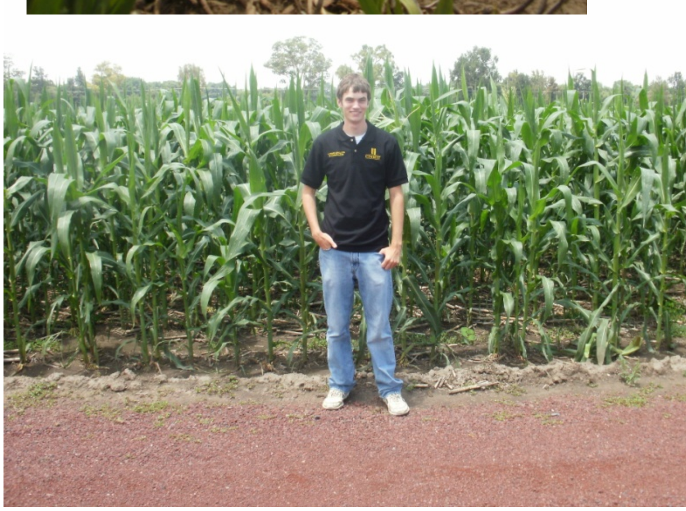
A MEXICAN ADVENTURE

Conservation Agriculture at the International Maize and Wheat Improvement Center

El Batán, México



Adam Riesselman

Manilla, Iowa

Ar-We-Va High School

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Thank you.

1.1 A Young Agriculturalist from Iowa

I am used to the roar of the tractor as it passes over the loamy, dark soil, planting sixteen rows of maize in a single pass. I am used to endless fields of maize and soybeans, seemingly uniform and unobstructed for miles. I am used to the perpetually bountiful harvests that are too large for the grain bins and must be stored on the ground through the bitter cold of winter. Growing up on a family farm has given me a unique opportunity to see the inner workings of agriculture in Iowa, where grain is produced on an industrial scale. I was under the impression that agriculture is easy. One simply runs the machine over the field and in a couple of months, the combine harvests the crop and it is easily stored in a large, electronically monitored bin. That was agriculture, to me.

I came to the International Maize and Wheat Improvement Center (CIMMYT) on May 19, 2010, on the pretense that agriculture is the same everywhere. Yes, other nations may not have such large machines or produce grain on an enormous scale, but the fundamentals are shared. Farming is farming.

In my first days at CIMMYT, I experienced agriculture in a whole new light. The din of the tractor was the same and the smell of the burning diesel brought back nostalgic memories of helping my father on the family farm, but things were different this time. I saw machinery only planting two rows of maize in one pass. I witnessed the planter cutting into raised rows of soil, called planting beds, where the nascent plant would soon grow and develop. I heard the calls of Mexican farm workers in Spanish to adjust the planting wheel or jump on the planter to add weight. This, this farming was new.

I have always been interested in agriculture, especially the plant sciences; I have worked on our family farm of two-hundred forty acres my entire life, helping my father and uncles with planting, crop monitoring, and harvest. I am familiar with the different types of machinery, the types of input required in agriculture, and the different daily tasks necessary to run a successful farm. On our farm near Manilla, Iowa, we have been practicing zero tillage farming for over ten years, but the technology has been in our area for much longer. I have become aware of these Conservation Agriculture practices slowly through my studies in and out of school.

In high school, I took part in Envirothon competitions, where students are challenged with questions of environmental problems and solutions, and many pertain to agricultural impacts. Outside of school while working with my father, I have witnessed yield drop because of soil quality loss and erosion due to malpractice on once-productive farmland. I have also intensely studied the native prairie ecosystem of Iowa and am aware of the benefits different plants can have on soil quality. This soil health is essential to feeding the hungry of the world.

When a teacher approached me with an opportunity to attend the World Food Prize Youth Institute in 2006—my sophomore year—I was thrilled to have the opportunity to learn more about the issues that press on global hunger. After attending the institute, my eyes were opened to the hungry masses of the world, and a passion to learn more was sparked. I applied for the Borlaug-Ruan Internship but was not called back for an interview because I was too young.

In 2009—my senior year—I again attended the Youth Institute and was once again amazed by the work being done to alleviate hunger. I listened to the testimonies from the past year's interns and marveled at their wonderful experiences. I challenged myself to apply for the internship and was called back for an interview. I was truly excited to travel to another nation to experience another face of agriculture. During the interview, I stated that it was not important whether I worked in the lab or in the field and I told of my prior agricultural experience. A few weeks later, I was notified that I would be working at the International Maize and Wheat Improvement Center (CIMMYT) with the Conservation Agriculture program.

Upon arrival and working in this field of study, my past agricultural experience was extremely useful and gave me a tremendous head start. I was already familiar with the planting and crop monitoring process. I knew about agricultural machinery, their uses, and how they can be improved. I have previously experienced conservation agriculture technologies—zero tillage, residue retention, and crop rotation—in my home farming system. With this knowledge, my placement in the Conservation Agriculture department was extremely well suited and extremely beneficial.

During the eight weeks, my work at CIMMYT gave me an entirely new perspective of agriculture. I have come to appreciate CIMMYT's commitment to helping smallholder farmers produce food and lift them out of poverty. This great institution has provided countless agricultural breakthroughs over its fascinating history, and I am proud to forever be a part of the CIMMYT family.

1.2 The History of CIMMYT

The International Maize and Wheat Improvement Center--or CIMMYT, derived from the Spanish acronym Centro International de Mejoramiento de Maiz Y Trigo--was created in the first global effort to eradicate hunger and improve food security by increasing crop yields. Starting in the 1940s, the American and Mexican government worked together to create a coalition that would increase agricultural production in Mexico. Dubbed the Office of Special Studies (OSS) in 1943, scientists affiliated with this organization worked to improve wheat, maize, and beans with the financial support drawn from the Mexican and American government. United States Vice President-elect George Wallace arranged leading scientists to access the declining food production and potential for success in the former food insecure state. As the program grew, OSS hired Norman Borlaug, the soon to be infamous wheat breeder credited for starting the Green Revolution and saving more lives than anyone in human history.

Under the direction of Norman Borlaug, wheat breeders in OSS applied two burgeoning scientific techniques to tackle wheat rust and improve wheat production: shuttle breeding and introduction of dwarf wheat varieties. The process of breeding wheat one season in the dry, hot, irrigated conditions of Ciudad Obregón and shipping the seed to the wet, cooler, rainfed conditions of Toluca proved to be extremely successful; not only were two breeding opportunities available in one year, but the wheat was adapted to almost any climatic condition or environmental stress. Though Borlaug and Mexican farmers rejoiced that these varieties were resistant to rust, lodging of the tall plants became a problem. Borlaug then bred the plants with a dwarf variety resistant to falling over; the result led to wheat plants that expended less energy on producing tall plant bodies and more energy on developing the edible seed. Soon enough, Norman Borlaug had bred the most productive, adaptable, and revolutionary wheat plant to date.

And this technology spread throughout the world. With the help of international scientists, this advanced seed spread to India, Pakistan, and many other developing nations, changing the face of agriculture for billions worldwide. Such technology allowed these countries to become self-sufficient in grain, removing millions from poverty, famine, and hunger.

Inspired by the success of this program, organizations within Mexico and others like the Rockefeller and Ford Foundation funded the creation of an institution that would allow crop breeders to collaborate and share germplasm to increase research potential. Started in 1963 and fully operational in 1966, CIMMYT provided a catalyst for scientific research in maize and wheat.

CIMMYT has grown into a massive network of research stations around the world, crossing cultural borders to reach nations such as Mexico, Turkey, India, China, Iran, Georgia, Kenya, Zimbabwe, and an ever growing list of others ready to help their farmers reach their potential. These institutions facilitate in the exchange of information, allowing new ideas and conclusions to percolate to the smallholder farmer.

1.3 Conservation Agriculture: Sustainability for the Future

Along with maize and wheat improvement programs, CIMMYT also houses the Conservation Agriculture (CA) program. This revolutionary system of agriculture uses a variety of tillage and cropping practices to reduce costs and inputs to increase yield and income.

The Conservation Agriculture program holds a five week course teaching the tenets of this technology each year at the beginning of the planting season in Central Mexico. I was fortunate emough to participate in the course with scientists around the world to learn about this system of agriculture. In the process, the group listened to presentations from scientists in all ranges of crop sciences, went out to the field to get a hands-on experience to field machinery calibration, and traveled to agricultural information stations around Mexico to see CA technologies in a real world setting. In our education, the three principles of Conservation Agriculture were introduced and elaborated on extensively: reduction of tillage, retention of crop residues, and proper crop rotation.

Normal agricultural practices in the highlands of Mexico are maize-maize rotation systems, removing residues, and tilling the soil to provide a soft bed for the seed. By implementing CA practices, rotating crops—especially using an alternation of maize and wheat—can allow the utilization of multiple nutrients and the addition of different organic matter to the soil. The retention of residues acts on natural principles of soil ecology to increase soil organic matter by allowing the carbon-rich residues to break up slowly and incorporate into the soil profile. By eliminating tillage as well, biological activity in the soil increases, infiltration improves, soil erosion decreases, and many pest and disease problems are reduced as well. The retention of residue on the soil surface protects the soil from raindrop impact, preventing soil surface sealing and allows more water to infiltrate. It also reduces evaporation, resulting in more plant-available water.

These CA-practices would not be available to the smallholder farmer without a myriad of other technologies and implementation techniques: hub management, environmental protection, machinery efficiency, and economic appeal.

The research and technology generated by scientists in the field of Conservation Agriculture would be useless unless they were accessible to the average farmer living far away from normal research stations. Even then, scientists need ideas to work with in the lab or in research plots. Thus the hub concept of Conservation Agriculture is used. Scientists, agronomists, and farmers bring the best of their practices to the table and everyone shares ideas. With this, the best practices are spread to the people that need it most using hubs.

Conservation Agriculture is also a more environmentally conscious agricultural practice than conventional farming. By utilizing crop rotation, residue retention, and tillage reduction, soil health and quality is substantially improved. Erosion by wind and water is reduced as well, protecting the earth for years of sustainable agricultural production.

The idea of “multi-use/multi-purpose machinery” is constantly intertwined with the ideology of CA. Proponents in the field are trying more efficient and cost effective ways to create a machine that will be able to reshape planting beds, fertilize, plant, cut the furrow, cover the seed, and apply granular pesticide. By utilizing one machine to its full extent, farmers need to only buy one machine to work the entire operation, putting CA in the grasp of smallholders.

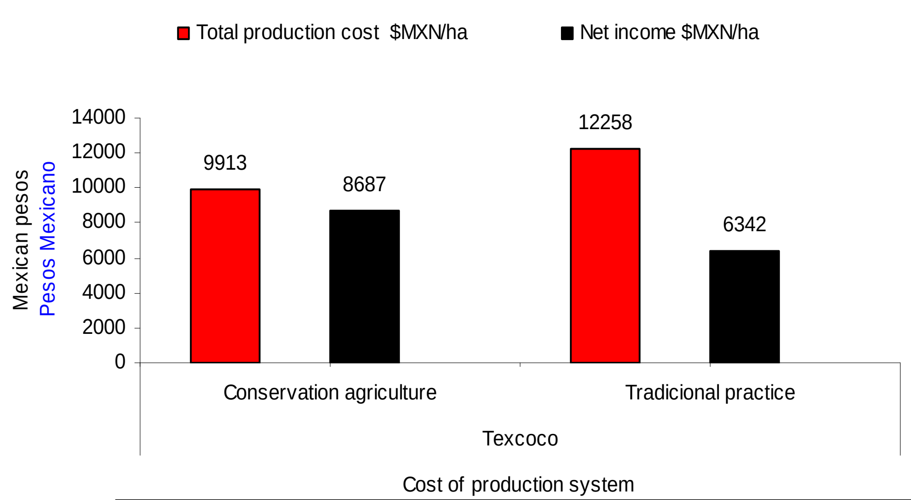


Figure 1. Farmer revenue when compared by practices. (Govaerts et al., 2010)

Most importantly, Conservation Agriculture is a lucrative alternative to conventional agricultural methods, not only because of the high and stable yields, but also because of a reduction in costs (Figure 1). Farmers do not have to till the soil—saving time and labor—and less irrigation water is required to sustain crops. Crop rotation allows a diversified merchantable product where revenue can be made from multiple sources; this allows alternatives if one crop fails to produce an adequate harvest. Finally, the practices of CA protect soil quality and produce high yielding and consistently yielding plots that remain so indefinitely (Figure 2).

This technology would not be so important unless it was shown to produce the same, if not better, yields than traditional practice. Throughout the years, tests across the world have shown that Conservation Agriculture delivers that very promise. Even in years when yield is below traditional practice, farmers still earn more money from the reduced tillage and irrigation costs.

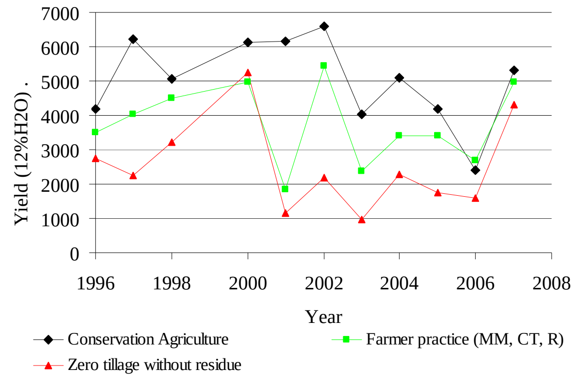


Figure 2. Yield when compared by practices. (Govaerts et al., 2010)

1.4 The People of CIMMYT

Everyone in this worldwide organization has a face, a name, and a story behind them, and I have been fortunate enough to cross paths with many of those who work or study at CIMMYT.

My advisor, Dr. Bram Govaerts, guided me through the main course of study with my work in the Conservation Agriculture department. He always took time out of his impossibly busy schedule to explain how an implement works, share a bit about Mexican culture, or answer a question about my research. He was seemingly always running around out in the field to fix the planter or figuring out how to solve a problem in the field. His expertise and passion for his work was contagious and I have been truly moved by his powerful, energetic lectures and personal discussions.

Nele Verhulst, Dr. Govaerts' doctoral student, instructed me on how to use the various implements to measure crop growth and development in the field. We have collaborated closely on data collection and organization and she has shown me the standards that must be kept when working at CIMMYT.

The majority of my research has been done with Vicente Federico, a college graduate from Chiapas, a state in Southern Mexico. He has not only been a companion and friend, but also a close collaborator and mentor with my work and studies; Vicente was always willing to describe a procedure or a scientific theory pertinent to our work.

I also worked closely with the farm workers from the surrounding city—Beto, Gerardo, Maricela, Don Jose, and Rogelio. We grew close with our work in the "bodega" fixing farm machinery, marking fields for planting, and measuring fertilizer for a precise application. On one occasion, we traveled together to Toluca, a nearby testing site to plant maize and wheat. Little did I know this would be an entire day of fixing machines, running after tractors to remove residue jammed in the planter, and meticulously passing over crop beds to make sure planting was done properly. As we finally finished at dusk, I felt a sense of accomplishment and friendship that only comes after a hard day of work. The crew was resiliently patient with my Spanish and at the end of the internship, jokes and stories were commonplace.

I also grew very close to the international trainees that participated in the five week Conservation Agriculture training course. As we learned together the tenets of CA, an entirely new perspective was brought out as they related the concepts to their home. Reigning from the countries Iran, India, Pakistan, Bangladesh, and Ethiopia, these scientists stepped out of their element to be challenged with new material in an entirely different context. Their perpetually inquisitive attitudes kept me interested as well as keen with my studies.

1.5 On-Field Experiments

The Conservation Agriculture department has many experiments throughout Mexico in locations such as Toluca, Ciudad Obregón, and El Batán, as well as other CIMMYT research stations around the world. These experiments not only test differences in tillage, residue retention, and crop rotation, but a plethora of other variables including disease pressure, phenotype by agronomic treatment, weed management, and fertilizer application rates and timing are investigated as well. Many of these experiments take years to set up and conduct fully: It takes a few years for a conventionally treated field to reach the soil and yield standard of a CA plot. After creation and maintenance of this field, the experiment must be set up and carried out fully. Thus, unlike experiments that take only a few weeks to months to have reputable results in other areas of the crop sciences, experiments in Conservation Agriculture run the course of years.

Figure 3. Aerial View of D5 – 10 Sustainability Trial

At the El Batán research station—where my summer internship was located—many experimental trials have been going on for years. The most infamous, and the one in which I did my individual research, is aptly named “D5 Sustainability Trial.” This experiment has been ongoing since 1991, making it nineteen years old; it is older than me and is unique in being the only experiment in the world of this caliber that has lasted this long. In this experiment, thirty-two different trials are tested on sixty-four plots with each treatment being repeated twice to deter errors (Figure 3). In these trials variations of residue retention, crop rotation, and tillage treatments are tested on a longer time period than most experiments; therefore, real impacts on soil quality can be seen (Figure 4). The treatments differ in the amount of residue retained (zero removed, all removed, partial removed, incorporated into soil), tillage treatments (zero tillage, conventional tillage, narrow permanent bed planting, wide permanent bed planting), and crop rotation (maize, wheat, barley, beans). By utilizing these trials, scientists at CIMMYT can analyze which treatment is the most productive and more importantly with this trial, sustainable for years to come.

Figure 4. Two alternating plots in D5 Sustainability Trial. Left: Wheat-Maize Rotation, Zero Tillage, Keep Residue (CA practice). Right: Maize-Maize Rotation, Zero Tillage, Remove Residue (Farmer practice).

2 - Research

My internship work is directly linked with the D5 Sustainability Trial. I spent a substantial amount of time in the plot gathering and analyzing data to further our knowledge and understanding of the impact of agricultural systems on the land. My work at CIMMYT can be quantified into two different areas of study: trace gas emission detection and monitoring of plant development.

2.1 Trace Gases Measurement

2.1.1 Trace Gases Measurement: Introduction

Agricultural practices have an extremely large impact on many natural systems, including the decomposition of organic materials to form a variety of smaller organic molecules, including gases that can be released into the atmosphere. Three main gases—methane, nitrous oxide, and carbon dioxide—are created by such decomposition and dumped into the atmosphere. Once there, they have the potential to create a greenhouse gas effect.

Scientific consensus now concludes that our atmosphere is changing because of an increased amount of greenhouse gases in the atmosphere. Also caused by the burning of fossil fuels, greenhouse gases—such as those created by agricultural means—accumulate in the atmosphere surpassing normal levels. The gases trap heat in the atmosphere that would be radiated back into space, causing the atmosphere and earth’s surface to rise in temperature. This change in temperature has an enormous impact on climactic conditions and on human activity and daily living.

Trace gases are emitted from the decomposition of soil organic matter at different rates according to different agricultural treatments. Differences in crop rotation, residue retention, and tillage treatments, as well as fertilizer application rates and application times, can extremely alter the amount of greenhouse gases, especially nitrous oxide, emitted by the soil.

Nitrogenous fertilizer, used by plants during growth, can be a major contributor to the formation and emission of nitrous oxide. This nitrogen can also come from organic matter already deposited in the soil. To test the amount of nitrous oxide that is created directly from the fertilizer, a special type of urea—the nitrogenous fertilizer—can be used. Though most nitrogen in organic compounds consists of fourteen protons, fourteen electrons, and fourteen neutrons, a nitrogen with fourteen protons, fourteen electrons, and fifteen neutrons can be isolated and formed into urea. This N15 fertilizer, as it is called, will not only be used by the plant, but also be turned into nitrous oxide by soil bacterium. Since it is of a special density unlike nearly all of the surrounding organic matter, it can be concluded that most of the nitrous oxide that contains N15 nitrogen atoms was created from the special urea fertilizer.

2.1.2 Trace Gases Measurement: Objectives

Since varying amounts of trace gases are emitted by different treatments, a measurement and analysis of the differences in trace gas emissions can be detected and recorded. By doing this, one can observe the amount of gases emitted by each treatment and include that information in the overall sustainability evaluation of the treatment.

2.1.3. Trace Gases Measurement: Hypothesis

It has been stated before that by leaving residue in the field and not incorporating it into the soil by tilling, organic matter will be preserved and not decomposed into trace gases. Therefore, tillage treatments that leave residue on the surface and are not incorporated will have lower amounts of trace gas emissions than residue that is incorporated into the soil. It is also expected that if all residue is removed from the field, zero tillage will release less gases than conventional tillage because less organic soil is moved to catalyze decomposition.

2.1.4 Trace Gases Measurement: Materials and Methods

Five different treatments were tested on ten different plots: Each treatment was repeated twice in D5. The treatments varied according to crop rotation, tillage treatment, and residue retention: wheat-maize rotation, conventional tillage, keep residue; wheat-maize rotation, conventional tillage, remove residue; wheat-maize rotation, zero tillage, keep residue; wheat-maize rotation, zero tillage, remove residue; and maize-maize rotation, conventional tillage, remove residue.

Three twelve inch PVC chambers were placed at equal intervals in the southern side of each plot. Every week on Monday, Wednesday, and Friday, lids were placed on the chambers and sealed with tape to create a windless environment inside the chamber that would capture any gases emitted by the soil. A syringe was then inserted through a rubber stopper on the lid and pumped five times to circulate the air inside of the chamber to obtain a consistent sample from each. A gas sample was then taken from the chamber and placed inside of a vial to be analyzed in a lab at a later time. This was repeated four times each day at twenty minute intervals. After taking the samples, the lids of the chambers were removed to allow the gases to escape and to resume a normal environment for the soil inside the chamber. The gases inside the vials were then taken to a laboratory in Mexico City and tested in a gas chromatograph to detect the percentages of methane, carbon dioxide, and nitrous oxide in each sample. With this machine, the samples are injected through a rubber stopper and run through a thin eight meter pipe. As the gases travel through the pipe, they arrange themselves from least massive to most massive. The machine detects the mass of each and how much of each mass there is. The mass of each gas is known, so the percentage of each sample is recorded. By using this method, the different amount of gases for each treatment can be recorded consistently and charted over a period of time.

At the seven leaf stage of maize, the N15 fertilizer was applied inside the chambers while normal urea was applied around the chamber to the surrounding plants at the normal planting rate. The N15 fertilizer was mixed with the normal urea at a ratio of six to four. The fertilizer was covered in the chamber with soil and gas samples were taken immediately after application. During each gas sampling after the application of N15 urea, one extra sample was taken from the second and third chamber after forty minutes of initially putting the lid on the chamber and taking the first sample. These samples will be sent to University of California, Davis to be analyzed for the amount of N15 atoms in the sample. By measuring this, one can know how much nitrogen in the nitrous oxide came from the fertilizer—which will contain the N15 atom—compared to other organic sources in the soil, which will only contain a small ratio of N15 compared to the normal N14.

Samples were taken three times a week to record a baseline of trace gas emissions. Extra care to take the samples on a timely manner was observed after the N15 urea was applied. The same sampling schedule will continue until later in the year; the number of sampling dates per week will dwindle down because as more of the organic matter decomposes or turns into stable organic particles, less will be able to be detected as an organic trace gas.

2.1.5 Trace Gases Measurement: Results

No final results have been calculated from this trace gas emission experiment, as it was ongoing after my stay at CIMMYT. Experimental data is to be recorded until a few months past the 2010 growing season, and after that, the recorded data must be run through computer software and analyzed for errors and calculated to find a clear answer to which treatment gave off the most greenhouse gases. After this careful analysis, a paper will be written outlining the results of this experiment.

2.1.6 Trace Gases Measurement: Discussion

The data created from the trace gas emission experiment is extremely important. Firstly, this data is coming from the longest-running Conservation Agriculture treatment experiment in the world. Next, this data pertains to not only agricultural issues, but also global climate change, an issue that touches every human on the planet. By studying the amount of greenhouse gas emissions that are released by different agricultural management practices, it is possible to evaluate them for their potential to sink carbon-based and nitrogenous compounds into the soil, keeping them from causing untold effects to the atmosphere if released in a gaseous form. Finally, if CA techniques are proven to sink greenhouse gases into the soil, the potential for governments to give smallholder farmers financial incentives to convert to better practices can become a reality. With this extra incentive, small famers and governments will have another reason to convert to CA technologies.

2.2 Monitoring of Soil Water Content and Plant Development: Introduction

The crops in D5 grew at different rates according to agronomic treatment. To monitor their growth accurately and in a controlled manner, a variety of tests and tools were utilized. By using these methods, differences in crop development could be monitored and recorded to locate differences and recommend the best treatment. Four different tests and tools were used on the plots of D5:

-Soil Moisture Tests
-Leaf Area Index (LAI) Meter
-Digital Ground Cover (DGC) Technology
-NDVI analysis

These tests were conducted throughout the growth stages of the maize and wheat once or twice a week (depending on the measurement, see below) and continued by workers at CIMMYT after my stay concluded.

For each graph below, abbreviations were used to facilitate in the production of the graphs. Each abbreviation stands for a variable. The variables are also coded on the graph in the form of line type, data point shape, and line color.

<u>Crop Rotation-Data Point Type</u>		
WM	Wheat-Maize Rotation (Maize-Wheat)	Solid Circle
MM	Maize-Maize Rotation (Wheat-Wheat)	Six-Sided Asterisk
<u>Tillage Treatment- Line Type</u>		
ZT	Zero Tillage	Solid Line
CT	Conventional Tillage	Small Dots Line
PB	Permanent Beds	Dashed Line
BB	Broad Beds	Dotted and Dashed Line
<u>Residue Retention-Line and Data Point Color</u>		
K	Keep all residue	Blue
R	Remove all residue	Red
RW/KM	Remove wheat cut by combine; keep maize	Green
KTM/RW	Remove wheat cut by combine; remove maize to below ear	Orange

A. Soil Moisture Tests: Introduction

Soil is composed of different ratios of inorganic parent material (such as stones, sand, silt, and clay), air, organic material, and water. Different ratios of parent material and organic matter can lead to different ratios of the amount of liquid water contained in a sample of soil. This soil is essential for plant growth, as this soil stores water to be used by the crop for growth after an immediate rain shower event. Differences in soil quality can change the rate of infiltration of water in the soil as well, making the water either penetrate into the soil or run off quickly from the surface.

Since all the plots in D5 contain the same parent material, the only thing that can change is the organic matter. This organic matter varies due to differences in crop rotation, tillage treatment, residue retention, erosion, soil organisms, and a myriad of other factors. By controlling certain factors of the planting process, analyzing the amount of water in soil samples in the different treatments of D5 can tell a great deal about soil health and current and future crop wellbeing.

A. Soil Moisture Tests: Objective

Determining the amount of water in each treatment will tell the effect crop rotation, tillage treatment, and residue management have on water content (and plant available water) in the soil.

A. Soil Moisture Tests: Hypothesis

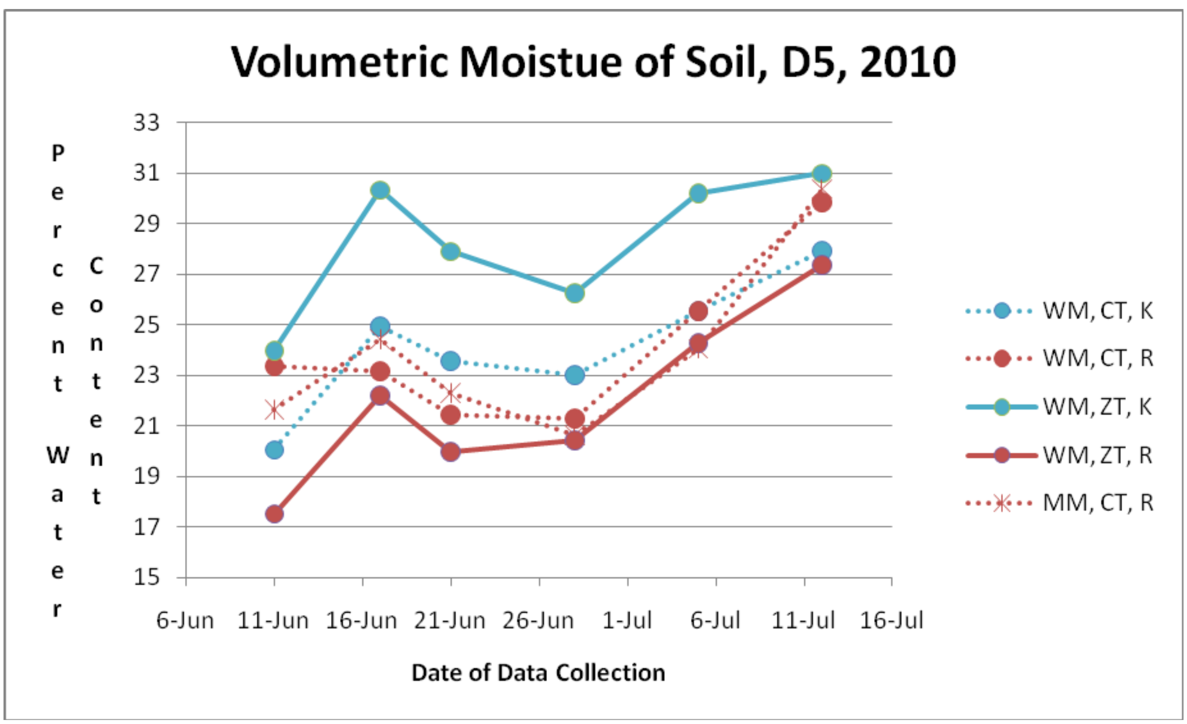
Conservation agriculture practices will have more water available for the plant because the higher amount of residue retention and the lower amount of soil disturbance will allow organic material to form large soil aggregates that act as a sponge to hold moisture for a longer period of time. Reducing the amount of residue retained and increasing the amount of tillage will reduce the soil's ability to form aggregates, thus resulting in less water infiltration and retention. A maize-maize monoculture will also lead to less water retention because wheat adds a greater amount of usable organic matter to the soil for aggregate formation.

A. Soil Moisture Tests: Materials and Methods

Five treatments with two repetitions were chosen for the soil sampling. Two samples were taken from each plot. Soil samples were taken from the first twenty centimeters of the soil using a soil probe. The soil was then promptly put in a labeled metal tin and sealed to reduce the amount of moisture lost. The soil samples were chilled in a cooler and taken back to the lab. Once in the lab, the tins were open and the contents were mixed. Twenty grams of soil were removed from each tin for another experiment. The sample was then massed and recorded and the lid was removed. Once all the samples were massed, they were put on a baking pan and placed in an oven to dry at 105^{o}C. After twenty-four hours, the samples were removed and promptly massed and recorded again to prevent any moisture from absorbing back into the dried samples. When all the samples were recorded, they were brought back to D5 and placed into the hole they were taken from in each plot to reduce the impact on the soil environment.

A. Soil Moisture Tests: Results

The data collected from these tests can be shown in this graph:



A. Soil Moisture Tests: Discussion

This graph shows that the Conservation Agriculture practice of wheat-maize rotation, zero tillage, and keeping all residue has the highest percentage of water in the soil for the plant to use over its lifetime. This data is the most compelling for CA practices over the span of June 16 to June 30. Over this time, the plots of D5 experienced some drought stress: the soil was relatively dry in all plots during these measurements. During this time, the CA practices kept a higher percentage of water throughout this time period while the others tapered off. This is important because keeping residue, using no-till, and utilizing crop rotation could save plants during a time of drought.

It is imperative to note as well that wheat-maize rotation, zero tillage, and *removal* of residue has the lowest percent of water. Even as we were taking the samples, it was difficult to penetrate the crust of this treatment because of the poor soil quality. The key here is the lack of residue. By removing residue, no new organic matter is added to the soil, reducing the number of soil organisms and soil aggregates.

At the end of the testing period, the plots of D5 became muddy and waterlogged due to excess rain. It is visible that when excess water is available, the differences in percentage of water in the soil are negligible. All soils have a limited capacity of how much water can be held in the soil, and when rain is plentiful, the soil will become full of water regardless.

B. Leaf Area Index: Introduction

Crop plants require sunlight to grow and as the growing season progresses, plants spread out to obtain all the light possible in the field. Soil conditions and plant health are the main limitations that cause different treatments of the same crop to spread at different rates in the same conditions. Knowing this, by analyzing which treatment's crops cover the most ground, one can understand the interaction between treatment and the plant by its phenotypic response.

One tool to measure this is the Leaf Area Index Meter, or LAI. The LAI is composed of a central processing box, a wand that has photosensors to detect the amount of light reaching the wand, and an independent photosensor that can be moved accordingly. When the wand is placed under the canopy of the crop, the eight imbedded light detectors record how much light penetrates through the rows of plants' leaves: The shadows created by the leaves fall on the wand, so a lesser light reading is detected there. The independent probe is held high in the air to find the baseline amount of light without any shadows. The two numbers are then compared—under-canopy light strength to above-canopy light strength—and a ratio of crop cover can be determined, giving a quick way to tell how the crop is performing.

B. Leaf Area Index: Objective

By measuring and recording the differences in light penetration of the canopy cover with the Leaf Area Index Meter, the general health and well being of the crop can be determined and differences in treatment and inputs can be evaluated throughout the course of the growing season.

B. Leaf Area Index: Hypothesis

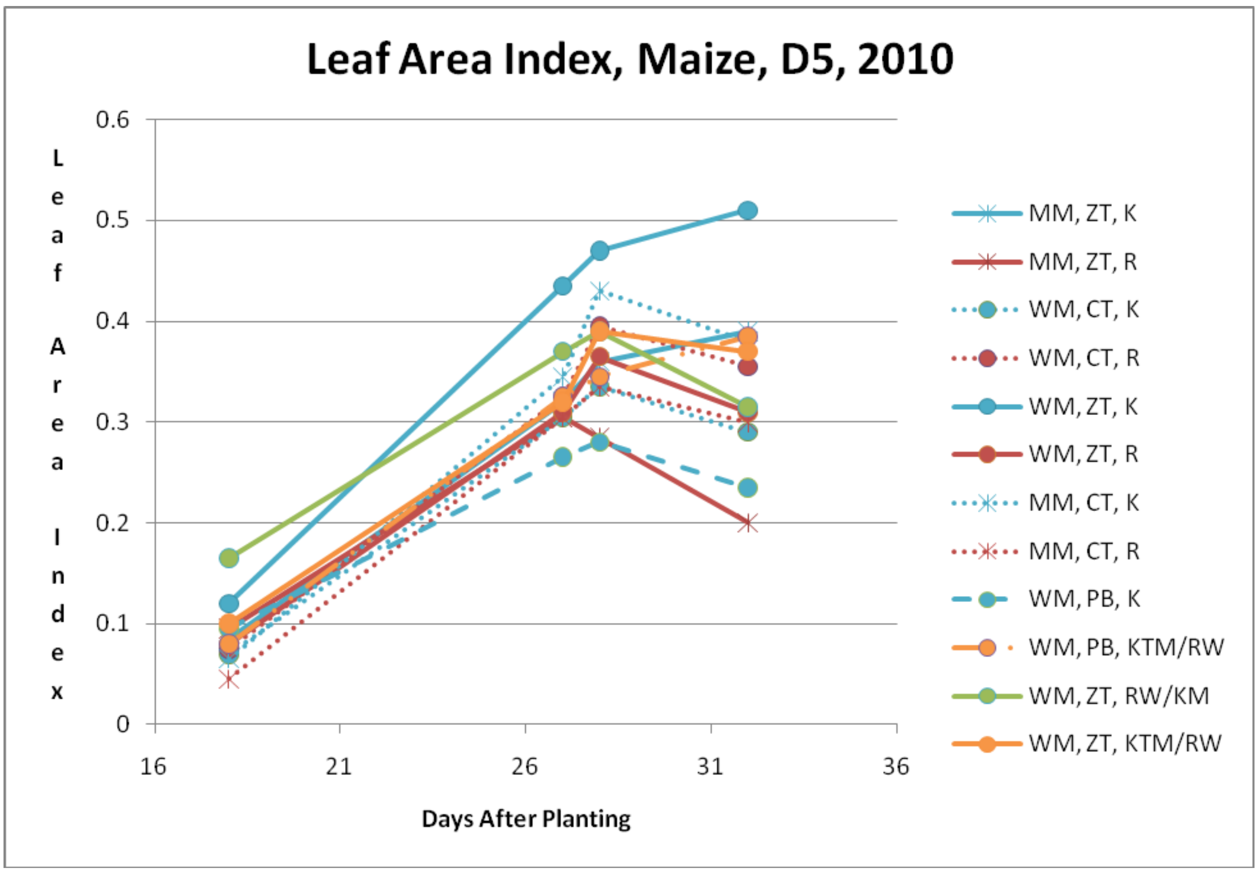
The Conservation Agriculture practices created a consistent and healthy crop throughout the plots of D5; therefore, it should have the highest LAI reading, meaning that it has the largest canopy cover. Poor practices of removing residue have created an unhealthier crop, leading to a less dense canopy cover, thus showing a lower LAI reading.

B. Leaf Area Index: Materials and Methods

The Leaf Area Index Meter was obtained and turned on. All data was cleared and a new data entry was formed. The meter was brought out to the different treatments and placed under the canopy of the crop at five different locations in each plot. Care was taken to makes sure that the leaves were placed above the wand of the meter. In the meantime, another worker held the independent probe high in the air to record the baseline amount of light. The button was pushed, taking a single reading from that location. After this was repeated at all five locations in the plot, another button was pushed that averaged the totals from the five locations in the plot. This total was written down so it would not accidentally be lost if something happened to the meter. This process was repeated in all plots as necessary. When finished, the Leaf Area Index Meter was taken to the computer and the data was taken off and processed to receive a final result.

B. Leaf Area Index: Results

The data collected from these tests can be shown in this graph:

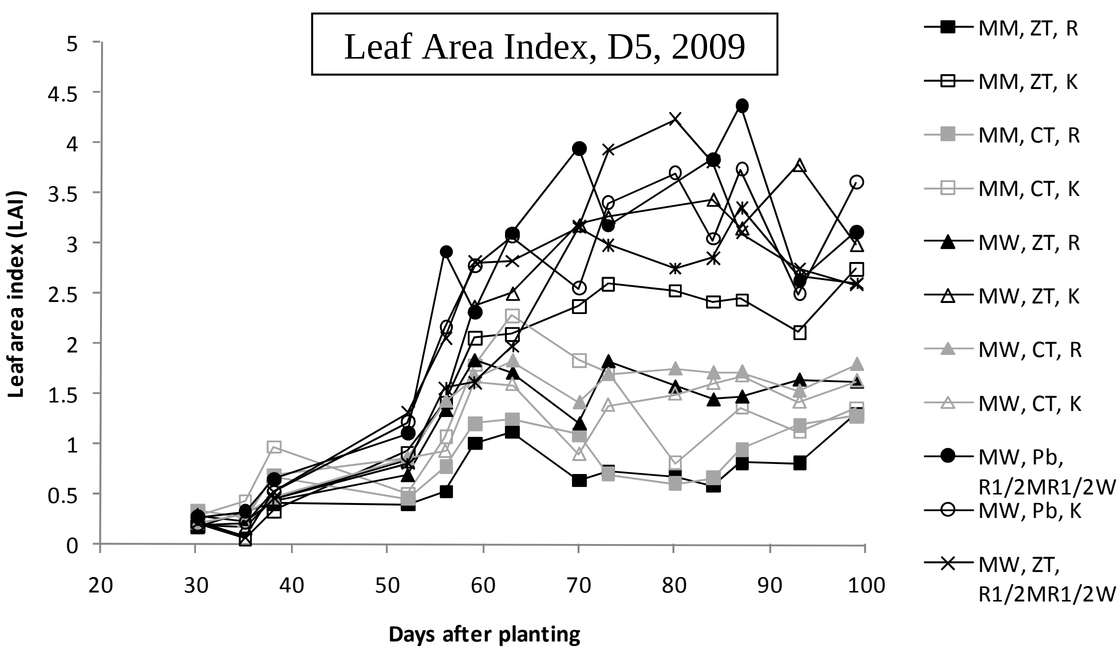


B. Leaf Area Index: Discussion

The best Conservation Agriculture practice—keeping all residue, zero till, and crop rotation—once again did the best of all by having the highest LAI—and therefore the thickest canopy cover. Keeping the residue (the lines colored in blue) have some of the highest LAI readings. It is also important to notice that some of the highest LAI readings come from treatments that only keep some of the residue (the orange line: remove wheat, remove maize to below ear.) This is probably due to the fact that not all the residue has to be retained to add beneficial effects to the soil; keeping only some of the residue is necessary.

Doing tests that take into account removing some of the residue is essential to modeling effects of smallholder agricultural practices. Many small farmers must collect and use residue for animal fodder, and if all is removed, dire effects can befall the land. By keeping some residue and removing the other, farmers reach a happy medium with crop health and livestock consumption.

Below a graph of the previous year's data can be seen:



My work is only part of the data that will create a graph like this. As it is shown, the treatments that keep residue on the field without tillage perform the best. Treatments that remove residue do poorly in this type of trial.

C. Digital Ground Cover: Introduction

As stated previously, the extent of ground cover can tell many things about the vitality and health of a crop. The size and quality can not only be detected and recorded by analyzing the amount of shade created by the plants, but also by determining the area the leaves cover.

Digital Ground Cover (DGC) is a method of analyzing the percentage of ground cover in a field. Instead of analyzing how strong the shadows of the leaves of the plants create, DGC simply tells a percentage of leaf area, from an aerial view that covers the ground from the ground itself.

C. Digital Ground Cover: Objectives

By measuring and recording the differences in the area of the ground cover in each treatment, the general health and well being of the crop can be determined. This test is very similar to the LAI sensor testing, so by utilizing results from both tests, crop health can be evaluated and adjustments to agricultural treatment can be made.

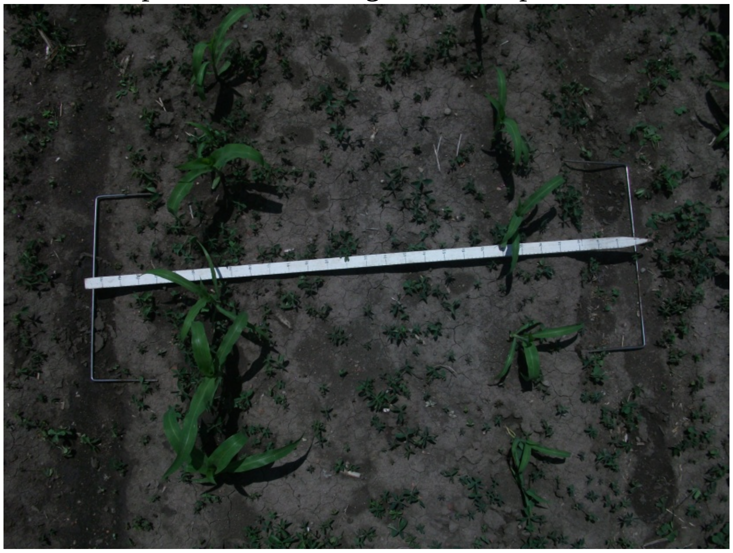
C. Digital Ground Cover: Hypothesis

The Conservation Agriculture practices have created a consistent and healthy crop throughout the plots of D5; therefore, it should have the largest area of leaves covering the earth. Poor practices of removing residue have created an unhealthier crop, leading to a thinner crop and a lower percentage of leaf area covering the ground.

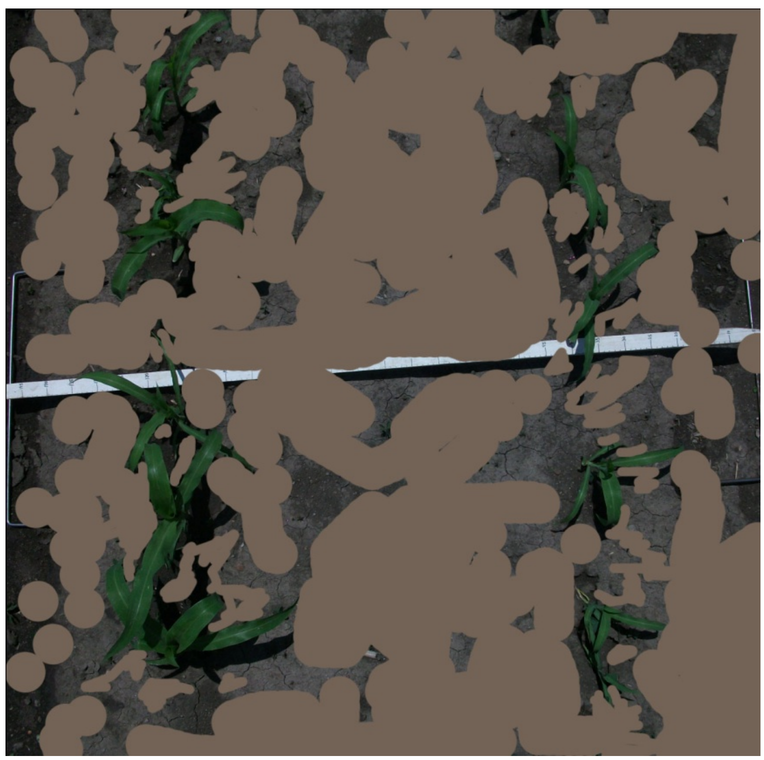
C. Digital Ground Cover: Materials and Methods

A digital camera was obtained and brought to the trial plots of D5. The camera was brought to a location between two rows of a selected maize treatment. Before the picture was taken, a meter stick and two metal wires were placed on the ground for scale. The camera was then held—extended from the body—at 1.75 meters to take a picture of the ground to get an aerial view of the plants. The picture was then taken. Three pictures were taken in each treatment, one at each side and in the middle. This process was repeated on each plot as necessary. The camera was then taken to a computer and the images were imported.

An average picture of a treatment appears, ready to be processed:



The image is then cropped along the meter stick and wire guides to create a long picture that is 1.5 meter wide. This assures a representative area is measured (planting distance between maize rows is 0.75m).

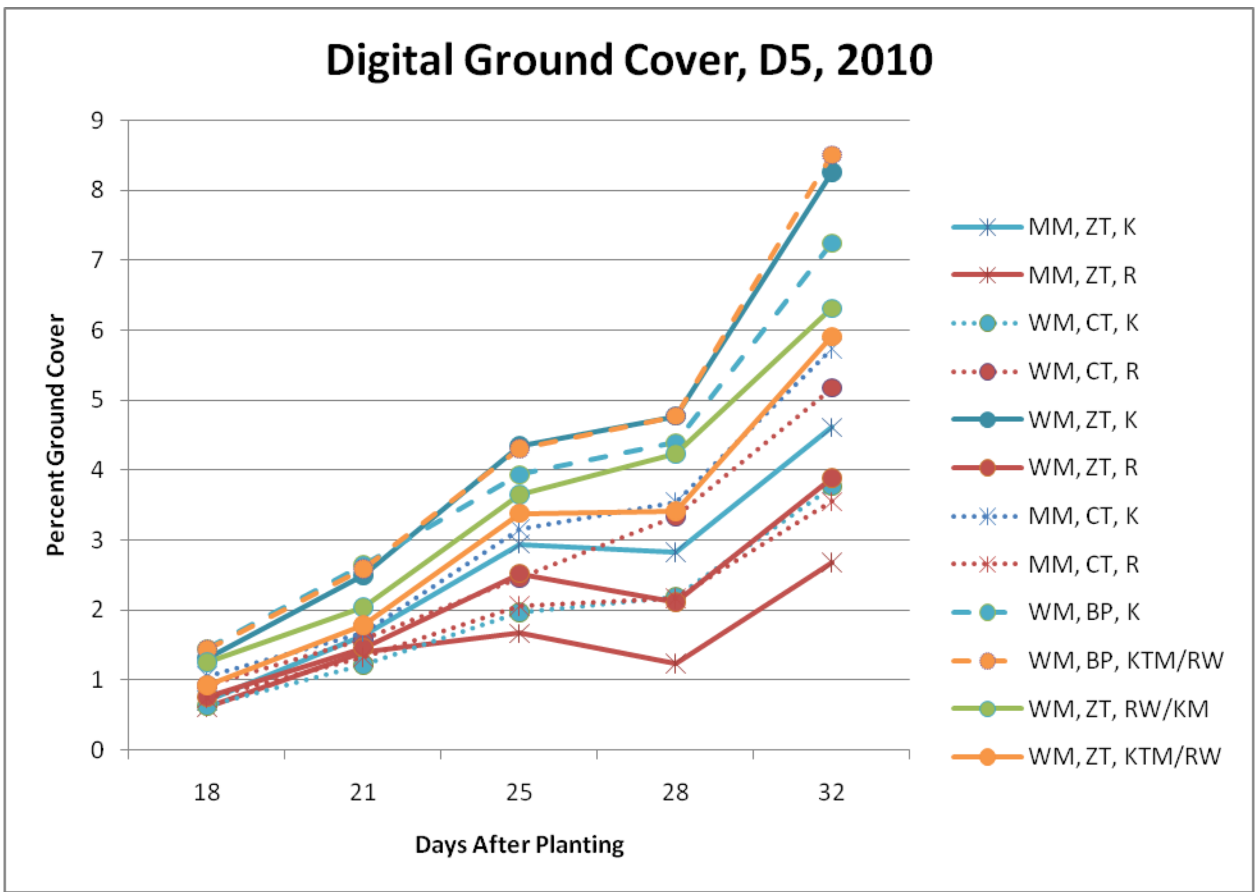


Digital Ground Cover uses a program that analyzes the amount of plant-colored material (green) to the amount of non-plant colored material in the photo, so to work with this program, any plant-colored material must be painted out of the picture, such as weeds.

The colors of the plants are exemplified to differentiate themselves from the soil and other residue cover. Plant colors are then selected—shades of green—and this area turns white. Everything else in the picture turns black. The program then compares the number of white pixels to the number of black pixels, thus telling the percentage of ground cover in each picture.

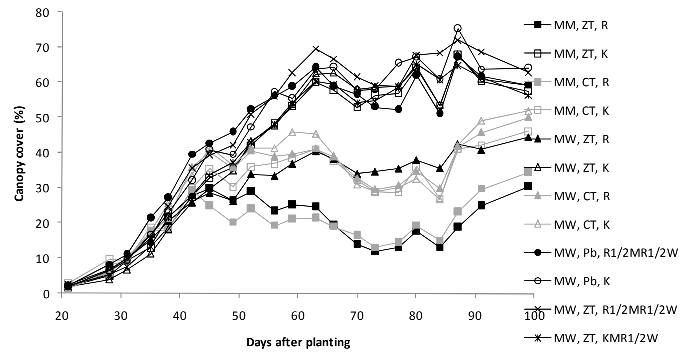
C. Digital Ground Cover: Results

The data collected from these tests can be shown in this graph:



C. Digital Ground Cover: Discussion

Retaining residue, even if it is not all of it, has led to the largest area of ground cover in these trials. Though permanent beds and keeping some of the residue came out on top, the other Conservation Agriculture practices were in a close second. Removing all the residue hampered ground cover growth to a great extent in these tests. All of the treatments that remove residue are in the bottom half of this graph, reinforcing once again that residue must be retained to have healthy soil structure to support vivacious plant growth.



A graph of last year's data was composed as well. My data will be used to create a full graph like this for the 2010 growing season.

D. NDVI Sensor: Introduction

Plants use light as the source of energy for all biochemical reactions that take place to create a fruitful harvest. Plants utilize different spectrums of light for different functions. Chlorophyll, the molecule ultimately responsible for all biochemical reactions in the plant, uses sections of the visible light for photosynthesis; one of these light regions ranges from 550-700 nanometers—red light—and is absorbed by the plant leaf tissues. Not all the electromagnetic radiation that hits the plant is utilized, though. Electromagnetic radiation in the near-infrared region (700-1300nm) is not used for any chemical purposes and is reflected off the plant by the plant surface and cell wall.

It has been shown that a healthy plant will absorb more red light to be used to create chemical compounds and reflect the near-infrared light because the healthy plant tissues are fit to reflect unnecessary electromagnetic radiation. Unhealthy plants will reflect more red light back into the atmosphere because they do not have the capability to create more sugars and absorb more near-infrared light because weaker plant tissues do not have the proper structure to protect the plant from this type of electromagnetic radiation. The utilization, accessibility, and proper placement of nitrogenous fertilizer are the keys to the health of the plant in this manner.

The NDVI—or Normalized Difference Vegetation Index—handheld sensor is used to measure and record the differences between the amount of reflectance and absorption ratios between red light and near-infrared light. This device, which is held on a strap over the shoulder and emits the dual spectrum of light, is walked over the crop at a consistent speed. The sensor records the amount of reflectance of red light and near-infrared light that comes back from the canopy not only from the light emitted by the sensor, but also from natural light from the sun. By using this tool, crop health through an entire field can be quickly and easily determined and recommendations to treatment can be determined.

Two different types of data—among many others—can be extrapolated from this device. The first is Average NDVI: This reading is derived from the average readings from the plot derived from this formula:

$$NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} - R_{Red}}$$

where: R_{NIR} is reflectance of Near Infrared Radiation
R_{Red} is reflectance of visible red radiation

Average NDVI is a good way to tell the general health of a plot. The other method used is Coefficient of Variance (CV): This calculation determines the amount of variation of the size and health of a crop. This means that a stand is better if all plants are the same size and are all using the fertilizer efficiently; a poor stand has a variance between the plants.

D: NDVI Sensor: Objectives

By determining the Average NDVI and Coefficient of Variance by measuring and interpreting the absorption and reflection of red and near-infrared light, a general idea of crop health can be determined.

D. NDVI Sensor: Hypothesis

It has been recorded in previous trials with the NDVI sensor that conventional agricultural practices—such as tillage—improves the appearance of nitrogen usage in early growth stages of plants. It is to be expected, then, that this will hold true in this test: conventional tillage will do better in each trial compared to zero tillage. Keeping residue should also improve plant health in the long run.

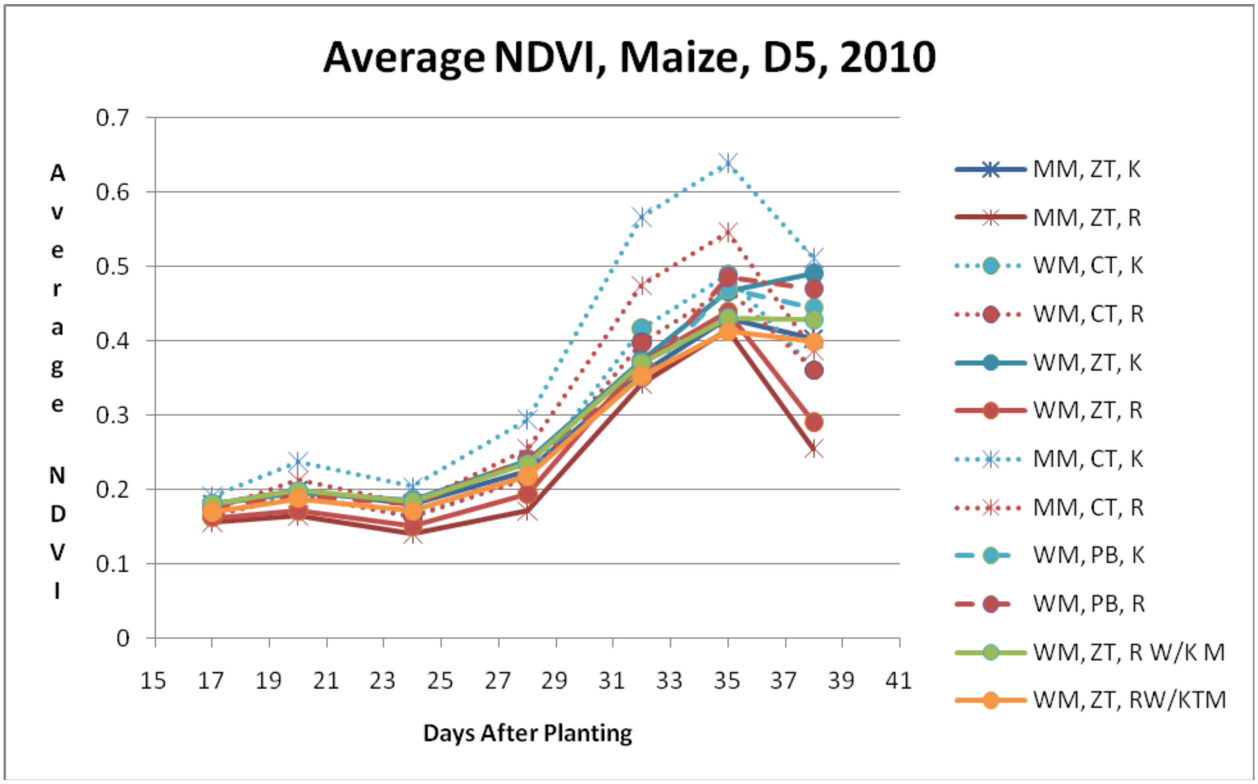
D. NDVI Sensor: Materials and Methods

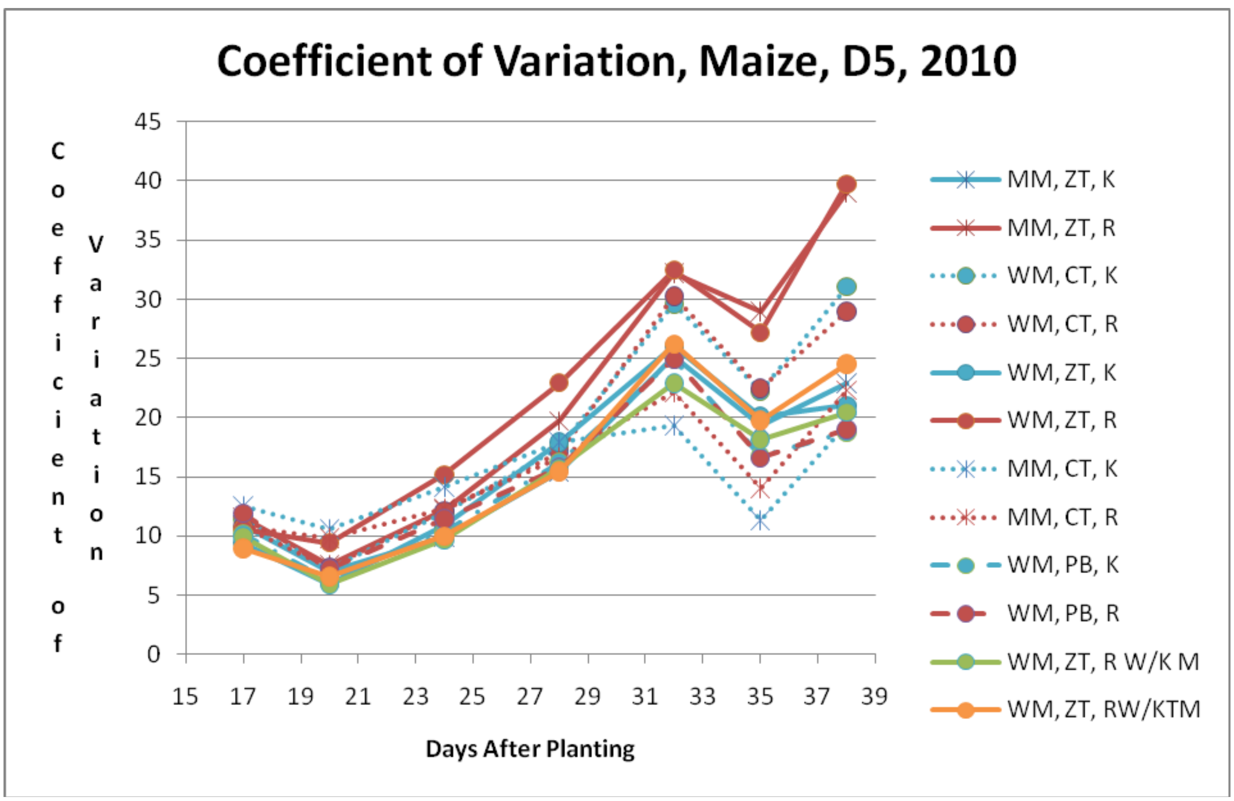
The NDVI Sensor, as well as the IPAQ, was obtained and hooked up together. The IPAQ is a handheld computer that stores the data that the NDVI produces. The devices were turned on and brought to the field. A button was pushed on the NDVI sensor to start the recording of the device as it was brought to the beginning of a row that was to be tested. The device was then carried over the plants at a height of sixty centimeters at a constant pace. The pace allowed an NDVI reading every ten centimeters. Care was taken to start walking early at the beginning of the plot before the button was pushed to get a consistent reading at the beginning of the row of crops. At the end of the row, the individual reading was finished. This process was repeated for each row as necessary. After finishing with all the plots, the data was saved on the IPAQ.

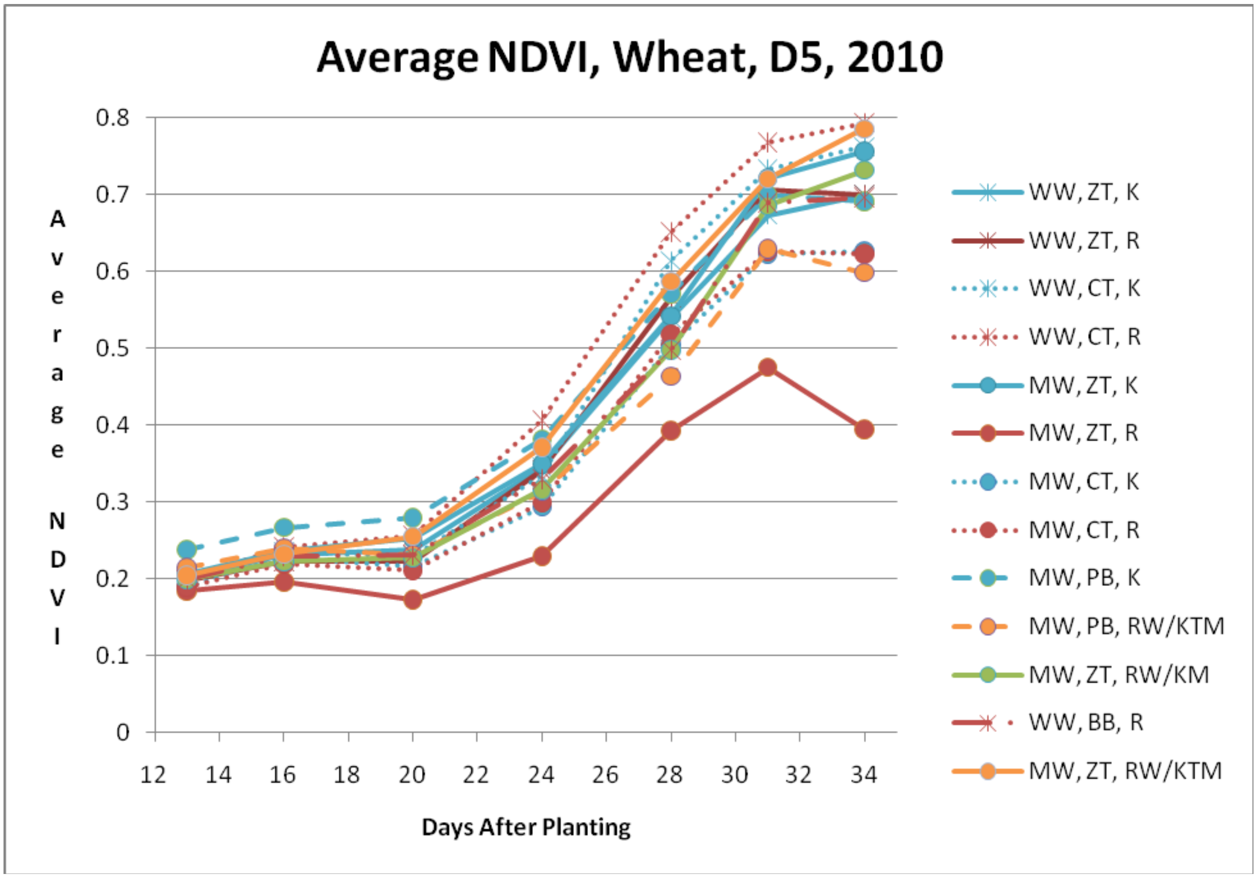
The IPAQ was then connected to a computer and the data was transferred over. The data was put into a Notepad format and outliers were erased. The revised data was then saved and put through a program that creates the Average NDVI and Coefficient of Variance. The data was finally saved in an Excel format.

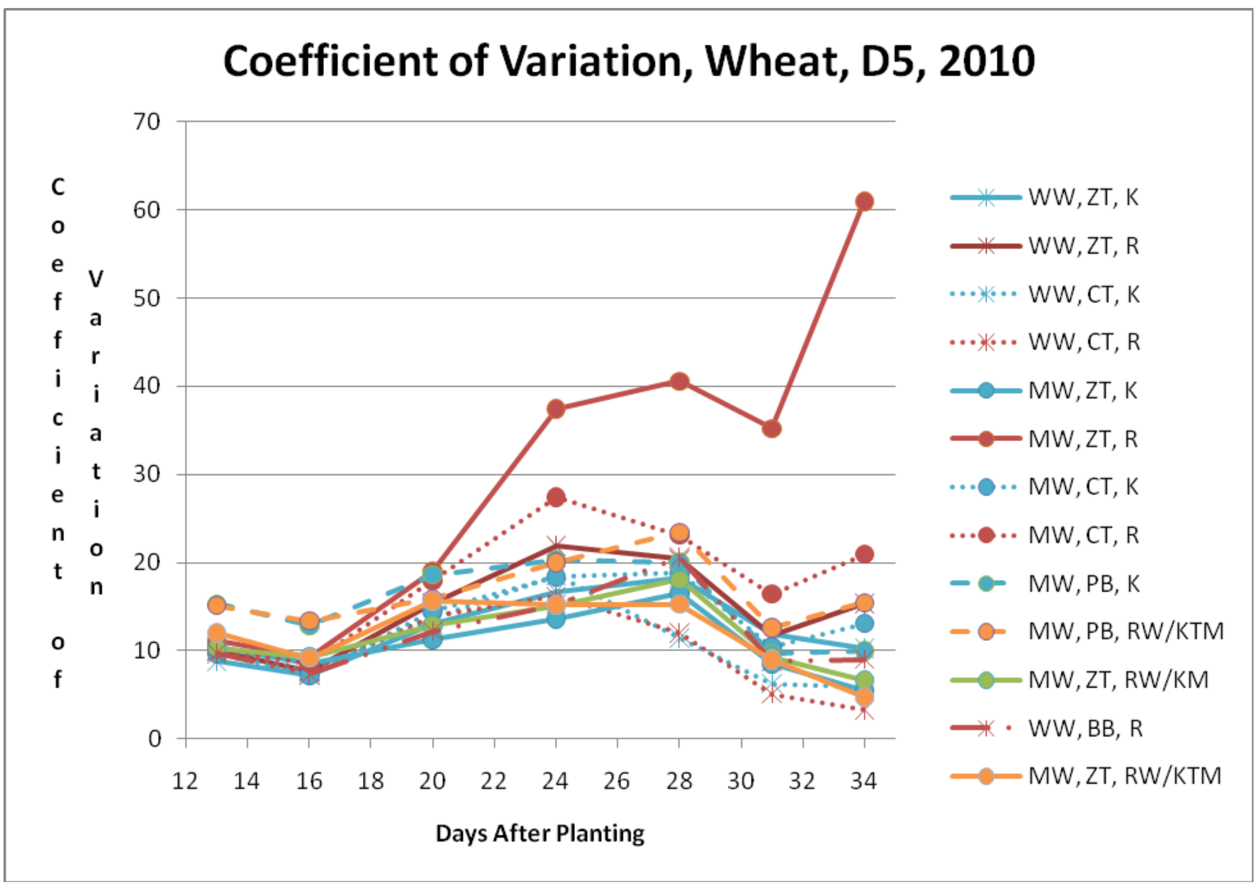
D. NDVI Sensor: Results

Data was produced for the Average NDVI and Coefficient of Variance for both maize and wheat.






Average NDVI, Wheat, D5, 2010
Average NDVI
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12
14
16
18
20
22
24
26
28
30
32
34
Days After Planting
WW, ZT, K
WW, ZT, R
WW, CT, K
WW, CT, R
MW, ZT, K
MW, ZT, R
MW, CT, K
MW, CT, R
MW, PB, K
MW, PB, RW/KTM
MW, ZT, RW/KM
WW, BB, R
MW, ZT, RW/KTM


Coefficient of Variation, Wheat, D5, 2010
Coefficient of Variation
70
60
50
40
30
20
10
0
12
14
16
18
20
22
24
26
28
30
32
34
Days After Planting
WW, ZT, K
WW, ZT, R
WW, CT, K
WW, CT, R
MW, ZT, K
MW, ZT, R
MW, CT, K
MW, CT, R
MW, PB, K
MW, PB, RW/KTM
MW, ZT, RW/KM
WW, BB, R
MW, ZT, RW/KTM

D. Discussion: NDVI Sensor

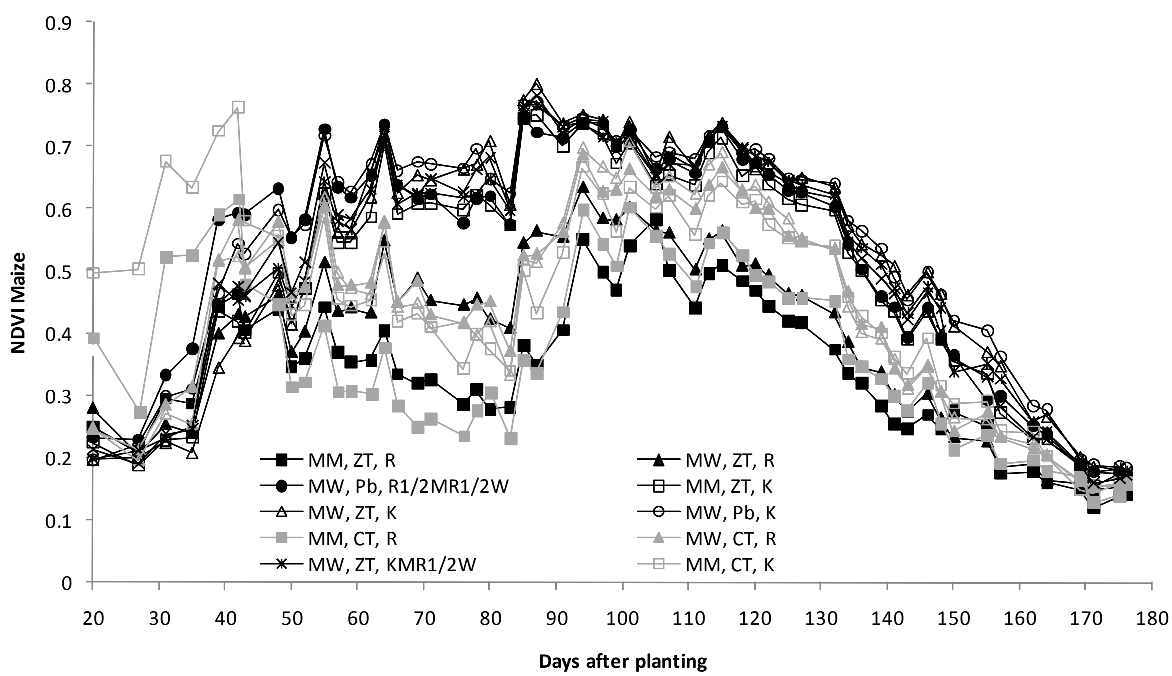
Unlike many other tests, the treatments with conventional tillage in both the maize and wheat plots performed best in the Average NDVI tests. This means that these crops were utilizing their nitrogen most efficiently of all the plants. Even in the Coefficient of Variance tests, the conventionally tilled plots had the most consistent plant-nitrogen-use-efficiency throughout the field. The reason for the benefit early in the year is still unknown, but this type of research shows that it has something to do with the usage and timing of nitrogenous fertilizer by the plants.

The Conservation Agriculture plants, though, did have a close second in all these tests. Rotating between maize and wheat, keeping residue, and withholding from tilling allowed a consistent crop to grow that uniformly developed and utilized fertilizer gradually.

One interesting observation on some of these tests is that in the conventionally tilled-monoculture plots, removing the residue did not have much effect on the usage of fertilizer by the plant. Other tests would predict that plant health would be hurt drastically, but these tests show otherwise, or at least early in the growing season.

It is important to note that the plots with the poorest practice—zero tillage, removing residue, and both monoculture and maize-wheat rotation—utilized nitrogen poorly and had an inconsistent crop. It shows that if zero tillage is to be achieved, residue must be retained to keep proper soil health.

A graph of last year's Average NDVI for maize was produced:



This graph shows that later in the season, the Conservation Agriculture plots utilize fertilizer more efficiently and consistently. It is still debated why this holds true, but at the end of the year, the CA plots are the best in this test.

2.2 Monitoring of Soil Water Content and Plant Development: Discussion

The work conducted on the crops of D5 was extremely important: The data that I was responsible for collecting will be added to the already eighteen years of scientific data about Conservation Agriculture techniques. My research will tell part of the story of long-term sustainability and the effects on crop and soil health. This data can be used to encourage others to convert to CA techniques by providing scientific data showing that these CA techniques will provide a better and more consistent crop for the smallholder farmer.

3- Regional and Cultural Experiences

3.1 Mexican Culture

My stay and travels in Mexico were nothing short of miraculous. I learned a countless number of things about Mexican culture, the people, and the Spanish language. I have a million stories that characterized my stay at CIMMYT in El Batán, and they all accumulated into making my time in Mexico the most memorable event of my life.

I fell in love with the culture of Mexico. The one thing that impacted me most in Mexico was Spanish. Utilizing my Spanish may have been the most frustrating and difficult part of my stay, but it was also hands-down one of the most rewarding and fulfilling. I took four years of Spanish at my high school but *learning* the language and *living* the language are two entirely different things. Though I had problems initially, my Spanish improved considerably and speaking with the natives was not a problem. Spanish was so rewarding to me because I could talk one on one with people without a translator: I could see their culture and live it. There was one person in my office I became friends with that had an extremely limited English vocabulary, so we spoke in Spanish. Also all the people that worked in the field could only speak Spanish and it was so fun to joke with them and truly get to know them. Finally, interacting with the people in the shops, stalls, and any other locale in and out of the city was unforgettable.

There are certain intricacies of Mexican culture that make it distinct. One of the most imperative is acknowledging someone at the beginning of the day. Whenever you see someone for the first time in the day, you shake their hand. I really started to appreciate this as my internship progressed; it made me feel acknowledged and like others cared for me. Another seemingly small cultural aspect is the utilization of the tortilla. This may be the most versatile food in the world. I am used to the tortilla only being able to be used to put meat and toppings in to make a taco. The tortilla can be used for that, but it has a higher purpose: Mexicans roll the plain tortilla up tightly and use it as a piece of silverware, taking a bite of it when they want. I had never seen that before in all the Mexican restaurants I had been in. It is so significant because tortillas are a staple of Mexican food; the meal is not complete without a stack of tortillas to eat it with.

The cuisine of Mexico was just as distinct and surprising as all my other cultural experiences. I am used to the basic “Mexican” taco or burrito, but rarely did I encounter anything I had ever had in the United States. Mexico has three different regions—the North, the Middle, and the South—and each has its own distinct tastes, as I once heard, “The North works, the Middle thinks about working, and the South eats!” I was exposed to Middle-Mexican cuisine and even as I travelled to different regions of Central Mexico, each locale had its own minute variants that made it distinct yet ever-so tasty.

Finally, as I traveled through the different regions of Mexico, I was astounded by the beauty of the locations and landscapes of the nation. I went to places like the crowded buzzing streets and shops of Mexico City, the beautiful farms nestled in the countryside, the rocky ever-changing mountains, and the wonder of an ancient ruined city. On one visit, I went to the Pyramids of Teotihuacán, an ancient city with three magnificent pyramids and an underground network of rooms and tunnels. I was astounded how such an ancient civilization created this with accuracy that rivals modern tools and equipment. I also visited Molino de Flores, an abandoned hacienda built during the times of the conquistadors. The buildings remain intact but nature has claimed back much of the complex architecture. I have also visited the busy shops of Mexico City where I translated for the people I was with so they could get a bargain in the shops. Most of the people did not have access to such goods in their home nation so I helped them find what they needed in the crowded stalls in the capital city. Finally I visited the canals of Xochimilco in the southern district of Mexico City. These canals were created by the ancient people of the region, and it is the only ancient, untouched area after the Spaniards drained the lake, leaving the small islands defined by the canals. There I went to Isla de Las Muñecas, or Island of the Dolls, an island covered in dilapidated dolls put there by a man haunted by the spirit of a young girl that drowned in the canals. After he died, the island full of dolls became a monument to the man and little girl’s spirit. I gained a new respect on my travels through Mexico and though I did not see near close to everything Mexico has to offer, I have gained a sense of what wonder and beauty the nation can offer.

3.2 International Culture

During my stay at CIMMYT, I was part of the Conservation Agriculture Training Course, a five week intensive program that teaches agricultural leaders about Conservation Agriculture practices in Mexico and challenges them to apply what they learned back in their country. Participants from India, Pakistan, Iran, Ethiopia, and Bangladesh brought not only their agricultural expertise, but also a little bit of their culture with them to Mexico.

One of the most interesting things that I noticed was that many of the trainees would have tea time in the afternoon. Listening to others and doing some research, I found out that it is customary in many South Asian nations to take a break in the afternoon to settle down and have some tea. I had some of the best hot tea with milk with the trainees on bright afternoons as we talked about the day or our home countries. Many times Bram—the leader of the course—would allot tea time breaks for the group, so it was always comforting to have a time to relax and talk to others.

Many of the people from India and Pakistan brought some of their own food and spices from their own country and made food in the kitchen for the group. I got a good taste of many dishes I have never seen or even imagined were possible. All had a liberal dose of spices but were amazing none the less. On the last day of the Conservation Agriculture course, the trainees made a dinner with dishes from their home. I had a spicy lentil soup, a fish dish from Bangladesh, and some piquant vegetables. As we were talking, a little bit of music stirred up: The trainees all sang a song from their country. Many of these songs dealt with being homesick or finding a love. All of the songs were beautiful and sung in each trainee’s native language; I ended up singing “You Are My Sunshine”. Our final dinner was a wonderful way to say goodbye to each other.

One thing I was amazed with was all the trainees’ ability to speak English. I have been told that English is the global language but I never believed it until then. Honestly, I had a difficult time overcoming the trainees’ accents and I felt extremely bad about it; it seemed that all the other interns could understand each other perfectly but I had been speaking English my entire life and I still couldn’t understand them. Their extensive vocabulary and use of syntax amazed me since they don’t have to speak English in their home nation. When I asked them about it, they told me that they have to use English in all works of academia. Any paper published is in English so if one is to read or write a paper, a sufficient knowledge of English is required.

Finally, the trainees were some of the kindest people in the world. They all adapted for each other’s culture and crossed political barriers. People are people, and they realized this to do something positive for the world.

4-Conclusion

Words cannot describe my stay in Mexico at CIMMYT. I learned about myself and what I could do and get through to better myself. I became aware of another culture and the people and lives that inhabit another land. I found the kindness and love in everyone’s heart.

With my work at CIMMYT in the Conservation Agriculture program, I gained a new respect for not only the agriculture our family does back home, but also farming done around the world. I never realized how important agriculture was, let alone the amount of research put into the science. I now know agriculture can be done in a manner that not only protects soil quality and life, but also is more productive and profitable for the farmer. Agriculture touches the life of everyone in the world and is imperative to sustaining the people on our planet. It keeps hungry mouths full and by doing all possible to improve agriculture, a better world without the scourge of hunger is possible.

When in a session for the Conservation Agriculture course, my boss Dr. Bram Govaerts said something that will always stay with me that shows the gravity of the work with agriculture:

“People rely on our research to eat and not go hungry. It is not morally acceptable for me to make mistakes.”

Works Cited

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Govaerts, Bram, Ken D. Sayre, Nele Verhulst, and Luc Dendooven. "Conservation agriculture, towards sustainable and profitable agricultural systems!?" *CIMMYT*. 2010. Presentation. 2010.