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

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Abstract

Increased concentration of greenhouse gases in the atmosphere, especially of carbon dioxide, has led to attempts to implement carbon policies in order to limit and stabilize gases at acceptable levels. Agricultural activities increase greenhouse gases in the atmosphere, but they can also mitigate concentration of carbon dioxide by sequestering additional carbon. This study evaluated carbon emissions and carbon sequestration and examined the impacts of payments for sequestration and taxes on carbon emissions on cropping choices, profitability, and water consumption in the Texas High Plains. The results showed that reduction of total carbon emissions to 15% of a baseline and imposing a tax reduced the amount of water consumed for irrigation, by about 20% and 16%, respectively. However, payment for sequestration did not affect reduction of carbon emissions, water consumption nor the product mix.

Key words: agriculture; carbon emissions; carbon sequestration; profit; Texas High Plains; water consumption.

1. Introduction

Scientists have observed that increasing concentrations of atmospheric greenhouse gases (GHG) could have important ecological impacts (Spencer, 2011). Approximately 80% of current GHG emissions are due to carbon dioxide (CO_2) production (Lashof and Ahuja, 1990) and there are concerns that continued increases in the atmospheric concentration of CO_2 could lead to significant changes in climate. In order to achieve cuts in emissions, especially of CO_2, all aspects of human activity, including agriculture, need to be considered. Agriculture contributes to GHG emissions mostly due to fuel consumption for a) farm machinery and field operations and b) irrigation (energy used to power pump and distribute water). Fertilizer and pesticide usage (herbicides, insecticides, fungicides) is also linked to CO_2 release because pesticides are manufactured from crude petroleum or natural gas products (West and Marland, 2002).

The continued political and scientific concern over GHG emissions has resulted in increased investigation of alternative techniques to reduce 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. In this process, atmospheric CO_2 is transferred into long-lived pools and stored, so that it is not immediately reemitted. Plants, trees and crops absorb CO_2 from the atmosphere through photosynthesis and store it as carbon in biomass (tree trunks, branches, foliage and roots) and soils in a process called "terrestrial carbon sequestration" (EPA, 2011). When carbon sequestration is greater than carbon releases over some period, a reservoir (carbon sink) that accumulates and stores carbon occurs. Agricultural activities can increase GHG in the atmosphere, but they can also sequester additional carbon, depending on practices, crops, and other variables.

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.

The main objective of this study was to evaluate carbon emission and carbon sequestration in the Texas High Plains (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.

2. Data 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 in Northwest Texas.

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). Moreover, using Wright and Hudson's model that measures carbon emissions, net carbon footprint (difference between carbon emissions and carbon sequestration) was evaluated (Wright and Hudson, 2011). 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, 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, 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. The same carbon and moisture content, root to shoot ratio and harvest index were assumed regardless of yield. 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:

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

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:

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

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:

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

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. This model was constrained in a way that the yield for each crop in each county was at least equivalent to the minimum yield from 2000-2009, found in 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 to be 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 (*ABG*) 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:

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

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:

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

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:

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

Total revenue from carbon sequestration was calculated by equation 8:

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

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:

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

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:

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

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 $S_{ij,}$ 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_{ij}), (equation 10). 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.

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

Results regarding comparison between conventional and no till were consistent across the entire THP and were illustrated for two counties, Dallam as a representative of the Northern High Plains (NHP) and Hale as a representative of the Southern High Plains (SHP). For more information and complete estimates for all counties, see Zivkovic, S. and Hudson, D. "Carbon sequestration and carbon management policy effects on production agriculture in the Texas High Plains".

Looking at the data on carbon emissions and carbon sequestration from dry sorghum in Dallam County (Table 1), carbon emissions (69.2 lbs/acre) under conventional till were higher than carbon emissions (52.02 lbs/acre) in no till. This is because the amount of carbon emissions in no till was reduced by all field operations because they were present only in conventional till.

Observing the data on carbon sequestration from the same crop (dry sorghum), it was found that more carbon was sequestered under conventional till (69.49 lbs/acre) than no till (23.2 lbs/acre). This result indicated that total net carbon from no till (difference between carbon emissions and carbon sequestration, multiplied by planted acres) was 590,894.62 lbs/acre. Under conventional tillage this difference was negative 5,843.34 lbs/acre, indicating that carbon sequestration was greater than carbon emissions. Finally, looking at the county level data for all crops, total net carbon under conventional till (147,249,701.36 lbs/acre) was less than total net carbon in no till (189,926,293.66 lbs/acre).

Table 1
Dallam County - total net carbon footprint (lbs/acre), conventional till vs. no till

	Conventional till				No till			
	Carbon emissions	Carbon sequestration	Planted acres	Total net carbon	Carbon emissions	Carbon sequestration	Planted acres	Total net carbon
Corn	1,016.86	411.70	172,200.00	104,208,682.76	1,001.54	218.14	172,200.00	134,900,955.14
Dry Cotton	96.80	0.00	0.00	0.00	75.34	0.00	0.00	0.00
Irr. Cotton	196.52	0.00	0.00	0.00	177.11	0.00	0.00	0.00
Peanuts	195.87	0.00	0.00	0.00	133.46	0.00	0.00	0.00
Dry Sorghum	69.20	69.49	20,500.00	-5,843.34	52.02	23.20	20,500.00	590,894.62
Irr. Sorghum	638.47	145.51	0.00	0.00	622.04	48.58	0.00	0.00
Dry Wheat	67.59	33.66	57,500.00	1,951,366.11	52.02	16.17	57,500.00	2,061,722.73
Irr. Wheat	576.29	184.91	105,000.00	41,095,495.84	559.04	88.83	105,000.00	49,372,721.18
Total	2,857.62	845.26	355,200.00	147,249,701.36	2,672.59	394.92	355,200.00	186,926,293.66

Data from Hale County (Table 2) indicated the same trend, as total net carbon in conventional till (176,144,779.94 lbs/acre) was less than total net carbon in no till (215,705,495.70 lbs/acre). There was only one crop in each county, dry sorghum in Dallam and irrigated sorghum in Hale, resulting in greater carbon sequestration than carbon emissions (negative net carbon). Although all other crops were net emitters, conventional till reduced the amount of carbon emitted; consequently the reminder of data analysis was based on conventional tillage as a baseline.

Table 2
Hale County - total net carbon footprint (lbs/acre), conventional till vs. no till

	Conventional till				No till			
	Carbon emissions	Carbon sequestration	Planted acres	Total net carbon	Carbon emissions	Carbon sequestration	Planted acres	Total net carbon
Corn	983.66	379.00	0.00	0.00	963.11	200.82	0.00	0.00
Dry Cotton	185.50	53.60	39,900.00	5,262,885.75	157.79	27.87	39,900.00	5,183,964.51
Irr. Cotton	836.27	214.23	275,300.00	171,247,897.70	813.23	111.38	275,300.00	193,219,497.68
Peanuts	197.93	0.00	0.00	0.00	133.46	0.00	0.00	0.00
Dry Sorghum	87.21	79.02	0.00	0.00	65.03	26.38	0.00	0.00
Irr. Sorghum	118.21	129.26	33,115.70	-366,003.52	565.63	43.16	33,115.70	17,302,033.51
Dry Wheat	67.59	37.01	0.00	0.00	52.02	17.78	0.00	0.00
Irr. Wheat	811.27	241.10	0.00	0.00	162.78	115.82	0.00	0.00
Total	3,287.65	1,133.22	348,315.70	176,144,779.94	2,913.06	543.20	348,315.70	215,705,495.70

There was a reason to believe that carbon emission estimates from the state extension services were overestimated. According to a previous study (Zivkovic and Hudson, 2012) the amount of carbon emissions for irrigated cotton as estimated from the budget was compared to the carbon emissions distribution from the actual farm operations. Results indicated that the budget-based emission value remained outside the 95% confidence interval of the distribution and were 44% higher than actual mean estimates. Nevertheless, further analysis was done with data from the state extension service, although it was believed that they were overestimated.

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. Tables 3 and 4 show results for two representative counties, Dallam and Hale. Carbon emissions per acre were calculated on per acre basis while the total carbon emissions (not shown in tables) were calculated as a product of planted acres and carbon emissions per acre. Total net carbon (shown in tables) is a difference between carbon emissions 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 almost half of total planted acres (355,200) in this county was allocated to corn (172,200), while the remaining planted acres included dry sorghum (20,500), dry wheat (57,500), and irrigated wheat (105,000). Corn consumed the maximum water allowed (23 inches) but water was applied to the other irrigated crops as well. Besides dry sorghum, all other crops were net emitters in this county.

Table 3
Dallam County – baseline results

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	172,200.00	23.00	1,016.86	411.70	104,208,682.76	$44,072,128.25	$0.00	$44,072,128.25
Dry Cotton	0.00	0.00	96.80	0.00	0.00	$0.00	$0.00	$0.00
Irr. Cotton	0.00	0.00	196.52	0.00	0.00	$0.00	$0.00	$0.00
Peanuts	0.00	0.00	195.87	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	20,500.00	0.00	69.20	69.49	-5,843.34	$386,354.63	$0.00	$386,354.63
Irr. Sorghum	0.00	14.49	638.47	145.51	0.00	$0.00	$0.00	$0.00
Dry Wheat	57,500.00	0.00	67.59	33.66	1,951,366.11	$1,364,094.98	$0.00	$1,364,094.98
Irr. Wheat	105,000.00	13.97	576.29	184.91	41,095,495.84	$25,462,832.45	$0.00	$25,462,832.45
Total	355,200.00	51.46	2,857.62	845.26	147,249,701.36	$71,285,410.32	$0.00	$71,285,410.32

Results in Hale County showed that 80% of total planted acres (348,316) were allocated to irrigated cotton (275,300) and the rest was applied to dry cotton (39,900) and irrigated sorghum (33,116). Although water was applied to corn, irrigated cotton, and irrigated wheat, only irrigated sorghum (which received no water) resulted in carbon sequestration greater than carbon emissions while all other crops were net emitters.

Table 4
Hale County – baseline results

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	0.00	23.00	983.66	379.00	0.00	$0.00	$0.00	$0.00
Dry Cotton	39,900.00	0.00	185.50	53.60	5,262,885.75	$6,683,849.57	$0.00	$6,683,849.57
Irr. Cotton	275,300.00	21.60	836.27	214.23	171,247,897.70	$242,816,091.99	$0.00	$242,816,091.99
Peanuts	0.00	0.00	197.93	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	87.21	79.02	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	33,115.70	0.00	118.21	129.26	-366,003.52	$947,913.16	$0.00	$947,913.16
Dry Wheat	0.00	0.00	67.59	37.01	0.00	$0.00	$0.00	$0.00
Irr. Wheat	0.00	23.00	811.27	241.10	0.00	$0.00	$0.00	$0.00
Total	348,315.70	67.60	3,287.65	1,133.22	176,144,779.94	$250,447,854.72	$0.00	$250,447,854.72

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 planted acres, water consumption, yield, and, therefore, net revenue from the production (Tables 5 and 6). Due to close connection between irrigation and carbon emissions, reduction of carbon emissions results in reduction of water applied to a crop. For more information and complete estimates of reduction in water consumption see Zivkovic, S. and Hudson, D. “Carbon sequestration and carbon management policy effects on production agriculture in the Texas High Plains”.

Table 5
Dallam County – constraint

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	163,490.05	20.96	955.50	392.67	92,017,504.47	$39,549,923.47	$0.00	$39,549,923.47
Dry Cotton	0.00	0.00	96.80	0.00	0.00	$0.00	$0.00	$0.00
Irr. Cotton	0.00	0.00	196.52	0.00	0.00	$0.00	$0.00	$0.00
Peanuts	0.00	0.00	195.87	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.28	0.00	69.20	69.49	-0.08	$5.27	$0.00	$5.27
Irr. Sorghum	0.00	14.49	638.47	145.51	0.00	$0.00	$0.00	$0.00
Dry Wheat	57,500.00	0.00	67.59	33.66	1,951,366.11	$1,364,094.98	$0.00	$1,364,094.98
Irr. Wheat	105,000.00	8.97	425.52	157.56	28,136,757.43	$23,459,079.27	$0.00	$23,459,079.27
Total	325,990.33	44.42	2,645.49	798.87	122,105,627.93	$64,373,102.99	$0.00	$64,373,102.99

Comparing results from this scenario with the baseline results for Dallam County found that planted acres for corn and dry sorghum decreased by 5.06% and 99.99%, respectively. Water per acre was reduced by 8.87% for corn and 35.79% for irrigated wheat. Reduction of total carbon emissions also resulted in a reduction of net carbon, 6.99% for corn and 31.53% for irrigated wheat. Therefore, net revenue from production decreased by 9.69%. In Hale county, planted acres of irrigated sorghum were reduced to zero. For irrigated cotton water was reduced by 18.06% while applied water for corn and irrigated wheat remained the same as in the baseline. Because water for irrigated cotton was reduced, net carbon from irrigated cotton was reduced as well (by 16.95%). Reductions in water usage caused a decrease in yield and, therefore, total net revenue from production was decreased by 3.19%.

Table 6
Hale County – constraint

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	0.00	23.00	983.66	379.00	0.00	$0.00	$0.00	$0.00
Dry Cotton	39,900.00	0.00	185.50	53.60	5,262,885.75	$6,683,849.57	$0.00	$6,683,849.57
Irr. Cotton	275,300.00	17.70	718.88	202.27	142,222,493.18	$235,772,080.96	$0.00	$235,772,080.96
Peanuts	0.00	0.00	197.93	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	87.21	79.02	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	0.00	0.00	118.21	129.26	0.00	$0.00	$0.00	$0.00
Dry Wheat	0.00	0.00	67.59	37.01	0.00	$0.00	$0.00	$0.00
Irr. Wheat	0.00	23.00	811.27	241.10	0.00	$0.00	$0.00	$0.00
Total	315,200.00	63.70	3,170.26	1,121.27	147,485,378.93	$242,455,930.53	$0.00	$242,455,930.53

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). Results of this scenario are shown in Tables 7 and 8.

According to the results for Dallam County, total planted acres were lower (by 5.77%) in the model where a tax was imposed compared to the unconstrained model (baseline). Although planted acres for corn, dry wheat and irrigated wheat remained the same as in the baseline, implementation of a tax forced all planted acres for dry sorghum to be zero. Even if the reduction of total carbon emissions reduced planted acres of corn by 5.06%, imposing of a tax brought them back to the same amount as in the baseline model. These results indicate that taking away planted acres from other crops and applying them to corn would be more profitable. The highest carbon emissions came from corn and irrigated wheat. The decline of total carbon emissions to 85% of the baseline forced reduction in water use while applying a tax resulting in much greater water reduction for these two crops, 14.17% and 40.23% for corn and irrigated wheat, respectively. Net carbon (from tax model) was also reduced by 11.07% for corn and 35.17% for irrigated wheat, compared to the baseline model, while total net revenue from production was reduced by 9.87% compared to the baseline.

Table 7
Dallam County – tax

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	172,200.00	19.74	918.57	380.39	92,675,104.07	$39,953,175.24	$0.00	$39,953,175.24
Dry Cotton	0.00	0.00	96.80	0.00	0.00	$0.00	$0.00	$0.00
Irr. Cotton	0.00	0.00	196.52	0.00	0.00	$0.00	$0.00	$0.00
Peanuts	0.00	0.00	195.87	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	69.20	69.49	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	0.00	14.49	638.47	145.51	0.00	$0.00	$0.00	$0.00
Dry Wheat	57,500.00	0.00	67.59	33.66	1,951,366.11	$1,364,094.98	$0.00	$1,364,094.98
Irr. Wheat	105,000.00	8.35	406.83	153.08	26,643,264.19	$22,931,215.51	$0.00	$22,931,215.51
Total	334,700.00	42.57	2,589.86	782.12	121,269,734.38	$64,248,485.73	$0.00	$64,248,485.73

In Hale County, a tax reduced planted acres to zero for dry cotton and irrigated sorghum, compared to baseline, indicating that allocation of acres to these two crops would not be profitable if producers were required to pay tax on carbon emissions. Planted acres for irrigated cotton remained the same as in the baseline. In this county, water use was reduced only for irrigated cotton (by 13.94%) and was eliminated for sorghum. Total net revenue from production was reduced by 4.72% compared to the baseline.

Table 8
Hale County – tax

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	0.00	23.00	983.66	379.00	0.00	$0.00	$0.00	$0.00
Dry Cotton	0.00	0.00	185.50	53.60	0.00	$0.00	$0.00	$0.00
Irr. Cotton	275,300.00	18.59	745.77	205.73	148,672,076.61	$238,629,131.83	$0.00	$238,629,131.83
Peanuts	0.00	0.00	197.93	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	87.21	79.02	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	0.00	0.00	118.21	129.26	0.00	$0.00	$0.00	$0.00
Dry Wheat	0.00	0.00	67.59	37.01	0.00	$0.00	$0.00	$0.00
Irr. Wheat	0.00	23.00	811.27	241.10	0.00	$0.00	$0.00	$0.00
Total	275,300.00	64.59	3,197.14	1,124.73	148,672,076.61	$238,629,131.83	$0.00	$238,629,131.83

3.4. Payment for sequestration

The next step in our data analysis introduced a carbon price and estimated net revenue from the sequestration. The carbon price used for this analysis was $90/metric ton or $0.0408/lbs, which is at the maximum of the EPAs expected carbon prices (EPA, 2009). 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 no change except for total net revenue, primarily due to the increase of the net revenue from the sequestration arising from dryland sorghum (Table 9). These results indicated that payment for sequestration did not change anything because planted acres and water consumption were already optimally applied.

Table 9
Dallam County – payment for sequestration

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	172,200.00	23.00	1,016.86	411.70	104,208,682.76	$44,072,128.25	$0.00	$44,072,128.25
Dry Cotton	0.00	0.00	96.80	0.00	0.00	$0.00	$0.00	$0.00
Irr. Cotton	0.00	0.00	196.52	0.00	0.00	$0.00	$0.00	$0.00
Peanuts	0.00	0.00	195.87	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	20,500.00	0.00	69.20	69.49	-5,843.34	$386,354.63	$238.54	$386,593.18
Irr. Sorghum	0.00	14.49	638.47	145.51	0.00	$0.00	$0.00	$0.00
Dry Wheat	57,500.00	0.00	67.59	33.66	1,951,366.11	$1,364,094.98	$0.00	$1,364,094.98
Irr. Wheat	105,000.00	13.97	576.29	184.91	41,095,495.66	$25,462,832.45	$0.00	$25,462,832.45
Total	355,200.00	51.46	2,857.62	845.26	147,249,701.18	$71,285,410.32	$238.54	$71,285,648.87

In Hale County there were changes regarding planted acres, net revenue and total net carbon. Planted acres for irrigated sorghum increased by 1.58%, indicating that planting of this crop was more profitable than planting other crops when including sequestration, consequently reducing total net carbon. An increase of planted acres of irrigated sorghum led to an increase in net revenue from both, production and sequestration. Therefore, total net revenue for the county was increased by 0.01% (Table 10).

Table 10
Hale County – payment for sequestration

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	0.00	20.16	898.23	347.58	0.00	$0.00	$0.00	$0.00
Dry Cotton	15,205.74	0.00	185.50	52.59	2,020,947.48	$2,246,284.01	$0.00	$2,246,284.01
Irr. Cotton	178,000.00	15.49	652.21	135.05	92,053,578.97	$90,269,139.24	$0.00	$90,269,139.24
Peanuts	6,300.00	23.00	890.92	171.06	4,535,136.83	$2,068,004.47	$0.00	$2,068,004.47
Dry Sorghum	4,042.94	0.00	87.21	78.00	37,216.95	$154,484.33	$0.00	$154,484.33
Irr. Sorghum	7,944.00	22.66	801.05	357.75	3,521,551.37	$734,338.16	$0.00	$734,338.16
Dry Wheat	0.00	0.00	67.59	35.80	0.00	$0.00	$0.00	$0.00
Irr. Wheat	0.00	23.00	811.27	221.99	0.00	$0.00	$0.00	$0.00
Total	211,492.68	104.32	4,393.98	1,399.82	102,168,431.61	$95,472,250.20	$0.00	$95,472,250.20

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. Results are shown in Tables 11 and 12.

Compared to the baseline, in both counties carbon emission reduction and payment for the sequestration decreased total planted acres, water consumption and, therefore, total net revenue by 9.67% in Dallam and 3.19% in Hale County. Net carbon was also reduced because a decrease in water caused a decrease in carbon emissions. On the other hand, water reduction caused lower yields and lower net revenue. This scenario was very similar to the model when only carbon emissions were reduced, the only difference was that net revenue was increased by the amount of payment for sequestration with no changes in crop mix.

Table 11
Dallam County – constraint and payment for sequestration

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	162,414.51	20.96	955.44	392.65	91,406,099.56	$39,287,470.92	$0.00	$39,287,470.92
Dry Cotton	0.00	0.00	96.80	0.00	0.00	$0.00	$0.00	$0.00
Irr. Cotton	0.00	0.00	196.52	0.00	0.00	$0.00	$0.00	$0.00
Peanuts	0.00	0.00	195.87	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	15,020.83	0.00	69.20	69.49	-4,281.55	$283,091.11	$174.79	$283,265.89
Irr. Sorghum	0.00	14.49	638.47	145.51	0.00	$0.00	$0.00	$0.00
Dry Wheat	57,500.00	0.00	67.59	33.66	1,951,366.11	$1,364,094.98	$0.00	$1,364,094.98
Irr. Wheat	105,000.00	8.97	425.50	157.55	28,134,636.46	$23,458,379.22	$0.00	$23,458,379.22
Total	339,935.34	44.42	2,645.41	798.85	121,487,820.58	$64,393,036.22	$174.79	$64,393,211.01

Table 12
Hale County – constraint and payment for sequestration

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	0.00	23.00	983.66	379.00	0.00	$0.00	$0.00	$0.00
Dry Cotton	39,900.00	0.00	185.50	53.60	5,262,885.75	$6,683,849.57	$0.00	$6,683,849.57
Irr. Cotton	275,300.00	17.70	718.88	202.27	142,222,493.18	$235,772,080.96	$0.00	$235,772,080.96
Peanuts	0.00	0.00	197.93	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	87.21	79.02	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	0.00	0.00	118.21	129.26	0.00	$0.00	$0.00	$0.00
Dry Wheat	0.00	0.00	67.59	37.01	0.00	$0.00	$0.00	$0.00
Irr. Wheat	0.00	23.00	811.27	241.10	0.00	$0.00	$0.00	$0.00
Total	315,200.00	63.70	3,170.26	1,121.27	147,485,378.93	$242,455,930.53	$0.00	$242,455,930.53

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 both counties, comparing the model from this scenario with the unconstrained (baseline) model indicated reduction in all components: planted acres, water use, net carbon, and net revenue. In Dallam County (Table 13), comparing this model with the tax imposing model, planted acres for dry wheat were reduced to zero, thus reducing the total net revenue by 0.45%. Water consumption for corn and irrigated wheat increased by 2.84% and 3.59%, respectively, resulting in higher carbon emissions and carbon sequestration. Because an increase in carbon emission was much greater than increase in carbon sequestration, total net carbon was increased by 1.01%, compared to the tax model, but decreased by 9.26%, compared to the baseline.

Table 13
Dallam County – tax and payment for sequestration

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	172,200.00	20.30	935.53	386.11	94,611,720.85	$40,759,189.90	$0.00	$40,759,189.90
Dry Cotton	0.00	0.00	96.80	0.00	0.00	$0.00	$0.00	$0.00
Irr. Cotton	0.00	0.00	196.52	0.00	0.00	$0.00	$0.00	$0.00
Peanuts	0.00	0.00	195.87	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	69.20	69.49	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	0.00	14.49	638.47	145.51	0.00	$0.00	$0.00	$0.00
Dry Wheat	0.00	0.00	67.59	33.66	0.00	$0.00	$0.00	$0.00
Irr. Wheat	105,000.00	8.65	416.02	155.31	27,374,665.88	$23,198,536.31	$0.00	$23,198,536.31
Total	277,200.00	43.44	2,616.02	790.07	121,986,386.73	$63,957,726.21	$0.00	$63,957,726.21

In Hale County, comparing model from this scenario with the tax imposing model, resulted in no change (Table 14). Comparing this scenario to the baseline, results indicated that dry cotton and irrigated sorghum were not profitable because total planted acres for these two crops were reduced to zero causing total net revenue to decrease by 4.72%. Water applied to cotton was reduced by 13.94% resulting in reduction (by 3.81%) of total net carbon.

Table 14
Hale County – tax and payment for sequestration

Crop	Planted acres	Water per acre	Carbon emission lbs/acre	Carbon sequestr. lbs/acre	Total net carbon	Net revenue from production	Net revenue from sequestr.	Total net revenue
Corn	0.00	23.00	983.66	379.00	0.00	$0.00	$0.00	$0.00
Dry Cotton	0.00	0.00	185.50	53.60	0.00	$0.00	$0.00	$0.00
Irr. Cotton	275,300.00	18.59	745.77	205.73	148,672,076.61	$238,629,131.83	$0.00	$238,629,131.83
Peanuts	0.00	0.00	197.93	0.00	0.00	$0.00	$0.00	$0.00
Dry Sorghum	0.00	0.00	87.21	79.02	0.00	$0.00	$0.00	$0.00
Irr. Sorghum	0.00	0.00	118.21	129.26	0.00	$0.00	$0.00	$0.00
Dry Wheat	0.00	0.00	67.59	37.01	0.00	$0.00	$0.00	$0.00
Irr. Wheat	0.00	23.00	811.27	241.10	0.00	$0.00	$0.00	$0.00
Total	275,300.00	64.59	3,197.14	1,124.73	148,672,076.61	$238,629,131.83	$0.00	$238,629,131.83

3.7. Summary for entire THP

3.7.1. Planted acres

Tables 15 and 16 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. NHP results showed slight changes in corn and irrigated wheat, greater changes in dry sorghum and dry wheat and no change in cotton acreage across the different scenarios. Results for SHP showed larger variations in acreage in all crops, particularly in the case of dry cotton, peanuts, sorghum, and wheat.

Table 15
NHP - percentage difference in planted acres

Crop	Constraint	Tax	Payment for sequestration	Constraint and payment for sequestration	Tax and sequestration
Corn	-3.70%	0.00%	0.00%	-4.35%	0.00%
Dry Cotton	0.00%	0.00%	0.00%	0.00%	0.00%
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	-34.38%	-43.02%	0.00%	-38.74%	-43.02%
Irr. Sorghum	0.00%	0.00%	0.00%	0.00%	0.00%
Dry Wheat	-14.77%	-47.18%	-10.19%	-16.72%	-43.06%
Irr. Wheat	-0.17%	0.00%	0.00%	-0.17%	0.00%
Total	-10.43%	-23.21%	-3.93%	-11.81%	-21.62%

Table 16
SHP - percentage difference in planted acres

Crop	Constraint	Tax	Payment for sequestration	Constraint and payment for sequestration	Tax and sequestration
Corn	-7.36%	-15.63%	-10.57%	-10.57%	-19.88%
Dry Cotton	5.91%	-15.43%	-2.27%	-1.40%	-12.01%
Irr. Cotton	-0.13%	0.00%	0.00%	-0.13%	0.00%
Peanuts	-61.05%	-30.93%	-20.13%	-50.42%	-23.14%
Dry Sorghum	-51.72%	-85.37%	4.95%	-65.31%	-82.13%
Irr. Sorghum	-61.31%	-64.58%	-0.30%	-61.31%	-62.78%
Dry Wheat	-100.00%	-100.00%	-9.24%	-100.00%	-100.00%
Irr. Wheat	-37.53%	-43.65%	-76.91%	-76.91%	-76.91%
Total	-10.01%	-17.42%	-4.90%	-14.12%	-17.54%

3.7.2. Net carbon footprint

Table 17 shows percentage difference in total net carbon in the THP, compared to the baseline results. The constraint and tax caused a decrease in net carbon by 7.4% and 6.32%, respectively, because constraining the model automatically reduced the water, and, therefore total carbon emissions. The payment for sequestration reduced the net carbon as well, but only by 0.06%.

Table 17
Percentage difference in total net carbon in THP

	Northern High Plains	Southern High Plains	Texas High Plains
Constraint	-8.85%	-5.43%	-7.40%
Tax	-7.99%	-4.03%	-6.32%
Sequestration	0.00%	-0.15%	-0.06%
Constraint and sequestration	-8.85%	-5.53%	-7.45%
Tax and sequestration	-8.11%	-3.55%	-6.18%

3.7.3. Net revenue

As a reduction of water use caused the decrease in yield and, therefore, a decrease in net revenue from production, total net revenue for the entire region (Table 18) was decreased by reducing the carbon emissions and imposing the tax, by 10.41% and 4.54%, respectively. As expected, payment for sequestration resulted in an increase in net revenue compared to a constraint and/or tax scenarios; however, the net revenue was even lower by 0.54% than net revenue from the baseline. This occurred due to 10 counties (2 in NHP and 8 in SHP) in which payment for sequestration caused a reduction of planted acres, mostly of dryland wheat, dryland sorghum and dryland cotton, which further caused reduction in net revenue from the production. Nevertheless, there were 16 counties (13 in NHP and 3 in SHP) in the THP in which carbon sequestration of dryland and irrigated sorghum was greater than carbon emission so these counties can make a profit from these two crops.

Table 18
Percentage difference in total net revenue in THP

	Northern High Plains	Southern High Plains	Texas High Plains
Constraint	-5.93%	-12.27%	-10.41%
Tax	-6.73%	-3.63%	-4.54%
Sequestration	0.11%	-0.81%	-0.54%
Constraint and sequestration	-5.78%	-3.59%	-4.23%
Tax and sequestration	-6.49%	-3.56%	-4.42%

4. Summary and Conclusions

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. The NHP results showed slight changes in the acreage of corn and irrigated wheat, greater change in dry sorghum and dry wheat, and no change in cotton. The results for SHP showed larger variations in acreage in all crops, particularly in the case of dry cotton, peanuts, sorghum and wheat. In the NHP the majority of water for irrigation was applied to corn while in the SHP the major part of water usage went to cotton. Total water consumption was reduced when carbon was restricted to 85% of the baseline and when a carbon tax was imposed. Total water was also reduced under a scenario when payment for carbon sequestration was introduced. While water per acre in NHP did not change at all, water consumption in SHP decreased because of a decrease in water in two counties, Castro and Swisher.

The carbon constraint and tax caused decrease in net carbon since constraining the model automatically reduced the water and therefore total carbon emissions. Payment for sequestration reduced the net carbon as well, however not substantially. Under this scenario, there was an increase in net revenue compared to constraint and tax scenarios, though the net revenue was not higher than net revenue from the baseline. This is because there are some counties in which payment for sequestration caused reduction of planted acres which further caused reduction in net revenue from the production.

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.

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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