IMPACT OF CONSERVATION PROGRAMS ON GREENHOUSE GAS EMISSION REDUCTIONS FROM AGRICULTURAL LANDS IN THE SOUTHERN PLAINS

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ABSTRACT

As research provides continuing alarming claims about the dangers of climate change, greater interest is being focused on the contribution of agriculture and its potential to reduce greenhouse gas emissions (GHGs). The Natural Resource Conservation Service (NRCS) administers a suite of conservation programs that provide a variety of environmental benefits, including the reduction of GHG emissions. As the legislation and funding of these programs change, enrollment in these programs change in tandem, as will GHG emission reductions. After the 2018 Farm Bill was passed, some are questioning its impact on these emission reductions. The purpose of this research is to estimate the total GHG emission reductions due to enrollment in NRCS conservation programs for the years 2014 – 2020 from agricultural lands for the states of Kansas, Oklahoma, and Texas. Two types of data are combined to achieve this objective. One is enrollment data, detailing the number of acres in each county enrolled in various NRCS programs. The other data are obtained from the Comet-Planner model, which provides county-level estimates of the amount of reduction in GHGs per year for each acre engaged in a conservation practice. The results indicate that a few NRCS programs experienced considerable changes in enrollment from 2014 – 2020. Examples are conservation crop rotation (34% decrease) and convention tillage to no-till (47% decrease). The biggest change in enrollment is in the establishment of seasonal cover crops, where acres enrolled rose by 318%. Total emission reductions in these three states directly attributable to NRCS program enrollment in 2014 was 704,312 megagrams of CO2-equivalent GHGs, which is the equivalent of removing 150,000 cars from the road, or 10,000 households becoming carbon neutral. These emission reductions fell in the two subsequent years, equaling 579,138 megagrams of CO2-equivalent in 2016. However, after 2016 emission reductions began rising, such that in 2019 and 2020 they approximately equaled their 2014 level.

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DEFINITIONS OF KEY TERMS

Conservation Practice	A category of actions taken on agricultural land. One "practice" may be a reduction in tillage, and another may be improved grazing management.
Conservation Practice Option	A specific way of implementing a conservation practice.
Conservation Program	A genre of Natural Resource Conservation Service (NRCS) programs largely targeting soil conservation but also promoting other environmental benefits like GHG emission reductions. Examples include Conservation Reserve Program (CRP) and Conservation Stewardship Program (CSP)
Emission reduction	Amount of greenhouse gas sequestered
Enrollment	Acres enrolled in any given year and county for each different practice and program combination, given by the "applied amount" datafield in NRCS data.
Cover crops	Grass, small grain, or legumes primarily used for seasonal protection, erosion control, soil health improvement, and water quality improvement. Cover crops are not harvested for revenues.
Tillage / no-till	A production practice that involves turning the soil to control for weeds and pests and to prepare for seeding. No-till is an agricultural practice where crops are raised without any tillage.
Comet-Planner model	An evaluation tool designed to provide generalized estimates of the greenhouse gas impacts of conservation practices.

CHAPTER I

INTRODUCTION

As research provides continuing alarming claims about the dangers of climate change, greater interest is being focused on the contribution of agriculture and its potential to reduce greenhouse gas emissions (GHGs) (Frank *et. al.,* 2017, Johnson *et. al*., 2007; McCarl and Schneider, 2000). To mitigate adverse effects of climate change, agriculture will have to contribute to GHG emission reductions and GHG sequestration to achieving net negative emissions targets by the end of the century (Frank *et. al.,* 2017). Evidence provided by past research established that GHG emissions from agricultural related activities are largely caused by reductions in soil carbon through intensive tillage, nitrous oxide emissions through fertilizer applications, livestock production, and crop residue management through burning (Watson *et. al.*, 1992*;* McCarl and Schneider, 2000). As such, modifying these practices may be necessary to meet targeted GHG emission reductions.

Given the significant role agriculture plays in climate change, the U.S. federal government through the Natural Resource Conservation Service (NRCS) has delivered conservation solutions in the form of conservation programs. These programs are known to reduce GHG emissions (Swan *et. al.*, 2020) by encouraging specific land management practices, like converting to no-till agriculture, reducing nitrogen fertilizer applications, and rotational livestock grazing strategies. As opposed to regulations which require changes, these programs elicit the voluntary participation of landowners through monetary incentives and technical assistance. Federal legislation regarding these programs are detailed in bills informally termed the ‘Farm Bill’ and are passed as a single bill every four years. Within the Farm Bill is the “Conservation Title” which is the broad subject heading under which the laws containing reauthorizations, amendments, and new programs is classified (Congressional Research Service (CRS), 2022). The current Farm Bill was passed in 2018 and the policy structures as well as their goals have evolved in the last century. Sometimes the policies favored changing the types of crops grown, sometimes they focused on removing acres from production, and lately they have expanded to concern wetlands, wildlife, and greenhouse gas emissions. While the 2014 Farm Bill focused on simplifying and consolidating conservation programs within the conservation title, the 2018 Farm Bill did not create new programs but reauthorized and amended existing programs and shifted funding priorities within the title (CRS, 2019a; CRS, 2019b). For example, the 2018 Farm bill reauthorized and expanded the Environmental Quality Incentives Program (EQIP) with an increased funding level in annual increments from $1.75 billion in 2019 to $2.025 billion in 2023. Meanwhile, the Farm Bill also reduced allocations for livestock related practices by 10% and increased the allocation for wildlife related practices by 5%.

Currently, it is unclear what impact these changes in the Farm Bill will have on enrollment in conservation programs, and how such enrollment will impact greenhouse gas emissions. However, effective climate change policy requires a detailed understanding of the GHG emission reductions resulting from the climate-friendly agricultural practices across different settings. The purpose of this research is to estimate the total GHG emission reductions due to enrollment in NRCS conservation programs for the years 2014 – 2020 from agricultural lands in the U.S. southern plains: specifically, Oklahoma, Texas, and Kansas.

To accomplish this objective, the study first determines the overall contribution and changes in enrollment of conservation programs over these years. Next, it calculates the total greenhouse gas emission reduction from 2014 to 2020. The latter is achieved by merging two data sets: enrollment data, detailing the number of acres in each county enrolled in various NRCS programs. The other data are obtained from the Comet-Planner model, which provides county-level estimates of the amount of GHGs reductions per year for each acre of land engaged in a conservation practice. Combining the two data sets is not straightforward, because within each NRCS conservation practice there can be multiple practice options. The enrollment data detail only aggregate participation at the practice level, but the Comet-Planner data calculates emission reductions for each practice option. For example, in one conservation practice, the enrollment data shows the number of acres where synthetic fertilizer is replaced with livestock manure, but the Comet-Planner data needs to know exactly what type of livestock manure is used. As such, combining the two data requires assumptions and/or estimates about the practice options farmers choose to implement.

This research thus provides a framework for combining the two data sets by first identifying reasonable assumptions about which practice options are likely chosen, and when assumptions are difficult to make, using the 2017 Census of Agriculture data to estimate the likely percent of acres in each practice option. This framework can be extended to other regions for a more expansive estimation of GHG emission reductions due to NRCS programs. Besides, no study has yet to quantify these emission changes from conservation programs especially in the U.S. southern plains. Hence, this is important to enable policymakers to better understand the impact of agricultural policies on climate change.

Research Objectives

The major objective is to provide a methodology for combining NRCS program enrollment data and data from the Comet-Planner model to estimate total GHG sequestered. In pursuing this objective this study also analyzes how GHG emission reductions directly attributable to enrollment in NRCS programs changes in the years 2014 - 2020.

CHAPTER II

LITERATURE REVIEW

Policy Summary

From the Soil Conservation and Domestic Allocation Act of 1936 to the 2018 Farm Bill, the U.S. federal government has played an active role in helping farmers reduce soil erosion, reduce GHG emission, and protect natural resources. The programs embedded in these bills mostly provide incentives to farmers for voluntarily altering their production practices. The policy structures and their goals have, however, changed over the years. Some of the evolution in the policies involved changing the types of crops grown; sometimes programs focused on removing acres from production. Currently, the policy evolution has extended its scope to concern wetlands, wildlife, and GHG emissions.

Since its beginning, soil conservation policies have been passed in an omnibus bill targeting not just conservation but farm income and the overall welfare of U.S. citizens. For example, the aforementioned 1936 bill not only sought to reduce soil erosion but to maintain high prices for farmers while also ensuring an adequate access to food for the nation. Likewise, the Agricultural Improvement Act of 2018 authorized $60 million dollars for conservation programs, $140 million to protect farm incomes, and $664 million to ensure an adequate food supply over a ten-year period (Congressional Budget Office (CBO), 2018).

The bills concerning agricultural policies, conservation, and food access are informally termed the ‘Farm Bill’ and is now passed as a single bill, typically every four years. The conservation aspects of the Farm Bill typically involve farmers enrolling parts of their land in a program aimed at improving natural resources. The first policies were little more than a way to deliver payments to farmers during the Great Depression without violating the U.S. Constitution, but they did involve farmers changing what they grew on their enrolled acres in ways that reduced erosion. Until the 1980s, most conservation programs were designed to not only conserve resources but aid in reducing agricultural production and rural development. However, after the 1985 Farm Bill (*i.e.*, the Food Security Act of 1985), pressure from environmental groups resulted in a section of laws genuinely aimed at conservation, and it has remained that way since.

The breadth of what is considered a resource has also changed. For example, a wetland would not have been considered a desirable land formation ninety years ago. The sophistication of the policies has also increased. Policies now recognize that natural systems encompass multiple farms and costs are lowered by having farmers bid to enroll acres. Moreover, rather than seeking similar conservation practices across all U.S. counties, policies use formulas to ensure the maximum amount of environmental benefits are realized for each dollar spent (CBO, 2018; Coppess, 2014; Zachary and Lovejoy, 2004; Hellerstein, 2017; SCDA, 1936). Hence, conservation planners assess a range of environmental, agronomic, and economic impacts of implementing conservation practices on farms in a specific state and county (Swan et. al, 2020).

Every new Farm Bill results in changes to conservation policies, and the 2018 Farm Bill, officially titled the Agricultural Improvement Act of 2018, is no exception. One change is to alter the allocation of total conservation spending among the various programs. Three important conservation programs are the Conservation Reserve Program (CRP), Conservation Stewardship Program (CSP), and the Environmental Quality Incentives Program.

Conservation Reserve Program (CRP)

Initially, CRP was enacted in the 1985 Farm Bill. Since then, the program has gone through series of amendments. The program typically provides producers and landowners with an annual for 10 to 15 years in return for replacing crops on lands that are highly erodible and environmentally sensitive with plants that possess long term resource conserving qualities (CRS, 2019a). Eligible lands mainly include marginal pasturelands, grasslands, cropland, and agricultural lands that have been devoted to buffer. One significant amendment made in the 2018 Farm Bill is the increase in enrollment from 24 million acres in 2018 to a maximum of 27 million acres in 2023 (CRS, 2019b). Unlike the 2014 Farm Bill, where grassland enrollment was capped at 2 million acres, the 2018 Farm Bill requires grassland enrollment of at least 2 million acres by the end of 2021. CRP is meant to improve environmental quality by enhancing soil and water quality, wild habitat, and germane to this study, reducing GHG emissions.

Conservation Stewardship Program (CSP)

Similarly, CSP provides financial and technical assistance to enrolled producers for solving natural resource problems on agricultural lands. CSP is currently the largest conservation program in the United States (USDA-NRCS, 2021a). The name “stewardship” suggest that enrolled producers must manage land properly by maintaining and improving existing conservation activities while adopting new conservation activities in a manner deemed as comprehensive (CRS, 2019a). CSP considers ways to check the amount of soil lost and mitigate the overall impact of excess water. It provides measures to reduce the rate at which agricultural operations contribute to airborne soil particles and emissions of GHG (USDA-NRCS, 2021b).

With the 2014 Farm Bill, limitations were placed on the total acreage enrollment. Specifically, 10 million acres annually from 2014 to 2018 with a national average rate of $18 per acre (CRS, 2019b). Looking at the new 2018 Farm Bill, acreage limitations and payments rate were removed, while amendments were geared towards funding limitations on yearly basis. The new amendments were projected by CBO to reduce the program funding cost by $12.4 billion over a ten-year period which requires that funds be channeled to other conservation programs (CRS, 2019b).

Environmental Quality Incentives Program (EQIP)

Technical assistance (especially one-on-one help on natural resource issues), environmental improvements, and financial assistance, are the primary aims of EQIP (USDA-NRCS, 2021b). Assistance is provided to agricultural producers, private landowners, and non-industrial forest managers to plan and install structural, vegetative, and land management practices on eligible lands (CRS, 2019b). The goal is to reduce natural resource problems such as nonpoint source pollution. The 2018 Farm Bill made significant amendments and reauthorizations to EQIP. Notable changes include a reduction of funding for livestock related practices from 60% to 50% and a clarification that grazing management practices are included in EQIP. There was an increase from 5% to 10% on wildlife habitat payment. Also, unlike the 2014 Farm Bill, where payments related to organic production were limited to a total of $20,000 per year or $80,000 during any 6-year period, the 2018 Farm Bill amended the payment limit to a total of $140,000 from 2019 through to 2023 (CRS, 2019b).

Mechanism of GHG Emission Reduction and Carbon Sequestration on Agricultural Lands

Agriculture in U.S. contributes about 10% of total greenhouse gas (GHG) emissions (EPA, 2021). Though this contribution is relatively small compared to other sectors, agriculture could play an important role in addressing climate change. GHGs can be emitted from numerous agricultural activities ranging from livestock and dairy operations to crop production activities including tilling, planting, pesticides application, fertilizer application, and harvesting. A major source of GHG emission from livestock operations is enteric fermentation. This takes place mainly among ruminants such as sheep, cattle, goats, and buffalo where methane (CH_4) is emitted from their digestive tracts as a result of microbial fermentation. The amount of methane released is largely dependent on feed quality, animal size, and environmental temperature. Another source of methane is through the decomposition of animal manure. Horowitz and Gottlieb (2010) list several ways to reduce methane emission from livestock and diary operations. One is to manipulate the livestock diet. IDN, (2008) also indicated that if manure is composted there is little methane produced.

Crop production activities usually emit GHGs from the soil in the form of CO2 or N2O when soil carbon or nitrogen chemically combines with oxygen. Emissions of CO2 can come from the burning of gasoline or diesel in the course of using mechanized farm equipment for the purposes of tilling and even application of pesticides as well as fertilizers. Many management practices on agricultural soils also lead to increased availability of nitrogen in the soil and results in emissions of N2O. Management practices may include synthetic fertilizer application, use of manure and other organic materials as fertilizer, production of nitrogen fixing crops and forages, retention of crop residues, drainage of soils with high organic matter content, irrigation, drainage, tillage practices, and fallowing of land (Massey and Kientzy, 2021).

Generally, the nitrogen fixed in the soil is important for increased agriculture productivity. Nonetheless, excessive amounts increase emissions of GHGs. The solution is to reduce nitrogen applications without reducing yields. One strategy is to practice precision agriculture (Horowitz and Gottlieb, 2010). Another practice involves the use of nitrification inhibitors, which slow the release of nitrogen fertilizer to crops and makes nitrogen readily available without wastage. That is, nitrogen is converted from ammonium (NH_4^+) to nitrate (NO_3^-), which reduces emissions. Another method to ensure GHG emission reductions is to create a long-term storage reservoir for carbon like the soil, wetlands, prairies, and forests (IDNR, 2008). This process is what is generally referred to as carbon sequestration or carbon farming. The notion is to provide minimal or no disturbance to the land in question, thereby keeping the carbon in the soil. Carbon sequestration include activities like no-till agriculture, conservation or reduced tillage, composting, integrated crop-livestock systems, rotational grazing, use of cover crops, etcetera (IDNR, 2008). For example, with no-till agriculture, crop residues on the land remain and the earth is largely left undisturbed during planting. Heavy machines that would have been used for intensive tillage would not also have the chance to burn gasoline or diesel. Hence, GHG emission is reduced. NRCS meets these objectives through a number of practices which comes with its own technical guides and standards about the implementation. The implementation guides are discussed in subsequent sections.

Conservation Practices

Imbedded in conservation programs are practices grouped under 5 main conservation classes: cropland management, grazing land management, croplands to herbaceous cover, croplands to woody plantings, and restoration of disturbed lands. Conservation practices are primarily technical guides that contain information and standards. These practices are specific to the geographic area due to climate differences. In this section, we provide some of the important requirements as well as explanations for each conservation practice under each class that helps to fulfill the purpose of GHG emission reduction.

Grazing Land Management

Grazing lands are used mostly for livestock production, and the land itself can be characterized as pasture, hayfields, steppes, grasslands, and rangelands (Sanz et al., 2017). Conservation practices for grazing land seeks to achieve the objectives of providing improved and sustainable forage while improving water and soil quality as well as reducing erosion (Swan et. al, 2020). Other important objectives involve improved shade for livestock, cover for wildlife, and increase carbon sequestration. NRCS Conservation practices for grazing lands include prescribed grazing, range planting and silvopasture.

528-Prescribed Grazing

The practice focuses on how to manage the harvest of vegetation with either grazing or browsing animals with the intent of achieving a specific ecological, economic, and management objectives (USDA-NRCS, 2017a). For this practice, its necessary to provide grazed or harvested plants sufficient recovery time. Stocking rates and grazing periods are managed to adjust the intensity, frequency, timing, duration, and distribution of grazing and or browsing. The movements of livestock are also managed depending on the rate of plant growth, available forage, plant height, residual dry matter, and animal performance (USDA-NRCS, 2017a). Implementing these guidelines helps to improve the efficiency of moisture management, increase organic matter content, and reduce emissions of particulate matter (Lozano et al., 2019).

550-Range Planting

USDA-NRCS (2011) describes range planting as the establishment of adapted perennial or self-sustaining vegetation which includes leguminous plants, grasses, forbs, shrubs, and trees. Range planting serves the purposes of increasing carbon sequestration, reducing soil erosion, and improving forages for livestock and wildlife (Hardegree et. al, 2016). While productivity of improved grasslands is enhanced, soil carbon stocks are expected to increase due to higher inputs of carbon from plant residues. Hence, selected vegetative types for planting must provide adequate cover for erosion control and adapt to the climatic conditions, soil, landscape position, and range site.

381-Silvopasture

Silvopasture, according to USDA-NRCS (2016a) has to do with the establishment and management of either trees or shrubs and forages on the same land used where grazing occurs. The purpose of the trees or shrubs is to provide shade for livestock, improve water quality, reduce erosion, enhance soil quality, improve health and productivity of trees, and increase carbon sequestration. Either the woody plants are added to existing grazing land or forages are added to existing woody plant stands (Swan et. al, 2020). In regards to the GHG impact, the woody biomass sequesters carbon from the atmosphere and stores it.

Cropland Management

Conservation practices under cropland management stands to accomplish several objectives that may include enhancement of soil moisture efficiency, reduction of soil erosion, and improvement in soil health, all of which sequesters GHGs. NRCS Conservation practices for cropland management comprises of conservation crop rotation, planting of seasonal cover crops, mulching, nutrient management, and residue and tillage management.

328-Conservation Crop Rotation

According to USDA-NRCS, (2014a), conservation crop rotation involves growing different crops in planned sequence on the same piece of land. The practice makes use of high-residue producing crops such as corn in rotation with low-residue producing crops like vegetables or soybeans. Forage crops can also be rotated with other field crops. This practice applies to all cropland where at least one annually planted crop is included in the crop rotation.

The rooting depth and time to maturity are two factors that should be considered when planning the sequence of crops in the rotation as this affect the optimization of water use (USDA-NRCS, 2014a). For example, it is efficient to rotate between deep and shallow rooted crops. Following this requirement helps to meet the GHG emission reduction property of this practice.

590-Nutrient Management

USDA-NRCS (2012a) explained nutrient management as a conservation practice that seeks to manage the amount, source, method of application, and timing of plant nutrients to achieve optimum yield and at the same time minimize the risk of surface and groundwater pollution. The purpose of doing so is to utilize manure or organic by-products effectively; improve air quality by reducing odors as well as nitrogen emissions; and either maintain or enhance the physical, chemical, and biological state of the soil (Swan et. al, 2020). This practice is permitted to be performed on any area of land where plant nutrients are expected to increase yield and improve the conditioning of the soil upon its application. The GHG impact of nutrient management is to reduce the emission of nitrous oxide from reduced application of nitrogen fertilizer.

340-Cover Crops

This practice establishes densely planted grasses, legumes, and/or small grain crops which are not harvested for sale. A cover crop is used to save soil and support soil processes with living roots during the nongrowing season (AgBMPs, 2022). The effectiveness of this practice sometimes depends on the type of seeding. Legumes such as alfalfa, soybean, clovers can be considered. For non-leguminous cover crops, we may consider rye, oats, wheat and even oilseed radish. There are many cover crops species that exist which may be considered as well. USDA-NRCS (2021c), explains that cover crops are established as part of a cropping system between production crops. Also, species and planting dates should be selected in a way that will not adversely affect crop yield or interfere with the harvest process.

484-Mulching

NRCS requires plant residues or other suitable materials to be applied to the land surface to achieve GHG emission reductions. There should be periodically inspection of the mulched areas and producers should take the trouble to reinstall mulch or repair as this is needed to accomplish the intended purpose (USDA-NRCS, 2017b). One thing to consider is mulch materials with high permeability so that the water needs of plants may not be adversely affected.

329/345- Residue and Tillage Management

Residue and Tillage Management take place on any land where a crop is grown. It tends to limit soil disturbance to manage the amount, orientation, and distribution of crop and plant residue on the soil surface throughout the year (USDA-NRCS, 2017c). The practice comes in the form of no-till or reduced tillage on croplands. Thus, production of adequate crop residues is encouraged, and this can be achieved by using cover crops, double cropping, and high residue crops. It is advised that residue should not be burned or shredded after harvest in order to increase the rate of soil organic matter accumulation, keep soil in a consolidated condition, and improved aggregate stability as well as sequester additional carbon in the soil (USDA-NRCS, 2017c).

Cropland to Herbaceous Cover

This group of practice converts either all or part of croplands to perennial herbaceous cover. Herbaceous plants usually have non-woody stems which may include sedges, grasses, rushes, ferns and even forbs (Mongkhonsin et. al., 2019). Such plants have an extensive root system adept at storing carbon in the long term even if the stems, leaves, and flowers above the soil are destroyed. Additionally, herbaceous cover crops reduce the rate at which nitrous oxide is emitted since they generally do not require fertilizer applications (Swan et. al, 2020). Conversion of croplands to herbaceous cover has added benefits: protection of crops from wind damage, stabilization of steep slopes, and reduction of soil erosion. Cropland to herbaceous cover practices include conservation cover, contour buffer strips, field border, filter strip, forage and biomass planting, grassed waterways, and riparian herbaceous cover.

512-Forage and Biomass Planting

USDA-NRCS (2012b) defined forage and biomass planting as the establishment of adapted and or compatible species, varieties, or cultivars of herbaceous species suitable for pasture, hay, or biomass production. It is important to perform this practice on all lands that suits the establishment of annual, biannual, or perennial species. Also, it can be managed through prescribed grazing rotations during dry periods. Forage and biomass planting involve minimal tillage which translates to minimal soil disturbance. The purpose of this practice is therefore to either improve or maintain livestock nutrition and health, reduce soil erosion, improve soil, and water quality, and produce feedstock for biofuel or energy production (Lozano et al., 2019).

390-Riparian Herbaceous Cover

For this practice, grasses, grass-like plants, and forbs that are tolerant of intermittent flooding or saturated soils are established and maintained usually in the transitional zone between terrestrial and aquatic habitats (USDA-NRCS, 2012c). The practice helps to attain the purpose of improving and protecting of water quality as well as reducing erosion. Thus, plant species that have stiff stems and a high stem density near the ground surface should be selected to achieve the purpose of this practice. Proper management practices require that farmers reduce the use of vegetation for haying and grazing until the desired plant community is well established.

386-Field Border

With field border, strips of permanent vegetation such as legumes, grasses, forbs, or shrubs are established on sides of a field to reduce erosion, protect soil and water, increase soil carbon, and improve air quality (USDA-NRCS, 2016b). Plants border the entire field, not just areas adjacent to where rainfall runoff typically flows. Good management practices for field borders includes removing sediment from above, within, and along the leading edge of the field border when accumulated sediment either alters the function of the field border or threatens the degradation of the planted species (Pierce and Milhollin, 2020).

327-Conservation Cover

This practice targets land retired from agricultural production or other lands needing permanent protective cover that will not be used for forage production. It establishes and maintains permanent vegetative cover that will reduce soil erosion, improve water, and air quality, and enhance soil quality (USDA-NRCS, 2010a). Some of the important things to consider in this practice has to do with the usage of certified seed and planting stock that is adapted to the site when it is available. To ensure good maintenance, mowing may be needed during the establishment period to reduce competition from weeds.

393-Filter Strip

Establishing filter strips will prevent transport and delivery of sediments, nutrients, pesticides, and adsorbed contaminants into water bodies. To achieve its objective, the NRCS documentation advises that filter strips are positioned down-slope of a field or disturbed area (USDA-NRCS, 2016c). Typically, filter strips are managed to have dense vegetative growth, and this may require mowing as well as reseeding after establishment to achieve that.

412-Grassed Waterway

Chow et. al., (1999) and Rundhaug et. al., (2018) explained this practice as a graded channel that is established with suitable vegetation to convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding. During the establishment of grassed waterways, NRCS encourages that producers use mulch anchoring, nurse crop, rock or hay bale dikes, fabric or rock checks, filter fences, or runoff diversion to protect the vegetation until it is established. To maintain grassed waterways, vegetation damaged by machinery, herbicides, or erosion must be repaired promptly (USDA-NRCS, 2014b). It is expedient to inspect grassed waterways regularly, especially following heavy rains. Producers should also fill, compact, and reseed damaged areas immediately. It is also advisable to remove sediment deposits to maintain capacity of grassed waterway.

332-Contour Buffer Strips

A contour buffer strip is a strip of grass alternated with wider cultivated strips that are farmed on a contour basically to slow runoff water, trap sediment, and reduce erosion (Foster and Dabney, 2005; Hirsh et. at., 2013). The effectiveness of a contour buffer strip is dependent on several variables like steepness, soil type, and crops grown. It requires management practices like mowing for at least a year, to maintain appropriate vegetative density and height (USDA-NRCS, 2019). Doing this ensures optimum trapping of sediment from the upslope cropped strip during the critical erosion periods.

Cropland to Woody Cover

These are perennial plants of trees, shrubs or vines with woody stems and roots that are long-term storage places for carbon. NRCS conservation practices that involve conversion of cropland to woody cover serve several purposes, most of which boils down to increasing the storage of carbon in biomass and soils. Other important benefits include creation of renewable energy sources, control of erosion and reduction of chemical runoff and leaching. The GHG emission reduction for this class of conservation practice can be likened to croplands converted to herbaceous cover where little or no fertilizer is applied to herbaceous cover and croplands are also not disturbed. Examples of NRCS conservation practices under cropland to woody cover comprises of hedgerow planting, riparian forest buffer, tree or shrub establishment, and windbreak establishment and renovation.

380/650-Windbreak and Windbreak Renovation

Brandle et. al., (2009) defined windbreak establishment as barriers that are used to reduce wind speed mainly to control erosion and protect crops and livestock. They usually consist of trees and shrubs or sometimes annual and perennial crops, grasses, or even wooded fences that are established in single to multiple rows in a linear fashion. NRCS documentation requires this be established upwind of the areas to be protected and renovated from time to time. The effectiveness of some windbreaks like trees and shrubs is dependent on the height of the mature plants (USDA-NRCS, 2021b). Therefore, it is worth noting that it may take a couple of years for the practice to become fully functional. Maintaining protection for trees and/or shrubs during establishment by regular inspection and after major storm events is crucial.

391-Riparian Forest Buffer

These are predominantly trees and/or shrubs located adjacent to and up-gradient from watercourses or water bodies to reduce excess amounts of sediment, organic material, nutrients, and pesticides in surface runoff (Maraseni and Mitchell, 2016). They are established to also increase carbon storage in plant biomass and soils. That is, species and plant communities that attain biomass more quickly will sequester carbon faster. In view of that, NRCS documentation suggests maximization of width and length of the riparian forest buffer while planting the appropriate stocking rate for the site (USDA-NRCS, 2010v). Plants that are adapted to the site should also be selected to assure strong health and vigor.

422-Hedgerow Planting

Just like windbreaks, hedgerow plantings involve the establishment of dense vegetation in a linear design to achieve increase carbon storage in woody biomass of trees, shrubs, as well as in the soils (Thiel et al., 2015). Plants selected must be suited and adapted to climate, soil, and site conditions. It is also necessary to control competing vegetation until the hedgerow becomes established. Hedgerows should be planned in combination with other practices to develop holistic conservation systems (USDA-NRCS, 2017d). That is, to reduce soil erosion, improve sediment trapping, improve water quality, and provide wildlife habitat. As a way of maintaining hedgerows, supplemental planting may be required when survival is too low to produce a continuous hedgerow.

612-Tree or Shrub Establishment

This practice plants seedlings or cuttings and creates conditions that tend to promote natural regeneration to enhance wildlife habitat, control erosion, improve water quality conserve energy, and store enough carbon as possible (USDA-NRCS, 2016d). Tree or shrub establishment works properly when activities such as trees and shrubs are inspected periodically and protected from insects, diseases, fire, competing vegetation and damage from livestock.

Restoration of Disturbed Lands

Agricultural lands become degenerated after long and unsustainable cultivation. Soils from such lands emit about two-thirds of their original soil carbon to the atmosphere as CO2. As stated by Yang et al., (2020), the atmosphere holds about five times less CO2 than the earth’s soils and vegetation holds as carbon. Most of the times, degraded soils come along with high nutrient loss, reduced microbial activities, and weakened physical structure of the soil (Hossain et al., 2020). This implies a decline in soil fertility and less ability for the soil to hold water. As such, restoring disturbed lands is an opportunity to sequester a large amount of carbon into the soil, The objectives of NRCS conservation practices for restoration of disturbed lands may include but are not limited to the stabilization of disturbed lands to decrease erosion, improvement of offsite water quality and quantity, as well as the enhancement of landscape visual and functional quality (Swan et. al, 2020). Two main examples of NRCS conservation practices under restoration of disturbed lands include riparian restoration and critical area planting.

342-Critical Area Planting

USDA-NRCS (2010c) described this practice as the establishment of permanent vegetation on sites that is deemed to have high level of erosion, and for that reason, requires special treatment. Critical area planting is mostly performed in combination with conservation practices including mulching, nutrient management, and herbaceous weed control (Lozano et al., 2019). It is important to select species that will have the capacity to achieve adequate density and vigor within an appropriate time frame to stabilize the site sufficiently. If lands are really degraded like gullies or deep rills at initial stage, lands are supposed to be filled and leveled as necessary to allow equipment operation and ensure proper site and seedbed preparation (USDA-NRCS, 2010c).

CHAPTER III

METHODS

Data

The study combines two main datasets to estimate greenhouse gas (GHG) sequestration from agricultural lands in Kansas, Oklahoma, and Texas: conservation enrollment data and Comet-Planner data. Enrollment data were made available from various NRCS state agencies for the years 2014 – 2020 and for the states Kansas, Oklahoma, and Texas. The Comet-Planner data (referred to as emissions data) are publicly available at http://comet-planner.com/.

Enrollment Data

The enrollment data provides information on the number of acres actively implementing a conservation practice for each county and each NRCS program. Recall that NRCS conservation practices describes general conservation strategies, and for each practice there may be multiple options for implementing it. The data also describe which NRCS program the acres are officially funded by, like the Conservation Reserve Program, Conservation Stewardship Program, and EQIP. For each program-practice combination, the enrollment data contain information on what is termed the 'land unit acres' and 'applied amount.'[1] Land unit acres can be thought of as the size of a field where the practice is implemented, while the applied amount describes the number of acres on which the practice is actually implemented. For instance, a county may have 4,000

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[1] Sometimes the 'applied amount' is stated in terms of feet instead of acres. This is for practices that involves narrow strips, like riparian filter strips or hedgerows. In these cases, the 'strips' are assumed to be 30 feet wide.

land unit acres on which 327—Permanent Cover Crops takes place, but the cover crops may only be established on 3,000 of those acres. The land unit acres would be 4,000 and the applied amount would be 3,000. When this study refers to 'enrolled acres' it refers exclusively to the applied amount.

The enrollment data are an unbalanced panel data. Moreover, due to policies regarding conservation programs and a range of environmental, agronomic, and economic reasons peculiar to each state and county, enrollment may take place in one county for the year 2014 for a practice, but its enrollment value may not be recorded in year 2016. Hence, considering that we have 77 counties in Oklahoma, we expect to have 77 observations each for a practice in all the years, however, the case is not so across all practices. Overall, the data has 22 conservation practices. These practices vary across each state. For instance, Oklahoma has 18 conservation practices covered in the data while Texas and Kansas have 20 and 21 conservation practices, respectively. Again, NRCS identifies each conservation practice by a unique number and descriptive title. For one practice titled Conservation Crop Rotation, its unique number is given as 328. However, it has enhanced versions with unique numbers (E328101R, E328136Z).[2] The "enhancement" usually involves some sort of addition to original practice, but these additional practices are not thought to alter the GHG emission reductions much (USDA 2017). For example, practice number E328136Z which is an enhancement of 328-Conservation Crop Rotation, requires producers to leave standing grain crops unharvested to benefit wildlife food

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[2] Enhancement of Practice 327 – E327136Z1, E327136Z2, E327137Z, and E327139Z
Enhancement of Practice 328 – E328101R, E328106R, E328106Z1, E328107R, E328109Z, and E328136Z
Enhancement of Practice 329 – E329101Z, E329102Z, E329106Z, E329114Z, and E329115Z
Enhancement of Practice 340 – E340101Z, E340102Z, E340106Z1, E340106Z2, E340106Z3, E340106Z4
Enhancement of Practice 345 – E345101Z, E345102Z, E345106Z, E345114Z, E345115Z, and E345144Z
Enhancement of Practice 512 – E512101Z1, E512101Z2, E512106Z2, E512136Z1, E512139Z2
Enhancement of Practice 528 – E528101Z, E528104Z, E528105Z, E528118Z1, E528126Z, E528132Z1
Enhancement of Practice 590 – E590118X, E590118Z, E590119Z, E590130Z

sources (USDA 2017). Thus, unique numbers for enhanced versions are converted to the original version to simplify calculations.

Note that treating enhanced versions of a practice as its non-enhanced counterpart leads to distinctions in the panel data. For example, instead of having Payne County occurring once for practice 328 in a particular year, we end up with multiple observations for Payne County within the same year and practice. In such cases, acres enrolled for all multiple observations under Payne County for practice 328 in that particular year are merged to obtain a single observation for Payne County. Therefore, the total number of observations for the enrollment data is 15,064 from 2014 to 2020. Illustrated in Table 3.3 is a summary statistic for the enrollment data.

More so, each of the conservation practices can entail a variety of different practice options that take place on the field. For example, practice 329- Conventional to No-Till, has practice options which may involve converting from intensive-till to no-till on irrigated cropland for one farm, but for another may involve converting from reduced-till to no-till or strip-till on non-irrigated cropland (Table A1). For another example, one farm enrolled in practice 590 - Nutrient Management, may simply reduce their application of synthetic nitrogen while another may replace all synthetic nitrogen with nitrogen from livestock manure sources (Table A1).

Emissions Data

While most conservation programs are thought to reduce GHG emissions from agricultural land, estimating the amount of emission reductions is difficult. Emissions vary considerably by soil type and climate, as well as the amount of carbon already contained in the soil. Hence, understanding the contribution of conservation programs to reducing climate change is no easy task, but it must be done for policymakers to design program changes.

One attempt at doing so is the Comet-Planner model. A model developed by the NRCS to provide county-level emission reduction factor (ERF) estimates for a large variety of conservation practices for all fifty states. For each practice, developers of the model carefully reviewed the scientific literature on emission changes for each practice in different climates. A variety of modeling and expert judgments were then employed to provide ERF's for each county and for each conservation practice option under every conservation practice (Swan, et. al., 2020). The ERF's state the megagrams (Mg) of GHG reductions per acre and per year for the practice options for each practice, where GHGs are measured in megagrams of CO2-equivalent. One weakness from the emission data is that it does not provide information on the cumulative GHG emission reductions from a conservation practice. Emission reduction values is based on what a typical conservation practice could sequester on average each year.

While most county-level ERFs are within the bounds suggested by the scientific literature, the ERF for some practices in some counties were incredibly high (above 20 in some cases) relative to other counties that had a similar climate and far outside the range stated in the Comet-Planner model documentation. This was presumed to be an anomaly produced by the equations used to compute the Comet-Planner model's parameters.

As such, all ERFs are capped at 4, based on the ranges stated in the Comet-Planner documentation (Swan et. al., 2020). In total, we have 40,380 observations for the Comet-Planner data given the practice names and their respective practice options for every county under the three different states. Oklahoma has 6,768 observations, Kansas has 9,821, and Texas has 23,791 observations. Table 3.1 and 3.2 details some of the enrollment and Comet-Planner Data.

Table 3.1- Enrollment Data for Cimarron County in Oklahoma

County	Practice number	Practice Name	Applied Year	Applied Amount (Acres)
Cimarron	327	Permanent Cover Crops	2014	4,896
Cimarron	327	Permanent Cover Crops	2015	3,090
Cimarron	327	Permanent Cover Crops	2016	3,090
Cimarron	327	Permanent Cover Crops	2018	930
Cimarron	327	Permanent Cover Crops	2019	5,621
Cimarron	327	Permanent Cover Crops	2020	4,132

Table 3.2- Comet-Planner Data for Cimarron County in Oklahoma

County	Practice number	Practice Name	Practice Options	Emission Reduction Factor (ERF)
Cimarron	327	Permanent Cover Crops	Convert irrigated cropland to permanent unfertilized grass cover	0.5601
Cimarron	327	Permanent Cover Crops	Convert irrigated cropland to permanent unfertilized grass/legume cover	0.7277
Cimarron	327	Permanent Cover Crops	Convert non-irrigated cropland to permanent unfertilized grass cover	0.4765
Cimarron	327	Permanent Cover Crops	Convert non-irrigated cropland to permanent unfertilized grass/legume cover	0.6725

Table 3.3- Summary Statistics for Conservation Practice Enrollment in Oklahoma, Kansas, and Texas from 2014 -2020

	Oklahoma (2,570)			Kansas (5,331)			Texas (7,163)		
Conservation practice name	Obs.	Mean (Acres)	Std. Dev.	Obs.	Mean (Acres)	Std. Dev.	Obs.	Mean (Acres)	Std. Dev.
327-Permanent cover crops	146	771	2,299	87	42	92	407	1,933	5,642
328-Conservation crop rotation	143	1,598	2,699	645	2,288	2,704	756	4,285	7,443
329-Conventional to no-till	228	3,254	9,290	520	1,311	1,711	330	1,781	3,690
332-Contour buffer strips	-	-	-	6	3.65	2.4	1	9.5	-
340-Seasonal cover crops	170	1,023	2,218	496	577	712	651	1,034	4,113
342-Critical area planting	271	8	14	498	17	21	132	6.18	7.5
345-Conventional to reduced tillage	120	1,683	2,646	462	1,128	1,574	433	4,138	7,366
380-Windbreak	4	1.4	2	99	2	2	2	1.86	2.45
381-Silvopasture on grasslands	-	-	-	-	-	-	4	18.7	7.5
386-Field border	36	6.3	15.13	27	19	30	30	8.91	9.83
390-Riparian herbaceous cover	3	62.9	78	2	1	1.13	5	59.5	74
391-Riparian forest buffer	6	117	155	18	3.39	2.87	48	76	97
393-Filter strip	8	2.5	4.45	51	8	14	10	4.23	5
412-Grassed waterway	86	10.96	12.5	472	13	14	136	12.22	35.74
422-Hedgerow planting	-	-	-	1	.06	-	-	-	-
484-Mulching	2	0.15	0.07	206	2.88	5.13	6	1.8	1.92
512-Forage and biomass planting	405	331.17	398	129	72	96	1,023	272.8	480
528-Prescribed grazing	499	6,714	11,020	615	2,700	3,766	1,625	25,750	39,159
550-Range planting	137	162	215	369	139.7	297	786	290	470
590-Nutrient management	262	984	1,790	326	2,016	4,352	543	1,201	3,045
612-Tree and shrub establishment	44	184	321	145	11.48	39	235	331	595
650-Windbreak renovation	-	-	-	157	2.16	2.30	-	-	-

Note(s): Obs is the number of observations from 2014 to 2020 and Std. Dev. is the standard deviation for the number of acres enrolled during this period. For total acres enrolled over the 7-year period, we multiply the mean by the number of observations.

Procedures

As indicated earlier, one weakness of the enrollment data is that the option chosen by a farmer to fulfill their obligations is not always provided. This is unavoidable, as doing so might violate anonymity of the landowner, but it requires some logical procedures on the researcher's part to combine the two data types. As such, a number of assumptions are required in combining the enrollment and the Comet-Planner data to estimate GHG sequestration from the enrollment data. Consider practice 327-Conservation Cover. This involves converting irrigated cropland to permanent unfertilized grass / legume cover and converting non-irrigated cropland to permanent unfertilized grass/legume cover. Notice that there are options one can pursue under this practice, and that the ERF depends on whether the activity takes place on irrigated or non-irrigated cropland (Table 3.4). Irrigated acres usually have higher factors due to the ability of plants to grow extra biomass under irrigation. Just as the factors vary across irrigated and non- irrigated cropland, they vary across regions as well, with counties having a larger rainfall having larger reductions.

Table 3.4 – Emission Reduction Factor from Comet-Planner Model for 327—Conservation Cover in Le Flore and Texas County.

Practice Options	Greenhouse Gas Emission Reduction Factors mg CO2-e / acre / year	
	Le Flore County, OK (52 inches rainfall per year)	Texas County, OK (17 inches rainfall per year)
Convert irrigated cropland to permanent unfertilized grass cover	0.9904	0.5601
Convert irrigated cropland to permanent unfertilized grass/legume cover	1.3001	0.7277
Convert non-irrigated cropland to permanent unfertilized grass cover	0.5138	0.4765
Convert non-irrigated cropland to permanent unfertilized grass/legume cover	1.0382	0.6725

Also, in consideration is whether the land is converted to grasses only or a grass / legume mixture. The enrollment data provide no indication of what is planted and the number of acres that were enrolled for a conservation practice option. In other words, it does not detail which type of practice option takes place, but only gives the number of acres that were enrolled at the practice level. So, one must decide how to amalgamate the “factors” in projecting emission reductions. To reconcile the fact that enrollment data do not contain information on which conservation practice option is used, the following strategies are employed. One strategy involves obtaining a county-level ERF based on a weighted average of individual practice-option ERFs. Let $\mathrm{ERF}_{c,p,i}$ denote the emission reduction factor in the Comet data for county c, practice p, and practice-option i, let $\mathrm{W}_{c,p,i}$ denote the weight assigned to it and I denote the total number of practice options. The county-level $ERF_{c,p}$ is then calculated as

$$ERF_{c,p} = \frac{\sum_{i=1}^{I}(ERF_{c,p,i})(W_{c,p,i})}{\sum_{i=1}^{I}(W_{c,p,i})} \tag{3.1}$$

The weights $W_{c,p,i}$ are assigned a number of ways, depending on the practice and data available. Many practice options have different ERFs depending on whether the land is irrigated or non-irrigated, and the enrollment data do not indicate what percent of land in the program is irrigated. As such, this percentage is estimated using the 2017 Census of Agriculture for that county. The weight for irrigated (non-irrigated) land is then the percent of irrigated (non-irrigated) land in the census. Table 3.5 provides a detailed presentation of how $ERF_{c,p}$ for practice 327-Conservation Cover is computed in Beaver and Alfalfa County. It follows equation 3.1, but is articulated in more detail as,

$$ERF_{Alfalfa\,,\,327} = \left(\frac{(E_{IC}*A_{IC})+(E_{NC}*A_{NC})+(E_{IIC}*A_{IC})+(E_{NNC}*A_{NC})}{(2*A_{IC}+2*A_{NC})}\right) \tag{3.2}$$

Table 3.5- Emission Reduction Factor for Conservation Practice 327 in Beaver and Alfalfa County

	Beaver				**Alfalfa**			
Practice Options (PO)	Emission Reduction Factor (ERF)	Acres of irrigated cropland	Acres of non-irrigated cropland	Weights assigned to PO	Emission Reduction Factor (ERF)	Acres of irrigated cropland	Acres of non-irrigated cropland	Weights assigned to PO
Convert **“irrigated”** croplands to permanent unfertilized grass cover	0.5931	21,501	-	21,501/B= 0.0363	0.4946	1387	-	1,387/A= 0.002
Convert **“irrigated”** cropland to permanent unfertilized grass/legume cover	0.9229	21,501	-	21,501/B= 0.0363	0.9051	1387	-	1,387/A= 0.002
Convert **“non-irrigated”** croplands to permanent unfertilized grass cover	0.6180	-	274,607	274,607/B= 0.4637	0.2751	-	341,853	341,853/A= 0.4980
Convert **“non-irrigated”** cropland to permanent unfertilized grass/legume cover	0.9573	-	274,607	274,607/B= 0.4637	0.8099	-	341,853	341,853/A= 0.4980

B = 21,501+274,607+21,501+274,607 = 592,216; **A** = 1,387+341,853+1,387+1,387=686,480

Emission factor (Beaver) = (0.5931)(0.0363)+(0.9229)(0.0363)+(0.6180)(0.4637)+(0.9573)(0.4637) = 0.7855 Mg CO_2 e/ac/yr
Emission factor (Alfalfa) = (0.4946)(0.0020)+(0.9051)(0.0020)+(0.2751)(0.4980)+(0.8099)(0.4980) = 0.5431 Mg CO_2 e/ac/yr

Note(s): PO is Practice options and units for $ERF_{Alfalfa\,,\,327}$ is Mg CO2-e/acre/year where, $\mathrm{ERF}_{\mathit{Alfalfa}\,,\,327}$ is the GHG emission reduction factor in Mg CO2-e / acre / year for practice 327 in Alfalfa County. E_{IC}, E_{NC}, E_{IIC} and E_{NNC} are the emission reduction factors in Mg CO2-e / acre / year for the practice options. E_{IC} and E_{NC} refers to ERF for converting irrigated and non-irrigated cropland to permanent unfertilized grass cover, respectively. Likewise, E_{IIC} and E_{NNC} refer to ERF for converting irrigated and non-irrigated croplands to permanent unfertilized grass/legume cover, respectively. A_{IC} is the total acres of cropland under irrigation and A_{NC} is the acres of cropland under no irrigation. Some conservation practices such as 328- Conservation Crop Rotation and 342- Critical Area Planting entail only one option, requiring no weighted average of practice option ERF's. Table A1 provides details on how the county-level ERF for each practice is estimated.

Conservation practice 590 – Nutrient Management is a particularly difficult practice to address because it has a large number of options. This practice can involve reducing synthetic nitrogen applications, applying nitrogen in a different manner, and/or replacing that nitrogen with livestock manure. Table 3.6 shows only a few of the options for implementing the practice. The Comet-Planner model actually has 23 different options for implementing practice 590, and the ERFs not only differ across each practice but also whether the land is irrigated or non-irrigated. When replacing synthetic nitrogen with livestock manure, the ERFs depend on the type of manure used. Just as the factors vary across irrigated and non-irrigated cropland, they vary across regions as well, with counties having a larger rainfall having larger reductions. The weighting procedure to calculate the ERF for this practice assumes the following:

1. One option entails replacing N fertilizer with compost application. This was thought to be a very unlikely practice to be adopted, and so it was assumed no landowner chose it.

2. There are no data indicating what percent of landowners chose to reduce nitrogen applications and what percent chose to replace nitrogen fertilizer with manure, yet the consequence for GHGs is heavily dependent on this choice. It was thus decided that the model would be estimated twice: once assuming a 15% reduction in nitrogen fertilizer and another time assuming the nitrogen fertilizer was replaced with manure for all enrolled acres in the county.
3. For those replacing nitrogen fertilizers with livestock manure, County-level livestock inventories are obtained from the 2017 Census of Agriculture and are used to create one ERF based on a weighted average of each livestock-specific ERF. The weights represent the amount of manure generated by each livestock type, with typical livestock weights being a proxy for manure generation.
4. The ERF for any one practice option is set to be a weighted average of the ERFs associated with irrigated and non-irrigated land.

Illustrated in Table 3.7 and Table 3.8 is the computation of the ERF for 590 – Nutrient Management in Texas County using the two different approaches of either reducing N fertilizer or replacing N fertilizer with livestock manure.

Table 3.6- Practice Option for 590-Nutrient Management

Practice Options	**Greenhouse Gas Emission Reductions mg CO2-e / acre / year**	
	Le Flore County	Texas County
Reduce N application by 15% on irrigated cropland	-0.0043	-0.0302
Reduce N application by 15% on non-irrigated cropland	-0.0130	-0.0105
Replace N with beef feedlot manure on irrigated cropland	0.1726	0.1231
Replace N with beef feedlot manure on non-irrigated cropland	0.1902	0.1096
Replace N with chicken broiler manure on irrigated cropland	0.0592	0.0015
Replace N with chicken broiler manure on non-irrigated cropland	0.0910	0.0328
Replace N with chicken layer manure on irrigated cropland	0.0595	0.0016
Replace N with chicken layer manure on non-irrigated cropland	0.0952	0.0328
Replace N with dairy manure on irrigated cropland	0.1728	0.1231
Replace N with dairy manure on non-irrigated cropland	0.1933	0.1096
Replace N with sheep manure on irrigated cropland	0.1728	0.1231
Replace N with sheep manure on non-irrigated cropland	0.1933	0.1096
Replace N with swine manure on irrigated cropland	0.3657	0.3373
Replace N with swine manure on non-irrigated cropland	0.2975	0.2660

Table 3.7- Emission Reduction Factor for Conservation Practice 590 in Texas County by Reducing Nitrogen Fertilizer

Practice options (PO)	**Emission reduction in Mg CO_2 e/ac/yr**	**Acres of irrigated cropland**	**Acres of non-irrigated cropland**	**Weights assigned to PO**
Reduce N application by 15% on irrigated cropland	-0.0302	168,841	-	168,841/ T= 0.2483
Reduce N application by 15% on non-irrigated cropland	-0.0105	-	511,165	511,165/T= 0.7517

T=168,841+511,165 = 680,006

Emission factor = (-0.0302*0.2483)+(-0.0105*0.7517) = -0.0154 Mg CO_2 e/ac/yr

Table 3.8- Emission Reduction Factor for Conservation Practice 590 in Texas County by Replacing Nitrogen Fertilizer with Livestock Manure

Practice options (PO)	**Emission Reduction Factor**	**Assumed weight of per animal**	**Livestock inventory**	**Acres of cropland**	**Weight assigned to PO**
Replace N with beef feedlot manure on irrigated cropland	0.1231	900	179,716	168,841 (irrigated)	(900*179,716*168,841)/ T = A
Replace N with beef feedlot manure on non-irrigated cropland	0.1096	900	179,716	511,165 (non-irrigated)	(900*179,716*511,165)/ T = B
Replace N with chicken broiler manure on irrigated cropland	0.0015	3.5	40	168,841 (irrigated)	(3.5*40*168,841)/ T= C
Replace N with chicken broiler manure on non-irrigated cropland	0.0328	3.5	40	511,165 (non-irrigated)	(3.5*40*511,165)/ T= D
Replace N with chicken layer manure on irrigated cropland	0.0016	3.5	1,291	168,841 (irrigated)	(3.5*1,291*168,841)/ T= E
Replace N with chicken layer manure on non-irrigated cropland	0.0328	3.5	1,291	511,165 (non-irrigated)	(3.5*1,291*511,165)/ T= F
Replace N with dairy manure on irrigated cropland	0.1231	1,000	0	168,841 (irrigated)	(1000*0*168,841)/ T = G
Replace N with dairy manure on non-irrigated cropland	0.1096	1,000	0	511,165 (non-irrigated)	(1000*0*511,165)/ T= H
Replace N with sheep manure on irrigated cropland	0.1231	75	276	168,841 (irrigated)	(75*276*168,841)/ T = I
Replace N with sheep manure on non-irrigated cropland	0.1096	75	276	511,165 (non-irrigated)	(75*276*511,165)/ T= J
Replace N with swine manure on irrigated cropland	0.3373	200	1,094,877	168,841 (irrigated)	(200*1,094,877*168,841)/ T= K
Replace N with swine manure on non-irrigated cropland	0.2660	200	1,094,877	511,165 (non-irrigated)	(200*1,094,877*511,165)/ T= L

T= (900*179,716*168,841)+ (900*179,716*511,165)+ (3.5*40*168,841)+ (3.5*40*511,165)+ (3.5*1,291*168,841)+ (3.5*1,291*511,165)+ (1000*0*168,841)+ (1000*0*511,165)+ (75*276*168,841)+ (75*276*511,165)+ (200*1,094,877*168,841)+ (200*1,094,877*511,165) =258,908,992,250,951

Emission factor = (0.1231*A)+(0.1096*B)+(0.0015*C)+(0.0328*D)+(0.0016*E)+(0.0328*F)+(0.1231*G)+(0.1096*H)+ (0.1231*I)+(0.1096*J)+(0.3373*K)+(0.2660*L) = 0.21115 Mg CO_2 e/ac/yr

To compute the total contribution of NRCS conservation practices to climate change mitigation, the number of acres enrolled in each practice from the enrollment data is multiplied by its corresponding ERF from the Comet-Planner model. This is performed on a county-level basis and then aggregated to identify total greenhouse gas reductions for all three states. Thus, if c denotes a county, p a conservation practice, $A_{c,p,t}$ refers to total acres enrolled in practice p for county c in year t, and $\mathrm{ERF}_{c,p}$ is the emission reduction factor for that county and conservation practice, then the total reductions in GHGs for any one year for practice p is computed as;

$$GHG\ Reduction_{p,t} = \sum_c \left(ERF_{c,p,t}\right)\left(A_{c,p,t}\right) \tag{3.3}$$

The total reductions in GHGs for any one year for all practice combination are computed as;

$$GHG\ Reduction_{t} = \sum_c \sum_p \left(ERF_{c,p,t}\right)\left(A_{c,p,t}\right) \tag{3.4}$$

The total GHG reduction for each year is a single value stemming from a deterministic model. The only statistical variation is in the $A_{c,p,t}$ values across years. Given there are only six years in the data, conducting statistical tests of yearly emission reductions is difficult. The Comet-Planner model does have additional data that can be used to partially account for the stochastic nature of actual emission reductions. For most practices and practice-options, the model also has a standard error for the ERF. The model documentation does not describe exactly how this standard error is calculated, but since the ERF is reported as an average of ERFs from various sources it is presumed this standard error is a standard deviation of those sources.

It is not necessarily a true standard error though, as it does not account for possible correlations of emission reductions from different sources. For example, the model estimates the total ERF based on the emission reductions from soil carbon sequestration and nitrous oxide separately, and the standard error are for each separately, and the total standard error is just the sum of the two assuming a zero correlation. Though these standard errors have weaknesses they can still be useful in calculating the extent to which a change in total emissions reductions between years could be caused by randomness and not actual changes in land use practices. However, the use of these standard errors is being explored in a separate research project and is not considered here.

Although the limited number of years of data makes statistical testing challenging, some statistical inference is attempted. The total emissions from any one practice can be stated as the sum of the county-level emissions. With 77, 105, and 254 counties in Oklahoma, Kansas, and Texas respectively, total emission reductions from a practice is the sum of 436 county-level reductions. Variations in county-level reductions can be modeled as

$$GHG\ Reduction_{p,t} = GHG\ Reduction_{p,t} + e_{p,c,t} \quad (3.5)$$

where t denotes the year and c denotes the county. The value of $GHG\ Reduction_t$ can be seen as the mean or median county-level emissions and $e_{p,c,t}$ is the stochastic component influenced by changes in practice enrollment. Of course, this is not a true standard error as its deterministic structure is known, but it provides data that can be used in a statistical test to help determine how total emissions are changing over time.

This study uses the Kruskal-Wallis H test to determine if the median county-level emissions for each practice changes across the years. The Kruskal-Wallis test is similar to the Mann–Whitney–Wilcoxon test non-parametric test, but is more robust and can test for statistical differences across k groups, as opposed to only two groups (Kossaï and Piget, 2014). The test compares the median difference for two or more independent groups with sample sizes that are not equal across comparison groups (Lin and Zhang, 2020). Kruskal-Wallis tests do not assume population normality, nor homogeneity of variance. Hence, the test is appropriate to be used when violations of population normality and/or homogeneity of variance are extreme (Figure

3.1). It is also less sensitive to outliers. Our data for GHG emissions reductions and conservation enrollment does not follow a normal distribution and has outliers, so the Kruskal-Wallis test is appropriate for comparison of medians across the years (Figure 3.1).[3]

Consider comparisons of practice 590—Nutrient Management between the years 2019 and 2020. This involves comparing the 436 county-level reductions for 2019 and 2020 to determine if the average for 2020 is higher. The test is performed by first placing the 436 county-level reductions for both years into a vector containing 436*2 = 872 observations. A concomitant index vector is created detailing the year to which the reductions belong, and the two vectors are combined to form an 872*2 matrix. The first column signifies the actual reductions for the county and the second column identifies whether the reductions occurred in 2019 or 2020.

The matrix is then sorted in ascending order according to the value of the first column (the county level reductions) and ranks are assigned where 1 = lowest reductions and 872 = highest reductions. Then, for each year, the sum of the ranks are calculated. There is one number indicating the sum of the ranks for the 436 counties in 2019 and another number for the 436 counties in 2020. Let R_{2019} and R_{2020} be the sums for 2019 and 2020, respectively. The Kruskal-Wallis H test statistic is then as follows:

$$\mathrm{KW}-\mathrm{H}=\frac{12}{436*2\times(436*2+1)}\times\left(\sum_{t=2019}^{2020}\frac{R_t^2}{436}\right)-3\times(436*2+1) \qquad (3.6)$$

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[3] A hanging rootogram ((HR) was used to depict the empirical distribution. HR is a type of histogram where the horizontal *x*-axis is slightly elevated and the vertical *y*-axis depicts the square root of frequencies using bars that "hang" downward from a curve showing the expected normal distribution. Hanging rootograms allowed us to see how well GHG emission reductions and conservation enrollment fits an expected normal distribution. Our distribution is positively skewed and indicates how the hanging histogram bars dropped below the elevated horizontal axis.

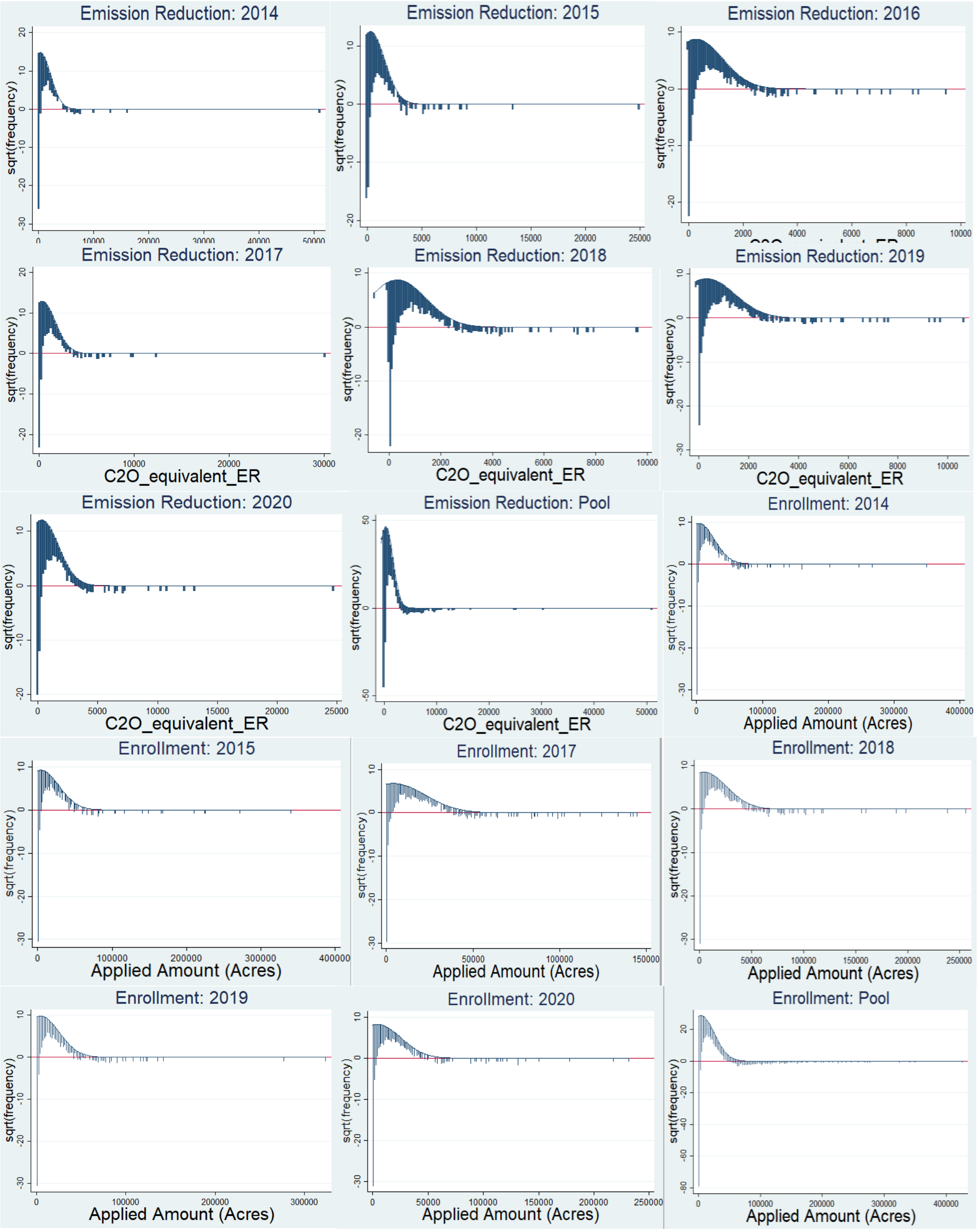

Figure 3. 1-Hanging Rootograms Displaying the Empirical Distribution of GHG Emission Reductions and Conservation Enrollment across Years to the Theoretical Normal Distribution

The general form of the test statistic according to Tufféry (2011) is

$$KW - H = \frac{12}{N \times (N+1)} \times \left(\sum_{i=1}^{K} \frac{R_i^2}{n_i}\right) - 3 \times (N+1) \qquad (3.7)$$

where K is the number of different groups in the data, n_i is the sample size of each group (436 for both years), N is the sum of the n_i's and R_i is the sum of the ranks of the observations of the group i. There can be more than two groups, so the test can compare the median reductions for the seven years (K= 2014 to 2020).

The test-statistic is distributed according to a chi-square distribution (χ^2) with (K-1) degrees of freedom. In our case we have six degrees of freedom since we are interested in comparing the difference in GHG emission reduction among the seven years. The test statistic is repeated on the conservation program enrollment across the years for each practice as well as the pooled data. For changes in conservation program enrollment, the aim is to test the null and alternate hypothesis which is defined as:

H_0 : No difference in the median enrollment in conservation programs across the years 2014 to 2020.

H_1 : The median enrollment in conservation programs differs across the years 2014 to 2020.

The null hypothesis is rejected if the P-value $\leq \alpha$ (significance levels: 0.01, 0.05 and 0.1) and conclude that the median enrollment in conservation programs differs across the years. For changes in GHG emission reductions, the aim is to test the null and alternate hypothesis which is defined as;

H_0 : No difference in the median of GHG emission reductions in conservation programs across the years 2014 to 2020.

H_1 : The median of GHG emission reductions in conservation programs differs across the years 2014 to 2020.

We reject the null hypothesis if the P-value $\leq \alpha$ (significance levels: 0.01, 0.05 and 0.1) and conclude that the median of GHG emission reductions in conservation programs differs across the years.

Significance in the median difference of GHG emission reduction across all years alone is not as interesting as whether any two indicator years are statistically different from each other. Also, the question of whether GHG emission reductions have fallen or risen over specific time period is important in analyzing the trends in the sequestration of GHGs over the years. The Dunn's test was used to conduct multiple pairwise comparisons for median difference upon rejection of the null hypothesis in the Kruskal-Wallis test. Dunn's test is regarded as the appropriate nonparametric pairwise multiple comparison procedure in statistical analysis following Kruskal-Wallis test (Dmitrienko, 2007). The test performs $m = K(K-1)/2$ multiple comparisons using the z-test statistics for each practice that is deemed statistically different in the Kruskal-Wallis test. In this study, we have a total of 21 pairwise statistical test for each practice. Following (Dinno, 2015), the Dunn's z-test uses mean rankings of the outcome in each group from the preceding Kruskal-Wallis test which is given as:

$$\bar{R}_i = R_i / n_i \tag{3.8}$$

where R_i is the sum of ranks, and n_i is the sample size for the *i*th group and basing inference on the differences in mean ranks in each group. For GHG emission reductions or conservation enrollment comparisons between two years, for example, between 2017 and 2019, we calculate z_i as:

$$z_i = y_i / \sigma_i \tag{3.9}$$

where *i* is one of the 1 to m multiple comparisons, $y_i = \bar{R}_{2017} - \bar{R}_{2019}$ and σ_i is the standard deviation of y_i, given as:

$$\sigma_i = \sqrt{\left\{\frac{N(N+1)}{12} - \frac{\sum_{s=1}^{r} \tau_s^3 - \tau_s}{12(N-1)}\right\}\left(\frac{1}{n_{2017}} + \frac{1}{n_{2019}}\right)} \tag{3.10}$$

where N is the total number of observations across all groups, r is the number of tied ranks, and τ_s is the number of observations tied at the sth specific tied value. In situations where there are no ties, the term with the summation in the numerator equals zero which simplifies the calculation considerably. For GHG emission reductions or conservation enrollment comparisons between two years like 2017 and 2019, the aim is to test the null and alternate hypothesis which is defined as;

H_0 : No difference between 2017 and 2019

H_1 : Difference exists between 2017 and 2019

We reject the null hypothesis if the P-value $\leq \alpha$ (significance levels: 0.01, 0.05 and 0.1) and conclude that difference exists between 2017 and 2019.

CHAPTER IV

RESULTS AND DISCUSSION

Enrollment for Conservation Programs

Table 4.1 provides data on total enrollment in each conservation practice for 2014 – 2020 in the southern plains. Conservation practice 528-Prescribed Grazing contributes more than 75% of total enrollment for each year—more than all the other practices combined. However, from 2014 to 2020 the number of acres in 528 fluctuated with nearly 2% overall change. This change is insignificant as Kruskal-Wallis tests indicate no statistical difference across the years. That is, enrollment increased by 10% from 2014 to 2018 and later decreased by 7% in 2020.

The second largest enrollment is practice 328—Conservation Crop Rotation. Enrollment in this practice behaved the same way as practice 528 except for a sharp decline in enrollment after the 2018 Farm Bill. From 2014 to 2015, enrollment increased by 3%, followed by a 16% decrease in 2016. After an increase of 33% in 2018, the number of acres dropped dramatically in2020 by 42% which the Dunn test depicts as highly significant at 1% level[4]. Conversely, some practices saw large increases after the 2018 Farm Bill, including 590—Nutrient Management and 340—Seasonal Cover Crops, which is no surprise as the Kruskal-Wallis test indicates a statistically significant difference across the years. Practice 340 is the only practice that experienced increases every year with a statistically significant difference in enrollment at 1%

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[4] Dunn’s test results for multiple pairwise comparisons for median difference can be found in appendix; Table A2 and Table A3

Table 4.1- Total Acres Enrolled in Conservation Practices in the Southern Plains

Conservation practice name	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**KW-H value**
327-Permanent cover crops	107,495	82,537	55,568	126,086	94,416	186,038	250,718	60***
328-Conservation crop rotation	747,777	772,176	642,442	747,668	855,604	685,240	492,424	18***
329-Conventional to no-Till	441,149	331,957	279,643	242,922	257,152	226,498	232,117	6.95^{ns}
332-Contour buffer strips	11	2	-	7	2	10	-	4.14^{ns}
340-Seasonal cover crops	83,378	93,915	95,676	107,176	201,662	203,249	348,480	51***
342-Critical area planting	2,160	1,553	1,418	1,655	1,798	1,357	1,556	3.43^{ns}
345-Conventional to reduced tillage	234,406	350,131	343,087	372,972	455,369	457,209	300,590	8^{ns}
380-Windbreak	42	39	19	24	32	32	20	6^{ns}
381-Silvopasture on grasslands	23	22	30	-	-	-	-	2.025^{ns}
386-Field border	63	123	101	279	149	220	60	7.19^{ns}
390-Riparian herbaceous cover	-	12	153	6	178	140	-	3.14^{ns}
391-Riparian forest buffer	686	588	887	684	449	609	487	7.81^{ns}
393-Filter strip	52	176	58	83	23	55	19	7.45^{ns}
412-Grassed waterway	1,685	1,448	1,074	1,330	1,444	759	1,137	14.07**
422-Hedgerow planting	-	-	-	-	-	0.1	-	NA
484-mulching	142	170	82	47	73	43	47	4.78^{ns}
512-Forage and biomass planting	39,317	47,669	69,431	67,103	59,223	71,807	67,863	16.04**
528-Prescribed grazing	6,509,189	7,050,319	6,213,953	6,325,406	7,144,637	6,980,160	6,631,722	4^{ns}
550-Range planting	42,729	41,587	35,631	47,576	40,245	53,684	40,628	8^{ns}
590-Nutrient management	226,197	137,102	155,531	110,890	255,393	304,801	377,189	48***
612-Tree and shrub establishment	19,047	15,513	10,667	11,047	9,407	9,365	12,549	13**
650-Windbreak renovation	75	73	73	33	33	29	23	2^{ns}
Total	8,455,623	8,927,113	7,905,522	8,162,994	9,377,289	9,181,306	8,757,629	3.79^{ns}

Note(s): *** Indicates significance at the 1% level, ** at the 5% level and ^{ns} indicates not significant. KW indicates Kruskal-Wallis level. Its percentage increases are 11%, 2%, 12%, 88%, 0.8% and 71% from 2014 to 2020, respectively. For 590—Nutrient Management, enrollment increased by 48% after the 2018 Farm Bill with a significant difference between 2018 and 2020 as shown by the Dunn test and vacillated between 2014 and 2018 where acres enrolled were the same on average.

As a percentage change between 2014 and 2020, practice 340 also experienced the largest change of 318%, with the second largest percentage increase of 133% going to 327—Permanent Cover Crops. The third largest percentage of 73% was recorded by 512-Forage and Biomass Planting. This was followed by 590—Nutrient Management with an enrollment increase of 67%. Interestingly, the Dunn test between the years 2014 and 2020 for all the four conservation practices recorded a significant increase at 1% level. A few practices experienced considerable decreases in enrollment over this time period, including 328—Conservation Crop Rotation and 329—Conventional to No-Till. That is a decrease of 34% and 47% for practice 328 and 329 correspondingly. Other practices combined also experienced a reduction in enrollment of 15%.

Emission Reduction of Greenhouse Gases from Conservation Programs

To determine how changes in enrollment of conservation programs affect greenhouse gas emissions, it is worth understanding the relative contribution of ERF for each practice. Figure 4.1 provides emission reduction factors for each practice across all regions. These are not emission reduction factors exclusively used in the calculations of the results but are instead provided as an illustration of how the practices vary and reduce GHG emissions. Each factor is calculated as a weighted average of the county specific ERF, with the weights being the acres enrolled in the practice across all years. The highest ERFs go to practices involved with the planting of trees and shrubs. That is 422-Hedgerow Planting, 381-Silvopasture on Grasslands and 612- Tree and Shrub Establishment as the three major practices.

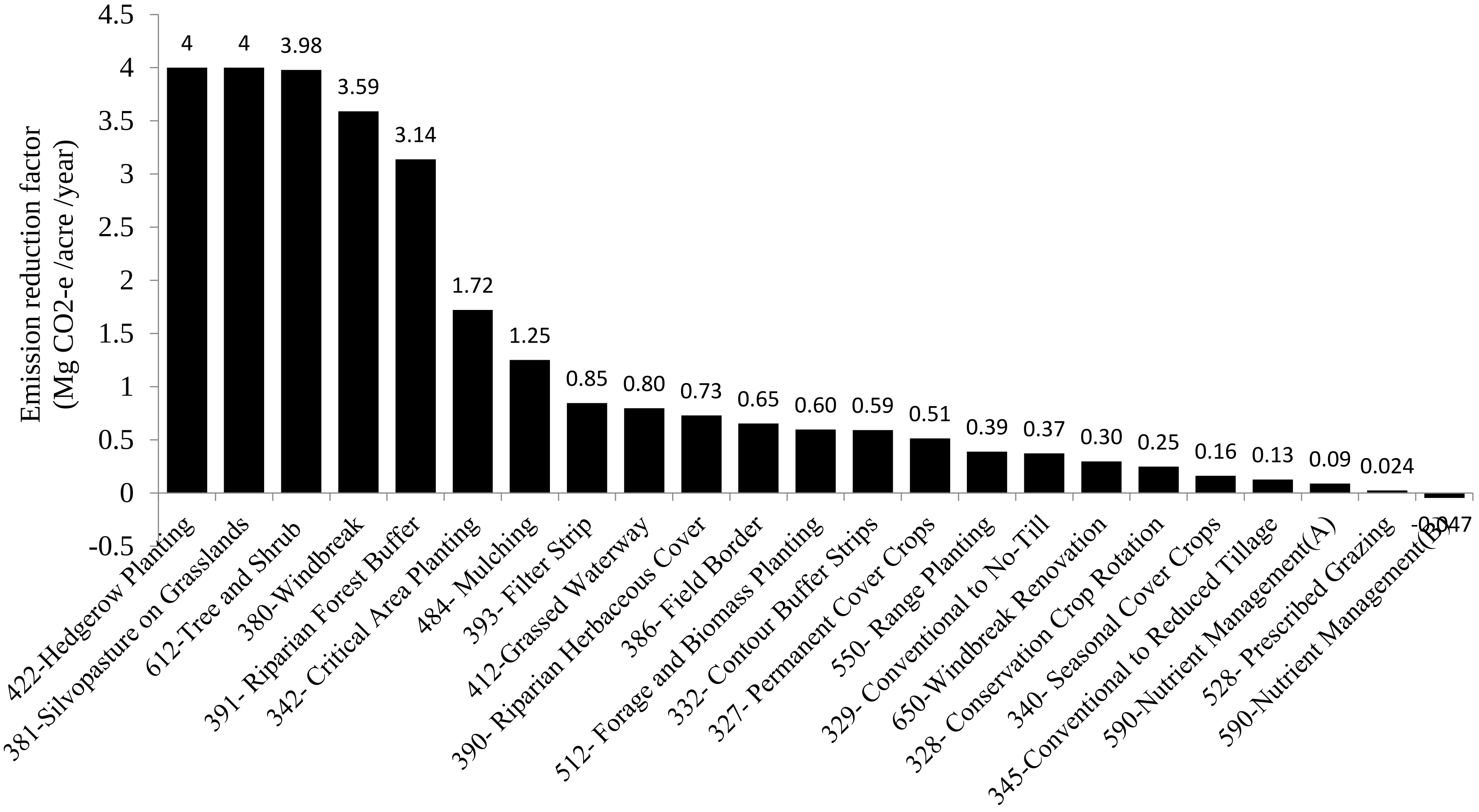

Figure 4. 1-Emission Reduction Factors by Practice for Kansas, Oklahoma, and Texas

Note: This indicates how Emission Reduction Factors vary by practice and not exclusively the values used in the results.

Notice that practice 590—Nutrient Management appears twice. Option set B (‘590 Nutrient Management—B’) assumes landowners implementing this practice all choose to reduce their applications of synthetic nitrogen, while option set A assumes they replace synthetic nitrogen fertilizer with livestock manure. When reporting total emission reductions, only one option is assumed. Practices taking land out of production and placing it in permanent herbaceous plants have higher ERFs than those where land remains in production. For example, placing an acre in permanent cover crops has an ERF of 0.5 relative to the use of seasonal cover crops, whose ERF is 0.16. Many practices with high ERFs will likely have low total acres of enrollment. Establishing a wind break or a riparian buffer consumes only a small part of a field, whereas converting from conventional to no-till agriculture may have a smaller ERF but involves the transition of entire fields.

With this understanding about the ERF’s for individual practices, it can be concluded that changes in enrollment do not automatically imply a specific change in total emission reductions. But total emission reductions depends on the type of conservation practice and where those practices take place. This stands to reason that a higher enrollment in a particular practice does not necessarily lead to greater total sequestration. For example, practice 590—Nutrient Management experienced large increases in enrollment, but if this was accompanied by a shift towards reducing synthetic nitrogen and away from replacing synthetic fertilizer with livestock manure, emissions could have risen. Though enrollment in 329— Conventional to No-Till fell by almost 50%, if new enrolled acres are located in counties with higher ERFs the concomitant reduction in emissions may be considerably less than 50%. Similarly, 528— prescribed grazing in Oklahoma has the highest ERF values located in the Southeast, and East-central region as indicated in Figure 4.2. In 2020, more than 60% of the counties with the highest

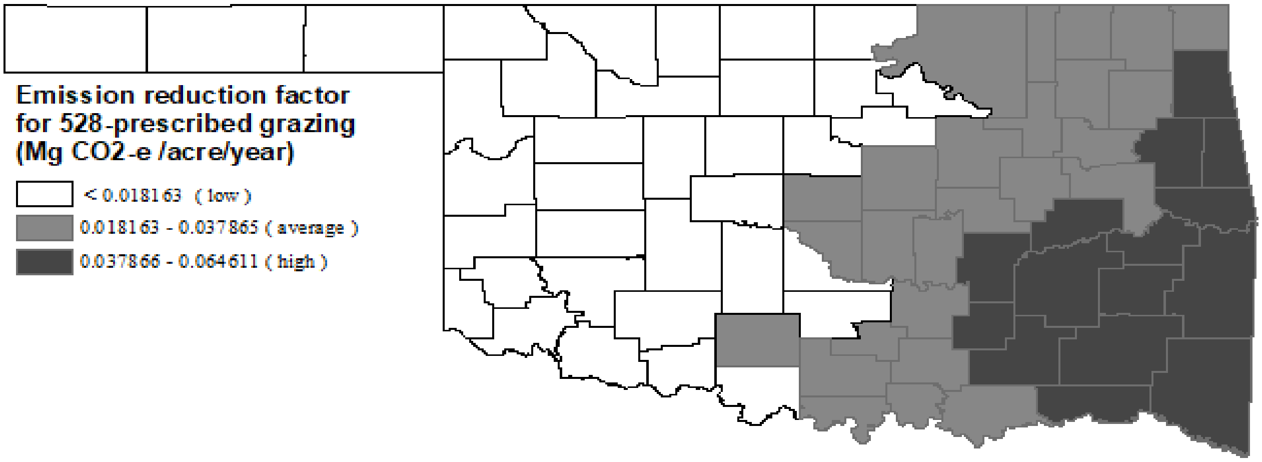

Figure 4. 2-Emission Reduction Factors for Practice 528-Prescribed Grazing in Oklahoma

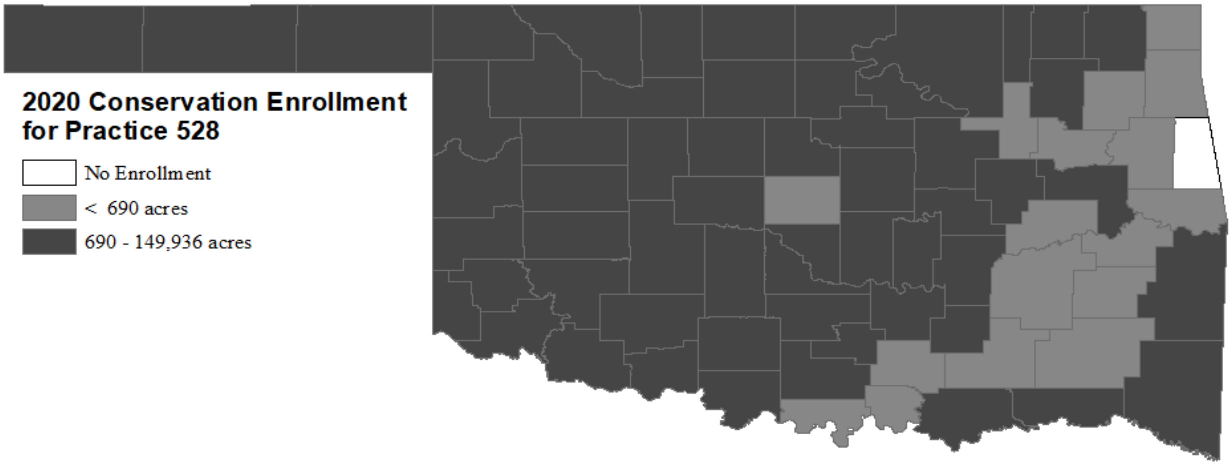

Figure 4. 3-2020 Conservation Enrollment for Practice 528-Prescribed Grazing in Oklahoma

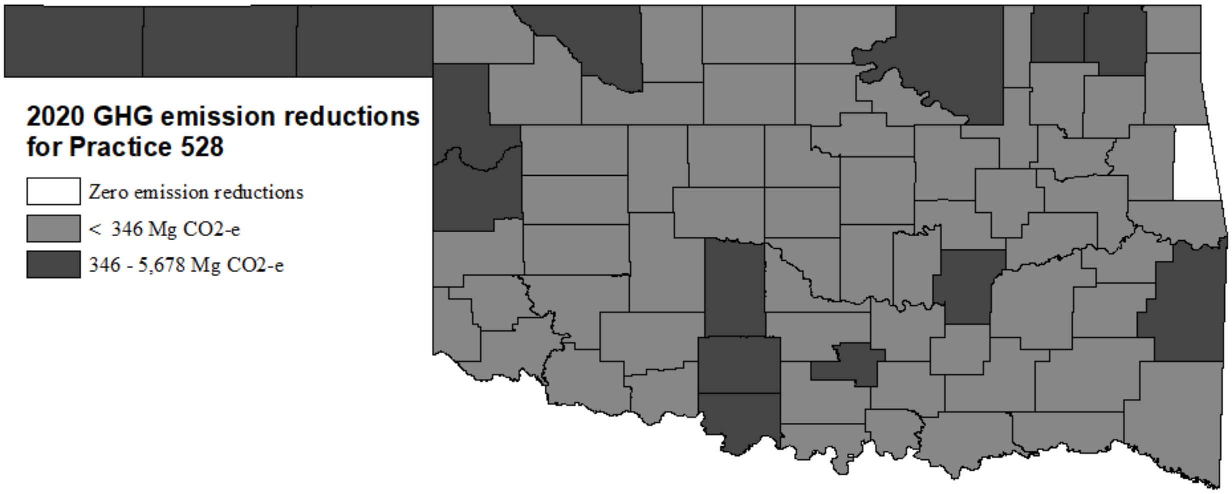

Figure 4. 4-2020 Total GHG Emission Reductions for Practice 528-Prescribed Grazing in Oklahoma

enrollment (Figure 4.3) were in areas with lower ERF. The corresponding total GHG emission reductions (Figure 4.4) involves more than 70% of counties with total GHG emission reductions in the average range.

Table 4.2 shows the exact total emission reductions numbers for each conservation practice over the years. Figure 4.5 also provides better illustration of how total emission reductions changed for the years 2014-2020, concentrating on the practices that exhibit a combination of variation over the years and significant emission reductions. The results suggest emission reductions initially fell 18% between 2014 and 2016; by 2019-2020 it returned to its approximate 2014 level. This was evident by the Kruskal-Wallis test which suggests no statistically significant difference in GHG emissions across the seven years for the pool data. However, there are some practices that proved significant across the years. Now the discussion is what led to these changes and what impact did the changes in enrollment had on emission reductions in relation to each practice?

Practice 328- Conservation Crop Rotation, even though it is relatively not considered as the practice with the highest enrollment dominated in GHG emission reduction for all the years except for 2020 where it became second in dominance. Moreover, its' GHG emission reductions was statistically significant across the years from the Kruskal Wallis test. For practice 528-Prescribed Grazing, its enrollment is more than 75% of total enrollment and 86% greater than that of practice 328 on average for all years. However, total emission reductions for 528 is 37% less than that of 328 on average for all years. This can be attributed to the fact that the ERF for 328 is higher than that of 528. Hence an increase in enrollment by a small margin for 328 might increase its total emission reduction more than a large enrollment increase in 528. Unlike 328, more enrollments are needed from 528 to increase its total emission reduction by a small

Table 4.2-Greenhouse Gas Emission Reductions from Conservation Practices (megagrams of CO2-e)

Conservation Practice Name	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**KW-H value**
327- Permanent cover crops	54,629	41,676	27,347	51,444	47,020	97,068	128,814	59***
328- Conservation crop rotation	183,916	191,418	160,350	185,041	215,884	171,186	125,304	18***
329- Conventional to No-Till	170,543	129,282	109,435	93,142	99,938	87,829	89,222	7^{ns}
332- Contour buffer strips	7	2	-	4	1	4	-	4.14^{ns}
340- Seasonal cover crops	12,311	14,053	14,229	18,840	32,093	35,608	55,069	51***
342- Critical area planting	3,786	2,634	2,342	2,733	3,036	2,070	2,593	5^{ns}
345-Conventional to Reduced Tillage	34,099	49,607	47,789	52,747	56,339	61,078	38,425	5.1^{ns}
380- Windbreak	151	140	68	86	114	116	71	6.37^{ns}
381-Silvopasture on Grasslands	91	89	119	-	-	-	-	2.25^{ns}
386- Field border	39	74	58	199	97	132	41	8.2^{ns}
390- Riparian herbaceous cover	-	10	44	4	133	110	-	1.76^{ns}
391- Riparian forest buffer	2,652	1,642	3,303	2,558	944	1,304	1,798	7.2^{ns}
393- Filter strip	43	158	48	69	20	47	16	9.35^{ns}
412-Grassed waterway	1,333	1,046	845	1,027	1,158	594	888	15.96**
422-Hedgerow planting	-	-	-	-	-	0.3	-	NA
484- Mulching	163	322	104	65	80	70	48	3.45^{ns}
512- Forage and Biomass Planting	25,965	28,552	41,955	39,455	35,476	40,912	39,359	15.32**
528- Prescribed grazing	99,136	105,508	100,594	104,570	120,143	118,662	105,420	4.74^{ns}
550- Range planting	15,796	15,074	13,281	17,683	14,924	19,445	15,160	8.4^{ns}
590-Nutrient management (a)	23,652	15,058	14,541	9,412	29,481	36,922	44,367	54***
590-Nutrient management (b)	(7,146)	(4,750)	(5,947)	(3,706)	(10,422)	(9,584)	(13,382)	36***
612- Tree and shrub establishment	75,979	62,003	42,622	44,101	37,574	37,447	50,150	13**
650-Windbreak renovation	22	23	24	9	9	7	8	3.5^{ns}
Total (A)	704,312	658,369	579,138	623,188	694,465	710,612	696,753	2.313^{ns}
Total (B)	673,513	638,562	558,649	610,070	654,562	664,107	639,004	10.38^{ns}

Note(s): *** Indicates significance at the 1% level, ** at the 5% level, * at the 10% level and ^{ns} indicates not significant. KW indicates Kruskal-Wallis. 590-Nutrient Management (A) indicates replacing nitrogen fertilizer with Livestock manure. 590-Nutrient Management (B) indicates reducing nitrogen fertilizer.

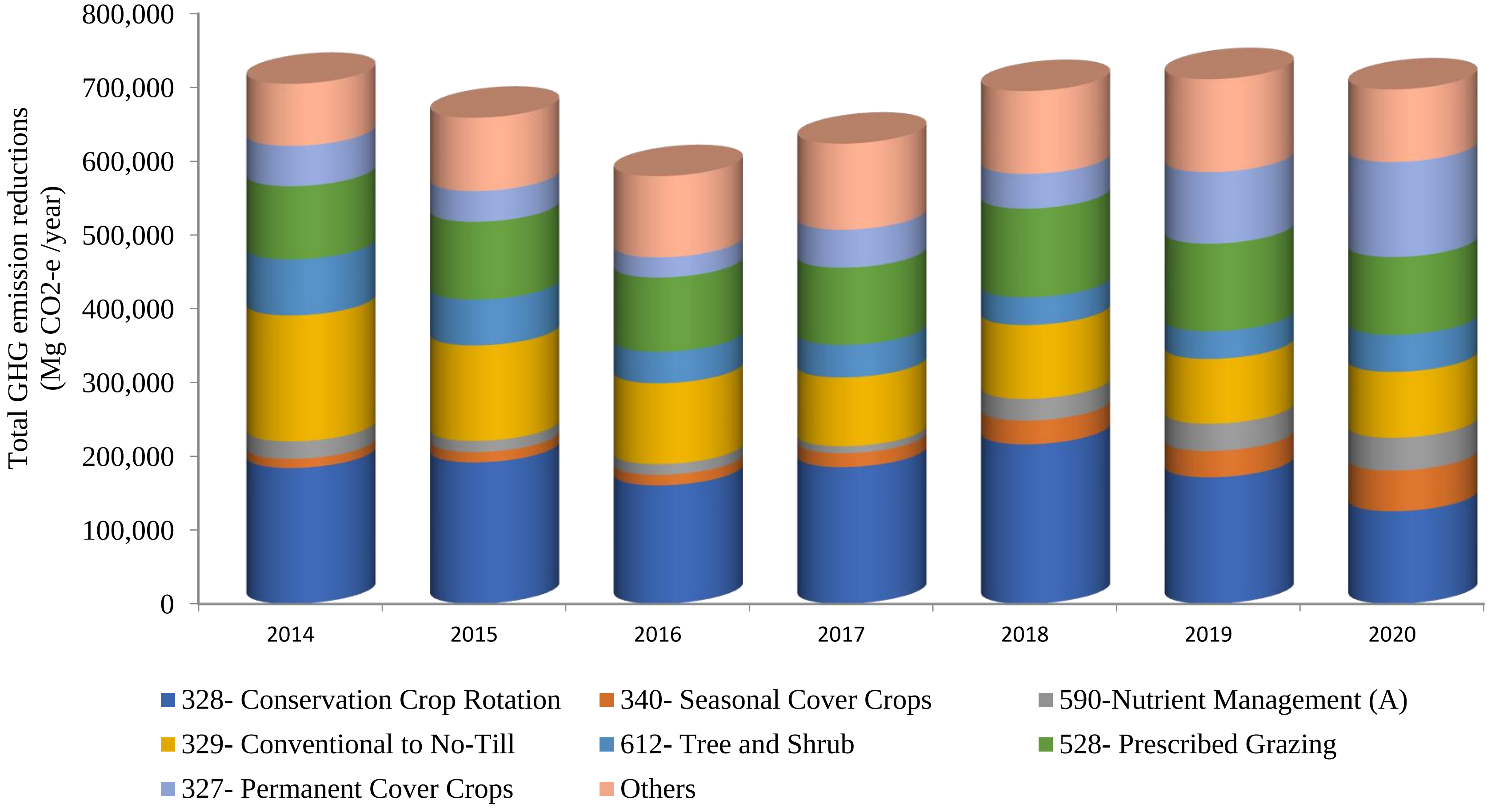

Figure 4. 5-Emission Reductions from Conservation Practices from 2014-2020

Note: The "Others" category includes practices 550, 332, 342, 345, 380, 512, 381, 386, 390, 391, 393, 412, 422, 484, and 650 percentage. Thus, considering the fluctuations in total emission reductions across the years, it is suggested that increasing total enrollment for practices that have higher ERF and also under counties that have relatively higher ERFs will be necessary to serve the purpose of agriculture contributing to GHG emission reductions provided its marginal cost will be relatively low.

For an illustration of how GHG reductions have changed over time for each practice, see Figure 4.6. By far, 327—Permanent Cover Crops has experienced the greatest increase in sequestration over the 2014-2020 period. It recorded a 135% increase in emission reductions with a statistical significance difference of 1% across all years. Between groups, the practice

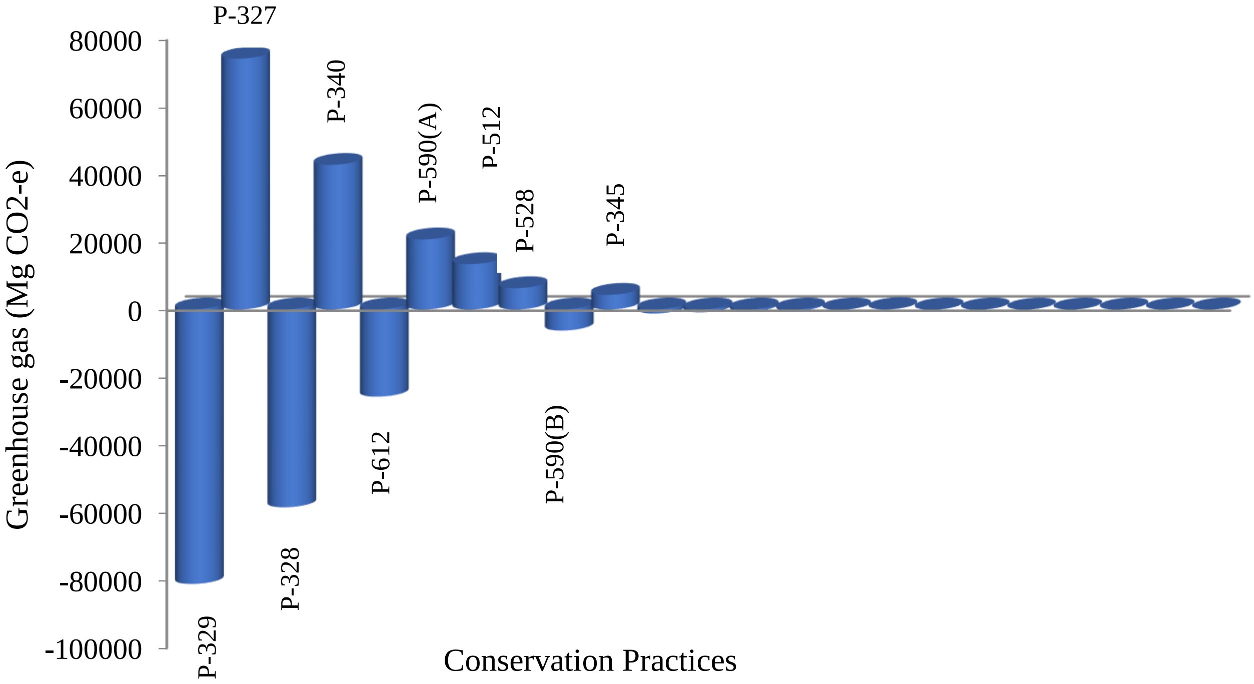

Figure 4. 6-How GHG Emission Reductions Have Changed over Time by Practice

Notes: 590—Nutrient Management (A) assumes all landowners replace synthetic fertilizer with livestock manure, while Nutrient Management (B) assumes all landowners reduce synthetic nitrogen applications by 15%.

recorded a statistically significant increase of 150% from 2017 to 2020. This is due to its large increase in acres enrolled plus its moderate ERF. While 329—Conventional to No-Till is still reducing GHG emissions, the amount of this reduction is falling over time due to lower enrollments. This might be due that as more conventional producers switch to no-till production methods there are fewer conventional farmers available to make the switch. If acres enrolled in 329 remained steady over many years this would likely signify that farmers are switching back and forth from conventional to no-till and in the process are continually increasing GHGs in some years and reducing them in others. It is thus perhaps a good thing that acres enrolled and GHG reductions from 329 are falling over time.

Establishing practice 340-seasonal cover crops reduces increasing amounts of GHGs with a statistically significant difference of 1% across all years. This increment in sequestration can partly be attributed to its moderate ERF and increasing enrollment over time. Employing conservation crop rotations (328) are reducing less with 31% decline in emission reductions over the time period. Again this fall in emission reductions can mainly be attributed to its decline in enrollment since it has a moderate ERF which could increase its total sequestration when enrollment increases. What about practice 590—Nutrient Management? It depends on how the practice is implemented. If all landowners replace synthetic nitrogen with livestock manure the practice is reducing GHGs emissions over time, whereas if they are all instead reducing nitrogen applications by 15% the practice is increasing GHGs. The actual impact then depends on which option landowners employ.

Economic Implications of Greenhouse Gas Emissions Reductions

To appreciate the economic contribution of GHG emission reductions from USDA conservation programs, payments given to landowners to implement conservation practices can be compared to the social benefits of the GHGs they sequester. This is only a step in achieving a complete cost-benefit analysis, as it does not include the administrative costs of USDA. Nor does it account for the GHG emissions involved in implementing the practice. For example, planting seasonal cover crops requires extra fuel and seed, both of which have carbon footprints of their own.

The social cost of carbon reflects both the damage GHGs inflict and so also reflects the amount of money society should be willing to pay to avoid climate change by reducing emissions of GHGs (Backman, 2021). This social cost is typically stated in US dollars per megagrams of CO2-e avoided. The exact cost is difficult to estimate and is not without controversy, but at the time of this writing a global social cost of $51 (Backman, 2021) is typically used.

A Freedom of Information Act data request reveals the total payments given to landowners to implement the 18 different conservation practices in Oklahoma was $8,390,444 in 2020. This research finds the total GHG emission reductions directly attributable to these USDA conservation programs in Oklahoma in 2020 was 90,104 Mg CO2-e. Thus, using the $51 social cost per megagram of CO2-e, the total benefit from GHG emission reductions is $4,595,290. This leads to a net loss of $3,795,154. However, as mentioned previously, these conservation programs provide other major benefits (soil conservation, water-quality improvement) beside GHG emission reductions. On the other hand, the total emission reductions are overstated due to the omission of the carbon footprint from implementing the practices. As such, these calculations are just an initial step to better understanding of the full benefits and costs of conservation practices.

Other estimates of the global social cost of carbon are higher than $51 per megagram (Reuters, 2021). According to International Monetary Fund (IMF) (2022) and Reuters (2021), the G-20 group of large economies may set the global average price of carbon per Mg CO2-e significantly higher, between $75 and $100. This is essential to fund net zero emissions by 2050. Now, assuming the social cost of carbon is $100 per Mg CO2-e in U.S., then the total benefit from GHG emission reductions in Oklahoma is $9,010,373. The corresponding net benefit is now recorded at $619,929, which makes the GHG emission reductions from conservation programs more likely to pay for itself due to its contribution to mitigating climate change alone. Given that the cost of carbon is a measure of global costs, other costs of the programs are not included, and that some of the carbon benefits will be temporary, it is clear that these conservation programs cannot be justified to U.S. taxpayers based only on reductions in greenhouse gas emissions.

CHAPTER V

CONCLUSSION AND RECOMMENDATION

When considering the three states of Kansas, Oklahoma, and Texas in the Southern Plains Climate Hub, participation in NRCS conservation programs reduces greenhouse gas emissions by around 700,000 megagrams of CO2-e each year. The emission reductions change across years due to changes in enrollment in specific conservation practices and where those practices take place. In conclusion, conservation programs thus contribute to the fight against climate change, but by how much?

The typical passenger vehicle in the U.S. emits roughly 4.7 megagrams of CO2-e each year (EPA, 2014). Therefore, these conservation programs are the equivalent of removing almost 150,000 cars from the road. The average U.S. household is responsible for emitting approximately 51 megagrams, so the conservation programs are the equivalent of 14,000 households becoming carbon neutral (Jones and Kammen, 2011). A typical U.S. household switching from a diet consuming meat to a vegetarian diet will reduce their emissions by 2.233 megagrams. The conservation program in these three states alone is thus equivalent to 313,500 households adopting a vegetarian diet (Gagelman and Norwood, 2018). Nevertheless, it is unclear what role the 2018 Farm Bill played with respect to GHG emission reductions through enrollment in NRCS conservation programs. Emission reductions had already started to increase from the 2016 level, and 2019 – 2020 reductions are similar to their 2014 level. Besides, the

Kruskal-Wallis test results for both conservation enrollment and GHG emission reductions for the pooled sample indicates no statistically significant difference across the seven-year period. Yet, using a social cost of \$100 per Mg CO2-e in U.S., the study records a net benefit of \$619,929 from GHG emission reductions in Oklahoma.

Thus, given the important contribution from these practices in fighting against climate change, it is crucial to make recommendations which could make the impact of conservation practices be noticed in future policies. Before that, it is recommended that a detailed cost-benefit analysis be conducted on each conservation practice. This will provide policy makers an idea of the marginal cost and its associated marginal benefit for implementing a specific conservation practice provided that this research has computed effectively the GHG emission reductions contribution for each practice.

If policy makers wish to increase carbon sequestration by a large amount it might be beneficial to enact policies which will increase the enrollment for practices involving trees and shrubs establishment as well as silvopasture on grasslands. These are practices with higher ERFs but with lower enrollments. Besides, trees and shrubs are perennials that can live for decades and are difficult to remove. As such, it is likely that most of those trees/shrubs will remain on the land, continually sequestering carbon. The study recommends further studies on factors that influence producer’s decision to enroll in key conservation practices, where producer’s incentives at each Farm Bill period can be used as a key indicator.

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APPENDICES

Table A 1 - Reconciling Enrollment and Comet-Planner Data

Conservation Practice and number	**Practice Option**	**Reconciling enrollment data and Comet-Planner data**
327—Conservation cover	1. irrigated land; grass cover 2. irrigated land; grass/legume cover 3. non-irrigated land; grass cover 4. non-irrigated land; grass/legume cover	Weigh ERFs based on percent of county land in irrigation. Equal weights to grass and grass/legume cover
328—Conservation crop rotation	1. Decrease fallow frequency or add perennial crops to rotation	Only one option in Comet-Planner data, so no reconciliation necessary
329—Residue and tillage management	1. intensive till to no-till or strip-till on irrigated land 2. reduced tillage to no-till or strip-till on irrigated land 3. intensive till to no-till or strip-till on non-irrigated land 4. reduced tillage to no-till or strip-till on non-irrigated land	Weigh ERFs based on percent of county land in irrigation. Equal weights to intensive till and reduced tillage.
332—Contour buffer strips	1. irrigated land; grass cover 2. irrigated land; grass/legume cover	Weigh ERFs based on percent of county land in irrigation.

	3. non-irrigated land; grass cover 4. non-irrigated land; grass/legume cover	Equal weights to grass and grass/legume cover.
340—Seasonal cover crop	1. Legume cover crop with 50% reduced N on irrigated land 2. Non-legume cover crop with 25% reduced N on irrigated land 3. Legume cover crop with 50% reduced N on non-irrigated land 4. Non-legume cover crop with 25% reduced N on non-irrigated land	Weigh ERFs based on percent of county land in irrigation. Equal weights to grass and grass/legume cover.
342—Critical area planting	1. Plant permanent cover crop on highly disturbed area	Only one option, so no reconciliation necessary
345—Residue and tillage management	1. Intensive tillage to reduced tillage on irrigated land 2. Intensive tillage to reduced tillage on non-irrigated land	Weigh ERFs based on percent of county land in irrigation.
380—Windbreak	1. Replace a strip of cropland with 1 row of woody plants 2. Replace a strip of cropland with 3 or more rows of woody plants 3. Replace a strip of grassland with 1 row of woody plants 4. Replace a strip of grassland with 3 or more rows of woody plants	Weigh all options equally
381—Silvopasture	Establish areas with both grass and trees together for	Only one option, so no reconciliation

establishment on grasslands	grazing, on unfertilized land.	necessary
386—Field border	1. Convert strips of irrigated cropland to grass cover 2. Convert strips of irrigated cropland to grass/legume cover 3. Convert strips of non-irrigated cropland to grass cover 4. Convert strips of non-irrigated cropland to grass/legume cover	Weigh ERFs based on percent of county land in irrigation. Equal weights to grass and grass/legume cover.
390—Riparian herbaceous cover	1. Convert strips of irrigated cropland to grass cover near aquatic habitat 2. Convert strips of irrigated cropland to grass/legume cover near aquatic habitat 3. Convert strips of non-irrigated cropland to grass cover near aquatic habitat 4. Convert strips of non-irrigated cropland to grass/legume cover near aquatic habitat	Weigh ERFs based on percent of county land in irrigation. Equal weights to grass and grass/legume cover.
391—Riparian forest buffer establishment	1. Convert strips of cropland to woody plants near aquatic habitat 2. Convert strips of grassland to woody plants near aquatic habitat	Weigh ERFs based on percent of county land in cropland and percent in grassland, where grassland and pasture are considered the same.
393—Filter strip	Same options as 390 except not near aquatic habitat but anywhere in field	Weigh all options equally

412—Grassed waterway	1. Convert strips of irrigated cropland to grass cover 2. Convert strips of irrigated cropland to grass/legume cover 3. Convert strips of non-irrigated cropland to grass cover 4. Convert strips of non-irrigated cropland to grass/legume	Weigh all options equally
	Cover	
422—Hedgerow	1. Replace a strip of cropland with 1 row of woody plants 2. Replace a strip of grassland with 1 row of woody plants	Weight by percent of land in cropland and percent in grassland/pasture
484—Mulching	1. Add mulch to cropland	Only one option, so no reconciliation necessary
528—Prescribed grazing	1. Grazing management to improve irrigated pasture 2. Grazing management to improve rangeland or non-irrigated pasture	Assume only option 2 is used
550—Range planting	Seeding forages to improve rangeland	Only one option, no reconciliation needed
612—Convert managed land to woodlot	1. Replace annual cropland with unfertilized woody plants 2. Replace grasslands with unfertilized woody plants	Weight by percent of land in cropland and percent in grassland/pasture
650—Renovate windbreak/shelterbreak	Replace woody plants in an existing windbread/shelterbreak	Only one option, so no reconciliation necessary
590—Nutrient	1. Reduce N 15% on irrigated land	Weigh option ERFs according to (1) percent of irrigated land in county (2)

management	2. Reduce N 15% on non-irrigated land *Each option below has four ERFs that changes according to whether it is irrigated and whether it is pasture or cropland* 3. Replace N with beef feedlot manure 4. Replace N with broiler manure 5. Replace N with layer manure 6. Replace N with sheep manure 7. Replace N with dairy manure 8. Replace N with swine manure 9. Replace N with compost (different carbon-nitrogen ratios have different ERFs)	percent of each livestock type in each county and (3) percent of pasture or cropland in each county. Assign zero weight to compost applications. Two estimates are conducted. a. Assumes all landowners adopt options 1 or 2. b. Assumes all landowners adopt 3 – 8.

Table A 2 - Multiple-Comparison z-Value Test (Dunn's Test) of Conservation Enrollment across Years

Conservation Practice Name		**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
327- Permanent Cover Crops	2015	-0.20^{ns}					
	2016	0.34^{ns}	0.54^{ns}				
	2017	1.53*	1.71**	1.15^{ns}			
	2018	4.43***	4.57***	3.87***	2.57^{ns}		
	2019	4.79***	4.92***	4.18***	2.81^{ns}	0.13^{ns}	
	2020	4.29***	4.44***	3.70***	2.33**	-0.49^{ns}	0.67^{ns}
328- Conservation Crop Rotation	2015	-0.45^{ns}					
	2016	0.49^{ns}	0.90^{ns}				
	2017	-0.14^{ns}	0.38^{ns}	-0.61^{ns}			
	2018	-0.46^{ns}	-0.02^{ns}	-0.90^{ns}	-0.30^{ns}		
	2019	0.44^{ns}	0.85^{ns}	-0.04^{ns}	0.56^{ns}	0.85^{ns}	
	2020	3.33***	3.65***	2.75***	3.34***	3.60***	2.78***
340- Seasonal Cover Crops	2015	0.87^{ns}					
	2016	0.85^{ns}	-0.04^{ns}				
	2017	-0.38^{ns}	-1.37*	-1.36*			
	2018	-2.82***	-4.02***	-4.07***	-2.78***		
	2019	-3.04***	-4.28***	-4.34***	-3.03***	-0.20^{ns}	
	2020	-3.31***	-4.58***	-4.66***	-3.34***	-0.49^{ns}	-0.30^{ns}
412-Grassed Waterway	2015	0.90^{ns}					
	2016	1.20^{ns}	0.33^{ns}				
	2017	2.24**	1.33*	0.95^{ns}			
	2018	0.09^{ns}	-0.81^{ns}	1.12^{ns}	-2.16**		
	2019	2.94***	2.10**	1.73**	0.86^{ns}	2.87***	
	2020	1.67**	0.78^{ns}	0.43^{ns}	-0.53^{ns}	1.59*	-1.34***
512- Forage and Biomass Planting	2015	-1.62*					
	2016	-3.58***	-1.98**				
	2017	-2.48***	-0.85^{ns}	1.15^{ns}			
	2018	-0.92^{ns}	0.70^{ns}	2.67***	1.55*		
	2019	-2.00**	-0.37^{ns}	1.64*	0.49^{ns}	-1.07^{ns}	
	2020	-2.38***	-0.76^{ns}	1.24^{ns}	0.09^{ns}	-1.45*	-0.39^{ns}

Table A2 (Continued)

Conservation Practice Name		2014	2015	2016	2017	2018	2019
590-Nutrient Management	2015	0.55^{ns}					
	2016	0.50^{ns}	-0.03^{ns}				
	2017	0.95^{ns}	0.45^{ns}	0.46^{ns}			
	2018	-2.32**	-2.72***	-2.58***	-2.83***		
	2019	-3.96***	-4.26***	-4.08***	-4.19***	-1.57*	
	2020	-3.91***	-4.22***	-4.03***	-4.15***	-1.48*	0.13^{ns}
612- Tree and Shrub Establishment	2015	0.27^{ns}					
	2016	-0.10^{ns}	-0.35^{ns}				
	2017	-1.05^{ns}	-1.25^{ns}	-0.89^{ns}			
	2018	1.99**	1.60*	1.96**	2.87***		
	2019	1.59*	1.23^{ns}	1.59*	2.50***	-0.37^{ns}	
	2020	1.43*	1.07^{ns}	1.43*	2.35***	-0.55^{ns}	-0.17^{ns}

*Note(s): *** Indicates significance at the 1% level, ** at the 5% level and * at the 10% level.*

Table A 3 - Multiple-Comparison z-Value Test (Dunn's Test) of GHG Emission Reductions across Years

Conservation Practice Name		2014	2015	2016	2017	2018	2019
327- Permanent Cover Crops	2015	-0.17^{ns}					
	2016	0.36^{ns}	0.52^{ns}				
	2017	1.59*	1.74**	1.19^{ns}			
	2018	4.47***	4.57***	3.89***	2.54***		
	2019	4.75***	4.85***	4.12***	2.71***	0.04^{ns}	
	2020	4.21***	4.31***	3.60***	2.17**	-0.63^{ns}	0.23^{ns}
328- Conservation Crop Rotation	2015	-0.42^{ns}					
	2016	0.50^{ns}	0.88^{ns}				
	2017	-0.13^{ns}	0.28^{ns}	-0.60^{ns}			
	2018	-0.44^{ns}	-0.04^{ns}	-0.90^{ns}	-0.30^{ns}		
	2019	0.43^{ns}	0.81^{ns}	-0.06^{ns}	0.53^{ns}	0.83^{ns}	
	2020	3.32***	3.61***	2.74***	3.31***	3.58***	2.77***
340- Seasonal Cover Crops	2015	0.16^{ns}					
	2016	-0.15^{ns}	-0.34^{ns}				
	2017	-1.44*	-1.73**	-1.41*			
	2018	-3.66 ***	-4.10***	3.83***	-2.48***		
	2019	-3.87***	-4.35***	-4.09***	-2.71***	-0.18^{ns}	

	2020	-3.95***	4.44***	-4.18***	-2.80***	-0.25 ^{ns}	-0.07 ^{ns}

Table A3 (Continued)

Conservation Practice Name		**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
412-Grassed Waterway	2015	0.87 ^{ns}					
	2016	1.29*	0.44 ^{ns}				
	2017	2.51***	1.64*	1.14 ^{ns}			
	2018	0.06 ^{ns}	-0.82 ^{ns}	-1.24 ^{ns}	2.47***		
	2019	3.00***	2.19**	1.71**	0.67 ^{ns}	2.97***	
	2020	1.71**	0.85 ^{ns}	0.39 ^{ns}	-0.76 ^{ns}	1.66**	-1.36*
512- Forage and Biomass Planting	2015	-1.51*					
	2016	-3.43***	-1.93**				
	2017	-2.44***	-0.93 ^{ns}	1.03 ^{ns}			
	2018	-0.77 ^{ns}	0.75 ^{ns}	2.67***	1.67**		
	2019	-1.87**	-0.34 ^{ns}	1.62*	0.59 ^{ns}	-1.10 ^{ns}	
	2020	-2.25**	-0.74 ^{ns}	1.22 ^{ns}	0.19 ^{ns}	-1.49*	-0.40 ^{ns}
590-Nutrient Management **(A)**	2015	0.38 ^{ns}					
	2016	0.43 ^{ns}	0.07 ^{ns}				
	2017	1.12 ^{ns}	0.76 ^{ns}	0.68 ^{ns}			
	2018	-2.48***	-2.71***	-2.67***	-3.14***		
	2019	-4.08***	-4.22***	-4.13***	-4.47***	-1.55*	
	2020	-4.36***	-4.49***	-4.38***	-4.69***	-1.75**	-0.17 ^{ns}
590-Nutrient Management **(B)**	2015	-0.57 ^{ns}					
	2016	-0.67 ^{ns}	-0.12 ^{ns}				
	2017	-0.87 ^{ns}	-0.36 ^{ns}	-0.24 ^{ns}			
	2018	2.53***	2.94***	2.5***	2.93***		
	2019	3.27***	3.65***	3.62***	3.56***	0.74 ^{ns}	
	2020	3.02***	3.40***	3.39***	3.33***	0.43 ^{ns}	-0.31 ^{ns}
612- Tree and Shrub Establishment	2015	0.26 ^{ns}					
	2016	-0.10 ^{ns}	-0.34 ^{ns}				
	2017	-1.05 ^{ns}	-1.24 ^{ns}	-0.90 ^{ns}			
	2018	1.99**	1.61*	1.96**	2.8***		
	2019	1.56*	1.21 ^{ns}	1.55*	2.47***	-0.41 ^{ns}	
	2020	1.45*	1.10 ^{ns}	1.45*	2.37***	-0.54 ^{ns}	-0.12 ^{ns}

*Note(s): *** Indicates significance at the 1% level, ** at the 5% level and * at the 10% level.*

VITA

Edwin Coleman

Candidate for the Degree of

Master of Science

Thesis: IMPACT OF CONSERVATION PROGRAMS ON GREENHOUSE GAS EMISSION REDUCTION FROM AGRICULTURAL LANDS IN THE SOUTHERN PLAINS

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