TILLAGE SYSTEM IMPACT ON SOIL HEALTH AND WEED MANAGEMENT

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2023

TILLAGE SYSTEM IMPACT ON SOIL HEALTH

AND WEED MANAGEMENT

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ACKNOWLEDGEMENTS

I would like to give my sincere appreciation and gratitude to Dr. Beatrix Haggard and Dr. Jason Warren for taking me on as a Ph.D. student. Both of them provided excellent mentorship and support throughout my Ph.D. program. I am deeply indebted to them for their impact on my confidence, career, and personal development. To my committee members, Dr. Rodney Jones and Dr. Amanda De Oliveira Silva, thank you for serving on my committee and providing valuable insight.

Thank you to the wonderful students who allowed me to be their instructor. I appreciate the patience they extended and the perspective they provided. Interacting with students was one of my favorite parts of this gig- thank you all for being so awesome.

A number of students were essential in bringing these projects to completion. Michaela Smith, Sarah Mustain, Brenna Cannon, Alyssa Thelin, Steven Sawatzky, Raedan Sherry, Matthew Thomas, Jackson Williams, Glenn & Chime Garcia, Reynilda Monteza, Caitlyn Carnahan, Hannah Lindell, and Chase Harris are just a few of the students who played a part in the success of these projects. Thank you to each and every person who was involved and helped me reach this milestone.

I am deeply grateful to my family and friends for their unwavering love, support, encouragement, and willingness to help throughout my time in college. Thank you to my husband, Jace, whom helped me balance the workload of being a student, teacher, researcher, mom, and wife and encouraging me every step of the way. Whitney Peterson, Haley Dean, Callie Kelley, and Michaela Smith were all vital friends who cheered me on every step of the way. To my sister, Jill, who was a source of sound advice through challenging time, particularly with her rendition of the metaphor “Burn the boats!” To my mom and dad, a hairstylist and mechanic duo who embraced their daughter’s desire to get a Ph.D. with enthusiasm and reassurance that I was capable at every turn. To Jack for growing with me and being patient when his mom was pulled in too many directions.

These projects were supported by the Agriculture and Food Research Initiative Competitive grant no. 2019-68012-29888 from the USDA National Institute of Food and Agriculture. Oklahoma State University Department of Plant and Soil Sciences provided the facilities for many of the research activities required to complete these projects. Thank you to Jerry Biby for the use of a portion of his farm for one of our field sites. A very special thank you to Dr. Brian Arnall for extended use of the Lake Carl Blackwell study site, equipment (especially the lawn mower), and personnel. Thank you to Dr. Lofton for use of equipment, and personnel. Additionally, Dr. Arnall and Dr. Lofton provided mentorship throughout my time at OSU and I am very grateful for their guidance.

Name: GRACE FLUSCHE OGDEN

Date of Degree: MAY, 2023

Title of Study: TILLAGE SYSTEM IMPACT ON SOIL HEALTH AND WEED MANAGEMENT

Major Field: SOIL SCIENCE

Abstract: The first chapter of this dissertation involves two studies that were conducted from 2022-2023 to determine the impact of sweep tillage on soil health and management of tumble windmill grass (*Chloris verticillata*). The first study, Occasional Sweep, compared a single application of sweep tillage + herbicide to herbicide alone (no-tillage) and tillage alone (disk) to determine the most effective option to manage tumble windmill grass. The second study, Multiple Sweep, evaluated tumble windmill grass control and soil response following one, two, or three passes of sweep tillage in comparison to herbicide alone in no-till. Soil response to a single application of sweep tillage was statistically similar to no-tillage in terms of aggregate stability, CO_2 emissions, volumetric water content, and soil organic matter in both studies. Sweep tillage + herbicide provided ≥92% control across all years. Treatments of herbicide alone in no-till did not provide visual control >88% in either study across all years. Disk tillage controlled tumble windmill grass ≥87% across all years but poses a significant risk in terms of soil erosion.

The second chapter of this dissertation evaluates the impact of soil surface residue, as influenced by tillage, on delayed preemergence herbicides in winter wheat for Italian ryegrass (*Lolium multiflorum*) management. Tillage treatments included no-tillage, sweep tillage, and disk tillage. No relationship was observed between tillage system and herbicide efficacy for Italian ryegrass control, indicating soil surface residue as influenced by tillage did not impact the efficacy of delayed preemergence herbicides in winter wheat. Furthermore, no differences in soil response was observed among tillage systems until after three years of consecutive tillage. Ryegrass control greater than 86% was achieved in May 2020, 2021, and 2022 with treatments of pyroxasulfone + metribuzin and pyroxasulfone + pinoxaden.

The third chapter of this dissertation describes curriculum development of a new course, Cropping Systems, and student perception shifts during the course. Student perceptions shifted from 19% of students perceiving Oklahoma farm progress negatively in pre-course surveys to 6% of students perceiving Oklahoma farm progress negatively in post-course surveys. Students benefitted from hands-on experiences and specialized guest lectures that reinforced classroom taught principles.

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CHAPTER I

SWEEP TILLAGE IMPACT ON TUMBLE WINDMILL GRASS CONTROL AND SOIL HEALTH

ABSTRACT

Tumble windmill grass (Chloris verticillata) has grown to be a problematic weed for no-till growers of the Great Plains, as it is difficult to control with herbicide once established. Two trials were conducted near Stillwater, Oklahoma in 2020 and Wakita, Oklahoma in 2021-2022 to assess the impact of sweep tillage on soil health and weed management of tumble windmill grass. The trial locations were fields that had been under no-tillage management for over 10 years prior to trial initiation. In the Occasional Sweep study, treatments were arranged in a split plot design and replicated four times, with tillage as the main plot and herbicide as the subplot. Main plots included sweep tillage, disk tillage, or no-tillage. Herbicides included treatments of glyphosate + 2,4-D + dicamba, glyphosate followed by paraquat, and clethodim + 2,4-D + dicamba followed by paraquat. In the Multiple Sweep study, treatments were arranged in a randomized complete block design and replicated three times. Treatments were one, two, or three single passes of a sweep plow or no-till with a herbicide treatment of glyphosate followed by paraquat. Visual weed control, weed and crop biomass, wheat yield, soil aggregate stability, soil CO_2 emissions, soil organic matter, and volumetric water content were collected. Sweep tillage served as an excellent tool to control this weed, particularly when paired with herbicide in the Occasional Sweep studyTreatments of sweep + any herbicide provided ≥ 92% control across all years. Treatments of herbicide alone in no-tillage did not provide visual control > 88% in either study across all years. Disk tillage controlled tumble windmill grass ≥ 87% across all years but poses a significant risk in terms of soil erosion. Soil response to a single application of sweep tillage was statistically similar to no-tillage in terms of aggregate stability, CO_2 emissions, volumetric water content, and soil organic matter at the 0-5 and 5-15 cm soil depth in both studies. Soil organic matter in the 0-5 cm depth did decrease when sweep was applied two or three times, however these additional applications of sweep tillage did increase weed control compared to a single application of sweep with no herbicide. Sweep tillage served as an excellent tool to control tumble windmill grass while eliciting little to no soil response.

1.1 INTRODUCTION

Conservation tillage is being explored as a method of management to control problematic weeds in reduced tillage systems (Shrestha et al., 2006). Conservation tillage is defined as any type of tillage that leaves 30% or more of crop residue on the soil surface following planting (CTIC, 2022). Adoption of conservation tillage has grown since its introduction after the Dust Bowl of the 1930s due to dramatic decreases in soil erosion (Anguelov et al., 2020). Based on estimates from the Conservation Technology Information Center 44,110,735 hectares of US cropland, or approximately 38% of all US cropland, are subject to conservation tillage (2022). Benefits of conservation tillage systems, as opposed to intensive tillage systems, include decreased time requirements, increased soil moisture, and increased crop residue to protect the soil surface from erosion (Anguelov et al., 2020). These benefits, in combination with other agronomic advancements, have allowed for improved crop production on decreased crop acres (Edgerton, 2009). One of the biggest challenges that comes with conservation tillage or no-tillage is weed management, not only due to heavy reliance on chemical weed control, but also due to weed population shifts (Moyer et al., 1994).

Sweep tillage, a form of conservation tillage commonly known as subsurface or mulch tillage, has been studied for its benefits to both weed management and soil health (Anderson, 2004). Although sweep tillage was introduced in the 1950s, this method is not a well-known form of tillage. In recent years it has become a tool of interest for weed management. However, limited data is available regarding sweep tillage impact on soil health. Specific insight into sweep tillage impact on soil aggregate stability, water content, organic matter, and microbial activity would provide more information for weed managers to make informed decisions on incorporating this tool into their management system to retain soil health while controlling troublesome weeds.

Each of the aforementioned soil characteristics have specific roles in their contribution to soil health and are thought to be influenced by tillage (Watts & Dexter, 1997; Moebius-Clune et al., 2017; Haney, 2022). Aggregate stability is a measurement that relates to the ability of soil microaggregates to withstand weather events, such as wind and rain (Bissionnais, 1996; Amezketa, 1998). Soil organic matter plays a role in aggregate formation and stability, as it serves as an adhesive between soil particles to help form and retain aggregates (Chaney & Swift, 1984; Six et al., 1999; Abiven et al., 2009). Soil water content is an important factor for crop production and has a complex relationship with soil organic matter and aggregate stability (Markgraf et al., 2012; Minasny & McBratney, 2017). Soil microbial activity, as recognized through CO_2 emissions produced during respiration, acknowledges the level of activity of organisms aiding in the decomposition of organic materials (Doran & Parkin, 1994; Franzluebbers et al., 1996). Soil health is dynamic and can be measured by many more characteristics than have been described thus far. However, those selected for this study are increasing in availability as commercial soil assessments tools. Therefore, the outlined characteristics were the focus for this paper and will be used to illustrate the general health of soils evaluated under tillage treatments in these studies.

Windmill grass (Chloris spp.) has grown to be a troublesome weed across the Great Plains of the United States (Anderson, 2004). Tumble windmill grass (Chloris verticillata Nutt.) in particular has become a weed of concern for Oklahoma producers. This native, warm season, perennial bunch grass has shallow root systems and panicle inflorescence which detaches at maturity and tumbles easily in the wind. Shallow root systems decrease the plant's ability to ward off drought stress, leading to stressed plants in drought conditions and reduced herbicide efficacy when applications are made in such conditions (Parker & Boydston, 2005; Lancaster & Falk Jones, 2021). The panicle inflorescence consists of at least 2 levels of spikes arranged in a classic "windmill", with 10-15 spikes total. Tumble windmill grass is closely related to windmill grass (Chloris Sw.), with some studies interchanging the two species, but for the purpose of this paper the two are differentiated as distinct species.

The growing behavior of this grass is typically in bunches close to the ground, which can make adequate spray coverage challenging. Factors such as an increase in no-tillage systems, long fallow periods between crops, and herbicide resistance have been favorable for tumble windmill grass invasion and allowed it to express weedy tendencies (Anderson, 2004). Although this grass is native, it has little agronomic value. It isn't considered to be a desirable cattle or wildlife forage (Lady Bird Johnson Wildflower Center, 2017). Due to these circumstances, its encroachment onto cropping acres has farmers and range managers interested in possible management methods.

Suggested chemical control of tumble windmill grass includes preemergence herbicides such as acetochlor, atrazine, dimethenamid, flufenacet, pendimethalin, S-metolachlor, and isoxaflutole (Hennigh et al., 2005; Lancaster & Falk Jones, 2021). Preemergence herbicides offer successful control of seedling tumble windmill grass, but do not offer adequate control of established stands (Hennigh et al., 2005). Postemergence options include glyphosate, along with typical grass herbicides such as clethodim (Hennigh et al., 2005; Ferguson et al., 2019). However, these herbicides alone often are insufficient for complete control of tumble windmill grass, particularly for well-established stands. Thus, further research is required to identify effective management programs for mature tumble windmill grass stands.

Research has been conducted at Kansas State University to evaluate the efficacy of sweep plowing for short-term tumble windmill grass control (Lancaster & Falk Jones, 2021). Further research is required to determine the long-term efficacy of sweep plowing in controlling tumble windmill grass and resulting effects to soil health, particularly in terms of aggregate stability, CO_2 emissions as influenced by microbial activity, soil water content, and soil organic matter. Two studies were established to investigate these objectives. One study, “Occasional Sweep", compared a single application of sweep tillage + herbicide to herbicide alone (no-till) and tillage alone (disk) to determine the most effective option to manage tumble windmill grass out of methods currently used in Oklahoma and analyze the soil response to each method. Another study, “Multiple Sweep”, evaluated tumble windmill grass control and soil response following one, two, or three passes of sweep in comparison to herbicide alone in no-till. Results from these studies have advanced the understanding of not only weed management, but also soil health following sweep tillage for up to two seasons after application.

1.2 MATERIALS AND METHODS

Study location, Tillage, and Experimental Design

The Occasional Sweep and Multiple Sweep studies were conducted in two locations across three years. In 2020, both studies were initiated at the Lake Carl Blackwell (LCB-20) Agronomy Research Station (36.144660, -97.283682) near Stillwater, Oklahoma. In 2021, the studies were moved to a producer field located near Wakita, Oklahoma (Wakita-21) (36.911667, -98.027917). In Wakita in 2022, each study was established in a new area approximately 50 meters to the east (Wakita-22). The winter wheat variety “Showdown” was planted at LCB-20 at 67.5 kg seed ha^{-1} on October 22, 2020 and October 25, 2021. Wakita-21 was planted “Gallagher” at 67.5 kg seed ha^{-1} on October 22, 2021. Wakita-21 and Wakita-22 were planted to “Gallagher” at 67.5 kg seed ha^{-1} November 11, 2022.

Each study site was agronomically maintained after the first year of study observation. As such, the LCB-20 studies were maintained through the 2021-2022 and 2022-2023 seasons with one preplant burndown herbicide application (glyphosate at 1543 g ai ha^{-1}) applied October 15, 2021 and one in-season herbicide application (pyroxsulam at 18.9 g ai ha^{-1}) applied on March 15, 2022. The Wakita-21 studies were maintained through the 2022-2023 season with one burndown application (glyphosate at 1543 g ai ha-1) applied on October 10, 2022. In total, three sites with one season of active treatment (tillage and/or herbicide) were established for each study.

The Wakita study site is predominately a Kirkland silt loam (Fine, mixed, superactive, thermic Udertic Paleustolls). The Lake Carl Blackwell site is a Port silt loam ((Fine-silty, mixed, superactive, thermic Cumulic Haplustolls).

The Occasional Sweep study was conducted as a split plot design and replicated four times. The whole plot factor was tillage, and the subplot factor was herbicide. Whole plot treatments were no-tillage, a single pass of sweep tillage applied midsummer within 30 days of wheat harvest, or multiple passes of a tandem disk applied three times throughout the fallow period following harvest.

The Multiple Sweep study was conducted as a randomized complete block design and replicated three times. Sweep treatments were one, two, or three single passes of a sweep plow applied in the fallow period beginning within 30 days of harvest and ending with the planting of continuous wheat. One no-tillage treatment received an application of glyphosate followed by paraquat.

Sweep tillage was performed with a sweep plow, which was composed of a 1.5 m V-shaped blade that undercuts 6-10 cm under the soil surface and is followed by a rotary hoe. Disk tillage was conducted with a tandem disk. Disk treatments were tilled once per month from June to September to imitate producer tillage practices. The disk provided a level seed bed after multiple passes throughout the fallow period, thus no secondary tillage followed. Each tillage method was conducted at a speed of approximately 6.4 kmh. Tillage was initiated on June 30, 2020, June 22, 2021, and July 12, 2022.

<u>Herbicide Treatments</u>

Herbicide treatments followed rate recommendations as per label instructions and are described in Tables 1.1 and 1.2. A handheld 1.93m CO_2-pressurized backpack calibrated to deliver 140 L ha^{-1} at 207 kPa^{-1} was used to apply all treatments. Application speed was 4.8 km $hour^{-1}$. Turbo TeeJet 11002 nozzles were used for all applications. Initial herbicide applications for both trials were made July 21, 2020, July 16, 2021, and July 21, 2022. Sequential applications were made August 4, 2020, August 13, 2021, and September 6, 2022. The sequential application in 2022 was delayed due to severe drought conditions. No in-season weed management was applied in the fall or spring after tillage to prevent obscuring treatment effects during spring green-up and biomass collection.

Weed Control Measurements

Visual weed control ratings were based on a scale of 0% to 100%, with 100% indicating complete control and 0% indicating no control (Frans et al., 1986). Visual control ratings were recorded throughout the fallow period and into the cropping season, however visual weed control ratings near optimal planting time for the region were evaluated for practicality. Visual ratings presented in this paper are as follows: September 15, 2020 (56 days after initial spray application); September 24, 2021 (70 days after initial spray application); and September 24, 2022 (64 days after initial spray application). Crop and weed biomass samples were taken from two m^2 areas of each plot one week prior to harvest in 2021 and 2022. Crop and weed biomass were cut at the soil surface, bagged, dried at approximately 50°C, and weighed. Wheat from each tillage by herbicide treatment was harvested with a Massey Ferguson 8XP combine with a 1.5m header and each plot was weighed. Plots were harvested at LCB-20 on June 16, 2021 and June 17, 2022. Wakita-21 plots were harvested on June 24, 2022.

Although tillage and herbicide treatments were only applied to LCB-20 in the summer of 2020 and Wakita-21 in the summer of 2021, both study sites were maintained in order to obtain soil samples and biomass in a second wheat growing season such that wheat yield and soil health could be evaluated 2 years after the tillage events. Each site was fertilized with 54 kg of nitrogen fertilizer during the 2021-22 growing season and bulk planted to wheat. Biomass samples of winter wheat and tumble windmill grass were collected in June prior to harvest at the LCB-20 and Wakita-21.

Soil Sampling and Analysis

Soil sampling occurred approximately three months after tillage application, once the crop had emerged after planting. Soil samples were collected in November of 2020 and 2021 following planting. Due to drought conditions and delayed planting, soil sampling did not occur until December in 2022. To evaluate soil response more than one year after tillage, LCB-20 was soil sampled two years after tillage in November 2022 and Wakita-21 was sampled one year after tillage in November of 2022. Soil cores were collected from each plot at 0-5 cm and 5-15cm soil depths using a handheld soil probe. Soil cores were removed from the probe and placed in a bucket to homogenize them before a subsample was placed in a bag and air-dried at 65°C, and then mechanically ground. Soils were analyzed at the Soil, Water, and Forage Analytical Laboratory at Oklahoma State University for pH, buffer index, N, P, K, and soil organic matter. Soils were returned to the lab for further analysis for CO_2 emissions and aggregate stability analysis.

To prepare samples for aggregate stability, soils were sieved between 1- and 2-mm. Soils that remained in the 1-2 mm sieve were considered to be aggregates and analyzed for aggregate stability as described by Yoder (1936) and modified by Kemper and Rosenau (1986) and Garcia et al. (2022). Oscillating equipment used was a wet sieving apparatus developed by Eijkelkamp Agrisearch Equipment (The Netherlands). This apparatus contains eight 60-mesh sieves which oscillated 8 samples in separate containers. Analysis was conducted with seven experimental samples and one check sample per run.

Four grams of 1- to 2-mm aggregates were placed in sieves in an oscillator, wetted, and then submerged in 100 ml of deionized water for 10 minutes. The samples were then oscillated, moving 1.3 cm vertically 35 times per minute for 3 minutes. The cups of deionized water and soil particles were removed, and cups were placed in the oven to dry at 110 °C. The stable aggregates remaining on the sieve were submerged in 100 mL of sodium hexametaphosphate (soils with pH > 7) or sodium hydroxide (soils with pH < 7) and the oscillating process was repeated for 3-5 minutes. Any aggregates that remained stable after 5 minutes of sieving were crushed with a rubber-tipped spatula and disintegrated into the dispersing solution. Sieving was continued until the sample was completely disintegrated into the solution and only sand remained on the sieve.

Cups of dispersing solution were placed in the oven at 110°C for 24 hours to dry. Both sets of cups were weighed once all water or solution had evaporated. To determine sample weight, the weight of the cup was subtracted from the total weight. For cups with dispersing solution, an additional 0.2g was subtracted from the total amount to account for the weight of the dispersion chemical. The percent of stable aggregates was calculated by dividing the weight of the soil obtained in the dispersing solution by the sum of the weights obtained in the deionized water + dispersing solution.

CO_2 emission analysis was conducted as described by McGowan et al. (2018) and modified by Garcia (2021). It is important to note that this method is intended to provide trends in overall microbial activity through CO_2 emitted during respiration but does not characterize microbial communities or their density. To prepare samples, 2 grams of soil were placed into 20 mL glass crimp top vials. 0.5 mL of deionized water was added to 8 vials every hour until all samples were wet. The 8 vials were wetted every hour because the GC can only analyze 8 samples per hour and this allowed for an approximate incubation time of 24 hours +/- 30 minute for all samples. Vials were sealed immediately after wetting by grey septa and aluminum crimp top. Vials containing soil samples plus 6 calibration standards were then analyzed via gas chromatographer (Varian 450 GC, the Netherlands, serial number GCD912B060). The concentration of CO_2 in the headspace of the vials was converted to a mass basis using the ideal gas law and this mass of CO_2 was divided by 2 such that all data is presented as mg CO_2-C kg^{-1} of soil.

Deep core soil samples (0-120 cm) were collected at LCB-20 in November of 2020 and at the Wakita-21 in March of 2022 and separated into 0-30, 30-60, 60-90, and 90-120 cm sections. These samples were put into plastic bags for transport, then weighed. Once wet weights were obtained, samples were dried at 110°C for 48 hours. Once dried, a dry weight was obtained. The volumetric water content was calculated as the volume of water determined by drying and the volume of each core segment based on its length and the cutting diameter of the probe tip.

Data Analysis

Data were analyzed using linear mixed models methods where the tillage and herbicide treatments were fixed and the location and block were random effects. The GLIMMIX procedure was used. All tests were performed at the 0.05 level of significance. The data were analyzed using SAS/STAT software, Version 9.4 of the SAS system for Windows. Copyright © 2014 SAS Institute Inc. SAS and all SAS Institute Inc. product or service names are registered trademarks of SAS Institute, Cary, NC, USA. Interactions were present between year, location, and treatment for measurements of tumble windmill grass control, winter wheat and weed biomass, and wheat yield. Thus, treatment results are separated by year and location. Interactions between year, location, and soil depth for aggregate stability results, CO_2 emissions, soil organic matter, and soil water content were present and results are separated by year, location, and soil depth. Significant means were separated using the Tukey-Kramer least square means test ($P \leq 0.05$).

Economic analysis

Cost analyses are listed in Table 1.12 for the Occasional Sweep study and 1.21 for the Multiple Sweep study. Tillage and herbicide application cost were estimated via Oklahoma Farm and Ranch Custom Rates 2021-2022 (Sahs, 2022). To determine herbicide costs, three local herbicide retail locations were contacted on March 30, 2023 to request prices and were averaged across the three locations (Table 1.12). To calculate the cost of each herbicide treatment, the grams of active ingredient used per hectare were multiplied by the average cost of herbicide per gram of active ingredient. Treatments that included herbicides included the application fee of one to two applications with a boom sprayer, depending on if there was a sequential application of paraquat in the treatment. Cost calculations do not include surfactants, water conditioners, or adjuvants. Disk treatments are calculated as three applications of disk. Cost is provided for offset and tandem disks. Sweep tillage costs are provided as described for blade or wide sweep tillage.

1.3 RESULTS AND DISCUSSION

Occasional Sweep

Treatments of sweep tillage + any herbicide provided greater control than no-till + herbicide at LCB-20 and Wakita-22 (Table 1.3). At Wakita-21, there was one exception to this trend with no-till treatments of glyphosate followed by paraquat being statistically similar to sweep + herbicide, providing 88% control of tumble windmill grass (Table 1.3). Glyphosate has a history of controlling tumble windmill grass, as described by Hennigh et al. (2005) whom noted 100% control of tumble windmill grass by glyphosate. Obour et al. (2021) observed similar success in weed control from sweep tillage alone when using two passes of sweep three days apart. Compared to two passes of sweep, the addition of herbicide may provide an alternative control method for areas where sweep-to-soil contact is inconsistent or for a second line of defense against newly emerged or non-responsive weeds.

Disk alone provided greater than 87% control across all years of the study, which was consistently among the highest levels of control across all treatments (Table 1.3). While disk was an effective form of control, it is associated with an increased risk of soil erosion (Zhang, 2012) and many producers are not willing to convert significant acreage to this tillage method due to this risk. This tillage method may be reserved for use on a limited basis depending on severity of tumble windmill grass infestation and site-specific susceptibility of soils to erosion. If disking was incorporated into a weed management program, it would be ideal to use the opportunity to include soil residual herbicides to aid in weed suppression and include herbicide modes of action that may not be as practical in no-tillage (Norsworthy et al., 2012; Evans et al., 2015; Kniss, 2017).

Out of treatments of herbicide used alone (no-till), clethodim + dicamba + 2,4-D followed by paraquat provided the lowest control at LCB-20 (66%) and Wakita-21 (53%) (Table 1.3). These results are similar to those of Lancaster & Falk Jones (2021) and Hennigh et al. (2005), which suggest clethodim does not provide adequate control of mature tumble windmill grass. There is research that suggests antagonism between clethodim and dicamba may exist (Underwood et al., 2016; Zollinger et al., 2017; Harre et al., 2019; Perkins et al., 2021), although many factors influence this phenomenon including herbicide rate and formulation, addition of adjuvants or water conditioners, plant species, weather, and application timing (Green, 2017). Even considering the wide array of variables that could have influenced control of treatments including clethodim, tank-mixing clethodim + dicamba + 2,4-D followed by paraquat did not provide adequate visual control of tumble windmill grass. Further research could incorporate using these herbicides sequentially or in separate tanks and booms simultaneously, as both have been shown to improve efficacy (Merritt et al., 2020).

Winter wheat biomass was impacted by treatments at LCB-20 and Wakita-22 (Table 1.4). The disk treatment yielded greater winter wheat biomass than all NT treatments in 2021 at LCB-20. The disk tillage treatment was also significantly greater than all sweep treatments except that which received glyphosate + dicamba + 2,4-D. This may be due to disk tillage incorporating nutrients into the tillage depth that were previously stratified (Wright et al., 2007; Rivera-Zayas et al., 2018), which could have led to a slight increase in wheat yield. Biomass harvest at Wakita-21 found glyphosate followed by paraquat in no-till provided the greatest wheat biomass of all no-till treatments, but was only significantly greater than clethodim + dicamba + 2,4-D followed by paraquat in no-till. Winter wheat biomass in sweep tillage plots was similar to no-till in each year, suggesting that sweep tillage did not induce a negative effect on winter wheat growth. Data collected from LCB-20 in June of 2022 suggests that the residual effect of tillage intensity on biomass production is short lived as no differences were observed two years after treatment application (Table 1.4).

Weed biomass was not significantly different among treatments for LCB-20 for samples collected in June 2021 approximately one year after treatment application or in June 2022 approximately two years after treatment application (Table 1.5). Interestingly, LCB-20 sampled in 2022 had no weed biomass to collect across any of the treatments. This sample timing was intended to evaluate the residual control of treatments and all tumble windmill grass was effectively terminated. However, this site did have a maintenance application of glyphosate applied prior to wheat planting in the fall of 2021 and an in-season application of pyroxsulam in March of 2022, which likely impacted tumble windmill grass regrowth. Furthermore, drought conditions may have limited plant growth in the spring of 2022. While it is unclear if the study treatments were the specific cause for seemingly complete eradication of tumble windmill grass from this site, this shift in weed presence does showcase the need to strategize management efforts across more than one timing or one season in order to achieve the most effective control.

At the Wakita-21 site sampled in June 2022, only one treatment had levels of biomass that were significantly different from all other treatments: clethodim + dicamba + 2,4-D followed by paraquat in no-till (Table 1.5). Interestingly, this treatment had similar visual control in September of 2021 prior to wheat planting as no-till treatments of glyphosate + dicamba + 2,4-D and glyphosate followed by paraquat. While visual control was similar, clethodim + dicamba + 2,4-D followed by paraquat likely saw decreased uptake and translocation of herbicide either due to severe drought conditions or antagonism (Parker & Boydston, 2005; Lancaster & Falk Jones, 2021), and was not as effective in damaging the perennial structures of the plant. Thus, during spring green up, tumble windmill grass plants were able to recover and produce more biomass than the other herbicide treatments. Biomass likely serves as a better representation of efficacy of control, due to the perennial nature of tumble windmill grass. While visual ratings provide insight into treatment efficacy, biomass provides quantification of plants that survive, regrow, and compete with the crop in the following spring. While a weed-free period of 30-50 days following planting is important for winter wheat success (Khan et al. 2002; Chaudhary et al., 2008; Welsh et al., 2008), competition during grain-fill has proven to have a significant impact on crop yield, particularly in terms of soil water availability (Thorsted et al., 2006).

Winter wheat grain yield was significantly different among treatments at LCB-20 in 2021, with treatments of disk or sweep + glyphosate followed by paraquat yielding greater than 3836 kg ha^{-1} of grain (Table 1.6). All sweep tillage treatments yielded greater than or similar to no-till treatments, reinforcing that sweep tillage did not illicit a negative effect on wheat growth or yield. Similar to results observed with winter wheat biomass, differences observed between disk-tilled and no-till treatments may be due to incorporation of stratified nutrients. These differences in winter wheat yield may also have been a result of competition between tumble windmill grass and wheat. Recent estimates indicate winter wheat can experience up to an 11% yield loss from tumble windmill grass competition (Obour et al., 2021), but this estimate is based on a study of limited scope and could be improved upon with further research. Overall, winter wheat yield can be significantly reduced by weeds (Flessner et al., 2021), such as Italian ryegrass (*Lolium multiflorum*) which can reduce wheat yield by up to 92% (Hashem et al., 2017). It has been suggested that winter wheat yield can be equivalent or greater under conventional tillage (Hofmeijer et al., 2019), but generally long-term no-tillage systems are thought to increase winter wheat yield in Oklahoma by up to 5% (Omara et al., 2019). No differences in yield were observed in Wakita-21 in 2022 due to drought conditions suppressing yields in all treatments. More interestingly, the effects of treatments applied at LCB-20 no longer impact yield in the second wheat crop after these treatments were applied. This is not surprising due to a loss of windmill grass pressure in all treatments.

No differences were observed in aggregate stability at the 0-5 cm depth across locations, regardless of time passed since tillage application (Table 1.7). Out of three years of sampling after planting, following tillage, only one year (Wakita-22) yielded significant aggregate stability differences among treatments at the 5-15 cm soil depth. In this case, disk tillage had greater aggregate stability than no-tillage and sweep tillage serving as the intermediate. This data is in direct opposition to a study conducted by Stavi et al. (2011) in eastern Ohio that suggests that even one year of tillage in a previously no-till system can induce significant soil response. Meanwhile other studies, particularly a study conducted in Kansas by Obour et al. (2021), found similar results and indicate that a single application of sweep tillage did not influence aggregate stability, soil organic carbon, or soil water content at wheat planting. Another study (Celik et al., 2019) found greater aggregate stability in the 10-20 cm soil depth following strategic moldboard plow + disk tillage than no-tillage. The data presented here validates Obour et al. (2021) and Celik et al. (2019), indicating that strategic tillage has no negative impact on aggregate stability in otherwise long-term no-till soils.

A difference in CO_2 emissions was noted among treatments at the 5-15 cm depth in Wakita-21 in the fall 2021 following tillage applied in the summer of 2021 (Table 1.8). Sweep tillage had significantly lower CO_2 emissions than disk with no-tillage serving as the intermediate. Disk may have had greater CO_2 emissions as a result of increased incorporation of soil surface vegetation at the 5-15 cm soil depth, leading to greater availability of organic matter and resulting priming of soil organism activity and increased CO_2 production (Xiao et al., 2014; Maestrini et al., 2015). Furthermore, the lack of significant differences in CO_2 emissions noted 2 years after tillage at LCB-20 and 1 year after tillage at Wakita-21, further suggests that it is reasonable to assume the increase in CO_2 in the fall following summer tillage observed at Wakita-21 was due to the short-term effect microbial priming rather than long-term increases in total available soil organic materials for microbial decomposition. No differences between tillage treatments were noted for the 0-5 cm soil depth.

No significant differences were noted among treatments for soil organic matter (Table 1.9) or volumetric water content (Table 1.10). In terms of weed control and little to no negative changes in soil characteristics, the results of this study largely agree with the recent studies by Obour et al. (2021) and Celik et al. (2019), which suggest that use of occasional or strategic tillage in otherwise no-tillage systems could be a viable option to control tumble windmill grass while maintaining soil health.

Regarding economic analysis, treatment costs ranged from \$60.87 to \$180.58 (Table 1.12). Treatments of glyphosate at 1123 g ai ha^{-1} + dicamba at 140 g ai ha^{-1} + 2,4-D at 402 g ai ha^{-1} in no-tillage systems had the lowest cost at \$60.87 ha^{-1}. The addition of sweep tillage to this herbicide treatment brought the cost to \$93.39 ha^{-1}. While adding over 50% to total treatment cost, the addition of sweep tillage increased visual tumble windmill grass control by 21-23% each year (Table 1.3). Treatments of glyphosate at 1543 g ai ha^{-1} followed by paraquat at 842 g ai ha^{-1} were \$111.16 in no-till and \$143.69 in sweep till with sweep tillage adding 11-25% increase to tumble windmill grass control.

Clethodim treatments included the most herbicide modes of action and the greatest costs of all treatments at \$148.05 in no-till and \$180.58 in sweep tillage. Considering the level of weed control observed with clethodim in no-till was ≤ 70% control, the cost of this treatment not likely to appeal to weed managers in no-till due to the risk of treatment failure. Furthermore, glyphosate treatments offered greater control at a lower cost.

Disk tillage treatment costs were less than all other treatments except for no-till + glyphosate at 1123 g ai ha^{-1} + dicamba at 140 g ai ha^{-1} + 2,4-D at 402 g ai ha^{-1}, with three passes of offset disk estimated at \$79.95 and three passes of tandem disk at \$90.92 (Table 1.12). While disk tillage was among the most affordable weed control option, it creates an increased risk of soil erosion, particularly under the premise of climate change (Zhang, 2012).

Multiple Sweep

Two and three applications of sweep provided greater control of tumble windmill grass (95-100%) than herbicide alone or a single application of sweep (Table 1.13), with one exception in Wakita-21 where a single application of sweep provided similar visual control as two or three applications. No-tillage treatments of glyphosate followed by paraquat provided the lowest levels of visual control across all years, ranging from 50% to 85%. Differences in control provided by a single application of sweep may be due to in-season rainfall from year to year, or timely rainfall following the first sweep application. No data is currently available in the literature for comparison of multiple sweep tillage and weed management or soil health outcomes.

No differences were noted among winter wheat biomass or weed biomass across all years (Tables 1.14 and 1.15). Drought conditions in spring of 2022 may have limited growth and resulting biomass of tumble windmill grass, preventing meaningful data collection. However, winter wheat yield differences were observed for the first harvest after tillage for LCB-20 and Wakita-21 (Table 1.16). In both years a single application of sweep was the lowest yielding treatment and was statistically similarly to herbicide alone (no-tillage). At LCB-20, three applications of sweep yielded greater than herbicide alone, while at Wakita-22 these treatments were statistically similar.

No differences were observed among treatments for aggregate stability (Table 1.17) or CO_2 emissions across all years (Table 1.18). However, soil organic matter differences were noted two years after tillage at LCB-20 (Table 1.19), in which no-tillage had similar soil organic matter to a single application of sweep tillage in the 0-5 cm depth. Two and three applications of sweep significantly lower the amounts of soil organic matter at 0-5 cm. This reduction in soil organic matter following two to three applications of sweep tillage may be due to multiple passes of sweep reducing stratification in this soil as indicated by elevated soil organic matter in the 5-15 cm depths in these treatments. Although this effect was not significant at the 5-15 cm depth, the elevated soil organic matter of 1.7 and 1.6 in the 2X and 3X sweep treatments, respectively, suggest that these tillage treatments are incorporating soil organic matter into the soil as compared to the no-till and single sweep treatments.

Differences in volumetric water content were noted for the 0-30 cm and 30-60 cm soil depths at LCB-20 when sampled in November of 2020 (Tables 1.20). At the 0-30 cm soil depth, three applications of sweep had greater soil water content than no-tillage or single application of sweep and was similar to two applications of sweep. At the 30-60 cm soil depth, three applications of sweep tillage had similar soil water content as no-tillage and greater soil water content than a single application of sweep. No differences were observed in lower soil depths for LCB-20. No soil water content differences were noted across any of the soil depths sampled at Wakita-21 in March of 2022. Treatments had no significant negative impact on soil water availability, and could potentially increase water availability to following crops by reducing competition with tumble windmill grass.

Sweep tillage performed up to three times had a lower cost ($97.59) than herbicide alone ($111.16) (Table 1.21). Paired with the cost analysis provided in Table 1.13, this analysis suggests that sweep tillage + glyphosate at 1123 g ai ha^{-1} + dicamba at 140 g ai ha^{-1} + 2,4-D at 402 g ai ha^{-1} ($93.39) or two to three passes of sweep tillage alone ($65.06 to $97.59) may be the most cost-effective means of controlling tumble windmill grass while retaining soil surface vegetation and reducing risk of soil erosion. However, sweep tillage alone provides no residual control and could result in escapes where sweep-to-soil contact is poor. Thus, the inclusion of herbicide may provide an additional layer of support in constructing a well-rounded weed management plan for not only tumble windmill grass, but all weeds considered in a system.

1.4 SUMMARY

Tumble windmill grass is challenging to control with herbicide alone. Sweep tillage served as an excellent tool to control this weed, particularly when paired with herbicide. Sweep tillage paired with glyphosate + dicamba + 2,4-D or glyphosate followed by paraquat could be suitable treatments to control tumble windmill grass. Sweep tillage with clethodim + dicamba + 2,4-D followed by paraquat could be used to control tumble windmill grass, but due to the risk of antagonism this treatment isn't recommended. Treatments of herbicide alone in no-tillage settings did not provide visual control greater than 88%, and thus are not likely to satisfy weed manager needs while seeking to control this plant. Disk tillage did successfully control tumble windmill grass (≥ 87% across all years) but poses a significant risk in terms of soil erosion and general lack of producer willingness to convert no-till acres to conventional tillage.

Soil response to a single application of sweep tillage was statistically similar to no-tillage in terms of aggregate stability, CO_2 emissions, and soil organic matter at the 0-5 and 5-15 cm soil depth in both studies. Soil organic matter in the 0-5 cm depth did decrease when sweep was applied two or three times, however these additional applications of sweep tillage did increase weed control compared to a single application of sweep with no herbicide.

Each study site will be agronomically maintained and monitored through harvest in 2024 to determine long-term efficacy of treatments in controlling tumble windmill grass and evaluate soil response in the seasons following tillage. Further research should incorporate a greater portfolio of chemical control and tillage options. A focus on soil residual herbicides in combination with postemergence herbicides could be beneficial in forming a multi-season approach to controlling tumble windmill grass.

CHAPTER II

TILLAGE SYSTEM IMPACT ON DELAYED PREEMERGENCE HERBICIDE EFFICACY IN WINTER WHEAT

ABSTRACT

Delayed preemergence herbicides can provide season-long Italian ryegrass (Lolium perenne L. ssp. multiflorum (Lam.) Husnot) control in winter wheat. However, heavy surface vegetation residues may reduce efficacy. A study was conducted from 2019-2022 near Stillwater, Oklahoma to evaluate the efficacy of delayed preemergence herbicides in no-till, sweep till, or disk till. Sweep tillage was applied with a sweep plow, which consisted of a 1.5m V-shaped blade that undercut the top 6-10 cm of soil with a rotary hoe following behind. Disk tillage was performed with multiple passes of a tandem disk and followed by a field cultivator. Treatments were arranged as a randomized complete block design, with tillage serving as the block, and replicated three times. Herbicide treatments consisted of metribuzin, pinoxaden, pyroxasulfone, and/or pyroxasulfone + carfentrazone-ethyl applied alone or in tank-mixture. No tillage by herbicide interaction was found for weed control, indicating soil surface residue as influenced by tillage did not affect the efficacy of delayed preemergence herbicides in winter wheat. Ryegrass control greater than 86% was achieved in May 2020, 2021, and 2022 with treatments of pyroxasulfone + metribuzin and pyroxasulfone + pinoxaden. Soil response to tillage was not observable after one or two years of tillage. However, after three years of tillage, sweep and disk tillage treatmentsexhibited lower aggregate stability and disk tillage treatments emitted greater amounts of CO_2-C per kg of soil at the 5-15 cm depth when compared to no-tillage. Three years of sweep tillage did decrease the surface soil aggregate stability but did not result in significant differences in CO_2 emissions and increased organic matter as compared to the no-till treatment. The data presented in this paper support the use of sweep tillage in combination with delayed preemergence herbicides, which could be beneficial for building sustainable and effective weed management systems with sweep as an alternative which maintains surface crop residues while having limited impact on soil health parameters and provides control of weeds in a conservation system.

2.1 INTRODUCTION

During the 2020 growing season, 4.25 million acres of winter wheat were sown in Oklahoma, making it the state's largest cash crop and ranking Oklahoma third in the nation for wheat production (NASS, 2022). Oklahoma's unique climatic conditions allow for dual-purpose production, in which cattle may graze wheat until stem elongation. At this stage cattle are removed, the wheat recovers, and grain is harvested. However, this production system is prone to increased weed occurrence by nature of budgeting weed management methods with cattle and wheat prices (Noble Research Institute, 2010). A recent survey by the Weed Science Society of America estimated losses due to presence of weeds in winter wheat up to 34.4% (Flessner et al., 2021). Grain yield losses specific to Italian ryegrass competition with winter wheat have been estimated from 60% to up to 92% (Appleby et al., 1976; Hashem et al., 2017). These factors, paired with Oklahoma's populations of introduced and native grassy weeds and extreme weather patterns, creates an environment where weed control can be highly variable season to season.

Another factor that has become increasingly important to consider for Oklahoma winter wheat management is herbicide resistant weeds. Neighboring states of Kansas, Missouri, Texas, and Colorado have each reported cases of herbicide resistance in weeds grown in winter wheat (Heap, 2022). With research underway to slow the spread of herbicide resistance and monitor potentially resistant herbicide populations, it is no surprise that pinoxaden resistant Italian ryegrass (Lolium multiflorum) populations were discovered in Central Oklahoma in 2018 (Heap, 2022). With this discovery, producers who are eager to manage their weeds are searching for reliable, effective methods to control their grassy weed populations, particularly Italian ryegrass

While approximately 40% of Oklahoma's production acres are under no-tillage management, some producers are considering various forms of tillage to combat intensifying weed problems (Sawadgo & Plastina, 2022). Although tillage can be an effective form of weed control, research shows it can reduce soil organic carbon, aggregate stability, and overall increase risk of soil erosion (Blevins & Frye, 1993; Lal, 2001). To further complicate the matter, one of the most effective options currently available for Italian ryegrass control are delayed preemergence herbicides that contain language stating that tillage, or residual vegetation as a result of tillage, rather, may negatively affect herbicide performance. Zidua, a preemergence herbicide with the active ingredient pyroxasulfone, has language on the label that reads "Herbicidal activity of Zidua may be reduced if trash on the soil surface from the previous crop covers more than 25% of the application area. Manage trash levels if needed with combine straw shredders/spreaders, earlier burndown of emerged weeds, or light tillage" (BASF, 2017).

Conservation tillage covers 38% of US cropland (CTIC, 2022). Conservation tillage is any form of tillage that leaves 30% or more crop residue on the soil surface after planting (CTIC, 2022). Under this definition, Zidua applied in conservation tillage systems may have decreased efficacy. However, little research is available regarding not only the validity of this statement, but also regarding weed control efficacy or soil response to sweep tillage. As producers continue to consider how to balance weed management with soil erosion prevention tactics, it is important that they are provided accurate information on the potential consequences of their practice choices. Thus, this study aimed to provide updated information regarding interactions between sweep tillage, soil response, and delayed preemergence herbicide use in winter wheat.

Soil response was evaluated by examining wet aggregate stability, CO_2 emissions, and soil organic matter changes over the course of the study. Wet aggregate stability to the soil's ability to resist quick wetting and maintain structural integrity. CO_2 emission analysis evaluates soil microbial respiration, which is intended to quantify microbial activity rather than characterize microbial communities within the soil. Soil organic matter provides nutrients and structural stability to soil. These parameters are often used when evaluating soil health, as noted in the Cornell Comprehensive Assessment of Soil Health (CASH) and the Haney soil health test (Moebius-Clune et al., 2017; Haney, 2022). Although a wide selection of parameters can be used to evaluate soil response, recent research advancements have made the application of these three parameters more accessible for commercial use and, in turn, cost effective and time efficient for this cross-disciplinary study (McGowan et al., 2018; Garcia et al., 2022).

This study investigated the use of 5 preemergence herbicide treatments and one postemergence herbicide treatment across no-tillage, disk tilled, and sweep tilled systems. The objectives for this study were to 1.) Determine if soil surface residue as influenced by tillage negatively influenced the efficacy of delayed preemergence herbicides and 2.) Evaluate soil health parameters of each tillage system.

2.1 MATERIALS AND METHODS

Study Site, Tillage, and Experimental Design

This study was conducted over three growing seasons at the Cimarron Valley Research Station in Perkins, Oklahoma. The study site was a field that was conventionally cultivated annually and planted to winter wheat prior to the start of this study. Tillage zones were established in late summer of 2019 and maintained through each growing season until the completion of the study after wheat harvest in 2022. Tillage treatments included no-tillage, sweep tillage, and disk tillage. Sweep tillage was applied with a sweep plow, which consisted of a 1.5m V-shaped blade that undercut the top 6-10 cm of soil with a rotary hoe following behind. Disk tillage was performed with multiple passes of a tandem disk and followed by a field cultivator to form a smooth seed bed. The treatments were arranged as a randomized complete block design, with tillage serving as the block, and replicated three times. Each tillage zone was 18.2 m wide and more than 30.4 m long, such that herbicide plots could be situated near the center of the main plot where the most uniform tillage was present. Herbicide plots were 2.1 m by 9.1 m in length.

Herbicide Treatments

Herbicide treatments followed rate recommendations as described on the label and included four delayed preemergence herbicides and one postemergence herbicide (Table 2.1). A handheld 1.93m CO_2-pressurized backpack calibrated to deliver 140 L ha^{-1} at 207 kPa^{-1} was used to apply all treatments. Application speed was 4.8 km $hour^{-1}$. Turbo TeeJet 11002 nozzles were used for all applications.

Wheat was planted on October 14, 2019, September 25, 2020, and October 26, 2021. The trial area was planted to wheat variety "Gallagher" at 67.5 kg seed ha^{-1} each year. Delayed preemergence applications were applied when the wheat was at spike and the early-postemergence application was made when Italian ryegrass had 3-4 tillers. Delayed preemergence application dates were October 29, 2019, October 6, 2020, and November 10, 2021. Early-postemergence applications were made March 11, 2020, March 19, 2021, and March 25, 2022. One untreated control was maintained in every tillage replication in every year.

Weed Control Measurements

Visual weed control ratings were based on a scale of 0% to 100%, with 100% indicating complete control and 0% indicating no control (Frans et al., 1986). Visual ratings were taken once in 2020 and throughout the season in 2021 and 2022. Crop and weed biomass samples were taken from two 0.25 m2 areas of each plot two weeks prior to harvest in 2021 and 2022. Crop and weed biomass were cut near the soil surface, bagged, dried in a forage drier at approximately 50°C, and weighed. Plots were harvested with a Winterstreiger combine with a 1.5 m header. Each plot's grain was collected in a paper sack and weighed.

Soil Sampling and Analysis

Soil samples were collected in August of 2020 before planting and July of 2021 and 2022 after wheat harvest. Soil cores were collected from 0-5 cm and 5-15 cm using a handheld soil probe within each tillage zone. Soil cores were removed from the probe and placed in a bucket to homogenize them before a subsample was placed in a bag, oven-dried at 65°C, and then mechanically ground. Soils were analyzed at the Soil, Water, and Forage Analytical Laboratory at Oklahoma State University for pH, buffer index, N, P, K, and soil organic matter. Soils were returned to the lab for further analysis for CO_2 emissions and sieved between 1 and 2 mm. The portion of the sample that remained in the 1-2mm sieve was considered to be aggregates and analyzed for aggregate stability. Due to malfunctions with equipment, soil samples from 2020 were not able to be analyzed for aggregate stability and CO_2 emissions.

Aggregate stability analysis was conducted as described by Yoder (1936) and modified by Kemper and Rosenau (1986) and Garcia et al. (2022). Oscillating equipment used was a wet sieving apparatus developed by Eijkelkamp Agrisearch Equipment (The Netherlands). This apparatus contains eight 60-mesh sieves which oscillated 8 samples in separate containers. Analysis was conducted with seven experimental samples and one check sample per run.

Four grams of 1- to 2-mm aggregates were placed in sieves in an oscillator, wetted, and then submerged in 100 ml of deionized water for 10 minutes. The samples were then oscillated, moving 1.3 cm vertically 35 times per minute for 3 minutes. The cups of deionized water and soil particles were removed, and cups were placed in the oven to dry. The samples remaining on the sieve were submerged in 100 mL of sodium hexametaphosphate (soils with pH > 7) or sodium hydroxide (soils with pH < 7) and the oscillating process was repeated for 3-5 minutes. Any aggregates that remained stable after 5 minutes of sieving were crushed with a rubber-tipped spatula and disintegrated into the dispersing solution. Sieving was continued until the sample was completely disintegrated into the solution.

Cups of dispersing solution were placed in the oven at 110°C for 24 hours to dry. Both sets of cups were weighed once all water or solution had evaporated. To determine sample weight, weight of the cup was subtracted from the total weight. For cups with dispersing solution, an additional 0.2g was subtracted from the total amount to account for solution contents. The percent of stable aggregates was calculated by dividing the weight of the soil obtained in the dispersing solution by the sum of the weights obtained in the deionized water + dispersing solution.

CO_2 emission analysis was conducted as described by McGowan et al. (2018) and modified by Garcia (2021). To prepare samples, 2 grams of soil were placed into 20 mL glass crimp top vials. 0.5 mL of deionized water was added to 8 vials every hour until all samples were wet. Vials were sealed immediately after wetting by grey septa and aluminum crimp top. Vials were incubated at room temperature for approximately 24 hours. Vials containing soil samples plus 6 calibration standards were then analyzed via gas chromatographer (Varian 450 GC, the Netherlands, serial number GCD912B060). The concentration of CO_2 in the headspace of the vials was converted to a mass basis using the ideal gas law and this mass of CO_2 was divided by 2 such that all data is presented as mg CO_2-C kg^{-1} of soil.

Data Analysis

Data were analyzed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, Cary, NC, USA). Tillage and herbicide treatments were treated as fixed effects while plot, replication, and year were treated as random effects. Interactions between tillage and herbicide treatments were evaluated for measurements of Italian ryegrass visual control, biomass, and wheat yield. No interaction was present between tillage and herbicide for weed control, thus weed control ratings are grouped by herbicide. An interaction was present between year and depth for aggregate stability results and CO_2 emissions analysis, thus both are provided by depth and year. Significant means were separated using the Tukey-Kramer least square means test ($P \leq 0.05$).

2.3 RESULTS AND DISCUSSION

The purpose of this study was to determine if soil surface vegetation, as influenced by tillage, impacted efficacy of delayed preemergence herbicides in winter wheat. No interaction was observed between herbicide efficacy and tillage system, thus it was determined that soil surface residue does not impact the efficacy of delayed preemergence herbicides in winter wheat. Further explanation regarding weed control and soil response are discussed below.

Weed Control

The selection of herbicides used in this study are common for the region (Manuchehri et al., 2019). In some regions of Oklahoma, pinoxaden resistant Italian ryegrass biotypes are present (Heap, 2022). These biotypes are not yet widespread and pinoxaden is still used frequently across the state. This study indicates this active ingredient is still viable for the area, with greater than 90% control within 60 days of application (Table 2.2). Given that pinoxaden provides no soil residual, lack of control 60 days after application is not surprising. This product is best utilized when it can be applied in synchronization with weed flushes and favorable weather. Additionally, applying this product alone is not recommended when considering the presence of herbicide resistant biotypes and general strategies to prevent further spread of herbicide resistance (Norsworthy et al., 2012; Evans et al., 2015; Kniss, 2017). For the purpose of this study it was used alone, but when considering its role in a weed management program it would be best suited to tank-mix with another mode of action to increase longevity of this product.

Pyroxasulfone + pinoxaden provided greater than 87% control across all rating dates, even up to 230 days after application (Table 2.2). This treatment pairs a soil residual herbicide (pyroxasulfone- Group 15) with a postemergence herbicide (pinoxaden- Group 1). This pairing provides 2 modes of action, which is helpful in preventing the spread of herbicide resistance (Norsworthy et al., 2012; Evans et al., 2015; Kniss, 2017). Similarly, pyroxasulfone + metribuzin (Group 5) provided greater than 83% control across all rating dates. This is another combination offering 2 modes of action, but metribuzin can cause crop injury in some cases (VanGessel et al., 2017; Newlin, 2021). Similar to control observed in this study, pyroxasulfone applied alone or in tank-mixes has been shown to provide excellent control for Italian ryegrass and a variety of other weed species (Hulting et al., 2017; Kumar et al., 2017; Johnson et al, 2018)

Overall, lower Italian ryegrass control was observed during the 2020-2021 growing season, particularly in the case of pyroxasulfone + carfentrazone-ethyl (Table 2.2). This decrease in control may have been the result of lack of timely rainfall following the delayed preemergence application, as it took several weeks to receive adequate rainfall in the fall of 2020. Timely rainfall occurred in 2020 and 2022.

The field in which this study was conducted normally has a dense population of Italian ryegrass. However, in the interest in evaluating the impact of multiple years of tillage on system characteristics including herbicide efficacy, soil health and crop performance, herbicide treatments were located in the exact same location within the established tillage zones in 2020-2021 and 2021-2022 growing seasons. Due to the general high levels of control in 2020-21, this could have led to fewer seeds entering the seed bank and less potential seeds to germinate in the fall of 2021. Thus, lack of weed density during the 2021-2022 growing season was an issue. Very little Italian ryegrass emerged, leading to no noticeable differences between herbicide treatments and the control. This lack of weed pressure was also observed in weed biomass; all treated plots had no Italian ryegrass present during biomass collection, and the untreated control only having 0.01 grams of Italian ryegrass present (Table 2.4).

Tillage treatment did not influence winter wheat yield. This trend is not uncommon to observe, although data from long-term continuous wheat trials in Oklahoma suggests a 5% wheat grain yield difference can be observed after 15 years of no-tillage (Omara et al., 2019). Differences in wheat yield due to herbicide treatment were only observed in 2020, when winter wheat yield for the untreated check was statistically different than all herbicide treatments (Table 2.3). However, statistical differences in winter wheat biomass were present in 2021 and 2022. In 2021, only pinoxaden applied POST produced biomass that was greater than the untreated control (Table 2.4). This may be due to the application of pinoxaden in early spring, when warm weather and timely rains can induce flushes of Italian ryegrass prior to wheat harvest. In this case, pinoxaden applied POST provided in-season control of Italian ryegrass while other herbicide treatments had weed competition. In 2022, only pyroxasulfone + pinoxaden produced greater biomass than the untreated control (Table 2.4). Without biomass data, these differences could have been attributed to season-long competition with weeds, but weed biomass was near zero for every single treatment in 2022. This data, in addition to the visual rating data provided in Table 2.2, indicate very little weed competition was present.

Soil Response

No significant differences in aggregate stability were observed in samples collected in 2021, suggesting that 2 years of tillage were insufficient to alter this soil health parameter. However, aggregate stability was statistically different among tillage treatments at 0-5 cm soil depth in 2022 (Table 2.6). Disk tillage treatments displayed the lowest amount of aggregate stability at 35.7%. Sweep tillage was intermediate at 43.1% stable aggregates. No-tillage had the greatest aggregate stability at the conclusion of the study at 54.4% stable aggregates. By this point in the study, tillage had been applied three times over three years. This soil response indicates that while tillage can impact soil aggregate stability, repeated tillage events are required to illicit a change in aggregate stability in some soils. Aggregate stability was not statistically different among tillage treatments at the 5-15 cm depth in 2022. Both tillage implements disturbed the soil at greater than 5 cm depths, however top soil may have provided protection from further aggregate weathering and allowed aggregates to remain undisturbed at a greater rate than soil closer to the surface.

CO_2 emission analysis results were not statistically different among tillage treatments in 2021, after two tillage treatments across two years. However, statistical differences begin to emerge after the third tillage event as indicated in soil samples collected in 2022 (Table 2.5). Soils at the 0-5 cm depth showed no statistical difference at an alpha value of 0.05 but if an alpha of 0.1 is applied we do see that the disk treatment had a lower CO_2 emission than remaining treatment in the 0-5 cm depth. The inverse was found in the 5-15cm depth. Disk tilled soils produced the greatest amount of mg CO_2-C kg-1 at 5-15cm, while sweep tilled and no-tilled soils were statistically similar. Similarities between sweep tilled and no-tilled treatments may be due to lack of burial of surface residue. While sweep tillage undercuts the soil surface, it does not chop and bury residue in the top 5-10 cm of soil as disk tillage does. This data suggests that disking delivers microbially active residue to the 5-15 cm depth where it maintains elevated microbial activity, also known as priming, even after wheat harvest 9 months after the last inversion tillage event was applied (Xiao et al., 2014; Maestrini et al., 2015).

Soil organic matter was not significantly different among treatments after one or two years of tillage (Table 2.7). However, after three years of tillage soil organic matter differences do occur in the 5-15 cm soil depth. Contrary to findings throughout the literature (Halvorson et al., 2002; Deen & Kataki, 2003; Alvarez, 2005; Omara et al., 2019; Jakab et al., 2023) soil organic matter under disk tillage was greater than no-tillage or sweep tillage at the 5-15 cm soil depth after three years of annual tillage (Table 2.7). These results do agree with findings of Haddaway et al. (2017), which indicate that soil organic carbon can be greater in “intermediate” or disk tilled soils at depths of 0-15 cm. This difference in soil organic matter could be due to the mixing action of disk tillage, which incorporates soil vegetation vigorously and can increase initial decomposition (Lupwayi et al., 2004).

2.4 SUMMARY

Based on the data collected in this study, the influence of tillage on soil surface residue does not have an impact on preemergence herbicide efficacy. Soil response to tillage was not observable after one or two years of tillage. However, after three years of tillage, sweep and disk tillage treatments exhibited lower aggregate stability and disk tillage treatments emitted greater amounts of CO_2 per kg of soil at the 5-15 cm depth when compared to no-tillage. This data suggests that single applications of tillage may not illicit significant soil responses, and thus could be incorporated on a periodic basis into weed management systems when troublesome weeds are at hand.

Sweep tillage is a viable tool for weed control on the Central and Southern Great Plains. This tool is unique in its ability to mechanically kill weeds while offering very little soil disturbance. Three years of sweep tillage did decrease the surface soil aggregate stability but did not result in significant differences in CO_2 emissions and increased organic matter as compared to the no-till treatment. The data presented in this paper support the use of sweep tillage in combination with delayed preemergence herbicides, which could be beneficial for building sustainable and effective weed management systems with sweep as an alternative which maintains surface crop residues while having limited impact on soil health parameters and provides control of weeds in a conservation system. Further research should assess the impact of tillage frequency versus the tillage intensity evaluated in this study on soil health parameters and weed ecology to further improve our understanding of interactions between weed management and soil health manageme

CHAPTER III

CROPPING SYSTEMS CURRICULUM DEVELOPMENT: CHANGING STUDENT PERCEPTIONS OF FARMING THROUGH FIELD-TRIP EXPERIENCES

ABSTRACT

A new course was implemented at Oklahoma State University to provide students with first-hand exposure to farming practices via field trips and supplemental information supplied via expert guest lectures. With many students now entering college with little to no experience in agriculture, this course was designed to reduce the agricultural experience gap between urban and rural students. Students could visit farms ranging in size from 1 acre to 15,000 acres and see commodity and specialty crops. Student perceptions were noted via pre- and post-course surveys. Survey results spanned over two semesters, with 26 students surveyed in total. Surveys asked for student views on Oklahoma farm progress over the last 20 years. In pre-course surveys, 19% of students perceived Oklahoma farm progress negatively. In post-course surveys, only 6% of students perceived Oklahoma farm progress negatively. Students benefitted from hands-on experiences that reinforced classroom-taught principles.

3.1 INTRODUCTION

Urbanization of the population is now at over 82% and increasing across the US (Center for Sustainable Systems, 2021), leading to fewer students entering college classrooms with agriculture experience. Public trust in modern farming methods is also declining (Lang & Hallman, 2005; Arnot, Vizzier-Thaxton & Scanes, 2016). Thus, agriculture educators are not only faced with a large disparity among student experiences which can lead to comprehension difficulty, but broaching subjects of modern farming methods are often met with distrust or skepticism. Therefore, a proposed solution would bring students to the field to experience agriculture first-hand. This solution was posed as a field-trip based course focusing on Oklahoma cropping systems. This course was funded through Agriculture and Food Research Initiative Competitive Grant no. 2019-68012-29888 from the USDA National Institute of Food and Agriculture.

This course was intended to allow upper-level plant and soil science undergraduates and graduate students to pair theories introduced through the previous core curriculum with hands-on field trip experiences. This course was not intended to introduce students to principles of agronomy, cropping systems, or soil science, but rather serve as a venue for students to connect abstract classroom ideas with tangible agronomic systems. Field trips are shown to be heavily influenced by previous student knowledge (DeWitt & Storksdieck, 2008). Thus, this course was intended for upper-level students to reinforce principles learned in other plant and soil science courses to develop and manage cropping systems in the Great Plains to use natural resources efficiently. Field trips were the focal point of the course because experiential learning has been shown to connect students with societal constructs and improve student success, particularly regarding student interest, knowledge, and attitude (Scarce, 1997; Pugsley & Clayton 2003; Behrendt & Franklin 2014). Additionally, field trips for environmental and agricultural students are thought to help students develop perceptions about the world that can prepare them for their careers and better equip them to solve environmental problems (Wright, 2000).

This paper aims to describe curriculum development and survey results from students enrolled in Oklahoma State University's Cropping System course in the fall of 2021 and 2022. The data provides insight into student perceptions of Oklahoma farm progress and teaching methods that may aid students in a more profound understanding of agronomic practices.

3.2 MATERIALS AND METHODS

Curriculum development

The course curriculum was centered on field trips and guest lectures to provide foundational knowledge of topics discussed during field trips. Foundational topics identified were soil formation impact on agronomic decisions, soil nutrient management, irrigation and water conservation, weed/insect/disease management with emphasis on Integrated Pest Management, dual-purpose wheat production in the Great Plains, crop selection and rotation, and economics with a focus in commodity futures, crop insurance, and sustainability. Guest lectures were given by Oklahoma State University faculty and extension personnel, research station managers, and industry professionals.

Field trips included visits to farms that produced bermudagrass hay, blackberries, canola, corn, sorghum, soybean, and wheat. Students visited at least three farms that produced "commodity" crops in both years. In 2022, students were able to visit a blackberry orchard, which is considered a specialty crop in Oklahoma. Students visited one commercial facility, Iron Monk brewery, in Stillwater, Oklahoma in both years. In total, students took 6 to 8 field trips and had 10 guest lectures over the duration of the course.

Participants

Participant data was collected by Oklahoma State University and made available via Cowboy Data Roundup (2023). Participant background information is based on data provided to

Oklahoma State University through the Office of the Registrar at enrollment. Two students enrolled but did not finish the course. Due to required removal of identifying information, data for students who did not finish the course could not be withdrawn from the population, thus this background information includes data for 28 students instead of 26. The course comprised 28 total students, 15 undergraduates, and 13 graduate students. Of the 28 students, 4 were first-generation students, 13 identified as male, 15 identified as female, and 6 were minority students. Student majors included animal science (1), entomology (1), agribusiness (2), and plant and soil science (24).

In lieu of data pertaining to this course specifically, data for the Plant and Soil Science Department (PSS) was used to describe the student population economic background and rural status of students. Economic background information is given by Pell Grant eligibility, as Federal Student Aid describes Pell Grant recipients as having "exceptional financial need". Rural status was defined as given by the United States Department of Agriculture (USDA) Rural Urban Commuting Area (RUCA) codes. Any community scoring greater than a 4 on the 1 to 10 scale is considered rural. A 4 on the RUCA scale is defined as a "micropolitan area core: primary flow within an urban cluster of 10,000 to 49,999" (USDA-ERS, n.d.). Community populations are based on data from the 2010 census and the 2006-2010 American Community Survey (USDA-ERS, n.d.). The student's high school zip code was used to determine this status. Currently, 18% of PSS students are Pell Grant eligible, and 51% of students in PSS are from rural communities.

Student Learning Evaluation

To evaluate student learning and knowledge retention, quizzes were assigned after each guest lecture day and field trip in which handout material was provided. Students were assigned one-page summaries with the choice to write over any two of the field trips. Two essay-style exams and one semester-long group project on cropping systems management were administered.

The semester-long project was divided into four parts: part one- farm location, soil type, and annual weather data; part two- crop rotation and nutrient management; part three- pest management; and part four- feedback incorporation, finalizing the plan, and presenting the plan during a class period. Graduate and honors students were required to write a 1-to-2-page extension-style factsheet on a topic related to cropping systems.

<u>Surveys</u>

Outside of coursework, pre- and post-course surveys were administered to determine student perception of cropping practices in Oklahoma. An initial survey was administered during the first week of class and a follow-up survey was administered during the last two weeks of class. Surveys were distributed on paper, and personal identifiers were removed after collection. The Oklahoma State University Institutional Review Board (IRB) determined that this study was classified as exempt. Course survey data is based on 26 pre-course surveys and 23 post-course surveys, as some students opted out of participating in the surveys.

At the end of each course, Oklahoma State University administered Student Survey of Instruction (SSI) evaluations composed of a standardized questionnaire with a Likert scale (Likert, 1932). Although separate from the course curriculum, this data has been provided as applicable to gauge course impact and success. The Likert scale of the questionnaire ranged from 1 to 5, with 1 indicating a student “strongly disagrees” with the posed statement and 5 indicating the student “strongly agrees” with the statement. Survey data was pooled across years and student classification levels. Averages were used to prevent personal identification of any student survey responses, given the small class size.

<u>Answer Categorization</u>

Due to the open-ended nature of the pre- and post-course surveys, student answers were generalized into categories. For the prompt “Do you think Oklahoma has made any progress/advancement in technology in the last 20 years?“ student answers were categorized as yes, no, or unclear. Unclear statements indicated that Oklahoma’s agriculture hadn’t advanced as much as other states. Thus the answer couldn’t be interpreted into an appropriate category. For the prompts “what type of crop are you most familiar with?” and “what system do you think is best for managing weeds?” student answers were analyzed for any language that was appropriate for their respective questions and then categorized as “Named a specific system, method, or crop” or “Did not name a specific system, method, or crop”. This generalization was essential as students entered the course with diverse backgrounds in agriculture, hailing from across the United States and even internationally.

Lastly, answers to the prompt “What are your thoughts on tillage” were categorized as positive, negative, or neutral. Student perceptions were categorized as neutral if they used language that suggested tillage has benefits and drawbacks, most often by utilizing the conjunction “but” or other phrases like “depending on the area” or “in some situations”. Positive answers were definitive and free from negative language about tillage. Likewise, negative answers did not include any language that indicated tillage could be a positive tool.

3.3 RESULTS AND DISCUSSION

Overall, students indicated that this course enhanced their learning and deepened their appreciation of the subject, with an average rating greater than 4 on a scale of 1 to 5 (Table 3.1). Student perception of this course was to agree with the statement describing this as an excellent course, as indicated by a ranking of 3.97 on a scale of 1-5.For comparison, the average course rating for courses in the Ferguson College of Agriculture was 4.24 in Fall 2021 and 4.29 in Fall 2022 (L. Burns, unpublished data, March 21 2023).

During pre-course surveys, 4% of students indicated they were unfamiliar with any cropping system (Table 3.2). By the end of the course, 100% of students were able to answer the prompt with a crop appropriate for growing in Oklahoma (Table 3.3). A similar trend was observed with student knowledge of weed management, with 4% of students initially indicating they didn’t know enough about weed management to answer pre-course surveys and 100% of students providing an appropriate answer by the end of the course (Tables 3.2 and 3.3). These small shifts suggest that students were familiar enough with the course material to put lecture and field trip content into appropriate context. In a climate where students often enter the classroom with very little background knowledge of cropping systems, this is an exciting development and will likely benefit students as they continue their studies or enter the workforce. As described by Wright (2000), experiential learning in higher education can help develop student perceptions in such a way that students are better prepared for their careers and solving problems outside of the classroom.

In pre-course surveys, nineteen percent of students indicated they did not believe Oklahoma agriculture had made progress or technological advancements in the last 20 years (Table 3.2). However, in post-course surveys, only 6% of students indicated they believed Oklahoma agriculture had not made advancements in the last 20 years (Table 3.3). This shows a positive shift in student perceptions regarding technological advancements in Oklahoma agriculture. This change in negative perceptions about Oklahoma agriculture indicates that field trip experiences can shift student perspectives and bring positive light to agriculture. A similar trend in shifts of student perceptions following field trips in agricultural and natural resource settings has been observed by Nesbit & Mayer (2010) and Farmer et al. (2010).

Perhaps the survey's most controversial prompt was “What are your thoughts on tillage?”. This prompt was purposefully open-ended to allow students to express various views and successfully elicited many perceptions. This was the only prompt that increased negative perceptions in the post-course survey, albeit only by 2% (Table 3.3). Most of the shifts on tillage perceptions were from positive to neutral. Many responses to this prompt included language such as “tillage can be a great tool but can negatively affect the soil when overused”. Some students were even able to give specific context on when tillage can be beneficial in post-course surveys, such as to manage herbicide resistant weeds or address compaction. Tillage was one topic that was discussed at every field trip and most lectures, likely the most discussed topic of the course. In most student responses, students were able to justify their stance on tillage with references to weed control, soil type limitations, regional differences in cropping traditions and needs, disease management, or conservation concerns. This range in perceptions mirrors that of Oklahoma’s tillage practices, with a strong mix of no-till, conventional till, and conservation tillage across the state (Write et al., n.d.; CTIC, 2023).

The educational outcomes of all students were not the same and, in some cases, not ideal. Through comments left in the SSI reports, it is clear a few students did not have adequate background information to fully understand field trips or guest lecture material. In SSI comments students requested a range of improvements for the course, from a glossary of terms to enforcing prerequisites. This course had no prerequisite courses required for enrollment. Moving forward, requiring prerequisite courses such as PLNT 1213 Introduction to Plant and Soil Systems and SOIL 2124 Fundamentals of Soil Science may be helpful in ensuring students are better prepared for course material. Further prerequisite courses such as SOIL 4234 Soil Nutrient Management or PLNT 4013 Principles of Weed Science could also be considered, however these courses are only offered in fall semesters and thus this restriction could create an issue with having an adequate pool of eligible students for the course each year.

Limitations of this study largely arise from the open-answer questions posed in pre- and post-course surveys. Although statistically insignificant, these surveys provided excellent feedback on student perceptions on the course and Oklahoma agriculture. Furthermore, these surveys were used to improve course delivery in 2022.

This research could be improved by formalizing the pre- and post-course surveys by using a Likert scale in the future. Additionally, a follow-up survey one semester or more after class could be helpful to determine if the course continues to impact student perceptions after other courses or when students enter the workforce. Another way to improve the course could be incorporating a short paper or discussion session at the end of the semester and ask students to reflect on what experiences impacted their perceptions. Reflection is a powerful tool and although it was used during class conversations in an informal capacity, a formal assignment explicitly guiding student reflection could be helpful (Ash & Clayton, 2004; Hatcher et al., 2004).

3.4 SUMMARY

Student perceptions of farming changed throughout this course. Perception shifts were largely from negative perceptions of farm progress to positive perceptions of farm progress; however, some perception shifts indicate that students may have gained a better understanding of the complex and nuanced decisions required to farm successfully. As public trust in modern farming practices continues to decline, it is imperative that appropriate measures be taken to allow students exposure to farming systems so that they gain a broader understanding of the complexity of agronomic systems and the interconnected nature of cropping systems.

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APPENDICES

Table 1.1 Tillage and herbicide treatments in the Occasional Sweep study.

Tillage System	Initial Herbicide[abcd]	Sequential Herbicide
	------------------------------------g ai ha^{-1}---	
Sweep	Glyphosate (1123) + dicamba (140) + 2,4-D (402) + NIS (0.5% v/v) + AMS (20 g L^{-1})	None
Sweep	Glyphosate (1543) + NIS (0.5% v/v) + AMS (20 g L^{-1})	Paraquat (842) + NIS (0.5% v/v) + AMS (20 g L^{-1})
Sweep	Clethodim (842) + dicamba (140) + 2,4-D (402) + COC (1% v/v) + AMS (20 g L^{-1})	Paraquat (842) + NIS (0.5% v/v) + AMS (20 g L^{-1})
Disk	None	None
No-Tillage	Glyphosate (1123) + dicamba (140) + 2,4-D (402) + NIS (0.5% v/v) + AMS (20 g L^{-1})	None
No-Tillage	Glyphosate (1543) + NIS (0.5% v/v) + AMS (20 g L^{-1})	Paraquat (842) + NIS (0.5% v/v) + AMS (20 g L^{-1})
No-Tillage	Clethodim (842) + dicamba (140) + 2,4-D (402) + COC (1% v/v) + AMS (20 g L^{-1})	Paraquat (842) + NIS (0.5% v/v) + AMS (20 g L^{-1})

[a]Herbicide rate given in grams of active ingredient per hectare. Adjuvants and other additives are given in units as appropriate.
[b]NIS: nonionic surfactant. Given in percentage of volume of surfactant per volume of spray solution.
[c]AMS: ammonium sulfate. Given in grams of ammonium sulfate per liter of spray solution.
[d]COC: crop oil concentrate. Given in percentage of volume of surfactant per volume of spray solution.

Table 1.2 Tillage and herbicide treatments in the Multiple Sweep study.

Tillage Treatment	Herbicide Treatment[abc]
	-----------------------g ai ha^{-1}----------------------
No-Tillage	Glyphosate (1543) + NIS (0.5% v/v) + AMS (20 g L^{-1}) followed by Paraquat (842) + NIS (0.5% v/v) + AMS (20 g L^{-1})
Sweep X 1	None
Sweep X 2	None
Sweep X 3	None

[a]Herbicide rate given in grams of active ingredient per hectare. Adjuvants and other additives are given in units as appropriate.
[b]NIS: nonionic surfactant. Given in percentage of volume of surfactant per volume of spray solution.
[c]AMS: ammonium sulfate. Given in grams of ammonium sulfate per liter of spray solution.

Table 1.3 Occasional Sweep study visual tumble windmill grass control in September following summer tillage and herbicide application at Lake Carl Blackwell, Oklahoma in 2020 and Wakita, Oklahoma in 2021 and 2022.

Tillage Treatment	Herbicide Treatment	LCB-20[a]	Wakita-21	Wakita-22
		--------------% visual control-----------		
No-Tillage	Glyphosate + dicamba + 2,4-D	71 b	78 c	70 b
No-Tillage	Glyphosate followed by paraquat	71 b	88 bc	70 b
No-Tillage	Clethodim + dicamba + 2,4-D followed by paraquat	66 b	53 d	70 b
Sweep	Glyphosate + dicamba + 2,4-D	94 a	99 ab	92 a
Sweep	Glyphosate followed by paraquat	92 a	99 ab	95 a
Sweep	Clethodim + dicamba + 2,4-D followed by paraquat	93 a	99 ab	99 a
Disk	None	87 a	100 a	97 a
p-value		<0.0001	<0.0001	<0.0001

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.

Table 1.4 Occasional Sweep study winter wheat biomass collected in June prior to winter wheat harvest at Lake Carl Black Well, Oklahoma in 2021 and 2022 and Wakita, Oklahoma in 2022.

		LCB-20		Wakita-21
Tillage Treatment	Herbicide Treatment	2021[a]	2022[b]	2022
		---------------------g m^{-2}	------------------	
No-Tillage	Glyphosate + dicamba + 2,4-D	94 b	152	68 ab
No-Tillage	Glyphosate followed by paraquat	90 b	155	87 a
No-Tillage	Clethodim + dicamba + 2,4-D followed by paraquat	101 b	165	53 b
Sweep	Glyphosate + dicamba + 2,4-D	127 ab	182	75 ab
Sweep	Glyphosate followed by paraquat	106 b	176	69 ab
Sweep	Clethodim + dicamba + 2,4-D followed by paraquat	106 b	156	74 ab
Disk	None	155 a	134	76 ab
p-value		0.0020	0.3374	0.0233

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.
[b]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.

Table 1.5 Occasional Sweep study tumble windmill grass biomass collected in June prior to winter wheat harvest at Lake Carl Blackwell, Oklahoma in 2021 and 2022 and Wakita, Oklahoma in 2022.

		LCB-20		Wakita-21
Tillage Treatment	Herbicide Treatment	2021[a]	2022[b]	2022
		--------g m^{-2}-------		
No-Tillage	Glyphosate + dicamba + 2,4-D	9	0	2 b
No-Tillage	Glyphosate followed by paraquat	4	0	1 b
No-Tillage	Clethodim + dicamba + 2,4-D followed by paraquat	23	0	11 a
Sweep	Glyphosate + dicamba + 2,4-D	12	0	1 b
Sweep	Glyphosate followed by paraquat	8	0	1 b
Sweep	Clethodim + dicamba + 2,4-D followed by paraquat	6	0	1 b
Disk	None	4	0	1 b
p-value		0.2818	0.4361	<0.0001

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.
[b]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.

Table 1.6 Occasional Sweep study winter wheat grain yield at Lake Carl Blackwell, Oklahoma in 2021 and 2022 and Wakita, Oklahoma in 2022.

		LCB-20		Wakita-21
Tillage Treatment	Herbicide Treatment	2021[a]	2022[b]	2022
		----------kg ha^{-1}----------		
No-Tillage	Glyphosate + dicamba + 2,4-D	2857 b	3484	1013
No-Tillage	Glyphosate followed by paraquat	2840 b	3737	970
No-Tillage	Clethodim + dicamba + 2,4-D followed by paraquat	2837 b	3548	726
Sweep	Glyphosate + dicamba + 2,4-D	3369 ab	3122	1080
Sweep	Glyphosate followed by paraquat	3836 a	3580	964
Sweep	Clethodim + dicamba + 2,4-D followed by paraquat	3624 ab	3547	1150
Disk	None	3965 a	3255	1049
p-value		<0.0001	0.4098	0.7146

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.
[b]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.

Table 1.7 Occasional Sweep study aggregate stability for 0-5 cm and 5-15 cm soil depths, sampled from Lake Carl Blackwell, Oklahoma in 2020 and 2022 and Wakita, Oklahoma in 2021 and 2022.

	LCB-20				Wakita-21				Wakita-22	
	2020		2022[a]		2021		2022[b]		2022	
Tillage Treatment	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
	------------------------- % stable aggregates-------------------------									
No-Tillage	24.2	22.8	30.0	32.2	44.2	39.8	43.4	38.9	33.3	37.3 b
Sweep	25.3	21.2	27.7	33.3	43.8	39.7	42.9	47.6	36.1	41.2 ab
Disk	26.4	23.4	26.2	32.7	38.4	37.1	45.9	44.4	43.9	49.9 a
p-value	0.4675	0.6427	0.4496	0.8801	0.0514	0.3133	0.7541	0.4294	0.0646	0.0241

[a]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.
[b]Wakita 21, 2022 depicts results from soil that was tilled in 2021. Thus, these results are from one year after tillage occurred.

Table 1.8 Occasional Sweep study CO2 emissions for 0-5 cm and 5-15 cm soil depths, sampled from Lake Carl Blackwell, Oklahoma in 2020 and 2022 and Wakita, Oklahoma in 2021 and 2022.

	LCB-20				Wakita-21				Wakita-22	
	2020[a]		2022[b]		2021		2022[c]		2022	
Tillage Treatment	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
	---------- mg CO_2-C kg^{-1} ----------									
No-Tillage	74.9	37.6	88.5	37.6	107.9	56.3 ab	81.8	38.4	118.9	56.6
Sweep	78.6	33.4	81.8	37.5	101.1	55.6 b	84.8	40.4	87.0	56.1
Disk	86.3	38.9	86.4	35.4	108.9	61.4 a	79.2	41.0	132.5	63.8
p-value	0.2946	0.1570	0.3713	0.7637	0.4178	0.0363	0.4416	0.7324	0.0813	0.7214

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.
[b]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.
[c]Wakita 21, 2022 depicts results from soil that was tilled in 2021. Thus, these results are from one year after tillage occurred.

Table 1.9 Occasional Sweep study soil organic matter for 0-5 cm and 5-15 cm soil depths, sampled from Lake Carl Blackwell, Oklahoma in 2020 and 2022 and Wakita, Oklahoma in 2021 and 2022.

	LCB-20				Wakita-21				Wakita-22	
	2020		2022[a]		2021		2022[b]		2022	
Tillage Treatment	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
	---------- % soil organic matter----------									
No-Tillage	1.6	1.1	1.9	1.2	2.7	1.5	2.7	1.6	2.5	1.3
Sweep	2.0	1.2	1.8	1.2	2.4	1.4	2.5	1.5	2.0	1.2
Disk	2.2	1.2	2.0	1.1	2.5	1.5	2.6	1.5	2.13	1.4
p-value	0.1953	0.3082	0.7980	0.9591	0.1568	0.5736	0.98	0.4211	0.2515	0.3747

[a]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.
[b]Wakita 21, 2022 depicts results from soil that was tilled in 2021. Thus, these results are from one year after tillage occurred.

Table 1.10 Occasional Sweep study volumetric water content for 0-120 cm soil depths at Lake Carl Blackwell, Oklahoma in November of 2020 and Wakita, Oklahoma in March of 2022.

	LCB-20 2020				Wakita-21 2022			
Tillage Treatment	0-30 cm	30-60 cm	60-90 cm	90-120 cm	0-30 cm	30-60 cm	60-90 cm	90-120 cm
	---------------------water cm^3 soil cm^{-3}---------------------							
No-Tillage	15.6	22.9	22.1	22.1	24.5	24.8	24.5	25.2
Sweep	18.1	25.2	22.5	27.7	20.1	25.2	24.7	23.1
Disk	19.0	25.0	22.2	23.8	19.5	29.2	25.1	25.4
p-value	0.2033	0.1397	0.918	0.3223	0.0831	0.2452	0.5737	0.3782

Table 1.11 Cost of herbicide per liter across three agricultural chemical retail locations in or near Payne County, Oklahoma in March of 2023.

Herbicide common name	Product formulation	Farmers Co-Op Association, Ponca City, OK	Helena Agri-Enterprises, LLC, Blackwell, OK	Stillwater Milling Company, Stillwater, OK	Average cost
	--g ai L^{-1}--	-------------------------	$ L^{-1}	-------------------------	
Glyphosate	360	8.73	6.21	6.87	7.27
Dicamba + 2,4-D	120 + 344	9.98	7.53	10.57	9.36
Clethodim	360	24.87	13.74	23.46	20.69
Paraquat	360	12.78	9.25	8.45	10.16

Table 1.12 Occasional Sweep study economic analysis.

Tillage Treatment	Herbicide Treatment[ab]	Average $ ha^{-1}
No-till	Glyphosate (1123) + dicamba (140) + 2,4-D (402)	60.87
No-till	Glyphosate (1543) followed by paraquat (842)	111.16
No-till	Clethodim (842) + dicamba (140) + 2,4-D (402) followed by paraquat (842)	148.05
Sweep	Glyphosate (1123) + dicamba (140) + 2,4-D (402)	93.39
Sweep	Glyphosate (1543) followed by paraquat (842)	143.69
Sweep	Clethodim (842) + dicamba (140) + 2,4-D (402) followed by paraquat (842)	180.58
Disk- offset		79.95
Disk- tandem		90.92

[a]Herbicide treatments include an application fee. Treatments that contain a sequential application of paraquat include two application fees.
[b]Surfactants, water conditioners, or other adjuvants are not included in this analysis.

Table 1.13 Multiple sweep visual tumble windmill grass control means in September prior to planting at Lake Carl Blackwell, Oklahoma in 2020 and Wakita, Oklahoma in 2021 and 2022.

Tillage Treatment	Herbicide Treatment[ab]	Average $ ha^{-1}
No-till	Glyphosate (1123) + dicamba (140) + 2,4-D (402)	60.87
No-till	Glyphosate (1543) followed by paraquat (842)	111.16
No-till	Clethodim (842) + dicamba (140) + 2,4-D (402) followed by paraquat (842)	148.05
Sweep	Glyphosate (1123) + dicamba (140) + 2,4-D (402)	93.39
Sweep	Glyphosate (1543) followed by paraquat (842)	143.69
Sweep	Clethodim (842) + dicamba (140) + 2,4-D (402) followed by paraquat (842)	180.58
Disk- offset		79.95
Disk- tandem		90.92

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.

Table 1.14 Multiple sweep study winter wheat biomass in June prior to harvest at Lake Carl Blackwell, Oklahoma in 2021 and 2022 and Wakita, Oklahoma in 2022.

	LCB-20		Wakita-21
Tillage Treatment	2021	2022	2022
	------------------------------------g m^{-2}--		
No-Tillage	71	144	107
Sweep x 1	91	131	99
Sweep x 2	73	89	95
Sweep x 3	109	133	96
p-value	0.4616	0.1818	0.8818

Table 1.15 Multiple sweep study tumble windmill grass biomass in June prior to winter wheat harvest at Lake Carl Blackwell, Oklahoma in 2021 and 2022 and Wakita, Oklahoma in 2022.

	LCB-20		Wakita-21
Tillage Treatment	2021	2022	2022
	----------------------------------g m^{-2}	----------------------------------	
No-Tillage	6	0	1
Sweep x 1	5	0	1
Sweep x 2	2	0	2
Sweep x 3	6	0	1
p-value	0.1142	0	0.2673

Table 1.16 Multiple sweep study winter wheat yield at Lake Carl Blackwell, Oklahoma in 2021 and 2022 and Wakita, Oklahoma in 2022.

	LCB-20		Wakita-21
Tillage Treatment	2021[a]	2022[b]	2022
	---kg ha^{-1}---		
No-Tillage	3062 bc	3150	1411 ab
Sweep x 1	2884 c	3275	1360 b
Sweep x 2	3363 ab	3233	1293 b
Sweep x 3	3682 a	3544	1903 a
p-value	0.0040	0.7290	0.0244

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.

[b]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.

Table 1.17 Multiple Sweep aggregate stability for 0-5 and 5-15 cm soil depths sampled from Lake Carl Blackwell, Oklahoma in 2020 and 2022 and Wakita, Oklahoma in 2021 and 2022.

	LCB-20				Wakita-21				Wakita-22	
Tillage Treatment	2020		2022[a]		2021		2022[b]		2022	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5	5-15
	---% stable aggregates---									
No-Tillage	17.8	14.3	18.3	24.7	34.5	36.0	36.9	42.6	34.7	36.6
Sweep x 1	15.7	13.7	16.1	25.2	30.2	41.3	36.2	47.3	36.7	40.2
Sweep x 2	15.7	14.3	20.6	24.7	35.8	39.3	39.1	45.5	37.4	45.4
Sweep x 3	15.9	17.3	16.8	24.1	32.0	42.6	37.1	46.0	34.2	42.8
p-value	0.1238	0.1298	0.0651	0.9303	0.2820	0.05729	0.6091	0.1404	0.4810	0.0903

[a]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.
[b]Wakita 21, 2022 depicts results from soil that was tilled in 2021. Thus, these results are from one year after tillage occurred.

Table 1.18 Multiple Sweep CO_2 emissions results for 0-5 cm and 5-15 cm soil depths sampled from Lake Carl Blackwell, Oklahoma in 2020 and 2022 and Wakita, Oklahoma in 2021 and 2022.

	LCB-20				Wakita-21				Wakita-22	
Tillage Treatment	2020		2022[a]		2021		2022[b]		2022	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5	5-15
	----------mg CO_2-C kg^{-1} ----------									
No-Tillage	64.0	24.2	60.3	25.3	70.6	35.8	57.0	23.9	93.3	49.0
Sweep x 1	56.2	46.3	64.7	32.5	77.1	37.0	61.8	28.7	103.7	55.0
Sweep x 2	72.3	37.2	64.5	30.9	65.1	37.8	66.4	24.8	110.1	40.0
Sweep x 3	49.7	23.6	66.4	31.6	64.9	35.3	61.8	23.1	108.7	52.3
p-value	0.6074	0.2311	0.8403	0.1931	0.2930	0.2189	0.3130	0.0912	0.6743	0.1146

[a]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.
[b]Wakita 21, 2022 depicts results from soil that was tilled in 2021. Thus, these results are from one year after tillage occurred.

Table 1.19 Multiple Sweep study soil organic matter for 0-5 cm and 5-15 cm soil depths sampled from Lake Carl Blackwell, Oklahoma in 2020 and 2022 and Wakita, Oklahoma in 2021 and 2022.

	LCB-20				Wakita-21				Wakita-22	
Tillage Treatment	2020[a]		2022[b]		2021		2022[c]		2022	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5	5-15
	---% soil organic matter---									
No-Tillage	1.5	1.0	1.5 a	1.2	1.6	0.9	1.5	0.9	2.3	1.5
Sweep x 1	1.4	0.9	1.8 a	0.8	1.5	0.9	1.7	0.9	2.5	1.5
Sweep x 2	1.3	0.8	0.8 b	1.7	1.4	0.8	1.7	0.8	2.2	1.3
Sweep x 3	1.3	0.8	0.9 b	1.6	1.4	0.8	1.7	0.8	2.3	1.4
p-value	0.1180	0.6309	0.0012	0.1858	0.2336	0.5893	0.3522	0.0691	0.3542	0.0539

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.
[b]Lake Carl Blackwell, 2022 depicts results from soil that was tilled in 2020. Thus, these results are from two years after tillage occurred.
[c]Wakita 21, 2022 depicts results from soil that was tilled in 2021. Thus, these results are from one year after tillage occurred.

Table 1.20 Multiple Sweep study volumetric water content for 0-120 cm soil depths sampled in November of 2020 at Lake Carl Blackwell, Oklahoma and in March of 2021 at Wakita, Oklahoma.

Tillage Treatment	LCB-20 2020[a]				Wakita-21 2022			
	0-30 cm	30-60 cm	60-90 cm	90-120 cm	0-30 cm	30-60 cm	60-90 cm	90-120 cm
	---------- water cm^3 soil cm^{-3} ----------							
No-Tillage	11.0 b	22.4 ab	20.9	20.5	17.5	25.2	25.3	25.2
Sweep x 1	12.8 b	16.3 b	20.6	18.9	15.5	26.8	25.6	25.1
Sweep x 2	14.8 ab	20.8 ab	20.7	21.2	14.2	25.8	25.8	26.0
Sweep x 3	17.4 a	25.4 a	20.7	21.1	14.9	33.9	26.2	26.4
p-value	0.0005	0.0370	0.9989	0.5886	0.1380	0.3260	0.7961	0.4338

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.

Table 1.21 Multiple sweep study economic analysis.

Treatment	Herbicide[ab]	\$ ha^{-1}
No-Tillage	Glyphosate (1543) followed by paraquat (842)	111.16
Sweep x 1	None	32.53
Sweep x 2	None	65.06
Sweep x 3	None	97.59

[a]Herbicide treatment included two application fees.
[b]Surfactants, water conditioners, or other adjuvants are not included in this analysis.

Table 2.1. Herbicides and application rates for 2020, 2021, and 2022 Italian Ryegrass control trial near Perkins, Oklahoma.

Herbicide common name	Brand names or designations	Manufacturer	Herbicide rate	Timing
Pyroxasulfone	Zidua® SC	BASF, Research Triangle Park, NC	119 g ai ha^{-}	Delayed PRE
Pyroxasulfone + carfentrazone-ethyl	Anthem® Flex	FMC Corporation, Philadelphia, PA	123 g ai ha^{-}	Delayed PRE
Pyroxasulfone + pinoxaden	Zidua® SC + Axial XL	BASF, Research Triangle Park, NC Syngenta Crop Protection, Greensboro, NC	119 + 60.4 g ai ha^{-}	Delayed PRE
Pyroxasulfone + metribuzin	Zidua SC + Sencor DF	BASF, Research Triangle Park, NC Bayer CropScience, Research Triangle Park, NC	119 + 105 g ai ha^{-}	Delayed PRE
Pinoxaden	Axial XL	Syngenta Crop Protection, Greensboro, NC	60.4 g ai ha^{-}	Delayed PRE
Pinoxaden	Axial XL	Syngenta Crop Protection, Greensboro, NC	60.4 g ai ha^{-}	POST

Table 2.2 Italian ryegrass control ratings during the 2020, 2021, and 2022 growing seasons near Perkins, Oklahoma.

	2020	2021				2022			
Herbicide Treatment	202 [ab]	63	174	202	230	78	128	153	187
	--%-- ------								
Untreated	0 b	0 c	0 c	0 c	0 c	0 b	0 b	0 b	0 b
Pyroxasulfone	88 a	87 a	76 ab	71 b	86 a	98 a	97 a	98 a	97 a
Pyroxasulfone + carfentrazone-ethyl	86 a	50 b	60 b	71 b	65 b	98 a	96 a	97 a	97 a
Pyroxasulfone + pinoxaden	87 a	93 a	94 a	95 ab	97 a	98 a	97 a	97 a	97 a
Pyroxasulfone + metribuzin	88 a	93 a	84 ab	83 ab	86 a	98 a	98 a	98 a	98 a
Pinoxaden	81 a	91 a	89 a	89 ab	88 a	98 a	98 a	98 a	98 a
Pinoxaden[c]	88 a	-	-	97 a	100 a	-	-	98 a	98 a
p-value	<0.0001	<.0001	<.0001	<.0001	< .0001	<.0001	<.0001	<.0001	< .0001

[a] Ratings are provided by date of rating days after initial herbicide application.
[b]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.
[c]Pinoxaden applied postemergence, once Italian ryegrass had 4-6 tillers and was actively growing. This application generally occurred in early spring, thus earlier rating dates do not include data on this treatment.

Table 2.3 Winter wheat grain yield in 2020, 2021, and 2022 in Perkins, Oklahoma.

Herbicide Treatment	2020[a]	2021	2022
	------------------------ kg ha^{-1}	------------------------	
Untreated	2959 b	2508	3776
Pyroxasulfone	3695 a	2627	3729
Pyroxasulfone + carfentrazone-ethyl	3796 a	2691	3678
Pyroxasulfone + pinoxaden	3666 a	2882	3584
Pyroxasulfone + metribuzin	3664 a	2663	3707
Pinoxaden	3444 a	2707	3667
Pinoxaden (POST)	3449 a	2846	3863
p-value	<0.0001	0.0990	0.7129

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.

Table 2.4 Italian ryegrass and winter wheat dry-weight biomass averages 2 weeks before harvest in 2021 and 2022 near Perkins, Oklahoma.

Herbicide Treatment	2021[a]		2022	
	Italian ryegrass	Winter wheat	Italian ryegrass	Winter wheat
	---g--			
Untreated	14.8	121.7 b	0.01	151.4 bc
Pyroxasulfone	1.7	142.6 ab	0	150.8 bc
Pyroxasulfone + carfentrazone-ethyl	9.7	146.8 ab	0	159.1 abc
Pyroxasulfone + pinoxaden	0.2	151.7 ab	0	198.0 a
Pyroxasulfone + metribuzin	1.7	134.6 ab	0	174.4 ab
Pinoxaden	3.44	135.9 ab	0	176.0 ab
Pinoxaden (POST)	0.6	154.7 a	0	126.3 c
p-val	0.1038	0.0324	0.4404	0.0007

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.

Table 2.5 CO_2 emissions produced by soils in no-tillage, sweep tillage, and disk tillage systems near Perkins, Oklahoma.

	2021		2022	
Tillage treatment	0-5 cm	5-15 cm	0-5 cm	5-15 cm
	---mg CO_2 kg^{-1}	--		
No-tillage	80.8	41.9	47.4	24.0 b
Sweep tillage	85.2	39.3	45.9	23.0 b
Disk tillage	87.5	44.5	37.9	29.5 a
p-value	0.3640	0.2762	0.0529	0.0105

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.

Table 2.6 Percent stable aggregates by tillage treatment after the 2021 and 2022 growing seasons near Perkins, Oklahoma.

Tillage treatment	2021		2022	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm
	--% stable aggregates--			
No-tillage	56.7	55.9	54.4 a	46.9
Sweep tillage	55.2	58.5	43.1 b	58.7
Disk tillage	59.3	57.7	36.3 b	49.1
p-value	0.1892	0.4478	0.0021	0.2071

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at P<0.05.

Table 2.7 Soil organic matter by tillage treatment after the 2021 and 2022 growing seasons near Perkins, Oklahoma.

Tillage treatment	2020		2021		2022	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
	--% soil organic matter--------------------------------------					
No-tillage	1.46	1.06	1.55	0.93	1.22	0.88 b
Sweep tillage	1.41	0.97	1.62	0.96	1.46	0.87 b
Disk tillage	1.39	1.20	1.63	0.97	1.40	1.07 a
p-value	0.7182	0.1607	0.5096	0.7596	0.5130	0.0291

[a]Means within a column followed by the same letter are not significantly different according to the Tukey-Kramer least squares means test at $P<0.05$.

Table 3.1 Student Survey of Instruction average ratings for Cropping Systems pooled across 2021 and 2022.

Prompt	Average Rating[a]	
Presentation of course content enhanced my learning.	4.04	
The course helped me develop a deeper appreciation of the subject.	4.25	
I would describe this as an excellent course.	3.97	
Overall indicators	4.08	\\

[a]Ratings are given out of a 5-point Likert scale.

Table 3.2 Pre-course survey results for students enrolled in Cropping Systems, combined years 2021 and 2022.

Prompt	Answer Categories		
	Yes	No	Unclear
	---%------------------------------ --------		
Do you think Oklahoma has made any progress/advancement in technology in the last 20 years?	78	19	3
	Named a specific system, method, or crop	Did not name a specific system, method, or crop	
What type of crop are you most familiar with?	96	4	
What system do you think is best for managing weeds?	96	4	
	Positive	Neutral	Negative
What are your thoughts on tillage?	40	48	12

Table 3.3 Post-course survey results for students enrolled in Cropping Systems, combined years 2021 and 2022.

Prompt	Answer Categories		
	Yes	No	Unclear
	--%-------------------------------------		
Do you think Oklahoma has made any progress/advancement in technology in the last 20 years?	94	6	0
Did this course meet your learning expectations?	94	0	6
	Named a specific system, method, or crop	Did not name a specific system, method, or crop	
What type of crop are you most familiar with?	100		
What system do you think is best for managing weeds?	100	0	
	Positive	Neutral	Negative
What are your thoughts on tillage?	43	48	9

VITA

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