Tillage Effects on Soil in Southern Guatemala

A case study using remote analyses

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Abstract

Guatemala lacks soils information, yet soils knowledge is essential in order to reduce environmental impacts, improve food security, determine best farming practices, and increase crop yields(Karlen et al., 1994). Reasons for the lack of information include lack of personnel and difficulty accessing equipment. This study's objective is to remedy those shortcomings via (a) the creation and sending of a soil testing kit, (b) corresponding manual written for non-soil scientist use, and (c) mechanisms to send data to ISU for thorough analysis. The soil testing kit included basic laboratory materials used to test essential soil characteristics such as soil aggregate stability, aggregate size, pH, color, and structure. The field site is an experimental farm owned by the non-profit sustainable agriculture organization, Semilla Nueva. Semilla Nueva has overseen a tillage experiment from 2013 to the present but has not collected soil health data. The present study utilized established experimental plots already subjected to three different management treatments (no-till, tilled, and burned) in order to better understand how different tillage practices affect soil health characteristics in this region. Preliminary results suggest that soil aggregate stability, pH, exchange capacity, and soil structure grade were all negatively impacted by tillage and plant residue burning.

Introduction

Guatemala is many miles away from Iowa, but is close to sharing the same longitude, as seen in Figure 1. Apart from this similarity, Guatemala differs in its taxonomy of soils and its lack of soils data compared to Iowa. In order to understand more about the soils of Guatemala, I contacted Semilla Nueva, the non-profit organization dedicated to more sustainable, small farming operations in Guatemala. I worked with them during the summer of 2016 and wanted their help in tackling this objective. The more structured objective became to understand how different tillage practices affect soil health characteristics in a Pacific Coast region of Guatemala. Determining how tillage types change soil characteristics such as stability or nutrient holding capacity will help in deciding how to manage a soil for optimal crop production. A manual outlining how to test soil for simplistic, yet crucial, soil properties was created and sent to Guatemala in a kit with all necessary soil testing equipment. The manual details how to test pH with distilled water, pH with sodium chloride, soil color, soil aggregate content, and Cation Exchange Capacity on soil under three different tillage treatments. Soil color determines amount of organic matter and thus carbon storage. Soil structure and aggregate stability helps determine how well components of soil hold up against disturbance(Beare and Hendrix, 1994). pH of soil/water solution determines how acidic or basic something is while pH soil/salt solution determines reserve acidity. Exchange capacity is the difference between the water and salt pH and indicates buffering ability(Kibblewhite et al., 2008). The manual was sent along with a handheld pH meter and other basic supplies to an experimental farm in Guatemala. This farm is owned by the non-profit, Semilla Nueva, and situated at 14°21'51.03"N , 91°33'7.36"W latitude and longitude. With the data gleaned from these tests, theories about what diagnostic tests are affected by mechanized churning of soil or "tilling" can be developed. Following an Analysis of Variance (ANOVA) and quasi-quantitative rating of soil structure, color, and aggregate stability, preliminary results suggest that soil aggregate stability, pH, exchange capacity, and soil structure grade are affected by management practices.

These findings can be used to further explore relationships between health of Vertisols and types of tillage and soil management under row-crop agriculture. Understanding how Vertisols react to tillage is especially important due to the inherent challenges of farming on soils with high levels of smectitic clays that produce deep, wide cracks following wetting and subsequent drying periods(Coulombe et al., 1996). These findings can also be applied to areas of the world under similar climatic patterns and similar soil characteristics. Seeing as Vertisols are “the most widely dispersed soils in the world”(Latham et al., 1987), discoveries within this order could have a widespread impact on farming practices around the world.

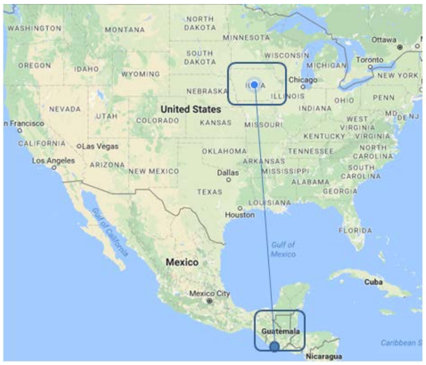

Figure 1: Iowa and Guatemala share similar longitudes but contain different soils.

Figure 2 shows randomly distributed plots at the experimental farm in Guatemala
A=No-till; B=Tilled; C=Burned

Methods and Results

An instruction manual was created detailing how to collect data on five soil parameters in order to analyze how soils differ under different management practices in the Suchitepequez region of Guatemala. This instruction manual included information detailing how to easily conduct these tests in areas without sophisticated laboratory equipment and while using common household items. A cardboard box containing a binder with the printed manual, a handheld pH meter (accurate to 0.1 pH unit), Kimwipes (to clean utensils), a squirt bottle, and other common lab supplies was sent to Guatemala City at the beginning of February 2017. Samples of soil were taken on February 25th, 2017 and measurements were completed on February 27th, 2017. Five random samples of soil were taken from the top 10 cm of each plot corresponding to plots A, E, and F as seen in Figure 2. These plots received tillage treatments no-till, tilled, and burned respectively.

Soil Color

Two soil samples from the same sample (such as from the fourth sample of plot A1), were arranged in diagonal squares on a 8.5X11 inch sheet of white paper divided into equally into four quadrants. An empty coca-cola bottle was placed in one of the two remaining squares to act as a reference color in case lighting during picture-taking was variable (Figure 3). The last square was left blank to serve as another constant color between the pictures. Natural sunlight was used instead of electrical lighting due to weak lighting fixtures at the farm center. Once the pictures were sent back, a Munsell's soil color book was used to identify value and chroma of the samples. Due to inconsistent photo quality, the better-lit soil quadrant was selected as the sample to note color from. No discernible differences in soil color were detected. This might have been in part because of the difficulty in reading soil color from a lit computer screen instead of seeing the soil sample under natural light in the field.

Figure 3: An example of soil structure and color quasiquantitative analysis

Soil Structure

Soil structure was assigned based on the size of the dominant aggregate identified in soil color pictures. The National Resources Conservation Service Field Guide was used to classify both the general structure and grade of the aggregates (Staff, 1993). The general structure of all of the treatment types was subangular blocky. The results are presented in Figure 4 with more no-till samples exhibiting a moderate structure grade.

Table 1: Ranking for soil structure grade

Structure Grade	NRCS Field Guide Definition
Weak (1)	mixture of whole and broken units
Moderate (2)	mixture of mostly whole units and some broken units
Strong (3)	separates mainly into whole units

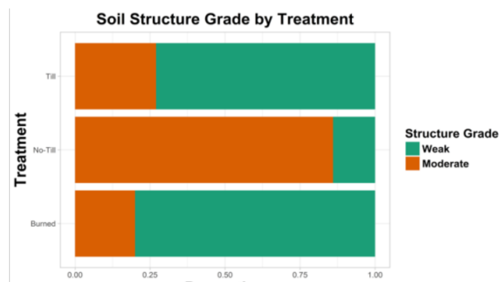

Figure 4: No-till exhibited a higher proportion of higher grade soil structure

Soil Aggregate Stability

Soil aggregate stability was analyzed based on a numerical rating system (Table 2). Two teaspoons of each dry soil sample was photographed before the addition of three teaspoons of tap water. Then subsequent pictures were taken at 10 and 30 seconds after the addition (Figure 5). After cropping and organizing the pictures according to plot and sample id, a number between zero and two was assigned based on how the aggregates reacted to the water . If the aggregates broke down completely, the sample was given a two, and if the aggregates remained fully intact, the sample received a zero. Samples given a one had partially intact aggregates, which served as a middle point for the two extremes. No-till was the only treatment with stable aggregates (Figure 6)

Samples from the burned plots had the most unstable aggregates and exhibited hydrophobicity. I noted that half of the burned plot samples seemed to keep the water from infiltrating the sample. This may be due to the creation of hydrophobic compounds during the residue burning process.

Table 2: Ranking for soil aggregate stability

Aggregate Stability	Definition
Stable (0)	All aggregates remained whole at the end of 30 seconds
Partially Destroyed (1)	Most aggregates remained whole at the end of 30 seconds
Completely Destroyed (2)	None of the aggregates remained whole at the end of 30 seconds

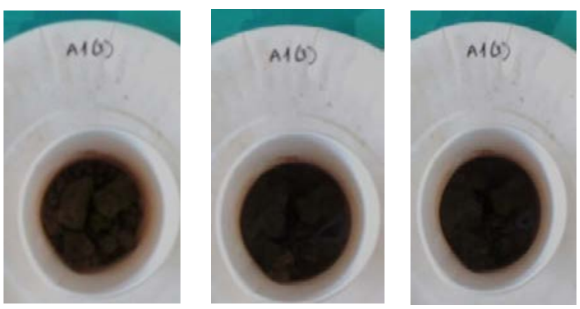

Figure 5: An example of a sample receiving a ranking of stable (0)

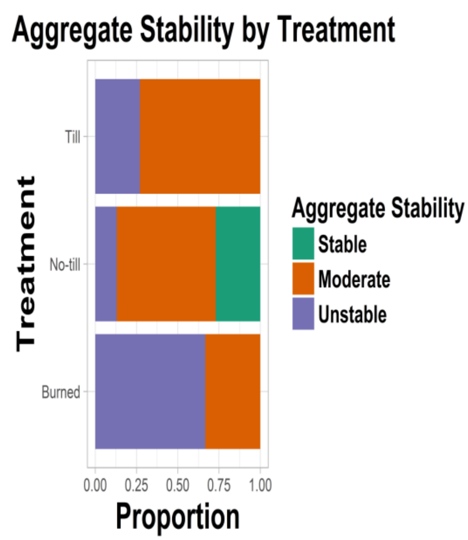

Figure 6: No-till exhibited a higher proportion of stable aggregates

pH with Water and pH with Sodium Chloride

A handheld pH meter was calibrated and sent to Guatemala where each of the 15 samples per treatment were measured twice using a 2:1 water-to-soil ratio and twice using a 2:1 0.01 M sodium chloride solution. These measurements were recorded in a google sheet by the Guatemalan tester and shared with the author by email attachment.

<u>ANOVA</u>

Analyses were performed using a 2-way ANOVA with interaction for Treatment and Plot, followed by adjustment using Tukey's HSD. Differences in pH means are likely due to different treatments. This test is appropriate for this study because the plots and samples were randomly distributes, which meets the assumptions of this test. ANOVA tests to see if the variance caused by the interaction between the samples is much larger when compared to the variance that appears within each group. Once the within treatment variation (the Sum of Squares within a treatment) is calculated, it is divided by the degrees of freedom, which is one less than the number of treatments (3-1=2). With this information, the F variable, which is the ratio of two independent chi-square variables divided by their respective degrees of freedom, can be found. This is simply a ratio of the between treatment variance by the within group variance. Thus, if the between treatment variance is smaller than the within treatment variance, the means are not significantly different, and the null hypothesis stands. The ANOVA also produced a probability that the variable in question was not responsible for the differences seen. This probability was used to evaluate if the presence of tillage treatments was responsible in differences seen in pH readings. Both pH of water/soil and salt solution/soil had significant differences with an alpha=0.05.

Next, ran Tukey test in R to see if significant differences between specific treatments. Tukey is just a complement to the ANOVA – so I did an ANOVA followed by adjustment of the p-values using Tukey's Honest Significant Difference. It's more conservative than just ANOVA, meaning it takes larger differences in means to produce a p-value of less than 0.05. Tukey test indicates significant differences between No-till/Till in pH with water and No-till/Burned in pH with salt according to adjusted p-values (Table 3). The adjustment means that the p-value was able to stand true for multiple comparisons between treatments. This test produced interesting results because even though the difference between treatment pH could be just 0.14 of a pH unit, the variance could be large enough to be a statistically significant difference. No significant difference was observed between plots when a Tukey test was run between plots. While the differences in mean pH between the treatments are not biologically significant in terms of plant health (Figure 7), the results are statistically significant, and warrant further research. This further study could uncover whether these results are real or simply an artifact of the sampling method or pH meter testing.

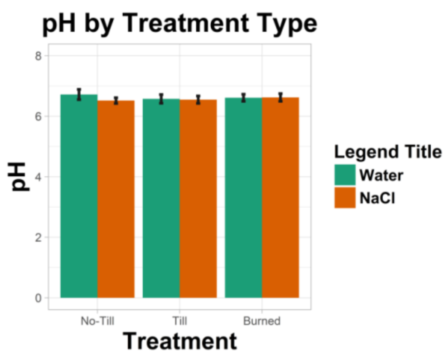

Figure 7: The relationship between pH and tillage appears small but is significant. Error bars are ±1 SD.

Table 3: Tukey test results of pH with water and salt indicates statistically significant differences between treatment mean pH at alpha=0.05 level

Treatment	p-value (adj)
pH with water No-till/Till	0.010*
pH with salt No-till/Burned	0.025*

Exchange capacity was calculated by averaging the pH for each treatment and then calculating the difference between the pH with water and the pH with salt solution. If the pH with the salt solution was lower than the pH with water, then the sodium in the salt solution was kicking off hydronium ions that were housed on negatively-charged exchange sites on soil particles and the soil possesses Cation Exchange Capacity (CEC). The more sites available for cations to latch on to, the better a soil is at buffering against large changes in pH if there is an influx of cations. If there isn't a difference between the two pH measurements, then the soil exhibits Point of Zero Charge or PZC. If a soil has more positively-charged sites available, then the soil would have Anion Exchange Capacity (AEC). The no-till and tilled plots exhibited Cation Exchange Capacity while the burned sample exhibited Point of Zero Charge exchange capacity (Table 4). No-till was able to hold more cations on exchange sites on soil particles than till or burned soil.

Table 4: No-till appears to have the highest buffering capacity

Treatment	Average pH water	Average pH salt	Difference	Exchange Capacity
No-till	6.7	6.5	0.2	CEC
Till	6.6	6.5	0.1	CEC
Burned	6.6	6.6	0.0	PZC

Conclusion

Preliminary results indicate that soil color and general soil structure were not impacted by tillage type. Soil aggregate stability, pH, exchange capacity, and soil structure grade appeared to be negatively impacted by tillage and plant residue burning. More studies need to be done in different parts of Guatemala and with other methods of analysis. I chose to pick the simplest methods with minimal equipment, but the accuracy of these tests could also be a further area of research. This information could be used to push for more adoption of conservation tillage practices if more correlations are found between poor soil structure and /or depleted cation exchange capacity and decreased yields. Yields of crops such as maize are vital to the survival of small-holder farms in Guatemala, and conserving the soil they rely on is of high importance. Due to the challenges of farming on Vertisols with their shrink-swell clays, soils information is especially significant for Guatemala.

Acknowledgements

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