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Carbon Sequestration and Carbon Management Policy Effects on Production Agriculture in the Texas High Plains

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Abstract

This study evaluated carbon emissions and carbon sequestration in the Texas High Plains (THP) in order to comprehend the effect that alternative carbon management policies would have on agricultural production. The objective was to examine the impacts of payments for sequestration and taxes on carbon emissions on cropping choices, profitability, and water consumption in the Texas High Plains. Results showed that reduction of total carbon emissions and tax on carbon emissions reduced the amount of water while payment for sequestration did not affect reduction of carbon emissions, water consumption nor product mix. However, payments for sequestration slightly increased net revenue for this region.

Keywords: Agriculture, Carbon emissions, Carbon sequestration, Profit, Texas High Plains, Water consumption

1. Introduction

The continued political and scientific concern over greenhouse gas (GHG) emissions has resulted in increased investigation of alternative techniques to reduce carbon dioxide (CO_2)

concentrations in the atmosphere. New studies point to alternatives as scientists have detected that the rate of emissions could be decreased by transferring CO_2 from the atmosphere to the terrestrial biosphere through the process known as sequestration. Agricultural activities can increase GHG in the atmosphere, but they can also sequester additional carbon, depending on practices, crops, and other variables. Agriculture management based on crop monoculture under conventional tillage is presently practiced in many places in the Texas High Plains (THP). Although irrigated cotton production increases yields, high water usage has surpassed the recharge potential of the Ogallala aquifer, which is the main irrigation water source in this semi-arid region. Besides water limitations, additional predicaments facing agricultural production in the West Texas region include soils of low fertility, high erosion potential, and unique and stressful climatic conditions. Reductions in availability of irrigation water are likely to change cropping type and cultivation techniques over time as they adapt to changes in water availability. Alternative management solutions for this region are found in an adaptation of continuous cotton culture to perennial pastures, or cotton/peanut rotations with other crops. It has been observed in the THP, that agricultural management practices have a significant influence on soil environment, more specifically carbon sequestration (Beare et al., 1992). Alternative management practices in the THP may result in reduced GHG emission (due to an enhanced carbon sequestration) and conservation of the severely depleted Ogallala aquifer, while generating increased crop yields and profits (Allen at el., 2005).

One of the studies which provided the base for this research was recent work by Nalley (2010) who conducted a life cycle assessment on carbon emissions and sequestration for the five largest cotton producing counties in the ten largest cotton producing states in the United States. This study indicated soil type as one of the most important factors influencing carbon sequestration, as some soils tend to confine carbon better than others. More specifically, clay and claylike soils (such as the ones found in the THP) tend to have enhanced holding capacity when compared to loamy or sandy soils (Nalley et al., 2010). In addition to soil type, Nalley’s study on ten states (including Texas) elucidates that land management (tillage or fertilization) and crops (emphasis on cotton) have a propensity to influence carbon sequestration. Interestingly, this study showed that, in general, all of the cotton producing states are sequesters or carbon neutral (at the very least) when it comes to net carbon sequestration. Nalley’s study, however, did not include all counties in the THP, and considered only one crop, irrigated and dryland cotton.

Another significant study for this research, conducted by Wright and Hudson, was related to carbon emissions (Wright and Hudson, 2011). They developed the model that measured carbon emissions for the THP region and estimated the effect of restricting carbon emissions on net revenue, acres planted, and the amount of water used. In order to analyze the effect of reduced carbon, the amount of carbon emitted was restricted to 95% and 85% of the baseline. According to results of the study, a carbon reduction significantly decreased the amount of water applied to crop for irrigation, while the number of acres planted in the region remained the same. What this study did not perform is calculation of carbon sequestration in the THP and comparison of net revenue before and after including carbon sequestration.

The main objective of this study was to evaluate carbon emission and carbon sequestration in the THP and develop an understanding of the effect that alternative carbon management policies would have on agricultural production. The specific objectives were to estimate total carbon emission and sequestration per acre under alternative management policies in the THP and examine the impacts of payments for sequestration and taxes on carbon emissions on cropping choices, profitability, and water use in the THP. Agriculture is currently not the target of carbon management policies; however it is often seen as a potential market for sequestration credits and the agricultural industry needs to have more information about the values of sequestration management in case it becomes one of the targets of carbon management policies.

In conclusion, given the fact that agricultural crops sequester carbon from the atmosphere, this study allowed for a total net carbon footprint to be estimated at the county level and the entire THP. In addition, as carbon sequestration entered the model, profitability of the THP was calculated considering changes in cropping patterns and water consumption.

2. Material and Methods

The main focus of this research project included a maximization problem and calculation of carbon sequestration impact on crop production in the THP, an area of 41 counties (Figure 1) in Northwest Texas.

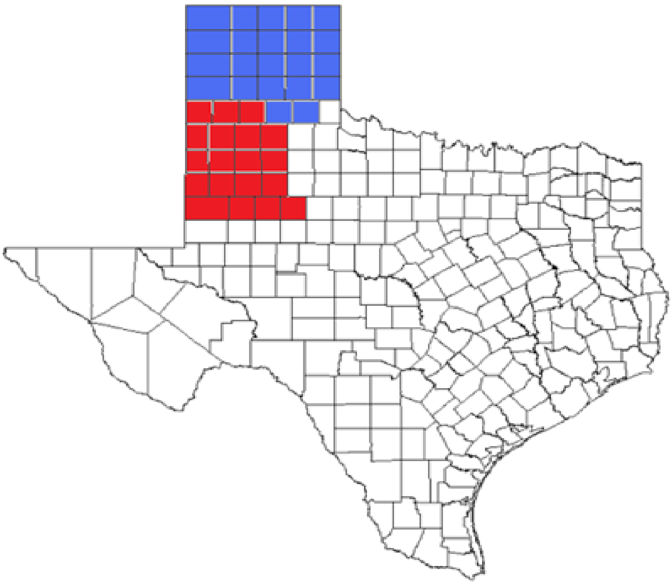

Figure 1. The Texas High Plains

There are 22 counties in the Northern High Plains (labeled with blue color on Figure 1): Armstrong, Briscoe, Carson, Collingsworth, Dallam, Deaf Smith, Donley, Gray, Hall, Hansford, Hartley, Hemphill, Hutchinson, Lipscomb, Moore, Ochiltree, Oldham, Potter, Randall, Roberts, Sherman, and Wheeler. Southern High Plains consists of 19 counties (labeled with red color on Figure 1): Bailey, Borden, Castro, Cochran, Crosby, Dawson, Floyd, Gaines, Garza, Hale, Hockley, Lamb, Lubbock, Lynn, Parmer, Scurry, Swisher, Terry, and Yoakum.

For each of these counties, a representative farm was established where corn, cotton, peanuts, sorghum, and wheat were grown. For corn and peanuts only irrigated production was considered, while for cotton, sorghum, and wheat both dryland and irrigated production was allowed. Therefore, there were eight different crops considered in this study. Relying on the model for carbon sequestration calculation from Nalley et al's study, this research attempted to estimate the carbon sequestration in all 41 counties in the THP (Nalley et al., 2010). According to Wright and Hudson, carbon emissions were estimated in a way in which each unit of input in the extension service budget is equated to a number of units of carbon emitted (Wright and Hudson, 2011). For example, if one kg of fertilizer is equivalent to 0.2 kg of carbon emitted, then applying twenty five kg of fertilizer to a hectare of a crop is equivalent to that hectare emitting five kg of carbon. Adding up the calculated emissions for each input results in the per hectare carbon emission for the particular crop. Using Wright and Hudson's model that measures carbon emissions, net carbon footprint (difference between carbon emissions and carbon sequestration) was evaluated. Afterwards, a programming model of the producers' net revenue was estimated. Finally, net carbon sequestration was introduced to the model in order to estimate producers' profitability from carbon sequestration.

Information for the crops, counties and carbon sequestration calculation originated from six primary sources:

1. Crop budgets published by Texas A&M Agrilife Extension Service for the years 2008 to 2010 provided information on crop prices, per acre costs (including irrigation costs), and per acre input quantities. The average over all three budgets was used.
2. National Statistics Service (NASS) for the years 2000 to 2009 provided data on planted acres, harvested acres, and yields for each crop. Harvested acres were calculated using the ratio of the mean harvested acres to the mean planted acres for each crop in each county. The yields were reported in pounds or bushels per acre and were adjusted to dry matter yields using standard moisture contents.
3. To calculate per acre yield for irrigated crops, functions were obtained from previous studies that had been conducted at the THP (Wheeler et al., 2006). The yield functions for each crop are quadratic functions that relate crop yield to water use in each county.
4. Previous study on carbon emissions (Wright and Hudson, 2011) provided data on carbon emissions.
5. Previous study on carbon sequestration (Nalley et al., 2010) provided a formula for carbon sequestration calculations and data necessary for those calculations such as: harvest index, root to shoot ratio, crop residue carbon content, root carbon content, estimated fraction of carbon contained in above- and below-ground biomass, etc. For harvest index, root to shoot ratio, and carbon content, this study used an average value reported from the literature (Nalley et. al, 2010).
6. Web soil survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) provided data on soil composition in each county.

Using data from these sources, profit was calculated for each county as:

$$Max\ \Pi_i = \sum_{j=1}^{8}(TR_{ij} - TC_{ij}) \tag{1}$$

where Π_i represents the profit in county i, TR_{ij} indicates the revenue of the crop j and TC_{ij} is the total cost of production of crop j in that county.

Revenue from production was defined as:

$$TR_{ij} = h_{ij} \cdot (y_{ij}\, p_j) \tag{2}$$

where h_{ij} specifies the number of acres of crop j harvested in a particular county i, p_j is the unit price for crop j, while y_{ij} represents per acre yield for crop j in county i.

Cost in the above mentioned function was defined as:

$$TC_{ij} = a_{ij} \cdot (f_{ij} + d_{ij}\, w_{ij}) \tag{3}$$

where a_{ij} is the number of acres of crop j planted in a county i, f_{ij} indicates per acre specified costs for crop j according to the extension service budgets and excluding irrigation costs. The $d_{ij}\, w_{ij}$ represents the irrigation cost per acre where d_{ij} is the cost associated with irrigation and w_{ij} is the number of acre inches applied. Irrigation costs were calculated separate from other expenditures so that the amount of water applied to each crop could be determined. Irrigation is a primary carbon source and can vary as producers adjust applied water to affect yields.

Preceding carbon emission research conducted by Wright and Hudson for this Texas region utilized a non-linear programming model to maximize net revenue for each county (Wright and Hudson, 2011). The present study employed a similar model, slightly modified and optimized to allow for carbon sequestration estimation in the same region, as well as secondary market price for carbon sequestrated. The decision variables in this model were planted acres a_{ij} and amount of water applied to each crop w_{ij}.

A non-linear programming model developed using Excel Premium Solver (Frontline Systems Inc., NV, USA) add-in allowed for net profit maximization in each of the relevant counties. NASS statistics for planted acres, harvested acres, and yields for the years 2000 to 2009 for each crop in each county were used to provide realistic boundaries for the model. This model was constrained in a way that the yield for each irrigated crop in each county was at least equivalent to the minimum yield from 2000-2009, found in NASS data. For irrigated crops, yield is a quadratic function of the amount of water applied, while for dryland crops the yield is equal to the ten year average yield according to the NASS data. Planted acres of each crop in a particular county were not higher than the maximum sum reported by NASS for ten year period. In addition to these constraints, the amount of water used cannot exceed 23 acre-inches for irrigated crops while for dryland crops the amount of water that can be applied is zero (Hudson and Wright, 2011).

The carbon sequestration estimation model used in this study was a cross of Hicke and Lobell (2004) model, used to convert agronomic data (recorded by USDA) into carbon fluxes. This model was modified by Nalley et. al (2010) to include the effects of soil on the holding potential of carbon sequestrated. This model allowed for an accurate estimation of kg of carbon sequestrated under a particular crop j.

2.1 Carbon Sequestration Calculations

This study used a methodology similar to Prince et al. (2001) where kilograms of carbon sequestered from above ground biomass (*AGB*) per hectare for crop j in county i under tillage method t can be estimated by equation 4:

$$AGB_{ijt} = \left[\left(Y_{ij} \cdot \lambda_j \cdot (1-\alpha_j)\right) \cdot \left(\frac{1}{H_j} - 1 \right) \cdot \beta_j \cdot \delta_t \cdot \eta_t \right] \tag{4}$$

Where Y_{ij} is yield of crop j in conventionally reported units per acre for the crop, λ_j converts said yield to kg ha^{-1}, α_j is the moisture content of crop harvested so that yields can be converted to a dry-mass basis, H_j is the harvest index, β_j is the estimated fraction of carbon of *AGB* and δ_t is the estimated amount of *AGB* incorporated in the soil depending on tillage method t and η_t is the tillage-dependent estimated fraction of plant residue that is sequestered in the soil (Nalley et al.,2010). This study considers two tillage methods, no till and conventional till.

In order to estimate kilograms of carbon sequestered from below ground biomass (*BGB*) per hectare for crop j in county i under tillage method t, equation 5 was used:

$$BGB_{ijt} = \left[\chi_j \cdot \eta_t \cdot \left(\frac{\phi_j \cdot \left[Y_{ij} \cdot \lambda_j \cdot (1-\alpha_j) \right]}{H_j} \right) \right] \tag{5}$$

Where χ_j is the fraction of carbon in below ground biomass and Φ_j is the shoot to root ratio. All other variables are the same as in equation 4. Both above and below ground biomass carbon sequestration was multiplied by an estimated soil factor ξ_{is} weighted by area of land with each soil texture in each county that adjusts soil carbon sequestration based on soil texture (Nalley et al., 2010). Web soil survey provided data on soil composition in each county. Due to high diversity of soil types, classification was simplified to clay, loam, and sand like soils. Some soil types allow for the sequestered carbon to release back in the atmosphere at a higher rate than others. Clay and clay-like soils have the largest holding potential of sequestered carbon with an average of 95%, loam and loam-like soils 70% and sandy and sandy-like soils were estimated to retain 40% of sequestered carbon (Nalley et al., 2010).

Total carbon sequestration S_{ijts} per hectare for crop j in county i under tillage method t and soil texture s was estimated by equation 6:

$$S_{ijts} = (AGB_{ijt} + BGB_{ijt}) \cdot \xi_{is} \tag{6}$$

Carbon sequestration was calculated under two tillage methods, conventional till and no till, generating two different sets of data. Once carbon sequestration was calculated for each crop, total carbon sequestration on a county level was estimated by multiplying the carbon equivalents for a particular crop by number of acres planted. Then, net carbon foot print (difference between total carbon emissions from a crop j grown in county i and total carbon sequestration for that crop, multiplied by planted acres), was estimated by equation 7:

$$NCF_i = \sum_{j=1}^{8}(E_{ij} - S_{ijts}) \cdot a_{ij} \tag{7}$$

Total revenue from carbon sequestration was calculated by equation 8:

$$RS_{ij} = \sum_{j=1}^{8}(E_{ij} - S_{ijts}) \cdot a_{ij} \cdot m_c \tag{8}$$

Where a_{ij} specifies the number of acres of crop j planted in county i, and m_c represents the carbon price.

In order to obtain results from the baseline the model without any constraint was estimated without introducing net revenue from sequestration. The model was used to maximize net revenue from production, finding optimal planted acres and water usage for each crop in each county. Using the data from the baseline there were five different scenarios in data analysis:

1) Reduction of total carbon emissions to 85% of the baseline,

2) Imposing the tax on carbon emissions:

$$Max\ \Pi = \sum_{i=1}^{41}\sum_{j=1}^{8}(TR_{ij} - TC_{ij}) - (E_{ij} - 0.85\ EB_{ij}) \cdot T_i \tag{9}$$

Where E_{ij} is defined as the total emissions for county i and crop j, EB_{ij} is the total emissions calculated in the baseline, and T_i is the per unit tax on emissions.

Once the total carbon emissions in baseline were calculated, 85% of that value was taken and was considered the constraint. The tax rate of $0.435 per pound of emitted carbon over the 85% threshold was used based on the optimal tax rate work by Wright and Hudson (2011).

3) Payment for sequestration, with the net revenue from sequestration, the optimization model was modified to add a carbon market to each county's crop profit function as:

$$Max\ \Pi_i = \sum_{j=1}^{8}(TR_{ij} + (BCF_{ij} - (E_{ij} - S_{ijts}) \cdot a_{ij} \cdot m_c) - TC_{ij}) \tag{10}$$

Where BCF_{ij} represents a baseline estimate of the net carbon footprint (difference between the sum total of carbon emissions from a crop grown using various production methods and the sum total of carbon sequestration for that crop in a county). The difference between E_{ij} and S_{ijts} was taken from one of the scenarios mentioned above. This model allowed us to determine how producer revenues for reductions or charges for additions to each crop and county carbon footprint would affect cropping patterns (Nalley et. al., 2010).

4) Reduction of total carbon emissions and payment for sequestration, and

5) Tax and sequestration at the same time.

3. Results and Discussion

Before proceeding to full results, an examination of estimated impacts based on conventional and no tillage methods was examined and data on carbon sequestration under these two practices were assessed separately. Previous studies showed that, in the short run, conventional tillage has an advantage compared to no till due to incorporation of a larger amount of above ground carbon below ground (Angers and Eriksen-Hammel, 2008). However, in the long run, no till is more beneficial in keeping carbon below ground. Even under the assumption that no till is better due to reduced cultivation, in reality aboveground carbon turns into the soil more efficiently under conventional till.

The baseline for further analysis was conventional till as it sequestered more carbon than no till and therefore reduced the total net carbon footprint (*NCF*), which represents the difference between the sum total of carbon emissions (E_{ij}) and the sum total of carbon sequestration (S_{ijts}), (equation 11). A positive difference denotes that carbon emissions are greater than carbon sequestration, while a negative difference indicates that carbon sequestration is greater than carbon emissions.

$$NCF_i = \sum_{j=1}^{8}(E_{ij} - S_{ijts}) \tag{11}$$

Results regarding comparison between conventional and no till were consistent across the entire THP and were illustrated for two counties, Dallam (Figure 2) as a representative of the Northern High Plains (NHP) and Hale (Figure 3) as a representative of the Southern High Plains (SHP).

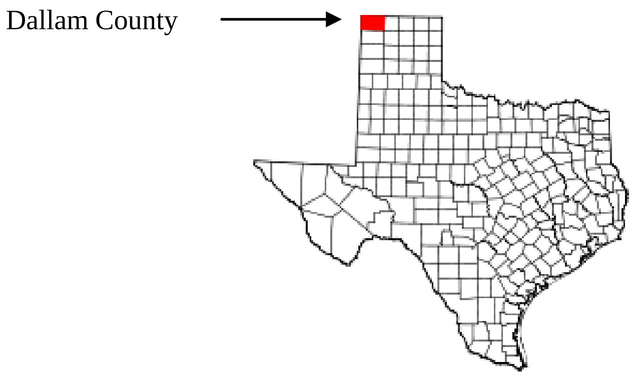

Figure 2. Dallam County in the Northern High Plains

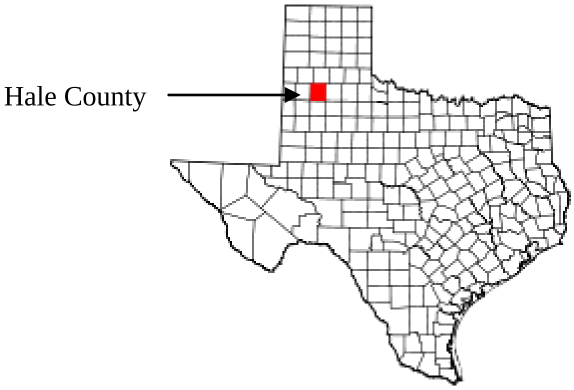

Figure 3. Hale County in the South High Plains

3.1 Baseline

The baseline for the model was estimated without any constraints on carbon or revenue from sequestration. The model was used to maximize net revenue from production, finding optimal planted acres and water usage for each crop in each county. Carbon emissions per acre were calculated on per acre basis while the total carbon emissions were calculated as a product of planted acres and carbon emissions per acre. Total net carbon is a difference between carbon emission per acre and carbon sequestration per acre, multiplied by planted acres. The water per acre was the optimal solution of the model for total number of acre inches applied to one acre of a particular crop. Carbon sequestration, converted to lbs per acre, was based on the calculated yield from the maximization model; subsequently if the crop was not planted it resulted in zero lbs of carbon sequestration per acre (e.g., dry cotton, irrigated cotton, and peanuts in Dallam County).

Baseline results from Dallam showed that more than a half of total planted acres in this county were allocated to corn, while the remaining planted acres included dry sorghum, dry wheat, and irrigated wheat. Corn consumed the maximum water allowed but water was applied to irrigated sorghum and irrigated wheat as well. Besides dry sorghum, all other crops were net emitters in this county.

Results in Hale County showed that 60% of total planted acres were allocated to irrigated cotton and the rest was applied to corn, dry cotton, irrigated sorghum, and dry sorghum. All crops were net emitters implying that carbon emissions were greater than carbon sequestration.

Using the data from the baseline there were five different scenarios in data analysis: 1) reduction of total carbon emissions to 85% of the baseline, 2) imposing a tax on carbon emissions, 3) payment for sequestration, 4) reduction of total carbon emissions and payment for sequestration, and 5) tax and sequestration at the same time.

3.2 Constraint-reduction of Total Carbon Emissions

The model was estimated for a second time with reduction of total carbon emissions to 85% of the baseline. Results of the two representative counties showed that reducing total carbon emissions caused reductions in water consumption, yield, and, therefore, net revenue from the production. Due to close connection between irrigation and carbon emissions, reduction of carbon emissions results in reduction of water applied to a crop.

Comparing results from this scenario with the baseline results for Dallam County found that planted acres did not change. Water per acre was reduced by 14% for corn and 57% for irrigated wheat. Reduction of total carbon emissions also resulted in a reduction of net carbon, 11% for corn and 48% for irrigated wheat. Therefore, net revenue from production decreased by 12%. In Hale county, planted acres remained the same for all the crops. Water for corn, irrigated cotton, and irrigated sorghum was reduced by 7%, 8%, and 64% respectively. Because water for these three crops was reduced, net carbon from these crops was reduced as well by 4%, 8%, and 71% respectively. Reductions in water usage caused a decrease in yield and, therefore, total net revenue from production was decreased by 2%.

3.3 Tax on Emissions

The next step in data analysis included imposing a "per unit tax" on carbon emissions. Once the total carbon emissions in baseline were calculated, 85% of that value was taken and was considered the constraint. The tax rate of $0.435 per pound of emitted carbon over the 85% threshold was used based on the optimal tax rate work by Wright and Hudson (2011).

According to the results for Dallam County, total planted acres remained the same compared to the unconstrained model (baseline). The highest carbon emissions came from corn, irrigated sorghum, and irrigated wheat. The decline of total carbon emissions to 85% of the baseline forced reduction in water use while applying a tax resulted in much greater water reduction by 14%, 36% and 57% for corn, irrigated sorghum, and irrigated wheat, respectively. Net carbon (from tax model) was also reduced by 11% for corn, 24% for irrigated sorghum, and 48% for irrigated wheat, compared to the baseline model, while total net revenue from production was reduced by 12% compared to the baseline.

In Hale County, a tax reduced planted acres to zero for corn, compared to the baseline, indicating that allocation of acres to this crop would not be profitable if producers were required to pay tax on carbon emissions. In opposite, planted acres for dry sorghum increased by 2% compared to the baseline, indicating that planting this crop is profitable even after paying a tax on carbon emissions from this crop. In this county, water use was reduced only for irrigated cotton (by 7%) and for irrigated sorghum (by 53%). Total net revenue from production was reduced by 1% compared to the baseline.

3.4 Payment for Sequestration

The next step in our data analysis introduced a carbon price and estimated net revenue from the sequestration. After a detailed literature review, the carbon price used for this analysis was $90/metric ton or $0.0408/lbs. Although the price may seem high, the idea was to use the price which is at the maximum of the EPAs expected carbon prices (EPA, 2009) and afterwards perform sensitivity analysis using lower carbon prices in order to avoid overestimation of the results. The model was estimated for the fourth time and it allowed payment for the sequestration in order to determine if there were changes of the amount of sequestered carbon, cropping patterns, and water consumption.

Analysis of Dallam County data showed that growing dry sorghum is profitable as carbon sequestration is greater than carbon emissions for this crop and thus planted acres increased by <1%. Total net revenue increased slightly, primarily due to the increase of the net revenue from the sequestration arising from dry sorghum. The results indicated that payment for sequestration affected planted acres and total net revenue for this county but not significantly.

In Hale County there were changes regarding planted acres, net revenue and net carbon. Planted acres for corn and dry sorghum increased by 20% and 2% respectively while planted acres for irrigated wheat increase by more than 100%. Although irrigated wheat consumes more water and therefore carbon emissions are higher, planting this crop is profitable in scenario where payment for sequestration is introduced which is why planted acres increased. Increase of planted acres for these three crops led to an increase in net revenue from production.

Although there was no revenue from sequestration, total net revenue for the county was increased by 1% due to an increase of revenue from production.

Even though the maximum carbon price was used for this scenario, payment for sequestration did not significantly affect variables in our model, which is why the sensitivity analysis was not performed.

3.5 Reduction of Total Carbon Emissions and Payment for Sequestration

The next scenario consisted of estimating the model with the reduction of total carbon emissions by 85% of the baseline and payment for sequestration.

In Dallam County, carbon emission reduction and payment for sequestration reduced total planted acres for corn, dry sorghum, dry wheat, and irrigated wheat by 7%, 3%, 3%, and 1% respectively. Water was reduced for corn and irrigated wheat by 9% and 36% respectively as these crops were the highest carbon emitters. Although dry sorghum was carbon sequestered and there was revenue from sequestration, total net revenue for this county was reduced by 11% due to a decrease in revenue from production. In Hale County, planted acres for corn were reduced to zero indicating that growing this crop is not profitable in this scenario. Water reduction for irrigated cotton and irrigated sorghum caused lower yields and therefore total net revenue for this county decreased by 2%.

3.6 Tax and Payment for Sequestration

Finally, the model was estimated the last time in order to allow tax and payment for sequestration at the same time. In Dallam County, planted acres for dry sorghum increased, comparing this model with the baseline, as this crop is carbon sequester. Water consumption for corn, irrigated sorghum, and irrigated wheat decreased by 14%, 36% and 57% respectively since these crops were high carbon emitters. Water reduction resulted in a lower net carbon for this county. Although there was an increase in revenue from sequestration, total net revenue decreased by 12% due to reduction in revenue from production.

In Hale County, planted acres for corn, dry sorghum and irrigated sorghum were reduced comparing the model from this scenario with the baseline. Water applied to irrigated wheat was significantly higher resulting in an increase of net carbon per crop. Total net revenue was reduced by 3%.

4. Summary for Entire THP

4.1 Planted Acres

Tables 1 and Table 2 summarize percentage differences in planted acres, in the NHP and SHP, respectively. Negative numbers represent a decrease while positive numbers denote an increase in planted acres, compared to the baseline results.

Table 1. Percentage difference in planted acres in Northern High Plains (NHP)

Crop	Constraint	Tax	Sequestration	Constraint and sequestration	Tax and sequestration
Corn	-0.31%	-2.23%	0.00%	-5.51%	-0.69%

Dry Cotton	0.00%	-11.15%	0.00%	-11.31%	-10.85%
Irr. Cotton	0.00%	0.00%	0.00%	0.00%	0.00%
Peanuts	0.00%	0.00%	0.00%	0.00%	0.00%
Dry Sorghum	0.00%	-39.45%	0.78%	-38.14%	-40.26%
Irr. Sorghum	0.00%	0.00%	0.00%	0.00%	0.00%
Dry Wheat	-0.70%	32.52%	-0.06%	-13.59%	-3.24%
Irr. Wheat	-0.07%	-8.93%	0.00%	-9.35%	-8.94%
Total	-0.21%	-2.04%	0.05%	-10.14%	-7.16%

NHP results showed slight changes in corn, dry cotton, and irrigated wheat; greater changes in dry sorghum and dry wheat and no change in irrigated cotton, irrigated sorghum acreage and peanuts across the different scenarios.

Table 2. Percentage difference in planted acres in Southern High Plains (SHP)

Crop	Constraint	Tax	Sequestration	Constraint and sequestration	Tax and sequestration
Corn	-3.06%	-5.46%	0.70%	-5.41%	-4.08%
Dry Cotton	-0.99%	-2.07%	0.00%	-22.79%	-2.07%
Irr. Cotton	-0.13%	0.00%	0.00%	-3.03%	0.00%
Peanuts	0.00%	-35.28%	0.00%	-4.90%	-35.28%
Dry Sorghum	-0.01%	-27.43%	0.23%	-62.46%	-33.37%
Irr. Sorghum	0.00%	-5.91%	0.00%	-20.75%	-25.61%
Dry Wheat	0.00%	-93.14%	0.00%	-94.24%	-93.17%
Irr. Wheat	0.00%	-48.61%	40.08%	-16.92%	-44.59%
Total	-0.47%	-10.13%	1.26%	-17.50%	-12.06%

Results for SHP showed larger variations in acreage for all the crops, particularly in the case of dry cotton, peanuts, sorghum, and wheat.

4.2 Net Carbon Footprint

Table 3. Carbon emissions (kg/ha) in THP

	Northern High Plains	Southern High Plains	Texas High Plains
Baseline	70 556	52 407	122 963
Constraint	63 765	46 646	110 411
Tax	65 668	49 204	114 872
Sequestration	70 556	52 897	123 453
Constraint and sequestration	66 624	49 210	115 835
Tax and sequestration	66 778	50 009	116 786

Table 3 shows carbon emissions in kilogram per hectare for the Texas High Plains across different scenarios.

Table 4. Percentage difference in net carbon in THP

	Northern High Plains	Southern High Plains	Texas High Plains
Constraint	-10.76%	-12.78%	-11.62%
Tax	-7.69%	-6.38%	-7.13%
Sequestration	0.00%	0.73%	0.31%
Constraint and sequestration	-6.34%	-6.85%	-6.56%
Tax and sequestration	-6.42%	-5.05%	-5.84%

Table 4 shows percentage difference in net carbon in the THP across different scenarios, compared to the baseline results. The constraint and tax caused a decrease in net carbon by 11.62% and 7.13%, respectively, as constraining the model automatically reduced water, and, therefore total carbon emissions. Although carbon sequestration increased when payment for sequestration was introduced in the model, carbon emissions increased as well leading to an increase in net carbon by 0.31%. The last two scenarios showed a decrease in net carbon compared to the baseline; however, a decrease is not as high as in constraint and tax scenarios due to the presence of sequestration which caused higher net carbon.

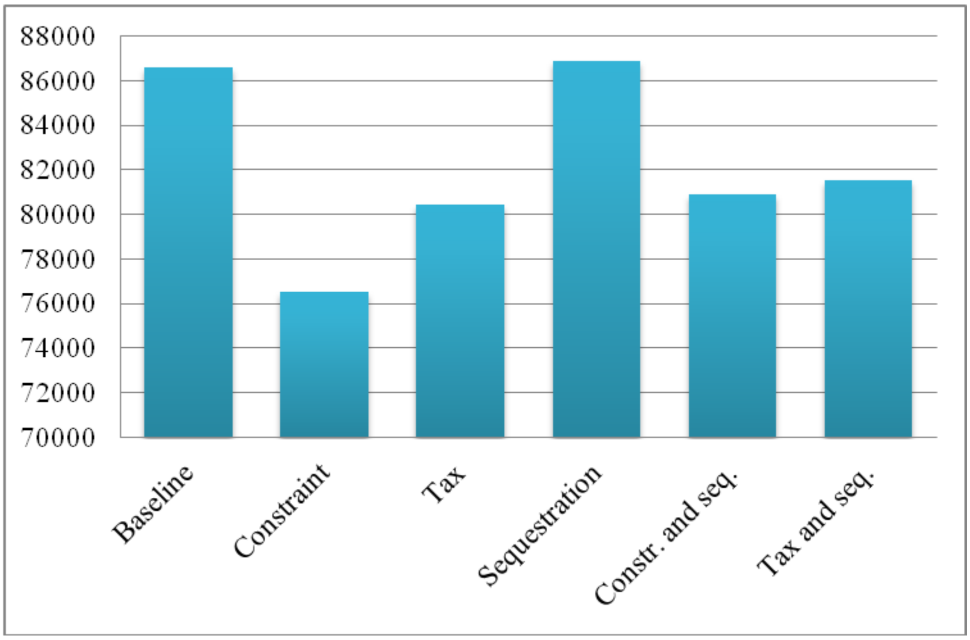

Figure 4. Net carbon (kg/ha) in Texas High Plains across different scenarios

Figure 4 shows net carbon in kilogram per hectare in the Texas High Plains across different scenarios. The largest reduction occurred in constraint scenario when net carbon from the baseline 86 595 kg/ha decreased to 76 534 kg/ha, which is 11.62% (presented in Table 4). Unlike other scenarios, payment for sequestration caused an increase in net carbon from 86 595 kg/ha in the baseline to 86 865 kg/ha when sequestration was introduced (an increase by 0.31% as shown in Table 4).

4.3 Net Revenue

Table 5. Percentage difference in total net revenue in THP

	Northern High Plains	Southern High Plains	Texas High Plains
Constraint	-5.96%	-4.29%	-4.72%
Tax	-8.03%	-2.79%	-4.16%
Sequestration	0.03%	0.26%	0.20%
Constraint and sequestration	-8.07%	-5.94%	-6.50%
Tax and sequestration	-8.36%	-3.08%	-4.45%

As reduction of water use caused a decrease in yield and, therefore, a decrease in net revenue from production, total net revenue for the entire region (Table 5) decreased by 4.72% in reduction of carbon emissions scenario and by 4.16% in imposing a tax scenario. As expected, payment for sequestration resulted in an increase in net revenue by 0.2% compared to the baseline as revenue from carbon sequestration was generated in both NHP and SHP.

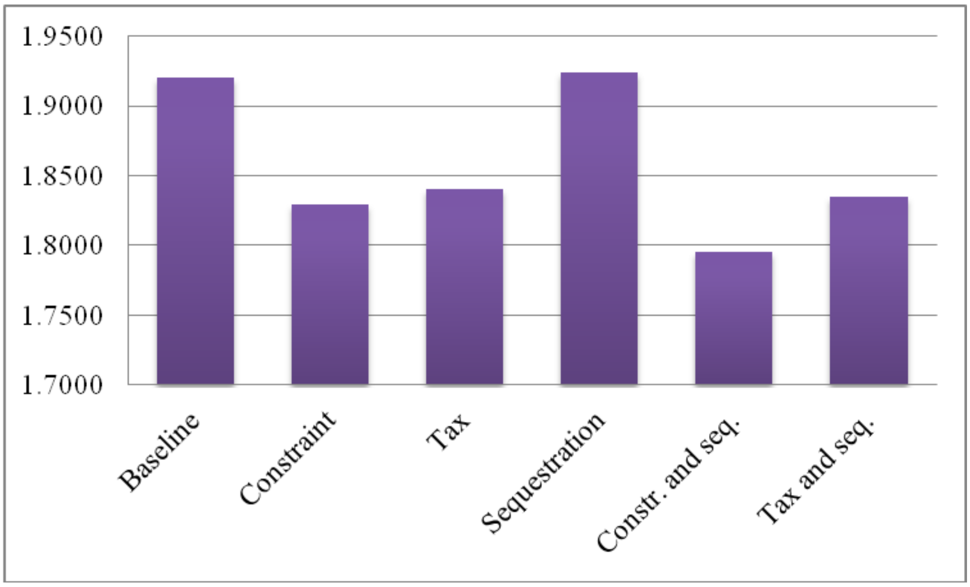

Figure 5. Net revenue (billion dollars) in Texas High Plains across different scenarios

Figure 5 represents total net revenue in billion dollars for the Texas High Plains across different scenarios. Total net revenue increased when payment for sequestration was introduced (from $1.9202 to $1.9241, while in other scenarios total net revenue compared to the baseline declined.

5. Conclusion

The main objective of this study was to evaluate carbon emissions and carbon sequestration in the THP and develop an understanding of the effect that alternative carbon management policies would have on agricultural production.

Implementation of production practices (irrigated vs. dryland crop, conventional vs. no till) caused variability in the net carbon footprint across the counties. In agriculture, carbon emissions are produced mostly by fuel consumption, irrigation and usage of fertilizers and pesticides. Therefore, carbon emissions are much higher for irrigated production compared to dryland. The amount of carbon emissions in no till was reduced by all field operations because they were present only in conventional till, but the data analysis showed that a greater amount of carbon can be sequestered under conventional till, thus causing less carbon footprint.

The results indicated that either capping or taxing total carbon emissions would cause a reduction in planted acres, water consumption, yield, and, therefore, net revenue from the production. Total water consumption was reduced when carbon was restricted to 85% of the baseline and when a carbon tax was imposed.

The carbon constraint and tax caused a decrease in net carbon since constraining the model automatically reduced the water and therefore total carbon emissions. Payment for sequestration increased the net carbon, however not substantially. Under this scenario, there was an increase in net revenue compared to the baseline due to generated revenue when payment for sequestration was introduced in the model.

The THP is agronomical unique compared to other regions because of the limited number of crops that can be grown effectively. Because of those restrictions, there is limited flexibility of choosing appropriate cropping rotations. In addition to crop feasibility another major factor which influences cropping decisions in THP is profitability. Looking at the alternative carbon management policies, carbon payment for sequestration does not affect reduction of carbon emissions, water use nor the product mix. Tax, on the other hand, achieves the goal of carbon reduction and intensely reduces the water use. Carbon sequestration affects net revenue but not substantially for the THP.

Looking at the profit maximization decision, carbon sequestration in itself is not the decisive crop selection factor, as the relative impact of sequestration value relative to the losses or gains in revenue from production determines producer’s decision about what crops to plant inside the framework.

This study was one of many studies conducted because of concerns that continued increases in the atmospheric concentration of CO_2 could lead to significant changes in climate. Although agriculture is currently not the target of carbon management policies, there is a chance that some form of a carbon policy will be implemented. Consequently, carbon sequestration could play a great role not only in reduction of net carbon footprint but also in increasing profitability for net sequester crops. Because agriculture is a potential market for sequestration credits the agricultural industry needs to have more information about the values of sequestration management.

This study did not consider alternative tillage techniques and changes in irrigation technology which may increase the sequestration potential for these crops. This study considered center pivot technology which emits greater amount of carbon compared to drip irrigation which generates higher yields while increasing carbon sequestration. Another limitation of this study is that it employed a static model, and did not address potential evolution in technology that could occur and make sequestration more profitable. At this point, under current technology, payment for carbon sequestration is not truly effective. One of the ideas for future studies is to employ a dynamic model using novel technology endogenous to the area of the study.

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References

Allen, V. G., Brown, C. P., Kellison, R., Segarra, E., Wheeler, T., Dotray, P. A., Conkwright, J. C., Green, C. J., & Acosta-Martinez, V. (2005). Integrating cotton and beef production to reduce water withdrawal from the Ogallala Aquifer in the Southern High Plains. *Agron. J. 97*, 556-567. http://dx.doi.org/10.2134/agronj2005.0556

Angers, D., & N. Eriksen-Hammel, N. (2008). Full Inversion Tillage and Organic Carbon Distribution in Soil Profiles: A Meta-Analysis. *Soil Science Society of America Journal 72*, 1370-1374. http://dx.doi.org/10.2136/sssaj2007.0342

Beare, M., Parmelee W. R., Hendrix F. P., Cheng W., Coleman, C. D., & Crossley, D. A. (1992). Microbial and Faunal Interactions and Effects on Litter Nitrogen and Decomposition in Agroecosystems. *Ecological Monographs*. *62*(4), 569-591. Web. 10 May 2011. http://dx.doi.org/10.2307/2937317

EPA (United States Environmental Protection Agency) - EPA Preliminary Analysis of the Waxman-Markey Discussion Draft. The American Clean Energy and Security Act of 2009 in the 111th Congress. Internet site: http://epa.gov/climatechange/economics/pdfs/WM-Analysis.pdf (Accessed May, 2011).

Extension Agricultural Economics. (2008). *2008 Texas Crop and Livestock Budgets*. [Online] Available: http://agecoext.tamu.edu/resources/crop-livestock-budgets/by-district/district-2/2008.html (August 2, 2010).

Extension Agricultural Economics. (2009). *2009 Texas Crop and Livestock Budgets*. [Online] Available: http://agecoext.tamu.edu/resources/crop-livestock-budgets/by-district/district-2/2009.html (August 2, 2010).

Extension Agricultural Economics. (2010). *2010 Texas Crop and Livestock Budgets*. [Online] Available: http://agecoext.tamu.edu/resources/crop-livestock-budgets/by-district/district-2/2010.html (August 2, 2010).

Frontline Solver, Premium Solver Platform. Version 10.0. Copyright 2010.

Hicke, J. A., & D. B. Lobell. (2004). Spatiotemporal patterns of cropland area and net primary production in the central United States estimated from USDA agricultural information. *Geophysical Research Letters* 31.

Nalley, L., M. Popp, & K. (2010). A Life Cycle Approach to Estimating Net Carbon Emissions and Agricultural Response to Potential Carbon Offset Policies. Invited Seminar presented at Mississippi State University, Department of Agricultural Economics. Starkville, Mississippi,

Prince, S. D., J. Haskett, M. Steininger, H. Strand, & R. Wright. (2001). Net primary production of U.S. midwest croplands from agricultural harvest yield data. *Ecological Applications. 11*, 1194-1205. http://dx.doi.org/10.1890/1051-0761(2001)011[1194:NPPOUS]2.0.CO;2

United States Department of Agriculture-Web Soil Survey. [Online] Available: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm (March 10, 2012).

Wheeler, E. A., S. Eduardo, N.J. Phillip, W. J. Jeffrey, & B. W. David. (2006). Policy Alternatives for the Southern Ogallala Aquifier. Paper presentated at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 5-8.

Wright, A., & D. Hudson. (2011). The Effect of Carbon Reducing Policies on Production on the Texas High Plains. Paper presented at the Beltwide Cotton Conferences, Atlanta, GA, January.

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