Angela Nevils

2 May 2000

ABSTRACT

The impact of no-till on soil quality differs from region to region, therefore West Tennessee needs to be studied individually to determine what, if any, effect no-till has on soil quality.

The objective of this study was to determine whether no-till agriculture increases soil quality in West Tennessee soils.

Data on enzymatic activity, microbial biomass, organic matter content, nutrient levels and pH were collected for both no-till and conventionally tilled fields growing soybeans for 20 years, on a Lexington silt loam (Fine-silty, mixed, active, thermic Ultic Hapludalf), in Milan, TN. The results were compared both independently and through the use of soil quality (health) cards from Georgia and Ohio.

In the no-till soil, enzymatic activity was significantly higher for four out of five parameters measured. Macronutrient levels differed significantly only for nitrate nitrogen, with the levels in the no-till field being over twice those in the conventionally tilled field. Carbon:Nitrogen ratios for both fields were ~8:1, but the overall amounts of carbon and nitrogen were almost twice as high in the no-till field. The pH levels in the no-till and conventionally tilled fields were significantly different (5.04 and 5.39 respectively). Mehlich I extractable nutrient levels seemed to follow patterns associated with pH instead of tilling practices, but also could have been influenced by a greater amount of residual chelates in the no-till soil. Microbial biomass carbon and organic matter content were both

significantly higher in the no-till soil. Soil quality (health) card results indicated that the no-till soil was between 65% and 28 times healthier than the conventionally tilled soil.

By examining a range of indicators, it has been shown that the no-till soil at the Milan experiment station demonstrates a higher soil quality than the conventionally tilled soil.

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INTRODUCTION

In recent years, both rising fuel costs, and increased environmental awareness have brought no-till to the forefront of both the farming community, and the agriculture research community. Much is known about the impacts of no-till farming on soil quality, but much remains to be learned, especially how no-till effects soil on a regional basis. At the Milan No-till Agricultural Experiment Station in Milan, Tennessee (see figure 1 in the Materials and Methods section), both tilled and no-till soybeans have been grown on adjacent plots for 19 years. The objective of this paper was to compare the impact of these two cropping methods on soil quality by examining selected soil biochemical properties. An additional objective of this study was to evaluate sample soil quality cards, also known as "soil health" cards, to see if these cards confirmed the results of the independent analysis. The working hypothesis for this study was that long-term no-till cropping would result in enhanced soil biochemical quality relative to a continuously tilled system. This paper consists of a literature review examining the impact of no-till on a variety of soil quality indicators, a materials and methods section outlining the procedures used for analysis of the soils, a results and discussion section presenting the findings and discussing their implications for soil quality, and a conclusion.

LITERATURE REVIEW

Several studies comparing soil quality, enzyme levels, nutrient content, soil organic matter, and microbial biomass in various tillage regimes have been conducted over the years. These studies have invariably included comparisons of these levels in conventionally tilled fields versus no-till fields.

Soil Quality

Soil quality is defined by Doran and Parkin as;

> "The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health." (Doran and Parkin, 1994).

In order to measure soil quality characteristics, therefore capacity, parameters must be used that in total represent a holistic picture of the soil itself. Many parameters have been set forth such as: physical indicators (Karlen and Stott, 1994), enzymatic activity (Dick, 1994), nitrate levels (Allan and Killorn, 1996), organic matter (Sikora and Stott, 1996), and microbial biomass (Rice et al. 1996). Several states have created test cards in an attempt to measure soil quality for farms in their area. Each of the following sections of the literature review contains a discussion on how this parameter relates to soil quality.

Enzymatic Activity

Enzymes are an important indicator of soil quality (Dick 1994). Because of their ability to catalyze mineralization, nitrogen fixation, nitrification, and

denitrification, they are often used as indicators of nutrient cycling potential in the soil environment (Dick, 1997). Higher enzyme activities generally indicate a more robust microbial community (Frankenburger and Dick, 1983). Dick (1994) found that soil enzymes are very sensitive to different types of soil management, and related parameters such as organic matter, soil physical properties, and microbial biomass. Therefore, they are often used as comparative indicators in crop management studies.

W. A. Dick (1984), in a study of influences of long-term tillage and crop rotation combinations on soil enzyme activities, found that the levels of acid phosphatase, arylsulfatase, invertase, amidase, and urease were significantly higher in no-till plots versus conventionally tilled plots. Deng and Tabatabai (1996b) found a significant increase in a-glycosidase in plots using no-till versus conventional tillage with a chisel plow.

Not all studies show a significant increase in enzymatic activity with no-till. In their 1996a and 1997 articles, Deng and Tabatabai found no significant difference between the two tillage regimes for aminohydrolases, β-glucosidases, phosphatases, and arylsulfatases. In fact for some of these enzymes, levels were actually higher in the fields tilled with chisel plow than with no-till.

Phosphatases

Phosphorous is an essential nutrient for plant growth, however it is often found in soils in forms unavailable for plant uptake (Havlin, 1999). Acid and alkaline phosphatases convert the phosphorous found in one of these forms, esters of H_3PO_4 in organic matter, into plant available phosphorous. This is done by catalyzing the hydrolysis of these esters (Tabatabai, 1994). Alkaline phosphatase

is thought to be only microbial in origin, while acid phosphatsase can be produced by both plants and microbes (Tabatabai, 1994, Dick et al., 1983).

Arylsulfatase

Another important nutrient in plant nutrition often found in organic forms in the soil is sulfur. The arylsulfatase enzyme catalyzes the hydrolysis of arylsulfate anions by severing the O-S bond:

$$R\text{-}OSO_3^- + H_2O \rightarrow ROH + H^+ + SO_4^{2-}$$

Arylsulfatase can be produced by plants, animals, and microorganisms (Farrell et al., 1994).

β-glucosidase

Glucosidases (also known as glycosidases) catalyze the hydrolysis of glycosides in cellulose to sugars and aglycons (Tabatabai, 1994). β-glucosidase is produced by higher plants, yeast and fungi and the sugars it releases are an important energy source for microbes (Tabatabai, 1994).

Dehydrogenase

Dehydrogenases are the enzymes that are most often responsible for biological oxidation of organic compounds. The overall equation for dehydrogenation is:

$$XH_2 + A \rightarrow X + AH_2$$

where XH_2 is a hydrogen donor (organic compound) and A is the hydrogen acceptor (Tabatabai, 1994). Dehydrogenase is often studied because it should exist only in living microbial cells (Curci, 1997, Dick, 1997).

Soil Organic Matter

Sikora and Stott (1996, p.157) state, "Soil organic matter has long been considered the key quality factor of soil". Soil organic matter is important in assisting infiltration of air and water, reducing erosion, and preserving tilth (Gregorich et al., 1993). It also releases nutrients slowly into the soil solution, reducing fertilizer needs (Stott and Martin, 1990).

As expected, many studies found significantly higher organic carbon contents in no-till versus conventionally tilled plots. Deng and Tabatabai (1996a) found a no-till/double mulched field to have 37% more organic matter than a field tilled conventionally with a moldboard plow. In their 1990 study, Arshad et al. (1990) found a 26% increase in carbon in a no-till versus conventionally tilled soil. Doran (1980) found on average a 25% increase in soil organic matter in no-till in the first 7.5 cm of the soil profile, with the greatest difference coming from a corn field in Kentucky that had 55% more organic matter in the first 7.5 cm of the soil profile. This same field showed a net increase of 18% organic matter for the first 15 cm of the soil profile.

Not all studies show a significant increase in soil organic matter with the adoption of no-till. Franzluebbers and Arshad (1996) found that after six years of continuous barley, their fine, montmorillonitic, frigid Typic Natriboralf showed no net increase in organic matter with the adoption of no-till methods.

Soil Nitrogen

Doran (1980) found an increase of almost 20% in Kjeldahl N in no-till corn and wheat versus conventionally tilled fields. This same study found potentially mineralizable N levels in no-till to be 13 to 58% higher in no-till versus conventionally tilled fields. This increase in potentially mineralizable N is to be expected with the significant increase in total soil N. This same study found that total organic C increased significantly also with no-till. As soil organic C and N increase, one expects an increased ability of the soil to provide slow release N (and other nutrients) to a crop.

Some studies have shown no difference in nitrogen levels in no-till versus conventionally tilled fields. A. J. Franzluebbers et al. (1994) found that mineralizable N levels in three different rotations (continuous wheat, rotated wheat/soybean, continuous wheat/soybean), demonstrated no significant difference between no-till and conventional till. In a different study, Franzluebbers and Arshad (1996) found no significant difference in mineralizable N between no-till and conventional till after six years of canola/wheat/barley rotation. This study was done in Northwestern Canada, and the authors conjectured that the cold, semiarid climate limited soil organic matter turnover, limiting mineralizable N.

Many studies have shown that no-till fields suffer from a larger net loss of nitrogen due to denitrification versus conventionally tilled fields. Dou et al. (1995) found that NO_3^- in no-till corn was almost half the level of NO_3^- in conventionally tilled corn grown in the same soil. This was attributed to an increase of denitrification and leaching in the no-till field. Doran (1980) found

that the increase in soil water content associated with no-till significantly increased the populations of denitrifiers. Schoenau and Campbell (1996) found lower recovery of broadcast N fertilizers in no-till systems. In a 1990 study, Arshad et al. (1990) found less mineral NH_4^+ in no-till versus conventionally tilled continuous barley fields. In this case, most of the NH_3 in the soil was tied up in the organic fraction of the soil.

Sikora and Stott (1996) determined that total N and mineralizable N in a soil were highly related to soil productivity and quality. Most research dealing with the concept of soil quality and nutrient levels deals predominately with the concept of potential pollution. Allan and Killorn (1996) state that sufficient NO_3^- -N concentrations for most crops is around 19 mg/ kg (the level varies depending on background nitrate levels), and excess may result in environmental liability. Karlen and Stott (1994) determined that average nitrate-N levels around 18 mg/ kg were considered indicative of healthy/ high quality soils.

Microbial Biomass

Microbial biomass carbon is an important indicator of soil quality (Rice et al. 1996). Its high turnover rate causes the microbial biomass to respond quickly to situations that eventually change other important soil quality factors such as organic matter, aggregate formation, aggregate stability, and buffering capacity (Paul, 1984).

Doran (1980) found that between row areas receiving high levels of residue application, microbial counts were significantly higher throughout the growing

season. Dalal et al. (1991) found similar results in fields that have been in no-till for 20 years. Salinas-Garcia et al. (1997) found that microbial biomass in a no-till system was 27% higher at planting, 45% higher at flowering and 50% higher at harvest. In all of these studies increases in microbial biomass populations were attributed to increases in organic matter.

However, Franzluebbers and Arshad (1996) found no significant difference in soil microbial biomass carbon after 6 years in conventionally tilled versus no-till fields. This study was performed in northwestern Canada, suggesting that the climate impeded organic matter turnover, therefore microbial population growth.

The literature indicates that high levels of enzymatic activity, microbial biomass, and organic matter are often associated with no-till systems and high soil quality. Overall total and organic nitrogen levels usually increase with the use of no-till systems, while nitrate levels often decrease due to the abundance of denitrifers in no-till soils. While total and organic nitrogen levels correlate well with soil quality, nitrate levels beyond what is needed for crop growth may be potentially environmentally harmful.

MATERIALS AND METHODS

The following is a description of the sampling and laboratory techniques used for this study. It includes field sampling data, microbial biomass carbon methodology, enzyme determination methodology, extractable nutrients data, C, N, and organic matter determination, pH, and the method used for evaluating the soil with sample soil health cards.

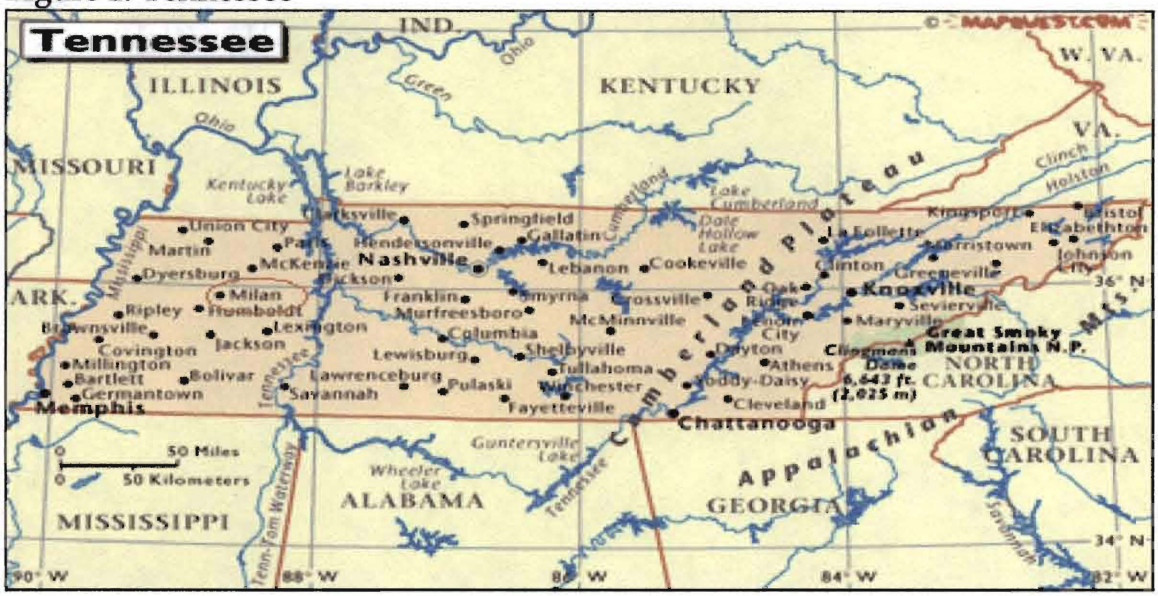
Soil Sampling

Field plots for this study were established at the Milan No-till Research Station in Milan, Tennessee (see Figure 1). These plots were on a Lexington silt loam (Fine-silty, mixed, active, thermic Ultic Hapludalf) on 5 to 8% slopes. Five contiguous 0.25 acre plots were established in 1979 and outfitted with rainfall simulator equipment to enable monitoring of soil erosion in tilled and no-tilled conditions (Shelton et al., 1983). This study was initiated in June, 1998. We chose two of these (plots 2 and 3) for examination of biochemical properties as affected by long-term no-tillage. The two plots studied had been in continuous soybeans for 19 years until the time of this study. One plot was conventionally tilled with chisel and disk plows, the other plot was no-tilled in soybean and wheat stubble (Shelton et al., 1983).

A transect was measured out across the second and third rainfall simulator plots. Each transect was perpendicular to the slope of the plots. Five sampling points were established approximately 90 cm apart starting about three meters in from the plot edge. At each sampling point, a soil sample was taken with a 7.5 cm diameter bucket auger to a depth of 7.5 cm. The samples were placed in

plastic bags, placed on dry ice, and transported to the laboratory at the University of Tennessee at Knoxville. With two treatments and five replications, ANOVA methods were used to evaluate significance, and means were separated using LSD at alpha = 0.05.

Figure 1. Tennessee



Source: Compuserve Travel. 2000. Maps and Directions. [Online] Available at http://cssvc.maps.compuserve.com/travel/main.dci?function=gemMaps

Microbial Biomass Carbon

The following section was adapted from Horwath and Paul (1994).

Fumigation and Extraction

Soil samples, each weighing 5g, were placed in glass beakers. The beakers were then placed into a vacuum desiccator with a beaker containing 50ml of $CHCl_3$. The desiccator was evacuated until the chloroform boiled vigorously. This was repeated four times. The desiccator valve was closed and the

fumigated samples were kept in the dark for 5 days at 25°C. Unfumigated samples were placed in mason jars and also kept in a desiccator in the dark for 5 days at 25°C. After this period, the chloroform was removed from the desiccator by evacuating eight times for three minutes, allowing air to pass through the desiccator after each evacuation. The fumigated and unfumigated samples were extracted with 25 ml of 0.5 *M* K_2SO_4. The soil solution was shaken on a reciprocal shaker at 180 strokes per minute for 1 hour. The soil suspension was filtered, and the filtrate was collected.

Determination and Calculation of Biomass Carbon

The soluble organic C was determined on both the fumigated and unfumigated samples using a commercial soluble C analyzer (Dohrman automatic C analyzer, Santa Clara, CA). The amount of biomass C was determined using the following formula:

$$\text{Biomass C} = (C_f - C_{uf})/0.35$$

where

C_f = C in the fumigated extract

C_{uf} = C in the unfumigated extract

0.35 = the proportion of the microbial C extracted from the soil (K_{ec})

Enzymes

The following section was adapted from M. A. Tabatabai (1994). It includes procedures for acid and alkaline phosphatase, arylsulfatase, betaglucosidase, and dehydrogenase.

Acid and Alkaline Phosphatase

One gram of soil was placed in a 50-mL Erlenmeyer flask, and 0.2 mL toluene, 4 mL of modified universal buffer (pH 6.5 for acid phosphatase, pH 11 for alkaline phosphatase also known as MUB), and 1 mL of *p*-nitrophenol phosphate (PNPP) solution were added to the flask and swirled. The flask was stoppered and placed in an incubator at 37° C for one hour. The stopper was removed and 1 mL of 0.5 *M* $CaCl_2$, and 4 mL of 0.5 *M* NaOH was added. The flask was swirled and the soil suspension was filtered. The yellow color intensity of the filtrate was analyzed with a spectrophotometer at 410 nm. Controls were performed by following the above procedure, except the addition of 1 mL of *p*-nitrophenol (PNP) was made after the additions of 0.5 *M* $CaCl_2$ and 4 mL of 0.5 *M* NaOH.

The PNP content of the filtrates were calculated as follows. A standard curve was developed by pipetting 0-, 1-, 2-, 3-, 4-, and 5-mL aliquots of a standard solution (10 mg *p*-nitrophenol ml^{-1}) into 50-mL Erlenmeyer flasks. The volume in the flasks was adjusted to 5-mL by addition of water. Then, 1 mL of 0.5 *M* $CaCl_2$ and 4 ml of 0.5 *M* NaOH were added to the flasks and mixed well. The resultant suspension was filtered. This resulted in standards containing 0, 10, 20, 30, 40 and 50 mg *p*-nitrophenol $flask^{-1}$. Absorbance was measured on the spectrophotometer, and a linear standard curve was calculated. The *p*-nitrophenol content of the sample filtrates were calculated using the results obtained with the standards. Results are expressed in units of μg PNP g $soil^{-1}$ hr^{-1}.

Arylsulfatase

One gram of soil was placed in a 50-mL Erlenmeyer flask with 0.25-mL of toluene, 4 mL of acetate buffer (0.5 *M* and pH 5.8), and 1 mL of *p*-nitrophenyl sulfate solution (0.05 *M*). The flask was swirled and stoppered. The flask was then placed in an incubator at 37°C for one hour. The stopper was removed and 1 mL of 0.5 *M* $CaCl_2$ and 4 mL of 0.5 *M* NaOH was added. The flask was swirled and the soil suspension was filtered. The yellow color intensity of the filtrate was measured with a colorimeter. Controls were created by following the above procedure, but the addition of *p*-nitrophenyl sulfate solution was made immediately before filtration. The PNP concentration was determined as described in the section labeled "Acid and Alkaline Phosphatase".

Betaglucosidase

One gram of soil was placed in a 50-mL Erlenmeyer flask with 0.25 mL of toluene, 4 mL of MUB at pH 6.0, and 1 mL of *p*-nitrophenyl-β-D-glucoside. The flask was swirled, stoppered and placed in an incubator at 37°C for one hour. The stopper was then removed and 1 mL of 0.5 *M* $CaCl_2$ and 4 mL of 0.1 *M* Trishydroxymethylaminomethane buffer pH 12 was added. The flask was swirled and the soil suspension was filtered. The intensity of the yellow color was measured on a colorimeter. The PNP concentration was determined as described in the above section labeled "Acid and Alkaline Phosphatase".

Dehydrogenase

This assay measures the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to 2, 3, 5 triphenylformazan (TPF). TPF is an intensely red-colored, methanol soluble compound. Twenty g of air-dried soil was thoroughly mixed with 0.2 g of $Ca\ CO_3$. Six grams of this mixture was placed in each of three test tubes. To

each tube, 1 mL of 3% aqueous solution of TTC and 2.5 mL of distilled water was added. The suspension was mixed, stoppered and incubated at 37°C for 24 hours. Then 10 mL of methanol was added and the tube was shaken for one minute. The suspension was filtered through a glass funnel plugged with absorbent cotton into a 100-mL volumetric flask. The tube was washed with methanol and the soil was transferred to the funnel. Ten-mL portions of methanol were then added to the funnel until the red color disappeared from the cotton plug. The filtrate was then diluted to 100-mL with methanol and the absorbance of the TPF red color was determined by using a Milton Roy Spectronic 401 spectrophotometer (Rochester, NY) at 485 nm. The concentrations were then determined by comparing the results to a standard curve created by a calibration graph. A calibration graph was prepared by diluting 10 mL of TPF standard solution to 100 mL with methanol, resulting in 100 mg of TPF mL^{-1}. Then, 5-, 10-, 15-, and 20-mL aliquots of this solution were pipetted into 100-mL volumetric flasks, and methanol was added to make up the volume. This resulted in standards containing 500, 1000, 1500, and 2000, mg of TPF 100 mL^{-1} respectively. The absorbance was measured, and a standard curve was created. Results are given in units of μg TPF g^{-1} soil hr^{-1}.

Extractable Nitrogen

The procedures outlined here were adapted from Mulvaney (1996).

Ammonia-N

Soils were extracted with 1 *M* KCl and the resultant filtrate was assayed by the indophenol blue method adapted for microtiter plate by Sims et al. (1995). Color

intensity was measured using a 7520 microplate reader (Cambridge Technology Inc., Watertown, MA) with a 650 nm filter

The ammonia concentration was determined using the following formula:

$$NH_4^+ \text{ (mg/L)} = (\text{absorbance} - 0.0099) / 0.12905$$

Nitrate-N

A filtrate was created using the above method for ammonia. Devarda's alloy was added to the microtiter plate and the plate was incubated at 35°C for 3 hours to promote reduction of nitrate to ammonia. The color intensity was measured as described above. This yielded the total inorganic nitrogen of the soil.

The concentration of NO_3^- was determined using the following formula:

$$NO_3^- \text{(mg/L)} = [(\text{absorbance} - 0.0099)/0.12905] - [NH_4^+ \text{ (mg/L)}]$$

Mehlich I Extractable Nutrients

The procedure outlined here was adapted from Helmke and Sparks (1996) and Soltanpour et. al. (1996).

Procedure

Four g of air-dried soil, sieved through a 60 mesh screen was combined with 20 mL of Mehlich I solution in a nalgene bottle. The bottle was capped and placed on a mechanical shaker for 10 minutes. The solution was then filtered into a volumetric flask and the filtrate was analyzed using inductively-coupled argon

plasma-optical emission spectrometer (ICAP61, Thermo Jarrell Ash Corp., Franklin, MA).

C, N, and Organic Matter

The following section was adapted from Nelson and Sommers (1996).

C and N

Total carbon and nitrogen concentrations within the soil were determined using a LECO CNS2000 analyzer (LECO, St. Joseph, MI). Approximately 0.2 g soil were weighed into ceramic boats and inserted into the LECO. The samples were then combusted at 1300° C in an O_2 environment. This converts all of the carbon and nitrogen to CO_2 and NO_x respectively. An infrared detector determines CO_2 concentration, while a thermal conductivity detector is used to detect NO_x concentration.

Organic Matter

Due to the non-calcareous, acid nature of this soil, it was assumed that total carbon would be approximately the same as organic carbon. Organic matter content in the sample was determined by the following formula:

$$OM = 1.72 \times \% C$$

where

OM = total organic matter

%C = percent carbon as determined by the LECO analysis

pH

Adapted from G. W. Thomas (1996).

The pH in water of the samples was determined using a digital pH meter. The meter was calibrated using a two-buffer standardization (at pH 7 and pH 4). Ten g of air-dry soil was weighed into a beaker. Then 20 mL of deionized water was added and the beaker was mixed well. The solution was allowed to stand for 10 minutes, then swirled. The electrodes were inserted into the supernatant and the pH was recorded.

Soil Quality Estimations

A new method for assessing soil quality is evaluating soil by the use of soil quality (health) cards. This author was interested in using sample cards to compare the results of her study with the determinations made by these cards. Many states have soil quality cards, unfortunately Tennessee is not among them. Therefore, it was decided that the soil quality cards for both Georgia and Ohio would be used for this study. The cards were downloaded from the United States Department of Agriculture, Natural Resources Conservation Service website (GCTA, 1999 and OSU, 1999). These cards were chosen because of the states with soil cards, these cards contained the factors this author associates with soil quality, and these cards were relatively easy to fill out with known information and educated assumptions.

Two copies of each card were made, one for the no-till soil, and one for the conventionally tilled soil. The cards were filled out by using both laboratory results and assumptions drawn from laboratory results.

There are many methods for creating a numerical value that indicates soil quality based on the results of a soil quality card. These methods range from multiple variable indicator kriging to multiplying each of the numbers by a weighting coefficient then either adding them or multiplying them (Doran and Parkin, 1994, Karlen and Stott, 1994, and Smith et al., 1994). In this study, it was decided that all of the weighting coefficients would be 1 for ease of comparison.

In the Georgia card, the number values for each rating were divided by ten to obtain percentages of maximum function with 1 being the highest, and 0.1 being the lowest. The results were then multiplied together to take into account limiting soil factors, and added together to give an indication of overall soil health.

In the Ohio card, the descriptive ratings were given the following numerical values: Good = 1, Fair = 0.5, and Poor = 0.1. As with the Georgia card, the results were then multiplied together to take into account limiting soil factors, and added together to give an indication of overall soil health.

The assumptions made on the soil cards were as follows:

Georgia

1) Crop residue after planting in the no-till would be between 65-70%.

2) Crop residue after planting in conventional till would be less than 30%

3) An equal amount of the till and no-till fields would be colonized by weeds in the winter.

4) The percent organic matter in the first 7.5 cm of the conventional till soil was not less than 85% of the organic matter in the top 1/2 inch of the soil.

5) The percent organic matter in the top 1/2 inch of the no-till soil was not less than the total percent organic matter in the soil sample.

Ohio

1) Earthworm populations would be higher in the no-till plots due to the increase in surface organic matter

2) Residue decomposition would be evident in many stages on the no-till soil.

3) The conventionally tilled soil would have little or no non-decomposed residue at the soil surface.

RESULTS AND DISCUSSION

The following is an examination of the results of the procedures performed and a discussion of their significance in comparison to soil quality indicators. The raw data for all the tests run can be found in Appendix 1.

Enzymes

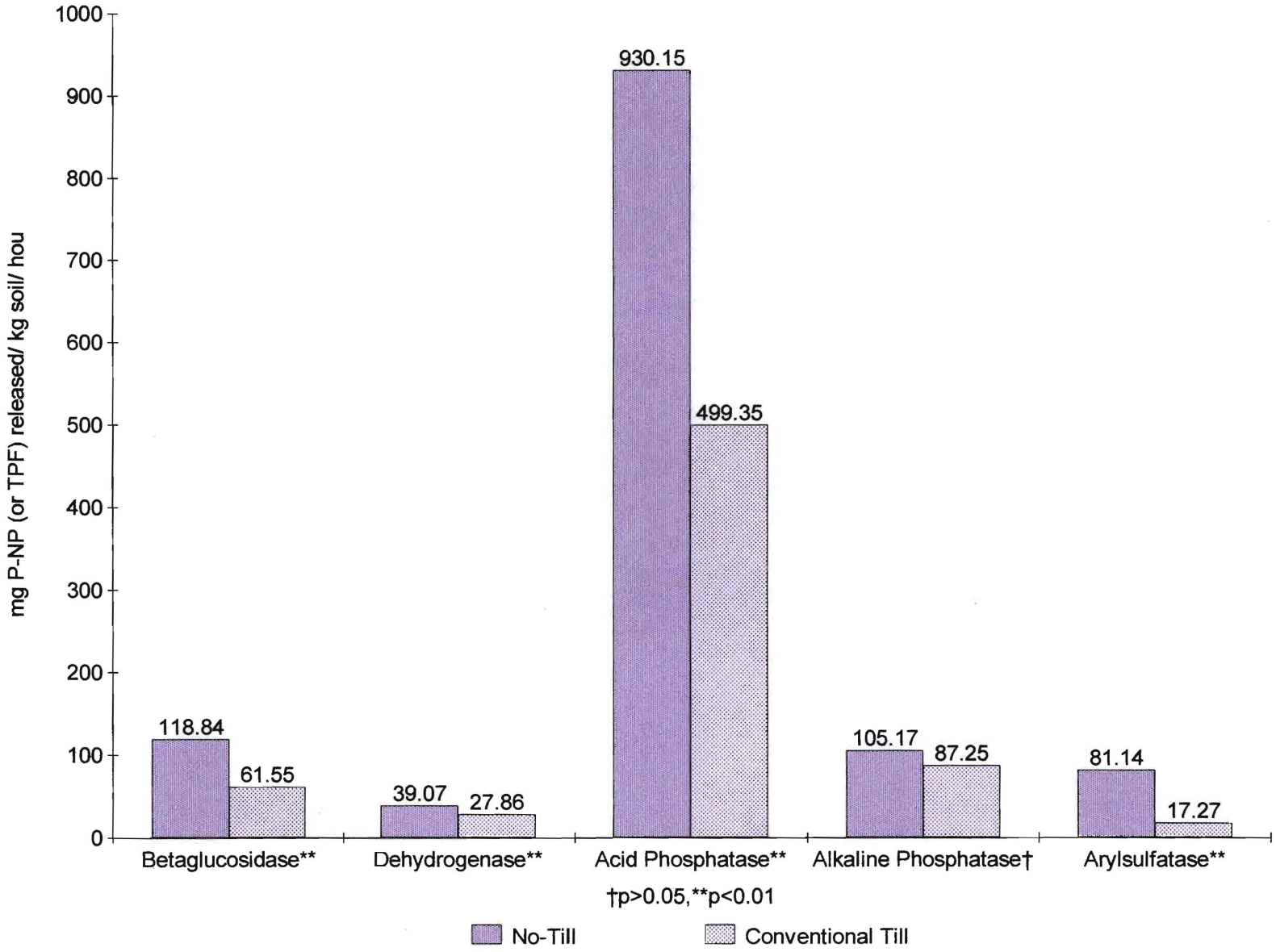
The enzyme levels in the no-till fields were significantly higher for enzymes measured except for alkaline phosphatase (see Table 1 and Figure 2).

Table 1. Enzyme activities in the tilled and no-tilled soybean plot.

	Arylsulfatase	Acid Phosphatase	Alkaline Phosphatase	Betaglucosidase	Dehydrogenase
	----------mg PNP/ kg soil/ hr----------			----------mg TPF/ kg soil/ hr----------	
Tillage					
Tilled	17**	499**	87†	62**	28**
No-till	81	930	105	119	39

*$p<0.05$, **$p<0.01$, †$p>0.05$

Figure 2. Values of Soil Enzymes



The pH of the soil was measured at a mean of 5.4 for the conventional tilled field and at a mean of 5.0 in the no-till field. Enzymes activity levels are often determined by soil pH (Coyne, 1999). The acidic nature of both of the fields is the most likely explanation for the lack of significant difference in the alkaline phosphatase levels. The rest of the enzymes had significant differences between 0.0001 (acid phosphatase) and 0.0014 (dehydrogenase). Enzymes are released from plants, animals, and microorganisms throughout their life cycle and during decomposition of dead organisms (Coyne, 1999). Higher levels of food source for these organisms would result in higher populations (Dick 1984, Deng and Tabatabai, 1996b).

Enzymatic activity is an important gauge of soil quality as it indicates a higher potential for mineralization of plant nutrients. The very high amount of enzymatic activity in the no-till field compared to the conventionally tilled field demonstrates both a higher soil quality in respect to this parameter, and a reflection of other soil quality parameters such as organic matter and microbial biomass (Dick 1994). It should be noted that although the phosphorous levels in the fields were not significantly different, the acid phosphatase levels were. This could either be an indication that enzymatic levels were a result of soil management or of pH.

Nutrient Levels

The following section deals C and N, and Mehlich I extractable nutrients.

C and N

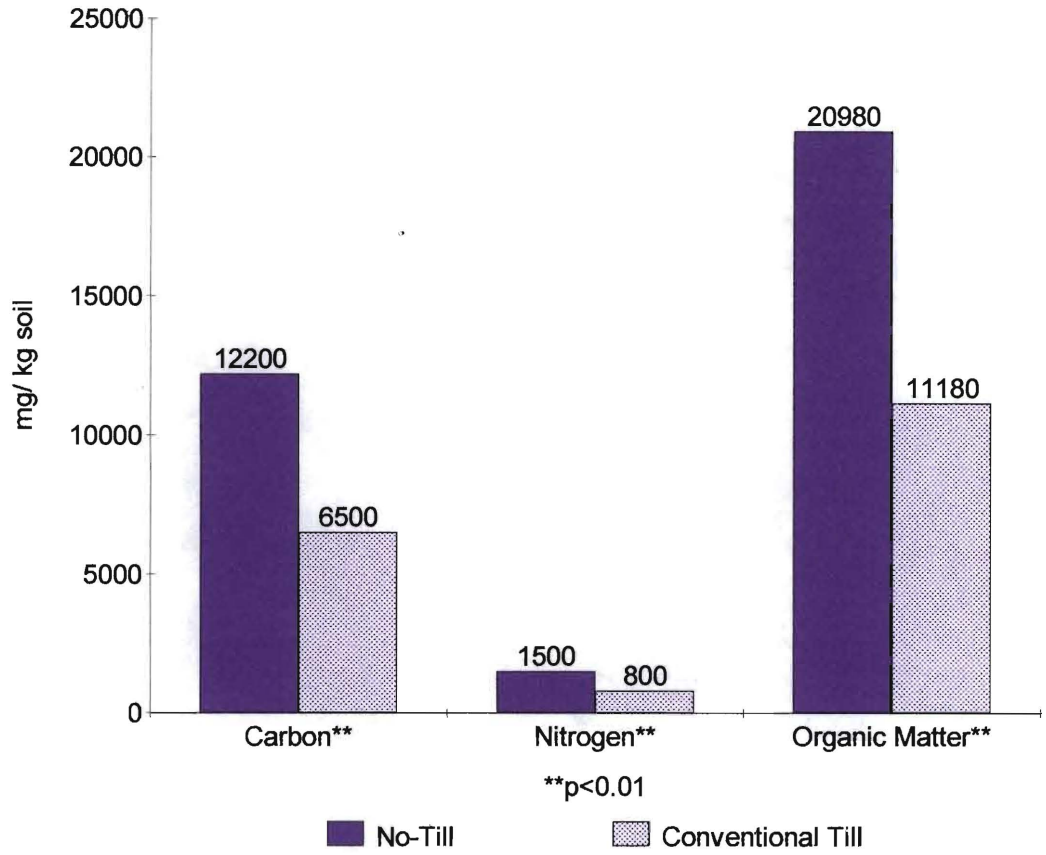
The organic matter content in the no-till field is almost twice that of the conventionally tilled field (see Table 2, and Figure 3). This is a typical result of the use of no-till. Deng and Tabatabai (1996a), Arshad et al., (1990), and Doran (1980), all found increases in organic matter ranging from 55% in the first 7.5 cm to 18% for the first 15 cm (Doran, 1980). Organic matter is considered a very important indictor of soil quality due to its contribution to buffering capacity, cation exchange capacity, structure development, water holding capacity, etc. (Sikora and Stott, 1996).

Table 2. Carbon, nitrogen, and organic matter in the tilled and no-till soybean plot

	Organic Carbon	Total nitrogen	Organic matter	C:N
	----------mg/ kg		---------%---------	
Tillage				
Tilled	6500**	800**	1.1**	~8:1†
No-tilled	12200	1500	2.1	~8:1

**$p<0.01$, †$p>0.05$

Figure 3. Values of C, N, and OM



Of the macronutrients, only nitrogen showed a significant increase of total levels in the no-till field. The nitrogen levels in the no-till field were approximately twice those of the conventionally tilled field (see Table 2 and Figure 3). These levels reflect the longer retention of crop and weed residues in no-till systems. This level of total N increase is higher than many of the increases found with the use of no-till. Doran (1980) found an increase of approximately 20% total N associated with no-till, and Dalal et al. (1991) found a significant increase in total N in the first 25 mm for wheat and barley fields in no-till.

In addition, the carbon to nitrogen ratios in both fields are approximately 8:1 indicating that nitrogen will be mineralized at the approximately the same rate

(depending on substrate quality). Since the total nitrogen levels are higher in the no-till, more N should be mineralized. Doran (1980) and Dalal et al. (1991), both found correlations between increases in Kjeldahl N and increases in potentially mineralizable nitrogen. Sikora and Stott (1996) determined that total N and potentially mineralizable N was highly related to soil productivity and quality.

The inorganic nitrogen data shows that nitrate-N levels in the no-till field are over twice that of the conventionally tilled field (see Table 3 and Figure 4). This is an unusual result in no-till studies. Doran (1980) found a great increase in denitrifiers in no-till fields. Denitrification resulted in significant decreases in NO_3^- in a study by Dou et al. (1995), and broadcast N fertilizer recovery in a study by Schoenau and Campbell (1996). The unusually high amount of nitrate found in this study is most likely related to sampling depth (7.5 cm).

Figure 4.Values of Ammonium and Nitrate

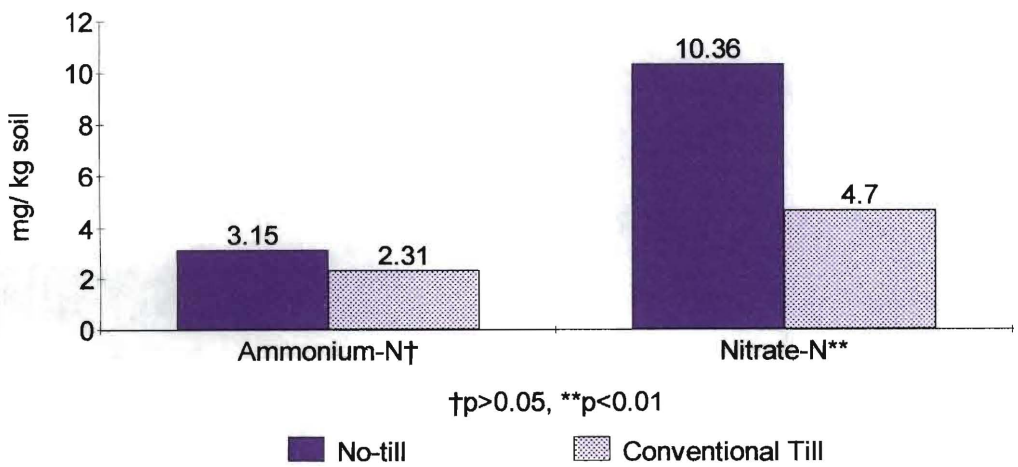


Table 3. Inorganic nitrogen in the tilled and no-tilled soybean plot.		
	Ammonium-N	Nitrate-N
	----------mg/ kg soil----------	
Tillage		
Tilled	2.3†	4.7**
No-till	3.2	10.4

**p<0.01, †p>0.05

The nitrate-N levels are high enough in the no-till to promote healthy plant growth, without exceeding the 19 mg/ kg soil level considered possibly environmentally detrimental (Allan and Killorn, 1996). Since this field is continuos soybeans, this result is mainly important if the crop was to be rotated with a non-leguminous species.

Mehlich I Extractable Nutrients

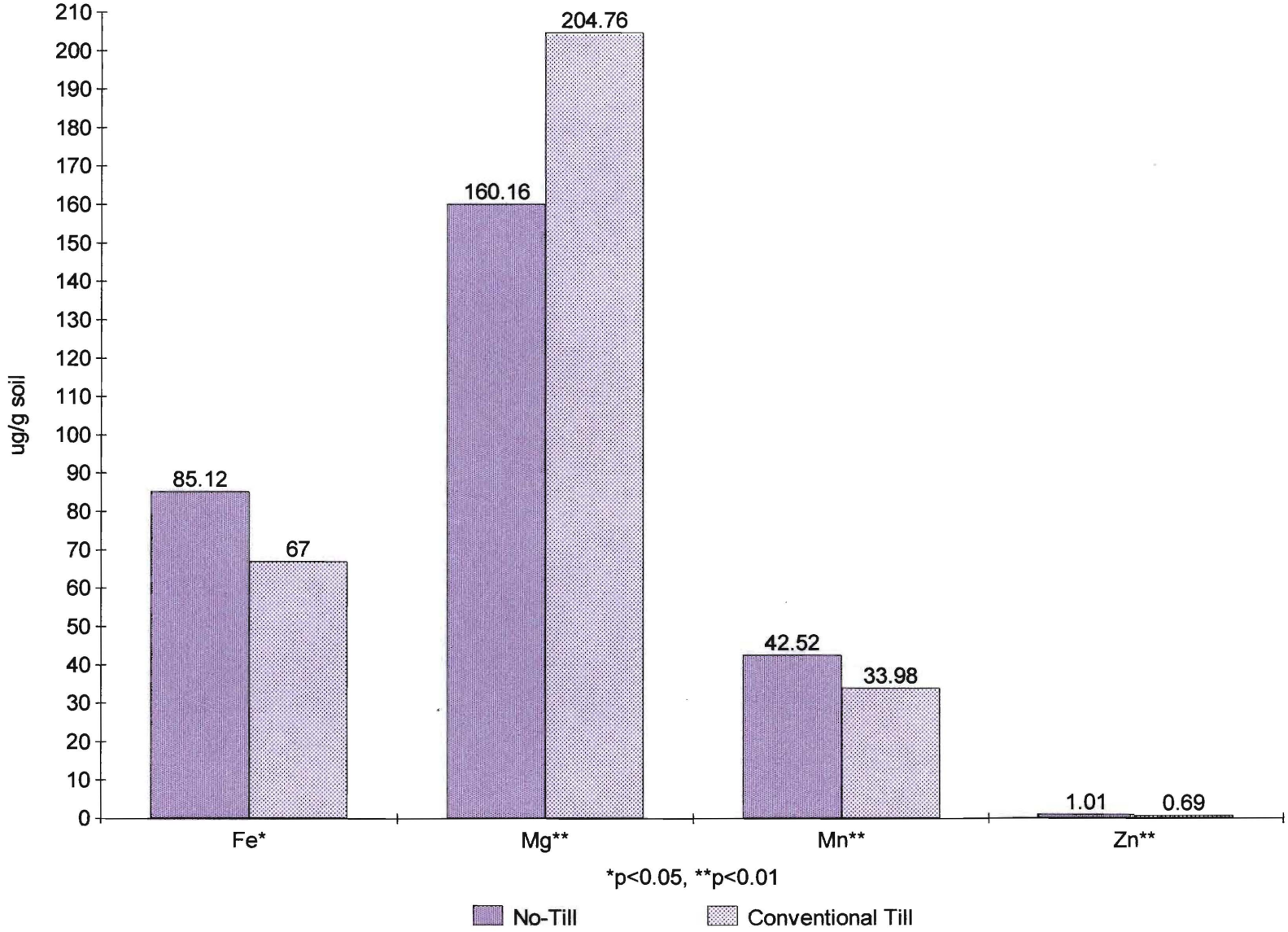
Iron, manganese, and zinc are all higher in the no-till field, while magnesium is higher in the conventionally tilled field (see Table 4 and Figure 5).

Table 4. Extractable nutrients and pH in the tilled and no-tilled soybean plot					
	Fe	Mg	Mn	Zn	pH
	----------mg/ kg soil----------				
Tillage					
Tilled	67.0*	204.8**	34.0**	0.7**	5.4**
No-till	85.1	160.2	42.6	1.0	5.0

*p<0.05, **p<0.01

Figure 5.Values of Mehlich I Nutrients

Only statistically different shown



Micro- and secondary nutrient availability is greatly affected by soil pH. As the soil pH decreases, metallic micronutrient solubility increases, and secondary nutrient solubility decreases (Havlin et al. 1999). The pH in the no-till field is significantly lower than the tilled field, and the statistically different micro- and secondary nutrients levels seem to be predominately associated with pH. Another explanation for the higher levels of extractable metallic nutrients in the no-till soil is a higher level of residual chelates from the organic matter in the soil.

This author was able to find no studies that linked micro- and secondary nutrient levels to soil quality. However, since all the statistically different nutrients, except for magnesium, were higher in the no-till, one can assume that the no-till field is more adequately providing nutrients to plants than the conventionally tilled system, provided there is no magnesium deficiency within the crop.

Microbial Biomass Carbon

The microbial biomass carbon in the no-till field was significantly higher than in the conventionally tilled field (see Table 5).

Table 5. Microbial biomass carbon in the tilled and no-tilled soybean plot.

	----------mg/ kg soil----------
Tillage	
Tilled	97*
No-till	163

*$p<0.05$

Microbial biomass is an important indicator of soil quality (Rice et al. 1996)). Its high turnover rate causes the microbial biomass to respond quickly to situations that eventually change other important soil quality factors such as organic matter, aggregate formation, aggregate stability, and buffering capacity (Paul, 1984). The microbial biomass level is probably higher in the no-till plot due to an increase in food source, and reflects the better overall ecological health of the no-till system. Microbial biomass populations respond to increases in organic matter (Doran, 1980), total N (Dalal et al., 1991, Salinas-Garcia, 1997), and moisture (Coyne, 1999).

Soil Health Card Results

The actual soil cards used are in Appendix 2.

Georgia

The Georgia soil quality card showed an incredible increase in soil quality in the no-till field over the conventionally tilled field (see Table 6).

Table 6. Georgia soil quality card - Multiplication

	No-till	Conventional till
Soil Fertility	1	0.7
Soil pH	0.5	0.9
Biological Activity	1	0.5
Crop Residue Right After Planting	0.9	0.1
Winter Cover Crop	0.5	0.5
Soil Organic Matter	1	0.5
Total	0.225	0.0079

According to this card, the no-till soil is 28 times healthier than the conventionally tilled soil. Soil quality cards are still in their infancy. More time

and study need to be devoted to creating soil cards that are effective reflections of soil health. While the no-till soil may indeed be generally healthier than the conventionally tilled soil, the difference is probably not 28 times. One of the main reasons that the results were so different is that the numbers for the different indicators were multiplied instead of added. When multiplying the numbers, one limiting factor (in this case, crop residue right after planting), can cause drastically different results. While this is the preferred way to calculate soil quality, (Karlen and Stott, 1994, Doran and Parkin, 1994) the results would look quite different if numbers were merely added (see Table 7.)

Table 7. Georgia soil quality card - Addition

	No-till	Conventional till
Soil Fertility	1	0.7
Soil pH	0.5	0.9
Biological Activity	1	0.5
Crop Residue Right After Planting	0.9	0.1
Winter Cover Crop	0.5	0.5
Soil Organic Matter	1	0.5
Total	4.9	3.2

It is seen in Table 7, that no-till is only 65% higher in health when the numbers are added. In this case, the impact of crop residue on the final number is reduced.

Ohio

The Ohio score card showed the no-till soil to be 8 times healthier than the conventionally tilled soil upon multiplication (see Table 8), but only twice as healthy upon addition (see Table 9).

Table 8. Ohio soil health card - Multiplication		
	No-till	Conventional till
Soil Life	1	0.5
Nutrient Levels	1	0.5
Organic Matter	1	0.5
Residue Decomposition	1	0.1
Soil pH	0.1	0.5
Total	0.1	0.00625

Table 9. Ohio soil health card - Addition		
	No-till	Conventional till
Soil Life	1	0.5
Nutrient Levels	1	0.5
Organic Matter	1	0.5
Residue Decomposition	1	0.1
Soil pH	0.1	0.5
Total	4.1	2.1

Once again we see that the limiting factor when using multiplication is residue. Just as with the Georgia soil card, this difference is drastically reduced when the numbers are added instead of multiplied.

CONCLUSION

By examining a range of indicators, it has been shown that the no-till soil at the Milan experiment station demonstrates a higher soil quality than the conventionally tilled soil. All biochemical data showed that applicable enzyme levels were higher in the no-till fields. Microbial biomass and organic matter levels were also much higher in the no-till field. Statistically different nutrient levels were higher in the no-till fields with the exception of magnesium. Comparisons using soil quality (health) test cards from Georgia and Ohio confirmed the results of these tests.

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APPENDIX 1: RAW DATA

---------- TRTMNT=2B ----------

Variable	Mean	Std Dev	Std Error
REP	3.00	1.58	0.71
ACIDP	930.15	113.08	50.57
ALKP	105.17	23.38	10.45
ARYLS	81.14	23.48	10.50

---------- TRTMNT=3B ----------

Variable	Mean	Std Dev	Std Error
REP	3.00	1.58	0.71
ACIDP	499.35	29.61	13.24
ALKP	87.25	10.53	4.71
ARYLS	17.27	5.20	2.32

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
TRTMNT	2	2B 3B

Number of observations in data set = 10

Analysis of Variance Procedure

Dependent Variable: ACIDP

Sum of Mean

Source	DF	Squares	Square	F Value	Pr > F
Model	1	463962.9840	463962.9840	67.91	0.0001
Error	8	54653.7305	6831.7163		
Corrected Total	9	518616.7146			

R-Square	C.V.	Root MSE	ACIDP Mean
0.894616	11.56410	82.65420	714.7480

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMNT	1	463962.9840	463962.9840	67.91	0.0001

Analysis of Variance Procedure

Dependent Variable: ALKP

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	802.6364810	802.6364810	2.44	0.1568
Error	8	2629.8405393	328.7300674		
Corrected Total	9	3432.4770203			

R-Square	C.V.	Root MSE	ALKP Mean
0.233836	18.84469	18.13091	96.21231

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMNT	1	802.6364810	802.6364810	2.44	0.1568

Analysis of Variance Procedure

Dependent Variable: ARYLS

Sum of Mean

Source	DF	Squares	Square	F Value	Pr > F
Model	1	10199.51809	10199.51809	35.28	0.0003
Error	8	2312.65461	289.08183		
Corrected Total	9	12512.17271			

R-Square	C.V.	Root MSE	ARYLS Mean
0.815168	34.55387	17.00241	49.20551

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRTMNT	1	10199.51809	10199.51809	35.28	0.0003

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: ACIDP

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 6831.716

Number of Means 2
Critical Range 120.5

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRTMNT
A	930.15	5	2B
B	499.35	5	3B

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: ALKP

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 328.7301

Number of Means 2
Critical Range 26.44

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRTMNT
A	105.17	5	2B
A			
A	87.25	5	3B

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: ARYLS

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 289.0818

Number of Means 2
Critical Range 24.80

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRTMNT
A	81.14	5	2B
B	17.27	5	3B

---------- TRT=CT ----------

Variable	Mean	Std Dev	Std Error
AMM	2.31	0.64	0.28
NIT	4.70	1.48	0.66
BETAG	61.55	15.54	6.95
DEHYD	27.86	4.39	1.96

---------- TRT=NT ----------

Variable	Mean	Std Dev	Std Error
AMM	3.15	1.84	0.82
NIT	10.36	2.72	1.22
BETAG	118.84	21.58	9.65
DEHYD	39.07	2.88	1.29

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
TRT	2	CT NT

Number of observations in data set = 10

Analysis of Variance Procedure

Dependent Variable: AMM

Sum of Mean

Source	DF	Squares	Square	F Value	Pr > F
Model	1	1.77080340	1.77080340	0.94	0.3610
Error	8	15.09514272	1.88689284		
Corrected Total	9	16.86594613			

R-Square	C.V.	Root MSE	AMM Mean
0.104993	50.38787	1.373642	2.726136

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	1.77080340	1.77080340	0.94	0.3610

Analysis of Variance Procedure

Dependent Variable: NIT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	80.11207464	80.11207464	16.69	0.0035
Error	8	38.39794100	4.79974262		
Corrected Total	9	118.51001564			

R-Square	C.V.	Root MSE	NIT Mean
0.675994	29.07975	2.190831	7.533873

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	80.11207464	80.11207464	16.69	0.0035

Analysis of Variance Procedure

Dependent Variable: BETAG

Sum of Mean

Source	DF	Squares	Square	F Value	Pr > F
Model	1	8206.283409	8206.283409	23.21	0.0013
Error	8	2828.797574	353.599697		
Corrected Total	9	11035.080983			

R-Square	C.V.	Root MSE	BETAG Mean
0.743654	20.84858	18.80425	90.19436

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	8206.283409	8206.283409	23.21	0.0013

Analysis of Variance Procedure

Dependent Variable: DEHYD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	313.9518473	313.9518473	22.77	0.0014
Error	8	110.3128755	13.7891094		
Corrected Total	9	424.2647228			

R-Square	C.V.	Root MSE	DEHYD Mean
0.739990	11.09654	3.713369	33.46419

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	313.9518473	313.9518473	22.77	0.0014

Analysis of Variance Procedure

T tests (LSD) for variable: AMM

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 1.886893
Critical Value of T= 2.31
Least Significant Difference= 2.0034

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	3.1469	5	NT
A			
A	2.3053	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: NIT

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 4.799743
Critical Value of T= 2.31
Least Significant Difference= 3.1952

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	10.364	5	NT
B	4.703	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: BETAG

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 353.5997
Critical Value of T= 2.31
Least Significant Difference= 27.425

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	118.84	5	NT
B	61.55	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: DEHYD

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 13.78911
Critical Value of T= 2.31
Least Significant Difference= 5.4157

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	39.067	5	NT
B	27.861	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: AMM

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 1.886893

Number of Means 2
Critical Range 2.003

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	3.1469	5	NT
A			
A	2.3053	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: NIT

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 4.799743

Number of Means 2
Critical Range 3.195

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	10.364	5	NT
B	4.703	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: BETAG

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 353.5997

Number of Means 2
Critical Range 27.42

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	118.84	5	NT
B	61.55	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: DEHYD

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 13.78911

Number of Means 2
Critical Range 5.416

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	39.067	5	NT

B 27.861 5 CT

---------- TRT=CT ----------

Variable	Mean	Std Dev	Std Error
MBC	97.12	31.44	14.06
C	0.65	0.05	0.02
S	0.01	0.00	0.00
N	0.08	0.01	0.00
PH	5.39	0.06	0.02

---------- TRT=NT ----------

Variable	Mean	Std Dev	Std Error
MBC	163.00	38.79	17.35
C	1.22	0.20	0.09
S	0.01	0.00	0.00
N	0.15	0.01	0.01
PH	5.04	0.03	0.01

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
TRT	2	CT NT

Number of observations in data set = 10

Analysis of Variance Procedure

Dependent Variable: MBC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	10847.74826	10847.74826	8.70	0.0184
Error	8	9970.93386	1246.36673		
Corrected Total	9	20818.68212			

R-Square	C.V.	Root MSE	MBC Mean
0.521058	27.14445	35.30392	130.0594

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	10847.74826	10847.74826	8.70	0.0184

Analysis of Variance Procedure

Dependent Variable: C

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.80428960	0.80428960	36.83	0.0003
Error	8	0.17471200	0.02183900		
Corrected Total	9	0.97900160			

R-Square	C.V.	Root MSE	C Mean
0.821541	15.80876	0.147780	0.934800

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	0.80428960	0.80428960	36.83	0.0003

Analysis of Variance Procedure

Dependent Variable: S

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00007508	0.00007508	7.83	0.0233
Error	8	0.00007673	0.00000959		
Corrected Total	9	0.00015180			

R-Square	C.V.	Root MSE	S Mean
0.494559	30.24350	0.003097	0.010240

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	0.00007508	0.00007508	7.83	0.0233

Analysis of Variance Procedure

Dependent Variable: N

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01204090	0.01204090	97.73	0.0001
Error	8	0.00098560	0.00012320		
Corrected Total	9	0.01302650			

R-Square	C.V.	Root MSE	N Mean
0.924339	9.693930	0.011100	0.114500

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	0.01204090	0.01204090	97.73	0.0001

Analysis of Variance Procedure

Dependent Variable: PH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.31329000	0.31329000	167.53	0.0001
Error	8	0.01496000	0.00187000		
Corrected Total	9	0.32825000			

R-Square	C.V.	Root MSE	PH Mean
0.954425	0.829214	0.043243	5.215000

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	0.31329000	0.31329000	167.53	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: MBC

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 1246.367
Critical Value of T= 2.31
Least Significant Difference= 51.489

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	163.00	5	NT
B	97.12	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: C

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 0.021839
Critical Value of T= 2.31
Least Significant Difference= 0.2155

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	1.21840	5	NT
B	0.65120	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: S

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 9.591E-6
Critical Value of T= 2.31
Least Significant Difference= 0.0045

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	0.012980	5	NT
B	0.007500	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: N

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 0.000123
Critical Value of T= 2.31
Least Significant Difference= 0.0162

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	0.149200	5	NT
B	0.079800	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: PH

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 0.00187
Critical Value of T= 2.31
Least Significant Difference= 0.0631

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	5.39200	5	CT
B	5.03800	5	NT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: MBC

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 1246.367

Number of Means 2
Critical Range 51.49

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	163.00	5	NT
B	97.12	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: C

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.021839

Number of Means 2
Critical Range .2155

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	1.21840	5	NT

B	0.65120	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: S

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 9.591E-6

Number of Means 2
Critical Range .004517

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	0.012980	5	NT
B	0.007500	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: N

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.000123

Number of Means 2
Critical Range .01619

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	0.149200	5	NT
B	0.079800	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: PH

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.00187

Number of Means 2
Critical Range .06307

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	5.39200	5	CT
B	5.03800	5	NT

---------- TRT=CT ----------

Variable	Mean	Std Dev	Std Error
CA	1114.42	26.31	11.77
CU	1.27	0.08	0.03
FE	67.00	4.40	1.97
K	83.02	12.71	5.68
MG	204.76	9.07	4.06
MN	33.98	4.34	1.94
NA	22.82	6.16	2.75
P	11.70	1.87	0.84
ZN	0.69	0.11	0.05

---------- TRT=NT ----------

Variable	Mean	Std Dev	Std Error
CA	1109.02	96.94	43.35
CU	1.73	0.61	0.27
FE	85.12	11.41	5.10
K	72.60	12.35	5.52
MG	160.16	15.33	6.86
MN	42.54	2.87	1.28
NA	18.50	2.24	1.00
P	12.56	2.01	0.90
ZN	1.01	0.12	0.05

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
TRT	2	CT NT

Number of observations in data set = 10

Analysis of Variance Procedure

Dependent Variable: CA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	72.90000000	72.90000000	0.01	0.9073
Error	8	40360.4160000	5045.05200000		
Corrected Total	9	40433.3160000			

R-Square	C.V.	Root MSE	CA Mean
0.001803	6.389066	71.02853	1111.720

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	72.90000000	72.90000000	0.01	0.9073

Analysis of Variance Procedure

Dependent Variable: CU

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.51076000	0.51076000	2.71	0.1385
Error	8	1.50884000	0.18860500		
Corrected Total	9	2.01960000			

R-Square	C.V.	Root MSE	CU Mean
0.252902	28.95245	0.434287	1.500000

Source	DF	Anova SS	Mean Square	F Value	Pr > F

TRT	1	0.51076000	0.51076000	2.71	0.1385

Analysis of Variance Procedure

Dependent Variable: FE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	820.8360000	820.8360000	10.97	0.0107
Error	8	598.3480000	74.7935000		
Corrected Total	9	1419.1840000			

R-Square	C.V.	Root MSE	FE Mean
0.578386	11.37040	8.648324	76.06000

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	820.8360000	820.8360000	10.97	0.0107

Analysis of Variance Procedure

Dependent Variable: K

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	271.4410000	271.4410000	1.73	0.2250
Error	8	1256.2880000	157.0360000		
Corrected Total	9	1527.7290000			

R-Square	C.V.	Root MSE	K Mean
0.177676	16.10513	12.53140	77.81000

Source	DF	Anova SS	Mean Square	F Value	Pr > F

TRT	1	271.4410000	271.4410000	1.73	0.2250

Analysis of Variance Procedure

Dependent Variable: MG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	4972.900000	4972.900000	31.34	0.0005
Error	8	1269.284000	158.660500		
Corrected Total	9	6242.184000			

R-Square	C.V.	Root MSE	MG Mean
0.796660	6.903459	12.59605	182.4600

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	4972.900000	4972.900000	31.34	0.0005

Analysis of Variance Procedure

Dependent Variable: MN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	183.1840000	183.1840000	13.55	0.0062
Error	8	108.1800000	13.5225000		
Corrected Total	9	291.3640000			

R-Square	C.V.	Root MSE	MN Mean
0.628712	9.611331	3.677295	38.26000

Source	DF	Anova SS	Mean Square	F Value	Pr > F

TRT	1	183.1840000	183.1840000	13.55	0.0062

Analysis of Variance Procedure

Dependent Variable: NA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	46.65600000	46.65600000	2.17	0.1785
Error	8	171.64800000	21.45600000		
Corrected Total	9	218.30400000			

R-Square	C.V.	Root MSE	NA Mean
0.213720	22.42044	4.632062	20.66000

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	46.65600000	46.65600000	2.17	0.1785

Analysis of Variance Procedure

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.84900000	1.84900000	0.49	0.5042
Error	8	30.25200000	3.78150000		
Corrected Total	9	32.10100000			

R-Square	C.V.	Root MSE	P Mean
0.057599	16.03139	1.944608	12.13000

Source	DF	Anova SS	Mean Square	F Value	Pr > F

TRT	1	1.84900000	1.84900000	0.49	0.5042

Analysis of Variance Procedure

Dependent Variable: ZN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.25921000	0.25921000	20.02	0.0021
Error	8	0.10360000	0.01295000		
Corrected Total	9	0.36281000			

R-Square	C.V.	Root MSE	ZN Mean
0.714451	13.34092	0.113798	0.853000

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TRT	1	0.25921000	0.25921000	20.02	0.0021

Analysis of Variance Procedure

T tests (LSD) for variable: CA

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 5045.052
Critical Value of T= 2.31
Least Significant Difference= 103.59

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	1114.42	5	CT

A			
A	1109.02	5	NT

Analysis of Variance Procedure

T tests (LSD) for variable: CU

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 0.188605
Critical Value of T= 2.31
Least Significant Difference= 0.6334

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	1.7260	5	NT
A			
A	1.2740	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: FE

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 74.7935
Critical Value of T= 2.31
Least Significant Difference= 12.613

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT

A	85.120	5	NT
B	67.000	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: K

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 157.036
Critical Value of T= 2.31
Least Significant Difference= 18.276

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	83.020	5	CT
A			
A	72.600	5	NT

Analysis of Variance Procedure

T tests (LSD) for variable: MG

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 158.6605
Critical Value of T= 2.31
Least Significant Difference= 18.371

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	204.760	5	CT
B	160.160	5	NT

Analysis of Variance Procedure

T tests (LSD) for variable: MN

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 13.5225
Critical Value of T= 2.31
Least Significant Difference= 5.3631

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	42.540	5	NT
B	33.980	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: NA

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 21.456
Critical Value of T= 2.31
Least Significant Difference= 6.7556

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	22.820	5	CT
A			
A	18.500	5	NT

Analysis of Variance Procedure

T tests (LSD) for variable: P

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 3.7815
Critical Value of T= 2.31
Least Significant Difference= 2.8361

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	12.560	5	NT
A			
A	11.700	5	CT

Analysis of Variance Procedure

T tests (LSD) for variable: ZN

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 8 MSE= 0.01295
Critical Value of T= 2.31

Least Significant Difference= 0.166

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRT
A	1.01400	5	NT
B	0.69200	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: CA

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 5045.052

Number of Means 2
Critical Range 103.6

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	1114.42	5	CT
A			
A	1109.02	5	NT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: CU

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.188605

Number of Means 2
Critical Range .6334

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	1.7260	5	NT
A			
A	1.2740	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: FE

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 74.7935

Number of Means 2
Critical Range 12.61

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	85.120	5	NT
B	67.000	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: K

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 157.036

Number of Means 2
Critical Range 18.28

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	83.020	5	CT
A			
A	72.600	5	NT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: MG

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 158.6605

Number of Means 2
Critical Range 18.37

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	204.760	5	CT
B	160.160	5	NT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: MN

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 13.5225

Number of Means 2
Critical Range 5.363

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	42.540	5	NT
B	33.980	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: NA

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 21.456

Number of Means 2
Critical Range 6.756

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	22.820	5	CT
A			
A	18.500	5	NT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: P

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 3.7815

Number of Means 2
Critical Range 2.836

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	12.560	5	NT
A			
A	11.700	5	CT

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: ZN

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 8 MSE= 0.01295

Number of Means 2
Critical Range .1660

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TRT
A	1.01400	5	NT
B	0.69200	5	CT

APPENDIX 2: SOIL QUALITY (HEALTH) CARDS

What is Soil Quality?

Some use the terms "soil quality" and "soil health" interchangeably. Basically, soil quality is the ability of the soil to:

1. support plant and animal life,
2. absorb and hold water, and
3. act as an environmental buffer.

Soil quality is very important. If we have good soil quality, we will have productive land, a healthy environment, good water quality,and good air quality. How we manage our soil greatly affects its quality.

Field Notes

Current field management (tillage, fertilizer, irrigation, crop rotation, other):

_____

_____

_____

_____

Ideas for changes in field management:

_____

_____

_____

_____

For more information on soil quality, contact your USDA Natural Resources Conservation Service office, county extension agent, the Georgia Conservation Tillage Alliance, Inc., or agribusiness representatives.

Georgia
Conservation
Tillage
Alliance

Soil Quality Card

for

Georgia

A Locally Adapted Tool Designed by Farmers for Farmers

About This Card

The **Soil Quality Card for Georgia** is a locally adapted field tool designed by Georgia farmers in collaboration with the Georgia Conservation Tillage Alliance, Inc. and the USDA-Natural Resources Conservation Service (NRCS). The card was designed by farmers for farmers.

It was developed to help users evaluate changes in soil quality as affected by field management. Regular use will allow you to record long term changes in soil quality among different fields and various farming systems. In addition to its use by farmers, the card can also be used by agricultural support professionals such as soil conservationists, soil scientists, county agents, and agribusiness representatives.

How to Use the Card

Tools Required

A shovel and a wire flag or probe

Soil Quality Assessment

Select a field for evaluation and record the field ID on the Soil Quality Card. Use the Field Notes/Inputs Sheet to enter any other significant information such as inputs, crops, weather, or field conditions.

Turn over a shovel full of soil (about 6-8" deep). On the Soil Quality Card, rate each indicator by marking an **X** or shading out the box that best represents the value for that indicator.

Determine compaction by simply pushing the wire flag or probe into the soil and noting the resistance.

Notes

- Assessments are most effective when filled out by the same person over time and under similar soil moisture levels.

- Assessments are qualitative, therefore, evaluation scores do not represent any absolute measure.

-Assessing more than one spot per field will provide a more representative assessment.

- Card users should examine the distribution of indicator values. Ideally, one would prefer to see all of the properties score in the preferred category of 10. Even if 90% or more of the indicators you scored are healthy, the soil may still have serious problems with the remaining properties.

-For the indicators needing improvement, careful consideration is necessary to identify what caused the property to be in a less than optimum condition.

-The impaired indicator properties should be closely monitored to determine if they are deteriorating or improving. Some properties may need immediate attention and action.

-It is recommended that evaluations be done periodically (at least once every three years) to document changes in soil quality.

-Keep completed cards on file for future reference.

No-till

Soil Quality Card for Georgia

Date:_____ Evaluation By:_____ County:_____ Farm:_____ Field:_____

Crop:_____ Soil Moisture (Check One) _____Good for planting; _____Too dry for planting; _____Too wet for planting

Indicator	Observations	1	2	3	4	5	6	7	8	9	10	1	5	10
		→ Preferred[1]												
1. Crop Growth												Uneven stand; stunted growth; discoloring common	Some uneven stand & stunted growth; slight discoloring	Even stand; healthy; vigorous; uniform
2. Soil Erosion												Excessive soil movement by water and/or wind	Some visible soil movement by water and/or wind	Little or no soil movement by water and/or wind
3. Soil Fertility[2]											X	More than two elements not within UGA recommendations	Two elements not within UGA recommendations	All elements within UGA recommendations
4. Soil pH[2]						X						pH 1.0 lower than needed	pH 0.5 lower than needed	Proper pH for the crop
5. Surface Soil Color												White, light gray, or red	Dark gray or light brown	Dark brown or black
6. Soil Tilth & Structure												Cloddy; hard; crusty; difficult to work	Some visible crumbly structure	Crumbly; mellow (loamy); easily worked
7. Water Infiltration/ Holding Capacity												Excessive runoff; ponding; or v. low water holding capacity	Some runoff; some ponding; or poor water holding capacity	Low rates of runoff; no ponding; & good water holding capacity
8. Biological Activity											X	Little or no signs of animal life in the soil	Some living organisms or signs of activity in the soil	Numerous signs of animal life in the soil
9. Compaction & Crusting												Can not push flag/probe into soil; crusting is prevalent	Can push flag/probe into soil with force; some crusting	Flag/probe enters soil easily; no crusting
10. Crop Residue Right After Planting										X		<30% of the soil surface covered with crop residue	50% of the soil surface covered with crop residue	>70% of the soil surface covered with crop residue
11. Winter Cover Crop						X						No living or dead cover on the soil surface	50% of soil surface is covered by cover crop/weeds	90% stand of introduced species of cover crop
12. Soil Organic Matter (O.M.)[2]											X	<1% O.M. in the top 1/2 inch of soil	1-2% O.M. in the top 1/2 inch of soil	>2% O.M. in the top 1/2 inch of soil
13. Other Indicator(s)														

[1]Ratings 1 to 5 and 5 to 10 are comparative and are determined by the user.

[2]Lab Analysis Needed

What is Soil Quality?

Some use the terms "soil quality" and "soil health" interchangeably. Basically, soil quality is the ability of the soil to:

1. support plant and animal life,
2. absorb and hold water, and
3. act as an environmental buffer.

Soil quality is very important. If we have good soil quality, we will have productive land, a healthy environment, good water quality,and good air quality. How we manage our soil greatly affects its quality.

Field Notes

Current field management (tillage, fertilizer, irrigation, crop rotation, other):

_____

_____

_____

_____

Ideas for changes in field management:

_____

_____

_____

_____

For more information on soil quality, contact your USDA Natural Resources Conservation Service office, county extension agent, the Georgia Conservation Tillage Alliance, Inc., or agribusiness representatives.

Georgia
Conservation
Tillage
Alliance

Soil Quality Card

for

Georgia

A Locally Adapted Tool Designed by Farmers for Farmers

About This Card

The **Soil Quality Card for Georgia** is a locally adapted field tool designed by Georgia farmers in collaboration with the Georgia Conservation Tillage Alliance, Inc. and the USDA-Natural Resources Conservation Service (NRCS). The card was designed by farmers for farmers.

It was developed to help users evaluate changes in soil quality as affected by field management. Regular use will allow you to record long term changes in soil quality among different fields and various farming systems. In addition to its use by farmers, the card can also be used by agricultural support professionals such as soil conservationists, soil scientists, county agents, and agribusiness representatives.

How to Use the Card

Tools Required

A shovel and a wire flag or probe

Soil Quality Assessment

Select a field for evaluation and record the field ID on the Soil Quality Card. Use the Field Notes/Inputs Sheet to enter any other significant information such as inputs, crops, weather, or field conditions.

Turn over a shovel full of soil (about 6-8" deep). On the Soil Quality Card, rate each indicator by marking an **X** or shading out the box that best represents the value for that indicator.

Determine compaction by simply pushing the wire flag or probe into the soil and noting the resistance.

Notes

- Assessments are most effective when filled out by the same person over time and under similar soil moisture levels.

- Assessments are qualitative, therefore, evaluation scores do not represent any absolute measure.

-Assessing more than one spot per field will provide a more representative assessment.

- Card users should examine the distribution of indicator values. Ideally, one would prefer to see all of the properties score in the preferred category of 10. Even if 90% or more of the indicators you scored are healthy, the soil may still have serious problems with the remaining properties.

-For the indicators needing improvement, careful consideration is necessary to identify what caused the property to be in a less than optimum condition.

-The impaired indicator properties should be closely monitored to determine if they are deteriorating or improving. Some properties may need immediate attention and action.

-It is recommended that evaluations be done periodically (at least once every three years) to document changes in soil quality.

-Keep completed cards on file for future reference.

Conventional Till

Soil Quality Card for Georgia

Date:_____ Evaluation By:_____ County:_____ Farm:_____ Field:_____

Crop:_____ Soil Moisture (Check One) _____Good for planting; _____Too dry for planting; _____Too wet for planting

Indicator	Observations	1	2	3	4	5	6	7	8	9	10	1	5	10
		→ Preferred[1]												
1. Crop Growth												Uneven stand; stunted growth; discoloring common	Some uneven stand & stunted growth; slight discoloring	Even stand; healthy; vigorous; uniform
2. Soil Erosion												Excessive soil movement by water and/or wind	Some visible soil movement by water and/or wind	Little or no soil movement by water and/or wind
3. Soil Fertility[2]								X				More than two elements not within UGA recommendations	Two elements not within UGA recommendations	All elements within UGA recommendations
4. Soil pH[2]										X		pH 1.0 lower than needed	pH 0.5 lower than needed	Proper pH for the crop
5. Surface Soil Color												White, light gray, or red	Dark gray or light brown	Dark brown or black
6. Soil Tilth & Structure												Cloddy; hard; crusty; difficult to work	Some visible crumbly structure	Crumbly; mellow (loamy); easily worked
7. Water Infiltration/ Holding Capacity												Excessive runoff; ponding; or v. low water holding capacity	Some runoff; some ponding; or poor water holding capacity	Low rates of runoff; no ponding; & good water holding capacity
8. Biological Activity						X						Little or no signs of animal life in the soil	Some living organisms or signs of activity in the soil	Numerous signs of animal life in the soil
9. Compaction & Crusting												Can not push flag/probe into soil; crusting is prevalent	Can push flag/probe into soil with force; some crusting	Flag/probe enters soil easily; no crusting
10. Crop Residue Right After Planting		X										<30% of the soil surface covered with crop residue	50% of the soil surface covered with crop residue	>70% of the soil surface covered with crop residue
11. Winter Cover Crop						X						No living or dead cover on the soil surface	50% of soil surface is covered by cover crop/weeds	90% stand of introduced species of cover crop
12. Soil Organic Matter (O.M.)[2]						X						<1% O.M. in the top 1/2 inch of soil	1-2% O.M. in the top 1/2 inch of soil	>2% O.M. in the top 1/2 inch of soil
13. Other Indicator(s)														

[1]Ratings 1 to 5 and 5 to 10 are comparative and are determined by the user.

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Centers

at Piketon

The Ohio State University Extension

The Ohio State University OARDC

Aquaculture, Business & Economic Development, Forestry, Horticulture, Soil & Water Resources

Soil & Water Resources Program

SWR - 1

OHIO SOIL HEALTH CARD

What Is the Ohio Soil Health Card?

The Ohio Soil Health Card evaluates a soil's health or quality as a function of soil, water, plant, and other biological properties identified by farmers. This Card was ***developed for farmers by farmers*** with assistance from Ohio State University Extension and the Natural Resources Conservation Service (USDA-NRCS). The Card is a tool to help you monitor and improve soil health based on your own field experience and a working knowledge of your soils. Regular use will allow you to record long-term trends and changes in soil health and to compare the effects of different soil management practices. This Card is most effective when filled out consistently by the same person over time. It provides a qualitative assessment of soil health, evaluation ratings do not represent an absolute measure or value. ***The purpose is not to measure one soil type against another, but rather to use indicators that assess each soil's ability to function within its capabilities and site limitations***

How Do You Use the Ohio Soil Health Card?

Step 1) The only tools required to use the Card are a pencil & a shovel or spade

Step 2) Use the chart on the back page for the best times to assess each indicator of soil quality & health

Step 3) Divide your farm & fields into separate sections for evaluation in the same way you would divide them for soil-fertility sampling: separate by factors like soil type, topography, and history of tillage, crop rotation & manure application

Step 4) Enter the **Date & Field Identification** information at the top of the Card

Step 5) Select 2-3 representative spots in your field & evaluate each soil **Indicator**

Step 6) Read the **Descriptive Ratings** in the rectangular boxes, and based on your judgement rate the indicator **Good, Fair,** or **Poor** by checking the small square in the lower left-hand corner of the box with the best description

Step 7) In the **Notes** section following each group of soil health indicators, record any observations or soil conditions that will help you review & evaluate your ratings

Step 8) Follow changes in each of the soil health indicators over time, examine current field management practices, and explore options & consider alternatives for management changes in problem areas

OHIO SOIL HEALTH CARD

Date: _____ Field Identification: No-till

Indicators	Descriptive Ratings		
	Good	***Fair***	***Poor***
SOIL TILTH			
Structure	☐ Good crumb structure, tills easily leaving no clods, soil breaks apart easily	☐ Moderate crumb structure, some clods, soil breaks apart with some pressure	☐ Hard, tills with difficulty, tillage creates lots of clods
Crusting	☐ Soil maintains open/porous surface all growing season, seedling emergence not affected	☐ Some surface sealing, minimal effect on seedling emergence	☐ Soil surface seals easily after tillage and rain events, inhibits seedling emergence
Compaction	☐ Loose soil, unrestricted root penetration	☐ Firm soil, root penetration somewhat restricted	☐ Hard layers, tight soil, severely restricted root penetration

Notes:

SOIL LIFE			
Earthworms	☒ Lots of earthworms, many holes and casts	☐ Some earthworms, few holes and casts	☐ No visible signs of earthworm activity
Smell	☐ Soil has a fresh, earthy smell	☐ Soil has little or no smell	☐ Soil has a swampy, stagnant smell
Residue Decomposition	☒ Residue at various stages of decomposition on soil surface and in the topsoil	☐ Some visible, non-decomposed residue in the topsoil	☐ Rapid decomposition with little or no visible residue in the topsoil <u>or</u> very slow decomposition with relatively unweathered residue in the topsoil

Notes:

SOIL AIR & WATER			
Drainage	☐ Soils drain and warm quickly in spring, limited delays in field operations, good balance between air and water in the soil, yield reduction in only very wet years	☐ Soils drain and warm more slowly in spring, some delays in field operations, water-logged after heavy rains, minimal yield reduction	☐ Soils stay wet for long periods, delays in field operations, soil doesn't breathe, reduces yields

Indicators	Descriptive Ratings: *Good*	*Fair*	*Poor*
Water-Holding Capacity	☐ Soil holds water well, deep topsoil for water storage, crops seldom suffer from moderate dry spells	☐ Soil has moderate capacity to hold water, crops are not the first in the area to suffer from dry weather	☐ Soil has limited capacity to hold water, crops suffer in moderate dry spells
Water Movement	☐ Rainfall soaks in, very little runoff & erosion, water does not pond	☐ Absorbs water, but more slowly, some runoff & erosion, ponding after heavy rains	☐ Absorbs water very slowly, lots of runoff & erosion, ponding after moderate rains

Notes:

PLANT VIGOR

Uniformity in Growth & Color	☐ Uniform deep-green color, rapid growth, even stand (height and population), no visible signs of stress	☐ Some variation in color, height, and population, moderate growth, mild stress	☐ Uneven color, variable height and population, stunted and stressed, nutrient deficiency symptoms
Seedling Emergence	☐ Rapid and even emergence	☐ Some variability in emergence	☐ Slow and uneven emergence
Root Systems	☐ Healthy, uninhibited root growth, lots of fine roots	☐ Root growth somewhat restricted, some fine roots	☐ Restricted root growth, few fine roots

Notes:

FERTILITY MANAGEMENT

Nutrient Levels	☒ Soil test levels are adequate for planned crops and yield goals, no visible signs of plant nutrient deficiency	☐ One or more soil test levels are less than adequate for planned crops and yield goals, no visible signs of plant nutrient deficiency	☐ One or more soil test levels are deficient **or** excessive for planned crops and yield goals, visible signs of plant nutrient deficiency may be present
Soil pH	☐ pH levels are within the acceptable range for the planned crops	☐ pH levels slightly above or below the acceptable range for planned crops	☒ pH levels are too high or too low for the planned crops
Organic Matter	☒ Organic matter levels are being maintained or increasing, dark, friable, with good structure	☐ Organic matter levels can be improved, some crusting and clods	☐ Organic matter levels are decreasing, light-colored, crusted, cloddy, hard

Notes:

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