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Contrasting Soil Management Practice, Nitrogen Source, and Harvest Method Effects on Corn Production in Ohio and Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Casey Theresa Sullivan entitled "Contrasting Soil Management Practice, Nitrogen Source, and Harvest Method Effects on Corn Production in Ohio and Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental and Soil Sciences.

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Contrasting Soil Management Practice, Nitrogen Source, and Harvest Method Effects on Corn Production in Ohio and Tennessee

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All figures and tables without citations were taken or created by the author.

This thesis is dedicated to my parents, Jann and Gregg Sullivan, who taught me determination, diligence, and patience. This thesis would not have been completed without your tireless love and support; and to Dr. Neal Eash, my mentor and friend.

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Abstract

Current global agricultural production is completed with little regards to sustainable soil use. It is clear that the research and use of sustainable management practices must be expanded in order to preserve this natural resource. The objectives of this research were to focus on improving soil fertility and resource use efficiency by 1) evaluating farm management practices to find those that conserve soil and improve yields, 2) looking at alternative methods of fertilizing through the reuse of waste materials in agriculture. The last objective was to 3) test a more efficient method data collection and research production, resulting in more rapid outreach and use of sustainable methods.

A study initiated in May 2015 in Ohio compared no-till (NT) and tillage (T) management practices by examining the release of preserved nitrogen (N) from a soil that has been under long-term no-till corn and soybean production. Crop N sufficiency and yields from the T and NT treatments were compared at varying urea application rates. The results showed that the T whole plot consistently provided higher N uptake, crop productivity, and yields when compared to the NT whole plot, but results may have been influenced by unusually high rainfall following fertilizer application.

A study initiated in May 2015 in Tennessee tested the use of an industrial byproduct, spent microbial biomass (SMB) as a potential N source for corn. The biomass was compared at varying rates to the current farmer urea application rate. Nitrogen availability and crop uptake was compared within the treatments and no significant differences between the urea treatment and SMB treatment yields were found, indicating that SMB could offer a sufficient source of N in local corn production.

To improve efficiency in corn research and data collection, a reduced effort hand-harvest method was compared to the currently accepted method in the Ohio and Tennessee studies. Yields extrapolated using the ten plant harvest method and the current hand harvest method were not found to be significantly different in either study ($p>0.05$). These results indicate the potential use of this method in future maize studies to improve project efficiency and increase research production.

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Nomenclature

A	acre
˚C	degrees Celsius
cm	centimeter
bu	bushels
bu A^{-1}	bushels per acre
ha	hectares
in	inch
kg	kilogram
kg ha^{-1}	kilograms per hectare
kg N ha^{-1}	kilograms of N per hectare
lb T^{-1}	lbs per ton
plants ha^{-1}	plants per hectare
m	meter
m s^{-1}	meter per second
Mg	megragam
Mg ha^{-1}	megagrams per hectare
T	U.S. ton
t	metric tonne
Tg	teragram
T A^{-1}	tons per acre
t ha^{-1}	tonnes per hectare

Conversions

1 cm = 2.54 in
1 m = 3.28 ft
1 ha = 2.47 A
1 kg = 2.20 lbs
1 T = 2,000 lbs
1t = 2,205 lbs
1 Mg = 1t
1 bu corn = 56 lbs
1 kg ha^{-1} = 0.89 lbs A^{-1}
1 °C = (°F – 32) * 5/9

0°C = 32°F (freezing)
37°C = 98.6°F (body temperature)
100°C = 212°F (boiling)

List of Abbreviations

ABR	Average bulk reading of the plot
ARR	Average reference strip reading
ASA	American Statistical Association
ANOVA	Analysis of Variance
C	Carbon
CH_4N_2O	Urea
CO_2	Carbon dioxide
CA	Conservation Agriculture
CRP	Conservation Reserve Program
CSP	Conservation Stewardship Program
CT	Conventional tillage
CTIC	Conservation Technology Information Center
DESA	Department of Economic and Social Affairs of the United Nations
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
K	Potassium
LCA	Life Cycle Assessment
LSSMB	Lime stabilizes spent microbial biomass
N	Nitrogen
NaOH	Sodium hydroxide
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared light
NO_3^-	Nitrate
NT	No till
NRCS	Natural Resource Conservation Service
OH	Ohio
OM	Organic
P	Phosphorus
PDO	1,3 propanediol
PET	polyethylene terephthalate
R	Reproductive stage
SAS	Statistical Analysis Software
SCS	Soil Conservation Service
SOM	Soil organic matter
SMB	Spent microbial biomass
SPAD	Soil Plant Analysis Division
T	Tillage
TN	Tennessee
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTK	University of Tennessee, Knoxville
V	Vegetative stage
VIS	Visible light
WSS	Web Soil Survey

Chapter 1
Literature Review

A Growing Population

Innovations in agriculture and medicine have allowed the global human population to exponentially increase over time. While we are now able to grow more food and extend life expectancies to levels higher than ever before, we need to remember that land, water, and food resources are limited. From 2010 to 2014, the global population growth rate was 1.2% per year, adding 82 million in 2014 alone (DESA, 2014). Continual growth at this rate will lead to a world population exceeding 9.5 billion by 2050 (DESA, 2014). The largest challenge that the millennial generation will face is finding resources to support an additional 2.3 billion people in the next 35 years.

In order to meet these demands, food production will need to be increased while resource use per capita declines. Based on population projections from 2005, the FAO estimated that global food production will need to increase by 70% by 2050 (FAO, 2009). Only 11% (13.4 billion ha) of global land surface is under cropland, with about 17% (165 million ha) in the U.S. (Alexandratos & Bruinsma, 2012, USDA, 2012). While there is an estimated 2.7 billion ha left with the potential for crop production, this land will have to compete with land for forests, grazing, cities, and industries (Alexandratos & Bruinsma, 2012). From this, it is evident that research efforts should focus on increasing productivity and cropping intensity on current cropland, while expanding cultivation onto more marginal lands.

Adding to the problem of increased agricultural demands is the degradation of our current cropland, decreasing productivity and causing negative offsite environmental impacts. In the past 50 years, human land use has degraded 5 billion ha of Earth's vegetated land (Brady & Weil, 2008). Agriculture has a large role in this degradation (Figure 1.1). Global agricultural soil loss is estimated at 75 billion tonnes (t) of soil each year (Pimentel & Burgess, 2013). In the U.S. alone,

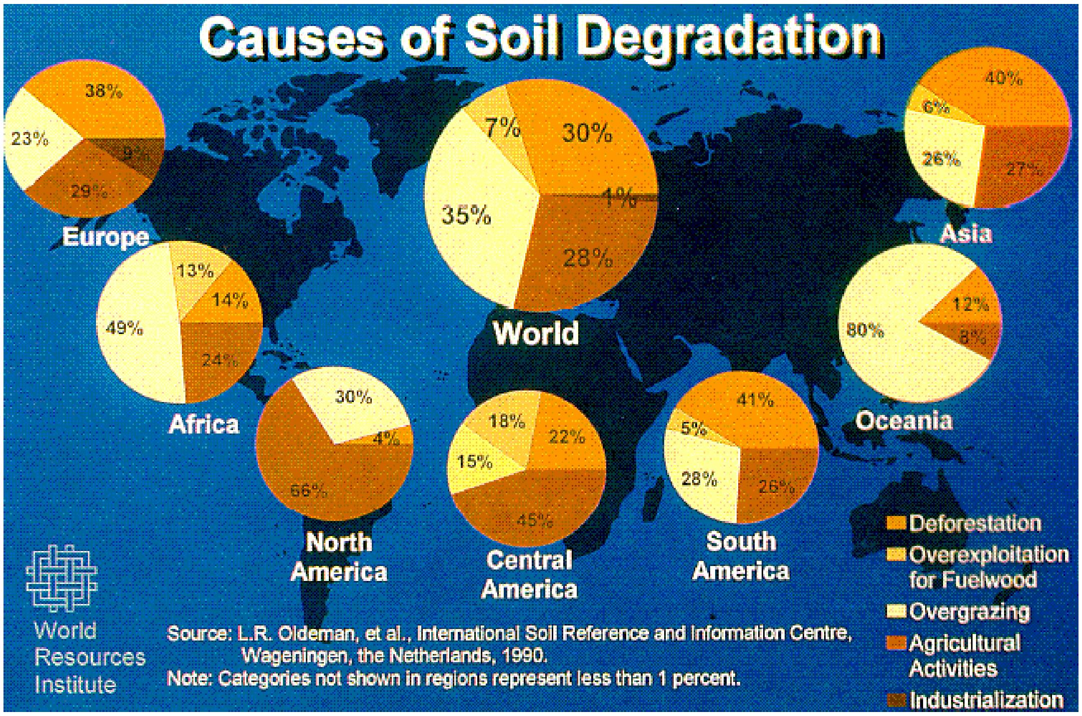

Figure 1.1. World map of human-induced soil degradation (Oldeman et al., 1990)

unsustainable agricultural practices cause an average annual erosion rate of 12 Mg of soil ha^{-1} from cropland. When we consider that it can take hundreds of years to form 2.54 cm (1 in) of topsoil, it is clear that erosion is occurring at an alarming rate which could threaten the future of food production.

There is a clear connection between soil quality and a nation's food production, health, and economy. The countries struggling with hunger today are those with the poorest soils, who must spend most of their day trying to attain enough food for survival. As of December 2015, 33 countries reported the need for external assistance for food (FAO, 2015). The countries listed were those that have soils with the poorest quality and the largest populations, and were predominantly African, Middle Eastern and Asian.

We need to produce more food than ever before, but must do so responsibly and sustainably in order to preserve essential resources for future generations. In order to meet the

growing demand for world crop resources, we need to improve soil fertility and resource use efficiency. This can be done by: 1) evaluating our farm management practices to find those that conserve soil and improve yields, 2) by looking at alternative methods of fertilizing and the reuse of waste materials in agriculture, and 3) by increasing the rate of research and outreach promoting sustainable practices.

Management Practices

Throughout history, tillage has been the predominant soil management technique. Tillage involves some form of soil disturbance in order to improve the quality of the seedbed and soil to seed contact, while decreasing the influence of pests and weeds on growing crops. Evidence of early tillage in agriculture has been found as far back as the Sumerian and Ancient Egyptian civilizations around ten thousand years ago (Derpsch, n.d.).

The earliest tillage was done using simple digging sticks, hoes, and then wooden plows, or "ards" developed by the Mesopotamians in 4000-6000 B.C. (Lal et al., 2007). By 1 A.D., the Romans were using plows, and the first iron plow was used by 500 A.D. in Europe (Lal et al., 2007). The first plow that inverted soil was used in Europe between 800-1000 A.D. (Lal et al., 2007). In the U.S., Thomas Jefferson designed a moldboard plow in 1784 (Lal et al., 2007), though others cite the use of the first moldboard plow in 1500 A.D. in Europe (McKyes, 1985). These plows completely inverted the topsoil of a field and left the soil loose and ready for planting. These early innovations paved the way for large-scale crop production and resulted in exponential increases in food production, but little regard was given to the negative side effects of such heavy soil disturbance.

The issue became most apparent only recently, as a result of the 1930's Dust Bowl in Midwestern America. Due to a culmination of factors, wheat production in the Midwest skyrocketed, resulting in the soil's exhaustion by tillage and monoculture cultivation (Lal et al., 2007). A series of droughts hit the country in 1931, leaving the soil loose, dry, and easily swept up by the wind into massive dust storms. After almost ten years of desperation and infertility, the droughts finally subsided in 1940. In 1935, the U.S. government created the Soil Conservation Service (SCS) to encourage farm management practices that would conserve soil instead of leaving it bare and susceptible to erosion (IRR & ACT, 2005).

The 1985 Farm Bill created the conservation reserve program (CRP), a program where the government would pay farmers subsidies to conserve their soil by increasing and maintaining soil cover. An article published eight years later in 1993 cites the success of program as 377,000 contracts covering 80% of cropland in the U.S., reducing soil erosion by 700 million T yr^{-1} (Osborne, 1993). The use of the CRP continues today, now paired with the conservation stewardship program (CSP) established by the 2014 Farm Bill (Bill, 2014).

Conservation Agriculture and No-Till

Conservation Agriculture (CA) is one practice that came out of the SCS and is still used today in order to meet the requirements of CRP and CSP contracts. In contrast to conventional tillage, CA focuses on improving soil quality and reducing the demands of time, labor, and fuel that plowing requires. This practice is composed of three principles: 1) decreased soil disturbance through minimal or no tillage (no-till), 2) permanent soil cover, and 3) diversified crop rotations (FAO, 2012). While the combination of all three components would result in the

greatest soil improvement, economic and temporal restrictions often cause many farmers to implement only one or two components to meet their soil quality goals.

No-till was probably the most influential shift in agricultural management that lead to decreasing soil loss. The UNFAO reported that in just nine years (1999-2008), the world's cropland under no-till more than doubled from 45 million to 105 million ha (Derpsch et al., 2010). In 2007, the U.S. led the world in no-till cropland with just over 25.29 million ha (CTIC, 2007).

The use of no-till as a management practice in large scale crop production only evolved fairly recently, after the development of plant selective herbicides such as 2,4-D and paraquat in the 1940's, making weed control more feasible for no-till fields (Lal et al., 2007, Phillips et al.,1998). Some of the earliest research on no-till machinery occurred early in the 1960's and the first commercial no-till planter was introduced by Allis-Chalmers in 1966 (Derpsch, 1998). These early planters were used mostly for research, but the evidence of their effect on soil conservation while maintaining vegetable yields got many farmers excited about this alternative to tillage. By the early 1990s, effective commercial no-till planters such as B&B No-Till's Subsurface Tiller-Transplanter, were being sold throughout the country (Coughenour, 2003).

No-till systems generally have higher amounts of soil organic matter (SOM) and soil nutrients than tillage systems. Tilling the soil breaks down organic matter quickly by incorporating above ground organic carbon (C) and aerating the soil for microbes. This rapid decomposition causes the loss of soil carbon as carbon dioxide (CO_2). Conversely, no-till systems reduce the rate of decomposition, resulting in a build-up of nutrients over time. Arshad et al. (1990) found soil organic C and N were 26% higher in a no-till silt loam under continuous barley compared to the same tilled soil. Alvarez et al. (1995) compared no-till, chisel tillage, and

plow tillage under a corn-wheat and soybean rotation and found that the no-till plot had 42-50% greater organic carbon than the chisel and plow treatments at a depth of 0-5 cm, and 5-8% greater than the plow treatment at the 0-20 cm depth.

No-till fields also have higher macroporosity than tilled fields due to rotting plant roots and active soil fauna such as earthworms. Macropores improve infiltration, drainage, and aeration in the soil, allowing plant roots to move more freely. Cullum (2009) studied infiltration rates of a no-till and tilled Loring silt loam. He found that for 5 hour and 3 hour storms, the no-till plots had higher preferential flow on a mass basis at 55% and 18%, compared to the tilled at 28% and 35%, respectively. Savabi et al. (1992) also studied paired no-till and till systems and found that no-till had higher infiltration rates than the till on silt loam and silty clay loam soils. The researchers determined that this result was directly related to the increased number of earthworms and plant residues on the no-till fields.

No-till soils are protected from erosion by the crop residues on the soil surface and increased aggregation. In a tilled field, the soil surface is broken up and left bare on a regular basis, exposed to erosion by wind and water. A paired watershed study in Nigeria compared soil erosion from no-till and tilled soils in continuous corn. The results were that over three growing seasons, the tilled watershed had approximately three times greater annual soil erosion and runoff than the no-till watershed (Lal, 1984). Another paired drainage study compared no-till and inversion tillage in Oregon and found that runoff and erosion were drastically higher in the inversion tillage plot (0.20 in of runoff, 0.19 T A^{-1} of erosion) compared to the no-till plot (0.03 in, 0.00 T A^{-1}) (Williams & Wuest, 2011).

Despite evidence of the positive impacts of no-till, the conversion from tillage has been slow. Figure 1.2 shows the U.S. areas under no-till both as counties and watersheds. The areas

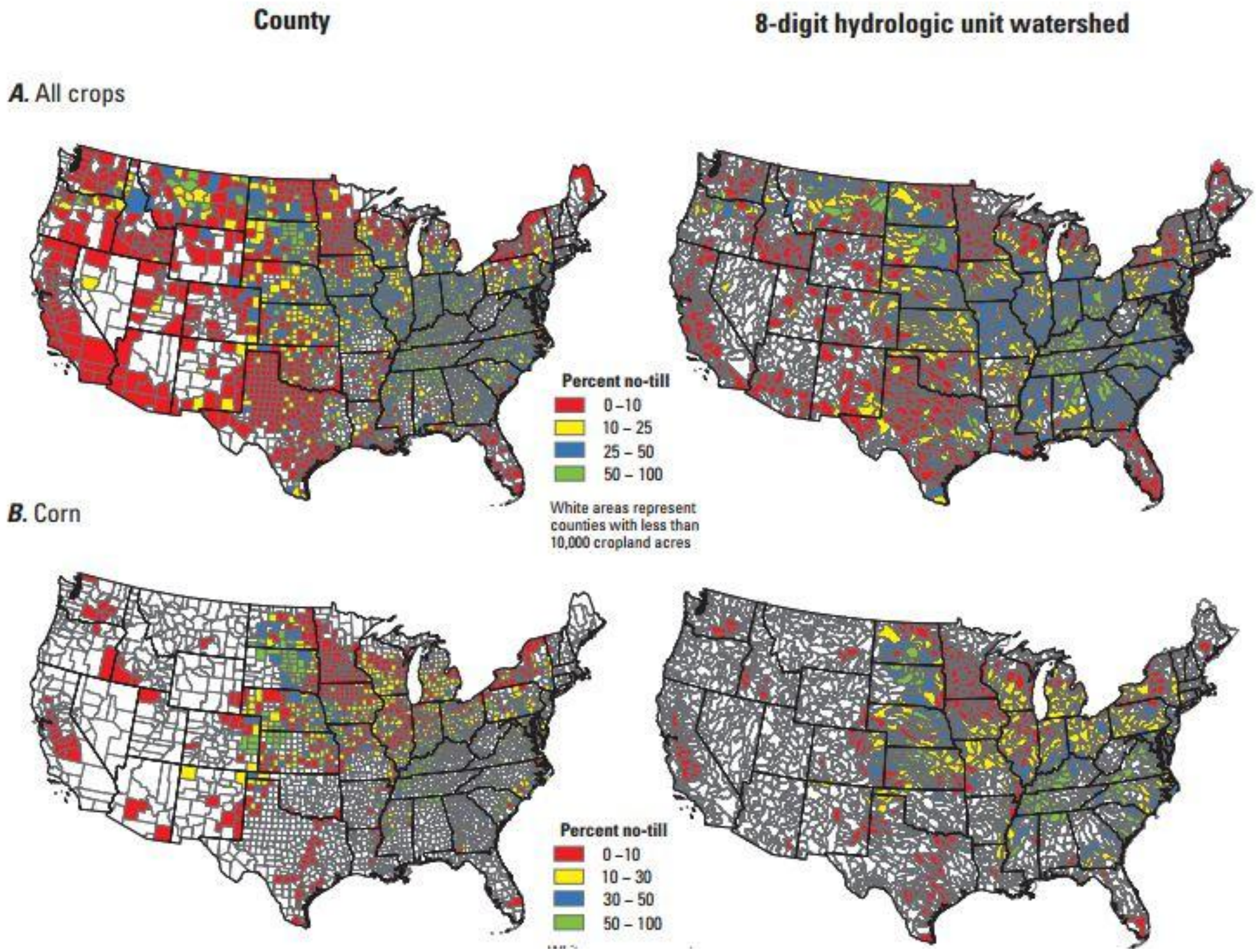

Figure 1.2. U.S. counties and watersheds under no-till agriculture in 2004 (Baker, 2011).

with the highest amount of cropland under no-till (50-100% of the county/watershed) are found primarily in the Southeast and the eastern states of the Midwest. Much of the West and Midwest U.S. farmers are still using some form of tillage in their agricultural practices. Phillips et al. (1998) estimated that by the year 2000, 45% of the U.S. cropland would be under no-till production, and rising. This so far has not been the case. A 2008 Crop Residue Management Survey by the CTIC found that only 23.7% of total planted acres and 21% of acres planted in corn were under no-till (CTIC, 2008). This indicates that some form of tillage is still used on three quarters of U.S. cropland.

Nitrogen Fertilizers and Alternative Sources

Nitrogen is one of the three essential plant macronutrients, and is often considered the most important for plant growth, chlorophyll production, and protein synthesis (Savoy, n.d.). Plants can take up N as either a cation or an anion, in the forms of ammonium (NH_4^+) or nitrate (NO_3^-). Some plants may also be able to directly take up N in the form of urea (CH_4N_2O) (Mattson et al., 2009).

Chemical N fertilizer production has been made possible by the Haber-Bosch process, invented in 1909 by Fritz Haber and Carl Bosch (Smil, 1999). The process uses natural gas to convert atmospheric N_2 gas into ammonia (NH_3). Today, Haber-Bosch is used on the industrial scale to produce nearly 100 teragrams (Tg) of N fertilizers per year (Erisman et al., 2008), and many argue that this may have been the most important invention of the 20th century, allowing increased food production to support an exponentially growing population.

Nitrogen can be applied as either a solid or a liquid. Available solid N fertilizers include ammonium nitrate (33.5% N), ammonium sulfate (20.5%), calcium nitrate (15.5%), cal-nitro (ammonium nitrate + limestone) (26.5%), diammonium phosphate (18%), and urea (46%) (Mengel, n.d.). Common liquid N fertilizers include anhydrous ammonia (82%), aqua ammonia (anhydrous ammonia + water) (20-25%), low-pressure N solutions (ammonium nitrate-urea-ammonia-water) (37-41%), and non-pressure N solutions (urea-ammonium nitrate-water or UAN) (28-32%) (Mengel, n.d.). In Tennessee, the most commonly available N fertilizers are anhydrous ammonia, urea, ammonium nitrate, liquid UAN solutions, and ammonium sulfate (Savoy, n.d.).

These chemical fertilizers do come at a cost. The 2015 UT Field Crop Budget estimated that in the production of no-till non-irrigated corn at 9.42 t ha^{-1} (150 bu A^{-1}), fertilizers comprised 25% of total production costs at \$360 ha^{-1}. Of this budget, urea was the most expensive amendment, making up 62% of total fertilizer costs and 15% of total production costs at \$222 ha^{-1} when applied at 190 kg N ha^{-1} (Smith, 2015).

Much of the cost of N fertilizers is directly tied to the cost of the natural gas used to produce it. Natural gas makes up 72-85% of the cost of producing ammonia (Huang, 2007).The amount of ammonia made in the U.S. is strongly affected by the price of natural gas, and relatively high natural gas prices in the U.S. have caused decreased production and increased importation in recent years.

Aside from the expense, there are several other problems with the use of N fertilizers. The application itself can be dangerous, especially with liquid forms at very high pressures and N concentrations. Anhydrous ammonia is flammable, can damage the respiratory system of the

applier at very low exposure, and even cause death (Savoy, n.d.). Many N fertilizers also decrease the pH of the soil, so additional costs are incurred through increased lime requirements.

The environmental consequences of N fertilizers are also of high concern. Because both inorganic forms of N are soluble in water, nitrogen can easily be lost to runoff or leached out of the soil profile into groundwater. This issue is especially severe if fertilizer application is followed by heavy rainfall. High N levels in surface waters cause eutrophication, and groundwater contamination can lead to health problems such as blue baby syndrome. The onsite impact of N loss on the farm is either the cost of applying additional fertilizer or the loss in yield.

Because of all of these issues, research into alternative, renewable sources of N has been increasing in recent years. Organic N sources include plant materials such as composts, cover crops, pelleted plant meals, and animal products such as manure, poultry litter, and blood and bone meals. While organic inputs are usually less expensive than fertilizers, they often provide fewer nutrients and result in decreased yields when compared to chemicals.

Spent Microbial Biomass

Spent microbial biomass (SMB) is an N source option for East Tennessee farmers (Figure 1.3). SMB is the by-product of the production of 1,3 propanediol (PDO) at DuPont Tate and Lyle, LLC, in Loudon, Tennessee. PDO is used in the production of the Sonora® 3GT polymer used in fibers for clothing and carpets, films and packaging, and engineering components. PDO was recently developed as an alternative to the dominant chemical used in polyester, polyethylene terephthalate (PET), 2GT (Kurian, 2005).

Figure 1.3. SMB prior to field application.

PDO improvements have been made since the 1990s, as it has several advantages over PET and nylon (Kurian, 2005). PDO has lower melt temperatures, a lower modulus, higher stretch, and better stretch recovery (Kurian, 2005). Fabrics dyed with PDO have brighter colors and higher resistance to breakdown by washing and UV (Kurian, 2005). Unlike nylon and PET, PDO also is free of heavy metals so it can be recycled (Kurian, 2005). PDO can be produced using petrochemicals or biological processes (Nakamura &Whited, 2003). DuPont, alongside Genencor International, Inc., was one of the first companies to genetically engineer a biocatalyst bacterium to produce PDO (Nakamura &Whited, 2003). Compared to petrochemically produced PDO, Bio-PDO has significantly less impurities at 0.003%, compared to 0.0325%. Bio-PDO production is also more energy efficient, emitting 40% less GHG than PDO (Kurian, 2005).

Dr. Jim Zahn, Vice President of Technology at DuPont Tate and Lyle at the Loudon plant, described the PDO production process. PDO is formed by first extracting glucose from corn kernels, then by fermenting that glucose using the biocatalyst. After fermentation, the

monomer is then shipped to other partners to be converted into PDO from which the fibers and fabrics are made (Zahn, personal communication, 2015). The byproduct of this process is the SMB, which turns over after a three-day life cycle. On a yearly basis around 19.8 million T of SMB are produced at the plant, which is currently disposed of in a landfill (Zahn, personal communication, 2016).

Recent analyses of the SMB indicate that there is a large potential for its use as an alternative N source in agriculture. On a mass basis, SMB contains 9.3% N, 1.1% phosphorus (P), and 0.6% potassium (K) (Figure 1.4). On an oxide basis, the N-P-K composition is 9-2.52-0.72. SMB has much a higher N content than many other common organic N sources including bone meal (4-12-0) milorganite (6-2-0), fish blood and bone (5-5-6), poultry manure (3-2-2), and horse manure (1-0-1) (Zahn, personal communication, 2015). Unlike most commercial fertilizers, SMB also contains small amounts of essential plant micronutrients including zinc, copper, molybdenum, sulfur, chlorine and calcium.

Another appealing aspect of SMB is that it contains a fairly high C content at 37.3%, which decreases the decomposition rate of the material and allows it to act as a slow release nutrient source. This is beneficial both to the crop and environment, by providing nutrients as the crop takes them up and by decreasing loss of N through leaching.

If SMB could be used in local crop production as an alternative to chemical fertilizers, both farmers and the industry could benefit. Farmers could purchase SMB at a much lower rate than commercial fertilizers, while maintaining fertility and cutting input costs. Continual SMB application would build SOM and improve fertility over the long term. On the industry side, it would improve the life cycle assessment (LCA) of the plant and reduce company costs of transport and disposal in a landfill. Environmentally, reliance on chemical fertilizers could be

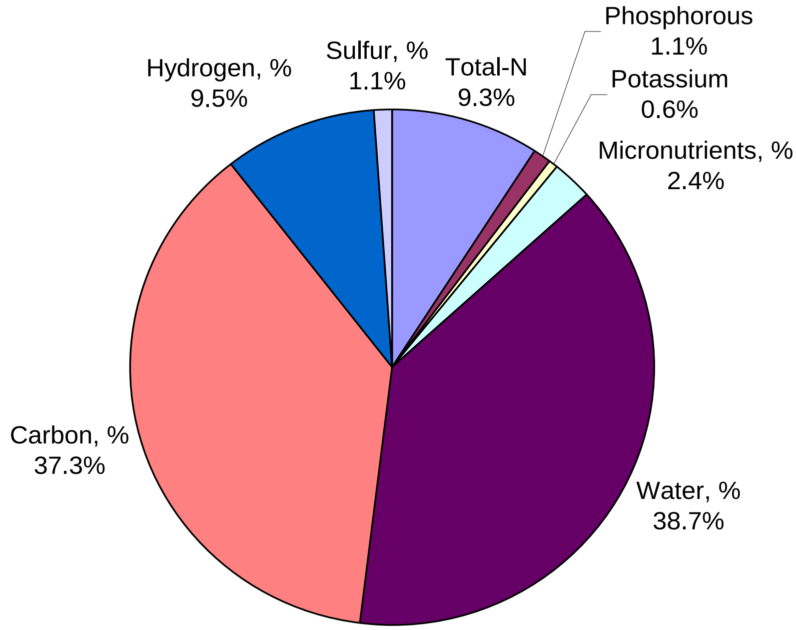

Figure 1.4. SMB elemental composition by mass (Zahn, personal communication, 2015).

reduced, as well as the amount of N leaching and the associated degradation of local water sources.

Research into the land application of SMB is so far very limited. A recent study at the University of Nebraska-Lincoln tested the use of lime stabilized spent microbial biomass (LSSMB) as a soil amendment on corn and soybean. The results showed that despite 10 kg N t^{-1} of material applied, LSSMB only actually provided 2.3 kg N t^{-1} to the crops over two consecutive years. The researchers hypothesized that N release was limited by the high pH of the LSSMB (Wortmann et al., 2015).

Measuring Soil Fertility and Crop Nutrient Uptake

Soil fertility and nutrient availability can be measured either through direct soil sampling or indirect crop measurements. Both soil and plant tissue N analyses are done using the Kjeldahl

Method. This method converts N in the soil or tissue to nitric acid (HNO_3) through digestion, which is then distilled with sodium hydroxide (NaOH) to release NH_3 in order to be measured (Bremner, 1965). For corn, N in the soil is typically measured through a pre-sidedress soil nitrate test when the crops are at the vegetative 4-6 (V4-V6) stage to determine if additional N should be added to meet the crop's needs. These tests are usually destructive to either the soil or the plant, and have to be taken back to the lab to be measured, so they do not provide in-the-field estimates of N.

Recent innovations in precision agriculture have allowed for non-destructive sampling of crop nutrient uptake. One common method of measuring N uptake is through a normalized difference vegetation index (NDVI), which can be used either aerially or on the ground. NDVI allows the determination of the N uptake of a crop through its chlorophyll production. Chlorophyll absorbs deep blue and red light and reflects the other colors of the spectrum, so NDVI essentially provides a measure of the "greenness" of the leaves. NDVI is calculated using the near infrared light (NIR) (700-1300 nm) and visible light (VIS) (400-700 nm) reflected by the leaves as (NASA, n.d.):

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

Green vegetation absorbs visible light and reflects infrared light, giving a higher reading, while dead or brown vegetation absorbs more infrared light and reflects more visible light, giving a lower reading (Weier & Herring, 2000). NDVI ranges between -1 and +1, with +1 being dark green leaves that indicate high chlorophyll production and N uptake by the crop.

If measured aerially, NDVI maps of a field are produced to show which regions are low in N and would benefit by additional fertilizer application. On the ground, a sensor can be held above the crops and can show deficiency in individual plants. The GreenSeeker™ (Trimble

Navigation Limited, Sunnyvale, CA) was developed in the mid 1990s (Lowenberg-DeBoer, 2004) and has been used on a variety of crops in calculating side-dress N rate requirements and yield (Shanahan et al., 2008, Trimble, n.d.). The GreenSeeker^{TM} uses VIS red light at 660 nm and NIR at 770 nm and provides an NDVI reading from 0.00 to 0.99 (Shaver et al., 2011, Trimble n.d.). This sensor is held 2-4 feet (0.61-1.22 m) above the plants and can be used either for spot measurements or walked down a row of crops to obtain an average reading (Barker & Sawyer, 2010, Shaver et al., 2011, Teal et al., 2006, Trimble, n.d.).

The GreenSeeker^{TM} is currently used in precision agriculture to measure nutrient deficiencies, weed cover, and drought stress in order to apply fertilizers or herbicides exactly where they are needed (Clay et al., 2006, Peña Barragán et al., 2012). For corn, NDVI readings usually range from 0.60-0.90 midseason (Trimble, n.d.).

Another ground sensor that can be used to measure N uptake is the Minolta SPAD-502 chlorophyll meter (Minolta Camera Co. Ltd., Osaka, Japan), developed in the 1980s. The SPAD meter is clamped onto an individual leaf and passes visible red (650 nm) and near infrared (940 nm) light through it, from which it provides an indexed chlorophyll content reading between -9.9 and +199.9 (Uddling et al., 2007). Higher numbers show sufficient N uptake by the crop and lower numbers indicate deficiency. In corn, measurements are typically made on the midrib of the leaves, and the leaf measured varies throughout the season. Prior to tasseling, measurements are made on the uppermost fully expanded leaf, and after tasseling on the ear leaf (Argenta et al., 2004, Feil et al., 1997, Salmerón and Cavero, 2011, Vig et al. 2012, Yang et al., 2012).

SPAD studies have been done on a variety of plants to assess N uptake, from crops such as corn, soybean, and wheat, to trees like birch and pear. For corn, SPAD readings usually range from 25-55 throughout the growing season (Piekielek & Fox, 1992, Ziadi et al., 2008). Many

studies that have compared SPAD readings to tissue sampling have found that while it does provide a useful relative chlorophyll reading, it is not a good instrument for use in calculating additional N fertilizer requirements (Bullock & Anderson, 1998, Piekielek & Fox, 1992, Uddling et al., 2007).

When measuring the NDVI or indexed chlorophyll contents, N-rich reference strips are required to calibrate the measurements (Trimble, n.d. Shanahan et al., 2008). These are areas of the field that had received an excessive amount of N. For NDVI, the reference strip allows the user to calculate side-dress N requirements. For both sensors, a sufficiency index (SI) can be calculated by comparing a plot's reading to that of the N-rich strip. The sufficiency index is calculated using the formula:

$$SI = \left(\frac{ABR}{ARR}\right) * 100\%$$

where ABR = average bulk reading of the plot and ARR = average reference strip reading (Shapiro et al., 2006). Sufficiency indices of 95% and above indicate no need for additional application of N fertilizers, while anything below 95% indicates deficiency (Shapiro et al., 2006).

References

Alexandratos, N. & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision. Retrieved from http://www.fao.org/docrep/016/ap106e/ap106e.pdf

Alvarez, R., Diaz, R. A., Barbero, N., Santanatoglia, O. J., & Blotta, L. (1995). Soil organic carbon, microbial biomass and CO 2-C production from three tillage systems. *Soil and Tillage Research*, *33*(1), 17-28.

American Statistical Association (ASA) (2015). "World population likely to surpass 11 billion in 2100: US population projected to grow by 40 percent over next 85 years." ScienceDaily. ScienceDaily, 10 August 2015. Retrieved from www.sciencedaily.com/releases/2015/08/150810110634.htm

Argenta, G., Silva, P. R. F. D., & Sangoi, L. (2004). Leaf relative chlorophyll content as an indicator parameter to predict nitrogen fertilization in maize.*Ciência Rural*, *34*(5), 1379-1387.

Arshad, M. A., Schnitzer, M., Angers, D. A., & Ripmeester, J. A. (1990). Effects of till vs no-till on the quality of soil organic matter. *Soil Biology and Biochemistry*, *22*(5), 595-599.

Baker, N. T. (2011). Tillage practices in the conterminous United States, 1989-2004—datasets aggregated by watershed. Data series 573. Retrieved from http://pubs.usgs.gov/ds/ds573/pdf/dataseries573final.pdf

Barker, D. W. & Sawyer, J. E. (2010). Using active canopy sensors to quantify corn nitrogen stress and nitrogen application rate. *Agronomy Journal*, *102*(3), 964-971.

Bill, P. F. (2014). Farm Bill. *UPDATE*.

Bremner, J. M. (1965). Total nitrogen. *Methods of soil analysis. Part 2. Chemical and Microbiological Properties*, (methodsofsoilanb), 1149-1178.

Bullock, D. G., & Anderson, D. S. (1998). Evaluation of the Minolta SPAD-502 chlorophyll meter for nitrogen management in corn. *Journal of Plant Nutrition*, *21*(4), 741-755.

Clay, D. E., Kim, K. I., Chang, J., Clay, S. A., & Dalsted, K. (2006). Characterizing water and nitrogen stress in corn using remote sensing. *Agronomy Journal*, *98*(3), 579-587.

Coughenour, C. M. (2003). Innovating Conservation Agriculture: The Case of No-Till Cropping. *Rural Sociology*, *68*(2), 278-304.

CTIC (2007). Amendment to the 2004 figures shown in http://www.conservationinformation.org/?action=members_crm Consulted in February, 2009, Subject amendment

Cullum, R. F. (2009). Macropore flow estimations under no-till and till systems. *Catena*, *78*(1), 87-91.

Den Biggelaar, C., Lal, R., Wiebe, K., & Breneman, V. (2001). Impact of soil erosion on crop yields in North America. *Advances in Agronomy*, *72*:1-52.

Department of Economic and Social Affairs of the United Nations (DESA) (2014). A Concise Report on the World Population Situation in 2014. Retrieved from http://www.un.org/en/development/desa/population/publications/pdf/trends/Concise Report on the World Population Situation 2014/en.pdf

Derpsch, R. (1998). Historical review of no-tillage cultivation of crops. In *FAO International Workshop, Conservation Tillage for Sustainable Agriculture* (pp. 205-218).

Derpsch, R. (n.d.). History of crop production, with and without tillage. Retrieved from http://notill.org/sites/default/files/history-of-crop-production-with-without-tillage-derpsch.pdf

Derpsch, R., Friedrich, T., Kassam, A., & Li, H. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*, *3*(1), 1-25.

Erisman, J. W., Sutton, M. A., Galloway, J., Klimont, Z., & Winiwarter, W. (2008). How a century of ammonia synthesis changed the world. *Nature Geoscience*, *1*(10), 636-639.

FAO (2009). Global agriculture towards 2050. Retrieved from http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

FAO (2012). What is Conservation Agriculture? Retrieved from http://www.fao.org/ag/ca/1b.html

FAO (2015). Crop prospects and food situation, no. 4. Retrieved from http://www.fao.org/3/a-I5197E.pdf

Feil, B., Garibay, S. V., Ammon, H. U., & Stamp, P. (1997). Maize production in a grass mulch system–seasonal patterns of indicators of the nitrogen status of maize. *Developments in Crop Science*, *25*, 227-235.

Huang, W. Y. (2007). *Impact of rising natural gas prices on US ammonia supply*. DIANE Publishing.

IIRR & ACT (2005). Conservation agriculture: A manual for farmers and extension workers in Africa. International Institute of Rural Reconstruction, Nairobi; African Conservation Tillage Network, Harare. Retrieved from http://www.fao.org/ag/ca/AfricaTrainingManualCD/PDF%20Files/Publishers.pdf

Kurian, J. V. (2005). A new polymer platform for the future—Sorona® from corn derived 1, 3-propanediol. *Journal of Polymers and the Environment*,*13*(2), 159-167.

Lal, R. (1995). Erosion–crop productivity relationships for soils of Africa. *Soil Science Society of America Journal*, 59, 661–667.

Lal, R. (1984). Mechanized tillage systems effects on soil erosion from an Alfisol in watersheds cropped to maize. *Soil and Tillage Research*, *4*(4), 349-360.

Lal, R., Reicosky, D. C., & Hanson, J. D. (2007). Evolution of the plow over 10,000 years and the rationale for no-till farming. *Soil and Tillage Research*,*93*(1), 1-12.

Lowenberg-DeBoer, J. (2004). The management time economics of on-the-go sensing for nitrogen application. *SSMC Newsletter*, (May).

Mattson N., Leatherwood, R., Peters, C. (2009). Nitrogen: not all forms are equal.

McKyes, E. (1985). Soil cutting and tillage. Amsterdam: Elsevier. pp 1-2.

Mengel, D. (n.d.). Types and uses of nitrogen fertilizers for crop production. *Agronomy Guide.* Purdue University Agronomy Department. Retrieved from https://www.extension.purdue.edu/extmedia/AY/AY-204.html

Nakamura, C. E., & Whited, G. M. (2003). Metabolic engineering for the microbial production of 1, 3-propanediol. *Current opinion in biotechnology*, *14*(5), 454-459.

Oldeman, L. R., Hakkeling, R. T. A., Sombroek, W. G. (1990). World map of the status of human-induced soil degradation. *Geoderma*, *52,* 367-373.

Osborn, T. (1993). The conservation reserve program: status, future and policy options. *Journal of Soil and Water Conservation*, *48*(4), 271-279.

Peña Barragán, J. M., Kelly, M., Castro, A. I. D., & López Granados, F. (2012). Object-based approach for crop row characterization in UAV images for site-specific weed management.

Phillips, S. H., & Young Jr, H. M. (1973). No-tillage farming. *No-Tillage Farming.*

Piekkielek, W. P., & Fox, R. H. (1992). Use of a chlorophyll meter to predict sidedress nitrogen. *Agronomy Journal*, *84*(1), 59-65.

Pimentel, D. & Burgess, M. (2013). Soil erosion threatens food production. *Agriculture, 3,* 443-463.

Salmerón, M., Isla, R., & Cavero, J. (2011). Effect of winter cover crop species and planting methods on maize yield and N availability under irrigated Mediterranean conditions. *Field Crops Research*, *123*(2), 89-99.

Savabi, M. R., Golabi M. H., Abou-Arab, A.A., & Kladivko, E. J. (1992) Infiltration Characteristics of No-Till vs. Conventional Tillage in Indiana and Illinois Farm Fields. *Soil Science Society of America*.

Savoy, H. (n.d.). Fertilizers and their use. UTK Agricultural Extension Service, PB1637. https://extension.tennessee.edu/publications/Documents/PB1637.pdf

Shanahan, J. F., Kitchen, N. R., Raun, W. R., & Schepers, J. S. (2008). Responsive in-season nitrogen management for cereals. *Computers and Electronics in Agriculture*, *61*(1), 51-62.

Shapiro, C., Francis, D., Ferguson, R., Hergert, G., Shaver, T., & Wortmann, C. (2006). Using a Chlorophyll Meter to Improve N Management. University of Nebraska-Lincoln Extension, Soil Resource Management. Retrieved from http://extensionpublications.unl.edu/assets/html/g1632/build/g1632.htm

Shaver, T. M., Khosla, R., & Westfall, D. G. (2011). Evaluation of two crop canopy sensors for nitrogen variability determination in irrigated maize. *Precision Agriculture*, *12*(6), 892-904.

Smil, V. (1999). Detonator of the population explosion. *Nature*, *400*(6743), 415-415.

Smith, A., Bowling, B., Danehower, S. (2015). Field crop budgets for 2015. UTIA Department of Agricultural and Resource Economics. Retrieved from http://economics.ag.utk.edu/budgets/2015/Crops/CornNonIrrNoTill.pdf

Teal, R. K., Tubana, B., Girma, K., Freeman, K. W., Arnall, D. B., Walsh, O., & Raun, W. R. (2006). In-season prediction of corn grain yield potential using normalized difference vegetation index. *Agronomy Journal*, *98*(6), 1488-1494.

Trimble (n.d.). GreenSeeker handheld crop sensor product overview. Retrieved from http://www.trimble.com/Agriculture/gs-handheld.aspx

Uddling, J., Gelang-Alfredsson, J., Piikki, K., & Pleijel, H. (2007). Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynthesis Research*, *91*(1), 37-46.

Víg, R., Huzsvai, L., Dobos, A., & Nagy, J. (2012). Systematic measurement methods for the determination of the SPAD values of maize (Zea mays L.) canopy and potato (Solanum tuberosum L.). *Communications in Soil Science and Plant Analysis*, *43*(12), 1684-1693.

Weier, J. & Herring, D. (2000). Measuring vegetation (NDVI & EVI). *NASA Earth Observatory*. Retrieved from http://earthobservatory.nasa.gov/Features/MeasuringVegetation/

Williams, J. D., & Wuest, S. B. (2011). Tillage and no-tillage conservation effectiveness in the intermediate precipitation zone of the inland Pacific Northwest, United States. *Journal of Soil and Water Conservation*, *66*(4), 242-249.

Wortmann, C., Sawyer, J., & Tonn, S. (2015). On-farm study researches novozymes fermentation spent residuals. University of Nebraska-Lincoln Extension. Retrieved from http://www.agronext.iastate.edu/soilfertility/info/Wortman2015-03-NovozymeFermentationSpentResiduals.pdf

Yang, Y., Timlin, D. J., Fleisher, D. H., Lokhande, S. B., Chun, J. A., Kim, S. H., ... & Reddy, V. R. (2012). Nitrogen concentration and dry-matter accumulation in maize crop: Assessing maize nitrogen status with an allometric function and a chlorophyll meter. *Communications in Soil Science and Plant Analysis*, *43*(11), 1563-1575.

Ziadi, N., Brassard, M., Bélanger, G., Claessens, A., Tremblay, N., Cambouris, A. N., ... & Parent, L. É. (2008). Chlorophyll measurements and nitrogen nutrition index for the evaluation of corn nitrogen status. *Agronomy Journal*, *100*(5), 1264-1273.

Chapter 2
Climatic and Tillage Effects on Nitrogen Release from a Long-Term No-Till Alfisol in North Central Ohio

Abstract

While it is known that no-till farming results in increased soil quality though the protection of soil carbon (C) and nitrogen (N) in undisturbed micropores, the mass retained is unclear and controversial. In order to quantify the amount of soil N preserved by no-till, a paired till (T) and no-till (NT) management study was established in May 2015. The objective of this study was to compare N release from a Centerburg silt loam at a farm in North Central Ohio (OH) that has been under long-term no-till corn (*Zea mays* L.) and soybean (*Glycine max* L.) production. Following the tillage treatments, N fertilizer was applied at six rates: 0, 28, 56, 112, 224, and 448 kg N ha^{-1}. In addition to common crop growth measurements and yield, crop N sufficiency throughout the growing season was measured using a Minolta SPAD-502 Chlorophyll Meter (SPAD) and Trimble GreenSeeker™ Handheld Crop Sensor. The results showed that the T whole plot consistently showed higher N uptake, crop productivity, and yield than the NT whole plot. These results may be due to unusually high rainfall following fertilizer application in June, 2015.

1. Introduction

As the global population increases, so does the pressure on our current agricultural systems to expand production on limited land resources. This growth is further challenged by the widespread use of unsustainable agricultural management practices and the resulting soil degradation, costing the loss of approximately 75 billion tonnes (t) of soil globally each year (Pimentel & Burgess, 2013) (Figure 2.1). This loss in soil decreases crop productivity, pollutes the environment, and costs farmers billions of dollars each year.

In contrast to conventional tillage (CT), conservation agriculture (CA) is an approach to farming that focuses on improving soil quality and reducing the high demands of time, labor, and fuel that plowing requires. This practice is composed of three principles: 1) decreased soil disturbance through minimal or no tillage (no-till), 2) permanent soil cover, and 3) diversified crop rotations (FAO 2012). While the combination of all three components would result in the

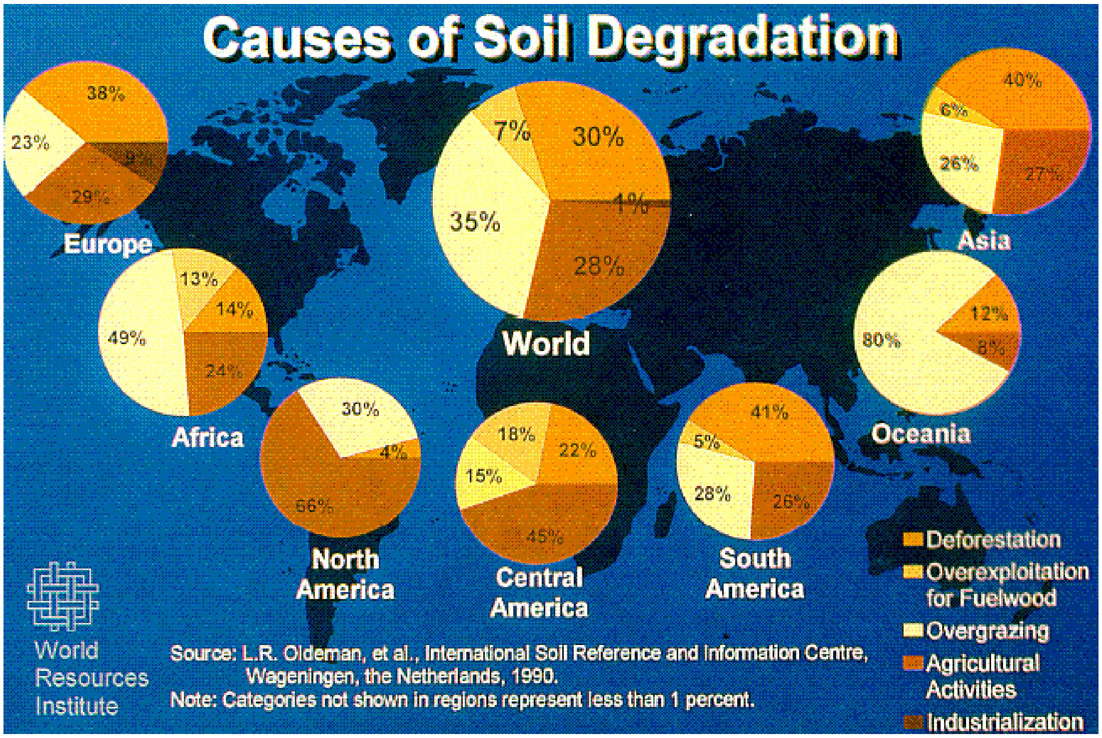

Figure 2.1 World map of human-induced soil degradation (Oldeman et al., 1990)

greatest soil improvement, economic and temporal restrictions cause many farmers to implement only one or two components to meet their soil quality goals.

No-till is the crux of CA and perhaps the most important component. No-till can be defined as planting crops into untilled soil through a narrow slot in the ground and then covering it up without any other soil disturbance (Derpsch & Friedrich, n.d.). No-till reduces erosion and improves soil structure, soil organic matter (SOM) content, infiltration, macroporosity, and aggregation. Because of the minimized disturbance, SOM breaks down more slowly in no-till systems and is able to accumulate, storing soil nutrients in the micropores of aggregates. The effect of no-till on soil nutrient levels has been proven, but the mass retained is unclear and controversial (Arshad et al., 1990, Alvarez et al., 1995, Grandy et al., 2006).

Despite the many benefits that no-till can provide, many farmers still choose to use some form of tillage. While the use of no-till has drastically increased in the past 30 years, it was only used on 105.9 million ha globally in 2007 (number includes rotational tillage but not direct seeding). The U.S. has the greatest amount of land under no-till compared to the rest of the world at 26.5 million ha, but this amounts to only 25.5% of cropland ha (only 10-12% is actually estimated to be under permanent no-till). Still, approximately 75% of cropland in the U.S. utilizes some form of tillage or reduced tillage (Derpsch & Friedrich, n.d.).

While many studies have compared the nutrient availability of paired continuous tillage and no-till systems, none have taken an ex poste approach to measuring nutrient accumulation of a no-till soil over time. The objective of this study was to compare and quantify the N preserved by a seven-year no-tilled Centerburg silt loam by tilling and measuring the nutrient release of protected soil organic matter.

2. Materials and Methods

2.1 Study area and soil characteristics

The area of study was a private farm in Mount Gilead, OH (40° 36’18”N, 82°40’32”W). The soil series was a Centerburg silt loam with 2-6% slopes (fine-loamy, mixed, active, mesic Aquic Hapludalf) with 30% sand, 54% silt, and 16% clay (WSS, n.d.). This site had previously been managed under CA practices, including seven years of no-till, a corn-soybean rotation, and maintained crop residue cover. The previous crop on the field used for this study was corn.

The climate in this region is classified by Köppen-Geiger as a Dfb, humid continental mild summer, and wet all year (Kottek et al., 2006, Pidwirny, 2011). The average annual rainfall is 98 cm, and the mean annual temperature is 9.4 °C (Climate, n.d.).

2.2 Experimental design

This study was set up as a completely randomized design with a split-plot treatment design. Two treatment plots, one tilled and one non-tilled were split into 24 plots each, for a total of 48 plots. Each plot was an area 4.57 m x 18.29 m and received one of six fertilizer rate treatments: 0, 28, 56, 112, 224, and 448 kg N ha^{-1}, which were replicated four times each within each tillage system. The tillage systems were compared in the whole plot and fertilizer rate treatments were compared in the split plots (Appendix 2.1).

The till whole plot was tilled May 4, 2015 with two passes of a disk and one pass of a moldboard plow. The average residue coverage following tillage in the whole plot treatments was 80% in the no-till plot and 8% in the till plot, using a 15.5 m transect (Morrison et al., 1993). All plots were planted on May 15, 2015 with Pioneer variety P0604AM, using a John Deere 7200 6-row MaxEmerge Conservation Planter. Seeds were planted at a density of 84,000 plants ha^{-1}, 5 cm deep, 15 cm apart, and with 76 cm rows. After emergence, plots were established to include 6 rows of corn. Soil samples were taken from the till and no-till plots prior to experiment start date in order to obtain baseline measurements and compare changes in soil properties. Seven soil samples 15 cm deep were collected from each tillage system, and a composite sample was sent to the Soil, Plant & Pest Center in Nashville, TN for analysis.

Fertilizers were hand-applied to all plots on June 3, 2015. Nitrogen was applied as granular urea (46-0-0) at rates of 0, 28, 56, 112, 224, and 448 kg N ha^{-1}. Phosphorus (P) was applied to all plots at a rate of 112 kg P_2O_5 ha^{-1} as triple super phosphate (0-46-0). Potassium (K) was applied to all plots at a rate of 112 kg K_2O ha^{-1} as potash (0-0-60) (Appendix 2.2).

Three samples to determine soil bulk density and water content were collected from both the till and no-till plots on July 22, 2015 using a 15 cm corer and sliding hammer. The samples

were weighed in the field and then transported to the lab where they were dried at 110 °C in an oven for 24 hours, and then reweighed to obtain dry mass measurements (Black, 1965, NRCS, 2004).

2.3 In-season data collection

Throughout the growing season, various measurements were taken to compare fertility and nutrient availability in each plot. Population stand count was collected at the V3-V4 stage by counting the number of plants on a 5.32 m length (1/1000th of an acre) on 3 random rows per plot (Gibson, 1998). An average crop height for each plot was obtained from the measurement of eight randomly selected crops on the four interior rows at 38, 56, and 68 days after planting by measuring from the base of the crop to end of the tallest extended leaf (Abendroth et al., 2011).

Two instruments measured in-season N uptake through crop chlorophyll production at 56 and 68 days after planting. A Minolta SPAD-502 chlorophyll content meter measured indexed chlorophyll contents at the midrib of 30 leaves per plot, which were averaged to give one reading across the plot. Prior to tasseling, SPAD measurements were made on the uppermost fully expanded leaf, and after tasseling on the ear leaf (Argenta et al., 2004, Feil et al., 1997, Salmerón and Cavero, 2011, Vig et al. 2012, Yang et al., 2012).

A Trimble Handheld GreenSeeker™ was also used to measure N uptake. The meter was held 60 cm above the crops and was walked down the length of the two interior rows of each plot at a constant rate of 1.3 m s^{-1} (Trimble, n.d., Barker & Sawyer, 2010, Shaver et al., 2011, Teal et al., 2006). The readings for these two rows were averaged to give one reading per plot.

2.4 Harvest methods

Corn was hand harvested on October 22, 2015. One of the interior two rows was randomly selected, and a 5.32 m length in the middle of the row was marked using flagging tape. The number of stalks within the length was counted, and all ears from these plants were counted and harvested (Lauer, 2002, Lee & Herbek, 2005, Nielson, 2015). Ears were taken back to the lab, where the weight for each plot was measured and recorded. All ears were then shelled using a Maximizer™ corn sheller, and the cobs were weighed. Grain weight was calculated by subtracting the weight of the cob from the total ear weight. The grain moisture and density for each plot was then measured using three samples of shelled grain in a Dickey John mini GAC moisture tester, and the average was taken.

To calculate yield, the total grain weight from each plot was multiplied by 1000 (harvest area was 1/1000ths of an acre), and corrected to 15.5% moisture using measured moisture values. All grain yields were converted to T ha^{-1} (Appendix 2.3).

2.5 Statistical Analysis

The data collected from this study was analyzed using mixed models analysis of variance (ANOVA) in SAS 9.4 to detect differences in crop height, N uptake, and yield between the tillage and fertilizer treatments. Means were separated using Tukey's significant difference test at α=0.05. The statistical model used was:

$$y_{ijk} = \mu + T_i + R(T)_{ik} + F_j + T * F_{ij} + F * R(T)_{ijk}$$

where T_i=treatments (2 tillage systems), F_j=fact (6 fertilizer rates), and R_k=reps (4). Type III test p-values for tillage, fertilizer, or tillage*fertilizer interaction effects are reported in each graph (Figure 2.2).

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Tillage	1	36	5.51	0.0245
Fertilizer	5	36	0.33	0.8896
Tillage*Fertilizer	5	36	0.68	0.6435

Figure 2.2. Example ANOVA table for OH CRD analysis.

3. Results and Discussion

3.1 Residue cover, population density and bulk density

Following planting, the mean residue cover for the no-till whole plot was 79%, while the tilled plot had only 8% cover (Figure 2.3). Tillage, fertilizer, and the interaction between the two did not have a significant effect on population density at the V3-V4 stage ($p>0.05$). The mean population density for each whole plot was 75,656 plants ha^{-1} in the no-till, and 73,414 plants ha^{-1} in the till (Figure 2.4). The mean bulk densities of the no-till plot and till plot were 1.50 g cm^{-3} and 1.31 g cm^{-3}, respectively. The mean volumetric and gravimetric water contents were 23.01% and 34.56% in the no-till, and 26.28% and 34.14% in the till, respectively.

3.2 Rainfall

It is important to note the rainfall this year before discussing the N availability and uptake results. The 2015 June rainfall was 2.5 times the average (~12 cm), with ~30 cm of rainfall measured on site (Figure 2.5) (Weather DB, n.d.). Fertilizers were applied on June 3, 2015, and only two weeks later, over 20 cm of rain fell during a five day period. Much of the N applied was most likely lost during this time due to leaching, runoff, or denitrification of waterlogged soils. When the crops reached the first reproductive stage of silking (R1) at the end of July, rainfall

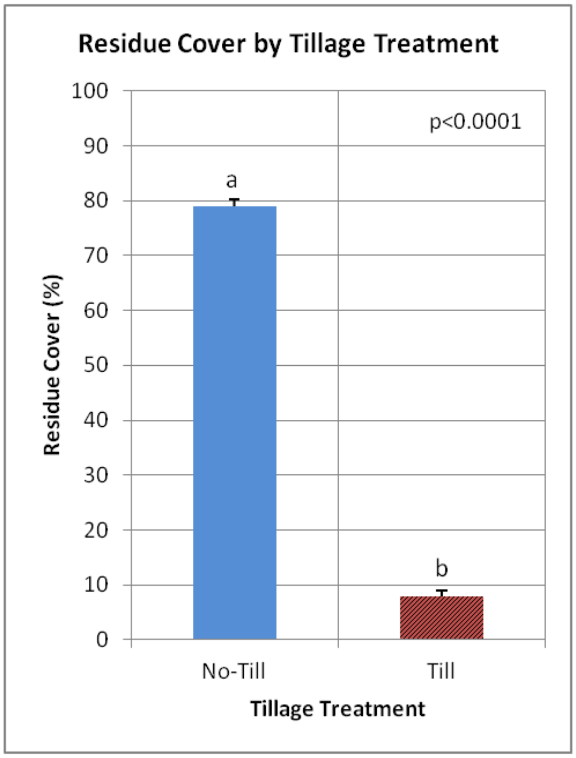

Figure 2.3. Residue cover in the whole plots following tillage in Mount Gilead, OH.

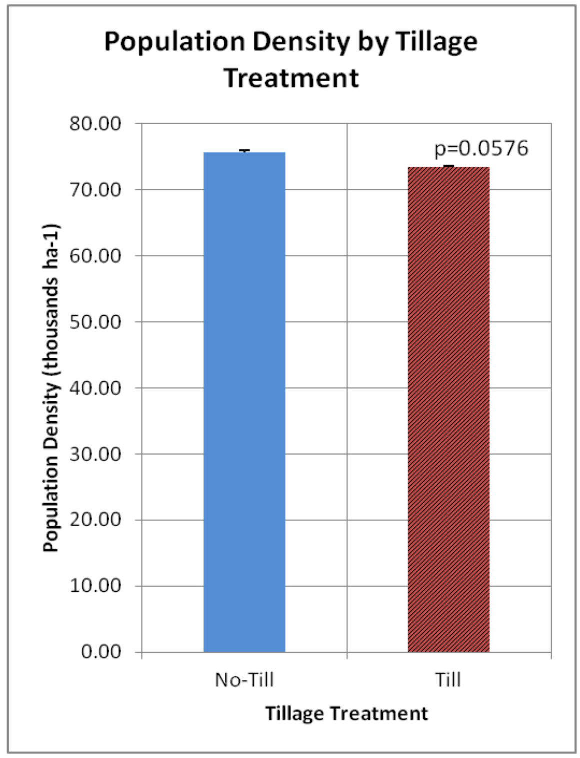

Figure 2.4. Effect of tillage treatment on population density in Mount Gilead, OH.

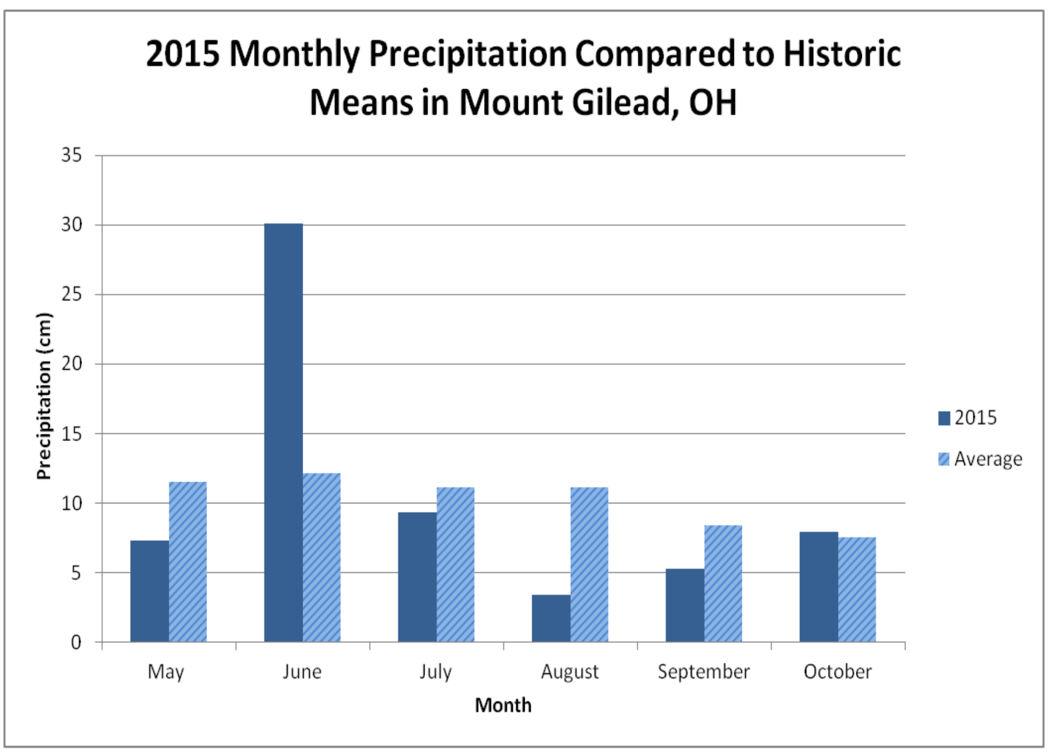

Figure 2.5. Rainfall from 2015 in Mount Gilead, OH compared to historic averages.

subsided and the area went into drought, with this year's August rainfall of 3.4 cm well below the monthly average of ~11 cm. This is an important time for crop nutrient and water uptake as well as grainfill. In a dry year, no-till would have the advantage over a tilled soil due to the residue cover conserving soil moisture and limiting evaporation. In a wet year such as the one observed, the residue keeps the soil waterlogged and promotes loss of N to denitrification. A 2015 meta-analysis of conservation agriculture vs. conventional tillage studies found that in dry climates, no-till in combination with residue retention and crop rotation increased yields by 7.3% when compared to tillage. When the researchers compared humid climates using no-till, residue retention, and crop rotation, they found decreased yields compared to tillage by ~6% (Pittelkow et al., 2015).

3.3 Crop height

The interaction between tillage treatment and fertilization rate did not have a significant effect on crop height on any of the three sampling dates ($p>0.05$).

Fertilization rate had a significant effect on crop height at 38 ($p=0.0005$), 56 ($p<0.0001$), and 68 days after planting ($p<0.0001$) (Figures 2.6, 2.7, 2.8, 2.9, 2.10). As expected, the 0 kg N ha^{-1} fertilizer rate had the lowest mean crop height on all three dates of 37.88, 60.37, and 74.11 cm, respectively. Interestingly, the 224 kg N ha^{-1} treatments had the highest mean crop height on all three sampling dates at 49.74, 111.28, and 160.87 cm, respectively, but were never significantly greater than the 448 kg N ha^{-1} treatments.

At 38 days after planting, the 56, 112, 224 and 448 kg N ha^{-1} treated plots were significantly taller than the other treatments. This difference became greater over time, with only the 112, 224, and 448 kg N ha^{-1} plots having the significantly tallest crops at 56 days after planting, and just the 224 and 448 kg N ha^{-1} plots at 68 days after planting.

Tillage had a significant effect on crop height only on the later two sampling dates, 56 (p=0.0398) and 68 days after planting (p=0.0065) (Figure 2.11). The till plots had significantly taller plants on the two dates measured with mean heights of 95.42 and 131.72 cm, respectively, than the no-till with mean heights of 81.47 and 106.09 cm, respectively. The reason for no significant differences at the earliest measuring date could be that the plants had not yet reached the V6 stage, the point at which they begin to heavily require and take up soil N (Abendroth et al., 2011).

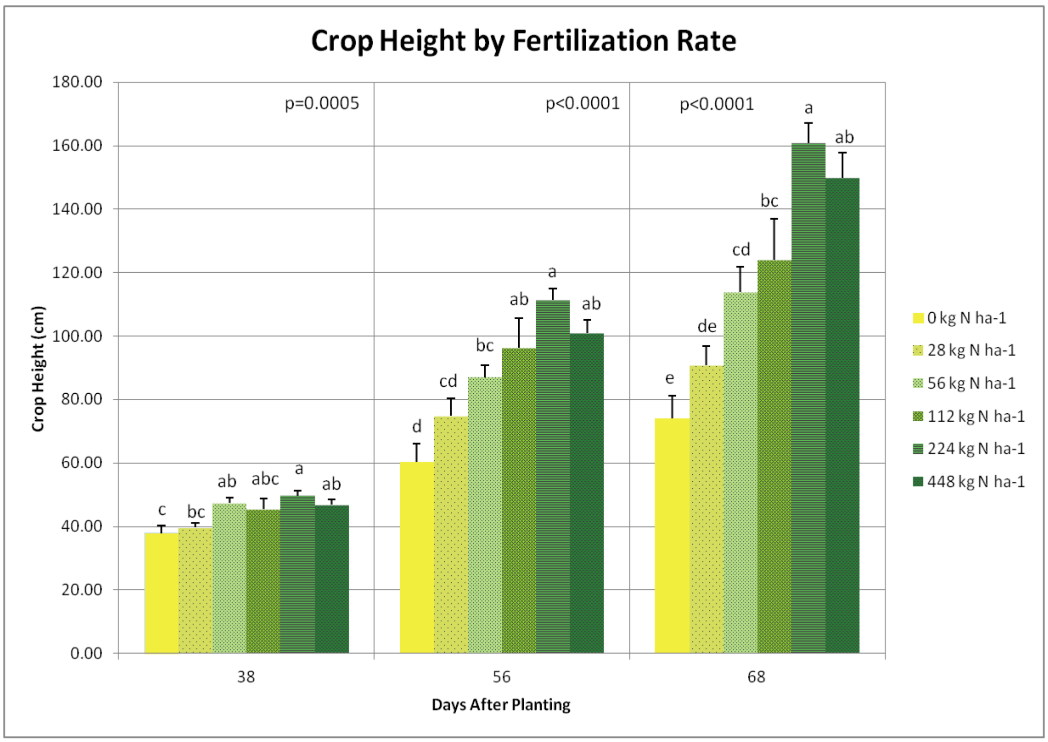

Figure 2.6. The effect of fertilization rate on crop height over time in Mount Gilead,OH.

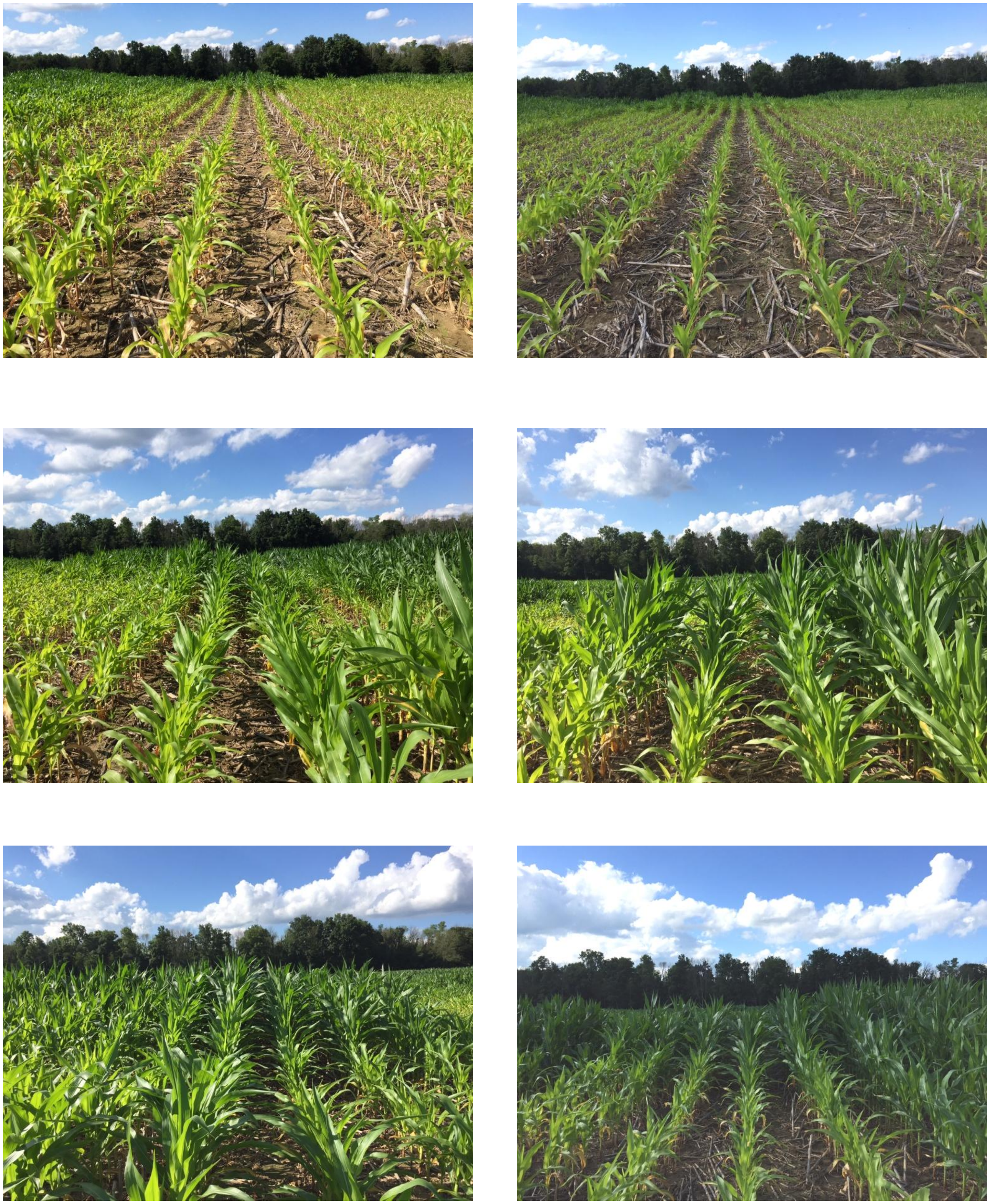

Figure 2.7. No-till subplots at 38 days after planting in Mount Gilead, OH (June 22, 2015): from top left 0 kg N ha^{-1}, top right 28 kg N ha^{-1}, middle left 56 kg N ha^{-1}, middle right 112 kg N ha^{-1}, bottom left 224 kg ha^{-1}, bottom left 448 kg N ha^{-1}.

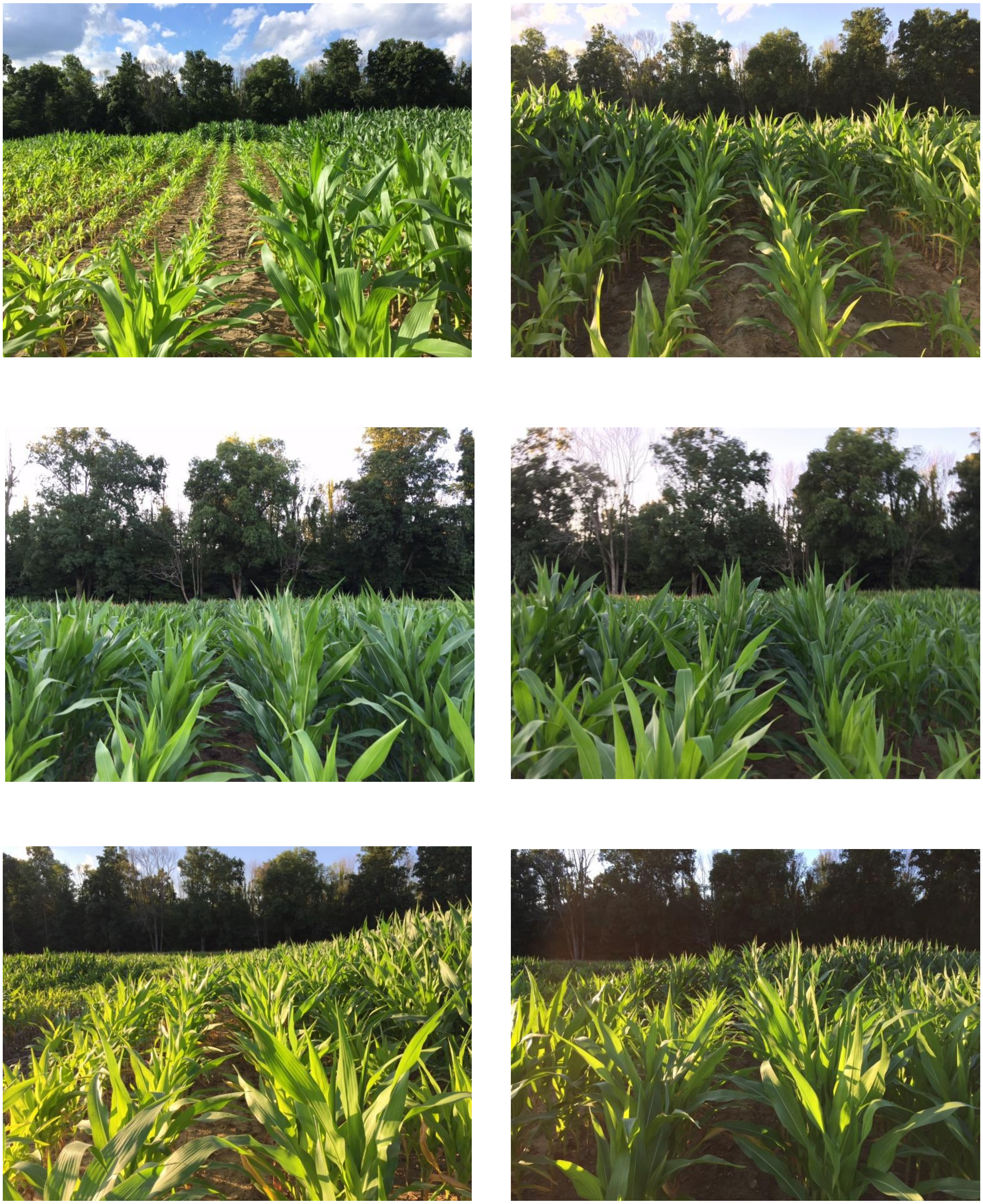

Figure 2.8. Till subplots at 38 days after planting in Mount Gilead, OH (June 22, 2015): from top left 0 kg N ha^{-1}, top right 28 kg N ha^{-1}, middle left 56 kg N ha^{-1}, middle right 112 kg N ha^{-1}, bottom left 224 kg ha^{-1}, bottom left 448 kg N ha^{-1}.

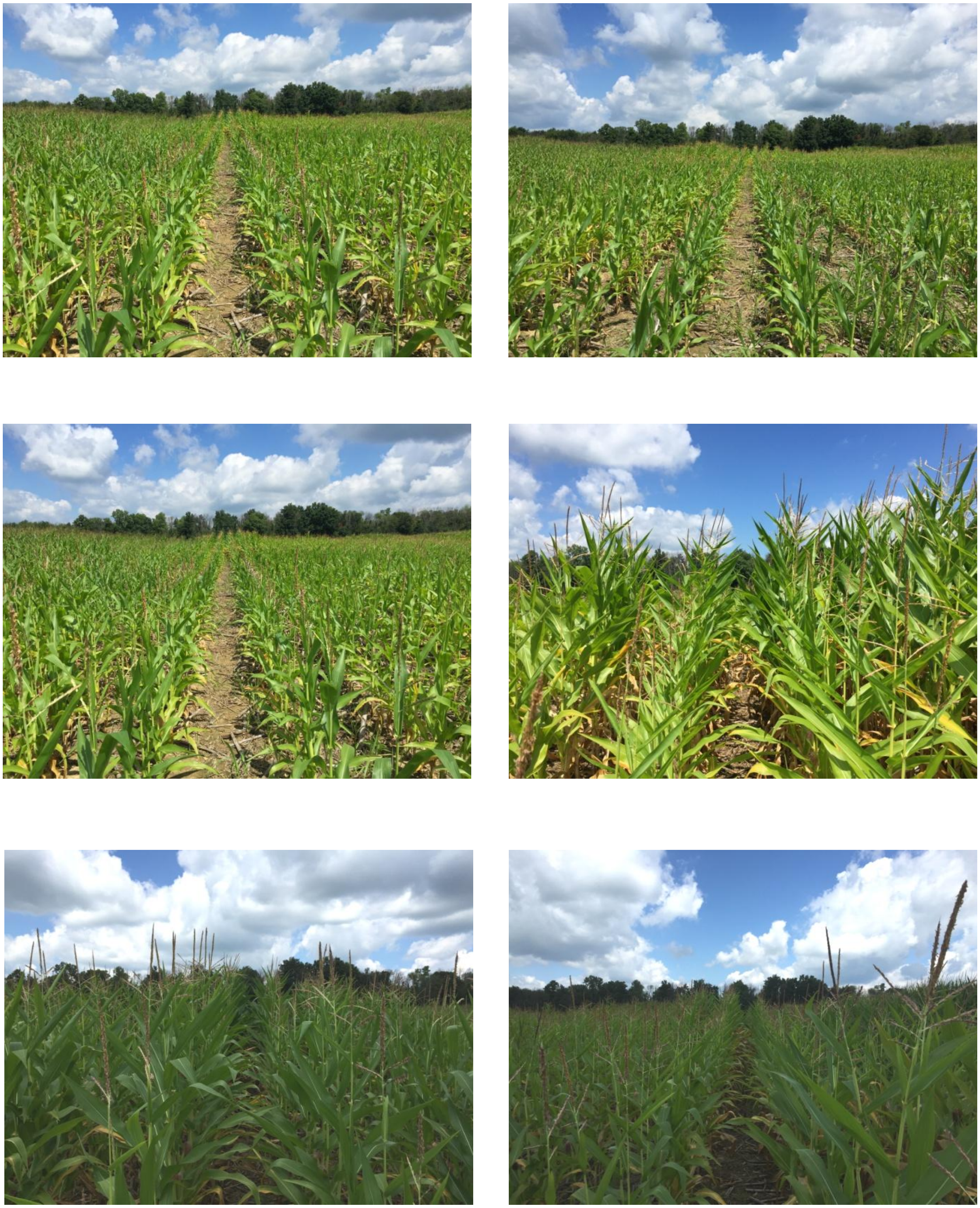

Figure 2.9. No-till subplots at 68 days after planting in Mount Gilead, OH (July 22, 2015): from top left 0 kg N ha^{-1}, top right 28 kg N ha^{-1}, middle left 56 kg N ha^{-1}, middle right 112 kg N ha^{-1}, bottom left 224 kg ha^{-1}, bottom left 448 kg N ha^{-1}.

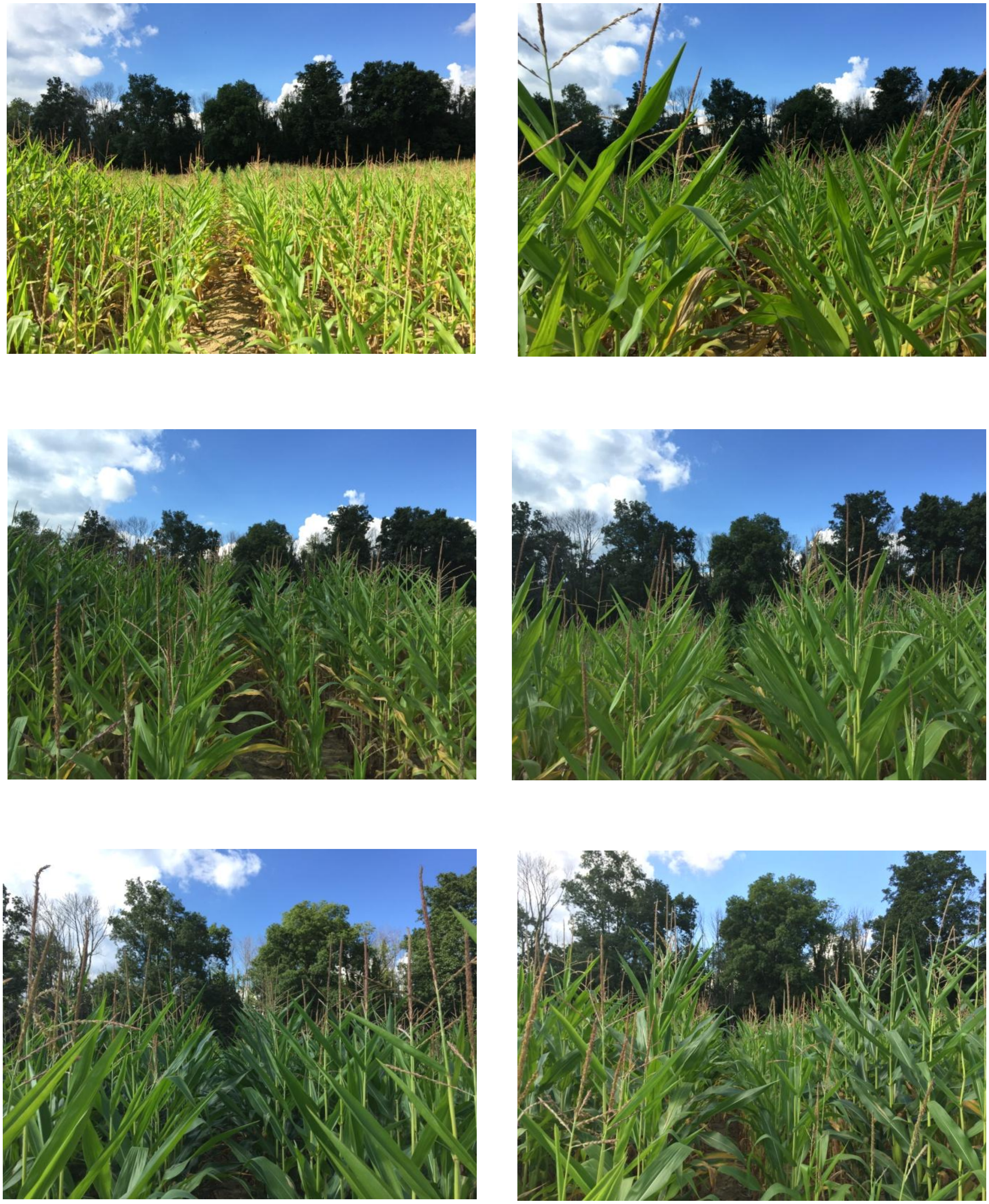

Figure 2.10. Till subplots at 68 days after planting in Mount Gilead, OH (July 22, 2015): from top left 0 kg N ha^{-1}, top right 28 kg N ha^{-1}, middle left 56 kg N ha^{-1}, middle right 112 kg N ha^{-1}, bottom left 224 kg ha^{-1}, bottom left 448 kg N ha^{-1}.

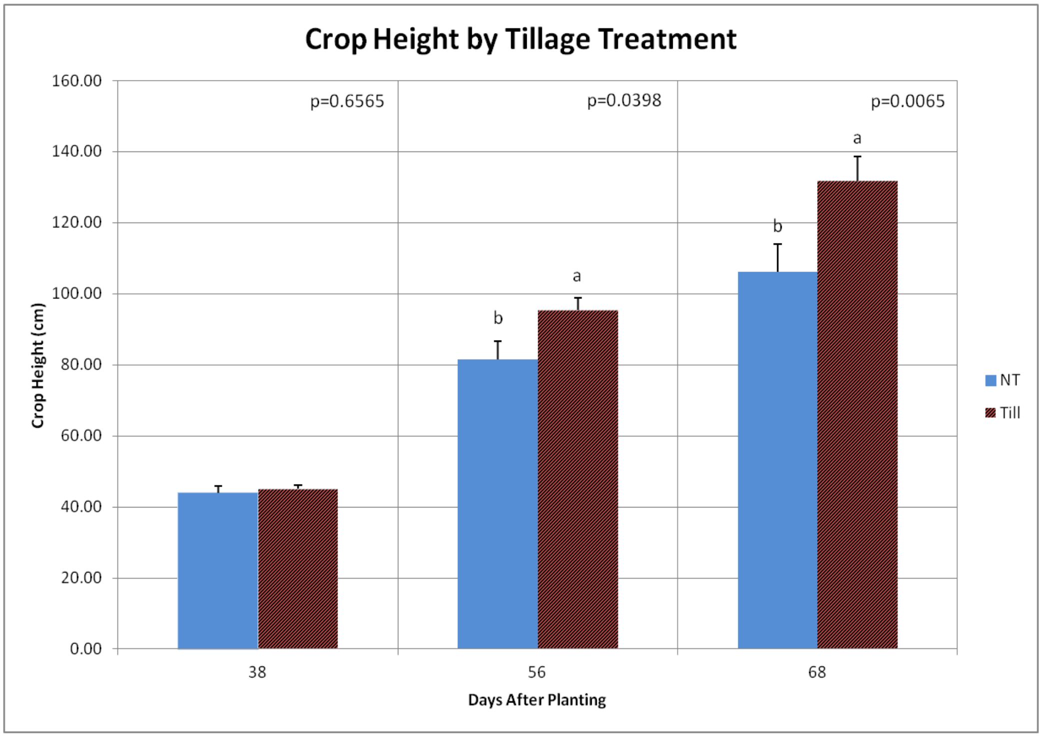

Figure 2.11. The effect of tillage treatment on crop height over time in Mount Gilead,OH.

3.4 GreenSeeker^{TM} NDVI readings

The interaction between tillage treatment and fertilization rate did not have a significant effect on GreenSeeker^{TM} readings on either of the sampling dates ($p>0.05$).

Fertilization rate had a significant effect on GreenSeeker^{TM} readings on both 56 and 68 days after planting ($p<0.0001$) (Figure 2.13). The 0 kg N ha^{-1} treatments had the lowest NDVI readings on both dates of 0.48 and 0.49, respectively. In agreement with the crop height trends, the 224 kg N ha^{-1} rates had the highest NDVI readings of 0.73 and 0.79, respectively. At 56 days after planting, the four highest application rates of 56, 112, 224, and 448 kg N ha^{-1} had significantly higher mean readings than the other treatments. At 68 days after planting, only the 112, 224, and 448 kg N ha^{-1} treatments were significantly greater than the other treatments.

Tillage treatment had a significant effect on GreenSeeker^{TM} readings on both 56

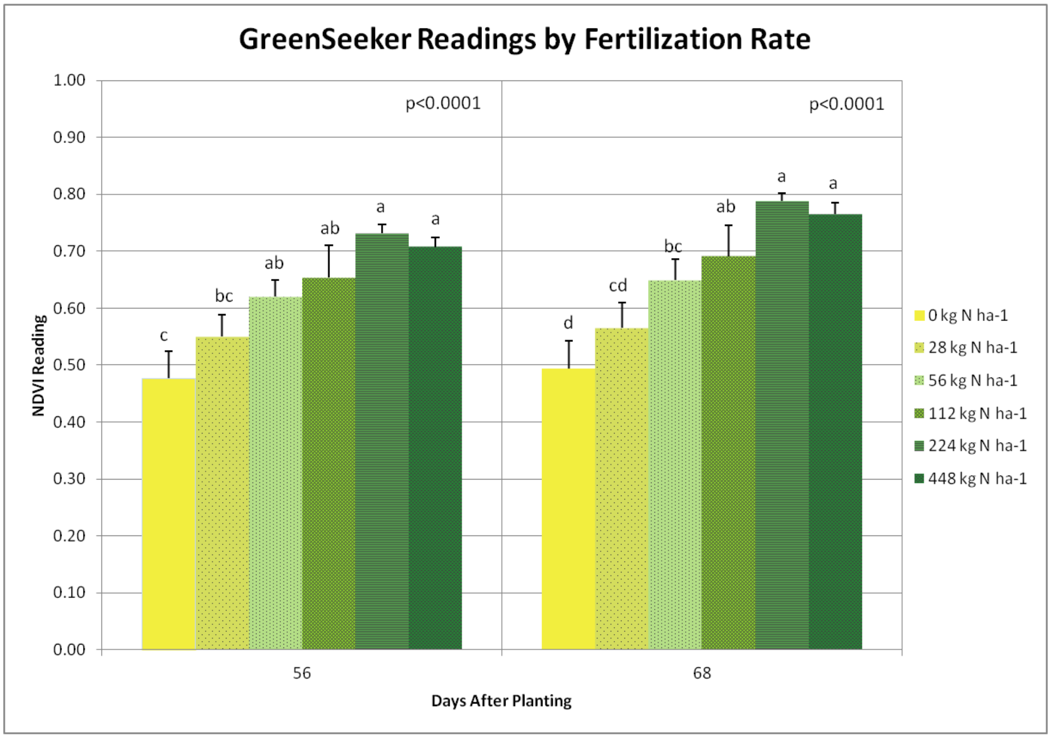

Figure 2.12. The effect of fertilization rate on GreenSeeker™ readings over time in Mount Gilead, OH.

(p=0.0071) and 68 days after planting (p=0.0120) (Figure 2.13). The till plots had higher mean readings than the no-till, with readings of 0.68 and 0.73 compared to 0.57 and 0.59, respectively.

3.5 SPAD chlorophyll content

The interaction between tillage treatment and fertilization rate did not have a significant effect on SPAD meter readings on either of the sampling dates (p>0.05).

Fertilization rate had a significant effect on SPAD meter readings on both 56 and 68 days after planting (p<0.0001) (Figure 2.14). At 56 days after planting, the 224 kg N ha^{-1} treatments had the highest mean reading of 46.48, but this not significantly different from the 448 kg N ha^{-1} treatments (45.36). At 68 days after planting, again these two treatments had significantly greater readings than the other treatments, but the 448 kg N ha^{-1} rate had a higher mean of 46.05.

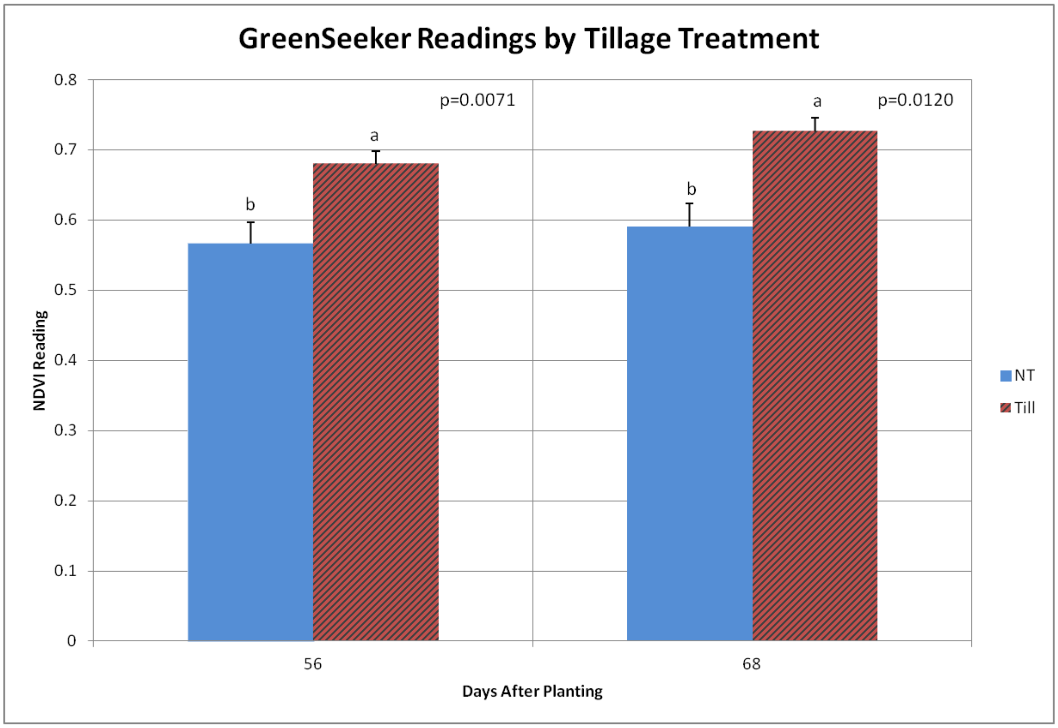

Figure 2.13. The effect of tillage treatment GreenSeeker™ readings over time in Mount Gilead, OH.

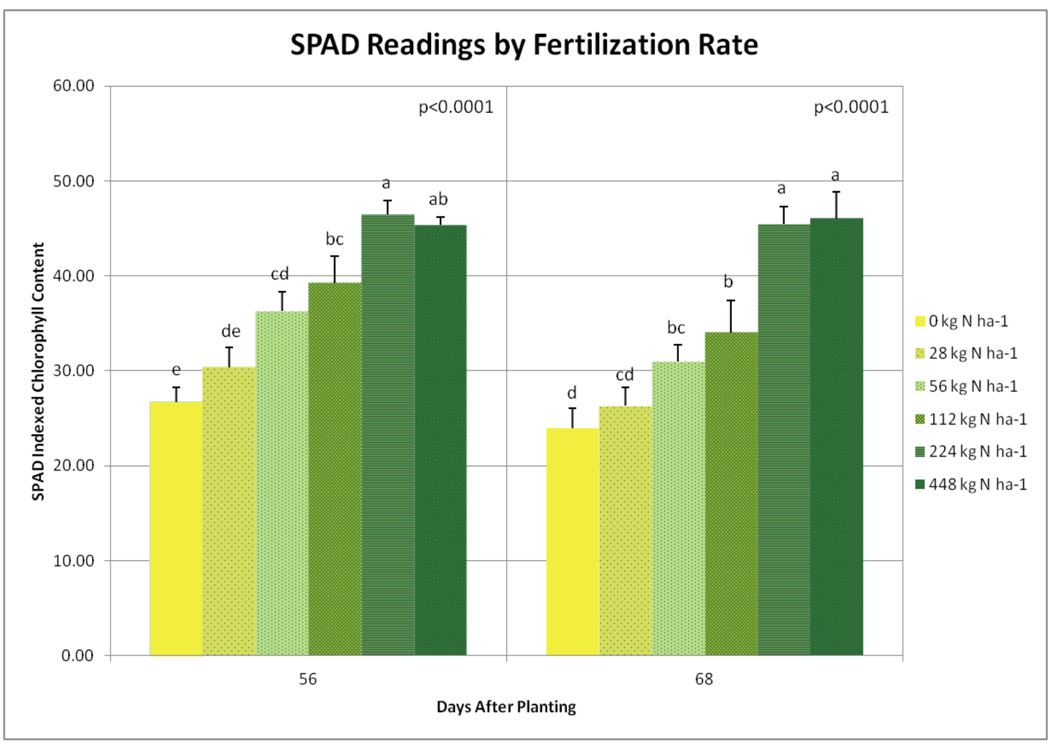

Figure 2.14. The effect of fertilization rate on SPAD values over time in Mount Gilead, OH.

Tillage had a significant effect on SPAD meter readings on both dates ($p<0.0001$ and $p=0.0022$, respectively) (Figure 2.15). The till plots had significantly higher readings of 40.65 and 39.25 at 56 and 68 days after planting, respectively, compared to the no-till readings of 34.19 and 29.70, respectively.

3.6 Yield

The interaction between tillage treatment and fertilization rate had a significant effect on dry grain yield ($p=0.0455$), but because the tillage treatments were not randomized, this relationship was not further examined.

Fertilization rate had a significant effect on yield ($p<0.0001$) (Figure 2.16, 2.17, 2.18). The 448 kg N ha^{-1} plots produced the highest yields (5.07 t ha^{-1}), which were not significantly different from the 224 kg N ha^{-1} plots (4.54 t ha^{-1}). The lowest yields overall surprisingly came from the 28 kg N ha^{-1} treated plots (1.20 t ha^{-1}), but this rate was not significantly greater than the 0 kg N ha^{-1} plots (1.45 t ha^{-1}).

Tillage treatment had a significant effect on yield ($p=0.0002$) (Figure 2.19). The till whole plot had a significantly greater mean yield than the no-till plot at 3.26 and 2.17 t ha^{-1}, respectively.

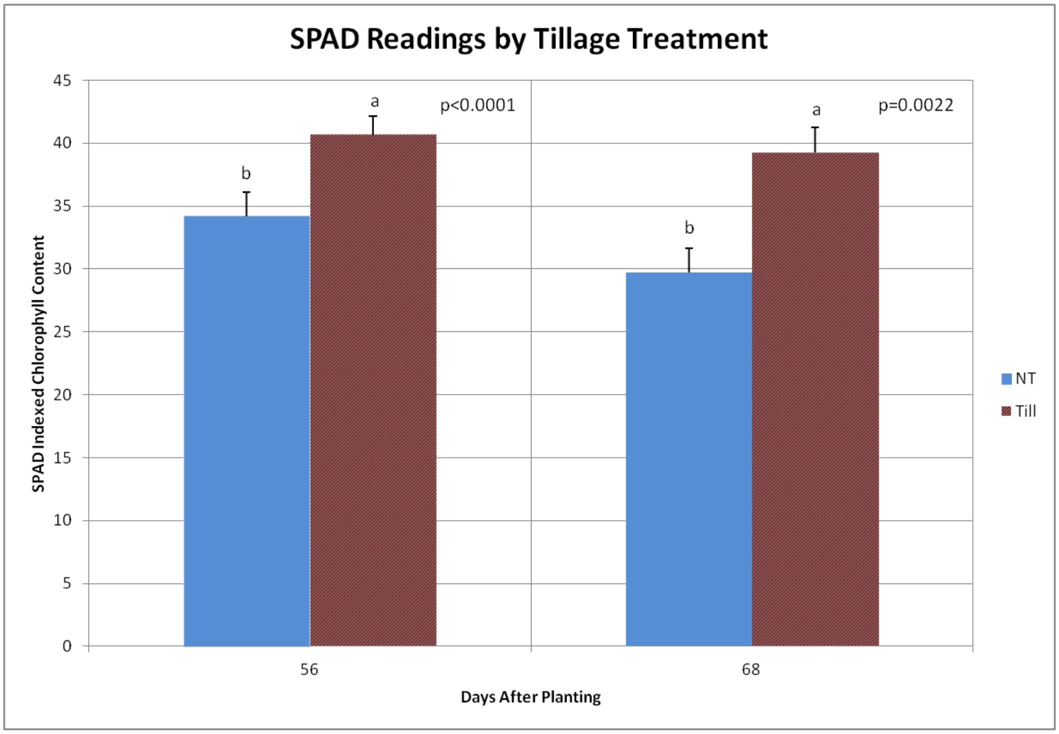

Figure 2.15. The effect of tillage treatment on SPAD values over time in Mount Gilead, OH.

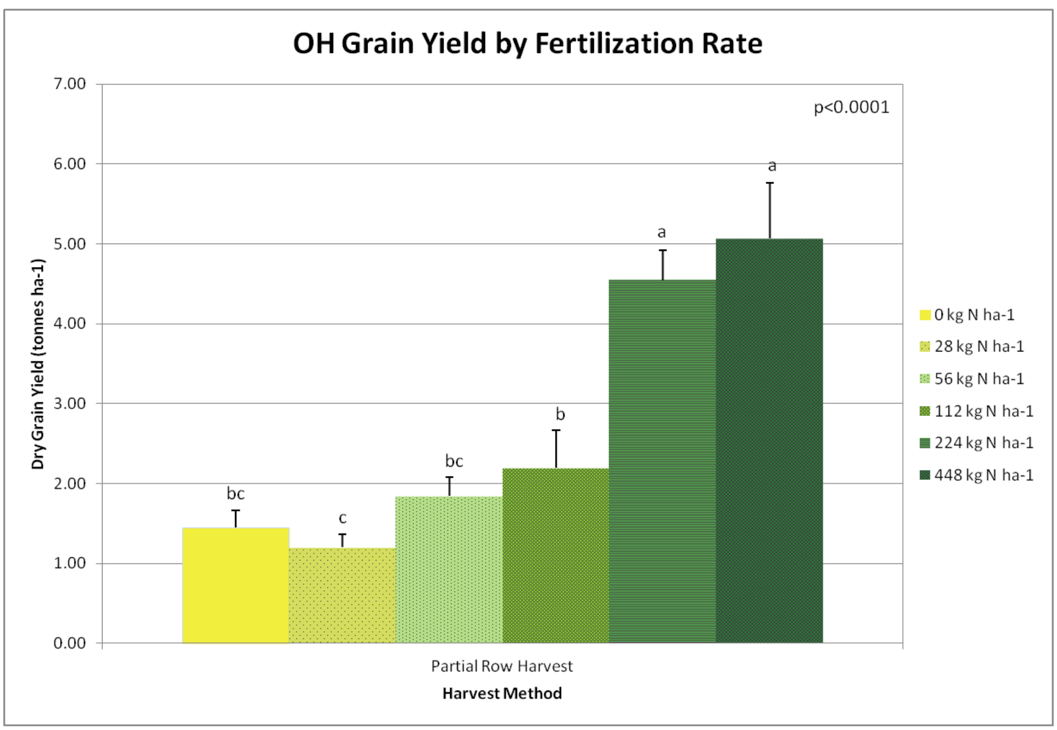

Figure 2.16. The effect of fertilization rate on grain yield in Mount Gilead, OH.

Figure 2.17. No-till whole plot yields by fertilization rate in Mount Gilead, OH: from top left 0 kg N ha^{-1}, top right 28 kg N ha^{-1}, middle left 56 kg N ha^{-1}, middle right 112 kg N ha^{-1}, bottom left 224 kg ha^{-1}, bottom left 448 kg N ha^{-1}.

Figure 2.18. Till whole plot yields by fertilization rate in Mount Gilead, OH: from top left 0 kg N ha^{-1}, top right 28 kg N ha^{-1}, middle left 56 kg N ha^{-1}, middle right 112 kg N ha^{-1}, bottom left 224 kg ha^{-1}, bottom left 448 kg N ha^{-1}.

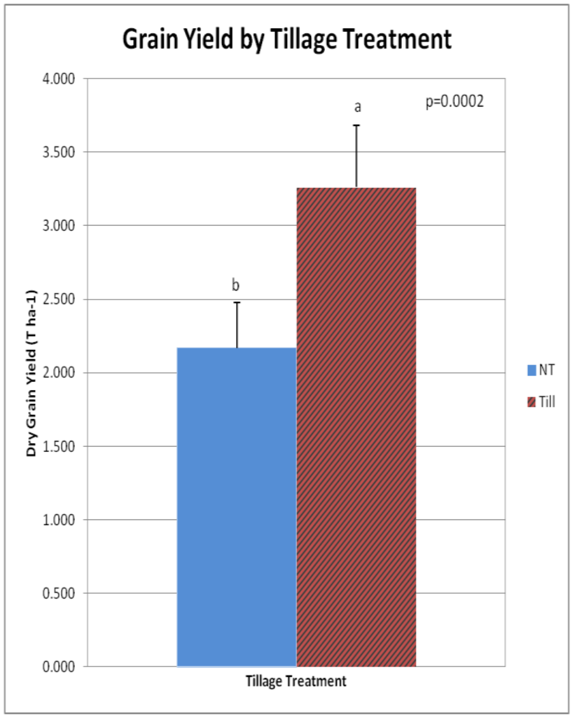

Figure 2.19. The effect of tillage treatment on grain yield in Mount Gilead, OH.

It is clear not only by the severely low yields, but also by the ears shown in Figures 2.17 and 2.18 that there were pollination issues that could have been caused by heavy rainfall following fertilizer application, and the following drought conditions that occurred when the plants had reached the R1 stage. In the lowest fertilization rates, especially 0-112 kg N ha^{-1}, these pollination issues are seen in the many large areas on the ears where kernels are missing.

Fertilization rates and tillage treatments also had significant effects on the ear:stalk ratios of the crops (p=0.0218 and p=0.0122, respectively). The 228 kg N ha^{-1} rate had the highest mean ear:stalk ratio of 0.96, but was not significantly different from the 448, 56, 28, or 0 kg N ha^{-1} rates with ratios of 0.94, 0.86, 0.82, and 0.83, respectively (Figure 2.20). The lowest ratio of 0.80 was found in the 112 kg N ha^{-1} rate, but it was not significantly different from the 0, 28, 56, or 448 kg N ha^{-1} rates. The till plot had a significantly higher mean ear:stalk ratio than the no-till plot (0.93 and 0.81, respectively) (Figure 2.21).

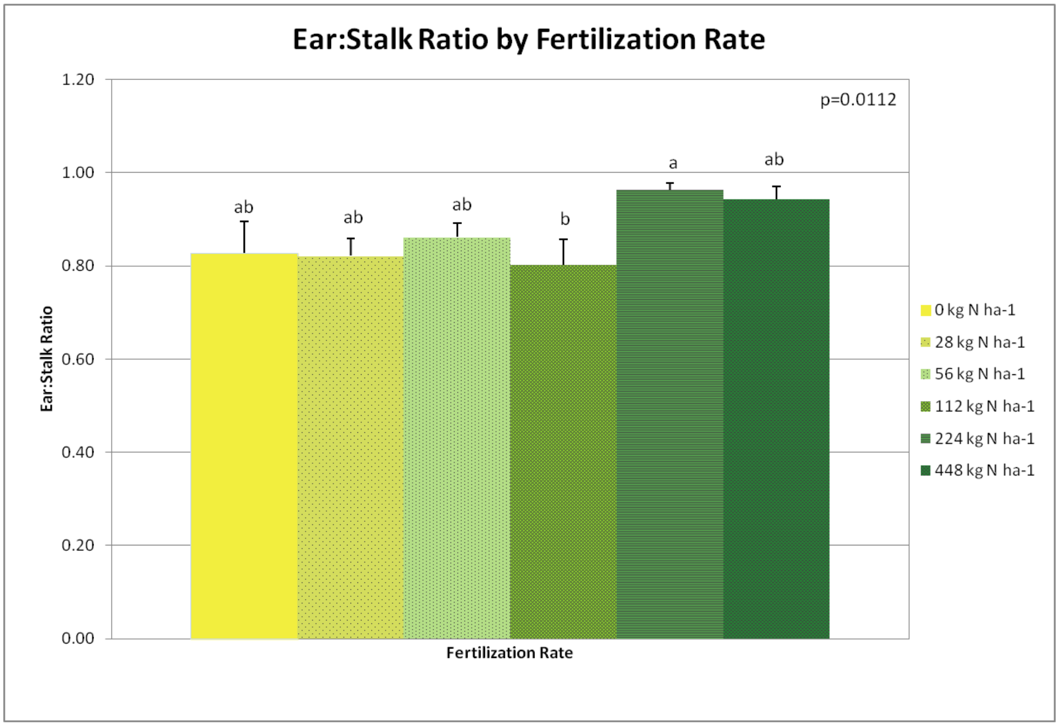

Figure 2.20. The effect of fertilization rate on ear:stalk ratio in Mount Gilead, OH.

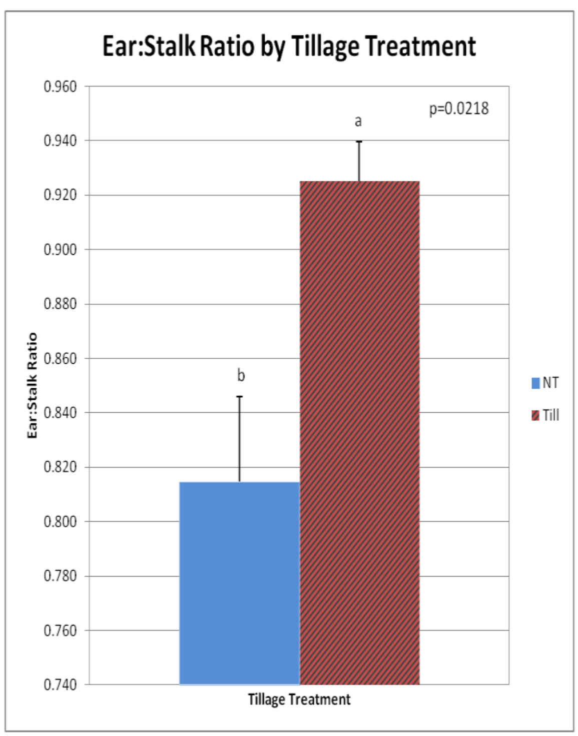

Figure 2.21. The effect of tillage treatment on ear:stalk ratio in Mount Gilead, OH.

4. Conclusions

Yields were relatively low overall this year due to heavy rainfall following application of fertilizers, and drought stress when the crops were at the R1 stage. Differences by fertilization rate showed that higher N fertilization rates had higher crop N uptake and productivity throughout the growing season. The highest two fertilization rates of 224 and 448 kg N ha^{-1} were never significantly different from each other in any of the crop height, GreenSeeker™, or SPAD data and consistently preformed better than the other treatments. As expected, crop height and nutrient uptake decreased with decreasing N application rate, and the 0 kg N ha^{-1} rate always had the lowest crop height and N uptake values.

Differences by tillage system consistently showed that the till whole plot preformed better than the no-till, with higher crop heights, GreenSeeker™, and SPAD readings on all dates measured. This is to be expected in the first growing season following tillage of a no-till soil, when nutrients preserved in undisturbed micropores are exposed to oxygen and microbial communities for mineralization. Despite these results, this data should not be misinterpreted as an argument for tillage. Due to the high precipitation, residues on the no-till soil surface conserved the soil moisture, allowing increased leaching and denitrification of N fertilizers. It is expected that in a dry year, no-till would perform better than the tilled soil because of their capacity for water conservation. Continuously tilled fields also tend to decrease in fertility over time, while no-till field nutrient levels remain consistent or actually result in a build-up of organic matter.

Future research on this study will focus on an economic analysis of the N preserved by no-till systems compared to tillage and the price of equivalent fertilizers required by continuous till systems.

References

Abendroth, L. J., R. W. Elmore, M. J. Boyer, and S. K. Marlay (2011). Corn growth and development. PMR 1009. Iowa State University Extension, Ames, Iowa.

Alvarez, R., Diaz, R. A., Barbero, N., Santanatoglia, O. J., & Blotta, L. (1995). Soil organic carbon, microbial biomass and CO 2-C production from three tillage systems. *Soil and Tillage Research*, *33*(1), 17-28.

Argenta, G., Silva, P. R. F. D., & Sangoi, L. (2004). Leaf relative chlorophyll content as an indicator parameter to predict nitrogen fertilization in maize.*Ciência Rural*, *34*(5), 1379-1387.

Arshad, M. A., Schnitzer, M., Angers, D. A., & Ripmeester, J. A. (1990). Effects of till vs no-till on the quality of soil organic matter. *Soil Biology and Biochemistry*, *22*(5), 595-599.

Barker, D. W., & Sawyer, J. E. (2010). Using active canopy sensors to quantify corn nitrogen stress and nitrogen application rate. *Agronomy Journal*, *102*(3), 964-971.

Black C.A. (1965). Methods of Soil Analysis: Part I Physical and mineralogical properties. American Society of Agronomy, Madison, Wisconsin, USA.

Climate: Mount Gilead. (n.d.) Retrieved from http://en.climate-data.org/location/137083

Derpsch, R. & Friedrich, T. (n.d.). Global overview of conservation agriculture adoption. Retrieved from http://www.fao.org/ag/ca/doc/derpsch-friedrich-global-overview-ca-adoption3.pdf

FAO (2012) What is Conservation Agriculture? Retrieved from http://www.fao.org/ag/ca/1b.html

Feil, B., Garibay, S. V., Ammon, H. U., & Stamp, P. (1997). Maize production in a grass mulch system–seasonal patterns of indicators of the nitrogen status of maize. *Developments in Crop Science*, *25*, 227-235.

Gibson, Lance R. (1998). Calculate Stand Density from Stand Counts. Document posted in Iowa State University Agronomy 212-Grain and Forage Crops, archived at: http://agron-www.agron.iastate.edu/Courses/agron212/calculations/Stand_counts.htm

Grandy, A. S., Loecke, T. D., Parr, S., & Robertson, G. P. (2006). Long-term trends in nitrous oxide emissions, soil nitrogen, and crop yields of till and no-till cropping systems. *Journal of Environmental Quality*, *35*(4), 1487-1495.

Kottek, M., J. Grieser, C. Beck, B. Rudolf, & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorol. Z.*, 15, 259-263. DOI: 10.1127/0941-2948/2006/0130. DOI: 10.1127/0941-2948/2006/0130.

Lauer, J. (2002). Methods for calculating corn yield. Agronomy Advice, University of Wisconsin-Madison. Retrieved from http://corn.agronomy.wisc.edu/AA/pdfs/A033.pdf

Lee, C. & Herbek, J. (2005). Estimating corn yields (AGR-187). University of Kentucky. Retrieved from http://www.ca.uky.edu/agc/pubs/agr/agr187/agr187.pdf.

Morrison, J. E., Huang, C. H., Lightle, D. T., & Daughtry, C. S. (1993). Residue measurement techniques. *Journal of Soil and Water Conservation*, *48*(6), 478-483.

Nielson, R. L. (2015). Estimating corn grain yield prior to harvest. Purdue University, Department of Agronomy. Retrieved from https://www.agry.purdue.edu/ext/corn/news/timeless/yldestmethod.html

NRCS (2004). 3.3 Bulk Density 3.3.1 Field State 3.3.1.4 Soil Cored. Retrieved from http://www.nrcs.usda.gov/internet/FSE_DOCUMENTS/nrcs142p2_051670.pdf.

Pidwirny, M. (2011). Moist Mid-latitude Climates with Mild Winters - C Climate Type. Retrieved from http://www.eoearth.org/view/article/162272

Pimentel, D. & Burgess, M. (2013). Soil erosion threatens food production. *Agriculture, 3,* 443-463.

Pittelkow, C. M., Liang, X., Linquist, B. A., Van Groenigen, K. J., Lee, J., Lundy, M. E., ... & van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365-368.

Salmerón, M., Isla, R., & Cavero, J. (2011). Effect of winter cover crop species and planting methods on maize yield and N availability under irrigated Mediterranean conditions. *Field Crops Research*, *123*(2), 89-99.

Shaver, T. M., Khosla, R., & Westfall, D. G. (2011). Evaluation of two crop canopy sensors for nitrogen variability determination in irrigated maize. *Precision Agriculture*, *12*(6), 892-904.

Teal, R. K., Tubana, B., Girma, K., Freeman, K. W., Arnall, D. B., Walsh, O., & Raun, W. R. (2006). In-season prediction of corn grain yield potential using normalized difference vegetation index. *Agronomy Journal*, *98*(6), 1488-1494.

Trimble (n.d.). GreenSeeker handheld crop sensor product overview. Retrieved from http://www.trimble.com/Agriculture/gs-handheld.aspx

Víg, R., Huzsvai, L., Dobos, A., & Nagy, J. (2012). Systematic measurement methods for the determination of the SPAD values of maize (Zea mays L.) canopy and potato (Solanum tuberosum L.). *Communications in Soil Science and Plant Analysis*, *43*(12), 1684-1693.

Web Soil Survey (WSS) (n.d.). Retrieved from http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

WeatherDB (n.d.). Mount Gilead, Ohio Average Rainfall. Retrieved from https://rainfall.weatherdb.com/l/17732/Mount-Gilead-Ohio

Yang, Y., Timlin, D. J., Fleisher, D. H., Lokhande, S. B., Chun, J. A., Kim, S. H., ... & Reddy, V. R. (2012). Nitrogen concentration and dry-matter accumulation in maize crop:

Assessing maize nitrogen status with an allometric function and a chlorophyll meter. *Communications in Soil Science and Plant Analysis, 43*(11), 1563-1575.

Appendix 2.1. Plot Information

Figure 2.22. Plot location: Mount Gilead, OH (40°36’18”N 82°40’32”W).

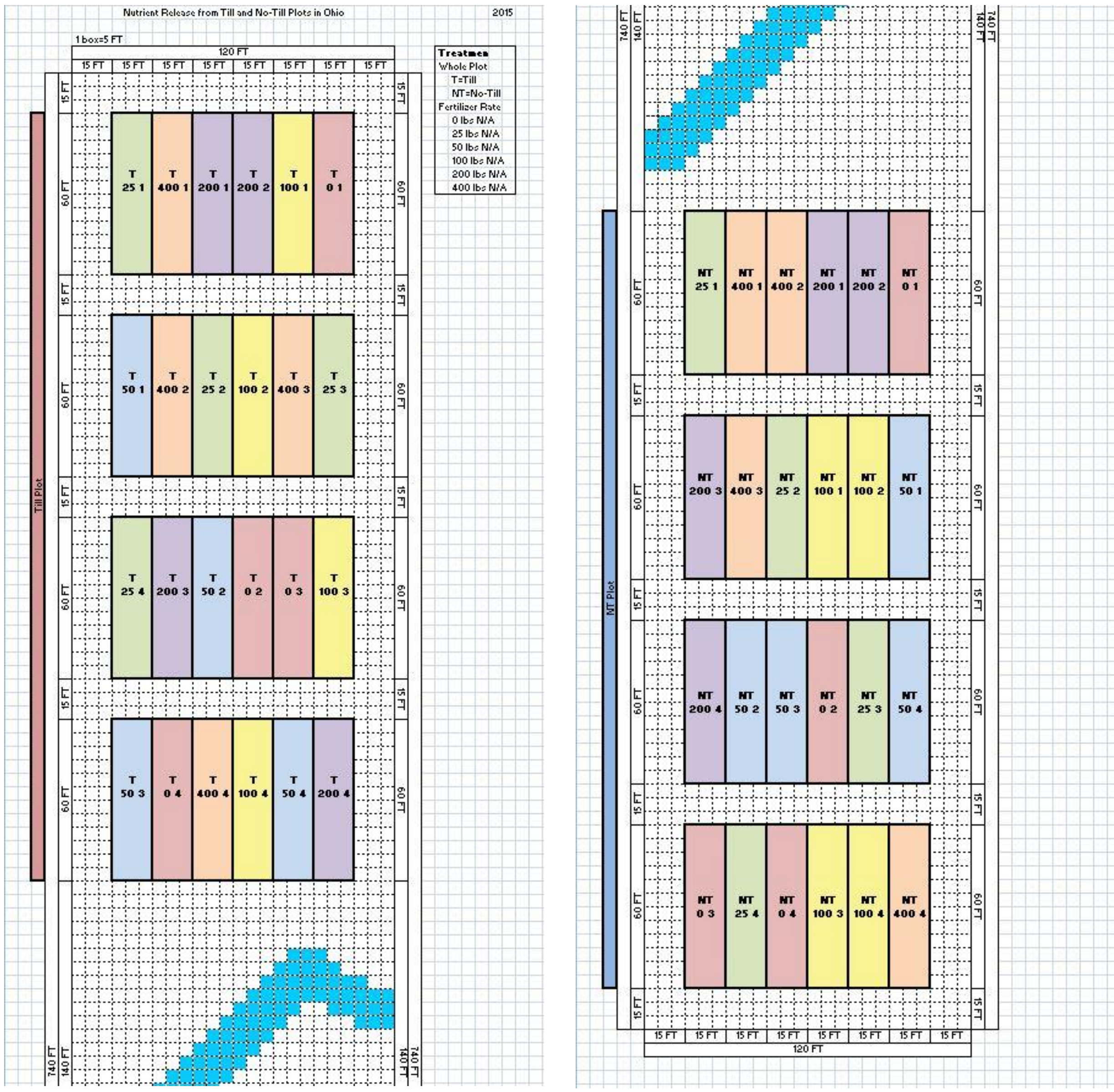

Figure 2.23. Study plot plan and experimental design in Mount Gilead, OH.

*Note: The blue area through the middle of the plots was a drainage stream.

Appendix 2.2. Fertilizer Calculations

Nitrogen

F1-0 lbs N A^{-1} (0 kg N ha^{-1}) as granular urea (46-0-0)

F2-25 lbs N A^{-1} (28.07 kg N ha^{-1})

25 lbs N/0.46 lbs N/lbs fertilizer = 0 lbs fertilizer A^{-1}

$$\frac{54.35 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 1.12 \text{ lbs fertilizer plot}^{-1}$$

F3-50 lbs N A^{-1} (56.14 kg N ha^{-1})

50 lbs N/0.46 lbs N/lbs fertilizer = 108.70 lbs fertilizer A^{-1}

$$\frac{108.70 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 2.25 \text{ lbs fertilizer plot}^{-1}$$

F4-100 lbs N A^{-1} (112.27 kg N ha^{-1})

100 lbs N/0.46 lbs N/lbs fertilizer = 217.39 lbs fertilizer A^{-1}

$$\frac{217.39 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 4.49 \text{ lbs fertilizer plot}^{-1}$$

F5-200 lbs N A^{-1} (224.55 kg N ha^{-1})

200 lbs N/0.46 lbs N/lbs fertilizer = 434.78 lbs fertilizer A^{-1}

$$\frac{434.78 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 8.98 \text{ lbs fertilizer plot}^{-1}$$

F6-400 lbs N A^{-1} (448.34 kg N ha^{-1})

400 lbs N/0.46 lbs N/lbs fertilizer = 896.57 lbs fertilizer A^{-1}

$$\frac{869.57 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 17.97 \text{ lbs fertilizer plot}^{-1}$$

Phosphorus

Rate: 100 lbs P_2O_5 A^{-1} as Triple Superphosphate 0-46-0

100 lbs P_2O_5/ 0.46 = 217.39 lbs fertilizer A^{-1}

$$\frac{217.39 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43{,}560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 4.49 \text{ lbs fertilizer/plot}$$

Potassium

Rate: 100 lbs K_2O A^{-1} as Potash 0-0-60

100 lbs K_2O/ 0.60 = 166.67 lbs fertilizer A^{-1}

$$\frac{166.67 \text{ lbs fertilizer}}{1 \text{ A}} \times \frac{1 \text{ A}}{43{,}560 \text{ ft}^2} \times \frac{900 \text{ ft}^2}{\text{plot}} = 3.44 \text{ lbs fertilizer plot}^{-1}$$

Appendix 2.3. Data

Table 2.1. Residue cover and population density data from June 22, 2015 (38 days after planting) in Mount Gilead, OH.

							Date: 6/22/2015
Plot	**Residue #**	**Residue %**	**Pop 1**	**Pop 2**	**Pop 3**	**Pop Mean**	**Pop Density (plants ha-1)**
N 0 1	42	84	29	32	30	30.33	74923
N 0 2	40	80	33	28	32	31.00	76570
N 0 3	33	66	30	32	25	29.00	71630
N 0 4	37	74	33	29	33	31.67	78217
N 25 1	42	84	31	31	33	31.67	78217
N 25 2	40	80	27	30	32	29.67	73277
N 25 3	43	86	32	34	31	32.33	79863
N 25 4	41	82	29	31	26	28.67	70807
N 50 1	38	76	31	25	30	28.67	70807
N 50 2	40	80	33	31	31	31.67	78217
N 50 3	43	86	34	32	28	31.33	77393
N 50 4	41	82	30	30	32	30.67	75747
N 100 1	37	74	34	33	33	33.33	82333
N 100 2	43	86	31	33	33	32.33	79863
N 100 3	39	78	28	26	28	27.33	67513
N 100 4	34	68	30	34	28	30.67	75747
N 200 1	42	84	34	29	33	32.00	79040
N 200 2	40	80	32	31	30	31.00	76570
N 200 3	41	82	30	32	32	31.33	77393
N 200 4	38	76	29	31	32	30.67	75747
N 400 1	38	76	29	28	30	29.00	71630
N 400 2	39	78	33	33	28	31.33	77393
N 400 3	40	80	30	31	31	30.67	75747
N 400 4	32	64	29	30	27	28.67	70807
T 0 1	9	18	30	32	30	30.67	75747
T 0 2	2	4	31	30	28	29.67	73277
T 0 3	1	2	28	32	30	30.00	74100
T 0 4	3	6	30	29	31	30.00	74100
T 25 1	4	8	31	30	29	30.00	74100
T 25 2	6	12	32	29	30	30.33	74923
T 25 3	7	14	32	31	30	31.00	76570
T 25 4	5	10	30	29	33	30.67	75747
T 50 1	2	4	27	28	29	28.00	69160
T 50 2	7	14	26	27	32	28.33	69983
T 50 3	4	8	31	31	32	31.33	77393
T 50 4	1	2	30	31	32	31.00	76570
T 100 1	6	12	29	32	29	30.00	74100
T 100 2	2	4	31	28	25	28.00	69160
T 100 3	0	0	30	27	31	29.33	72453
T 100 4	3	6	32	29	31	30.67	75747
T 200 1	3	6	28	28	27	27.67	68337
T 200 2	6	12	30	28	31	29.67	73277
T 200 3	4	8	29	28	29	28.67	70807
T 200 4	5	10	32	28	31	30.33	74923
T 400 1	5	10	28	29	30	29.00	71630
T 400 2	3	6	27	31	30	29.33	72453
T 400 3	5	10	30	28	30	29.33	72453
T 400 4	4	8	31	30	30	30.33	74923

Table 2.2. Bulk density and water content measurements and calculations from July 22, 2015 (68 days after planting) in Mount Gilead, OH.

				Date: 7/22/2015	
Sample	**Wet Mass (g)**	**Dry Mass (g)**	**Bulk Density (g cm-3)**	**Ɵg (%)**	**Ɵv (%)**
T 1	447.03	342.78	1.20	30.41	36.37
T 2	499.62	398.36	1.39	25.42	35.33
T 3	471.06	383.00	1.34	22.99	30.72
NT 1	499.55	412.55	1.44	21.09	30.35
NT 2	554.46	455.83	1.59	21.64	34.41
NT 3	535.68	424.11	1.48	26.31	38.92

Table 2.3. Crop height measurements from June 22, 2015 (38 days after planting) in Mount Gilead, OH.

									Date: 6/22/2015
Plot	**Ht 1 (cm)**	**Ht 2**	**Ht 3**	**Ht 4**	**Ht 5**	**Ht 6**	**Ht 7**	**Ht 8**	**Ht Mean (cm)**
N 0 1	35.6	34.3	47.2	35.6	39	36.5	39.4	44.1	38.96
N 0 2	34.5	50.5	36.1	36.9	39.4	44.6	39	40	40.13
N 0 3	27.5	25.5	30.1	33.2	22.2	28.5	39.4	27	29.18
N 0 4	27.8	33.2	31	29.2	27.1	28.1	27.5	31	29.36
N 25 1	32.9	60.5	37.1	40.5	40.6	51.1	30.4	23.7	39.60
N 25 2	46	31.6	43	37.3	27.4	34.3	35.7	23.5	34.85
N 25 3	36.1	43	34	54.6	48.9	44.1	47.9	38.2	43.35
N 25 4	32	41.5	40.5	38.8	39.2	37.9	31	23.2	35.51
N 50 1	62.1	51.6	44.9	48.2	54.5	47.5	58.7	62.3	53.73
N 50 2	48	44.4	60.2	52.3	48.7	40.3	45.5	34.5	46.74
N 50 3	36.5	37.6	48.3	39.6	36.6	40.9	46.5	40.1	40.76
N 50 4	35.4	74.4	46.7	64.5	54.5	56.3	39.8	44.7	52.04
N 100 1	60.3	48	61.5	67.1	49.1	54.5	53	58.4	56.49
N 100 2	59.2	54.5	59.1	51.3	64	60.9	52.1	67.5	58.58
N 100 3	38	25.6	37.7	35.8	37	39	24.7	31.2	33.63
N 100 4	34.6	21.2	31.5	32.5	37.1	36.5	33	36	32.80
N 200 1	55	55.9	50.7	53.2	53.1	50	69	48.2	54.39
N 200 2	44.3	46.9	34	47.8	47.5	52.3	62.3	61	49.51
N 200 3	39.1	60.7	68.1	59	56.4	67.5	49	42.5	55.29
N 200 4	39.3	52.8	46.6	54	46.5	42.5	70.5	43.8	49.50
N 400 1	36.4	44.6	51.5	48.7	56.4	38.7	66.4	48.4	48.89
N 400 2	41	63.1	60.2	45	45.2	37.5	45.5	50.1	48.45
N 400 3	58.5	44	30.9	46.5	37	24.9	44	43.4	41.15
N 400 4	49.5	35.7	40.4	40.9	46.2	52	42.5	31.1	42.29
T 0 1	43.9	64.8	41	62.6	57.6	42.1	37.9	42.5	49.05
T 0 2	41.6	48.6	41	42	50.9	42.7	31.2	49.6	43.45
T 0 3	43.1	35.8	30.3	29	44	38	37.2	45.2	37.83
T 0 4	42.3	35.7	29.4	27.2	41	36	34.1	35.3	35.13
T 25 1	28	46.9	43.3	34	49	35.9	46.1	55.2	42.30
T 25 2	28.7	39.5	47.7	53.7	26.2	25.5	40.6	39.2	37.64
T 25 3	40.9	39.5	33.7	34.7	39.5	41.6	39.9	44.6	39.30
T 25 4	63.6	38.4	35.7	62.4	37	35.5	52.6	42.5	45.96
T 50 1	41.8	46.1	39.5	45.6	59.6	52.5	41.8	44.7	46.45
T 50 2	48.6	42	34.5	25.6	35.2	48.4	59.2	51.3	43.10
T 50 3	63.2	47.5	35.6	50.9	38.3	63.5	42.1	31.2	46.54
T 50 4	50.8	57.1	59	50.4	53.7	51.9	35	44.8	50.34
T 100 1	54.3	42.9	38	64.3	50.8	49.7	53.3	56.2	51.19
T 100 2	39.1	46	45.5	38.8	38	56.2	36.2	47.9	43.46
T 100 3	61.7	42.1	60.2	43.8	36.9	37.4	34.2	46.8	45.39
T 100 4	38.2	45.8	34.8	46.9	35.2	41.8	35.6	57.1	41.93
T 200 1	51.4	41	37.5	31	60	56	58.1	42	47.13
T 200 2	59.2	43.3	62.3	50.6	49.5	37.3	56.6	45.8	50.58
T 200 3	43.9	39.2	50.6	58.8	46.2	50.9	49.7	55.3	49.33
T 200 4	42.3	26.6	45.8	59.1	56.2	46.9	26.8	33.7	42.18
T 400 1	52.2	45.7	70.6	45.2	47.2	67.1	66.5	45	54.94
T 400 2	39.3	56.7	47.7	49.4	47.5	57	44.5	53.4	49.44
T 400 3	41.1	66.5	45.5	40.9	41.3	38.8	38.9	44.6	44.70
T 400 4	45	42.7	42.4	49.6	42	51.4	50.8	35.1	44.88

Table 2.4. Crop height (Ht), GreenSeeker™ (GS), and SPAD measurements from July 10, 2015 (56 days after planting) in Mount Gilead, OH.

												Date: 7/10/2015	
Plot	**Ht 1 (cm)**	**Ht 2**	**Ht 3**	**Ht 4**	**Ht 5**	**Ht 6**	**Ht 7**	**Ht 8**	**GS 1**	**GS 2**	**Ht Mean (cm)**	**GS Mean**	**SPAD**
N 0 1	43.9	51.7	58.7	55.7	47.2	54.2	51.2	52	0.34	0.39	51.83	0.365	24.2
N 0 2	49.6	66.3	53.3	58.9	68.1	62.2	47.6	55.3	0.47	0.44	57.66	0.455	20.4
N 0 3	59.8	38.1	36.2	38.6	54.2	52.1	45.7	39.2	0.34	0.34	45.49	0.34	23.3
N 0 4	32.2	34.2	36.3	42.6	33.8	39.7	34.6	31.5	0.31	0.31	35.61	0.31	24
N 25 1	7.5	105.7	104.2	91.5	86.1	88.7	72.8	82.4	0.63	0.57	79.86	0.6	32.6
N 25 2	59.1	56.9	34.8	40	48	90.1	60.9	66.3	0.47	0.49	57.01	0.48	22.8
N 25 3	57.5	60	99	64.5	108.4	110.3	78.9	57.6	0.49	0.54	79.53	0.515	25.7
N 25 4	55.9	55.1	39.6	51.2	50.2	45	41.9	52.4	0.33	0.37	48.91	0.35	24.1
N 50 1	126.8	106.9	81	139.5	91.2	88.9	105	102	0.71	0.72	105.16	0.715	38.3
N 50 2	70.5	87.3	89.3	68	89.9	78.3	71.5	81	0.57	0.58	79.48	0.575	30.9
N 50 3	62	66.2	69.6	90.1	56.8	62.6	75.2	70.6	0.52	0.46	69.14	0.49	25.9
N 50 4	77	93.2	123.3	96	63	104.2	62.9	71.3	0.6	0.64	86.36	0.62	40.5
N 100 1	134.5	67.2	92.2	62.3	105.8	144.1	116.8	104.2	0.68	0.66	103.39	0.67	31.5
N 100 2	142.2	139.8	132.3	127.8	136.1	132.5	128.9	139.6	0.77	0.77	134.90	0.77	47
N 100 3	57.2	67	56.5	69.4	60.7	63.3	73	66.4	0.45	0.44	64.19	0.445	30.8
N 100 4	43.9	44.6	37.5	46.6	59.2	59.6	69.2	73.4	0.38	0.35	54.25	0.365	27.4
N 200 1	124.7	122.4	102.6	99.1	128.9	120.9	157.4	73	0.7	0.68	116.13	0.69	40.7
N 200 2	66.2	113.9	83.3	87.3	92.8	122.5	99.6	105.3	0.68	0.61	96.36	0.645	42.1
N 200 3	77.7	111.8	106.5	81	128	122.1	128.3	149.6	0.82	0.7	113.13	0.76	48.9
N 200 4	82.1	122.7	138	132.5	88.5	67.5	92.4	144.7	0.78	0.67	108.55	0.725	44
N 400 1	76	88.2	74.7	89.3	78.9	89.4	130.5	118.9	0.66	0.7	93.24	0.68	44.1
N 400 2	85.6	142.9	108.5	83.5	76.5	104.2	139.8	69.2	0.68	0.63	101.28	0.655	44.2
N 400 3	111.6	183	63.8	94.8	88.2	68.9	46.6	66.9	0.66	0.66	90.48	0.66	42.6
N 400 4	74.2	48.6	64.1	82.3	81.6	84.4	103.6	127.3	0.75	0.69	83.26	0.72	44.5
T 0 1	69.9	54.6	86	99.4	115	86.8	78.8	82.7	0.73	0.67	84.15	0.7	33.4
T 0 2	89.2	76.4	77.2	75.9	68.2	68.6	85.3	59.3	0.59	0.59	75.01	0.59	29.7
T 0 3	94.2	76.3	55	70.2	79.5	67.3	58.7	63.5	0.49	0.58	70.59	0.535	30.1
T 0 4	79.9	50.6	57.1	52.3	58.3	97.5	51.3	54	0.56	0.48	62.63	0.52	28.6
T 25 1	102.5	89.4	99.4	91.3	53.5	125.8	75	106.4	0.64	0.66	92.91	0.65	36.6
T 25 2	94.9	92.1	86.4	85.6	42.1	63.4	59.3	83.1	0.35	0.65	75.86	0.5	31.4
T 25 3	65.1	87	66.8	69.8	57	70	77.4	78.9	0.6	0.65	71.50	0.625	30.7
T 25 4	91.2	98.2	102.3	87.7	113.9	83	80	83.3	0.72	0.64	92.45	0.68	39.3
T 50 1	84.5	84.7	97.6	80	87.9	84.3	89.6	94	0.68	0.61	87.83	0.645	37.2
T 50 2	123.5	80.9	103.2	54.7	84.5	78.9	91.6	98	0.43	0.65	89.41	0.54	36
T 50 3	130.3	87	106.1	73	73.5	80	68.5	44.3	0.65	0.62	82.84	0.635	36.5
T 50 4	108.1	102.9	103.9	99.9	114.4	68.7	96.5	76.2	0.75	0.73	96.33	0.74	45.1
T 100 1	114.4	120.6	99	118	106.9	120	120.8	110.4	0.77	0.74	113.76	0.755	45.3
T 100 2	77	133.3	105	90.9	87	116	143.1	111.7	0.73	0.81	108.00	0.77	41.2
T 100 3	78	73.9	103.7	108.4	78.9	93.7	113.2	114.5	0.71	0.74	95.54	0.725	46.4
T 100 4	81.6	58.8	85.6	143.1	72	107.7	109.3	110.6	0.75	0.71	96.09	0.73	44.6
T 200 1	56.3	97.9	75.7	120.9	80.4	120.6	116.6	98.6	0.75	0.76	95.88	0.755	45.8
T 200 2	114.4	127	97.9	148.4	125.2	157.5	86.4	101.5	0.76	0.72	119.79	0.74	46.8
T 200 3	127	120.9	109.8	110.3	127.9	109.9	127.7	123.2	0.78	0.77	119.59	0.775	50.4
T 200 4	127.1	126	153.5	126.7	131.6	149.3	74	78.6	0.77	0.76	120.85	0.765	53.1
T 400 1	110	118.7	132.7	132.7	130.7	124.3	113.5	97	0.81	0.74	119.95	0.775	48.3
T 400 2	109.8	105.4	86.6	115.5	122.4	118.2	104.4	102.8	0.79	0.73	108.14	0.76	49.2
T 400 3	106.6	135.3	111.5	80.6	86.4	97	121.1	99	0.7	0.73	104.69	0.715	45.4
T 400 4	97.5	99	131.6	92.1	127.4	106.1	93.1	103.5	0.69	0.71	106.29	0.7	44.6

Table 2.5. GreenSeeker™ (GS) and SPAD readings from July 22, 2015 (68 days after planting) in Mount Gilead, OH.

				Date: 7/22/2015
Plot	**GS 1**	**GS 2**	**GS Mean**	**SPAD**
N 0 1	0.47	0.47	0.47	22.8
N 0 2	0.48	0.48	0.48	21.9
N 0 3	0.32	0.33	0.33	18
N 0 4	0.31	0.27	0.29	14.1
N 25 1	0.64	0.63	0.64	29.5
N 25 2	0.46	0.38	0.42	20
N 25 3	0.49	0.55	0.52	23.3
N 25 4	0.35	0.34	0.35	17.4
N 50 1	0.76	0.77	0.77	34
N 50 2	0.65	0.61	0.63	27.8
N 50 3	0.44	0.51	0.48	23
N 50 4	0.44	0.65	0.55	27.8
N 100 1	0.64	0.73	0.69	29.7
N 100 2	0.83	0.79	0.81	40.4
N 100 3	0.52	0.46	0.49	21.3
N 100 4	0.46	0.38	0.42	19
N 200 1	0.75	0.71	0.73	37.9
N 200 2	0.76	0.73	0.75	42.2
N 200 3	0.84	0.76	0.80	44.7
N 200 4	0.76	0.74	0.75	40.2
N 400 1	0.75	0.71	0.73	42.4
N 400 2	0.75	0.67	0.71	42.8
N 400 3	0.73	0.71	0.72	38
N 400 4	0.72	0.67	0.70	34.4
T 0 1	0.64	0.78	0.71	31.6
T 0 2	0.59	0.55	0.57	27.7
T 0 3	0.48	0.59	0.54	27.1
T 0 4	0.56	0.58	0.57	28.4
T 25 1	0.66	0.67	0.67	30.8
T 25 2	0.58	0.65	0.62	28.2
T 25 3	0.63	0.69	0.66	29.1
T 25 4	0.68	0.65	0.67	32.5
T 50 1	0.69	0.7	0.70	34
T 50 2	0.62	0.7	0.66	33.4
T 50 3	0.67	0.62	0.65	29.2
T 50 4	0.76	0.8	0.78	38.7
T 100 1	0.81	0.81	0.81	41.3
T 100 2	0.8	0.77	0.79	38.5
T 100 3	0.75	0.77	0.76	40.8
T 100 4	0.77	0.77	0.77	41.5
T 200 1	0.79	0.82	0.81	49.9
T 200 2	0.83	0.78	0.81	45.4
T 200 3	0.84	0.83	0.84	51.1
T 200 4	0.83	0.84	0.84	52
T 400 1	0.83	0.82	0.83	54.9
T 400 2	0.84	0.83	0.84	54.6
T 400 3	0.8	0.81	0.81	52.9
T 400 4	0.81	0.79	0.80	48.4

Table 2.6. Yield measurements and calculations from October 22, 2015 in Mount Gilead, OH.

								Date: 10/22/2015
Ohio Harvest Data								
Plot	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Yield (T ha-1)	Grain Moisture %	**Yield (T ha-1) corrected for 15.5% moisture**
NT 0 1	29	25	479.55	63.4	416.15	1.02789	12.53	**1.064**
NT 0 2	32	30	842.7	116.39	726.31	1.79399	12.43	**1.859**
NT 0 3	24	20	423.67	81.92	341.75	0.84412	12.48	**0.874**
NT 0 4	25	9	318.18	36.67	281.51	0.69533	12.48	**0.720**
NT 25 1	29	24	703.47	110.26	593.21	1.46523	13.20	**1.505**
NT 25 2	29	19	332.13	63.3	268.83	0.66401	13.10	**0.683**
NT 25 3	33	28	662.65	104.54	558.11	1.37853	13.00	**1.419**
NT 25 4	27	22	456.74	99.19	357.55	0.88315	13.10	**0.908**
NT 50 1	30	29	1042.36	164.76	877.6	2.16767	12.07	**2.256**
NT 50 2	33	23	684.69	114.76	569.93	1.40773	12.30	**1.461**
NT 50 3	29	25	566.72	96.22	470.5	1.16214	12.90	**1.198**
NT 50 4	34	28	994.17	146.92	847.25	2.09271	12.17	**2.175**
NT 100 1	32	22	594.5	93.22	501.28	1.23816	12.20	**1.287**
NT 100 2	31	25	1195.09	208.86	986.23	2.43599	12.30	**2.528**
NT 100 3	26	17	294.02	48.31	245.71	0.6069	12.25	**0.630**
NT 100 4	26	14	335.53	62.91	272.62	0.67337	12.25	**0.699**
NT 200 1	30	26	1956.65	285.91	1670.74	4.12673	13.57	**4.221**
NT 200 2	31	30	1513.84	234.94	1278.9	3.15888	13.10	**3.249**
NT 200 3	32	31	1752.06	278.05	1474.01	3.6408	13.80	**3.714**
NT 200 4	30	29	2231.51	350.38	1881.13	4.64639	12.63	**4.804**
NT 400 1	29	29	3003.1	441.39	2561.71	6.32742	14.43	**6.408**
NT 400 2	30	28	1753.04	279.57	1473.47	3.63947	14.53	**3.681**
NT 400 3	28	25	1325.45	207.97	1117.48	2.76018	15.20	**2.770**
NT 400 4	32	25	932.54	161.17	771.37	1.90528	13.20	**1.957**
T 0 1	28	27	1189.74	178.21	1011.53	2.49848	13.93	**2.545**
T 0 2	28	24	526.9	77.07	449.83	1.11108	13.42	**1.138**
T 0 3	25	22	717.06	106.68	610.38	1.50764	13.30	**1.547**
T 0 4	26	24	817.63	100.62	717.01	1.77101	13.03	**1.823**
T 25 1	31	28	738.01	120.14	617.87	1.52614	13.83	**1.556**
T 25 2	22	15	227.03	45.56	181.47	0.44823	13.38	**0.459**
T 25 3	32	30	760.87	121.06	639.81	1.58033	13.00	**1.627**
T 25 4	32	29	683.34	113.39	569.95	1.40778	13.30	**1.444**
T 50 1	29	27	1006.51	160.76	845.75	2.089	13.00	**2.151**
T 50 2	23	21	419.79	80.44	339.35	0.83819	13.17	**0.861**
T 50 3	31	25	810.28	119.44	690.84	1.70637	13.06	**1.756**
T 50 4	29	26	1347.1	205.12	1141.98	2.82069	13.46	**2.889**
T 100 1	29	26	1128.06	203.37	924.69	2.28398	13.27	**2.344**
T 100 2	26	25	2209.13	341.17	1867.96	4.61386	14.67	**4.659**
T 100 3	30	28	1178.67	182.42	996.25	2.46074	12.90	**2.536**
T 100 4	32	30	1342.84	213.77	1129.07	2.7888	12.97	**2.872**
T 200 1	31	30	1786.34	278.22	1508.12	3.72506	14.00	**3.791**
T 200 2	28	28	2108.06	312.92	1795.14	4.434	13.93	**4.516**
T 200 3	31	30	2678.58	386.97	2291.61	5.66028	15.83	**5.638**
T 200 4	30	30	3010.81	460.8	2550.01	6.29852	13.90	**6.418**
T 400 1	32	32	3105.23	441.5	2663.73	6.57941	16.70	**6.486**
T 400 2	24	24	3113.3	436.5	2676.8	6.6117	14.93	**6.656**
T 400 3	28	28	3223.85	458.63	2765.22	6.83009	14.13	**6.941**
T 400 4	33	31	2655.15	399.93	2255.22	5.57039	14.70	**5.623**

Chapter 3
Testing the Use of Spent Microbial Biomass as an Alternative Nitrogen Source for East Tennessee Corn Farmers

Abstract

Due to the rising cost of fertilizers, many farmers are now looking for alternative nitrogen (N) sources. A by-product of an East Tennessee corn fermentation plant, spent microbial biomass (SMB), could provide a greater source of N than many other common organic fertilizers. If land applied as a N source, SMB could reduce input costs for farmers, the cost of disposal in a landfill for the industry, and environmental degradation by chemical N. The objective of this study was to test if SMB could be a viable N source for corn (*Zea mays L.*) production on a Dewey silty clay in Lenoir City, TN. The SMB was applied at rates of 2.24, 4.48, 6.72, 8.96, and 11.20 t ha^{-1} and was compared to the current farmer practice of 212.8 kg N ha^{-1} granular urea (46-0-0). Nitrogen availability and crop uptake throughout the growing season was measured through crop height and two plant sensors: the Trimble Handheld GreenSeeker^{TM} and the Minolta SPAD-502 Chlorophyll Meter. This research found no significant differences between treatment yields, and the higher rates of the SMB treatments (6.72, 8.96, and 11.20 t ha^{-1}) provided similar amounts of N compared to the conventional N fertilizer sources, if not more in some cases. The results of this study indicate that SMB could offer a sufficient source of N to corn, while reducing costs for local farmers and the industry.

1. Introduction

Corn (*Zea mays* L.) is the number one crop grown in the US, with over 360 million tonnes (t) produced in 2014 (USDA, 2015). Approximately 27% of harvested crop acres in the U.S. are used to produce corn, 93% of which is grown for grain, while the remaining 7% is grown for silage (EPA, 2013). Tennessee is a major producer of corn, especially in the western region of the state. In 2015, 296,000 ha were planted with corn for grain and 20,000 ha for silage in the Tennessee (USDA, 20156

Nitrogen fertilizers are an essential agricultural input for the production of corn (Figure 3.1). In 2014, 40% of fertilizers applied in the U.S. were used in corn production (Foley, 2013, USGS, 2015). These fertilizers come at a significant cost to the farmer and the environment. The

2015 University of Tennessee Field Crop Budget estimated that in the production of no-till non-irrigated corn at 9.41 t ha^{-1}, fertilizers comprised 25% of total input costs at $360 ha^{-1}. Of the fertilizers applied, urea was the most expensive amendment, making up 62% of total fertilizer costs and 15% of total production costs at $222 ha^{-1} when applied at190 kg N ha^{-1} (Smith et al., 2015).

The cost of ammonia is directly tied to the cost of the natural gas used to produce it (Figure 3.2). Natural gas prices can determine the amount of ammonia produced or imported by the U.S., and recent years have seen increased reliance on importation from countries including Trinidad and Tobago, Canada, Russia, and Ukraine (USGS, 2015). These increased costs fall on the farmer, who is forced to either pay the asking price or find an alternative. When comparing Figures 3.1 and 3.2, it is clear that an increase in fertilizer cost results in a reduction in use, as seen after the historically high jump in prices in 2008 and the following drop in use in 2009.

The use of chemical N fertilizers also comes at a cost to the environment, both on and off the farm. Heavy rainfall following application can result in a huge loss of nutrients through runoff and leaching, and a cost to the farmer from additional application or a loss in yield. Offsite, N transported to surface waters can cause eutrophication, and groundwater contamination can lead to health problems such as blue baby syndrome.

Spent microbial biomass (SMB) is one alternate N source option for local East Tennessee farmers. SMB is the by-product of corn fermentation processes in the production of 1,3 propanediol (PDO) at DuPont Tate and Lyle, LLC, in Loudon, Tennessee (Figure 3.3). PDO is used in the production of the Sonora® 3GT polymer used in fibers for clothing and carpets, films and packaging, and engineering components (Kurian, 2005). Around 19.8 million U.S. tons (T) of SMB are produced at the plant on an annual basis, which are currently disposed of in a

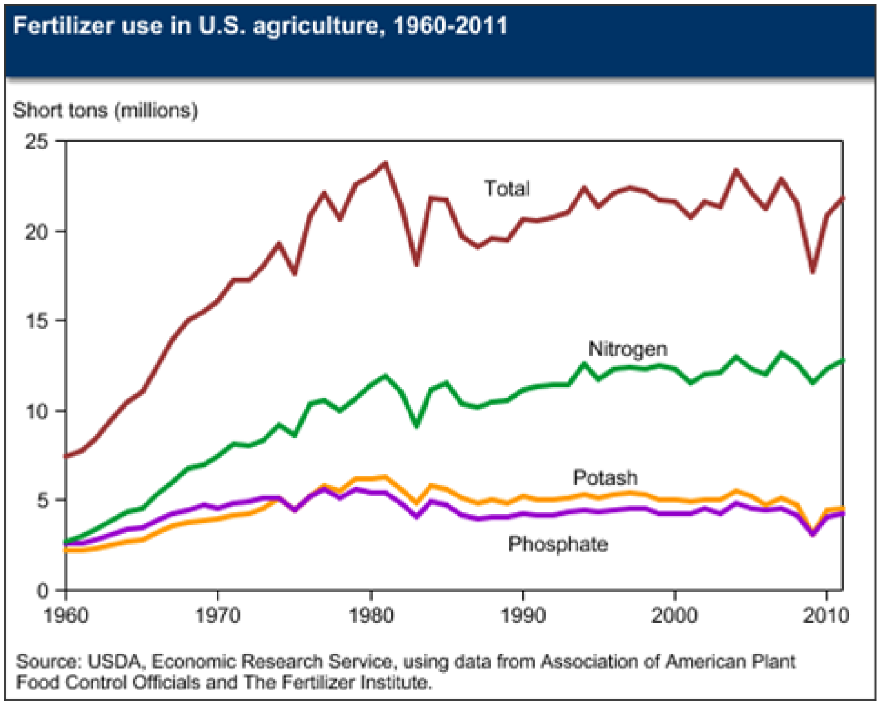

Figure 3.1. Fertilizer use in the U.S. from 1960-2011 (USDA ERS, 2013).

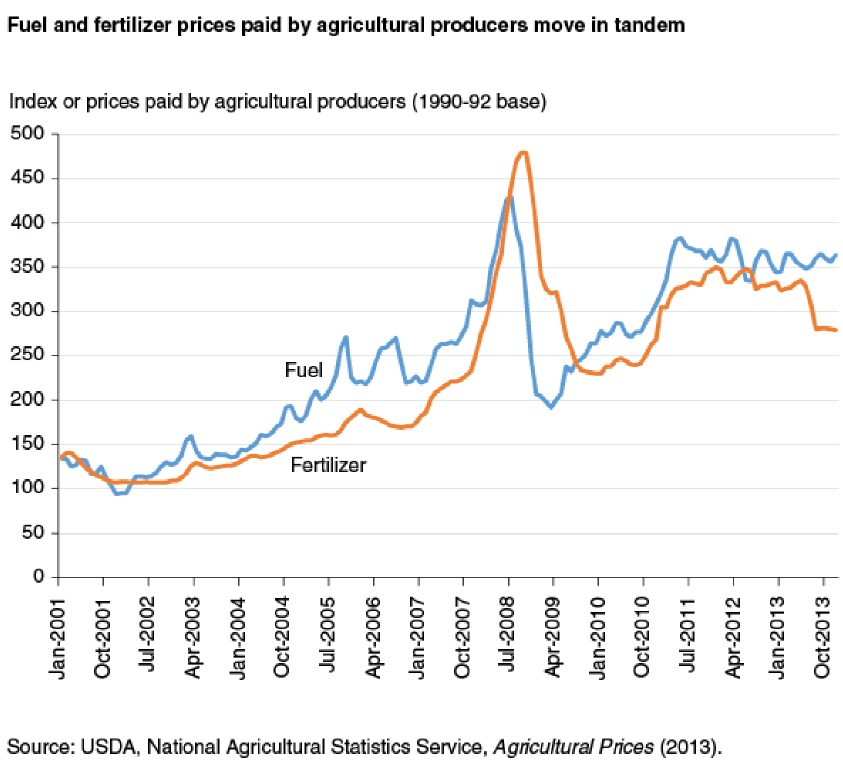

Figure 3.2. The cost of fuel and fertilizer in the U.S. from 2001-2013 (USDA NASS, 2013).

landfill, according to the Vice President of Technology at DuPont Tate and Lyle, Dr. Jim Zahn (Zahn, personal communication, 2016).

Elemental analyses of SMB indicate that there is a large potential for its use as an alternative N source in local agriculture. On a mass basis, SMB contains 9.3% N, 1.1% phosphorus (P), and 0.6% potassium (K) (Figure 3.4). On an oxide basis, the N-P-K composition is 9-2.52-0.72. SMB has a much higher N content than many other common organic N sources including bone meal (4-12-0) milorganite (6-2-0), fish blood and bone (5-5-6), poultry manure (3-2-2), and horse manure (1-0-1) (Zahn, personal communication, 2015). Unlike most commercial fertilizers, SMB also contains trace amounts of essential plant micronutrients including zinc, copper, molybdenum, chlorine and calcium (Appendix 3.3).

Another appealing aspect of SMB is that it contains a fairly high carbon (C) content at 37.3%, which decreases the decomposition rate of the material and allows it to act as a slow release nutrient source. This is beneficial both to the crop and environment, by providing nutrients as the crop takes them up and by decreasing the loss of N through leaching.

If SMB could be used in local crop production as an alternative to chemical fertilizers, both farmers and the industry could benefit. Farmers could purchase SMB at a much lower rate than commercial fertilizers, while maintaining fertility and cutting input costs. Continual SMB application would build soil organic matter (SOM) and improve fertility over the long term. On the industry side, it would improve the life cycle assessment (LCA) of the plant and reduce the company's costs of transport and disposal in a landfill. Environmentally, local reliance on chemical fertilizers could be reduced, as well as the amount of N leaching and the associated degradation of local water sources.

Figure 3.3. SMB after drying at DuPont Tate and Lyle BioProducts, LLC.

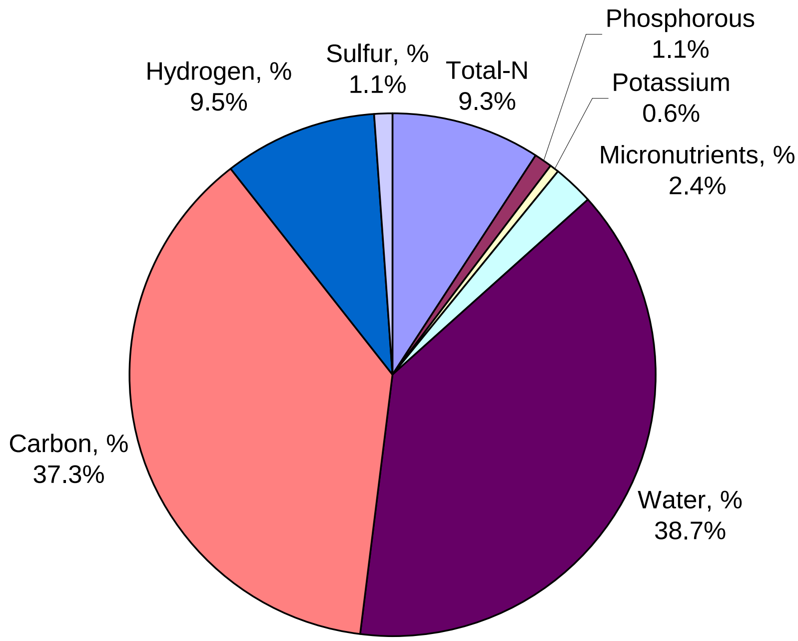

Figure 3.4. SMB elemental constituents by mass (Zahn, personal communication, 2015).

Research so far into the land application of SMB is very limited. One recent study at the University of Nebraska-Lincoln tested the use of lime stabilized spent microbial biomass (LSSMB) as a soil amendment on corn and soybean. The results showed that despite 10 kg N t^{-1} of material applied, LSSMB only provided 2.3 kg N t^{-1} to the crops over two consecutive years. The researchers hypothesized that N release was limited by the high pH of the LSSMB (Wortmann et al., 2015).

The objective of this study was to test SMB as a viable N source for corn on Dewey silty clay in Lenoir City, TN, and assess the potential impacts of SMB distribution on both the industry and local farmers.

2. Materials and Methods

2.1 Study area and soil characteristics

This study was conducted on a private farm in Lenoir City, TN (35°44'6.48" N, 84°11'2.23" W). The soil series was Dewey silty clay with 12-20% slopes (fine, kaolinitic, thermic Typic Paleudult) with 8% sand, 50 % silt, and 42% clay (WSS, n.d.). This site has previously been managed under conservation agriculture (CA) practices, including 15 years of no-till, maintained residue cover, and a corn-soybean rotation, with soybean as the previous crop on the field used for this study.

Köppen-Geiger classifies this region as a Cfa, humid subtropical climate (Kottek et al., 2006, Pidwirny, 2011). The average annual rainfall is 135 cm, and the mean annual temperature is 14.4 ˚C (Climate, n.d.).

2.2 Experimental design

This study was a randomized complete block design with six treatments and four blocks based on topography. Each plot was an area 4.57 m x 9.14 m and received one of six fertilizer rate treatments: 2.24 (treatment 1), 4.48 (treatment 2), 6.72 (treatment 3), 8.96 (treatment 4), and 11.20 T ha^{-1} of SMB (treatment 5), and a farmer practice treatment of 212.8 kg N ha^{-1} as granular urea (46-0-0) (FP). In addition, six N test strips of equal size were established parallel to the study that received 280 kg N ha^{-1} as granular urea (Appendix 3.1).

Prior to the study, twenty 15-cm deep soil samples from the whole plot were collected and a composite sample was sent to the Soil, Plant, and Pest Center in Nashville, TN to be analyzed. An initial analysis of the spent microbial biomass was run on June 10, 2015. The analysis tested for macro and micronutrients, heavy metals, and water content (Appendix 3.3). Corn was planted on April 12, 2015, using a John Deere 1790 Planter at 5 cm deep, 15 cm apart, and with 76 cm rows. SMB and urea were hand applied to the plots on April 21, 2015 (Figure 3.5). In addition, P and K were applied to all plots at rates of 89.6 kg P_2O_5 ha^{-1} as triple superphosphate (0-46-0), and 89.6 kg K_2O ha^{-1} as potash (0-0-60) (Appendix 3.2).

2.3 In-season data collection

The corn plots were monitored throughout the growing season, and various in-season measurements were taken to compare N availability and uptake by the crop. Population stand count was collected at 21 days after planting by counting the number of plants on a 5.32 m length on three random rows per plot (Gibson, 1998). Residue measurements on each plot were collected the same day using 15.24 m transects (Morrison et al., 1993), and an average for each

Figure 3.5. SMB hand application to plots in Lenoir City, TN on April 21, 2015.

treatment was taken. Crop heights of eight randomly selected crops from the interior four rows were measured at 30 and 57 days after planting using the extended leaf method (Abendroth et al., 2011).

Nitrogen uptake of the crops was measured during the growing season using a Minolta SPAD chlorophyll content meter and a Trimble Handheld GreenSeeker™. The SPAD meter was used in a variety of methods throughout the season. At 57 days after planting, the SPAD meter was used on the uppermost fully expanded leaf and four measurements moving down the leaf from the first quarter to the third quarter on the midrib on one side of the leaf were averaged. This was done on five random plants from the interior two rows of each plot. At 66 days after planting, the SPAD meter was used on the same leaf but five measurements were obtained and averaged – at the quarter distance from the collar to the tip and the midleaf point on the right and left sides of the leaf, then at the leaf apex (Vig et al., 2012). At 68 days after planting, the crops overall had tassels and the ear leaf was measured instead (Argenta et al., 2004, Bullock and

Anderson, 1998, Feil et al., 1997, Salmerón and Cavero, 2011, Vig et al. 2012, Yang et al., 2012) using the five-point method again. The last collection on 85 days after planting was done using a single point measured on the midrib in the middle of both the ear leaf and the leaf opposite and below on 30 leaves per plot, from which an average was taken (Schepers et al., 1992).

The GreenSeeker™ was used at 57, 66, and 68 days after planting by holding the instrument approximately 30 cm above the crop canopy at five random locations in each plot and the readings were recorded and an average was taken (Trimble, n.d., Barker & Sawyer, 2010, Shaver et al., 2011, Teal et al., 2006).

When measuring N uptake with the GreenSeeker™ or SPAD-502 meter, the N-rich reference strips were used calibrate the measurements through calculation of sufficiency indices (Trimble, n.d. Shanahan et al., 2008). The sufficiency index was calculated using the formula:

$$SI = \left(\frac{ABR}{ARR}\right) * 100\%$$

where ABR = average bulk reading of the plot and ARR = average reference strip reading . Sufficiency indices of 95% and above indicate sufficient N application, while anything below 95% indicates deficiency (Shapiro et al., 2006).

2.4 Harvest methods and yield calculations

Corn was hand harvested on September 17, 2015. First, a 5.32 m length in the middle of each of the two interior rows was marked. The number of stalks within each of these lengths was counted, and then all ears from these same plants were counted and harvested (Lauer, 2002, Lee & Herbek, 2005, Nielson, 2015). Ears were then transported back to the lab for shelling. In the lab, the total ear weight for each plot was measured and recorded, and ears were shelled using a Maximizer™ corn sheller. After shelling, the cobs were weighed, and grain weight was

calculated by subtracting this number from the total ear weight. The grain moisture and density for each plot was then measured using three samples of shelled grain in a Dickey John mini GAC moisture tester, and an average was taken.

To calculate yield, the total grain weight from each plot was multiplied by 500 (harvest area was 2/1000ths of an acre), and corrected to 15.5% moisture using the measured moisture values. All grain yields were converted to t ha^{-1} (Appendix 3.4).

2.5 Statistical analysis

The data collected from this study was analyzed using mixed models analysis of variance (ANOVA) in SAS 9.4 to detect differences in crop height, N uptake, and yield between the treatments. Means were separated using Dunnett's method to compare treatments to the farmer practice at α=0.05. The statistical model used was:

$$y_{ij} = \mu + B_i + T_j + B * T_{ij}$$

where B_i=blocks based on topography (4), and T_j=treatments (6 fertilization rates). Type III test p-values for treatment effects are reported in each graph (Figure 3.6).

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
treat	5	15	0.15	0.9767

Figure 3.6. Example ANOVA table for TN RBD analysis.

2.6 Partial budget analysis

A partial budget analysis comparing the cost savings for the producer and farmer was conducted using total SMB production costs and calculated savings provided by DuPont Tate and Lyle, LLC (Zahn, personal communication, 2016), and the 2016 UTIA Field Crop Budget

for corn. This analysis focused on calculating the decreased costs for the industry of distributing SMB to the farmers instead of disposing of it in a landfill, and for the farmer in using SMB instead of N fertilizers.

3. Results and Discussion

3.1 Residue cover, population density, and crop height

The mean residue cover following biomass and fertilizer application for treatments 1, 2, 3, 4, 5 and FP was 67.5, 68.5, 71, 65, 62, and 65.5%, respectively (Figure 3.7). The mean population density for the 24 plots was 77,120 plants ha^{-1} and there were no significant differences between the treatments and the FP at 21 days after planting ($p>0.05$) (Figure 3.8). There were no significant differences in crop heights between the SMB treatments and the FP at either date measured (30 and 57 days after planting) ($p>0.05$) (Figure 3.9). Mean

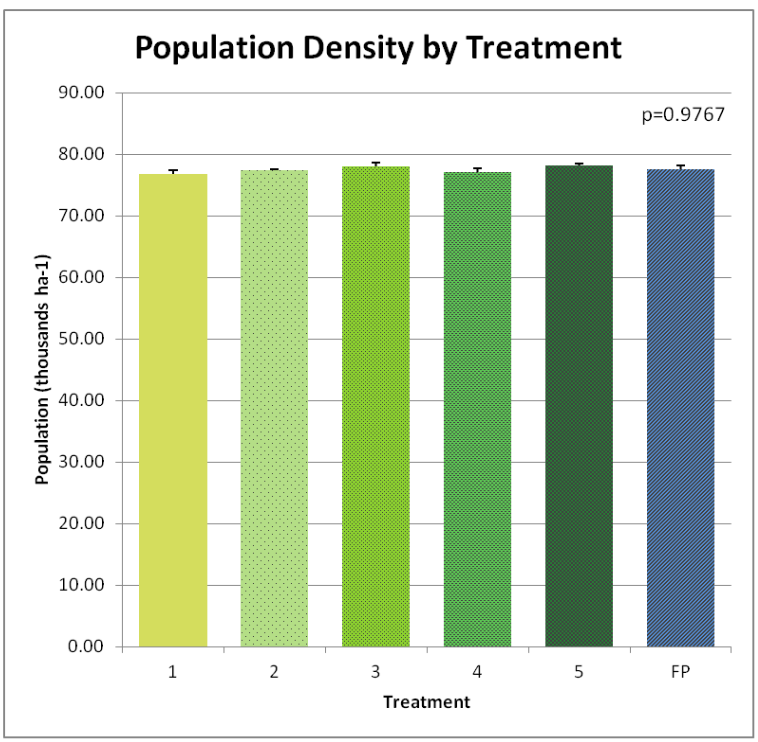

Figure 3.7. Treament effects on residue cover in Lenoir City, TN.

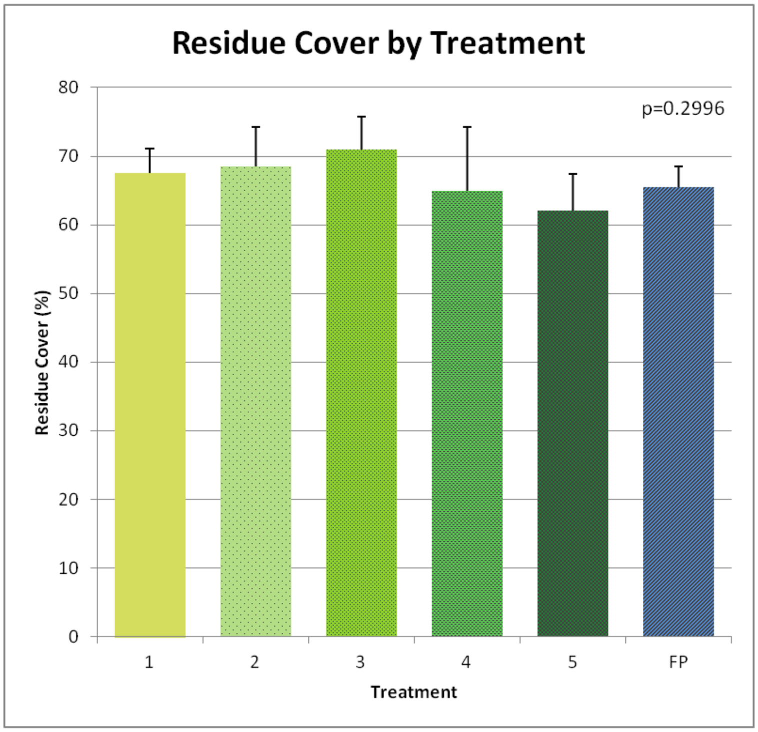

Figure 3.8. Treament effects on population density in Lenoir City, TN.

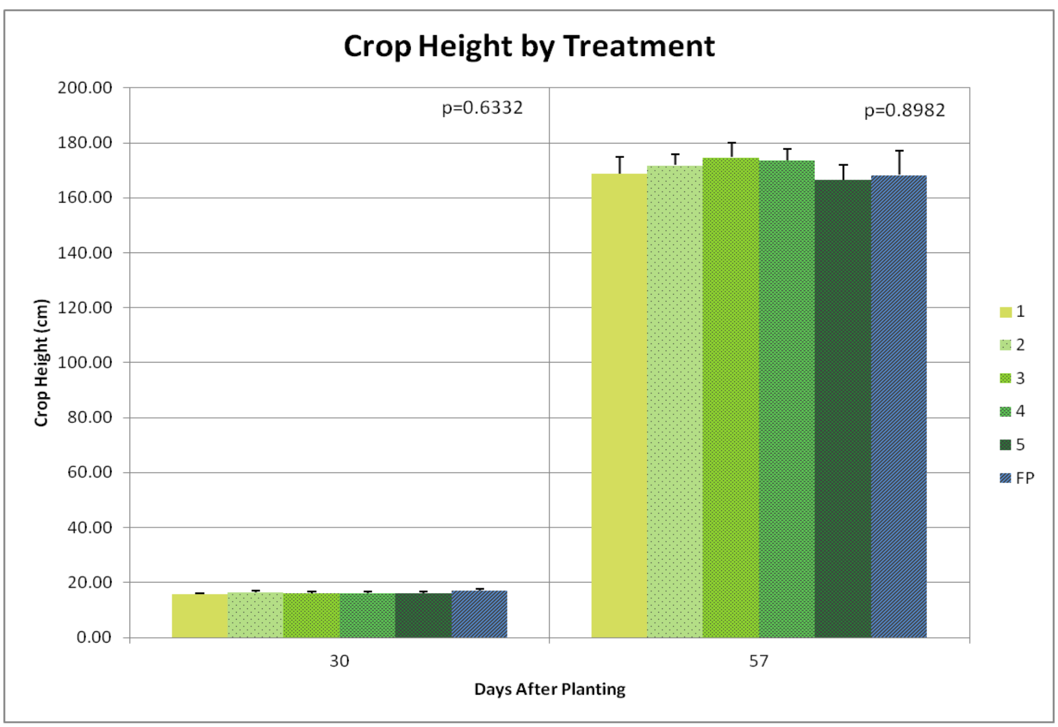

Figure 3.9. Treament effects on crop height over time in Lenoir City, TN.

heights for the treatments at 30 days after planting were 15.73, 16.34, 16.15, 16.11, 16.11, and 17.13 cm in treatments 1, 2, 3, 4, 5, and FP, respectively. At 57 days after planting, mean heights for each treatment were 168.67, 171.84, 174.70, 173.60, 166.45, and 168.33 cm, respectively.

3.2 GreenSeeker™ and SPAD-502 readings

The treatments did have a significant effect on GreenSeeker™ readings at 57 and 68 days after planting, ($p=0.0077$ and $p=0.0268$, respectively), but not on 66 days after planting ($p>0.05$) (Figure 3.10). At 57 days after planting, treatment 2 had the highest NDVI reading of 0.823, and was not significantly different from the farmer practice (FP). Treatments 3 (0.800), 4 (0.792), and 5 (0.798) were also not significantly different from the farmer practice (0.804). Treatment 1 however, was significantly lower than the FP with a reading of 0.736. At 68 days after planting, treatment 3 had the highest NDVI reading of 0.799, and was significantly different from the FP reading of 0.765. Treatments 1, 2, 4, and 5 were not significantly different from the FP with readings of 0.76, 0.778, 0.773, and 0.782, respectively.

At the earliest date that GreenSeeker™ measurements were taken, all of the SMB treatments except the lowest rate (2.24 t SMB ha^{-1}) had similar N availability compared to the farmer practice. By the third measurement date however, the third highest SMB rate (6.72 t ha^{-1}) had significantly greater GreenSeeker™ readings than the farmer practice, indicating that SMB provided a slower release of N over time than the urea.

When GreenSeeker™ N sufficiency indices were calculated based on N test strip means, the only insufficient treatment was found to be treatment 1 at 57 days after planting, though the sufficiency index was still high at 94.16% (Figure 3.11). All other treatments were found to have sufficient N supply at 57, 66, and 68 days after planting. Because nearly all of the treatments

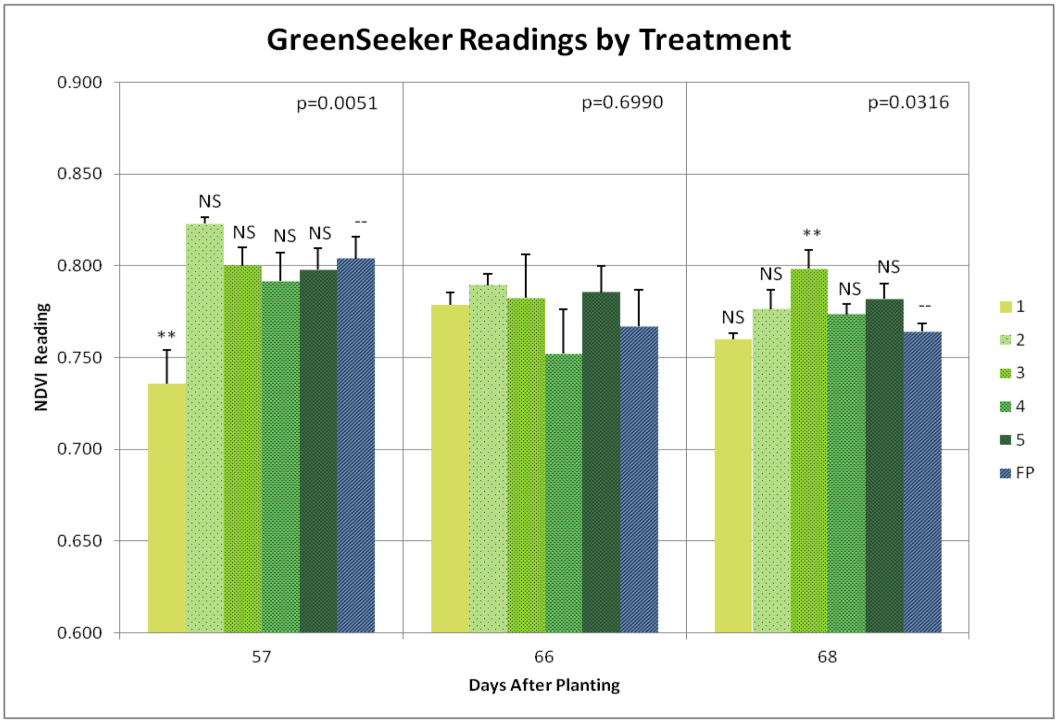

Figure 3.10. Treament effects on GreenSeeker^{TM} values over time in Lenoir City, TN.

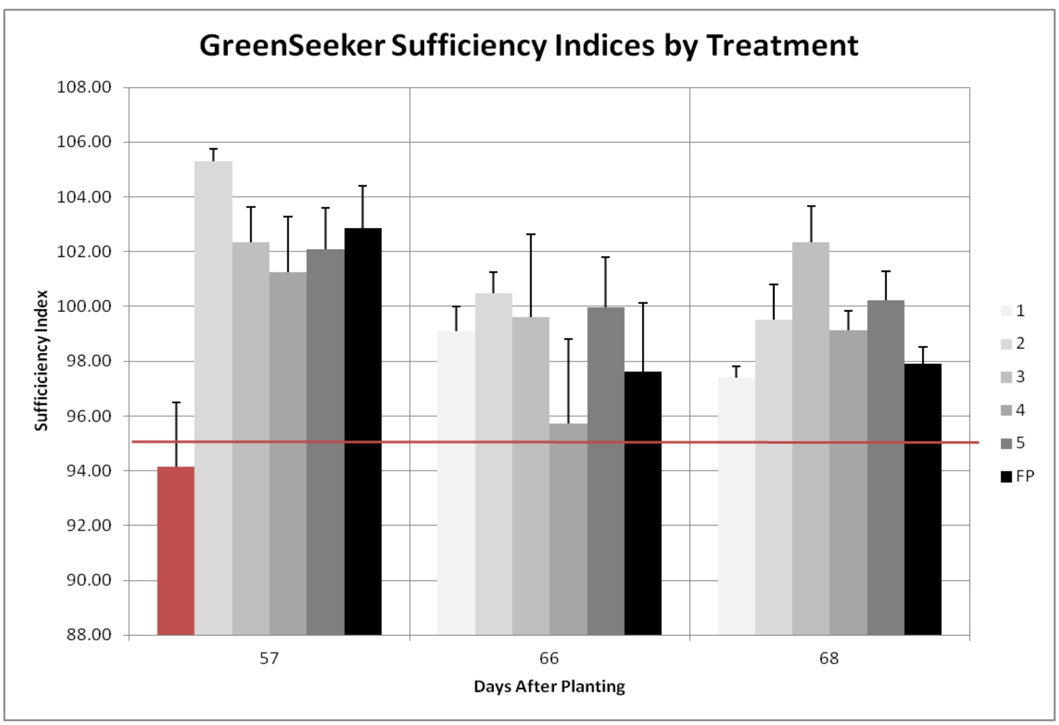

Figure 3.11. GreenSeeker^{TM} treatment nitrogen sufficiency indices over time in Lenoir City, TN.

had sufficiency indices at or greater than 95%, this indicates that all of the plots could have been over fertilized with N.

The treatments had a significant effect on SPAD meter readings on only the first out of the four dates tested (Figure 3.12). At 57days after planting there were significant differences in SPAD values of the treatments (p=0.0428), but not at 66, 68 or 85 days after planting (p>0.05). At 57 days after planting, treatment 4 had the highest SPAD meter reading of 58.94, and was significantly greater than the FP reading of 53.41. The other treatments were not significantly different from the FP with readings of 55.28, 54.01, 56.9, and 56.4 for treatments 1, 2, 3, and 5, respectively.

When SPAD N sufficiency indices were calculated based on N test strip means, none of the treatments were found to be insufficient (Figure 3.13). Again, this indicates that all plots could have been over fertilized with N.

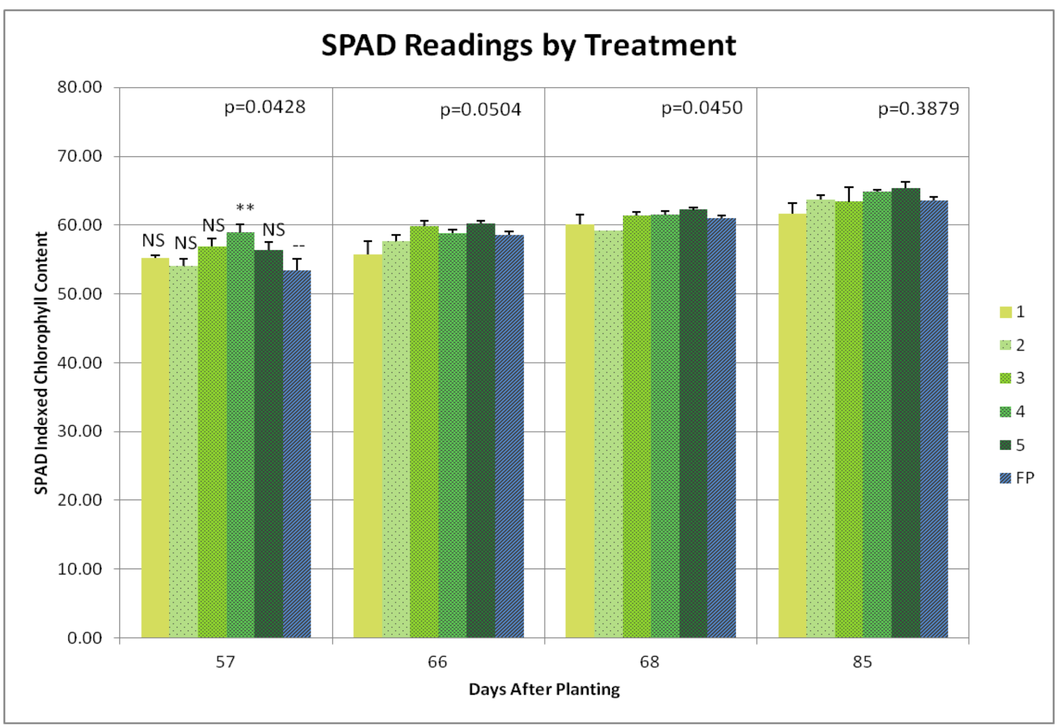

Figure 3.12. Treament effects on SPAD values over time in Lenoir City, TN.

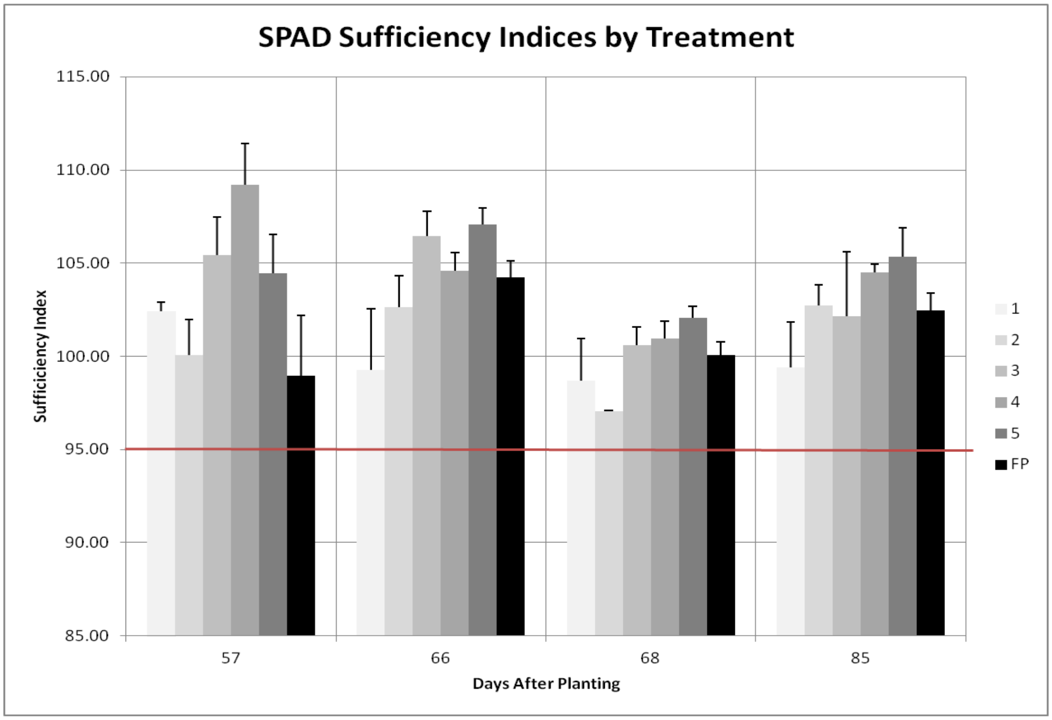

Figure 3.13. SPAD treatment nitrogen sufficiency indices over time in Lenoir City, TN.

3.3 Yield

The SMB treatments had no significant effect on dry grain yield when compared to the FP (p>0.05) (Figure 3.14). The farmer practice had the highest yield of 15.08 t ha^{-1}, but was not significantly different from treatments 1, 2, 3, 4, or 5 with yields of 14.18, 14.60, 15.06, 14.37, and 14.07 t ha^{-1}, respectively. Since there were no significant differences in yields, this indicates that the SMB, even at the lowest application rate, provided as much N as the urea. The ear:stalk ratio between treatments and the FP was also found to be insignificant (p=0.6760), with means of 0.96, 0.99, 0.96, 0.95, 0.97, and 0.96, for the treatments, respectively (Figure 3.15).

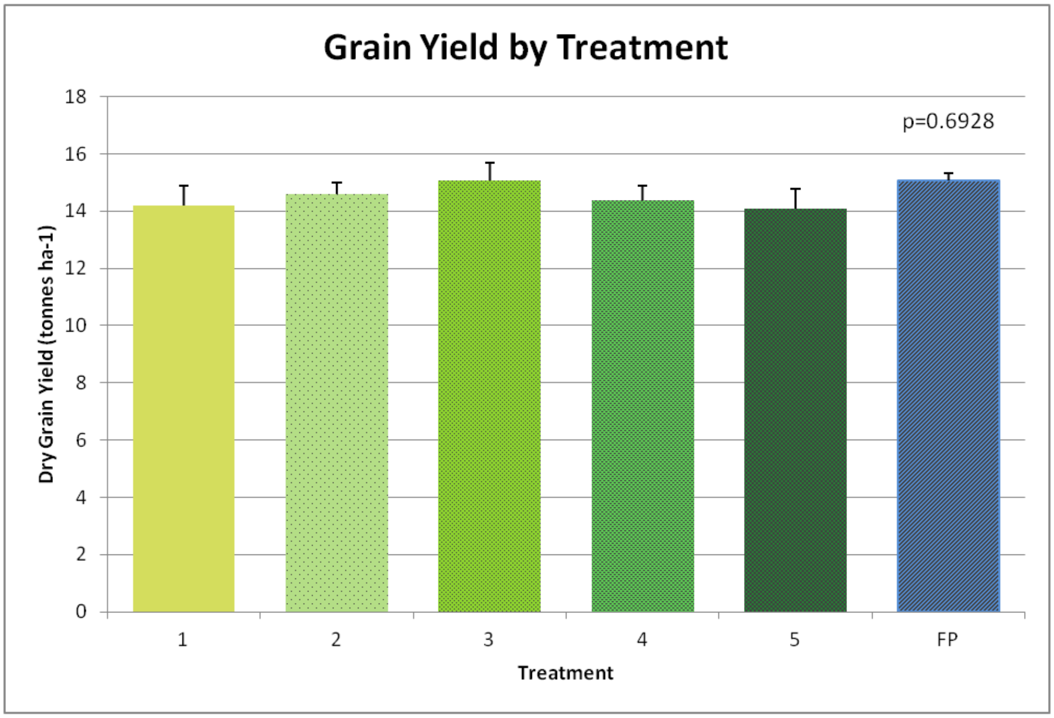

Figure 3.14. Treatment effects on dry grain yield in Lenoir City, TN.

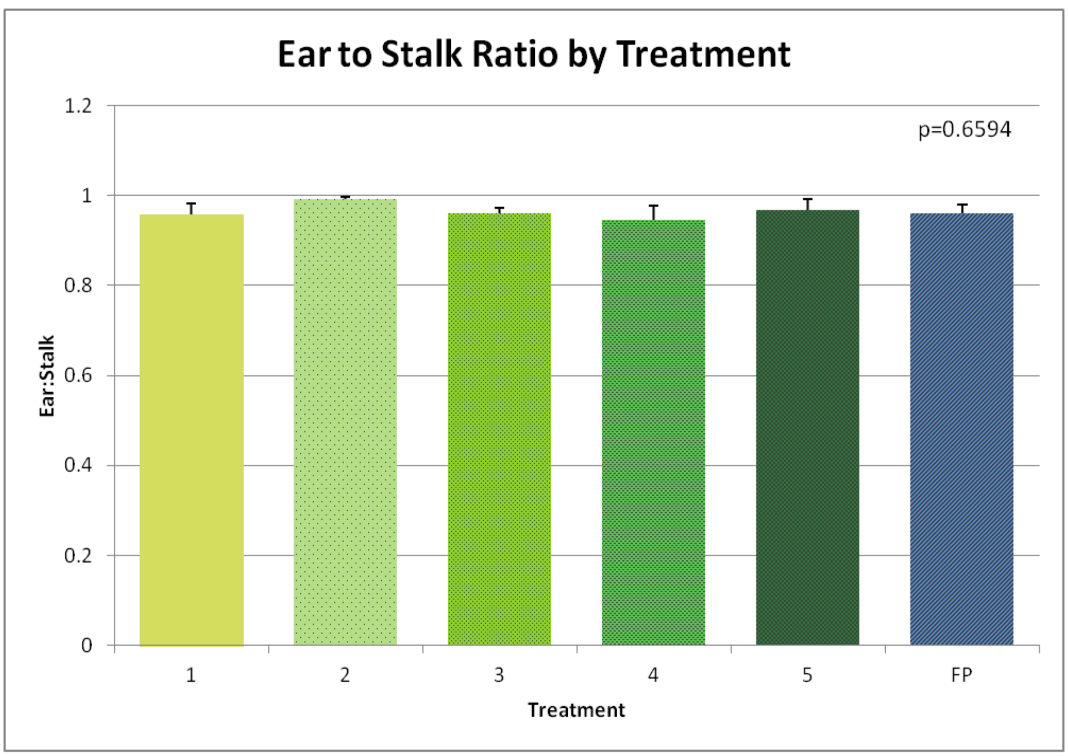

Figure 3.15. Treatment effects on ear:stalk ratio in Lenoir City, TN.

3.4 Partial budget analysis

The plant produces on average 1.8 million T $month^{-1}$ and 19.8 million T $year^{-1}$ (Zahn, personal communication, 2016). If the industry does not dispose of the SMB in a landfill and instead takes it to one central location without a tipping fee, they have estimated \$0.02 lb SMB^{-1} in savings, amounting to an annual savings of \$396,000 (Zahn, personal communication, 2016). There is also a potential for a 40% increase in SMB production, yielding 27.72 million T $year^{-1}$, with a potential cost savings of \$554,000 $year^{-1}$. Using the current amount of SMB produced by DuPont Tate and Lyle, LLC., at 19.8 million T $year^{-1}$, this amount could be applied at a rate of 2.24 t ha^{-1} (1 T A^{-1}) to 4,000 ha (9,900 A).

The 2016 UT Field Crop Budget (FCB) for no-till non-irrigated corn is benchmarked to a yield of 9.41 t ha^{-1} (150 bu A^{-1}) (Smith et al., 2015). The FCB estimates the cost of urea applied at a rate of 191 kg ha^{-1} (170 lbs A^{-1}) to be \$181.20 ha^{-1} (\$73.36 A^{-1}) (Appendix 3.4) (Smith et al., 2016). If a model is assumed where the SMB is delivered by DuPont Tate and Lyle, LLC., and there are no changes in the budget for machinery, operation, and wear, this would be the cost of savings ha^{-1} in input costs for the farmer.

Examining a case study where a farmer applies SMB to 400 ha of land (1,000 A), his total cost savings on urea would be \$72,500, or a 14% reduction in total input costs. It is clear from these calculations that the use of SMB as an N source for local corn farmers could be beneficial to both parties.

4. Conclusions

The results of this research show that overall the SMB treated plots had consistent N availability and crop productivity when compared to the farmer practice. There were no

significant differences between population densities, crop heights, or yields from the different treatments.

The in-season N availability data collected by the GreenSeeker^{TM} and SPAD meter did provide some interesting information about the decomposition of the SMB and N mineralization. The GreenSeeker^{TM} data showed a slow release of N over time from the SMB when compared to the urea, with the lowest SMB treatment showing significantly lower N uptake early in the season, then third highest SMB rate showing significantly higher N uptake at the last measuring date. The SPAD meter actually showed the opposite effect, with treatment 3 showing higher N uptake than the farmer practice at the first measuring date, and then the differences disappearing by the second date.

It is very interesting that there were no significant differences in yields between even the lowest SMB rate and the farmer practice. This may have been due to the prime location of the study, somewhat downhill and next to a creek. Some N taken up by the crops could also have come from the previous soybean crop. Unlike the Wortmann et al. (2014) study, the SMB used in this research was not lime stabilized, and this may have been the reason that so much more N was available to the crops throughout the season.

The implications of this research show that SMB could be land applied in local corn production as an alternative to N fertilizers, without a loss in crop productivity or yield. If the industry is willing to provide SMB to farmers at little to no cost, it could be an important future N source for corn production in East Tennessee.

More studies in various locations would be useful to see if these results are consistent on different soil types, topographies, and crop-rotations. Future research on SMB should examine how to best spread SMB as a fertilizer so it can be applied on a larger scale than just hand

applied. If SMB can be mechanically applied, more farmers would be interested in its use as an alternate N source. Another important area of research on SMB is the economics of its distribution, for both the farmer and the industry, to determine the most cost-effective distribution logistics model.

References

Abendroth, L. J., R. W. Elmore, M. J. Boyer, and S. K. Marlay (2011). Corn growth and development. PMR 1009. Iowa State University Extension, Ames, Iowa.

Argenta, G., Silva, P. R. F. D., & Sangoi, L. (2004). Leaf relative chlorophyll content as an indicator parameter to predict nitrogen fertilization in maize. *Ciência Rural*, *34*(5), 1379-1387.

Barker, D. W., & Sawyer, J. E. (2010). Using active canopy sensors to quantify corn nitrogen stress and nitrogen application rate. *Agronomy Journal*, *102*(3), 964-971.

Bullock, D. G., & Anderson, D. S. (1998). Evaluation of the Minolta SPAD-502 chlorophyll meter for nitrogen management in corn. *Journal of Plant Nutrition*,*21*(4), 741-755.

Climate: Lenoir City (Climate graph, Temperature graph, Climate table) (n.d.). Retrieved from http://en.climate-data.org/location/137053/

EPA (2013). Major Crops Grown in the United States. Retrieved from http://www.epa.gov/oecaagct/ag101/cropmajor.html

FAO (2015). World fertilizer trends and outlook to 2018. Retrieved from http://www.fao.org/3/a-i4324e.pdf

Feil, B., Garibay, S. V., Ammon, H. U., & Stamp, P. (1997). Maize production in a grass mulch system–seasonal patterns of indicators of the nitrogen status of maize. *Developments in Crop Science*, *25*, 227-235.

Foley, J. (2013). It's time to rethink America's corn system. *Scientific American*. Retrieved from http://www.scientificamerican.com/article/time-to-rethink-corn/

Gibson, Lance R. (1998). Calculate Stand Density from Stand Counts. Document posted in Iowa State University Agronomy 212-Grain and Forage Crops, archived at: http://agron-www.agron.iastate.edu/Courses/agron212/calculations/Stand_counts.htm

Kottek, M., J. Grieser, C. Beck, B. Rudolf, & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorol. Z.*, 15, 259-263. DOI: 10.1127/0941-2948/2006/0130. DOI: 10.1127/0941-2948/2006/0130.

Kurian, J. V. (2005). A new polymer platform for the future—Sorona® from corn derived 1, 3-propanediol. *Journal of Polymers and the Environment*,*13*(2), 159-167.

Lauer, J. (2002). Methods for calculating corn yield. Agronomy Advice, University of Wisconsin-Madison. Retrieved from http://corn.agronomy.wisc.edu/AA/pdfs/A033.pdf

Lee, C. & Herbek, J. (2005). Estimating corn yields (AGR-187). University of Kentucky. Retrieved from http://www.ca.uky.edu/agc/pubs/agr/agr187/agr187.pdf.

Morrison, J. E., Huang, C. H., Lightle, D. T., & Daughtry, C. S. (1993). Residue measurement techniques. *Journal of soil and water conservation*, *48*(6), 478-483.

Nielson, R. L. (2015). Estimating corn grain yield prior to harvest. Purdue University, Department of Agronomy. Retrieved from https://www.agry.purdue.edu/ext/corn/news/timeless/yldestmethod.html

Pidwirny, M. (2011). Moist Mid-latitude Climates with Mild Winters - C Climate Type. Retrieved from http://www.eoearth.org/view/article/162272

Salmerón, M., Isla, R., & Cavero, J. (2011). Effect of winter cover crop species and planting methods on maize yield and N availability under irrigated Mediterranean conditions. *Field Crops Research*, *123*(2), 89-99.

Schepers, J. S., Francis, D. D., Vigil, M., & Below, F. E. (1992). Comparison of corn leaf nitrogen concentration and chlorophyll meter readings.*Communications in Soil Science & Plant Analysis*, *23*(17-20), 2173-2187.

Shanahan, J. F., Kitchen, N. R., Raun, W. R., & Schepers, J. S. (2008). Responsive in-season nitrogen management for cereals. *Computers and electronics in agriculture*, *61*(1), 51-62.

Shapiro, C., Francis, D., Ferguson, R., Hergert, G., Shaver, T., & Wortmann, C. (2006). Using a Chlorophyll Meter to Improve N Management. University of Nebraska-Lincoln Extension, Soil Resource Management. Retrieved from http://extensionpublications.unl.edu/assets/html/g1632/build/g1632.htm

Shaver, T. M., Khosla, R., & Westfall, D. G. (2011). Evaluation of two crop canopy sensors for nitrogen variability determination in irrigated maize. *Precision Agriculture*, *12*(6), 892-904.

Smith, A., Bowling, B., Danehower, S. (2015). Field crop budgets for 2015. UTIA Department of Agricultural and Resource Economics. Retrieved from http://economics.ag.utk.edu/budgets/2015/Crops/CornNonIrrNoTill.pdf

Smith, A., Bowling, B., Danehower, S. (2016). Field crop budgets for 2016. UTIA Department of Agricultural and Resource Economics. Retrieved from http://economics.ag.utk.edu/budgets/2016/Crops/CornNTNonIrr.pdf

Teal, R. K., Tubana, B., Girma, K., Freeman, K. W., Arnall, D. B., Walsh, O., & Raun, W. R. (2006). In-season prediction of corn grain yield potential using normalized difference vegetation index. *Agronomy Journal*, *98*(6), 1488-1494.

Trimble (n.d.). GreenSeeker handheld crop sensor product overview. Retrieved from http://www.trimble.com/Agriculture/gs-handheld.aspx

USDA, Economic Research Service (2013). Fertilizer Use and Markets. Retrieved from http://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets.aspx

USDA, National Agricultural Statistics Service (2013). Agricultural Prices. Retrieved from http://www.nass.usda.gov/Charts_and_Maps/Agricultural_Prices/

USDA, National Agricultural Statistics Service (2015). Crop Production 2014 Summary. Retrieved from http://www.usda.gov/nass/PUBS/TODAYRPT/cropan15.pdf

USGS, United States Geological Survey (2015). Mineral commodity summaries 2015. Retrieved from http://minerals.usgs.gov/minerals/pubs/commodity/nitrogen/mcs-2015-nitro.pdf

Víg, R., Huzsvai, L., Dobos, A., & Nagy, J. (2012). Systematic measurement methods for the determination of the SPAD values of maize (Zea mays L.) canopy and potato (Solanum tuberosum L.). *Communications in soil science and plant analysis*, *43*(12), 1684-1693.

Web Soil Survey (Web Soil Survey) (n.d.). Retrieved from http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Wortmann, C. S., Sawyer, J., Tonn, S. (2014). Research Identifies Attributes of Industrial Byproduct for Soils. University of Nebraska-Lincoln. *CropWatch*. Retrieved from http://cropwatch.unl.edu/archive/-/asset_publisher/VHeSpfv0Agju/content/research-identifies-attributes-of-lime-byproduct-for-soils

Yang, Y., Timlin, D. J., Fleisher, D. H., Lokhande, S. B., Chun, J. A., Kim, S. H., ... & Reddy, V. R. (2012). Nitrogen concentration and dry-matter accumulation in maize crop: Assessing maize nitrogen status with an allometric function and a chlorophyll meter. *Communications in soil science and plant analysis*, *43*(11), 1563-1575.

Appendix

Appendix 3.1. Plot Information

Figure 3.16. Plot location: Lenoir City, TN (35°44’6.48” N, 84°11’2.23” W).

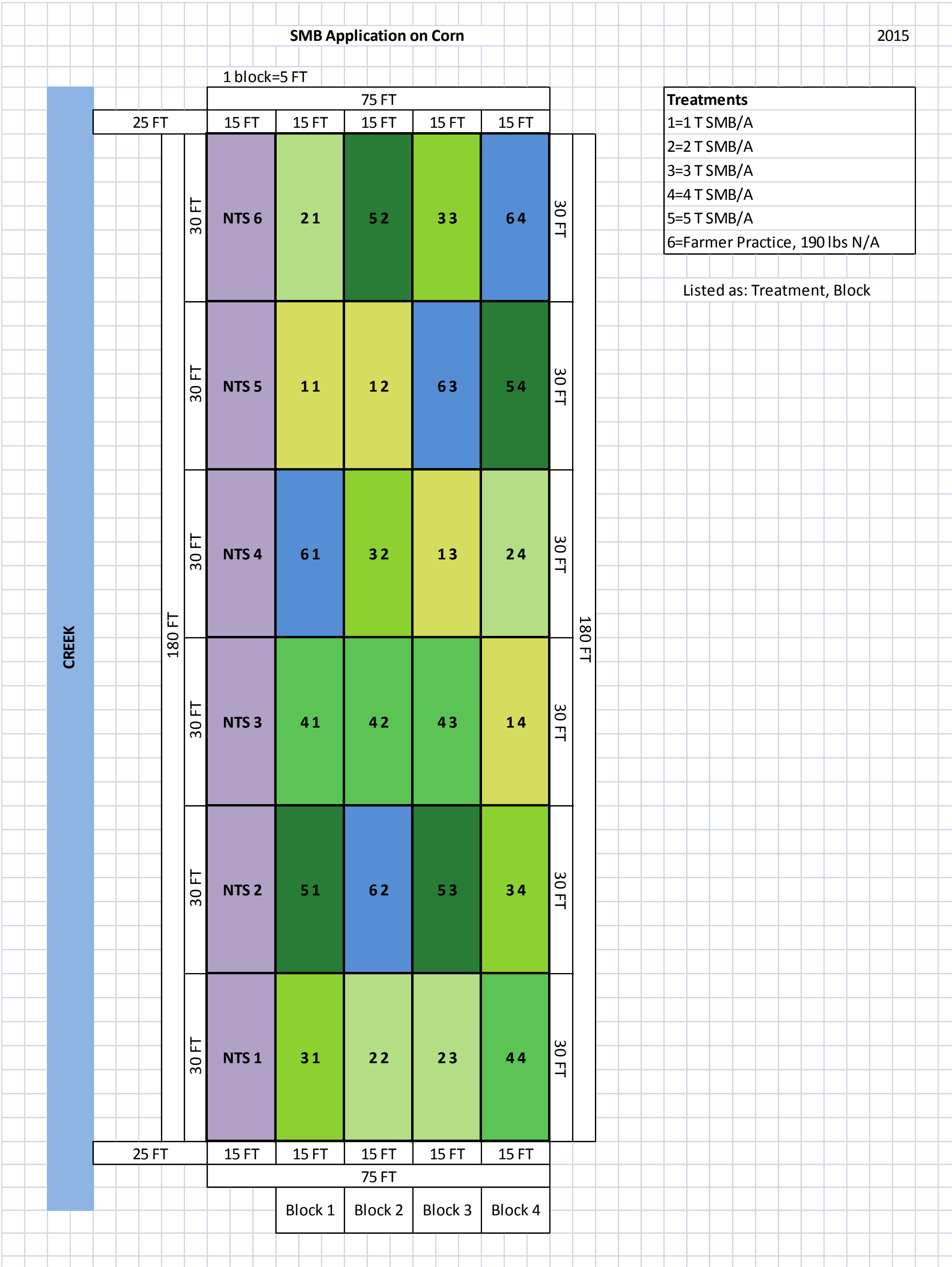

Figure 3.17. Study plot plan and experimental design in Lenoir City, TN.

Appendix 3.2. Fertilizer Calculations

Treatment 1-1 T SMB A^{-1} (2.24 t SMB ha^{-1})

$$\frac{1\ \text{Ton}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} \times \frac{2{,}000\ \text{lbs}}{1\ \text{Ton}} = 20.66\ \text{lbs biomass plot}^{-1}$$

Treatment 2-2 T SMB A^{-1} (4.48 t SMB ha^{-1})

$$\frac{2\ \text{Ton}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} \times \frac{2{,}000\ \text{lbs}}{1\ \text{Ton}} = 41.32\ \text{lbs biomass plot}^{-1}$$

Treatment 3-3 T SMB A^{-1} (6.74 t SMB ha^{-1})

$$\frac{3\ \text{Ton}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} \times \frac{2{,}000\ \text{lbs}}{1\ \text{Ton}} = 61.98\ \text{lbs biomass plot}^{-1}$$

Treatment 4-4 T SMB A^{-1} (8.98 t SMB ha^{-1})

$$\frac{4\ \text{Ton}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} \times \frac{2{,}000\ \text{lbs}}{1\ \text{Ton}} = 82.64\ \text{lbs biomass plot}^{-1}$$

Treatment 5-5 T SMB A^{-1} (11.23 t SMB ha^{-1})

$$\frac{5\ \text{Ton}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{180\ \text{ft}^2}{\text{plot}} \times \frac{2{,}000\ \text{lbs}}{1\ \text{Ton}} = 103.3\ \text{lbs biomass plot}^{-1}$$

Farmer Practice-190 lbs N A^{-1} (213 kg N ha^{-1}) as granular urea (46-0-0)

0.46 * 190 lbs N = 413.04 lbs fertilizer/Acre

$$\frac{413.04\ \text{lbs fertilizer}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} = 4.27\ \text{lbs fertilizer plot}^{-1}$$

Nitrogen Test Strip

Rate: 250 lbs N A^{-1} (281 kg N ha^{-1}) as granular urea (46-0-0)

0.46 * 250 lbs N = 543.48 lbs fertilizer A^{-1}

$$\frac{543.48\ \text{lbs fertilizer}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} = 5.61\ \text{lbs fertilizer plot}^{-1}$$

Phosphorus

Rate: 80 lbs P_2O_5 A^{-1} (90 kg P_2O_5 ha^{-1}) as Triple Superphosphate (0-46-0)

80 lbs P_2O_5/0.46 = 173.91 lbs fertilizer A^{-1}

$$\frac{173.91\ \text{lbs fertilizer}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} = 1.80\ \text{lbs fertilizer plot}^{-1}$$

Potassium

Rate: 80 lbs K_2O A^{-1} (90 kg K_2O ha^{-1}) as Potash(0-0-60)

80 lbs K/0.60 = 133.33 lbs fertilizer A^{-1}

$$\frac{133.33\ \text{lbs fertilizer}}{1\ \text{Acre}} \times \frac{1\ \text{Acre}}{43{,}560\ \text{ft}^2} \times \frac{450\ \text{ft}^2}{\text{plot}} = 1.38\ \text{lbs fertilizer plot}^{-1}$$

Appendix 3.3. SMB Elemental Analysis

Table 3.1. Elemental Analysis of SMB from DuPont Tate and Lyle, LLC.

Analysis	Method	042415-Bailey
352: Ammonia (NH3)		
	GLI Procedure E7-7	1.18%
a17: Chloride (Cl-)		
	GLI Procedure ME-4A	83 ppm
	GLI Procedure ME-4A (matrix spike)	95.75%
Ag : Silver	EPA SW-846 Method 6010B (matrix spike)	
	EPA SW-846 Method 6010B	< 5.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	103%
	EPA SW-846 Method 6010B (matrix spike)	85%
As : Arsenic		
	EPA SW-846 Method 6010B	< 1.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	97%
	EPA SW-846 Method 6010B (matrix spike)	101%
Ba : Barium		
	EPA SW-846 Method 6010B	< 1.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	97%
	EPA SW-846 Method 6010B (matrix spike)	100%
C : Carbon		
	GLI Procedure ME-14	31.09%
Ca : Calcium		
	EPA SW-846 Method 6010B	282 ppm
Cd : Cadmium		
	EPA SW-846 Method 6010B	< 1.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	96%
	EPA SW-846 Method 6010B (matrix spike)	97%
Co : Cobalt		
	EPA SW-846 Method 6010B	< 7.2 %
Cr : Chromium		
	EPA SW-846 Method 6010B	< 1.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	97%
	EPA SW-846 Method 6010B (matrix spike)	98%
Cu : Copper		
	EPA SW-846 Method 6010B	< 7.2 %
H : Hydrogen		
	GLI Procedure ME-14	8.10%

Table 3.1. Continued.

Analysis	Method	042415-Bailey
K : Potassium		
	EPA SW-846 Method 6010B	0.128%
k02: Karl Fischer Water		
	GLI Procedure S-300	40.13%
k07: Nitrogen, Kjeldahl		
	GLI Procedure E7-1	6.87%
LCH: TCLP Leachate Procedure		
	EPA SW-846 Method 1311	4.91
m07: Nitrate as N		
	GLI Procedure ME-4A	< 10 ppm
Mg : Magnesium		
	EPA SW-846 Method 6010B	0.12%
mHg: Mercury CVAA		
	EPA SW-846 Method 7471A	< 0.0094 ppm
Mo : Molybdenum		
	EPA SW-846 Method 6010B	< 7.2 %
N : Nitrogen		
	GLI Procedure ME-14	7.04%
Na : Sodium		
	EPA SW-846 Method 6010B	150 ppm
Ni : Nickel		
	EPA SW-846 Method 6010B	< 7.2 ppm
P : Phosphorus		
	EPA SW-846 Method 6010B	0.517%
Pb : Lead		
	EPA SW-846 Method 6010B	< 1.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	94%
	EPA SW-846 Method 6010B (matrix spike)	98%
S : Sulfur		
	GLI Procedure E16-2	0.732%
	GLI Procedure E16-2	0.76%
Se : Selenium		
	EPA SW-846 Method 6010B	< 1.0 mg/L
	EPA SW-846 Method 6010B (matrix spike)	98%
	EPA SW-846 Method 6010B (matrix spike)	102%
Zn : Zinc		
	EPA SW-846 Method 6010B	37 ppm

Appendix 3.4 UT Field Crop Budget

Figure 3.18. UTIA Field Crop Budget 2016 for no-till, non-irrigated corn production in TN (Smith et al., 2016. http://economics.ag.utk.edu/budgets/2016/Crops/CornNTNonIrr.pdf).

2016 Corn, No-Till, Non-Irrigated Budget

	Unit	Quantity	Price	Total	Your Farm
			Gross Revenue ($/Acre)		
Revenue					
Corn [1]	Bu	150	$3.82	$573.00	________
			Total Revenue	**$573.00**	________
Variable Expenses					
Seed [2,3]	Thous.	32	$3.13	$100.00	________
Fertilizer & Lime (Table 1.)	Acre	1	$140.98	$140.98	________
Chemical (Table 2.) [3,4]	Acre	1	$48.60	$48.60	________
Crop Scout or Consultant	Acre	1	$6.00	$6.00	________
Repair & Maintenance (Table 3.)	Acre	1	$21.18	$21.18	________
Fuel, Oil & Filter (Table 3.)	Acre	1	$8.72	$8.72	________
Operator Labor (Table 3.)	Acre	1	$5.20	$5.20	________
Machinery Rental	Acre	1	$0.00	$0.00	________
Custom Work	Acre	1	$0.00	$0.00	________
Drying (Fuel/Electric)	Bu	150	$0.00	$0.00	________
Cash Rent [5]	Acre	1	$98.00	$98.00	________
Crop Insurance [6]	Acre	1	$13.84	$13.84	________
Operating Interest [7]	%	$442.51	6.00%	$13.28	________
Other Variable Costs	Acre	1	$0.00	$0.00	________
			Total Variable Expenses	**$455.79**	________
			Return above Variable Expenses	**$117.21**	________
Fixed Expenses					
Machinery [8]					
Capital Recovery (Table 3.)	Acre	1	$41.13	$41.13	________
Other Fixed Machinery Costs	Acre	1	$0.00	$0.00	________
Property Taxes	Acre	1	$0.00	$0.00	________
Insurance (Non-Machinery)	Acre	1	$0.00	$0.00	________
Management Labor	Acre	1	$15.00	$15.00	________
Other Fixed Costs	Acre	1	$0.00	$0.00	________
			Total Fixed Expenses	**$56.13**	________
			Return Above All Specified Expenses	**$61.08**	________

Breakeven Price for Selected Yield

Yield (bu)	Variable Cost ($/bu)	Total Specified Cost ($/bu)
100	$4.56	$5.12
110	$4.14	$4.65
120	$3.80	$4.27
130	$3.51	$3.94
140	$3.26	$3.66
150	**$3.04**	**$3.41**
160	$2.85	$3.20
170	$2.68	$3.01
180	$2.53	$2.84
190	$2.40	$2.69
200	$2.28	$2.56

Breakeven Yield for Selected Price

Price ($/bu)	Variable Cost (bu)	Total Specified Cost (bu)
$2.57	177	199
$2.82	162	182
$3.07	148	167
$3.32	137	154
$3.57	128	143
$3.82	**119**	**134**
$4.07	112	126
$4.32	106	119
$4.57	100	112
$4.82	95	106
$5.07	90	101

Table 1. Fertilizer & Lime

Fertilizer	Description	Quantity (lbs)	Price ($)	Total ($/Acre)	Your Farm ($/Acre)
Nitrogen	Urea	170	$0.43	$73.36	________
Phosphorous	P_2O_5	70	$0.40	$28.00	________
Potassium	K_2O	70	$0.35	$24.62	________
Lime	Limestone	1,000	$30.00	$15.00	________
Other		0	$0.00	$0.00	________
Total				$140.98	________

Table 2. Chemicals [3,4]

Chemical	Function	Description	Unit	Number of Apps.	Quantity	Price	Total ($/Acre)	Your Farm ($/Acre)
Herbicides [3]	Burndown	Gramoxone SL	oz.	1	40	$0.25	$10.00	________
		Surfactant	pt.	1	0.2	$3.52	$0.70	________
	Pre-Emerge	Atrazine 4L	qt.	1	1	$3.60	$3.60	________
		Gramoxone SL	oz.	1	40	$0.25	$10.00	________
	Post-Emerge	Halex GT	pt.	1	3.6	$5.25	$18.90	________
		Atrazine 4L	qt.	1	1.5	$3.60	$5.40	________
						$0.00	$0.00	________
						$0.00	$0.00	________
Insecticides						$0.00	$0.00	________
						$0.00	$0.00	________
Fungicides [4]						$0.00	$0.00	________
Total							$48.60	________

Table 3. Machinery [8]

	Power Unit	Implement	Size	Capital Recovery	Repairs & Maintenance	Fuel, Oil & Filter	Labor	Total	Your Farm ($/Acre)
Plant	Tractor, 215 hp	Planter	16-row	$6.46	$3.71	$1.00	$0.79	$11.96	________
Weed Control	SP Boom Sprayer		90'	$4.19	$0.24	$0.19	$0.16	$4.78	________
Weed Control	SP Boom Sprayer		90'	$4.19	$0.24	$0.19	$0.16	$4.78	________
Weed Control	SP Boom Sprayer		90'	$4.19	$0.24	$0.19	$0.16	$4.78	________
Fertilize	Tractor, 215 hp	Fertilize Spreader	900#	$1.65	$2.03	$1.06	$0.84	$5.58	________
Harvest	Combine	Corn Head	8-row	$13.30	$13.13	$4.30	$1.64	$32.37	________
Haul	Tractor, 215 hp	Grain Cart		$2.31	$1.06	$0.65	$0.52	$4.53	________
Haul	Semi Tractor/Trailer		800 bu	$4.83	$0.52	$1.16	$0.93	$7.44	________
Other									________
Other									________
Total				$41.13	$21.18	$8.72	$5.20	$76.23	________

Appendix 3.5. Data

Table 3.2. Residue and population density data from May 3, 2015 (21 days after planting) in Lenoir City, TN.

							Date: 5/3/2015
Plot	**Residue #**	**Residue %**	**Pop 1**	**Pop 2**	**Pop 3**	**Pop Mean**	**Pop Density (plants ha-1)**
1 1	32	64	31	31	30	30.67	75747
1 2	33	66	34	31	30	31.67	78217
1 3	39	78	30	28	34	30.67	75747
1 4	31	62	30	33	31	31.33	77393
2 1	32	64	31	33	29	31.00	76570
2 2	38	76	32	34	30	32.00	79040
2 3	32	64	29	30	34	31.00	76570
2 4	35	70	30	32	32	31.33	77393
3 1	35	70	32	34	33	33.00	81510
3 2	34	68	29	30	32	30.33	74923
3 3	39	78	32	35	32	33.00	81510
3 4	34	68	31	29	30	30.00	74100
4 1	29	58	32	29	29	30.00	74100
4 2	28	56	29	31	31	30.33	74923
4 3	36	72	31	33	31	31.67	78217
4 4	37	74	37	32	30	33.00	81510
5 1	30	60	32	30	31	31.00	76570
5 2	29	58	32	33	31	32.00	79040
5 3	35	70	32	33	32	32.33	79863
5 4	30	60	32	31	31	31.33	77393
6 1	32	64	31	29	30	30.00	74100
6 2	32	64	35	32	33	33.33	82333
6 3	35	70	30	31	33	31.33	77393
6 4	32	64	29	32	32	31.00	76570
NTS 1	34	68	28	31	28	29.00	71630
NTS 2	30	60	28	29	33	30.00	74100
NTS 3	29	58	34	35	30	33.00	81510
NTS 4	28	56	33	29	28	30.00	74100
NTS 5	30	60	29	32	33	31.33	77393
NTS 6	29	58	30	30	30	30.00	74100

Table 3.3. Crop height (Ht) data from May 12, 2015 (30 days after planting) in Lenoir City, TN.

								Date: 5/12/2015	
Plot	**Ht 1 (cm)**	**Ht 2**	**Ht 3**	**Ht 4**	**Ht 5**	**Ht 6**	**Ht 7**	**Ht 8**	**Ht Mean (cm)**
1 1	17.7	18.1	17.3	18.0	14.0	14.6	15.8	12.5	16.00
1 2	15.6	16.5	13.0	12.1	14.0	16.0	17.1	14.4	14.84
1 3	17.6	17.5	16.5	12.1	17.6	16.2	18.0	16.0	16.44
1 4	12.3	13.4	13.5	14.2	16.5	16.7	19.5	19.1	15.65
2 1	16.4	17.1	19.1	17.0	18.8	18.1	17.8	19.9	18.03
2 2	16.2	17.7	18.1	9.1	17.0	14.1	15.3	14.2	15.21
2 3	15.8	13.9	15.2	12.7	13.2	16.3	14.1	16.5	14.71
2 4	21.5	18.2	20.1	13.6	15.5	16.5	18.4	15.4	17.40
3 1	14.0	16.3	14.6	15.5	16.6	17.5	12.6	11.5	14.83
3 2	16.5	17.9	15.3	16.0	16.4	18.1	16.5	18.0	16.84
3 3	15.5	17.7	19.6	17.5	16.7	16.4	15.4	18.1	17.11
3 4	14.6	13.0	15.8	17.9	15.5	16.0	17.0	16.9	15.84
4 1	15.2	18.6	18.5	14.1	17.7	18.5	15.6	14.2	16.55
4 2	16.2	18.1	16.1	17.0	15.3	17.2	18.1	19.2	17.15
4 3	17.8	16.2	18.8	16.4	15.7	14.5	15.5	17.9	16.60
4 4	15.9	15.8	14.0	17.0	13.6	12.4	11.5	13.0	14.15
5 1	14.6	13.0	15.5	15.9	17.1	17.0	18.2	16.1	15.93
5 2	17.9	15.9	17.6	18.9	12.8	17.4	19.1	17.7	17.16
5 3	15.6	15.5	9.0	15.9	16.5	16.6	14.5	15.5	14.89
5 4	16.7	16.4	17.4	18.3	17.4	17.3	13.5	14.8	16.48
6 1	18.3	15.0	18.2	18.5	19.1	15.2	15.0	16.9	17.03
6 2	15.6	17.1	16.8	13.0	19.6	10.9	18.5	17.9	16.18
6 3	19.4	17.0	15.9	18.5	15.0	16.1	18.1	16.8	17.10
6 4	17.5	17.1	16.8	19.0	19.9	20.5	18.1	16.9	18.23
NTS 1	17.4	16.8	18.5	20.1	14.0	14.9	18.4	18.6	17.34
NTS 2	19.0	16.0	19.6	12.7	15.0	18.1	17.2	17.7	16.91
NTS 3	18.7	18.3	17.1	16.0	20.1	17.5	17.7	19.5	18.11
NTS 4	18.3	16.8	16.1	17.5	19.1	16.8	16.8	20.3	17.71
NTS 5	16.5	14.6	15.9	15.5	13.5	14.5	18.9	18.1	15.94
NTS 6	14.6	15.5	17.1	14.7	15.5	14.7	16.8	10.4	14.91

Table 3.4. Crop height, GreenSeeker™ (GS), and SPAD data from June 8, 2015 (57 days after planting) in Lenoir City, TN.

																					Date: 6/8/2015
Plot	**Ht 1 (cm)**	**Ht 2**	**Ht 3**	**Ht 4**	**Ht 5**	**Ht 6**	**Ht 7**	**Ht 8**	**GS 1**	**GS 2**	**GS 3**	**GS 4**	**GS 5**	**SPAD 1**	**SPAD 2**	**SPAD 3**	**SPAD 4**	**SPAD 5**	**Ht Mean (cm)**	**GS Mean**	**SPAD Mean**
1 1	175.2	203.2	170.3	195.6	197	177.3	174.2	154.6	0.78	0.70	0.82	0.86	0.39	55.7	55.8	56.2	57.3	52.9	180.93	0.710	55.58
2 1	154.1	139.8	141.3	151.7	165.9	162.8	162.1	173.9	0.66	0.70	0.84	0.84	0.72	59.5	54.3	53.4	54.6	55.3	156.45	0.752	55.42
3 1	168.7	151.5	176.4	160.9	144.6	162.3	157	158.1	0.82	0.82	0.82	0.56	0.49	53.5	52.3	57.6	59	55.8	159.94	0.702	55.64
4 1	170.3	178.1	169.3	189.5	177.6	191.7	189	153.5	0.84	0.72	0.80	0.79	0.75	56.7	54.5	50.4	55.3	55.5	177.38	0.780	54.48
5 1	163.1	169	163.1	179.3	162.3	149.2	167.5	166.2	0.83	0.83	0.77	0.87	0.84	53.2	52.3	49	56.2	44.9	164.96	0.828	51.12
6 1	184	147.8	205.5	183.1	194.5	199	190.4	143.4	0.82	0.85	0.84	0.81	0.83	54.3	55.6	59	55.3	54.5	180.96	0.830	55.74
1 2	177.4	159.5	168.5	179	193.3	189.9	191.1	150	0.83	0.81	0.83	0.83	0.79	54.5	52.1	54.4	58.9	50.1	176.09	0.818	54.00
2 2	174.1	169.6	174.9	157.9	169.1	161.7	164.4	151	0.85	0.79	0.83	0.79	0.82	54.9	57.2	55.1	55.4	53.3	165.34	0.816	55.18
3 2	179.7	195	175.2	151.1	171.7	170.9	176.2	176.4	0.81	0.81	0.77	0.84	0.86	56.6	59.2	61.6	56.1	67.7	174.53	0.818	60.24
4 2	178.1	179.1	183.6	185.1	153.5	171.3	181.5	171.7	0.68	0.84	0.78	0.85	0.82	51.8	57.2	55.5	59	56.9	175.49	0.794	56.08
5 2	159.6	182.8	192.9	185	195.8	192.7	204.8	186.4	0.83	0.79	0.57	0.85	0.83	55.3	53.2	55.6	53.5	59.3	187.50	0.774	55.38
6 2	163.7	176.3	161.4	161	159	156.6	162.1	150.3	0.80	0.81	0.81	0.84	0.81	57.2	57.4	54.5	59.8	50.6	161.30	0.814	55.90
1 3	179	176.5	177.1	182.5	157.3	185.9	193.8	173.1	0.83	0.84	0.75	0.78	0.85	56.8	75.1	56.2	55.4	58.8	178.15	0.810	60.46
2 3	168	165.1	160.2	159.7	150.5	172	157.6	165	0.75	0.66	0.84	0.74	0.74	57.7	60	56.4	62.8	62.5	162.26	0.746	59.88
3 3	195.2	172.4	192	180.5	158.5	185	184.6	172.2	0.83	0.78	0.81	0.74	0.82	54.2	68	56.5	61.9	59.6	180.05	0.796	60.04
4 3	191.5	154.1	170.4	170.8	183.4	175.4	179.3	166.7	0.82	0.78	0.84	0.82	0.81	58.7	54.1	54.7	55	54.4	173.95	0.814	55.38
5 3	170.2	157.9	154.5	111.6	157.8	160.2	149.6	147.5	0.83	0.80	0.80	0.83	0.70	58.6	55.1	62.2	61.1	54.5	151.16	0.792	58.30
6 3	169.2	177.9	162.5	172.7	158.9	174.3	168.7	167.6	0.82	0.83	0.82	0.80	0.84	56.6	53.2	50.6	52.5	53.2	168.98	0.822	53.22
1 4	179.1	151.2	161.3	176.6	168.1	170.1	185.5	152.1	0.82	0.80	0.82	0.79	0.82	59.2	54.5	57.2	57.2	59.4	168.00	0.810	57.50
2 4	206.8	167.5	177	171.3	180.7	164.5	179.1	174.4	0.74	0.83	0.74	0.70	0.83	55.7	57.8	57.1	60	52.2	177.66	0.768	56.56
3 4	147.1	167	164.5	93.8	128.9	140.2	178.1	176	0.77	0.80	0.80	0.75	0.77	45	51	48.9	48.2	50.5	149.45	0.778	48.72
4 4	157.9	155	144.1	144.3	167.1	164.9	172.9	152.5	0.79	0.79	0.87	0.88	0.72	52.6	50.8	55.3	57.4	52.1	157.34	0.810	53.64
5 4	186.9	166.3	194.1	166	195.4	181.6	193.7	183.1	0.75	0.83	0.77	0.79	0.83	60.3	56.1	54.1	53.2	62.2	183.39	0.794	57.18
6 4	195.4	173.2	184.5	206.2	178.4	187.4	177.5	162.5	0.83	0.84	0.81	0.85	0.84	54.2	50.6	54.3	58.4	52.9	183.14	0.834	54.08
NTS 1	148.9	169.9	165.6	157.7	170.5	159.1	168.3	163.6	0.77	0.80	0.84	0.79	0.81	58.6	53.5	55.3	54.8	50.3	162.95	0.802	54.50
NTS 2	177	147.4	171.9	183.4	172.6	146.8	169.2	172.3	0.82	0.84	0.82	0.81	0.85	53.8	52.9	57	54.4	54.3	167.58	0.828	54.48
NTS 3	159.9	165.2	181.5	179.4	201.5	182	193.6	177.3	0.78	0.80	0.75	0.52	0.80	52.4	47.1	51.5	52.1	48.8	180.05	0.730	50.38
NTS 4	153.2	153.2	170.5	148.7	143.6	152	190.3	201.1	0.82	0.71	0.74	0.77	0.67	54.9	53	53.6	51.4	54	164.08	0.742	53.38
NTS 5	185.5	178.4	168	175.6	158.2	167.6	169.2	162.1	0.71	0.78	0.81	0.80	0.81	57.8	54.6	55.5	53.1	53.9	170.58	0.782	54.98
NTS 6	145.9	152.1	140	146.6	140.4	138.3	177.1	190.3	0.82	0.79	0.78	0.80	0.84	57.2	57.5	53.4	56.4	56.3	153.84	0.806	56.16

Table 3.5. GreenSeeker^{TM} and SPAD data from June 17, 2015 (66 days after planting) in Lenoir City, TN.

											Date: 6/17/2015
Plot	**GS 1**	**GS 2**	**GS 3**	**GS 4**	**GS 5**	**SPAD 1**	**SPAD 2**	**SPAD 3**	**SPAD 4**	**SPAD 5**	**GS Mean**	**SPAD Mean**
1 1	0.78	0.74	0.79	0.83	0.77	59.9	56.9	55.8	59.2	59.9	0.78	58.34
1 2	0.79	0.82	0.87	0.7	0.79	57.5	58.5	56.3	57.2	56.9	0.79	57.28
1 3	0.74	0.72	0.75	0.79	0.8	56.5	57.5	58.3	56.6	57.4	0.76	57.26
1 4	0.75	0.77	0.82	0.78	0.77	45.8	51.2	56.7	43.9	53.6	0.78	50.24
2 1	0.73	0.84	0.82	0.83	0.81	59.7	59.3	57.1	60.6	56.1	0.81	58.56
2 2	0.8	0.75	0.81	0.81	0.78	59.3	56.3	59.8	61.9	57.8	0.79	59.02
2 3	0.8	0.8	0.81	0.73	0.78	57.8	56.2	56.6	58.4	62.2	0.78	58.24
2 4	0.72	0.72	0.83	0.83	0.79	56.9	53.6	52.3	53.9	57.9	0.78	54.92
3 1	0.82	0.75	0.51	0.79	0.7	62.5	55.1	55.9	58	58.9	0.71	58.08
3 2	0.83	0.8	0.78	0.83	0.86	59.8	58.3	62.5	65.1	62.5	0.82	61.64
3 3	0.76	0.8	0.86	0.8	0.82	56.6	59.9	60.1	58.1	61.5	0.81	59.24
3 4	0.77	0.84	0.7	0.81	0.82	55.8	60	64	58.8	62.9	0.79	60.30
4 1	0.87	0.78	0.75	0.71	0.81	59.8	60.1	60.4	60.1	55.8	0.78	59.24
4 2	0.76	0.77	0.8	0.75	0.81	61.5	57.3	56.4	52.6	59.8	0.78	57.52
4 3	0.69	0.56	0.81	0.57	0.77	57.2	57.8	57.8	64.6	62.7	0.68	60.02
4 4	0.68	0.79	0.79	0.72	0.85	58.6	56.7	61	56.8	58.4	0.77	58.30
5 1	0.65	0.83	0.84	0.71	0.78	60.6	60.8	61.5	60.4	62.2	0.76	61.10
5 2	0.78	0.85	0.81	0.77	0.83	62.2	56.4	64.1	58.9	60.9	0.81	60.50
5 3	0.73	0.76	0.81	0.7	0.8	62.5	61	59.6	58.2	60.2	0.76	60.30
5 4	0.83	0.8	0.75	0.84	0.84	61.2	54.3	59.6	61.2	57.7	0.81	58.80
6 1	0.78	0.76	0.78	0.84	0.75	56.8	59.7	58.7	57.7	59	0.78	58.38
6 2	0.77	0.63	0.74	0.8	0.6	52.1	57.5	59.6	60.5	57.4	0.71	57.42
6 3	0.79	0.76	0.73	0.87	0.79	58.7	56.9	57.5	58.8	61.7	0.79	58.72
6 4	0.8	0.78	0.79	0.83	0.75	63.4	58.3	56.6	60.5	60.2	0.79	59.80
NTS 1	0.76	0.75	0.77	0.71	0.73	63	61.1	60.5	62.6	58	0.74	61.04
NTS 2	0.74	0.82	0.74	0.83	0.79	55.1	55.7	63.2	58.6	58	0.78	58.12
NTS 3	0.76	0.8	0.8	0.77	0.79	50.8	55.7	59.7	57.5	54.2	0.78	55.58
NTS 4	0.76	0.72	0.77	0.75	0.78	55.6	49.7	49.7	55.9	53.6	0.76	52.90
NTS 5	0.84	0.86	0.83	0.78	0.81	56.6	54.2	55.1	57.8	62.7	0.82	57.28
NTS 6	0.8	0.79	0.84	0.86	0.82	50.8	47.8	63.1	48.7	51	0.82	52.28

Table 3.6. GreenSeeker™ and SPAD data from June 19, 2015 (68 days after planting), and SPAD data from July 6, 2015 (85 days after planting) in Lenoir City, TN.

												Date: 6/19/2015		Date: 8/5/2015
Plot	**GS 1**	**GS 2**	**GS 3**	**GS 4**	**GS 5**	**SPAD 1**	**SPAD 2**	**SPAD 3**	**SPAD 4**	**SPAD 5**	**GS Mean**	**SPAD Mean**		**85 Day SPAD**
1 1	0.71	0.82	0.76	0.77	0.71	59.2	59.7	58.4	62.9	62.8	0.75	60.60		63.1
1 2	0.76	0.76	0.74	0.83	0.72	60.4	63.1	58	60.1	63.9	0.76	61.10		63.8
1 3	0.75	0.82	0.76	0.74	0.77	62.8	62	70.1	60.2	58.4	0.77	62.70		62.5
1 4	0.71	0.77	0.67	0.8	0.83	62	55.3	52.2	56.9	54.5	0.76	56.18		57.2
2 1	0.78	0.77	0.77	0.76	0.73	58.6	58.7	60.1	58.4	60.3	0.76	59.22		64.7
2 2	0.82	0.83	0.82	0.76	0.75	61	56.5	57.7	61.7	58.6	0.80	59.10		63.8
2 3	0.81	0.8	0.78	0.79	0.78	59.2	58.5	60.1	56.1	62	0.79	59.18		64.6
2 4	0.75	0.75	0.79	0.73	0.76	62.4	57.2	61.5	58.2	56.5	0.76	59.16		61.7
3 1	0.81	0.81	0.8	0.82	0.78	61.1	59.7	60.6	57.8	59.5	0.80	59.74		57
3 2	0.84	0.8	0.84	0.77	0.81	61.8	60.8	64.4	63.4	61.9	0.81	62.46		65.8
3 3	0.76	0.75	0.75	0.77	0.81	64.7	64.3	58.8	60.8	60.6	0.77	61.84		66.2
3 4	0.81	0.83	0.81	0.79	0.81	60.1	60.1	60.5	60.4	65.3	0.81	61.28		64.4
4 1	0.75	0.77	0.77	0.79	0.79	63.2	59.3	61.8	58.6	60.7	0.77	60.72		64.9
4 2	0.75	0.85	0.78	0.76	0.75	64.3	61.7	62.8	66.4	60.5	0.78	63.14		65.3
4 3	0.82	0.69	0.81	0.81	0.79	61.4	59.1	60.7	64.2	61.7	0.78	61.42		64
4 4	0.77	0.71	0.77	0.78	0.76	58.8	61.9	62.4	61	60.2	0.76	60.86		65
5 1	0.81	0.79	0.82	0.79	0.77	61.9	60.5	63.3	63.4	61.2	0.80	62.06		67.7
5 2	0.75	0.85	0.8	0.77	0.81	62.5	61.7	65.8	61.2	61.7	0.80	62.58		63.4
5 3	0.8	0.78	0.74	0.79	0.70	66.4	62.4	61.3	63.5	61.4	0.76	63.00		66
5 4	0.74	0.79	0.8	0.77	0.77	60.4	59.2	61.4	62.9	62.2	0.77	61.22		64.2
6 1	0.76	0.77	0.77	0.75	0.78	60.9	59.7	61.4	64	61.1	0.77	61.42		62.5
6 2	0.78	0.76	0.73	0.83	0.78	56.9	58.5	59.9	62.9	61.6	0.78	59.96		63.2
6 3	0.77	0.83	0.74	0.73	0.73	58.6	61.2	57.3	66	66.4	0.76	61.90		65.2
6 4	0.77	0.74	0.7	0.76	0.80	65	59.6	60.9	58.6	59.5	0.75	60.72		63.3
NTS 1	0.81	0.76	0.78	0.81	0.81	62.3	64.7	65.3	66.7	60.5	0.79	63.90		61.2
NTS 2	0.79	0.77	0.73	0.74	0.75	67	60.1	57.6	63.5	62.8	0.76	62.20		62.2
NTS 3	0.84	0.76	0.82	0.76	0.80	59.8	60.4	59.6	60	57.5	0.80	59.46		58.8
NTS 4	0.81	0.83	0.8	0.79	0.86	56	56.9	58.4	59.7	55.9	0.82	57.38		61.9
NTS 5	0.72	0.77	0.82	0.73	0.80	60.1	61	62.3	65.2	63.4	0.77	62.40		63.4
NTS 6	0.8	0.7	0.79	0.73	0.73	60.3	58.5	60.4	64.4	58.4	0.75	60.40		64.6

Table 3.7. Yield data and calculations from September 17, 2015 in Lenoir City, TN.

								Date: 9/17/2015
Plot	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Yield (T ha-1)	Grain Moisture (%)	**Yield (t ha-1) corrected for 15.5% moisture**
1 1	63	59	12512.00	1084.50	11427.50	14.12	14.10	14.35
1 2	67	67	13993.50	1166.00	12827.50	15.85	14.20	16.09
1 3	66	59	11813.00	1133.00	10680.00	13.20	13.47	13.51
1 4	65	65	11380.50	1195.00	10185.50	12.58	14.23	12.77
2 1	64	64	12280.50	1099.50	11181.00	13.81	14.40	13.99
2 2	64	63	13722.00	1294.00	12428.00	15.35	14.20	15.59
2 3	61	61	13058.00	1266.00	11792.00	14.57	13.47	14.92
2 4	61	60	12315.50	1261.00	11054.50	13.66	14.10	13.88
3 1	68	65	13565.50	1253.00	12312.50	15.21	14.30	15.43
3 2	63	62	12942.00	1219.50	11722.50	14.48	14.43	14.67
3 3	66	64	14550.50	1395.50	13155.00	16.25	13.97	16.55
3 4	62	58	12157.00	1284.00	10873.00	13.43	14.47	13.60
4 1	66	61	13046.00	1242.00	11804.00	14.58	14.23	14.80
4 2	60	57	12502.00	1228.00	11274.00	13.93	14.03	14.17
4 3	64	56	11516.50	1128.00	10388.50	12.83	14.27	13.02
4 4	60	62	13702.50	1388.00	12314.50	15.21	13.90	15.50
5 1	60	60	11599.50	1113.50	10486.00	12.96	13.57	13.25
5 2	66	64	13303.00	1233.00	12070.00	14.91	14.60	15.07
5 3	61	55	11027.00	1094.50	9932.50	12.27	14.03	12.49
5 4	67	67	13706.50	1341.50	12365.00	15.28	14.53	15.45
FP 1	68	65	13491.00	1246.00	12245.00	15.13	14.17	15.37
FP 2	69	70	13653.50	1390.00	12263.50	15.15	14.43	15.34
FP 3	59	55	12641.00	1263.00	11378.00	14.06	13.97	14.31
FP 4	64	60	13516.00	1314.50	12201.50	15.07	14.27	15.29

Chapter 4
Assessing the Efficacy of a Reduced Effort Maize Hand Harvest Method

Abstract

Maize harvests for agricultural research projects in developing countries are often limited by time, labor, and economic resource restrictions. This study was conducted to assess the efficacy of a reduced effort ten plant harvest method in maize (*Zea mays* L.) yield estimates. Yields from this method were compared to those from another more intensive hand harvest method (the row method) in two maize studies located in Lenoir City, TN, and Mount Gilead, OH in 2015, and a mechanical whole plot harvest in the OH study. The TN study was a randomized block design (RBD) with 24 plots, and the OH study was a completely randomized design (CRD) with 48 plots. The yields extrapolated from the two hand harvest methods were found to be significantly different in the TN study ($p<0.05$), with the ten plant method overestimating yields compared to the row method by 5.02% on average (15.3 and 14.6 t ha^{-1}, respectively). In the OH study, yields from the two hand harvest methods were analyzed without the mechanical harvest, and were not found to be significantly different from each other with a mean yield of 2.75 t ha^{-1} in the ten plant method and 2.72 t ha^{-1} in the row method ($p=0.6437$). The ten plant method was found to have a moderate to strong positive correlation to the row method in the TN and OH studies of 40% and 95%, respectively ($p<0.05$). The results of these analyses indicate that the ten plant method could be used as a replacement for maize research in developing countries where resources are limited.

1. Introduction

The global population continues to grow while the amount of available natural resources remains limited. Recent estimates project a 2.3 billion increase in the global population in the next 35 years, exceeding 9.5 billion by 2050 (DESA, 2014). Much of this growth will occur in developing countries, already struggling to meet their food production demands due to low resource availability or income to use new machinery or apply soil amendments. The population of Africa alone is expected to double from 1.1 billion to 2.4 billion by 2050, the majority of which will occur in sub-Saharan Africa (SSA), the poorest area in the world (PRB, 2013).

More than 80% of farms in SSA are smallholder farms, meaning that they take up two or less hectares of land, but these contribute up to 90% of total food production in some countries (FAO, 2015). Maize is the most widely produced staple crop in SSA, grown on nearly 27 M ha, and is predominately produced on smallholder farms under rain fed conditions (Cairns et al., 2012, FAO, 2010). While maize yields have been improving in other parts of the world, SSA maize production has been increasing at a much slower rate due to farmers' limited access to soil amendments, new technology, and information regarding agricultural practices (Cairns et al., 2012). The need for inexpensive and accessible agricultural innovations to improve yields in SSA is more crucial than ever.

In order for these advances to occur, the amount of research surrounding new agricultural technologies, machinery, and sustainable practices in these countries must be increased. One of the factors limiting research in developing countries is that researchers are often restricted by time, economics, or both. Much of the current agricultural research in SSA is operated from outside the country where the study is taking place, with researchers traveling to their sites during important stages of a project, but largely managing studies from a distance. For all of these reasons, the efficacy of our current methods of conducting research and collecting data need to be re-evaluated and if possible, improved.

Crop harvests and yield measurements can often provide the most important indicator of success when testing a new practice or technology. Efficiency and timeliness of harvesting and lab analysis is important for many crops, especially maize, as the grain can dry out and yield comparisons can be highly affected by varying moisture measurements. Despite the need for efficiency, harvesting can still demand high amounts of labor and time. Large projects may

sometimes require many researchers or hired assistants to complete the job. However, increasing the number of workers increases the opportunity for error in data collection.

A common method used by researchers to estimate corn grain yields is to harvest a length of row and extrapolate to get an approximation of yields on an area basis (the row method). For fields planted at a density of 84,000 plants ha^{-1} (34,000 plants A^{-1}) with a row spacing of 76 cm (30 in), a 5.32 m (17.45 ft) length of row is harvested completely. This length is equal to $1/2471^{th}$ of a hectare ($1/1000^{th}$ of an acre) and should have approximately 34 plants (Lauer, 2002, Lee & Herbek, 2005, Nielson, 2015). Grain yields from this length are easily multiplied by 2,471 to provide an estimate of yield on a hectare basis, or by 1,000 for yield estimates on an acre basis. In large projects however, even this method of yield estimation can still require time and energy that may not be available during busy harvest periods.

A study comparing the row method to a ten plant harvest method was completed in 2012 in Lesotho (Bruns, 2012). The yields extrapolated from a ten plant subsample collected from the center of each plot were compared to those from three 5.55 m row lengths. The two yields produced by the same plot were not found to be significantly different at α=0.1, but the ten plant harvest method on average overestimated row method yields by 26% (Bruns, 2012).

The objective of this study was to compare a similar ten plant harvest method to the row method and a mechanical whole plot harvest in order to determine whether it could be used as a more efficient and inexpensive alternative for maize harvesting and yield estimations in developing countries when time, labor, or resources may be limited.

2. Materials and Methods

2.1 Study areas and soil characteristics

Two studies were used in this analysis, both completed in 2015: one in Lenoir City, TN (35˚44'6"N, 84˚11'2"W), and the other in Mount Gilead, Ohio (40˚36'18"N, 82˚40'32"W). The TN soil was a Dewey silty clay with 12-20% slopes (fine, kaolinitic, thermic Typic Paleudult) with 8% sand, 50% silt, and 42% clay (WSS, n.d.). The site was previously managed under conservation agriculture (CA) practices, including 15 years of no-till, maintained residue cover, and a maize-soybean rotation with soybean as the previous crop. The climate in this region is classified as a Cfa, humid subtropical climate (Kottek et al., 2006, Pidwirny, 2011) with an average annual rainfall of 135 cm and a mean annual temperature of 14.4˚C (Climate, n.d.).

The OH soil was a Centerburg silt loam with 2-6% slopes (fine-loamy, mixed, active, mesic, Aquic Hapludalf) with 30% sand, 54% silt, and 16% clay (WSS, n.d.). The site prior to this study was managed under CA practices, including seven years of no-till, maintained crop residue cover, and a maize-soybean rotation with maize as the previous crop. The climate in this region is classified as a Dfb, humid continental mild summer, and wet all year (Kottek et al., 2006, Pidwirny, 2011) with an average annual rainfall of 98 cm and a mean annual temperature of 9.4˚C (Climate, n.d.).

2.2 Experimental design

The TN study experimental design was a randomized complete block with six nitrogen (N) fertilization rate treatments and four blocks based on topography, for a total of 24 plots. Each plot was an area 4.57 m x 9.14 m and included six rows of maize (Appendix 3.1). For the purposes of this study, the treatments are labeled 1, 2, 3, 4, 5, and 6.

Maize was planted on April 12, 2015, using a John Deere 1790 Planter at a density of 84,000 plants ha^{-1}. Nitrogen fertilizers were hand applied to the plots on April 21, 2015, and phosphorus (P) and potassium (K) were applied to all plots at rates of 90 kg P_2O_5 ha^{-1} as triple superphosphate (0-46-0) and 90 kg K_2O ha^{-1} as potash (0-0-60).

The OH study was a completely randomized design with a split-plot treatment design. There were two whole plot tillage treatments and six subplot N fertilization rate treatments for a total of 12 treatment combinations. Each treatment was replicated four times for a total of 48 plots. Plots were an area 4.57 m x 18.29 m and included six rows of maize (Appendix 2.1). For the purposes of this study, the combinations of treatments are labeled 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.

Tillage in OH was done May 4, 2015, with one pass of a moldboard plow and two passes of a disk. Maize was planted on May 15, 2015, using a John Deere 7200 6-row MaxEmerge Conservation Planter at a density of 84,000 plants ha^{-1}. N, P, and K fertilizers were hand applied on June 3, 2015, with P and K applied to all plots at rates of 112 kg P_2O_5 ha^{-1} as triple superphosphate (0-45-0) and 112 kg K_2O ha^{-1} as potash (0-0-60).

2.3 Harvest methods

The TN corn was harvested on September 17, 2015, using two hand harvest methods: a ten plant harvest and a row harvest. Ohio corn was harvested on October 22, 2015, and compared the two hand harvest methods and an additional whole plot mechanical harvest.

2.3.1 Ten plant method

In TN, the ten plant harvest was done by first marking the crops at the beginning and end of a 5.32 m length in the middle of each of the two interior rows ($2/1000^{th}$ of an acre). Five random plants from each length (approximately every fifth plant), for a total of ten plants were selected, and all ears from these plants were counted and hand harvested.

In the OH study ten plant harvest, only one row was marked and harvested. The row used was randomly chosen from one of the two interior rows, and the crops at the beginning and end of a 5.32 m length were marked ($1/1000^{th}$ of an acre). Ten plants from this length (approximately every third plant) were selected, and all ears from these plants were counted and hand harvested.

2.3.2 Row method (5.32 m)

The row harvests for both studies were completed on the same 5.32 m lengths used for the previous harvest method. All stalks in these lengths were counted and recorded, including those that had already been harvested for the ten plant harvest method (Lauer, 2002, Lee & Herbek, 2005, Nielson, 2015). Then, all ears from these stalks were counted, harvested, and transported back to the lab.

2.3.3 Whole plot method

The whole plot harvest was only used in the OH study. Following the two hand harvest methods, the entire plot was harvested mechanically using a John Deere 9500 combine harvester. The shelled corn was transferred into a weigh wagon, and the grain weight for the plot was measured using an Avery weigh tronix model 715 scale (Fairmount, MN) (Figure 4.1).

Figure 4.1. Whole plot harvest transferring grain from the combine to the weigh wagon in Mount Gilead, OH.

2.3.4 Lab analysis

For each of the two hand harvest methods, the ears were taken back to the lab for processing. In the lab, total ear weight (including cob and grain weight, without husks) for each plot was measured and recorded, and ears were shelled using a hand powered, rotary Maximizer™ corn sheller. After shelling, the empty cobs were weighed, and grain weight was calculated by subtracting this number from the total ear weight.

For each method, grain moisture and density for each plot were measured using a Dickey John mini GAC moisture tester on three samples of shelled grain, from which an average was taken. In the OH study, yields from the ten plant harvest method were relatively low and did not provide enough grain for moisture measurements, so grain moisture from the row harvest method were used in the ten plant method yield calculations. Row harvest moisture values were also used for the whole plot method moisture corrections, as this value was not measured in the field.

2.4 Yield calculations

Yields for the ten plant method were calculated by first obtaining a grain weight for just one ear by dividing the grain weight by the number of ears harvested, which was then multiplied by the number of stalks in the 5.32 m length, then by 1,000 in order to obtain a mass estimate on a hectare basis in lbs A^{-1}. This value was then converted to t ha^{-1}, and yields were corrected from the measured moisture values to 15.5% moisture (Lauer, 2002). For the OH study, the moisture values used were those obtained from the row method

In the row harvest method, grain weight from the ten plant method was first added to the total grain weight for each plot before extrapolating yields. In the TN study, grain weight per two rows was multiplied by 500, as the area harvested represented $2/1000^{th}$ ($1/500^{th}$) of an acre. In the OH study, grain weight per one row was multiplied by 1000, as the area harvested represented $1/1000^{th}$ of an acre. These yields were then converted to t ha^{-1} and moisture was corrected to 15.5%.

For the whole plot method used in the OH study, grain yields from the two hand harvest methods were added to the total grain weight measured by the weigh wagon. The grain yield was then converted from the plot size to t ha^{-1}, and corrected to 15.5% moisture using the moisture content measured from the row harvest method (Appendix 4.1, 4.2).

2.5 Statistical analysis

The yield data collected from these studies were compared using mixed models analysis of variance (ANOVA) to detect differences in harvest methods. Means were separated using Tukey's significant difference test at α=0.05. The TN yield data were analyzed as a RBD with a split-plot treatment design, and the statistical model used was:

$$y_{ijk} = \mu + B_i + T_j + B * T_{ij} + F_k + F * T_{jk} + B * F * T_{ijk}$$

where B_i=treatments (6), T_j=reps (4)., and F_k=fact (2harvest methods). The OH yield data were analyzed as a CRD with a split-plot treatment design, and the statistical model used was:

$$y_{ijk} = \mu + T_i + R(T)_{ik} + F_j + T * F_{ij} + F * R(T)_{ijk}$$

where T_i=treatments (12), F_j=fact (3 harvest methods), and R_k=reps (4). For each of the studies, the treatments were analyzed in the whole plot, and the harvest methods were analyzed in the split-plot. A correlation analysis between the two hand harvest method yields in each study was also run in SAS 9.4 (Cary, NC).

3. Results and Discussion

3.1 Tennessee

In ANOVA, the yields produced from the two harvest methods were found to be significantly different (p=0.0063), with the ten plant harvest mean yield of 15.3 t ha^{-1} significantly greater than the row harvest mean yield of 14.6 t ha^{-1} (Figure 4.2, 4.3). On average, the ten plant harvest method overestimated yields from the row method by 5.02%, with values ranging from -10.05 to 15.79%.

The yields were relatively high and production was consistent throughout the plot. The mean ear:stalk ratio using the ten plant method was 1.01, compared 0.97 in the row method, and ratios were significantly different (p<0.0001) (Figure 4.4). These ratios are comparable to the expected ear:stalk ratio of 1 at a planting density of 84,000 plants ha^{-1} (Elmore et al., 2011).

A moderate positive correlation between the ten plant harvest and row harvest methods was found (r=0.63, p=0.0010) (Figure 4.5). Forty per cent of the variation in the ten plant method could be explained by the row method (r^2=0.3969).

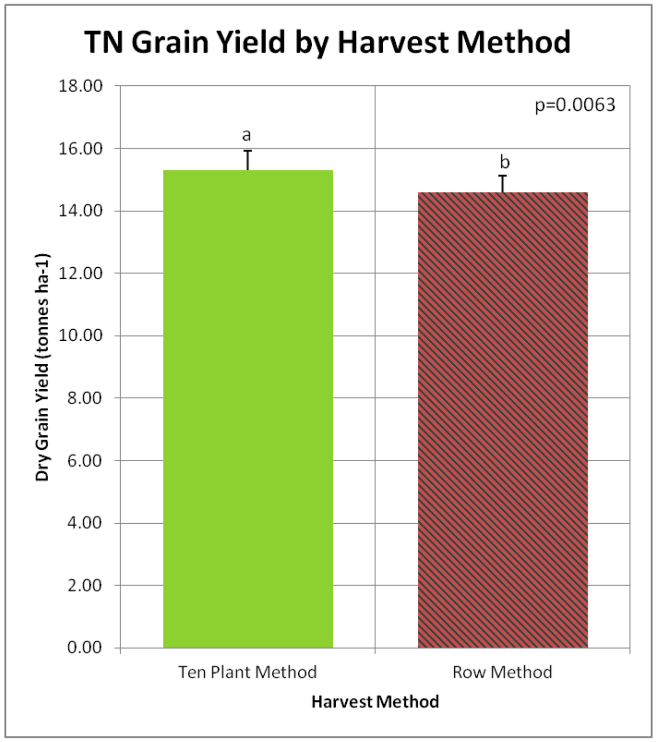

Figure 4.2. Comparison of TN grain yields using ten plant and row harvest methods.

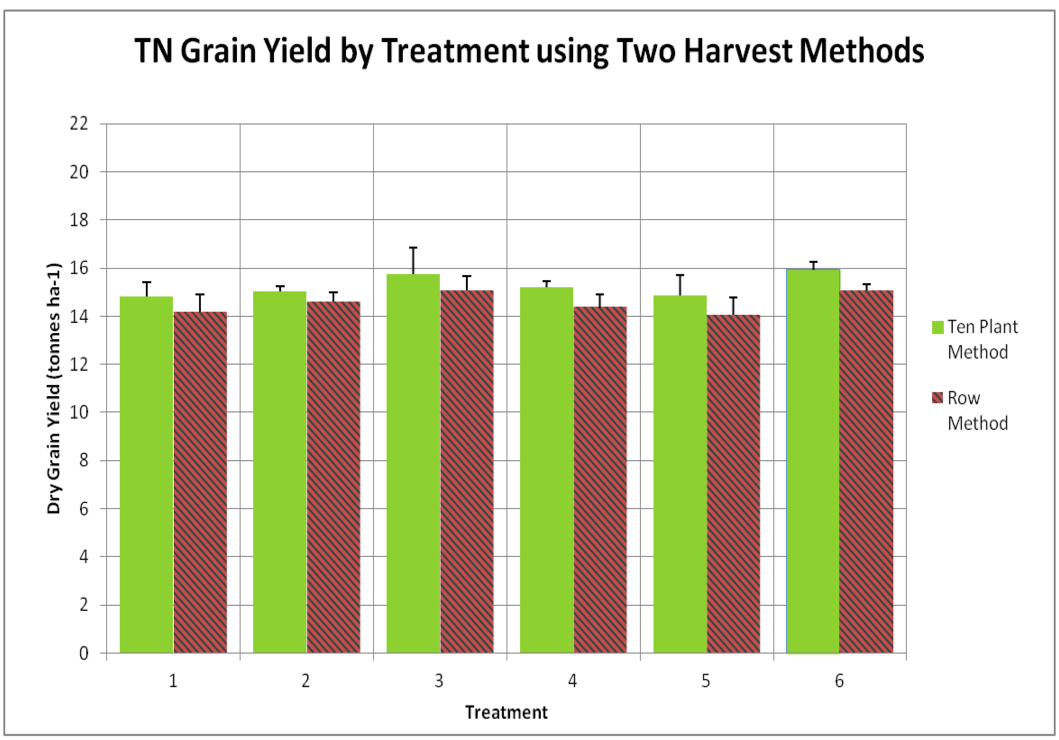

Figure 4.3. Comparison of TN grain yields using ten plant and row harvest methods, by treatment.

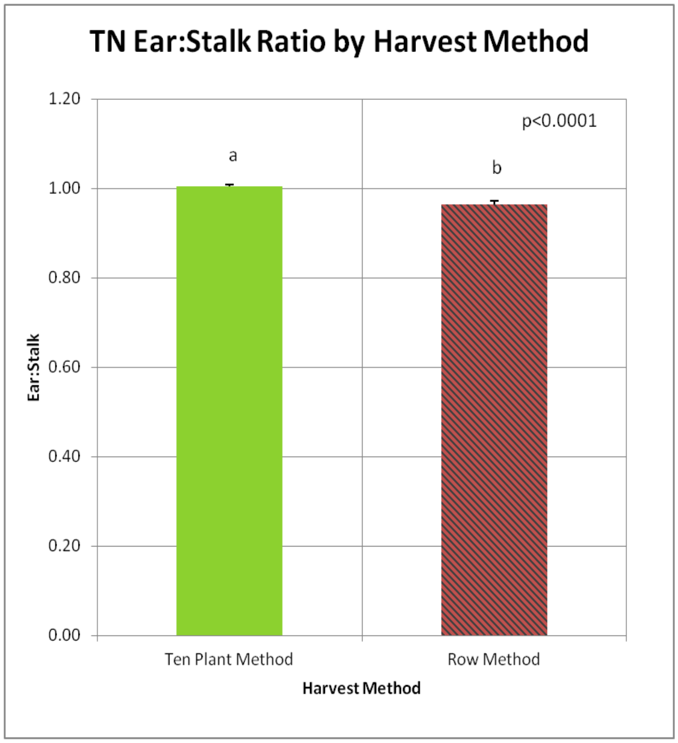

Figure 4.4. Comparison of TN ear:stalk ratios using a ten plant and row harvest method.

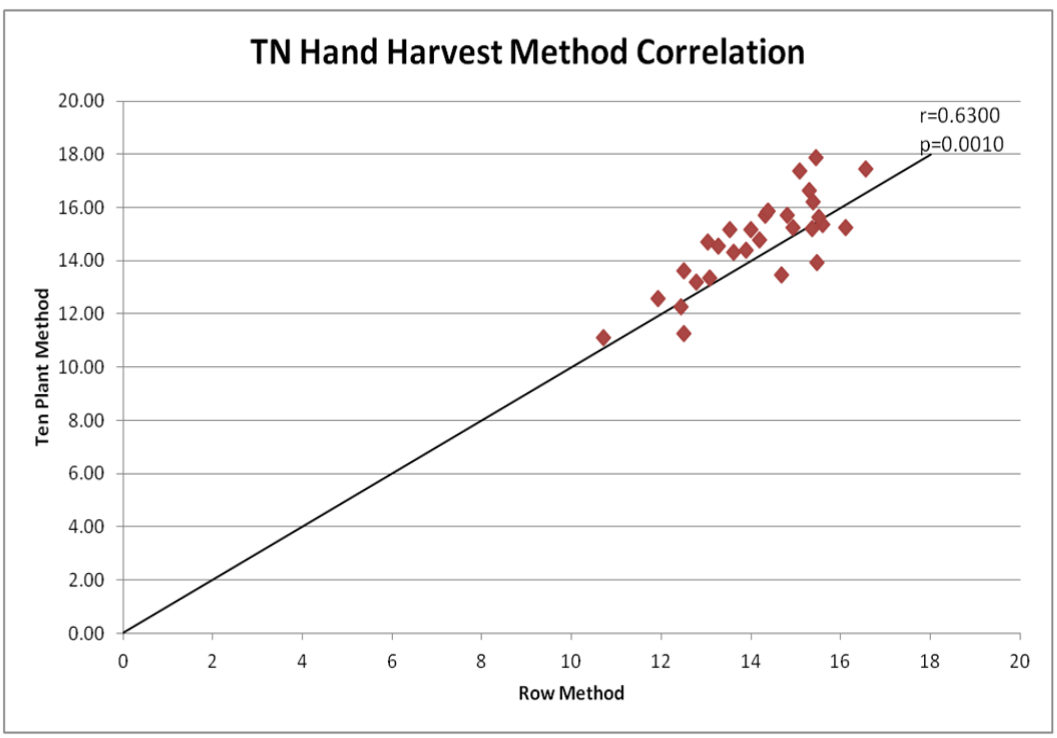

Figure 4.5. Correlation of hand harvest method yields in TN.

3.2 Ohio

Yields calculated from the ten plant, row, and whole plot harvests were found to be significantly different ($p<0.0001$) (Figure 4.6). The whole plot method yield was significantly lower than the two hand harvest methods, with a mean yield of 1.70 t ha^{-1} compared to 2.75 t ha^{-1} in the ten plant method and 2.72 t ha^{-1} in the row method. This was most likely due to the imprecision of the weigh wagon at low yields. The weigh wagon precision was only 2 lbs, so in the lower fertilization rates, especially treatments 1-4, the wagon would sometimes detect a yield of 0 lbs $plot^{-1}$, though grain was visibly being collected and transferred into it. It is also possible that in some of the low yielding treatments, the ears were so low to the ground that they were not collected by the combine. Another factor affecting imprecision in whole plot method yields was the wind, which caused fluctuations of 2-8 lbs, creating a huge difference in comparisons at low yields.

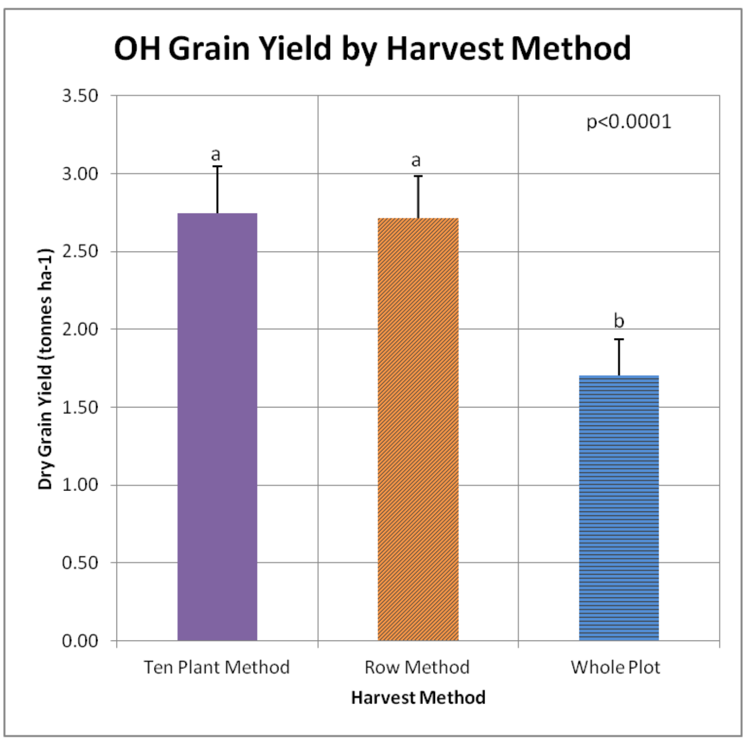

Figure 4.6. Comparison of OH grain yields using ten plant, row, and whole plot methods.

For these reasons, the whole plot harvest data was removed and the two hand harvest methods were compared independently. The yields produced from the two hand harvest methods were not found to be significantly different (p=0.6437), with the ten plant harvest mean yield of 2.75 t ha^{-1} significantly greater than the row harvest mean yield of 2.72 t ha^{-1} (Figure 4.7, 4.8). On average, the ten plant harvest method underestimated yields from the row method by 1.96%, with values ranging from -67.64 to 65.02%. The mean ear:stalk ratio from the ten plant harvest was 0.86, and 0.87 from the row harvest (Figure 4.9).

A strong positive correlation between the ten plant harvest and row harvest methods was found in the OH study (r=0.9741, p<0.0001) (Figure 4.10). The r^2 value was 0.95, meaning that 95% of the variation in the ten plant method could be explained by the row method.

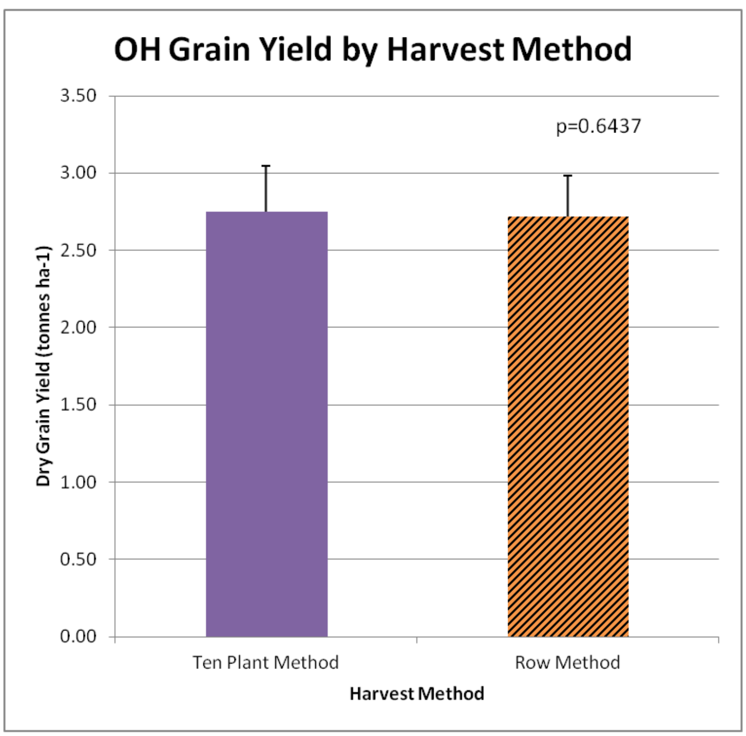

Figure 4.7. Comparison of OH grain yields using a ten plant and row method.

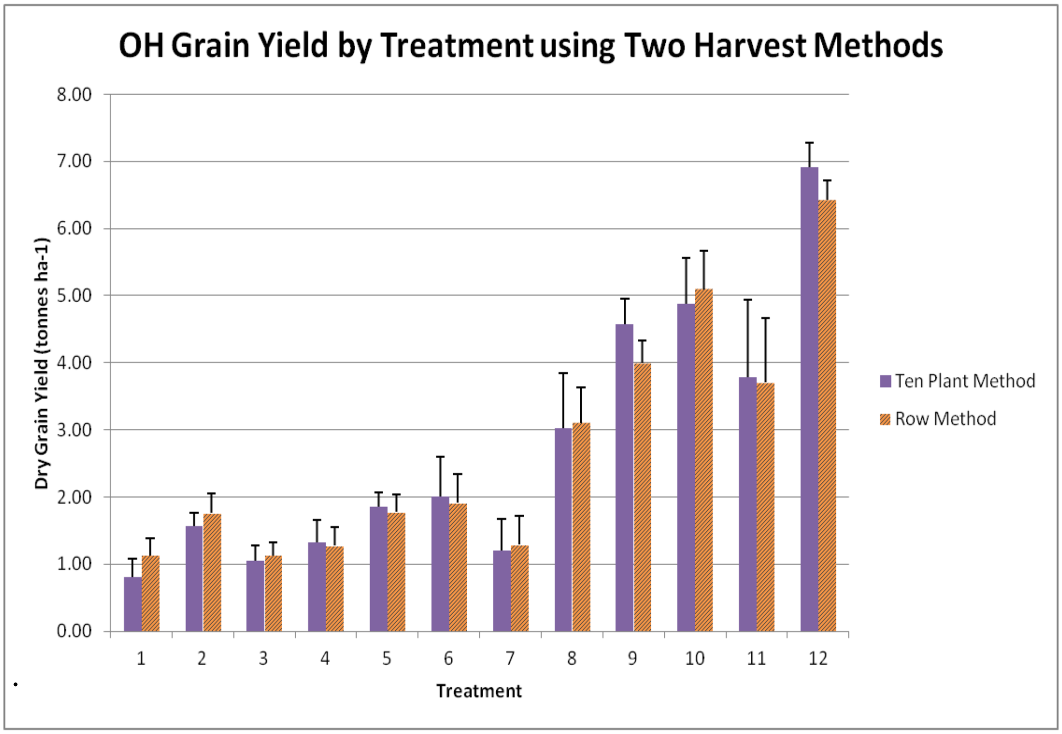

Figure 4.8. Comparison of OH grain yields using a ten plant and row harvest method, by treatment.

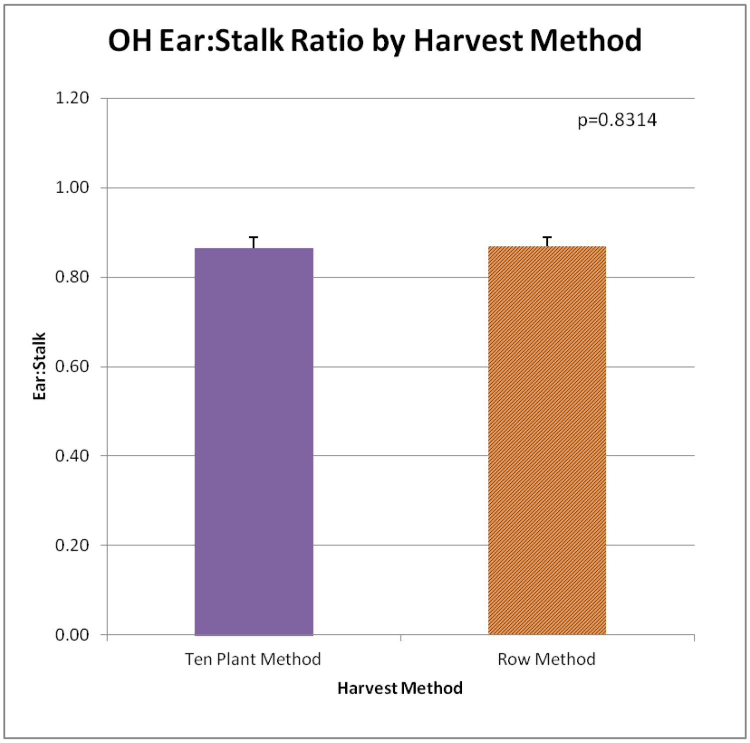

Figure 4.9. Comparison of OH ear:stalk ratios using a ten plant and row harvest method.

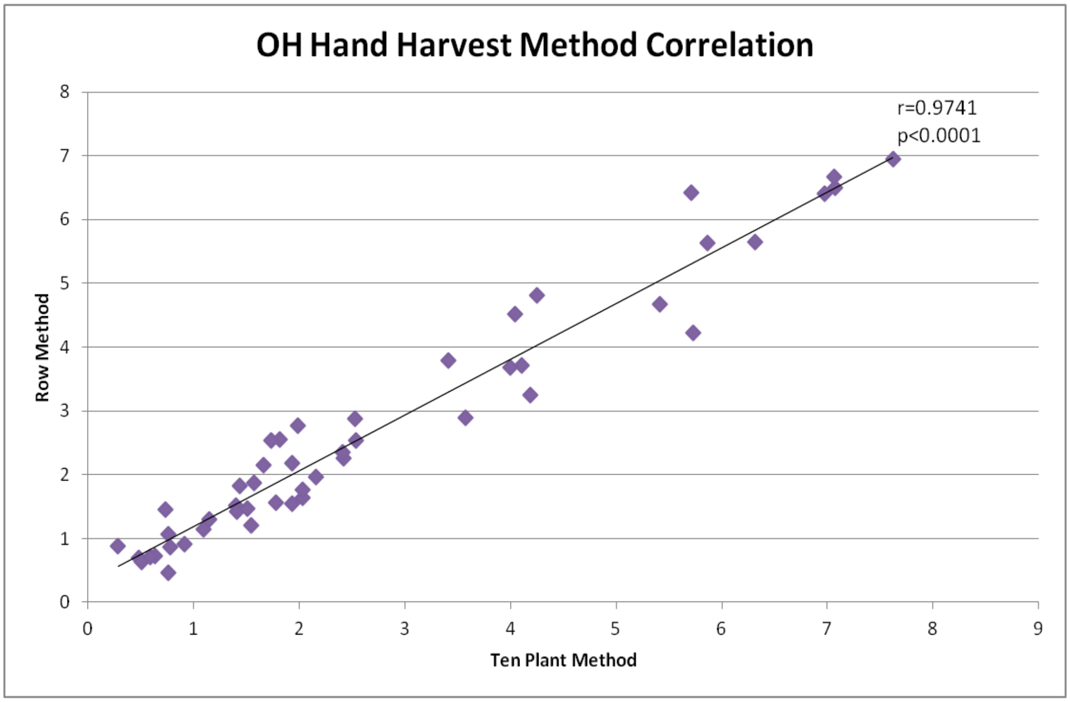

Figure 4.10. Correlation of hand harvest method yields in OH.

4. Conclusions

The results from these two studies indicate that the ten plant harvest method could be a viable alternative to more labor intensive hand harvest methods used for research. The accuracy of this method is largely affected by the plants selected, so it is important to ensure that the plants selected are randomly selected.

The ten plant method could be especially important for use in developing countries where research relies on efficient and inexpensive methods with reduced labor requirements. This method could be utilized for grain research in testing new agricultural technology or practices used to improve yields in smallholder agriculture.

The whole plot mechanical harvest data were compared to the hand harvest methods in the OH study, but the large difference in yields between the methods was not of concern due to

imprecision of the weigh wagon and large fluctuations in readings due to wind. More research is needed in order to compare a mechanical whole plot harvest to hand harvest methods. This research should be done using a more precise weigh wagon, and if possible, in a controlled environment or during weather where wind would not so heavily affect grain weight measurements.

Future research could expand harvest method comparisons to other crops commonly grown in developing countries where research on improving yields in smallholder agriculture is focused. In SSA, this research could be focused on decreasing harvest demands for research on cassava, sorghum, millet, and sweet potato.

The next step in this work is to create simulations to compare ten plant and row method yields under varying conditions, yields, and field spatial variation. This data will be used to compare the ten plant method to the row method further in order to determine whether it could be used as a replacement harvest method when time, labor, or harvesting resources are restricted.

References

Bruns, M. R. (2012). Optimizing maize planting date, plant population, and fertilizer application rates for Lesotho subsistence farmers (Master's thesis). Retrieved from http://trace.tennessee.edu/cgi/viewcontent.cgi?article=2307&context=utk_gradthes

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, *5*(3), 345-360.

Climate: Lenoir City (Climate graph, Temperature graph, Climate table) (n.d.). Retrieved from http://en.climate-data.org/location/137053/

Climate: Mount Gilead. (n.d.) Retrieved from http://en.climate-data.org/location/137083

Department of Economic and Social Affairs of the United Nations (DESA) (2014). A Concise Report on the World Population Situation in 2014. Retrieved from http://www.un.org/en/development/desa/population/publications/pdf/trends/Concise Report on the World Population Situation 2014/en.pdf

Elmore, R. W., Boyer, M. J., & Marlay, S. K. (2011). *Corn growth and development*. Iowa State University, University Extension.

FAO. (2010). FAO statistical database. Rome: Food and Agricultural Organization of the United Nations (FAO).

FAO (2015). Prepared by Dixon, J., Tanyeri-Abur, A, & Wattenbach, H. Smallholders, globalization, and policy analysis: framework for analyzing impacts of globalization on smallholders. Retrieved from http://www.fao.org/docrep/007/y5784e/y5784e02.htm

Kottek, M., J. Grieser, C. Beck, B. Rudolf, & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorol. Z.*, 15, 259-263. DOI: 10.1127/0941-2948/2006/0130. DOI: 10.1127/0941-2948/2006/0130.

Lauer, J. (2002). Methods for calculating corn yield. Agronomy Advice, University of Wisconsin-Madison. Retrieved from http://corn.agronomy.wisc.edu/AA/pdfs/A033.pdf

Lee, C. & Herbek, J. (2005). Estimating corn yields (AGR-187). University of Kentucky. Retrieved from http://www.ca.uky.edu/agc/pubs/agr/agr187/agr187.pdf.

Nielson, R. L. (2015). Estimating corn grain yield prior to harvest. Purdue University, Department of Agronomy. Retrieved from https://www.agry.purdue.edu/ext/corn/news/timeless/yldestmethod.html

Pidwirny, M. (2011). Moist Mid-latitude Climates with Mild Winters - C Climate Type. Retrieved from http://www.eoearth.org/view/article/162272

Pidwirny, M. (2011). Moist Continental Mid-latitude Climates - D Climate Type. Retrieved from http://www.eoearth.org/view/article/162285/

Population Reference Bureau (PRB) (2013). 2013 world population data sheet. Retrieved from http://www.prb.org/pdf13/2013-population-data-sheet_eng.pdf

Web Soil Survey (Web Soil Survey) (n.d.). Retrieved from http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Appendix

Appendix 4.1 Yield Calculations

Tennessee:

Ten Plant Method:

$$\frac{grain\ weight\ (g)}{\sim 10\ plants} * \frac{\#\ plants}{34.84\ ft} * \frac{43{,}560\ ft^2}{A} * \frac{}{2.5\ ft} * \frac{1\ t}{1{,}000{,}000\ g} * \frac{2.47\ A}{ha}$$

Row Method:

$$\frac{grain\ weight\ (g)}{row} * \frac{row}{34.84\ ft} * \frac{43{,}560\ ft^2}{A} * \frac{}{2.5\ ft} * \frac{1\ t}{1{,}000{,}000\ g} * \frac{2.47\ A}{ha}$$

Ohio:

Ten Plant Method:

$$\frac{grain\ weight\ (g)}{\sim 10\ plants} * \frac{\#\ plants}{17.45\ ft} * \frac{43{,}560\ ft^2}{A} * \frac{}{2.5\ ft} * \frac{1\ t}{1{,}000{,}000\ g} * \frac{2.47\ A}{ha}$$

Row Method:

$$\frac{grain\ weight\ (g)}{row} * \frac{row}{17.45\ ft} * \frac{43{,}560\ ft^2}{A} * \frac{}{2.5\ ft} * \frac{1\ t}{1{,}000{,}000\ g} * \frac{2.47\ A}{ha}$$

Whole Plot Method

$$\frac{grain\ weight\ (lb)}{plot} * \frac{plot}{900\ ft^2} * \frac{43{,}560\ ft^2}{A} * \frac{453.592\ g}{1\ lb} \frac{1\ t}{1{,}000{,}000\ g} * \frac{2.47\ A}{ha}$$

Moisture Correction:

$$\frac{grain\ weight\ (t)}{ha} * \frac{\left(1 - \left(\frac{measured\ moisture\ (\%)}{100}\right)\right)}{\left(1 - \left(\frac{15.5\%}{100}\right)\right)}$$

Appendix 4.2 Data

Table 4.1. TN Ten plant method yield measurements and calculations from September 17, 2015.

									Date: 9/17/2015
TN Ten Plant Harvest									
Plot	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Grain Weight (g plant-1)	Yield (t ha-1)	Grain Moisture (%)	**Yield (t ha-1) corrected for 15.5% moisture**
1 1	10	10	2228.00	195.50	2032.50	203.25	15.81	15.50	15.81
1 2	10	10	1939.50	90.00	1849.50	184.95	15.30	15.90	15.23
1 3	10	10	2061.00	209.00	1852.00	185.20	15.10	15.20	15.15
1 4	10	10	1859.50	199.50	1660.00	166.00	13.33	16.50	13.17
2 1	10	10	2129.50	189.50	1940.00	194.00	15.33	16.50	15.15
2 2	10	10	2146.00	198.00	1948.00	194.80	15.40	15.70	15.36
2 3	10	10	2239.00	218.00	2021.00	202.10	15.23	15.50	15.23
2 4	10	10	2106.50	208.00	1898.50	189.85	14.30	15.07	14.38
3 1	10	10	2372.50	230.00	2142.50	214.25	17.99	16.10	17.86
3 2	10	10	1939.00	196.50	1742.50	174.25	13.56	16.10	13.46
3 3	10	10	2377.50	234.50	2143.00	214.30	17.47	15.70	17.43
3 4	10	10	2119.00	249.00	1870.00	187.00	14.32	15.67	14.29
4 1	10	10	2114.00	204.00	1910.00	191.00	15.57	14.90	15.68
4 2	10	10	2192.00	207.00	1985.00	198.50	14.71	15.10	14.78
4 3	10	10	2063.50	205.00	1858.50	185.85	14.69	15.60	14.67
4 4	10	10	2351.50	234.00	2117.50	211.75	15.69	15.93	15.61
5 1	10	10	2143.50	202.50	1941.00	194.10	14.38	14.60	14.54
5 2	10	10	2360.00	222.00	2138.00	213.80	17.43	15.90	17.34
5 3	10	10	1996.00	194.50	1801.50	180.15	13.57	15.30	13.60
5 4	10	10	1865.50	199.50	1666.00	166.60	13.79	14.80	13.90
6 1	10	10	2122.00	212.00	1910.00	191.00	16.04	14.70	16.19
6 2	10	11	2026.50	247.00	1779.50	177.95	15.16	15.43	15.18
6 3	10	10	2391.00	227.00	2164.00	216.40	15.77	15.83	15.71
6 4	10	10	2335.00	238.50	2096.50	209.65	16.57	15.20	16.63

Table 4.2. TN row method yield measurements and calculations from September 17, 2015.

														Date: 9/17/2015
TN Row Harvest without Ten Plants							TN Row Harvest with Ten Plants							
Plot	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Grain Moisture (%)	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Yield (T ha-1)	Grain Moisture (%)	**Yield (t ha-1) corrected for 15.5% moisture**
1 1	63	49	10284.00	889.00	9395.00	14.10	63	59	12512.00	1084.50	11427.50	14.12	14.10	14.35
1 2	67	57	12054.00	1076.00	10978.00	14.20	67	67	13993.50	1166.00	12827.50	15.85	14.20	16.09
1 3	66	49	9752.00	924.00	8828.00	13.47	66	59	11813.00	1133.00	10680.00	13.20	13.47	13.51
1 4	65	55	9521.00	995.50	8525.50	14.23	65	65	11380.50	1195.00	10185.50	12.58	14.23	12.77
2 1	64	54	10151.00	910.00	9241.00	14.40	64	64	12280.50	1099.50	11181.00	13.81	14.40	13.99
2 2	64	53	11576.00	1096.00	10480.00	14.20	64	63	13722.00	1294.00	12428.00	15.35	14.20	15.59
2 3	61	51	10819.00	1048.00	9771.00	13.47	61	61	13058.00	1266.00	11792.00	14.57	13.47	14.92
2 4	61	50	10209.00	1053.00	9156.00	14.10	61	60	12315.50	1261.00	11054.50	13.66	14.10	13.88
3 1	68	55	11193.00	1023.00	10170.00	14.30	68	65	13565.50	1253.00	12312.50	15.21	14.30	15.43
3 2	63	52	11003.00	1023.00	9980.00	14.43	63	62	12942.00	1219.50	11722.50	14.48	14.43	14.67
3 3	66	54	12173.00	1161.00	11012.00	13.97	66	64	14550.50	1395.50	13155.00	16.25	13.97	16.55
3 4	62	48	10038.00	1035.00	9003.00	14.47	62	58	12157.00	1284.00	10873.00	13.43	14.47	13.60
4 1	66	51	10932.00	1038.00	9894.00	14.23	66	61	13046.00	1242.00	11804.00	14.58	14.23	14.80
4 2	60	47	10310.00	1021.00	9289.00	14.03	60	57	12502.00	1228.00	11274.00	13.93	14.03	14.17
4 3	64	46	9453.00	923.00	8530.00	14.27	64	56	11516.50	1128.00	10388.50	12.83	14.27	13.02
4 4	60	52	11351.00	1154.00	10197.00	13.90	60	62	13702.50	1388.00	12314.50	15.21	13.90	15.50
5 1	60	50	9456.00	911.00	8545.00	13.57	60	60	11599.50	1113.50	10486.00	12.96	13.57	13.25
5 2	66	54	10943.00	1011.00	9932.00	14.60	66	64	13303.00	1233.00	12070.00	14.91	14.60	15.07
5 3	61	45	9031.00	900.00	8131.00	14.03	61	55	11027.00	1094.50	9932.50	12.27	14.03	12.49
5 4	67	57	11841.00	1142.00	10699.00	14.53	67	67	13706.50	1341.50	12365.00	15.28	14.53	15.45
6 1	68	55	11369.00	1034.00	10335.00	14.17	68	65	13491.00	1246.00	12245.00	15.13	14.17	15.37
6 2	69	59	11627.00	1143.00	10484.00	14.43	69	70	13653.50	1390.00	12263.50	15.15	14.43	15.34
6 3	59	45	10250.00	1036.00	9214.00	13.97	59	55	12641.00	1263.00	11378.00	14.06	13.97	14.31
6 4	64	50	11181.00	1076.00	10105.00	14.27	64	60	13516.00	1314.50	12201.50	15.07	14.27	15.29

Table 4.3. OH Ten plant method yield measurements and calculations from October 22, 2015.

								Date: 10/22/2015
OH Ten Plant Harvest								
Plot	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Grain Weight (g plant-1)	Yield (t ha-1)	**Yield (t ha-1) corrected for 15.5% moisture**
NT 0 1	10	9	119.29	17.08	102.21	10.22	0.73	**0.758**
NT 0 2	10	10	232.22	39.63	192.59	19.26	1.52	**1.578**
NT 0 3	10	5	60.17	14.09	46.08	4.61	0.27	**0.283**
NT 0 4	10	3	118.23	19.31	98.92	9.89	0.61	**0.633**
NT 25 1	10	9	228.85	38.08	190.77	19.08	1.37	**1.404**
NT 25 2	10	4	79.43	14.27	65.16	6.52	0.47	**0.480**
NT 25 3	10	8	198.15	30.31	167.84	16.78	1.37	**1.409**
NT 25 4	10	7	161.37	28.57	132.8	13.28	0.89	**0.911**
NT 50 1	10	10	362.81	49.26	313.55	31.36	2.32	**2.418**
NT 50 2	10	7	213.26	34.43	178.83	17.88	1.46	**1.513**
NT 50 3	10	11	251.54	42.26	209.28	20.93	1.50	**1.545**
NT 50 4	10	9	265.88	44.73	221.15	22.12	1.86	**1.930**
NT 100 1	10	6	164.09	24.15	139.94	13.99	1.11	**1.149**
NT 100 2	10	9	389.04	69.82	319.22	31.92	2.44	**2.537**
NT 100 3	10	6	93.35	17.15	76.2	7.62	0.49	**0.508**
NT 100 4	10	6	113.63	25.37	88.26	8.83	0.57	**0.589**
NT 200 1	10	10	888.58	132.62	755.96	75.60	5.60	**5.730**
NT 200 2	10	10	628.42	96.29	532.13	53.21	4.07	**4.190**
NT 200 3	10	10	612.88	103.75	509.13	50.91	4.02	**4.105**
NT 200 4	10	10	658.56	103.51	555.05	55.51	4.11	**4.253**
NT 400 1	10	10	1126.38	164.51	961.87	96.19	6.89	**6.977**
NT 400 2	10	9	635.61	102.12	533.49	53.35	3.95	**3.999**
NT 400 3	10	6	341.37	54.89	286.48	28.65	1.98	**1.988**
NT 400 4	10	9	319.29	53.15	266.14	26.61	2.10	**2.161**
T 0 1	10	9	311.94	53.69	258.25	25.83	1.79	**1.819**
T 0 2	10	9	180.56	26	154.56	15.46	1.07	**1.095**
T 0 3	10	10	358.98	53.92	305.06	30.51	1.88	**1.933**
T 0 4	10	9	256.77	38.69	218.08	21.81	1.40	**1.441**
T 25 1	10	10	266.28	38.76	227.52	22.75	1.74	**1.777**
T 25 2	10	8	166.21	30.09	136.12	13.61	0.74	**0.758**
T 25 3	10	10	296.37	46.83	249.54	24.95	1.97	**2.031**
T 25 4	10	8	109.12	18.29	90.83	9.08	0.72	**0.737**
T 50 1	10	9	273.01	47.9	225.11	22.51	1.61	**1.660**
T 50 2	10	8	169.17	35.18	133.99	13.40	0.76	**0.782**
T 50 3	10	8	302.24	44.74	257.5	25.75	1.97	**2.029**
T 50 4	10	10	575.46	87.55	487.91	48.79	3.49	**3.579**
T 100 1	10	9	406.75	78.17	328.58	32.86	2.35	**2.416**
T 100 2	10	10	983.31	148.22	835.09	83.51	5.36	**5.416**
T 100 3	10	8	273.46	45.88	227.58	22.76	1.69	**1.738**
T 100 4	10	8	370	59.58	310.42	31.04	2.45	**2.527**
T 200 1	10	9	522.15	83.65	438.5	43.85	3.36	**3.417**
T 200 2	10	10	675.52	101.33	574.19	57.42	3.97	**4.045**
T 200 3	10	10	969.54	141.55	827.99	82.80	6.34	**6.315**
T 200 4	10	10	896	138.95	757.05	75.71	5.61	**5.716**
T 400 1	10	10	1058.22	150.1	908.12	90.81	7.18	**7.076**
T 400 2	10	10	1377.68	193.16	1184.52	118.45	7.02	**7.069**
T 400 3	10	10	1263.08	178.63	1084.45	108.45	7.50	**7.622**
T 400 4	10	10	837.46	124.22	713.24	71.32	5.81	**5.869**

Table 4.4. OH row method yield measurements and calculations from October 22, 2015.

													Date: 10/22/2015
	OH Row Harvest without Ten Plants					OH Row Harvest with Ten Plants							
Plot	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Stalk Count	Ear Count	Ear Weight (g)	Cob Weight (g)	Grain Weight (g)	Yield (t ha-1)	Grain Moisture %	**Yield (t ha-1) corrected for 15.5% moisture**
NT 0 1	29	16	360.26	46.32	313.94	29	25	479.55	63.4	416.15	1.02789	12.53	**1.064**
NT 0 2	32	20	610.48	76.76	533.72	32	30	842.7	116.39	726.31	1.79399	12.43	**1.859**
NT 0 3	24	15	363.5	67.83	295.67	24	20	423.67	81.92	341.75	0.84412	12.48	**0.874**
NT 0 4	25	6	199.95	17.36	182.59	25	9	318.18	36.67	281.51	0.69533	12.48	**0.720**
NT 25 1	29	15	474.62	72.18	402.44	29	24	703.47	110.26	593.21	1.46523	13.20	**1.505**
NT 25 2	29	15	252.7	49.03	203.67	29	19	332.13	63.3	268.83	0.66401	13.10	**0.683**
NT 25 3	33	20	464.5	74.23	390.27	33	28	662.65	104.54	558.11	1.37853	13.00	**1.419**
NT 25 4	27	15	295.37	70.62	224.75	27	22	456.74	99.19	357.55	0.88315	13.10	**0.908**
NT 50 1	30	19	679.55	115.5	564.05	30	29	1042.36	164.76	877.6	2.16767	12.07	**2.256**
NT 50 2	33	16	471.43	80.33	391.1	33	23	684.69	114.76	569.93	1.40773	12.30	**1.461**
NT 50 3	29	14	315.18	53.96	261.22	29	25	566.72	96.22	470.5	1.16214	12.90	**1.198**
NT 50 4	34	19	728.29	102.19	626.1	34	28	994.17	146.92	847.25	2.09271	12.17	**2.175**
NT 100 1	32	16	430.41	69.07	361.34	32	22	594.5	93.22	501.28	1.23816	12.20	**1.287**
NT 100 2	31	16	806.05	139.04	667.01	31	25	1195.09	208.86	986.23	2.43599	12.30	**2.528**
NT 100 3	26	11	200.67	31.16	169.51	26	17	294.02	48.31	245.71	0.6069	12.25	**0.630**
NT 100 4	26	8	221.9	37.54	184.36	26	14	335.53	62.91	272.62	0.67337	12.25	**0.699**
NT 200 1	30	16	1068.07	153.29	914.78	30	26	1956.65	285.91	1670.74	4.12673	13.57	**4.221**
NT 200 2	31	20	885.42	138.65	746.77	31	30	1513.84	234.94	1278.9	3.15888	13.10	**3.249**
NT 200 3	32	21	1139.18	174.3	964.88	32	31	1752.06	278.05	1474.01	3.6408	13.80	**3.714**
NT 200 4	30	19	1572.95	246.87	1326.08	30	29	2231.51	350.38	1881.13	4.64639	12.63	**4.804**
NT 400 1	29	19	1876.72	276.88	1599.84	29	29	3003.1	441.39	2561.71	6.32742	14.43	**6.408**
NT 400 2	30	19	1117.43	177.45	939.98	30	28	1753.04	279.57	1473.47	3.63947	14.53	**3.681**
NT 400 3	28	19	984.08	153.08	831	28	25	1325.45	207.97	1117.48	2.76018	15.20	**2.770**
NT 400 4	32	16	613.25	108.02	505.23	32	25	932.54	161.17	771.37	1.90528	13.20	**1.957**
T 0 1	28	18	877.8	124.52	753.28	28	27	1189.74	178.21	1011.53	2.49848	13.93	**2.545**
T 0 2	28	15	346.34	51.07	295.27	28	24	526.9	77.07	449.83	1.11108	13.42	**1.138**
T 0 3	25	12	358.08	52.76	305.32	25	22	717.06	106.68	610.38	1.50764	13.30	**1.547**
T 0 4	26	15	560.86	61.93	498.93	26	24	817.63	100.62	717.01	1.77101	13.03	**1.823**
T 25 1	31	18	471.73	81.38	390.35	31	28	738.01	120.14	617.87	1.52614	13.83	**1.556**
T 25 2	22	7	60.82	15.47	45.35	22	15	227.03	45.56	181.47	0.44823	13.38	**0.459**
T 25 3	32	20	464.5	74.23	390.27	32	30	760.87	121.06	639.81	1.58033	13.00	**1.627**
T 25 4	32	21	574.22	95.1	479.12	32	29	683.34	113.39	569.95	1.40778	13.30	**1.444**
T 50 1	29	18	733.5	112.86	620.64	29	27	1006.51	160.76	845.75	2.089	13.00	**2.151**
T 50 2	23	13	250.62	45.26	205.36	23	21	419.79	80.44	339.35	0.83819	13.17	**0.861**
T 50 3	31	17	508.04	74.7	433.34	31	25	810.28	119.44	690.84	1.70637	13.06	**1.756**
T 50 4	29	16	771.64	117.57	654.07	29	26	1347.1	205.12	1141.98	2.82069	13.46	**2.889**
T 100 1	29	17	721.31	125.2	596.11	29	26	1128.06	203.37	924.69	2.28398	13.27	**2.344**
T 100 2	26	15	1225.82	192.95	1032.87	26	25	2209.13	341.17	1867.96	4.61386	14.67	**4.659**
T 100 3	30	20	905.21	136.54	768.67	30	28	1178.67	182.42	996.25	2.46074	12.90	**2.536**
T 100 4	32	22	972.84	154.19	818.65	32	30	1342.84	213.77	1129.07	2.7888	12.97	**2.872**
T 200 1	31	21	1264.19	194.57	1069.62	31	30	1786.34	278.22	1508.12	3.72506	14.00	**3.791**
T 200 2	28	18	1432.54	211.59	1220.95	28	28	2108.06	312.92	1795.14	4.434	13.93	**4.516**
T 200 3	31	20	1709.04	245.42	1463.62	31	30	2678.58	386.97	2291.61	5.66028	15.83	**5.638**
T 200 4	30	20	2114.81	321.85	1792.96	30	30	3010.81	460.8	2550.01	6.29852	13.90	**6.418**
T 400 1	32	22	2047.01	291.4	1755.61	32	32	3105.23	441.5	2663.73	6.57941	16.70	**6.486**
T 400 2	24	14	1735.62	243.34	1492.28	24	24	3113.3	436.5	2676.8	6.6117	14.93	**6.656**
T 400 3	28	18	1960.77	280	1680.77	28	28	3223.85	458.63	2765.22	6.83009	14.13	**6.941**
T 400 4	33	21	1817.69	275.71	1541.98	33	31	2655.15	399.93	2255.22	5.57039	14.70	**5.623**

Table 4.5. OH whole plot method yield measurements and calculations from October 22, 2015.

					Date: 10/22/2015
Ohio Combine Harvest with Weigh Wagon (goes down to 2 lb)					
Plot	Weigh Wagon Grain Weight (lb)	Grain Weight (lb plot-1)	Grain Weight (lb A-1)	Yield (t ha-1)	**Yield (t ha-1) corrected for 15.5% moisture**
NT 0 1	0	0.92	44.40	0.05	**0.052**
NT 0 2	0	1.60	77.50	0.09	**0.090**
NT 0 3	2	2.75	133.27	0.15	**0.155**
NT 0 4	0	0.62	30.04	0.03	**0.035**
NT 25 1	16	17.31	837.70	0.94	**0.966**
NT 25 2	2	2.59	125.49	0.14	**0.145**
NT 25 3	2	3.23	156.35	0.18	**0.181**
NT 25 4	0	0.79	38.15	0.04	**0.044**
NT 50 1	26	27.93	1352.04	1.52	**1.580**
NT 50 2	2	3.26	157.61	0.18	**0.184**
NT 50 3	2	3.04	147.00	0.17	**0.170**
NT 50 4	12	13.87	671.20	0.75	**0.784**
NT 100 1	14	15.11	731.09	0.82	**0.853**
NT 100 2	38	40.17	1944.43	2.18	**2.267**
NT 100 3	2	2.54	123.02	0.14	**0.143**
NT 100 4	2	2.60	125.89	0.14	**0.147**
NT 200 1	36	39.68	1920.67	2.16	**2.207**
NT 200 2	34	36.82	1782.06	2.00	**2.058**
NT 200 3	50	53.25	2577.28	2.89	**2.953**
NT 200 4	38	42.15	2039.92	2.29	**2.369**
NT 400 1	30	35.65	1725.34	1.94	**1.962**
NT 400 2	48	51.25	2480.42	2.79	**2.818**
NT 400 3	64	66.46	3216.84	3.61	**3.626**
NT 400 4	42	43.70	2115.11	2.38	**2.440**
T 0 1	20	22.23	1075.93	1.21	**1.231**
T 0 2	2	2.99	144.80	0.16	**0.167**
T 0 3	6	7.35	355.53	0.40	**0.410**
T 0 4	2	3.58	173.31	0.19	**0.200**
T 25 1	26	27.36	1324.33	1.49	**1.517**
T 25 2	12	12.40	600.16	0.67	**0.691**
T 25 3	2	3.41	165.07	0.19	**0.191**
T 25 4	16	17.26	835.22	0.94	**0.963**
T 50 1	14	15.86	767.84	0.86	**0.888**
T 50 2	16	16.75	810.61	0.91	**0.936**
T 50 3	16	17.52	848.12	0.95	**0.980**
T 50 4	28	30.52	1477.05	1.66	**1.699**
T 100 1	46	48.04	2325.07	2.61	**2.680**
T 100 2	24	28.12	1360.92	1.53	**1.544**
T 100 3	16	18.20	880.70	0.99	**1.020**
T 100 4	38	40.49	1959.68	2.20	**2.267**
T 200 1	62	65.32	3161.72	3.55	**3.614**
T 200 2	80	83.96	4063.55	4.56	**4.649**
T 200 3	80	85.05	4116.52	4.62	**4.606**
T 200 4	62	67.62	3272.90	3.68	**3.746**
T 400 1	112	117.87	5705.03	6.41	**6.317**
T 400 2	92	97.90	4738.42	5.32	**5.358**
T 400 3	68	74.10	3586.26	4.03	**4.093**
T 400 4	64	68.97	3338.24	3.75	**3.785**

Table 4.6. Ear:stalk ratios for hand harvest methods in TN (September 17, 2015) and OH (October 22, 2015).

		Tennessee		Ohio	
Treatment	**Rep**	10 Plant Ear:Stalk	Row Ear: Stalk	10 Plant Ear:Stalk	Row Ear:Stalk
1	1	1.00	0.94	0.90	0.86
1	2	1.00	1.00	1.00	0.94
1	3	1.00	0.89	0.50	0.83
1	4	1.00	1.00	0.30	0.36
2	1	1.00	1.00	0.90	0.83
2	2	1.00	0.98	0.40	0.66
2	3	1.00	1.00	0.80	0.85
2	4	1.00	0.98	0.70	0.81
3	1	1.00	0.96	1.00	0.97
3	2	1.00	0.98	0.70	0.70
3	3	1.00	0.97	1.10	0.86
3	4	1.00	0.94	0.90	0.82
4	1	1.00	0.92	0.60	0.69
4	2	1.00	0.95	0.90	0.81
4	3	1.00	0.88	0.60	0.65
4	4	1.00	1.03	0.60	0.54
5	1	1.00	1.00	1.00	0.87
5	2	1.00	0.97	1.00	0.97
5	3	1.00	0.90	1.00	0.97
5	4	1.00	1.00	1.00	0.97
6	1	1.00	0.96	1.00	1.00
6	2	1.10	1.01	0.90	0.93
6	3	1.00	0.93	0.60	0.89
6	4	1.00	0.94	0.90	0.78
7	1			0.90	0.96
7	2			0.90	0.86
7	3			1.00	0.88
7	4			0.90	0.92
8	1			1.00	0.90
8	2			0.80	0.68
8	3			1.00	0.94
8	4			0.80	0.91
9	1			0.90	0.93
9	2			0.80	0.91
9	3			0.80	0.81
9	4			1.00	0.90
10	1			0.90	0.90
10	2			1.00	0.96
10	3			0.80	0.93
10	4			0.80	0.94
11	1			0.90	0.97
11	2			1.00	1.00
11	3			1.00	0.97
11	4			1.00	1.00
12	1			1.00	1.00
12	2			1.00	1.00
12	3			1.00	1.00
12	4			1.00	0.94
Mean		**1.01**	**0.97**	**0.86**	**0.87**

Chapter 5
Conclusions

The majority of our current global food production methods are completed using practices that degrade soil, decrease on-farm fertility, and pollute the environment. As the global population continues to increase, it is imperative that these destructive practices are replaced with more sustainable implementations that focus on improving soil fertility and resource use efficiency for use by future generations. This can be done by improving farm management practices by using those that conserve soil and build fertility, and by finding alternative methods of fertilizing and reusing waste materials in agriculture.

Tillage is the predominant soil management practice used in seedbed preparation, but results in a devastating amount of soil lost to erosion every year. No-till is an alternate soil management practice which improves soil structure, infiltration, porosity, biodiversity, and fertility when compared to tillage, but the application of no-till is still underutilized in the U.S. and elsewhere. No-till allows the buildup of SOM and preserves soil nutrients such as C and N in micropores, protecting them from microbial access and decomposition.

The research in this thesis examined the amount of soil N preserved by no-till by tilling a seven year no-till field and comparing it to a still untilled portion of the field. The tilled plots resulted in the release of built up organic matter and N for use by microbes and transformation into plant available forms, causing increased plant N uptake and greater yields when compared to the no-till plots. No-till has been found to improve yields when compared to tillage during dry years due to greater soil water conservation, but in very wet years a loss of yield may occur, as was the case in Ohio during the year this study was preformed.

The current methods of plant N fertilization rely heavily on chemical fertilizer use, which make up a significant portion of farm input costs and can cause environmental degradation when lost to ground or surface waters. Soil fertility could instead be improved using available waste

products from local industries at reduced costs, benefitting both the farmer and company producing the waste.

At DuPont Tate and Lyle, LLC, in Loudon TN, close to 20 million T of SMB are produced annually and disposed of in landfills at a significant cost to the producer. A study included in this thesis found that SMB could provide equivalent amounts of N to corn in East Tennessee when compared to the current farmer urea application rate. SMB treated plots produced similar yields to those treated with fertilizer, and this research implicates that SMB could serve as a sufficient N source. The replacement of N fertilizers with SMB could also improve local environmental quality, as the slow-release characteristics of the byproduct could cause decreased transport of N to surface and groundwater sources.

Through research and analysis, the global use of sustainable practices can be increased. In order to make the necessary improvements in agricultural management, this research must be completed with precision and efficiency. To improve methods of corn research by decreasing the required labor and time resources to harvest the crops at the end of the growing season, a ten-plant hand harvest method was compared to the currently accepted hand harvest method. The ten plant method, when preformed on a representative population of plants in the plot, performs well compared to the current method and could be used as a replacement harvest method in areas with low labor or mechanical resource availability for harvesting.

Vita

Casey was born in Medford, Massachusetts in 1990. She received a Bachelor of Science Degree in Environmental and Soil Science in 2013 from the University of Tennessee, Knoxville.