INVESTIGATING THE EFFECT OF TILLAGE AND COVER CROPPING ON SOIL HEALTH PARAMETERS IN TEXAS WINTER WHEAT

An Undergraduate Research Scholars Thesis

by

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RESEARCH COMPLIANCE CERTIFICATION

Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

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This project did not require approval from the Texas A&M University Research Compliance & Biosafety office.

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ABSTRACT

Investigating the Effect of Tillage and Cover Cropping on Soil Health Parameters in Texas Winter Wheat

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Managing for healthy soil through conservation practices is key to increasing the production of global agriculture and resources in a sustainable manner. In Texas, a major agricultural state, there are low adoption rates of soil conservation practices by producers due to incomplete regional soil health information. Wet aggregate stability (WAS) is an important physical indicator that measures how resistant soil is to breakage in water. WAS plays a role in important soil functions and characteristics such as soil structure, infiltration, water/chemical, and transportation. WAS often refers to the stability of macroaggregates (>250 μm) as they are especially sensitive to soil use and management practices in comparison to microaggregates. The objective of this study was to assess the impacts of tillage intensity and summer cover cropping on macroaggregate WAS and winter wheat yield. This research was conducted for 3 years in two locations (Beeville and Thrall, TX) which are located on different soil series (Parrita sandy clay loam and Burleson clay, respectively). Soil samples were manually wet sieved for WAS quantification. The impacts of these practices on WAS and wheat yield were variable across both locations. There was a minimal effect of tillage on WAS in both locations while the sorghum cover crop did increase WAS in Beeville. There was an interaction between tillage and crop cover type in Thrall WAS. We further investigated the relationship between WAS and wheat yield. A correlation exists between WAS and wheat yield with weak fits, but sorghum has the best fit (R^2 = 0.83, P-value = <.0001). These results are a step toward understanding how well aggregate stability can be used as an indicator of soil functions such as productivity. With only some of the practices influencing WAS positively within 3 years of implementation, a long-term study would better identify when we observe the benefits of the selected sustainable practices on WAS in these Texas soil types.

DEDICATION

To my family, friends, and instructors for all the support and encouragement throughout the research process.

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All other work conducted for the thesis was completed by the student independently.

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NOMENCLATURE

CT	Conventional tillage
DI	Deionized water
EPA	Environmental Protection Agency
ha	hectare
ICL	Integrated crop-livestock
kg	kilogram
NT	No-till
NASS	National Agricultural Statistics Service, USDA
NRCS	Natural Resources Conservation Service, USDA
OM	Organic matter
SH	Soil health
SHPP	Soil health promoting practice
SOC	Soil organic carbon
SOM	Soil organic matter
USDA	United States Department of Agriculture
WAS	Wet aggregate stability

1. INTRODUCTION

1.1 Overview

As sustainability continues to be a pressing topic in agriculture, soil conservation efforts have gained more scientific and political support. In the Agriculture Improvement Act of 2018 (i.e. 2018 Farm Bill), the United States Congress recognized the importance of protecting the nation's soils by promoting soil health practices such as cover cropping, crop rotation, no-tillage, and prescribed grazing (Harrigan & Charney, 2019). Soil health, previously referred to as soil quality or soil tilth, presents soil as a vital living system which can sustain and promote biological activity and provide ecosystem services that support plant, animal, and human health (Doran & Zeiss, 2000; Natural Resources Conservation Service, 2018). Even with increased interest in conservation agriculture, there are low adoption rates of soil health promoting practices (SHPPs) in the south-central region of the United States, including Texas (Bekewe, 2021; Zulauf & Brown, 2019a, 2019b). Thus, there is a need for more regional and localized understanding of soil health and conservation practices to help encourage the implementation of SHPPs in Texas (Bagnall et al., 2020; Bekewe, 2021; Carlisle, 2016).

Fully assessing soil health requires a holistic set of measurable physical, chemical, and biological indicators to evaluate the complex dynamics within a soil system (Allen et al., 2011; Cardoso et al., 2013). By taking a holistic approach, we can improve our ability to understand the soil health condition or trend of a soil as well as give better insight on how to influence and predict a soil's responds to management and land use (Allen et al., 2011). However, examining individual or a select few indicators can give a baseline understanding of soil health condition.

One important physical indicator is wet aggregate stability (WAS) which measures how resistant soil aggregates are to disassociation when disturbed by wetting events (i.e. rainfall and irrigation) (Allen et al., 2011; Flynn et al., 2020). The stability of soil aggregates influences crop yields as it plays a role in important soil functions such as infiltration, water/chemical transport, microbial activity, and soil organic matter/carbon accumulation (Abid & Lal, 2008; Allen et al., 2011; Cardoso et al., 2013; Stott, 2019). Soil aggregates are a major part of soil carbon dynamics as stable aggregates can protect, bind to, and store carbon (Allen et al., 2011; Paul et al., 2013). Often used to describe soil organic matter (SOM) dynamics, the concentration of soil organic carbon (SOC) is a primary indicator as it influences many important soil processes like nutrient storage, aggregate stability/soil structure, water holding capacity, and microbial activity (Abid & Lal, 2008; Allen et al., 2011; Cardoso et al., 2013; Stott, 2019).

In Texas, WAS has been used to analyze the impacts of conservation agricultural practices such as no-till (Bordovsky et al., 1999; Flynn et al., 2020), integrated crop-livestock systems (Fultz et al., 2013), and cover- and double-cropping (Schirmacher, 2019). Many of these studies measure WAS in agricultural systems managed under SHPPs for more than a decade (Bordovsky et al., 1999; Fultz et al., 2013; Wright & Hons, 2005) and are primarily located in the Texas High Plains and Rolling Plains (Acosta-Martínez et al., 2004; Baumhardt et al., 2017; Bordovsky et al., 1999; Fultz et al., 2013; Teague et al., 2011). However, less is known about how recently adopted SHPPs, namely summer cover cropping and tillage, influence WAS in Central and South-Central Texas.

1.1.1 Objectives

This study focuses on wet macroaggregate stability as a testing indicator to measure soil health in two Texas winter wheat systems in different ecoregions, the Texas Blackland Prairies and the West Gulf Coastal Plains. We investigated how WAS responds to five years of no tillage and cover cropping practices compared to conventional tillage and summer fallow. To gain further insight into the effects of SHPPs on soil health and agricultural productivity, we also compared WAS with crop production (yield). We hypothesized that:

1. WAS would increase under no tillage systems compared to conventional tillage systems due to the disruption mechanized tillage can have on soil structure,
2. Use of summer cover cropping would increase WAS compared to fallow systems, and
3. WAS and wheat yeild are positively related.

Measuring WAS and its relationship to crop yeild will bring more localized insight on how well SHPPs affect soil health in winter wheat production systems in Texas.

1.2 Literature Review

1.2.1 Soil Health

An estimated 850 million tons of topsoil was lost in the Southern Plains over a one year period during the 1930s Dust Bowl (Tatarko et al., 2013). Such severe degradation of the land created the foundation of soil conservation in America. The establishment of the USDA Soil Conservation Service in 1935, now the Natural Resources Conservation Service (NRCS), originally focused on the threat of soil erosion and creating conservation practices (Helms, 1992). Now the mission of the NRCS has expanded to include other natural resources and the soil conservation efforts currently center around soil health (Natural Resources Conservation Service, 2022; Stewart et al., 2018). The modern soil health movement emphasizes soil as a complex, living system which provides important ecosystem services and plays a key role in global cycles (Lehmann et al., 2020; Natural Resources Conservation Service, 2022). Healthy soils, especially the microorganisms within them, are often viewed as an integral part to solving today's sustainability issues such as climate change, food security, and even plastic pollution (Allen et al., 2011; Lehmann et al., 2020; Sivan, 2011).

To meet the world's food production demands and sustainability goals, there is great interest within the agricultural sector to investigate and promote cropping systems and practices which protect or enhance soil functions and properties without jeopardizing crop yields (Cardoso et al., 2013). Such practices generally include no or reduced/minimal tillage, cover crops, diversified crop rotations, and prescribed grazing are often referred to as "conservation practices" (Natural Resources Conservation Service, 2017) or, more specifically, "soil health-promoting practices" (SHPPs) (Bagnall et al., 2020). Due to the complexity of soil properties and processes, multiple different indicators are used to quantify, evaluate, and identify the impact of conventional and SHPPs on soil health (Allen et al., 2011; Lehmann et al., 2020; Stott, 2019). Soil health indicators are grouped into three categories (physical, chemical, and biological), but many of the indicators are involved in soil processes which span these categories (Allen et al., 2011; Lehmann et al., 2020; Stewart et al., 2018). When examined collectively, these indicators indirectly measure the functions and processes within a soil relative to a set threshold of target values (Allen et al., 2011). By incorporating physical and biological parameters alongside the traditional soil chemistry and fertility approach, we can improve our ability to understand the baseline soil health status of a soil as well as give better insight on how to influence and predict a soil's responds to management and land use (Lehmann et al., 2020; Stott, 2019).

The implementation of SHPPs varies across America not only regionally but also changes by state and within each state (USDA-NASS, 2017). According to the 2017 Census of Agriculture, the majority of no-till acreage is concentrated in the Midwest, Northeast, and the eastern-half of South regions, whereas the adoption of reduced tillage practices are concentrated along the Mississippi River and the Great Lakes region (Figure 1.1) (USDA-NASS, 2017). When compared to 2012, there was a clear shift towards reduced tillage and away from intensive or conventional tillage practices (Zulauf & Brown, 2019b). However, cover crops are underutilized as a SHPP across the nation (Zulauf & Brown, 2019a). In 2017, cover crops were planted predominately in the Eastern US, especially in the states surrounding the Chesapeake Bay.

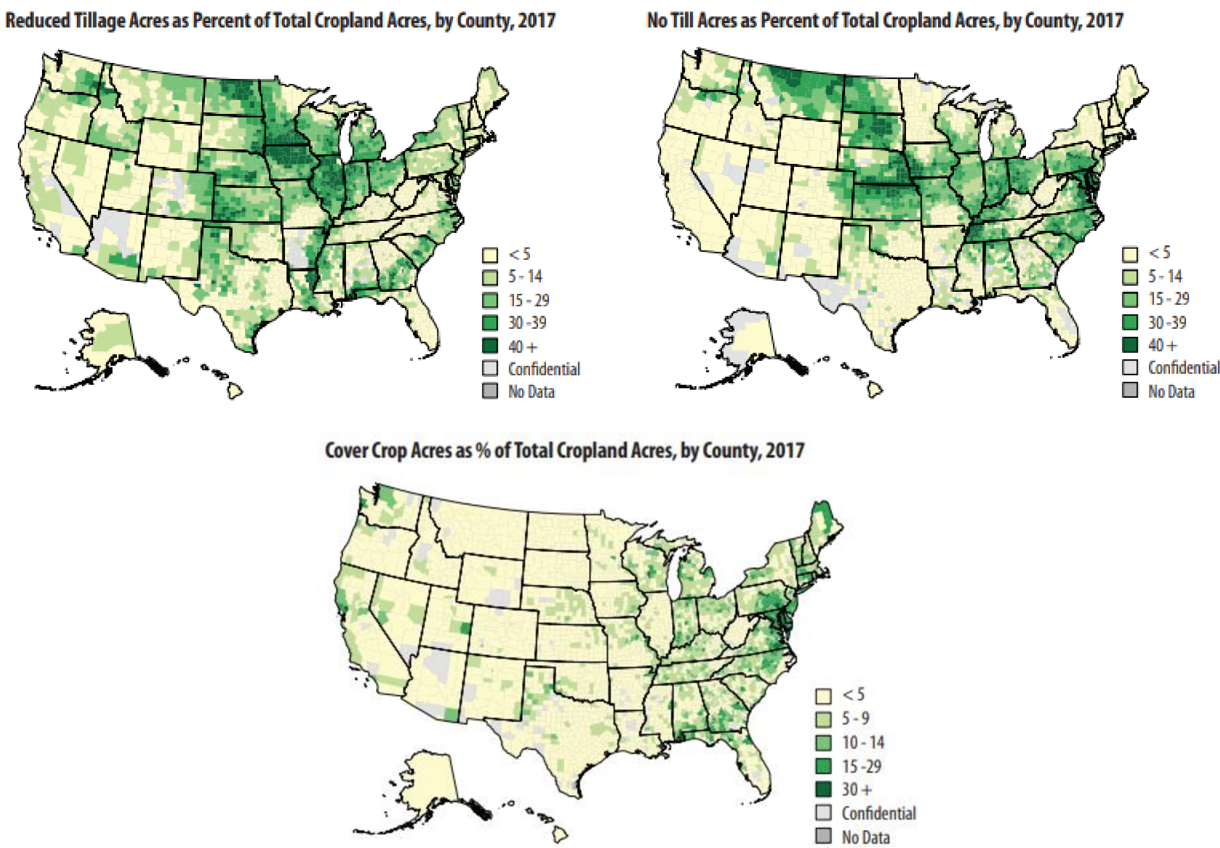

Figure. 1.1: Acres of conservation tillage and cover crop adoption as a percentage of total US cropland acres by county. Source: 2017 Census of Agriculture (USDA-NASS, 2017)

Even though Texas is consistently in the top 10 agriculture-producing states (USDA-ERS, 2022) with approximate 74% of the state's total land area consisting of agricultural land, more than 127 million acres (Hundl, 2021), there is a lack of published research on soil health and SHPPs across Texas (Schirmacher, 2019; Stewart et al., 2018). The lack of regional and local soil health data and understanding contributes to the low adoption rates of SHPPs by landowners (Carlisle, 2016). As of 2017, only 3% of Texas cropland acres were planted with cover crops, 15% implemented no-till, and 31% used reduced tillage practices (Zulauf & Brown, 2019a, 2019b).

1.2.2 Aggregate Stability as a Soil Health Indicator

Physical properties of soil are primarily related to the structure of the soil matrix and how soil and water move into and throughout the soil (Allen et al., 2011; Stott, 2019). These properties also influence weathering and erosion processes as well as impact biotic activity such as germination and root growth (Allen et al., 2011).

A key physical property and soil health indicator, includes the stability of soil aggregates. Aggregate stability refers to how resistant the aggregates are to physical stress and disturbances (Abiven et al., 2009; Allen et al., 2011). Stable aggregates help facilitate hydraulic, chemical, physical, and biological processes which makes it one of the most well rounded and versatile indicators (Amézketa, 1999; Stott, 2019). For example, aggregates physically protection SOM from degradation (Six et al., 2004), act as microsites for microorganisms and influence microbial community composition (Cardoso et al., 2013; Six et al., 2004), and partially determine water storage and movement (Allen et al., 2011; Six et al., 2004; Stott, 2019). When aggregates are weak and are subjected to physical disruptions such as rainfall, irrigation, or tillage, they break apart and disperse (Cardoso et al., 2013; Six et al., 2004; Stott, 2019). This breakdown not only makes soil more suspectable to erosion, but it also causes the dispersed soil to fill macropores and physically inhibit soil oxygenation as well as release stored organic carbon (Cardoso et al., 2013; Six et al., 2004; Stott, 2019).

Aggregates are commonly classified in two size categories: macroaggregates (> 250 µm) and microaggregates (20 - 250 µm) (Amézketa, 1999; Six et al., 2004). Macroaggregates have been shown to be related to soil C dynamics and nutrient cycling and is more susceptible to management practice and land use change (Cardoso et al., 2013; Six et al., 2004; Stott, 2019). Microaggregates, a dominant component of macroaggregates, are more resilient to management compared to macroaggregates and are essential to the long-term storage and stabilization of SOC (Cardoso et al., 2013; Six et al., 2004; Stott, 2019). The most used and well accepted aggregate stability methods are based on macroaggregates and their stability in water due to the sensitivity of macroaggregates to management (Amézketa, 1999; Stott, 2019). WAS, also known as water-stable aggregates, refers to how resistant soil aggregates are to breakdown caused by wetting events (e.g. rainfall) (Amézketa, 1999; Stott, 2019).

1.2.3 Use of Aggregate Stability in Texas

In Texas, aggregate stability has been used as a parameter to analyze soil health under various research objectives. In this brief review, only studies which examined aggregate stability in Texas agricultural systems were included.

Studies in the Texas High Plains and Rolling Plains have used aggregate stability to assess the impact of integrated crop-livestock (ICL) management (Acosta-Martínez et al., 2004; Fultz et al., 2013) and grazing (Baumhardt et al., 2017; Teague et al., 2011) on soil properties. Acosta-Martínez et al. (2004) and Fultz et al. (2013) both compared the same continuous cotton system to an ICL system consisting of a cotton-forage-beef cattle plots after 5 years and 13 years of implementation, respectively. Both demonstrated an increase in aggregate stability under the ICL system, especially in the perennial pastures, relative to the cotton system. Additionally, Fultz et al. (2013) reported that larger water stable aggregates were formed, and SOC storage was enhanced in ICL system after 13 years of establishment. This is likely due to the diversified ICL system benefiting from multiple residue inputs, perennial vegetative cover, and NT planting (Acosta-Martínez et al., 2004; Fultz et al., 2013). Comparatively, Baumhardt et al. (2017) found the addition of cattle grazing in a dryland wheat-sorghum-fallow system located in Texas High Plains did not influence the distribution of non-water-stable nor water-stable aggregates in one 3-year rotation cycle. However, the difference in implementation periods is likely a key driver in the opposing results. When studying the effect of grazing intensity in tall grass prairies in North Central Texas, Teague et al. (2011) saw that aggregate stability and other physical soil properties were the poorest under heavy continuous grazing relative to ungrazed, multi-paddock grazing and light continuous grazing treatments. This is consistent with the current consensus that intensive or overgrazing often leads to soil degradation due to increased soil disturbance and decreased vegetative cover (Teague et al., 2011).

The effect of tillage management often includes aggregate stability or distribution measurements. Physical disruption of soil aggregates, especially less stable macroaggregates, often leads to a break down in soil structure and shifts the aggregate size distribution towards microaggregates (Six et al., 2004; Wright & Hons, 2005). A 20-year field experiment in central Texas along the Brazos River floodplain found that tillage had a minimal impact on soil aggregation but cropping intensity impacted aggregate-size distribution in the top 5 cm of the soil (Wright & Hons, 2005). However, the proportion of macroaggregates increased under NT continuous sorghum compared to CT and found that the macroaggregates under NT had greater SOC storage than those under CT. Baumhardt et al. (2017) also saw a decrease in aggregate size and stability under stubble-much tillage for sorghum-fallow compared to NT after one cycle of a 3-year rotation. In the Texas Rolling Plains, an 11-year field experiment saw minimal differences between microaggregation in between conventional and reduced tillage under sorghum and wheat (Bordovsky et al., 1999).

There are fewer published studies on cover cropping and double cropping in Texas that clearly utilize aggregate stability as a parameter. Cover crops are traditionally defined as crops grown in the off-season of an annual cash crop to protect from loss of soil and nutrients due to erosion, leaching, and runoff (Delgado et al., 2007; Reeves, 1994). While cover cropping only yields in the harvest of one main cash crop within a calendar year, double cropping involves the harvesting two cash crops per year (Borchers et al., 2014). It is generally found that more vegetative cover protects soil and promotes soil-building processes (Amézketa, 1999; Six et al., 2004). Schirmacher (2019) reported an increase of macroaggregates under specific cover crop treatments but a decrease in legume double-crop treatments in a wheat-fallow rotation in Texas Rolling Plains region. This is likely due to disturbance cause by biomass removal and lack of protect from reduced residue return (Blanco-Canqui & Lal, 2009; Schirmacher, 2019).

In effort to find more accessible and accurate ways to measure aggregate stability, a free smartphone application from the University of Sydney was evaluated as a simplified and legitimate method to measure WAS in high-clay soils from Texas (Flynn et al., 2020). This was shown to be more sensitive than the Cornell Wet Aggregate Stability Test, a USDA-recognized but expensive and tedious method, when differentiating between the effects of different tillage practices. Preliminary data from our study sites showed that physical aggregate stability measurements were more sensitive to management effects compared to data measured from the smartphone application.

Soil health research in Texas has continued to grow with increased public and private interest in soil conservation and sustainable agriculture. The current research shows that further studies are needed to better understand the impact of management practices on soil health in various cropping systems. To contribute to this understanding, this study aims to provide insight on the short-term impact of conservation practices on soil aggregate stability, a key soil health indicator, in two Texas winter wheat systems.

2. METHODS

2.1 Experimental Location

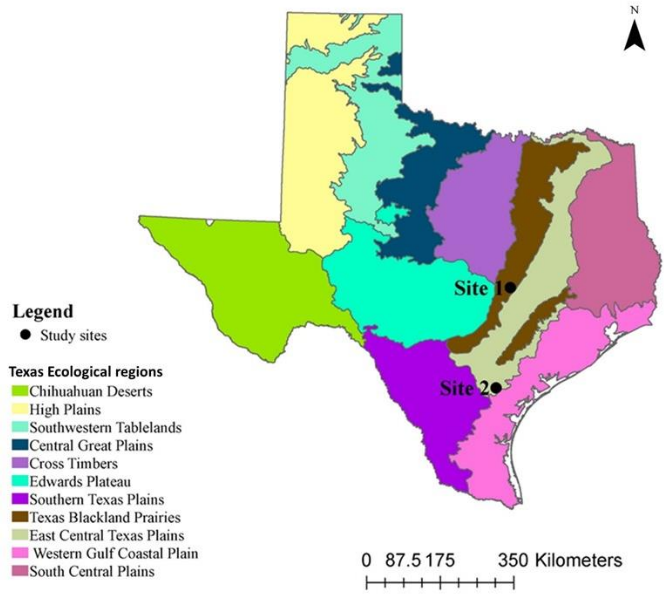

Figure. 2.1: Study site locations overlaying an ecoregion map of Texas. Site 1 is in Thrall and Site 2 is in Beeville. (EPA 2012)

The research sites are located in Texas, USA at two research field sites in two different agriculturally important Texas ecoregions (Figure 2.1). The Thrall site (Site 1) is located at the Stiles Farm Foundation (30° 36’N 97° 18’W; 173 m elevation) in Thrall, Texas. This site represents the Blackland Prairie ecoregion which narrowly spans from Central Texas towards the Texas-Oklahoma border. Climate at the Thrall Site is warm and temperate with an annual average temperature of 17.2 ºC to 21.1 ºC (63 ºF to 70 ºF) and annual average precipitation of 812.8 to 1143 mm (32 in to 45 in) (Soil Survey Staff, 2022). The soil type was classified as a Bureleson clay (fine, smectitic, thermic Udic Haplusterts) (Soil Survey Staff, 2022). This heavy clay soil is characteristic of the Blackland ecoregion. For the previous decade, the land use at the Thrall site was conventionally tilled cotton [*Gossypium hirsutum*].

The Beeville site (Site 2) is located at the Texas A&M AgriLife Research Station in Beeville, Texas (28° 27'N 97° 42'W; 74 m elevation). This site represents the Coastal Plains ecoregion which borders the Gulf of Mexico. Climate at the Beeville Site is humid subtropical with an annual average temperature of 21.1 ºC to 22.7 ºC (70 ºF to 73 ºF) and anural average precipitation of 685.8 mm to 914.4 mm (25 in to 36 in) (Soil Survey Staff, 2022). The soil type was classified as a Parrita sandy clay loam (loamy, mixed, superactive, hyperthermic, shallow Petrocalcic Paleustoll) (Soil Survey Staff, 2022). For the previous 25 years, the land use at the Beeville site was perennial peanut [*Arachis hypogaea*].

2.2 Treatments and Experimental Design

A randomized complete block split-plot design was implemented at both locations in 2015 (Thrall site) and 2016 (Beeville site). There was a total of six treatment combinations (2 tillage * 3 cover crops) tested which were replicated in three blocks (N = 3). Tillage treatments, conventional (CT) and no-tillage (NT), were the main whole plot factor. The sub-plot factor was the cover crop treatment: cover crop mixture, grain sorghum, and fallow control.

The conventional tillage plots were tilled to a depth of 15 cm using a disk Case IH 370 (Racine, WI, USA) and received three passes. At Thrall, the no-till plots were planted with either a modified 1.5 m Great Plains NT drill (2015, 2016, and 2019), a 3.7 m JD 8200 (2017), or a Sunflower 9.1 m NT drill 9421 (2018). The size of each experimental plot at Thrall was 22.86 m long by 7.62 m wide. At Beeville, a modified 1.5 m Great Plains NT drill was used. The size of each experimental plot at Beeville was 9.14 m long by 3.05 m wide.

The cover crop mixture included seven species: buckwheat ['Mancan', *Fagopyrum esculentum* Moench], cowpea 'Iron and Clay', guar ['Kinman', *Cyamopsis tetragonoloba* (L.) Taubert], lablab ['Rio Verde', *Lablab purpureus* (L.) Sweet] short stature sunflower ['8H668S', *Helianthus annuus* L.], pearl millet [*Pennisetum glaucum* (L.) R. Br.], sunn hemp [*Crotalaria juncea* L.], peanut 'Tamrun OL 11', and German foxtail millet [*Setaria italic* (L.) P. Beauv.]. For both locations, the cover crop treatments were planted with a John Deere Max Emerge Plus planter unit fitted with Almaco 31-cell cones for seed metering. All cover crops were planted with a row spacing of 76 cm.

Winter wheat was planted as a cash crop in all the plots between mid-November and January each year. Wheat and cover crop fertilization rates were determined based on recommendations from the Texas A&M AgriLife Extension Service Soil, Water, and Forage Testing Laboratory (College Station, TX). For additional information regarding the varieties, seeding rate, and application of fertilizers and herbicides for winter wheat and cover crops, refer to Bekewe (2021).

2.3 Soil Sampling

In September 2019, soils (0-5 cm) were collected using a 1.8 cm diameter punch corer at both sites. Soils were sampled before summer cover crop treatments were terminated (September 2019). To prevent edge effects and visual bias, a grid system was used in each plot where sampling points (X,Y coordinates of the grid) were randomly generated using R software (R Development Core Team, 2010). Five samples were taken within the rows of each plot resulting in 15 samples per treatment (n = 15). A total of 180 samples (5 replicate samples * 6 tillage & cover crop treatments * 3 blocks * 2 locations) were taken for this study. Soil samples were kept on ice in a cooler and taken to the laboratory immediately after field sampling. Once in the laboratory, each sample was separated into subsamples and air dried to quantify WAS and other measurements (which are outside the scope of this thesis). The air-dried subsamples for WAS were homogenized using a 8 mm sieve.

2.4 Data Collection

2.4.1 Wet Aggregate Stability

The stability of macroaggregates (0.25 mm – 8 mm) was measured using a wet aggregate stability single sieve method which was modified from Stott (2019) to be conducted manually. Since the recommended and mechanized Yoder-style wet sieving apparatus was not accessible, all samples were wet sieved by hand in the following procedure. Air-dried, 8-mm sieved soils (25 g) were placed on a 250 µm sieve. The soil and sieve were submerged in DI water and then manually shaken in and out of the water at a rate of 30 strokes per minute for 5 minutes. The aggregates remaining on the sieve were washed with DI water into collection pans and air dried until standing water evaporated. Then the air-dried aggregates were oven dried at 100 ºC for 12 hours and weighed. To account for non-soil materials such as gravel, the oven dried aggregates were rinsed into a 250 µm sieve to wash away the soil. The sand, gravel, and organic material remaining on the sieve was then air dried and oven dried prior to being weighed. The difference in weight of the initial aggregates collected and the weight of the sand, gravel, and organic materials is considered the corrected weight of the stable macroaggregates as shown in Equation 2.1:

$$Wet\ Aggregate\ Stability\ (\%) = \frac{Corrected\ Soil\ Aggregate\ Weight}{Corrected\ Sample\ Weight} \times 100 \qquad (2.1)$$

To ensure the modifications made to the wet sieving method introduced in Stott (2019) were replicable, trial samples were ran using the modified manual method (Figure A.1). Briefly, there were four trial samples with three replications for each sample. The results were within an acceptable range of variance (< 6 %) and confirmed the replicability of the method. As the adapted method was found to be replicable, we used this method to quantify WAS.

2.4.2 Wheat Yield

Winter wheat grain was harvested from each replicate plot at both locations using a classic plot combine with a 1.5 m header (Wintersteiger Ag, Ried, Austria). Grain was dried and weighed. Refer to Bekewe (2021) for more information.

2.5 Statistical Analysis

To measure the effect of tillage and summer cover cropping on WAS and crop yield, we used a restricted maximum likelihood (REML) mixed effects model with treatments of tillage and crop type and their interaction included as fixed effects and block included as a random effect. Sites were analyzed separately. Means of significant effects were compared using Student's T for tillage and Tukey HSD for crop type and the interaction between tillage and crop type. Prior to the statistical analysis, data was checked for normality and log transformation was used for the Beeville WAS data. To identify links between WAS and crop yield, data were analyzed using simple regression model including linear trends. Winter wheat yield was regressed against mean aggregate stability as an independent variable separated by crop type. The regression was not evaluated within each location to avoid losing robustness in the statistical analysis. Effects were considered significant at $P < 0.05$. Standard error is reported with mean values in the results and appendix. Data were analyzed using JMP Pro Version 16 (SAS Institute Cary, NC)

3. RESULTS

3.1 Wet Aggregate Stability

3.1.1 Tillage and Summer Cover Cropping Treatments

The impact of tillage and summer cover cropping treatments on wet aggregate stability (WAS) results differed for each location (Figure 3.1). At Beeville, there was no effect of tillage on WAS, but there was an effect of cover cropping treatment (Table 3.1). WAS was higher under sorghum (8.22% ± 0.51) compared to the other cropping treatments (6.35 % ± 0.03 for fallow and mixed-cover crop combined). Fallow (6.38% ± 0.42) did not differ from mixed-cover crop (6.32% ± 0.43). At Thrall, the effect of the tillage treatment was not observed for every cover cropping treatments (Table 3.1). The mixed-cover crop treatment had higher WAS under NT (44.47% ± 2.94) than CT (33.60% ± 1.32) management (Figure 3.1). The mean and standard error of WAS for each tillage and crop treatments separated by location is included in Table A.1.

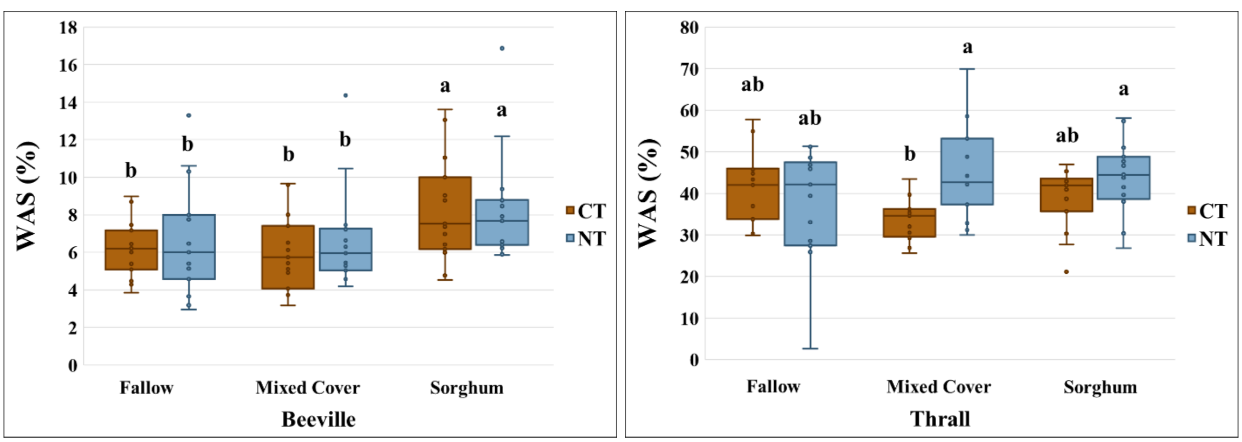

Figure 3.1: Box plots showing the effect of cover crop types (separated by tillage) on WAS. The effect of cover crop treatments is separated into pairs of associated conventional tillage (CT, brown) and no-till (NT, blue) treatments. Letters not shared among tillage and cover treatments represents mean differences via Tukey's HSD.

Overall, mean WAS was higher at Thrall compared to Beeville with WAS ranging from 2.65 – 69.90 % at Thrall and 2.93 – 18.87 % at Beeville. Block (i.e., replicate plots) contributed to 43% of estimated variance at Thrall, whereas it didn't contribute to any variance (0%) at Beeville (Table 3.1).

Table 3.1: Significance of treatment effects on WAS and wheat yield.

		WAS	**Wheat Yield**
Effect	df	P value	P value
Thrall			
Tillage	1	**0.01***	**<.0001***
Crop	2	ns	**<.0001***
Tillage*Crop	2	**0.003***	ns
Block (random var. comp.)		43%	35%
Beeville			
Tillage	1	ns	**<.0001***
Crop	2	**0.003***	**<.0001***
Tillage*Crop	2	ns	**<.0001***
Block (random var. comp.)		0%	58%
*significant at $\alpha \leq 0.05$			

*Note: P-values are listed for treatment effects, tillage and crop type interaction (Tillage*Crop), and random variation component of the plot replicates (Block). Not significant values are marked ns.*

3.2 Wheat Productivity

3.2.1 Tillage and Summer Cover Cropping Treatments

Yield rates are still one of the most important determinates of whether a farmer will adopt a new practice, especially SHPPs. Similar to WAS, the treatment effect on winter wheat yields differed between the two locations (Table 3.1, Figure 3.2).

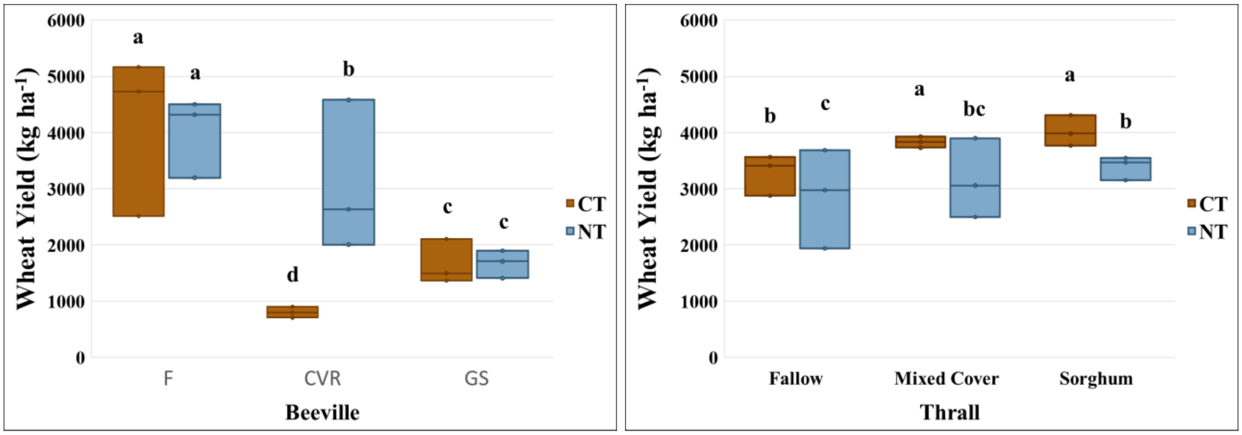

Figure 3.2: Box plots showing the effect of cover crop types (separated by tillage) on winter wheat yields. The effect of cover crop treatments is separated into pairs of associated conventional tillage (CT, brown) and no-till (NT, blue) treatments. Letters not shared among tillage and cover treatments represents mean differences via Tukey's HSD.

The highest wheat yields at Beeville were under the fallow treatments (4069 kg ha^{-1} ± 411). There was an effect of tillage, but it was only observed in the mixed cover treatment (Table 3.1). In the mixed cover crop treatment, the wheat yield under CT was lower (801 kg ha^{-1} ± 56.58) is than the yield under NT (3074 kg ha^{-1} ± 775). The yield for CT in the mixed cover treatments was the lowest yield across all other treatment. However, the low yield of the CT-mixed cover crop treatment may be due to the relatively high block effect (Table 3.1) found in the Beeville wheat yield data. This indicates that the location of the randomly assigned plot replicates may have an influence on the yields.

At Thrall, there was an effect of tillage and cropping treatment on wheat yield (Table 3.1). Overall, the CT treatments had higher yields (3711 kg ha^{-1}± 135) compared to NT treatments (3136 kg ha^{-1} ± 206) (Figure 3.2). The highest yields were observed under the sorghum treatment (3704 kg ha^{-1} ± 167) compared mixed cover crops (3491 kg ha^{-1} ± 238) and fallow (3076 kg ha^{-1} ± 263). Thus, the highest average yields were in the CT-sorghum treatment (4019 kg ha^{-1} ± 158). See Table A.1 in Appendix for further details on the yield data.

3.2.2 *Relationship to Wet Aggregate Stability*

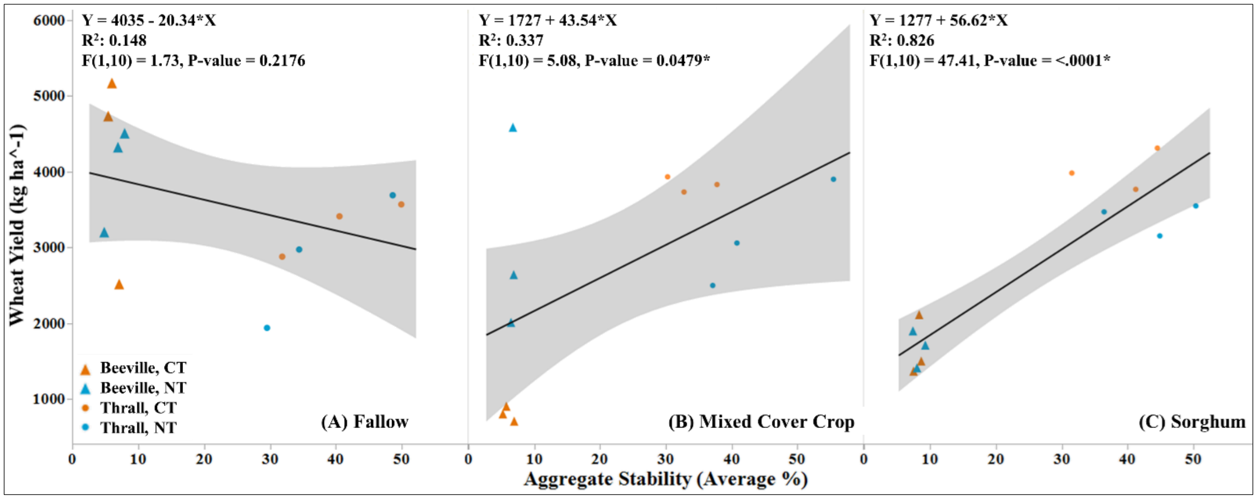

Figure 3.3: Relationship between WAS and wheat yield, separated by cover cropping treatment. WAS samples were averaged to match the yield collection data. Data points are colored by location (Beeville or Thrall) and tillage (conventional or no-till) as shown in the graph legend.

Correlation analysis (Figure 3.3) showed that the relationship between WAS and wheat yield was variable between different cover cropping treatments. There was a strong and positive correlation under the sorghum treatment ($R^2 = 0.826$, p-value < 0.0001), whereas there was a weak positive correlation under the mixed cover crop treatment ($R^2 = 0.337$, p-value = 0.0479), and there was no relationship between WAS and yield under the fallow treatment. It should be noted that relationship between WAS and wheat yield was not separated by location or tillage. Any further separation of the relatively small data set caused a loss in the robustness of the statistical analysis. Additionally, the WAS data was averaged to match the number of yield data points. There were five WAS samples measured for each of the three treatment replicates, while only one yield measurement was taken for each of the three replicate plots. Thus, the mean of the five WAS samples was used in the correlation analysis.

4. DISCUSSION

4.1 Tillage

4.1.1 Influence on Aggregate Stability

Even though it is commonly recognized that intensive tillage management causes aggregates to breakdown and decrease stability (Amézketa, 1999), tillage had minimal impact on wet macroaggregate stability at both locations in this study. Baumhardt et al. (2017) also found no significant difference in the distribution of non-water-stable and water-stable aggregates under the wheat-fallow phase after one 3-year cycle of an ICL system in a clay loam soil. This agrees with our findings that tillage had no significant impact on the wheat-fallow treatment at both locations. Within the first three year of implementing various tillage systems, Hajabbasi and Hemmat (2000) also saw a weak influence of tillage on soil aggregate properties between CT and NT methods in a continuous wheat system in Iran (clay-loam soil texture). Yet, in the fourth year of the study, NT methods had distinctly larger proportion of macroaggregates and larger sized macroaggregates compared to CT methods (Hajabbasi & Hemmat, 2000). This shift in influence of tillage during the fourth year indicates that time since implementation of tillage practices plays a major role in its impact on aggregate stability. Furthermore, multiple long-term studies conducted on various soil types across the world, such as Nath and Lal (2017) (over 25 years), Kasper et al. (2009) (18 years), Lipiec et al. (2006) (18 years), and Castro Filho et al. (2002) (21 years), emphasize the importance of time as all show greater macroaggregate stability under reduced, minimal, or no-till systems.

4.1.2 Influence on Wheat Yields

Cereal-based crop yields have been known to be difficult to achieve when adopting conservation tillage methods like NT due to compaction of untilled surface soil (Munkholm et al., 2013). However, there are many conflicting results on the effect of tillage on wheat yield, as seen in our own results. In Thrall, there was a significant increase in yield under CT compared to NT. While in Beeville, the effect of tillage on wheat yields is not as clear due to the high block effect (Table 3.1). Besides the mixed cover crop, there is no tillage effect on wheat yields in the fallow and sorghum cropping treatments at Beeville.

Other studies show that the impact of tillage on wheat yield is highly variable and complex (Bordovsky et al., 1998; De Vita et al., 2007; Hajabbasi & Hemmat, 2000; Jones & Popham, 1997). In agreement to our findings in Thrall, Hajabbasi and Hemmat (2000) saw that conventional tillage methods (e.g. moldboard plow or chisel plow with disking) were associated with greater wheat production while NT had the lowest production after four years in Iran. Conversely, Jones and Popham (1997) found no significant effect of tillage on grain yield in both wheat and sorghum in the High Plains of Texas. Additionally, De Vita et al. (2007) showed that within a 3-year period the effect of tillage on wheat yield changed yearly depending on the precipitation at two different locations in same ecoregion of southern Italy. These results showcase how the response of wheat yield to differing tillage systems is influenced by other factors including climate (especially precipitation), soil moisture, disease/pest management, and residue management (Bordovsky et al., 1998; De Vita et al., 2007; Jones & Popham, 1997).

4.2 Summer Cover Cropping Treatments

4.2.1 Influence on Aggregate Stability

Growing cover crops, double crops, or forages during traditional fallow periods in the growing season is a common conservation method. Increasing cropping intensity on a field can be used to protect soil from wind and water erosion and nutrient loss but can also help suppress weeds and pests, increase carbon sequestration, and improve water quality (Dabney et al., 2001). Additionally, replacing fallow periods with vegetation is known to prevent the breakdown of soil aggregates by intercepting rain drops and decreasing the velocities of wind and water (Dabney et al., 2001).

At Beeville, there was a significant effect of the cover cropping treatment on macroaggregate stability as WAS was higher under sorghum compared to fallow and mixed cover crop. This could potentially be due to the large amount of biomass produced by the sorghum (Figure A.2). The biomass (dry matter yield) of sorghum was significantly higher than the mixed cover crop biomass in year the soil samples were collected (2019). In 2018, even though the sorghum biomass was not significantly greater than the mixed cover crop biomass, it was still relatively high. This larger biomass would likely increase residue accumulation in the soil which would increase the amount of OM in the soil. Additions of OM through residue promotes the formation and stabilization of aggregates and improve overall surface soil structure (Amézketa, 1999; Six et al., 2004).

In Thrall, there was a minimal effect of the cover cropping treatment as there was an interaction effect with tillage. WAS was slightly increased under NT-mixed cover crop and NT-sorghum. Blanco-Canqui and Ruis (2020) found that cover crops increased WAS, whether reported as a mean weight diameter, geometric mean diameter, or percentage of water stable aggregates, in approximately half of 56 study locations reviewed. The inconsistency of the results reflects the complex relationship between plants and soil properties.

4.2.2 Influence on Wheat Yields

The relationship between crop yields and intensifying a cropping system with cover crops or other vegetation during a traditionally fallow period is not well understood. Conflicting results across studies are likely due to the impact of multiple factors including plant species, growing season, duration since implementation, and climate (Blanco-Canqui et al., 2012).

Such variability can be seen in the differing results between Thrall and Beeville in this study. The significant interaction between tillage and cover crop type and high block effect in Beeville makes the impact of the cover cropping treatments difficult to interpret. At Beeville, the fallow fields had the wheat yields while sorghum had the lowest. In Thrall, the exact opposite was found as the wheat yields ranked in order by crop type was sorghum > mixed cover crop > fallow. Consistent with our results at Beeville, Nielsen et al. (2016) did not see wheat yields increase following various cover crop treatments in comparison to fallow in the central Great Plain region of the USA. Contrasting our Thrall results, Crabtree et al. (1990) saw that wheat yields were higher in a monocrop system in comparison to double-cropped wheat with sorghum over a 12-year period. However, Blanco-Canqui et al. (2012) found that summer cover crops help increase wheat and sorghum yields in Kansas. Even though cover cropping and intensify cropping systems are often viewed as an important component of sustainable crop production, the impact on wheat yields is not clear and requires further investigation.

4.3 Site

As this study was conducted at two different locations, different site characteristics influence the WAS and wheat yield results. One important difference was the soil texture at each site. At Beeville, the soil is coarser and is classified as a Parrita sandy clay loam (20-35% clay sizes particles). At Thrall, the soil is classified as a Burleson clay and is much finer in texture (> 40% clay). Due to the higher clay content at Thrall (approx. 50%), WAS measurements were generally higher at Thrall than at Beeville. Texture is one of the defining factors of microaggregation as the flocculation of clay is the first step in forming and stabilizing aggregates resulting in greater aggregate stability in finer-textured soils (Amézketa, 1999; Stott, 2019).

Even small or localized changes in soil texture can result in large changes in soil physical, biological, and chemical properties. At Thrall, there is a slight increase in clay content in one block. This is likely the cause of the high random variance from block at Thrall in the WAS and wheat yield data (Table 3.1). Plot and block-scale heterogeneity may also be a factor at Beeville, where the estimated variance contributed by block was 58% for wheat yield. Measuring clay content or soil texture class at the block or plot scale rather than at a site scale may help better explain the high variance we observed.

5. CONCLUSION

This study showed that wet aggregate stability and winter wheat yield responded variably to soil health prompting practices and that soil texture is a driving force for the WAS results at the two study sites. This three-year study shows that SHPPs do not immediately (within three years) or clearly benefit the soil structure and yield of winter wheat in these two South Central Texas wheat systems. As these treatments continue, a long-term study at these sites will better identify and understand the changes in WAS and yields under various tillage and summer cover crop treatments. Further studies will be needed to continue building knowledge about soil health in Texas winter wheat systems in order to make better recommendations to landowners regarding soil health promoting practices.

REFERENCES

Abid, M., & Lal, R. (2008). Tillage and Drainage Impact on Soil Quality. Aggregate Stability, Carbon and Nitrogen pools. *Soil and Tillage Research*, *100*(1-2), 89-98. https://doi.org/10.1016/j.still.2008.04.012

Abiven, S., Menasseri, S., & Chenu, C. (2009). The Effects of Organic Inputs Over Time on Soil Aggregate Stability–A Literature Analysis. *Soil Biology and Biochemistry*, *41*(1), 1-12.

Acosta-Martínez, V., Zobeck, T. M., & Allen, V. (2004). Soil Microbial, Chemical and Physical Properties in Continuous Cotton and Integrated Crop-Livestock Systems. *Soil Science Society of America Journal*, *68*(6), 1875-1884. https://doi.org/10.2136/sssaj2004.1875

Allen, D. E., Singh, B. P., & Dalal, R. C. (2011). Soil Health Indicators Under Climate Change: A Review of Current Knowledge. In (pp. 25-45). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-20256-8_2

Amézketa, E. (1999). Soil Aggregate Stability: A Review. *Journal of Sustainable Agriculture*, *14*(2-3), 83-151. https://doi.org/10.1300/J064v14n02_08

Bagnall, D. K., McIntosh, W. A., Morgan, C. L. S., Woodward, R. T., Cisneros, M., Black, M., Kiella, E. M., & Ale, S. (2020). Farmers' Insights on Soil Health Indicators and Adoption. *Agrosystems, Geosciences & Environment*, *3*(1). https://doi.org/10.1002/agg2.20066

Baumhardt, R. L., Johnson, G. L., Schwartz, R. C., & Brauer, D. K. (2017). Grazing and Tillage Effects on Soil Properties, Rain Infiltration, and Sediment Transport during Fallow. *Soil Science Society of America Journal*, *81*(6), 1548-1556. https://doi.org/https://doi.org/10.2136/sssaj2017.04.0133

Bekewe, P. E. (2021). *Building Soil and Food Security in Wheat Production Systems in Texas* Texas A&M Univerisity.

Blanco-Canqui, H., & Lal, R. (2009). Crop Residue Removal Impacts on Soil Productivity and Environmental Quality. *Critical Reviews in Plant Sciences*, *28*(3), 139-163. https://doi.org/10.1080/07352680902776507

Blanco-Canqui, H., Claassen, M. M., & Presley, D. R. (2012). Summer Cover Crops Fix Nitrogen, Increase Crop Yield, and Improve Soil–Crop Relationships. *Agronomy Journal*, *104*(1), 137-147. https://doi.org/10.2134/agronj2011.0240

Blanco-Canqui, H., & Ruis, S. J. (2020). Cover Crop Impacts on Soil Physical Properties: A Review. *Soil Science Society of America Journal*, *84*(5), 1527-1576. https://doi.org/10.1002/saj2.20129

Borchers, A., Truex-Powell, E., Wallander, S., & Nickerson, C. (2014). Multi-cropping Practices: Recent Trends in Double-Cropping. *Economic Information Bulletin*(262122). https://ideas.repec.org/p/ags/uersib/262122.html

Bordovsky, D., Choudhary, M., & Gerard, C. (1999). Effect of Tillage, Cropping, and Residue Management on Soil Properties in the Texas Rolling Plains. *Soil Science*, *164*(5), 331-340.

Bordovsky, D. G., Choudhary, M., & Gerard, C. J. (1998). Tillage Effects on Grain Sorghum and Wheat Yields in the Texas Rolling Plains. *Agronomy Journal*, *90*(5), 638-643. https://doi.org/10.2134/agronj1998.00021962009000050012x

Cardoso, E. J. B. N., Vasconcellos, R. L. F., Bini, D., Miyauchi, M. Y. H., Santos, C. A. d., Alves, P. R. L., Paula, A. M. d., Nakatani, A. S., Pereira, J. d. M., & Nogueira, M. A. (2013). Soil Health: Looking for Suitable Indicators. What Should be Considered to Assess the Effects of Use and Management on Soil Health? *Scientia Agricola*, *70*, 274-289.

Carlisle, L. (2016). Factors Influencing Farmer Adoption of Soil Health Practices in the United States: A Narrative Review. *Agroecology and Sustainable Food Systems*, *40*(6), 583-613. https://doi.org/10.1080/21683565.2016.1156596

Castro Filho, C., Lourenço, A., de F. Guimarães, M., & Fonseca, I. C. B. (2002). Aggregate Stability Under Different Soil Management Systems in a Red Latosol in the State of Parana, Brazil. *Soil and Tillage Research*, *65*(1), 45-51. https://doi.org/https://doi.org/10.1016/S0167-1987(01)00275-6

Crabtree, R. J., Prater, J. D., & Mbolda, P. (1990). Long-Term Wheat, Soybean, and Grain Sorghum Double-Cropping under Rainfed Conditions. *Agronomy Journal*, *82*(4), 683-686. https://doi.org/10.2134/agronj1990.00021962008200040007x

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using Winter Cover Crops to Improve Soil and Water Quality. *Communications in Soil Science and Plant Analysis*, *32*(7-8), 1221-1250. https://doi.org/10.1081/css-100104110

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., & Pisante, M. (2007). No-tillage and Conventional Tillage Effects on Durum Wheat Yield, Grain Quality and Soil Moisture Content in Southern Italy. *Soil and Tillage Research*, *92*(1), 69-78. https://doi.org/https://doi.org/10.1016/j.still.2006.01.012

Delgado, J. A., Dillon, M. A., Sparks, R. T., & Essah, S. Y. C. (2007). A Decade of Advances in Cover Crops. *Journal of Soil and Water Conservation*, *62*(5), 110A. http://www.jswconline.org/content/62/5/110A.abstract

Doran, J. W., & Zeiss, M. R. (2000). Soil Health and Sustainability: Managing the Biotic Component of Soil Quality. *Applied Soil Ecology*, *15*(1), 3-11. https://doi.org/10.1016/s0929-1393(00)00067-6

Flynn, K. D., Bagnall, D. K., & Morgan, C. L. S. (2020). Evaluation of SLAKES, a Smartphone Application for Quantifying Aggregate Stability, in High-clay Soils. *Soil Science Society of America Journal*, *84*(2), 345-353. https://doi.org/10.1002/saj2.20012

Fultz, L. M., Moore-Kucera, J., Zobeck, T. M., Acosta-Martínez, V., & Allen, V. G. (2013). Aggregate Carbon Pools after 13 Years of Integrated Crop-Livestock Management in Semiarid Soils. *Soil Science Society of America Journal*, *77*(5), 1659-1666. https://doi.org/10.2136/sssaj2012.0423

Hajabbasi, M. A., & Hemmat, A. (2000). Tillage Impacts on Aggregate Stability and Crop Productivity in a Clay-loam Soil in Central Iran. *Soil and Tillage Research*, *56*(3), 205-212. https://doi.org/https://doi.org/10.1016/S0167-1987(00)00140-9

Harrigan, K., & Charney, A. (2019). Impact of 2018 Farm Bill Provisions on Soil Health. *National Sustainable Agriculture Coalition and Soil Health Institute Report. Available online at: https://sustainableagriculture. net/wp-content/uploads/2019/09/FINAL-DIGITAL-Impact-of-2018-Farm-Bill-Provisionson-Soil-Health. pdf (accessed March 24, 2020)*.

Helms, D. (1992). *Readings in the History of the Soil Conservation Service*. US Department of Agriculture, Soil Conservation Service, Economics and Social Sciences Division, NHQ.

Hundl, W. (2021). *Texas Agriculture – Growing in Many Ways*. Retrieved February 28, 2022 from https://www.usda.gov/media/blog/2019/07/17/texas-agriculture-growing-many-ways

Jones, O. R., & Popham, T. W. (1997). Cropping and Tillage Systems for Dryland Grain Production in the Southern High Plains. *Agronomy Journal*, *89*(2), 222-232. https://doi.org/10.2134/agronj1997.00021962008900020012x

Kasper, M., Buchan, G. D., Mentler, A., & Blum, W. E. H. (2009). Influence of Soil Tillage Systems on Aggregate Stability and the Distribution of C and N in Different Aggregate Fractions. *Soil and Tillage Research*, *105*(2), 192-199. https://doi.org/https://doi.org/10.1016/j.still.2009.08.002

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The Concept and Future Prospects of Soil Health. *Nature Reviews Earth & Environment*, *1*(10), 544-553.

Lipiec, J., Kus, J., Nosalewicz, A., & Turski, M. (2006). Tillage System Effects on Stability and Sorptivity of Soil Aggregates. *International Agrophysics*, *20*(3).

Munkholm, L. J., Heck, R. J., & Deen, B. (2013). Long-term Rotation and Tillage Effects on Soil Structure and Crop Yield. *Soil and Tillage Research*, *127*, 85-91. https://doi.org/10.1016/j.still.2012.02.007

Nath, A. J., & Lal, R. (2017). Effects of Tillage Practices and Land Use Management on Soil Aggregates and Soil Organic Carbon in the North Appalachian Region, USA. *Pedosphere*, *27*(1), 172-176. https://doi.org/https://doi.org/10.1016/S1002-0160(17)60301-1

Natural Resources Conservation Service, USDA (2017, April 2017). *Conservation Choices: Soil Health Practices*. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1318196.pdf

Natural Resources Conservation Service, USDA (2018). Principles for High Functioning Soils. In (pp. 2). Washington, DC: USDA Natural Resources Conservation Service.

Natural Resources Conservation Service, USDA (2022). *Soil Health*. Retrieved February 16, 2022 from https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/soils/health/?cid=stelprdb1048783

Nielsen, D. C., Lyon, D. J., Higgins, R. K., Hergert, G. W., Holman, J. D., & Vigil, M. F. (2016). Cover Crop Effect on Subsequent Wheat Yield in the Central Great Plains. *Agronomy Journal*, *108*(1), 243-256. https://doi.org/10.2134/agronj2015.0372

Paul, B. K., Vanlauwe, B., Ayuke, F., Gassner, A., Hoogmoed, M., Hurisso, T. T., Koala, S., Lelei, D., Ndabamenye, T., Six, J., & Pulleman, M. M. (2013). Medium-term Impact of Tillage and Residue Management on Soil Aggregate Stability, Soil Carbon and Crop Productivity. *Agriculture, Ecosystems & Environment*, *164*, 14-22. https://doi.org/10.1016/j.agee.2012.10.003

Reeves, D. (1994). Cover Crops and Rotations. *Advances in soil science: Crops residue management*, 125-172.

Schirmacher, M. T. (2019). *Cover-and Double-Cropping Impacts on Soil Health and Moisture of a Dryland Winter Wheat System in the Texas Rolling Plains*

Sivan, A. (2011). New Perspectives in Plastic Biodegradation. *Current opinion in biotechnology*, *22*(3), 422-426.

Six, J., Bossuyt, H., Degryze, S., & Denef, K. (2004). A History of Research on the Link Between (Micro) Aggregates, Soil Biota, and Soil Organic Matter Dynamics. *Soil and Tillage Research*, *79*(1), 7-31.

Soil Survey Staff. (2022). Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: http://websoilsurvey.sc.egov.usda.gov/. Accessed 03/31/2022.

Stewart, R. D., Jian, J., Gyawali, A. J., Thomason, W. E., Badgley, B. D., Reiter, M. S., & Strickland, M. S. (2018). What We Talk about When We Talk about Soil Health. *Agricultural & Environmental Letters*, *3*(1), 180033. https://doi.org/10.2134/ael2018.06.0033

Stott, D. (2019). Recommended Soil Health Indicators and Associated Laboratory Procedures. *Soil Health Technical Note*.

Tatarko, J., Sporcic, M. A., & Skidmore, E. L. (2013). A History of Wind Erosion Prediction Models in the United States Department of Agriculture Prior to the Wind Erosion Prediction System. *Aeolian Research*, *10*, 3-8. https://doi.org/10.1016/j.aeolia.2012.08.004

Teague, W. R., Dowhower, S. L., Baker, S. A., Haile, N., Delaune, P. B., & Conover, D. M. (2011). Grazing Management Impacts on Vegetation, Soil Biota and Soil Chemical, Physical and Hydrological Properties in Tall Grass Prairie. *Agriculture, Ecosystems & Environment*, *141*(3-4), 310-322. https://doi.org/10.1016/j.agee.2011.03.009

USDA-ERS. (2022). *Farm Income and Wealth Statistics: Cash Rreceipts by Commodity State Ranking*. https://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics.aspx

USDA-NASS. (2017). *2017 Census of Agriculture Highlights: Land Use Practices*. https://www.nass.usda.gov/Publications/Highlights/2020/census-land-use-practices.pdf

Wright, A. L., & Hons, F. M. (2005). Carbon and Nitrogen Sequestration and Soil Aggregation Under Sorghum Cropping Sequences. *Biology and Fertility of Soils*, *41*(2), 95-100. https://doi.org/10.1007/s00374-004-0819-2

Zulauf, C., & Brown, B. (2019a). Cover Crops, 2017 US Census of Agriculture. Farmdoc Daily 9, 136. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.

Zulauf, C., & Brown, B. (2019b). Tillage Practices, 2017 US Census of Agriculture. Farmdoc Daily 9, 136. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.

APPENDIX: SUPPLEMENTARY MATERIAL

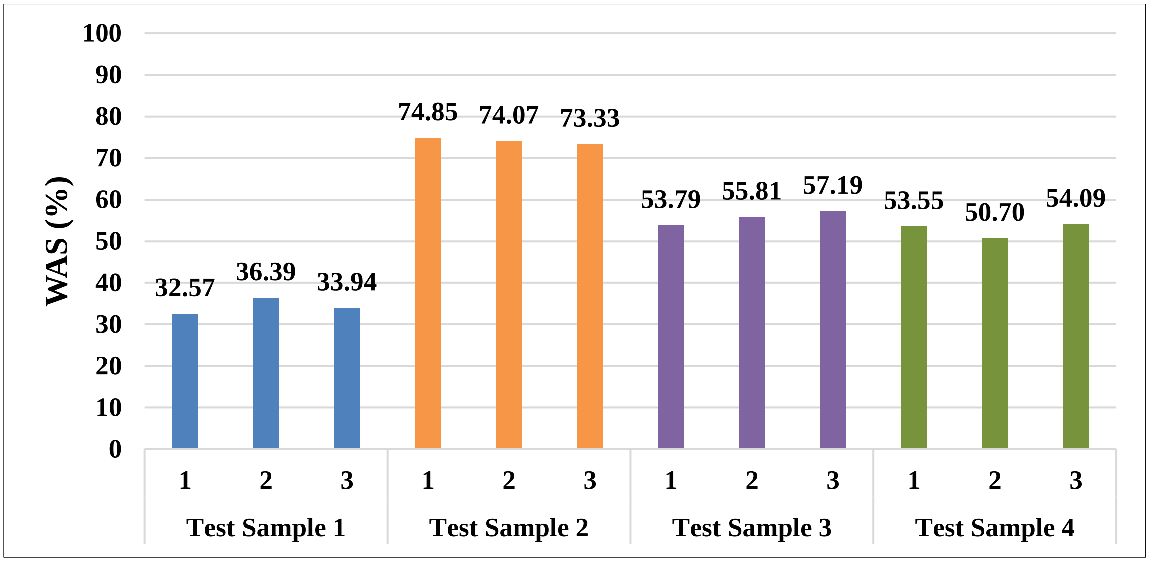

Figure A.1: Bar graph depicting the WAS results of the trial test samples.

Table A.1: Means of WAS and yield per treatment for both locations. Letters not shared among tillage and cover treatments represents mean differences via Tukey's HSD at P < 0.05.

Effect	WAS Mean (%) ± SE	Wheat Yield Mean (kg ha^{-1}) ± SE
Thrall		
CT-Fallow	40.77 ± 2.25 ab	3285 ± 208.49 b
CT-Mixed Cover Crop	33.6 ± 1.32 b	3830.33 ± 57.74 a
CT-Sorghum	39.08 ± 1.90 ab	4019 ± 158.18 a
NT-Fallow	37.53 ± 3.47 ab	2866 ± 507.95 c
NT-Mixed Cover Crop	44.47 ± 2.94 a	3151.67 ± 407.14 bc
NT-Sorghum	43.88 ± 2.23 a	3389.33 ± 120.78 b
Beeville		
CT-Fallow	6.19 ± 0.38 b	4134.67 ± 821.04 a
CT-Mixed Cover Crop	5.96 ± 0.52 b	801.33 ± 56.58 d
CT-Sorghum	8.19 ± 0.71 a	1656 ± 229.19 c
NT-Fallow	6.57 ± 0.76 b	4004 ± 407.48 a
NT-Mixed Cover Crop	6.68 ± 0.68 b	3074 ± 774.65 b
NT-Sorghum	8.25 ± 0.75 a	1670.33 ± 141.84 c

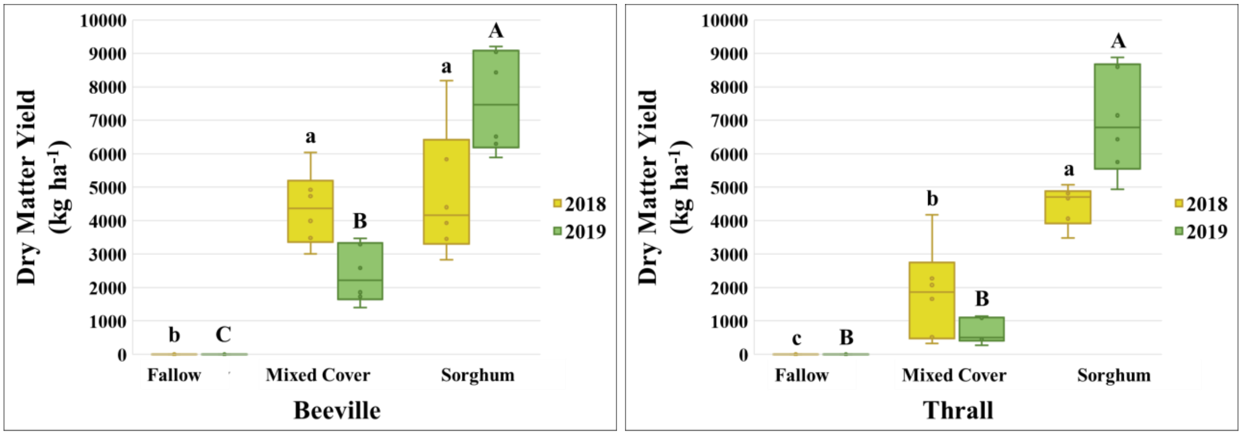

Figure A.2: Box plots of summer cover crop biomass (dry matter yield, kg ha^{-1}) separated by year (yellow = 2018, green = 2019). Lowercase letters show significance between biomass in 2018 and capital letters for 2019 Letters not shared among tillage and cover treatments represents mean differences via Tukey's HSD at P < 0.05.