Evaluating the Effect of Management Practices on Soil Moisture, Aggregation and Crop Development

By: Dakota Olson

Hometown: Keswick, IA

The World Food Prize Foundation

2014 Borlaug-Ruan International Internship

Research Center: International Maize and Wheat Improvement Center (CIMMYT)

Location: El Batan, Mexico

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Preface and Acknowledgements

My success at the International Maize and Wheat Improvement Center (CIMMYT) would not be possible without the multitude of supporters that allowed me to pursue this incredible opportunity.

A massive thank-you to the World Food Prize Organization and the staff and supporters that supply hundreds of youth and adults across the world with empowerment and opportunities to play as a stake-holder in international development issues. A big thank-you to Lisa Fleming of the World Food Prize Foundation for playing an integral role in the success of my international internship while in Mexico. Thanks to Ambassador Kenneth Quinn for the leadership and guidance that is supplied to the World Food Prize and to the Ruan family and individual donors who supply the program with financial assets. Thank you to Dr. Norman Borlaug for creating the World Food Prize legacy, and for the opportunity to allow me to carry his name and represent his ideals.

Thank you to the outstanding CIMMYT team in El Batán, Mexico for allowing me to learn alongside a team of incredible researchers and support staff. Thank you to Dr. Nele Verhulst, Dr. Bram Govaerts and Dr. Ken Sayre for your guidance and leadership throughout the Conservation Agriculture program and my individual research project. Thanks to Rachael Cox and Virginia Nichols for their generous hospitality and guidance throughout my internship and research project. A thank you also goes to Paulina Cerda González for accommodating my stay on CIMMYT campus and for arranging cultural immersion excursions.

A big thank you to Mom, Dad, and siblings Wyatt and Sydney for not putting up too much of a fight to leave home for 8 weeks, as well as the emotional support and love that was given to me. Thanks to my grandparents, aunts, uncles, cousins, friends, and lifelong mentors who supported me throughout the internship and occasionally sent me care packages and letters. The love is very much appreciated.

Finally, thank you to my high school FFA advisor, Mrs. Kristin Flander for steering me towards this opportunity and pushing me to pursue the internship. Thank you to my lifelong mentor and sign language interpreter, Misty Dewitt for her continued dedication to develop my character for the past 13 years of my life. My success cannot be credited without the efforts of these two outstanding leaders of youth education.

To whoever may be reading this report, thank you for your interest. A lot of time and effort has been invested into this research project, and I sincerely hope you gain a fresh perspective of conservation agricultural concepts. I really enjoyed the time I spent on this project, as well as the weeks spent at the International Maize and Wheat Improvement Center (CIMMYT) in El Batán, Mexico.

With my deepest gratitude,

Dakota Olson

Background Information

CIMMYT

The International Maize and Wheat Improvement Center (CIMMYT) (CIMMYT, 2014) was formally launched in 1966 in Mexico City, Mexico (later moved to El Batán, Mexico). CIMMYT roots from a pilot program in collaboration with the Mexican Government and the Rockefeller Foundation with the goal of raising Mexico's agricultural productivity. Today, CIMMYT seed varieties are grown in more than 100 countries, over 10,000 researchers have graduated from CIMMYT endorsed courses, 91,000 maize and 158,000 wheat varieties from the CIMMYT Seed Bank (which also houses the largest collection of wheat and maize) have been distributed to farmers and researchers all over the world, and employs more than 700 people from 38 countries in 18 offices from all around the world.

CIMMYT's work branches out into five fields of study:
1) Global Maize Program
2) Global Wheat Program
3) Conservation Agriculture Program
4) Socioeconomics Program
5) Genetic Resources Program

CIMMYT is an award winning institution that has been recognized with international fame among the agricultural community. Many CIMMYT scientists have been given prestigious awards for their accomplishments in the field and in the labs, and many have been recognized as World Food Prize Laureates. Perhaps the most famous of these CIMMYT scientists to work with the facility was Dr. Norman E. Borlaug- a distinguished wheat scientist credited with saving millions of lives and sparking the Green Revolution.

The Dr. Borlaug Legacy

Dr. Borlaug started from humble beginnings. Born and raised in Iowa, Borlaug always had a passion for agriculture. (World Food Prize, 2014) Following his education in plant pathology from the University of Minnesota, Dr. Borlaug was enlisted by The Office of Special Studies to work towards breeding wheat with a resistance to stem rust. While in Mexico, Dr. Borlaug developed a new technique called "shuttle breeding" in order to accelerate his research and the development of new varieties. Dr. Borlaug's new wheat variety enabled poverty stricken Mexican farmers to increase their production by six fold and for the first time, attain a self-sufficient food source.

The breakthrough in Mexico inspired the UN Food and Agriculture Organization and the Rockefeller Foundation to ask Dr. Borlaug to focus his attention to the Middle East and

South Asia. Dr. Borlaug and a team of CIMMYT trained scientists were faced with the task of convincing Indian and Pakistani leaders to embrace an entirely new approach to agriculture. With the support of the Indian and Pakistani Ministries of Agriculture, both countries had adopted Borlaug's techniques. As a result, crop yields increased, and two countries known for food deficiencies were now self-sufficient. He would later receive the Nobel Peace Prize in recognition of his work in India and Pakistan. He has been dubbed as the "Father of the Green Revolution."

Introduction

Conservation Agriculture Program

Conservation Agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and available biological resources combined with external inputs (FAO, 2014).

The Conservation Agriculture Program at CIMMYT functions with three pillars (CIMMYT, 2014):

1) Catalyze innovations to maintain experimental stations.
2) Strategic research based on long-term and component technology trials in three agro-ecological environments.
3) Develop Conservation Agriculture based hubs in different agro-ecological areas in Mexico and the world.

Conservation Agriculture itself serves three components:

1) Minimal soil impact and movement
2) Rational soil surface cover
3) Economic crop rotation system

Introduction to Field Management Practices

In reference to the H9 Sustainability Trial, there are three factors that are observed- 1) crop rotation, 2) tillage method, and 3) crop residue. There are fourteen treatments that produce all possible combinations with two repetitions totaling 28 individual test plots (Mexico based Conservation Agriculture Program, 2014).

Crop Rotation- In crop rotation, we observe a Maize (M)-Wheat (W) seasonal rotation.

Tillage Method- There are three different tillage methods studied in H9; 1) Permanent Bed (PB), 2) Conventional Tillage Bed (CB), and 3) Broad Permanent Bed (BB).

Crop Residue- We study three possibilities of crop residue management; 1) Retain (K), 2) Remove (R), and 3) Partial (P).

H9 Bed-Planted Sustainability Trial

The H9 Bed-Planted Sustainability Trial is a CIMMYT long-term research plot (1999-2014) initiated by Dr. Ken Sayre and is located in El Batán, Mexico. The test plot serves two objectives:

1) To compare permanent beds versus conventional till beds
2) To compare the effect of residue management and tied-ridges for permanent beds

The plot functions on a Maize-Wheat crop rotation in rain-fed conditions. Irrigation is applied only in the germination phase if needed for establishment. This plot will be the focus of this report.

Objectives

This report serves 3 objectives:

1) Observe the effect of tillage method and crop residue on soil moisture.
2) Observe the effect of tillage method and crop residue on crop yield.
3) Observe the relationship between time to pond and crop yield.

Procedures and Methodology

This report is derived from a number of methodologies used to collect data in the field. The following are methods used in order to collect the data.

Measuring Volumetric Water Content of Soil (Soil Moisture)

The volumetric water content is measured by comparing the difference between the initial weight of moist soil, and the dry weight of soil. Soil samples are collected from four different soil depths: 1) 0-20 cm, 2) 20-40 cm, 3) 40-60 cm, and 4) 60-80 cm. For each plot that is sampled, two samples are taken from each depth range. For each treatment observed, soil samples are collected from both plot repetitions one and two (producing four soil samples from each depth range for each treatment).

Soil sample is weighed immediately upon collection. Samples are then oven-dried at 105˚C and weighed once more (Govaerts, Verhulst 2014).

$$\text{Volumetric Water Content (mm)}=[[[\frac{\text{Wet Weight-Dry Weight}}{\text{Dry Weight}}] \times \text{Bulk Density}]\times 10]\times 2$$

Measuring Time to Pond

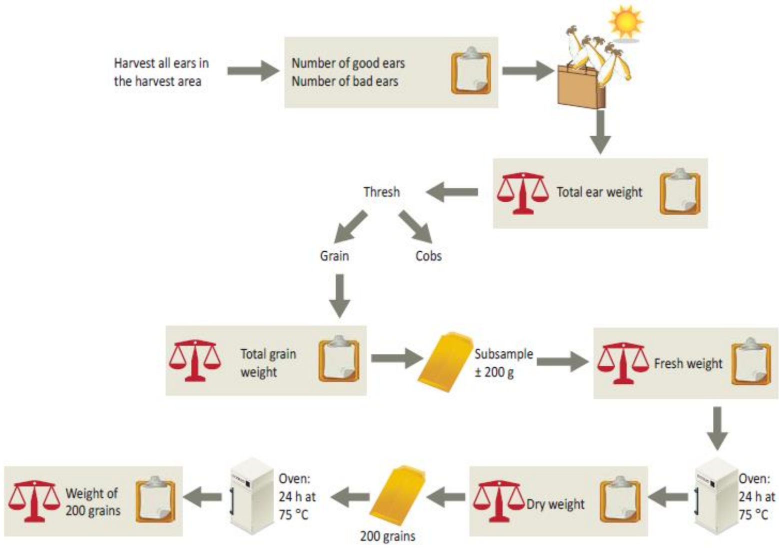
Time to pond is a number that allows us to measure infiltration vs. runoff of a soil surface. For our purposes, a field measurement is collected by placing a metal wire ring (40 cm diameter) in beds. Water is then poured at a constant rate (app. 75 cm height) from a watering can while the recorded time begins. When the water flows out of the metal ring, the water flow from the can is stopped as well as the recorded time. Furthermore, the initial and final volume of the watering can is recorded (Govaerts, Verhulst, 2013).

Measuring Dry Yield- Maize

The graphic and equations below describe the process in which crop yield data was gathered in this project. A harvest area is determined and length and width are recorded. All grain within the harvest area is then harvested and cleaned, if necessary. The weight of the total grain is then recorded as “Total grain weight.” A subsample of approximately 200 g is collected, weighed, and recorded as “Fresh weight.” This subsample will produce a fresh weight and will be utilized in order to determine the moisture content of the harvested grain. The subsample is then placed in an oven at a temperature of 75˚ C for 48 hours or until it has a constant dry weight. This is then weighed and recorded as “Dry weight.” 200 grains is then extracted from the dry weight subsample and are oven-dried at a constant temperature of 75˚ C for 24 hours or until they are completely dried. The subsample is then weighed and recorded as “Weight of 200 grains” (Govaerts, Verhulst 2014).

All recorded weight data is then plugged into the mathematical equations that follow the graph, supplying us with valuable results that can be utilized to analyze and compare crop management practices.

Figure 1. Measuring Dry Yield- Maize



(Image credit: Govaerts, Verhulst, 2013)

$$\text{Percentage Moisture} = \frac{\text{Fresh Weight of the Subsample} - \text{Dry Weight of Subsample}}{\text{Fresh Weight of Subsample}}$$

$$\text{Moisture Content (g)} = \text{Total Grain Yield} \times \text{Percentage Moisture}$$

$$\textbf{Dry Yield (kg/ha)} = \frac{\textbf{Total Grain Yield} - \textbf{Moisture Content}}{\textbf{Area}} \times 10$$

Results

Objective 1: Effect of Tillage Method and Crop Residue on Soil Moisture

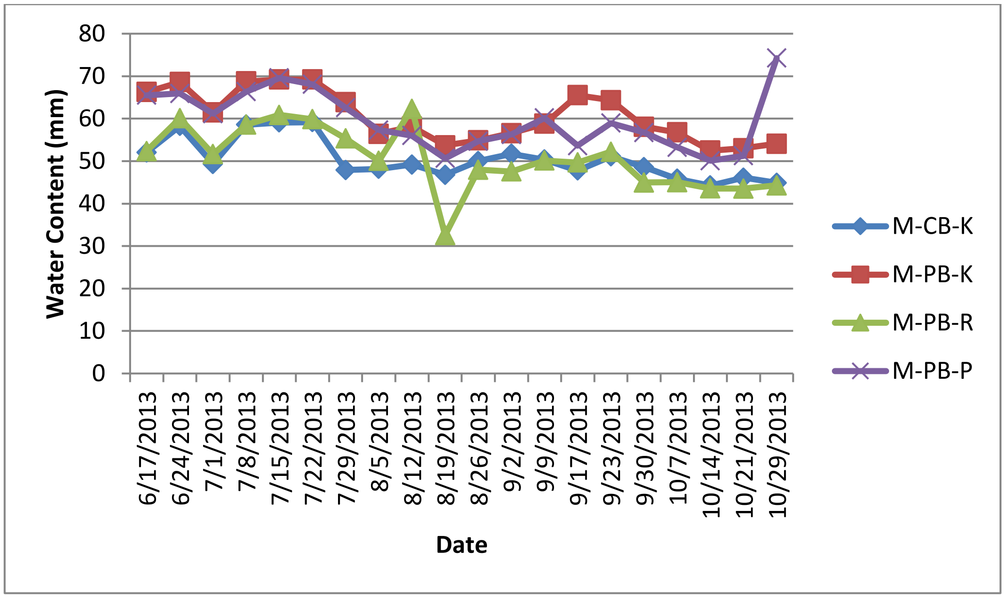
1.1 Soil Moisture

Data was collected from H9 in 2013 every seven days over a period of twenty weeks. Four treatments from eight different test plots were observed.

1) Maize- Conventional Tillage Bed- Residue Retention
2) Maize- Permanent Bed- Residue Retention

3) Maize- Permanent Bed- Residue Removal
4) Maize- Permanent Bed- Partial Residue Retention

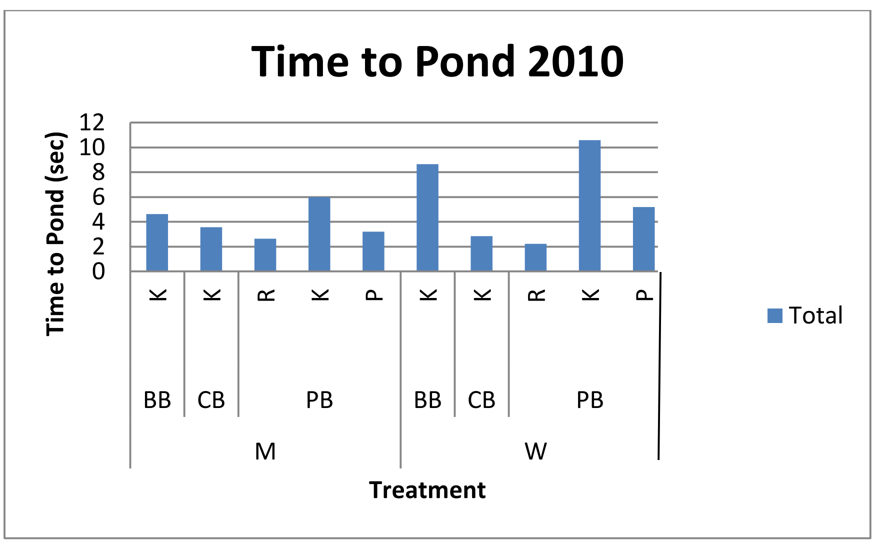
Figure 2: Soil Moisture data in H9, 2013



1.2 Time to Pond

When comparing time to pond data between maize and wheat crops, the trends are consistent. Our best scenario in both crops is retaining residue on permanent beds. The treatments with the shortest time to pond were treatments that removed residue.

Figure 3: Time to Pond 2010

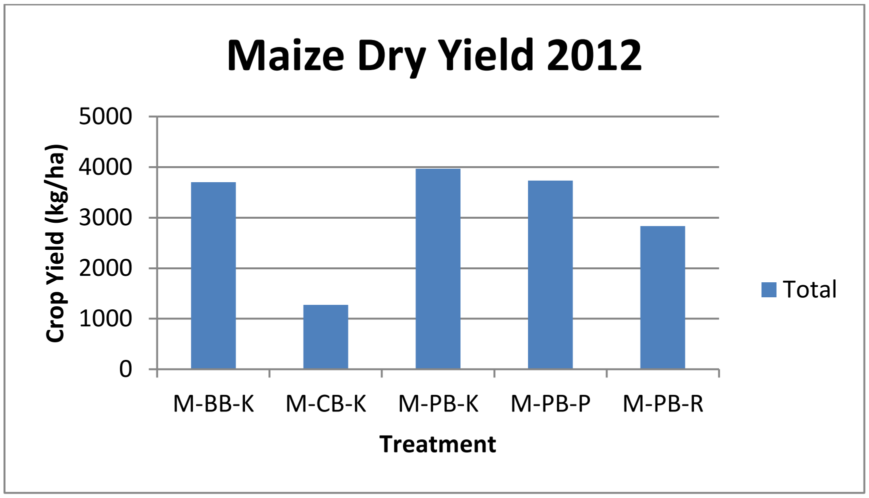


Objective 2: Effect of Tillage Method and Crop Residue on Crop Yield

2.1 Maize Dry Yield 2012

Table 4 depicts yield data from 2012. The treatment that produced the smallest yield is the M-CB-K treatment. The highest yield was observed with the M-PB-K treatment.

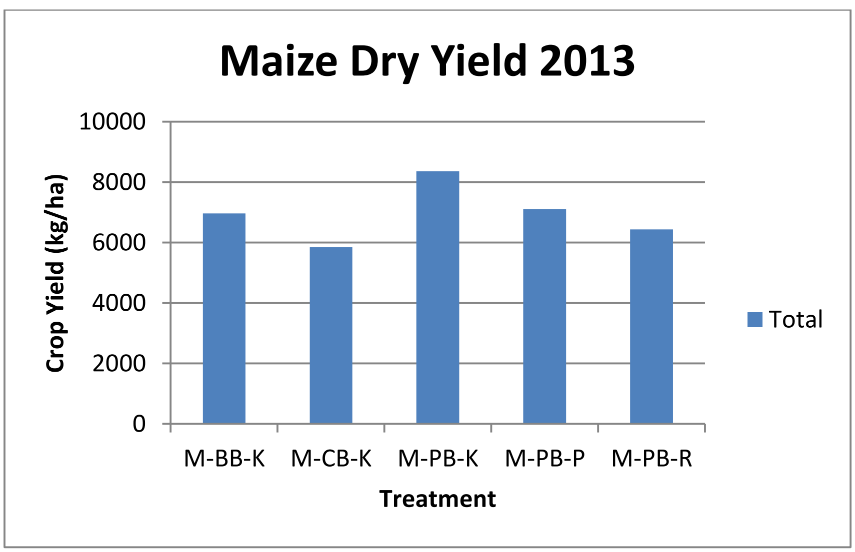
Figure 4: Maize Dry Yield 2012



2.2 Maize Dry Yield 2013

Table 5 reflects maize yield data from 2013. The lowest yield was produced by the M-CB-K treatment. The highest yield was produced by the M-PB-K treatment.

Figure 5: Maize Dry Yield 2013



2.3 Maize Dry Yield 2012 and 2013

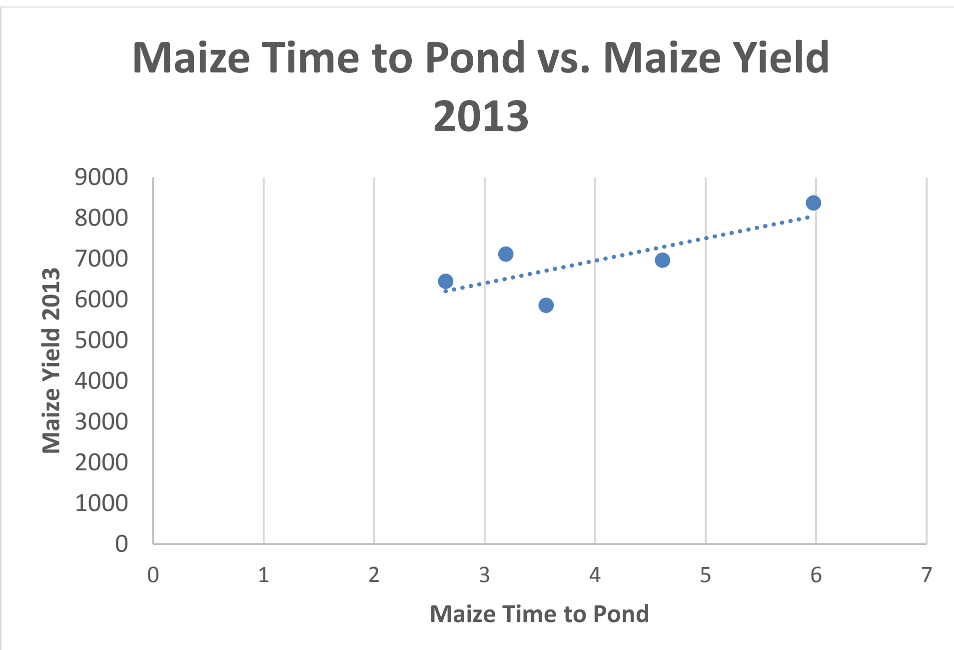
While maize yields from 2012 and 2013 are very different, both share consistent trends between the treatments. The treatment with the highest yield was the M-PB-K, and on the latter, the lowest yielding treatment was M-CB-K. Treatments M-BB-K and M-PB-P produced nearly the same results in both years.

Objective 3: Relationship between Time to Pond and Crop Yield

3.1 Time to Pond vs. Maize Yield 2013

I compared the maize yield from 2013 and the time to pond of each respective treatments. A positive trend was observed between the time to pond data and the crop yield. As the time to pond increases, we see that the yield output generally increases.

Figure 6: Time to Pond vs. Maize Yield 2013



Analysis of Results

The goal of conservation agriculture is to create a sustainable farming method utilizing the three components that influence this crop management system. In the perfect agrarian system, farmers would minimize soil impact, maintain soil surface cover, and operate the most profitable cropping rotation system.

Farmers in any part of the world, however, are faced with a multitude of factors that prevent the perfect crop management system. To quote the Dr. Ken Sayre, “there is no recipe for farming.” Each geographical location presents its’ own set of challenges and factors to account for.

What factors present challenges to implementing conservation agriculture into every farming system in the world? Markets, for one, are a powerful driving force of any agricultural system. Commodity prices may influence a farmer to continue to grow the same crop year after year when; in fact, mono-cropping may not be a sustainable option.

Tradition is also a major factor in any part of the world. While in Toluca, Mexico, I visited a wealthy farmer named Hector; who had been growing maize on the same plot of land for over 50+ consecutive years. Why did he do it? Because that’s the way his dad had done it before the land was passed on to him. Consequently, Hector has to apply massive amounts of nitrogen and other fertilizers in order to feed his nutrient-hungry maize. Hector could slash his fertilizer costs and increase his profit margin if he would adopt a more economic crop rotation, *but he won’t*. That’s not the way his dad farmed.

In some areas in the world, crop residue retention is simply not an economically viable solution, or is simply not desired. Many farming systems contain livestock and to a farmer, crop residue is free cattle food. If a farmer should not own livestock, there is a good chance that his neighbors will. In many cultures, cattle are sent to graze on neighboring crop fields without permission or prior approval. If a farmer should decide to bar neighboring livestock from grazing on his or her crop residue, he or she may wake up the next morning to find that crop residue in ashes as a punishment. Other regions such as India purposely burn their residue- even if it is against the law.

In many regions, many farmers can sell their residue for an immediate cash surplus. In areas like Iowa in the United States, the bio-fuel industry will seek to purchase crop residue and provide farmers with a premium in exchange. Livestock producers may also seek to purchase residue to feed to the animals. The idea of an instant premium can be enticing to almost anybody, and difficult to turn down.

Furthermore, much of conservation agriculture requires specialized machinery in order to practice. Many farmers throughout the world are either not comfortable investing in the technology, converting all of their current machinery or do not have the capital or credit to afford the implements. It is also observed that conservation agriculture can and is practiced with simple tools, such as a hoe, and is planted by hand or a hand-seeder.

While there are many factors at play in the world of agriculture, there are scientific bases that present many benefits to conservation agriculture; in terms of ecological sustainability to economic gain. Several of these scientific arguments are presented in the results of this report.

The first result that is consistently reproduced is that conservation agriculture produces water efficient fields. The best possible conservation agriculture scenario observed in our results is permanent beds with crop residue retention. Figures 2 and 3 demonstrate that in the plots that had M-PB-K treatment displayed high water efficiency.

Figure 3 noted that in both maize and wheat fields, permanent beds with crop retention showed a significantly higher time to pond rate. This number provides a measure of soil infiltration vs. runoff (Govaerts, Verhulst 2013). A higher time to pond provides several vital conclusions.

Our soil has a high water-holding capacity meaning that when rain pours onto the field, the plants are going to utilize the water more efficiently and can last a longer period of time between showers. Furthermore, a higher time to pond equates to reduced runoff. Reduced runoff is translated to reduced soil erosion. It is estimated that soil erosion rates of conventional tillage methods average 1-2 orders of magnitude greater than erosion under natural vegetation (Verhulst, Francois 2012). Conservation agriculture methods produce a much closer soil production rate, laying ground for sustainable agriculture.

Figure 6 demonstrates a positive correlation between time to pond and maize yield.

The second observation is conservation agriculture produces a higher yield, as evidenced in Figures 4 and 5. The maize yield trends are reproduced in both 2012 and 2013. The treatment M-PB-K produces the highest yield in both years, with the lowest performing treatment being M-CB-K. There are several hypothesizes as to why one performs better than the other.

Permanent beds provide for controlled traffic. With established furrows for tractors and other machinery to roll through, soil compaction is reduced in the beds. Conventionally tilled fields do not provide this benefit.

Zero-tillage with residue retention improves aggregate distribution compared to conventional tillage (Verhulst, Francois 2012). Zero tillage also provides for a stable soil structure with a dramatic increase in water efficiency in comparison to conventional tillage practices.

It is noted that permanent bedding with residue retention increases the organic matter content of the soil. (Verhulst, Francois 2012). A direct positive relationship has been observed between increases in water-holding capacity and increases in soil organic matter. This observation demonstrates that conservation agriculture practices have the potential to increase water-holding capacity of soil.

Soil porosity influences several agronomic factors such as infiltration, storage and drainage of water, the movement and distribution of gases, and penetrability of the soil by plant roots (Verhulst, Francois 2012). Soil pores are influenced by numerous abiotic and biotic factors. The impact of soil porosity by conservation agriculture techniques are typically observed in the topsoil.

Table 1. Pore classes with diameter and primary function

Name	Diameter	Primary function
Macropore	>30 µm	Water flow during infiltration and drainage, soil aeration, place of initiation of root growth
Mesopore	0.2-30 µm	Storage of water for plant growth
Micropores	<0.2 µm	Microbiological activity

(Table credit: Verhulst, N., Francois, I., Govaerts, B.)

Changes in soil porosity in relation to crop management techniques are observed in distribution of soil pore classes. Generally observed, micro and meso-porosity is noted to be higher in zero tillage when compared to conventional tillage.

Finally, under the management of zero till, soils continue to grow and develop root and earthworm systems, as opposed to demolishing macrofauna populations in the soil at the start of each crop season under conventional tillage methods.

Discussion, Conclusion, and Recommendations

Today agriculture faces a multitude of challenges. We are losing farmable land; crop farming draws a significant portion of freshwater away from human populations, agriculture presses a massive carbon footprint on the Earth (United Nations University, 2010), and on top of that, an additional 2 billion mouths are going to need more food in 2050 (National Geographic, 2014). Agriculture needs to produce more, while consuming less and the problem will only intensify as time progresses and the human population increases. We are not practicing sustainable agriculture today.

I don't believe that agricultural instability is even the greatest challenge we face. The challenges lie within each and every person that is a consumer and producer of food. Our farmers must be able to adapt and change- throwing away cherished traditions passed from generation to generation. Research is completely meaningless if the farmer refuses to commit to an entirely new way of thinking.

Farmed products are meaningless if the food doesn't meet the needs or expectations of the consumer. Farmers could possess the best technologies and produce massive amounts of a product, but without a market, the product is meaningless.

The question is: how can we develop new methods if the farmer won't accept them? Or produce more food if consumers push it away? How can we produce more food in the next 35 years that exceeds the total amount produced since the birth of agriculture? How do we accomplish this task while using fewer resources than we have today? It is a daunting task we face with no easy answers.

Dr. Borlaug sparked the Green Revolution during his lifetime. His success lifted several million people from a life of hunger and poverty, and saved many billion people. He spoke frequently saying that his accomplishments would not be enough. The world is in desperate need for a second Green Revolution. Do we have the available knowledge and technology for our next agricultural defining moment? I believe that we do. I believe what is preventing large strides in agriculture are various obstacles such as farmer adaptability, consumer hesitancy, natural resource depletion, bureaucratic red tape, lack of 3rd world credit, distribution networks and a post-harvest plan.

A sustainable agriculture system is integral to the future of mankind. As stated in my results section, conventional till methods produce high soil erosion rates. In addition to erosion, conventional tillage practices are quickly increasing production costs (Verhulst, Francois 2012). These input factors include improved varieties and fertilizers in a combination with inefficient usage to result in higher input costs.

Conservation agriculture is a proposed method of crop management that is both high-yielding as well as sustainable. The conservation agriculture methods follow the three components introduced in the beginning of this report in order to create a sustainable system of crop farming. Those components are:

1) Reduction in tillage- in which the objective is to achieve zero tillage. This component may also fall under a controlled till method that does not disturb more than 20-25% of the soil surface.

2) Retention of crop residue and maintain soil surface cover- the objective of this component is to protect the soil from water and wind erosion, improve water efficiency, and enhance soil properties in terms of a long-term sustainable production.
3) Utilizing crop rotations- by using a diverse crop rotation system, we can help moderate possible weed, disease, and pest problems as well as take advantage of the positive benefits of some crops on soil conditions and increase the productivity of the next-season crop.

While there are a wide variety of factors to consider, the conservation agriculture model can be applied to a large range of cropping conditions. When considering implementing a conservation agriculture model into any planting system, factors that must be accounted for include pest and weed control tactics, nutrient management, and crop rotation systems. Certain tillage methods have greater advantages in certain conditions. For example, under gravity-fed irrigated conditions, a permanent raised bed system with furrow irrigation may be more suitable and sustainable as opposed to a reduced or zero tillage system on the flat (Verhulst, Francois 2012).

While the science shows that conservation agriculture can indeed be a viable and sustainable solution to our agricultural crisis, why don't we see it in every farm in the world? Implementing a new agriculture method comes with many challenges and hurdles. How do you convince a farmer to invest in the tools and implements needed in order to successfully practice conservation agriculture?

The message that I heard so frequently at CIMMYT could not be more true- "the biggest impact you can make is to involve the farmer in the research process." What better way to build faith and trust then to involve the farmer in the development process? Valuable input would be well received by both parties, and together they would work towards a mutual goal.

The challenges are great, and the problems are real. However, based on my time at CIMMYT, I don't believe we are beat yet. There is a lot of determination in the agricultural research field, and I can't wait to see what happens next.

Personal Experiences

I had, without a doubt, one of the most incredible experiences at CIMMYT in Mexico. This was truly an amazing learning experience that will have a profound impact on the rest of my life. Having the opportunity to explore a new culture and work with some of the top agricultural scientists in the world is an incredible gift. Many thanks to CIMMYT and the World Food Prize.

Reflecting over the eight weeks that I spent in Mexico, I can't help to call myself lucky. I walked in the very fields that Dr. Norman Borlaug revolutionized the agricultural industry and where he sparked the Green Revolution. I sat in the same office where he spent hundreds of hours scrutinizing data and working on his latest and greatest projects. I call myself lucky because of the amazing people that I worked with. I had the opportunity to work with Dr. Bram Govaerts, who would be recognized as the 2014 Borlaug Field Award recipient. In addition, I had the great honor of meeting Dr. Sanjaya Rajaram- the 2014 World Food Prize laureate and predecessor of Dr. Borlaug who has done incredible work with wheat at CIMMYT.

The outstanding people at CIMMYT immersed me into the agricultural industry and exposed me to many aspects of research. Whether it was analyzing roots in the lab or visiting native farmers on their fields, I gained a sharpened perspective on the research field and the many challenges that come with it. Being a part of the Borlaug-Ruan Internship has made it definitively clear that agriculture is the right path for me.

In addition to working with agriculture, I had many fantastic cultural immersions. I visited many culturally significant and historic locations throughout Mexico. I ate some amazing dishes that are exclusive to the country. And finally, I met some of the coolest people that my paths would never have crossed with had I stayed in the United States.

This is probably the most significant realization that I brought home with me. "Alone we can do so little, but together we can do so much." This quote from Hellen Keller resonates in my mind when I reflect on my trip. I realize just how significant other people in the world are in our success. We have so much to learn from people of other cultures.

Figure 1: A “selfie” with my Mexican agronomists after a hard day of work

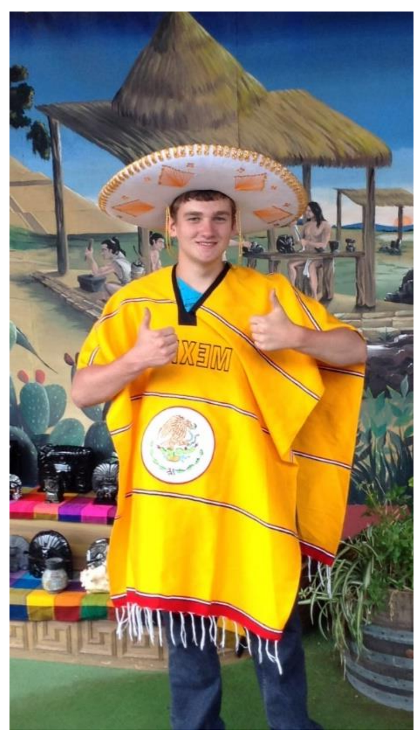
I chose to include this picture to demonstrate what I took away from the people. On the day this picture was taken, myself and a team of Mexican agronomists spent the whole day in a wheat field measuring various data and performing numerous tests. They spoke no English, and my Spanish was awful (and there was no translator). Despite the communication barrier, I had learned so much from them by the end of the day.

The combination of cultural and research exposure I received in Mexico is unparalleled to any experience I have ever had. Having the opportunity to immerse myself in a world-known research institution and into an entirely different culture for eight weeks changed the way I perceive the world and the challenges we face.

The Borlaug-Ruan Internship lit a clear path for me to pursue a career in agriculture. Before my internship, I might have told you that I was considering a career in agronomy or some other technical ag field. I now know that I want to work at an international scale with agriculture and food security. In addition, the conservation agriculture program at CIMMYT has pushed me to specialize in sustainability. I am now a first-year student at Iowa State University pursuing a major in Global Resource Systems and a minor in sustainability.

My Borlaug-Ruan Internship has made me so excited to work in agriculture, and the people that I met has made me confident that we are moving in the right direction in agriculture and achieving global food security. Thank you for the incredible opportunity.

Pictures



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