Consortium for Agricultural Soil Mitigation of Greenhouse Gases

Montana State University

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Susan Capalbo, Montana State University, Bozeman, MT; 406-994-5619; scapalbo@montana.edu

Department of Agricultural Economics and Economics

John Antle, Montana State University, Bozeman, MT; 406-994-3706; jantle@montana.edu
Duane Griffith, Montana State University, Bozeman, MT; 406-994-2580; griffith@montana.edu
Linda M. Young, Montana State University, Bozeman, MT; 406-994-5604; lmyoung@montana.edu
Leslie Jones, Montana State University, Bozeman, MT, 406-994-5636, lesliej@montana.edu

Land Resources and Environmental Sciences

Perry R. Miller, Montana State University, Bozeman, MT; 406-994-5431; pmiller@montana.edu
Richard E. Engel, Montana State University, Bozeman, MT; 406-994-5295; rengel@montana.edu

Cooperators

Siân Mooney, University of Wyoming, Laramie, WY; 307-766-2389; smooney@uwyo.edu
Jetse Stoorvogel, Wageningen University, The Netherlands; 31-317-484043; jetse.stoorogel@wur.nl

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Task 1. Basic Processes and Mechanisms

Item #1 :

Project Title: Effect of Surface Residues on Carbon Sequestration under No-Till

Carbon sequestration is defined as the net removal of CO_2 from the atmosphere into long-lived pools of carbon. In terrestrial ecosystems, this process begins with photosynthesis. Plants absorb carbon dioxide from the atmosphere and use it to build the carbon skeletons that form the plant shoot and root tissues. Once the plant dies the carbon in the shoot (above-ground biomass) and root tissue is decomposed by microorganisms. A portion of this carbon is assimilated by the microbes and eventually becomes part of the stable soil organic carbon pool. However, which of these residue materials, shoot or root, is more important to accumulation of soil organic carbon in agricultural ecosystems? The objective of this research project has been to answer this question, and better understand the basic processes responsible for soil carbon sequestration.

More specifically, the project did the following:
- contrasted changes in soil organic C levels under three no-till cropping sequences (fallow-wheat, continuous wheat, pulse-wheat) as influenced by varying levels of shoot residue inputs.
- determined the relative importance of root or shoot material to carbon sequestration in terrestrial managed ecosystems.

Project Results:
- Field experiments were established on the property of the MSU-Post Research Farm and consisted of three cropping system main-plots including a fallow-wheat, spring wheat-winter wheat, and spring pea-winter wheat rotations. All cropping systems were managed as no-till.
- Three micro-plots (1.5 x 2.5 m) with permanent markers were identified within each main-plot for conducting the following shoot residue comparisons:
  - removal of all shoot material (i.e., no residue)
  - all shoot material produced (minus grain) returned (i.e., 1x residue)
  - shoot material is returned at twice the rate applied to the 1x residue treatment. (i.e., referred to as a 2x residue treatment).
- Soil samples were collected during September 2002 and September 2004, consistent with recommendations by Conant and Paustian (2002).
- Results showed no effect of cropping system and residue management on soil organic C levels (Table 1) at any of the three sampling depths (0-10, 10-20, and 20-30 cm) or for the sum of the three depth layers.

Table 1. Organic C levels as affected by cropping system and residue management at MSU-Post Farm, September 2004.

Cropping system	**Residue**	**Organic carbon**			
		0-10 cm	**10-20 cm**	**20-30 cm**	**Total**
		metric tones/ ha			
fallow-wheat	No residue	14.5	13.2	9.9	37.6
	1x residue	14.0	12.9	10.7	37.6
	2x residue	14.6	13.9	9.9	38.3
wheat-wheat	No residue	15.3	13.5	10.2	38.9
	1x residue	14.8	13.8	10.3	39.0
	2x residue	14.7	13.1	10.3	38.1
pea-wheat	No residue	14.9	13.3	9.8	37.9
	1x residue	14.4	13.5	10.3	38.2
	2x residue	14.8	13.5	11.1	39.4
ANOVA					
Cropping system (CS)		NS	NS	NS	NS
Residue		NS	NS	NS	NS
CS x Residue		NS	NS	NS	NS

Note: NS = not significant

<u>Item #2 – Impact Statement</u>:

While significant changes in soil organic C levels typically occur over a longer time span than the 2–3 years supported by this study, and hence, the lack of detected response to the applied treatments, the study is important as part of our ongoing efforts to provide a long enough time frame to detect if there are significant differences. This study, using the methodology established through the CASMGS efforts is being continued through 2006 season with other research funding including NSF, USDA, and DOE. Soil organic C levels will be measured based on samples collected in September 2006. The findings from this research will be significant as the United States attempts to address the opportunities and challenges associated with potential carbon markets as an offset for CO_2 emissions. In addition, the long-term needs within agriculture are to address the environmental services that alternative land-use management provides, including the opportunity to sequester carbon as well as address other environmental concerns.

Task 2. Best Management Practices

Item #1:

Project Title: Estimating C Sequestration Due to Sustainable Cropping Systems

More specifically, the objectives of Task 2 were to:

- Estimate direct and indirect changes in soil organic C and N_2O emissions as result of changes in tillage and cropping intensity.
- Compare alternative tillage systems and cropping intensity for full GHG accounting (energy-related and soil-sequestered C and N_2O) in dryland farm field settings.
- Compare economic net returns among alternative cropping system strategies and estimate the economic costs of converting to no-till from conventional till for a group of surveyed participants within Montana.
- Enable a move toward a full GHG accounting framework within the economic modeling efforts under Task 3.
- Estimate the potential for C sequestration as a result of adopting windbreaks and riparian plantings using different tree species in locations across the state.
- Collaborate with MSU Task Groups 3, 4 and 5 to assist with modeling, measurement, and outreach objectives in on-farm scenarios to provide "on-the-ground" assessments of economic benefits to farmers in return for GHG mitigation practices.

Project Results:
The results for Task 2 are organized under five activities. Since there are numerous tables, we have included some of these in an Appendix to this report.

- To provide information about C sequestration rates in Montana cropland, three studies were initiated:
    - The first study, completed in 2003, used a predictive model (Century) to estimate historic gains in soil carbon 6–10 years following conversion to no-till management at six farm fields in north central Montana. When field-specific soil textures were used the model predicted soil C gains within 10% of measured values with soil C sequestration rates ranging from 0.07 to 0.38 tons/acre/yr among the field sites.
    - The second study, initiated in 2002, contrasts the effects of tillage system and cropping intensity on C sequestration in six farm fields in north central Montana. This study is still ongoing; costs, returns and net GHG emissions are being closely monitored for each treatment and augmented with data collected from a survey instrument developed for this study. These farmers will be engaged in further negotiations for C credit contracts and their full GHG emissions will be estimated using data from a previous study of crop production practices within Montana, as well as collaboration from agricultural engineers at Kansas State University.
    - The third study was initiated in 2002, jointly with Task 1, and compares C sequestration in 9 cropping systems within a replicated experimental plot design.
    - Both the second and third studies are planned to run for 10 years. The information from these studies is being incorporated into an economic analysis that seeks to

incorporate a full GHG accounting system within existing models of C sequestration within Montana; in parallel these results are also being used to examine the economics of soil carbon sequestration in perennial ecosystems and the potential co-costs and co-benefits.

1. On-Farm Tillage Systems Comparison

- Six paired farm fields in north central Montana were selected to compare conventional with no-till wheat cropping systems (Fig. 1). Site selection was constrained by management history, soil characteristics, and current crop growth to enable valid inferential comparisons of these fields based on tillage management.

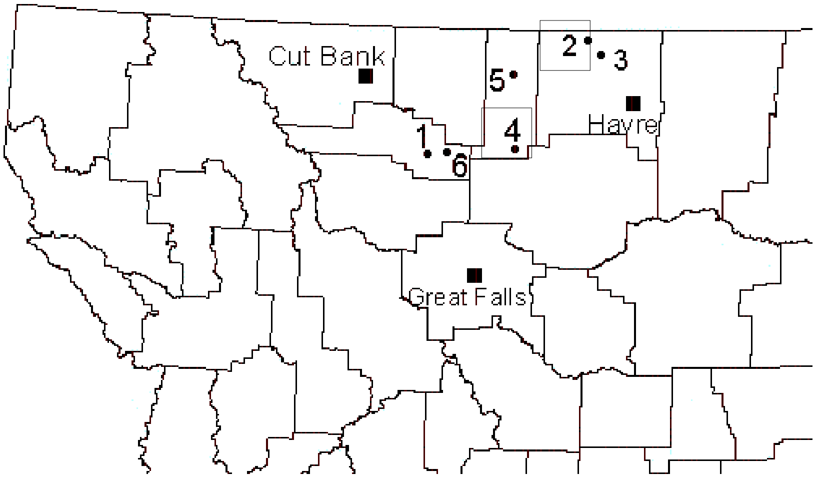

Fig. 1. Locations of six farms in north central Montana for the on-farm tillage systems comparison.

- This study was completed in 2003 and the results have been summarized in a M.S. thesis (Bricklemyer, 2003) listed in Item #3 (publications). This research combined field-scale soil sampling and the use of the Century model to explore field-scale SOC variability and the effects of soil texture input data sources (STATSGO and SSURGO databases) on predicted SOC dynamics in north central Montana.
- The Century model accurately predicted SOC content at five sites using site-specific soils data (10% deviation from measured values). Neither the STATSGO (1:250,000 scale) nor SSURGO (1:24,000 scale) soil databases adequately predicted soil textures, nor supplied adequate soil textural information for use in the Century model and so introduced error to field-specific predictions.
- Century proved to be sensitive to the effects of clay content when predicting the amount of SOC in a particular field; however, the model was insensitive to the effects of soil texture on C sequestration rates as a result of no-till management.
- Additional research is needed to determine if a consistent relationship exists between soil texture and the effect of tillage on SOC and thus determine if adjustments are needed to the Century model's treatment of soil texture.

- These research results will support future measurement, prediction, and general understanding of soil organic carbon sequestration in semiarid dryland agricultural systems. Reliable measurement of soil organic carbon change associated with a shift in tillage management can be difficult, for SOC varies spatially and the degree of variability can be substantial.
- The effect of soil textural variation at field-, 1:24,000 (SSURGO), and 1:250,000 (STATSGO) scales on the predictive capability of the Century model were explored. Both the SSURGO and STATSGO databases were limited in their accuracy of predicting soil textures at the sampled fields.
- Using field-scale soil textures and site-specific management data, Century accurately predicted soil organic carbon at five sites in north central Montana to within an average of 10% (range of -1 to +28%) of measured values.
- Model results for the five sites in Montana showed little difference in the amount of carbon stored in coarse-textured soils (5% clay) compared to fine-textured soils (35-40% clay), with the exception of the Ft. Benton site. The insensitivity of Century to a soil textural effect on C storage under no-till management assumes that a strong relationship exists between soil texture and the effect of tillage on soil organic carbon.
- This research was not an exhaustive look at the effects of soil texture on Century's predictive capabilities. Largely, it was shortcomings of the SSURGO and STATSGO soils databases that limited the effectiveness of Century. The model was sensitive to the effects of soil texture when predicting the amount of SOC in fields managed with and without tillage; however, the model was not sensitive to the effects of soil texture on the ability of a particular soil texture to accumulate SOC over a 6 to 10 year period of no-till management.
- From a modeling standpoint, neither the SSURGO nor the STATSGO databases provided adequate soil textural information for use in the Century model, thus site-specific soil information is recommended for use with the Century model.

2. Farm Benchmark Comparisons of Cropping Intensity and Tillage Systems and Their Opportunity Cost of Adoption under a Full GHG Accounting System

(It is noted that the cropping systems experiment is planned to run 5–10 years. The results reported here pertain to the first 2–3 years of the experiment.)

- Experimental sites were established at six cooperative farm sites in north central Montana (same region as shown in Fig. 1, but different specific field sites).
- Tillage and cropping intensity effects (i.e., tilled and no-till, continuous and crop-fallow) are compared using adjacent tillage blocks and splitting them into crop-fallow and continuous crop. Thirty-two-ha fields were split into four contiguous 8-ha fields to facilitate sampling of the same soil type within the experimental site. In the continuous crop system (i.e., wheat-pulse), a crop is seeded every year and managed according to seasonal water availability, at the producer's discretion.
- This activity is providing valuable information on variability and uncertainty in yields (i.e., risk), input use, C production and other factors for modeling in Task 3, measurement in Task 4, and complement outreach activities under Task 5.
- Summary Statistics for selected questions are given in Appendix Table 1.

- Farm benchmark sites were established and baseline soil samples were obtained by Ross Bricklemyer in September and October of 2002. Baseline soil carbon values show greater variability than soil texture and pH values.
- Statistical analysis of carbon change between 2002 and 2004 shows inconclusive results after only 2 years of a management change. Studies in agoecozones similar to the study area have not seen statistically significant changes in SOC until a minimum of 4 years after a management change. The plots are scheduled for the 4-yr SOC sampling after harvest in 2006.
- In addition to changes in soil carbon, the agronomic effects of the treatments were also investigated. Total biomass was measured at precisely the same locations that soil carbon is measured. Crop biomass (Appendix Table 6) was measured during the legume rotation for each plot at each site in June and July of 2003. No statistically significant differences (α= 0.1) occurred in crop biomass in 2003.
- Crop biomass samples were also harvested for total biomass and yield determination at all sites during the wheat rotation in August of 2004. Comparison of total 2004 wheat crop biomass showed that no-till was 9% greater than the tilled system and the continuous cropping system was only 72% of the alternate year fallow-wheat system (Appendix Tables 7 and 8). Crop biomass differences are likely attributable to soil water status differences between treatments. 2004 wheat yield results shared similar results as wheat biomass (Appendix Tables 9 and 10). Wheat protein tended to be higher in tilled and recrop fields (Appendix Tables 11 and 12). The amount of C returned to the soil in 2003–4 was greatest in NT and continuous crop plots (Appendix Tables 13 and 14).
- Soil emissions of NO_2 were measured during the 2003 growing season (see Fig. 2 below). Greater NO_2 emissions occurred in the higher N fertilizer treatment and emission pulses appear to coincide with precipitation events.

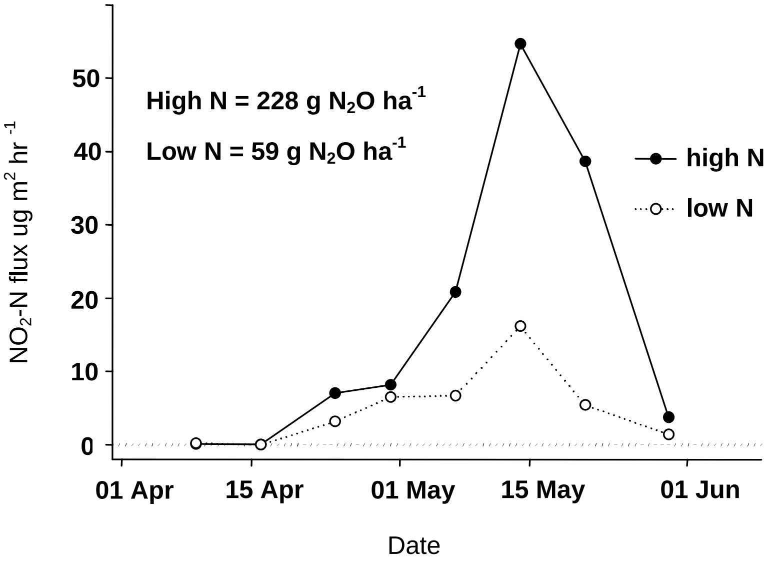

Fig. 2. Nitrous oxide emissions from a continuous wheat rotation where two N rates (65 and 155 kg ha-1) were applied. Post Research Farm, Bozeman, MT, 2003.

3. Cropping Systems Study

- This study was established in the fall of 2002 to service and complement Tasks 1 and 2. Nine cropping system (Table 2) main-plots (24.4 x 7.4 m) are replicated four times in a randomized complete block design. The site is managed as a single-phase cropping system study with only one phase of the rotation occurring in any one season.

Table 2. Description of treatments at the long-term cropping systems study site near Bozeman, MT. Nitrous oxide emission measurements will be made in Treatments 1-4 and 9.

Trt #	Cropping Sequence
1	Fallow - winter wheat (conventional tillage)
2	Fallow - winter wheat (no-till)
3	Spring wheat - winter wheat (no-till)
4	Spring pea - winter wheat (no-till)
5	Winter pea - winter wheat (no-till)
6	Winter pea (forage) - winter wheat (no-till)
7	Winter pea (forage) - spring wheat (no-till)
8	Winter pea (manure) - spring wheat (conventional tillage-organic)
9	Grass-legume mixture or western wheatgrass (Pascopyrum smithii), slender wheatgrass (Elymus trachycaulus), green needlegrass (Nassella viridula), alfalfa (Medicago sativa L.)

- Treatments 1-7 are divided into sub-plots representing moderate and high N fertility, plus a zero N control. Fertilizer N was applied during phases of the rotation where spring or winter wheat was grown. The moderate and high N fertility rates are determined from spring soil samples to a 60-cm depth. The fertilizer N rates are adjusted to provide 90 and 180 kg ha-1 available N (soil NO_3-N + fertilizer N), respectively. Details are provided in the full report.
- Data from the 2003 and 2004 Montana wheat growers survey was used to develop enterprise and cropping system budgets of wheat-fallow and wheat-legume rotations under till and no-till production schemes. Additionally, enterprise budgets were developed for all separate enterprises. The budgets were generated using the MBMS software package.
- Tables 3 and 4 below summarize results. It is interesting to note that no-till production has lower returns than till production. This appears to be due to two factors: fuel costs and chemical costs.

Table 3. Farming system costs and returns.

	NT Wheat/ NT Fallow	NT Wheat/ NT Legume	Till Wheat/ Till Fallow	Till Wheat/ Till Legume
Gross income	$220,018.00	$374,898.00	$220,018.00	$374,898.00
Total variable costs	$306,088.00	$472,577.00	$184,108.00	$366,729.00
Income-variable costs	-$86,070.00	-$97,679.00	$35,910.00	$8,169.00
Total fixed costs	$122,050.00	$138,742.00	$126,725.00	$143,024.00
Total costs	$428,138.00	$611,319.00	$310,833.00	$509,753.00
Net returns	-$208,120.00	-$236,421.00	-$90,815.00	-$134,855.00

Table 4. Per acre costs and returns for enterprises.

	No-till Legume	No-till Wheat	No-till Fallow	Till Legume	Till Wheat	Till Fallow
Gross income	$88.00	$125.01	$0.00	$88.00	$125.01	$0.00
Total variable costs	$130.72	$137.79	$36.12	$114.93	$93.44	$11.17
Income-variable costs	-$42.72	-$12.78	-$36.21	-$26.93	$31.57	-$11.17
Total fixed costs	$40.41	$38.42	$30.92	$41.27	$40.00	$32.01
Total costs	$173.13	$176.21	$67.05	$156.19	$133.44	$43.17
Net returns	-$83.13	-$51.20	-$67.05	-$68.19	-$8.44	-$43.17

4. Conversion of Existing Modeling Efforts to Incorporate Full GHG Accounting

- Field level fuel and fertilizer usage collected in a previous survey of MT producers was used to obtain estimates of changes in fossil fuel use and net GHG emissions resulting from a change to continuous cropping. This activity augments previously completed work on continuous cropping by moving closer to a full GHG accounting framework that will be comparable to those proposed for the tillage changes.
- This activity represents a move toward full GHG accounting and supports economic modeling efforts under Task 3 of the CASMGS efforts.
- Conversion factors that enable calculation of the GHG emissions expected from fertilizer use have been collected from existing literature and field level fertilizer usage from a 1995 survey of Montana producers has been revised to reflect the GHG potential resulting from its use.
- A new input data set has been created for the existing suite of models used to estimate soil C sequestration supply curves within Montana (see later discussion).

5. Direct Opportunity Costs of Adopting Agroforestry Practices to Sequester C in Addition to Co-Costs and Benefits

- This project focused on the potential for C sequestration as a result of adopting windbreaks and riparian plantings using different tree species in locations across the state. It examined: a) the direct economic costs of adopting these practices; b) the indirect energy changes in fossil fuel use (e.g., fuel and fertilizer among others

– in collaboration with Kansas State) and; c) the physical co-benefits and estimates of their potential economic value.

- The potential environmental co-benefits and costs were identified with assistance from NRCS, University and other appropriate sources. Existing non-market valuation studies were reviewed to provide an initial assessment of the possible ranges in economic value of these costs/benefits.
- Although studies are often site specific, this activity served as a low cost scoping study to provide recommendations for further valuation efforts. Completion of this research provided estimates of the biophysical and economic potential for adoption of these practices within a full GHG and economic accounting framework.
- A literature review of the economics of riparian buffers and riparian plantings; crop yield response in the presence of windbreaks, as well as the potential environmental co-costs and benefits was undertaken and the review was incorporated into a related research project that considered the private and public co-benefits of soil carbon sequestration. A general summary of some of these findings is presented in Appendix Tables 15, 16, and 17 and include:
  - The use of no-tillage as a percent of total planted cropland has increased from 6% in 1990 to 22% in 2004 (CTIC, 2005). The increase of 2.9 percentage points from 2002 to 2004 was the largest 2-yr increase since the 1992 to 1994 period.
  - During the 1990 to 2004 time period conventional tillage declined from 48.7% to 37.7% and reduced tillage declined 25.3% to 21.5%.
  - Prices for inputs used for no-tillage systems have been increasing at a slower rate than those for conventional tillage systems over the last 10 years. Herbicide applications are a substitute for tillage operations and use relatively less fuel, machinery, repairs, and labor than tillage operations. Herbicides costs in no-tillage systems have in some cases been shown to offset the savings in labor, energy, repairs, and machinery costs.
  - Information on agricultural input prices compiled by USDA (2004) show that herbicide prices have increased by an average of less than 1% per year from 1994 to 2003. Alternatively, prices of those inputs used more intensively in conventional tillage systems including diesel fuel have increased at an annual average rate of 7.3%, while wage rates, machinery, and repairs have increased at 3.9%, 3.2%, and 2.4%, respectively. If these trends continue, the cost savings from using no-tillage practices should continue to increase.
  - Although the research literature clearly identifies cost savings due to reduced labor, energy, repairs, and equipment, there are mixed results concerning yields and profitability. Numerous studies show either increased, decreased or similar yields. An examination of net return yields similar results. Dhuyvetter and Kastens (1999b) suggest that traditional research and analysis may not be appropriate for uncovering the actual gains associated with less tillage.
  - This research is often conducted using a traditional enterprise budgeting approach which does not totally capture the ability of a farm manager to adjust the whole farm operation to take advantage of reductions in labor, energy, and machinery use. Increased cropping intensity due to reducing

> tillage and an increase in crop hectares made feasible because of less tillage may play an important role in adopting no-tillage. However, no-till adoption on a large scale is still relatively slow, so this would indicate that many farm managers regard it as unprofitable or there are high transactions costs associated with changing tillage practices. The types and magnitude of incentives required to encourage farm managers not already using no-tillage practices to adopt them are important considerations.

Item #2 – Impact Statement:

The use of agricultural best management practices, most notably the adoption of no-till systems, has become a potential technique to sequester (store) carbon in soils and help mitigate the effects of global warming. Efficient sampling designs and the use of process-based soil organic carbon (SOC) dynamics models are potential methods of monitoring and verifying soil carbon change.

The methods used to measure SOC and the Century model proved to be useful tools for determining carbon stored due to no-till management. Additional research is needed to determine if a consistent relationship exists between soil texture and the effect of tillage on SOC and thus determine if adjustments are needed to the Century model's treatment of soil texture. These research results will support future measurement, prediction, and general understanding of soil organic carbon sequestration in semiarid dryland agricultural systems.

The estimates show that the societal value of increased C sequestration could be substantial. Farm management practices that increase C sequestration can reduce sedimentation and nutrient run off, thus improving and protecting water quality. They can also add value to recreation and wildlife. Significant problems exist in trying to estimate the non-market value of increased C sequestration. First it is not clear how much additional C will be sequestered in the future, thus the impact of C sequestration on soil erosion, run-off etc. If soil C sequestration quantities could be estimated, tools already exist to calculate the effect on soil erosion and nutrient run off (see McCarl and Scheider, 1999; Feng, Kling, and Gassman, 2004). The link between physical changes in the environment and economic values is still very weak and an area in which considerable additional work is needed. The studies reported above show that the societal benefits from activities that sequester soil C are thought to be considerable. One caution in interpreting these values is that they could include value generated by other factors in addition to soil C sequestration and thus the benefit of soil C sequestration is some portion of the total values reported.

Finally, although there are many benefits from adopting management practices that sequester additional soil C, as with all technological adoption, some producers will find that additional C sequestration is economically beneficial while others will not. However, as input costs rise, cost savings from no-till increase, enhancing its profitability and potentially resulting in wider adoption in future years. In addition, it is likely that as a market for carbon credits matures within the United States, these prices will also rise, providing producers with an additional commodity to market that could supplement revenues received from crop production, further increasing the financial attractiveness of managing soil carbon.

Task 3: Prediction and Assessment

Part II: Integrated Economic/Ecosystem Modeling and Policy Assessment

Item #1:

Project Title: Integration of Economic and Biophysical Models: Climate Change and Greenhouse Gas Mitigation in Montana and U.S. Agriculture

Project Results:

- Bio-physical ecosystem models (Century) were linked with econometric-process simulation models to simulate economic potential for soil carbon sequestration in central-U.S. agriculture. New methods were investigated to link processes in the Century model with land use and input use decisions in the field/farm scale econometric process model developed at Montana State, so that feedbacks between ecosystem and economic processes are better represented: (1) developing an interface between the Century model, as it is being run on a Unix-based parallel processing system at Colorado State University, and the economic models that are being run in the Windows environment using the Statistical Analysis System (SAS); (2) utilizing the Tradeoff Analysis software developed at Montana State University in collaboration with Wageningen University in the Netherlands.
- The dynamic and spatial properties of the integrated models were studied to assess how estimates of the impacts of soil C and other GHG measures are affected by the choice of spatial scale, temporal scale, and degree of model coupling. These properties were compared at the farm/field, county and MLRA scales in the central United States using primary data collected in previous research by the PIs, and using secondary data collected by various state and federal agencies (see related projects under field-, farm-, and regional-scale modeling). A general conclusion is that the spatial and temporal scale of analysis of soil C rates should match the scale of the policy decision. Therefore, if policy decision makers would like to assess soil C potential at, say, the regional scale, highly detailed, disaggregate soil C estimates are not needed.

Item #2 – Impact Statement:

Using the results of this work, researchers are now able to assess economic potential for soil C sequestration on a regional scale using available data and models.

Item #1:

Project Title: Model Comparisons and Databases for Integrated Assessment Models Climate Change and Greenhouse Gas Mitigation in Montana and U.S. Agriculture

Project Results:

- Results of analysis of economic potential for soil C sequestration were compared from farm-scale and county-scale economic models in the central U.S. region. Sensitivity of results to various model assumptions, economic assumptions, and C rates were investigated. Results were found to be sensitive to C rate estimates and assumptions about design of soil C contracts.
- Minimum-data methods for economic analysis of soil C sequestration were developed, implemented and validated. These methods can be implemented rapidly, at relatively low cost, using simpler models with available secondary data rather than highly detailed farm survey data.

Item #2 – Impact Statement:

Researchers are better able to assess the sources of uncertainty in estimates of soil C sequestration potential. Researchers are able to produce analysis of economic potential for soil C sequestration needed to support policy decision makers more rapidly and at much lower cost than was previously possible. These methods are being adopted by researchers at USDA-ARS and various other research institutions in the United States and elsewhere in the world.

Item #1:

Project Title: Integrated Assessments of Greenhouse Gas Mitigation at Field and Farm Scale: Predict and Assess the C Cycle and GHG Emissions/Mitigation Using Computer Models, Databases and Other Appropriate Tools.

Project Results:

- Integrated economic assessment of soil C costs and changes in GHG in the Northern and Central Great Plains was implemented. Results of these analyses were published in professional journals and included in a survey of research aimed at policy decision makers.
- More specifically, a simplified soil C model (CSTORE) intended for use by field personnel etc and based on the soil C components of Century would be linked to the farm-level economic/financial decision model developed by MSU under alternative ongoing funded research (through Sept 2007). The model includes user-supplied inputs on crop production and management practices as well as default climate and soils data from linked state and county based data sets and enterprise budgets. The work under this activity would be for linking the economic/financial component that addresses the economic feasibility and economic risk at the farm and field scale to the CSTORE model described above.

- This linkage is critical to developing the outreach materials for assessment of carbon sequestration potential at the farm and county levels that is described under Task 5.
- Dissemination and evaluation of decision support tools: funding for the technical development of Decision Support Systems (DSS) such as CSTORE and their programming linkages with enterprise budgets. Availability of a DSS for use by field personnel, crop consultants, etc. can be used to assess alternative strategies for C sequestration. The five regional extension associates have assisted with evaluation and feedback for selected DSS such as CSTORE and serve as points of contact for interested users in their area.
- The on-farm DSS is driven by linkages between CSTORE and economic models. Early efforts in the CASMGS project made good progress in linking these models, but CSU stopped development work on CSTORE. The economic portion of this on-farm DSS required the collection of enterprise budgets from around the United States and development of a model that would allow producers to evaluate the economics of tillage systems and crop mixes. The economic analysis portion of this model was completed and is posted on the web for producers to download and run analysis on their individual farms. Two versions of the same model are available.
- The first is an Excel spreadsheet that can be used by anyone to make detailed calculations for their own operation. Link to Full Excel Spreadsheet: http://www.montana.edu/extensionecon/cropdownloads.html. Scroll down to the link labeled “CASMGS Tillage System Economics.”
- The second is a compiled version of the full Excel spreadsheet but condensed to allow producer evaluation of a pre-selected crop mix for the economics of conventional, minimum and no-till farming systems. The condensed version can be run on the web or on a desktop computer. Link to Condensed Version of Tillage Economics Spreadsheet: http://www.montana.edu/extensionecon/software/CASMGS%20Tillage%20Economics.swf
- The data base of crop enterprise budgets was collected from across the United States and is being used to finish development of a national enterprise budget generator that will be driven by over fifteen hundred land grant university crop enterprise budgets.

Item #2 – Impact Statement:

The policy community is better informed about economic potential for soil C sequestration and its impacts on U.S. agriculture, and the role for the agricultural sector to have in reducing GHG buildup. This has major spillover effects for other sectors of the U.S. economy if a carbon-constrained policy is part of the U.S. program to address climate change.

Item #1:

Project Title: Regional and National Level Integrated Models and Policy Assessment Climate Change and Greenhouse Gas Mitigation in Montana and U.S. Agriculture

Project Results:

- Research has used the econometric-process simulation model for the central U.S. region to assess impacts of changes in agricultural policy and prices on C sequestration supply curves.

Item #2 – Impact Statement:

This work will enable policy decision makers and stakeholders to assess how changes in policy and economic conditions may affect the economic potential for soil C sequestration.

Task 4: Measurement and Monitoring

Item #1:

Project Title: Economic and Social Dimensions of C Sequestration:
Assess the Economic and Behavioral Aspects of Soil C Contract Design and Their Implications for Measurement of Soil C and Monitoring of Compliance with Soil C Contracts

Project Results:

- A conceptual framework was developed that could be used to assess the transactions costs associated per-hectare and per-credit contract types for soil C credit and was used in empirical applications to estimate the potential magnitude of transactions costs associated with measuring soil C credits under a per-credit contract within the dry-land crop region of Montana.
- The empirical applications used econometric and simulation models that compared producer expected returns from a choice of different cropping systems. These models were coupled with the Century ecosystem model that was used to estimate changes in the rate of soil carbon sequestration as a result of crop system changes.
- Three different analyses were conducted using this general approach, their results are presented below:

1. **Magnitude of Measurement Costs**
    - In this empirical analysis, the total measurement costs for soil C-credits was estimated;
    - Investigated how changes in contract (and region) size as well as increases in C-credit variability affected total measurement costs.
    - The empirical analyses suggest that increasing the size of the contract and aggregating credits over a larger number of producers can lower measurement costs associated with the per-credit contract, even in the face of increasing C variability thus contracts for large quantities of soil credits increase the likelihood that the per-credit contract remains more efficient than the per-hectare contract.
    - These empirical results reflect the specific data and conditions present within the case study region. The theoretical expectation is that sample size and measurement costs can either increase or decrease as the population to be sampled increases. Thus, the measurement costs associated with a per-credit contract could respond differently from this analysis across the spatial extent of the United States.
    - Measurement costs per credit are inversely related to the price offered for each credit. In addition, at every credit price examined, the measurement cost per credit is larger in regions that exhibit higher spatial heterogeneity. A decrease in the acceptable sampling error or, an increase in the confidence level result in higher measurement costs.
    - The results presented above have several implications for the costs of measuring soil credits and the relative efficiency of a per-credit contract design versus a per-hectare contract design:

  - First, and most importantly, the measurement costs per credit could be a very small percentage of the value of the credit as reflected in the payment level. In this analysis the measurement costs ranged between a maximum of 3% to 10.6% of total credit value (depending on the assumed error and confidence level).
  - In addition, we showed that total measurement costs at the sub-MLRA scale are a small percentage of the efficiency difference between the two contracts and that measurement at finer scales could be economically feasible in some areas. These results suggest that in most cases the additional costs of a measurement are unlikely to render per-credit contracts less efficient than the per-hectare contract, unless the opportunity costs of supplying credits are very similar under both contract schemes.
  - Regions that exhibit more heterogeneity are able to support higher measurement costs because they have the greatest difference in the opportunity cost of supplying credits under each contract type.

2. Contract Size and Measurement Costs

- We estimated the total measurement costs for soil C-credits and investigated how changes in contract (and region) size as well as increases in C-credit variability affect total measurement costs.
- The empirical analyses suggest that increasing the size of the contract and aggregating credits over a larger number of producers can lower measurement costs associated with the per-credit contract, even in the face of increasing C variability thus contracts for large quantities of soil credits increase the likelihood that the per-credit contract remains more efficient than the per-hectare contract.
- However, these empirical results reflect the specific data and conditions present within the case study region. The theoretical expectation is that sample size and measurement costs can either increase or decrease as the population to be sampled increases. Thus, the measurement costs associated with a per-credit contract could respond differently from this analysis across the spatial extent of the United States.

3. Incorporating Spatial Autocorrelation

- We examined how information about the range of spatial autocorrelation can be used in a measurement scheme to reduce the size of the confidence intervals that bound estimates of the mean number of C-credits generated per hectare. A tighter confidence interval around the mean number of C-credits sequestered could increase producer payments for each hectare enrolled in a contract to supply C-credits.
- An empirical application to dry land cropping systems in three regions of Montana shows that information about the spatial autocorrelation exhibited by soil C could be extremely valuable for reducing transactions costs associated with contracts for C-credits but the benefits are not uniform across all regions or cropping systems.
- Accounting for spatial autocorrelation greatly reduced the standard errors and narrowed the confidence intervals associated with sample estimates of the mean

number of C-credits produced per hectare. For the payment mechanism considered in this paper, tighter confidence intervals around the mean number of C-credits created per hectare enrolled could increase producer payments by more than 100% under a C-contract.

Item #2 – Impact Statement:

Rates of participation in soil C contracts were simulated over a range of potential carbon prices. Results show that soil C sequestration participation is sensitive to carbon prices and sensitive to transaction costs at low carbon prices. These results help policy decision makers and stakeholders assess the potential for agriculture to participate in emerging markets for greenhouse gas mitigation.

Task 5. Outreach and Technology Transfer

Subtask 1: Multi-Media Education Materials and Training
Subtask 2: Decision Support Systems
Subtask 3: Website and Newsletter Development and Maintenance

Item #1:

Project Title: CASMGS Outreach and Technology Transfer

Project Results:

- Two basic types of educational material were developed. First was information on the basic carbon cycle and how the CASMGS project is trying to take advantage of this process to store carbon in agricultural soils. The second type was educational material developed from ongoing research conducted under the other tasks of the CASMGS project.
- The objective of the research were met: to provide scientifically-based information to target audiences to assist them in decision making. Target audiences include policymakers, agricultural producers and their organizations, and the energy production and distribution sector. The information included:
  - the potential for soils to serve as a sink for atmospheric carbon;
  - management options and new technologies that can increase soil C while reducing net GHG in the atmosphere;
  - potential on and off farm benefits and costs of adopting alternative practices or technologies;
  - benefits and risks of entering into contracts with government or private entities; and;
  - policy options and their consequences for program implementation.
- The focus was on the cost side of the typical cost benefit analysis because the benefit side can come from multiple sources. Potential sources include government incentives paid to farmers to adopt these practices and private markets that pay producers to adopt the practices.
- Because the private markets are still developing within the United States and globally and there are, as yet, no payments included in government programs, focusing on the costs of adopting these practices allow the producer to estimate the dollar amount of payments from one or more sources that would be necessary to fully compensate them for the adopting the type of farming practices required.
- Changing the type of farming system has additional benefits other that just storing carbon. One such potential benefit is the hours of labor saved by switching from a conventional to a no-till farming system. Many producers are already adopting farming practices that store carbon because of tight labor supplies.
- The development of the decision aids discussed here allows producers to estimate their costs and analyze the potential benefits of adopting a particular farming practice with consideration given to all the potential benefits resulting from adopting a particular farming practice.

- The total dollar impact of the efforts discussed here are the combined benefits of on-farming savings and the combined benefits of private and public payments for adopting farming practices that store carbon.
- Montana State University has developed a decision aid that will allow individual producers to estimate the economic costs of adopting the necessary farming practices for their selected enterprise mix by state and region as a necessary first step in getting large scale adoption of the type of farming practices necessary to reduce GHG. In addition to the costs of the practices, the amount of carbon stored will vary by crop mix, and geographical region.
- Table 8 contains summary results from the desktop computer model comparing a conventional (mechanical), minimum and no till farming system on a dryland operation of 4,500 acres in Montana. The information in Table 8 uses current input prices of fuel and fertilizer. Table 9 contains the same summary with energy input prices that are 25% higher.

Table 8. Summary results comparing tillage systems on a 4,500 acre dryland grain farm in Montana.

	Total Costs for All Enterprises by Tillage System		
	Mechanical Tillage	Minimum Till	No Till
Acres in this operation	4,500	4,500	4,500
Total Income	$306,579	$306,579	$306,579
Seed and Treatments	$11,754	$11,754	$11,754
Total Chemicals	$38,528	$42,650	$63,568
Total Fertilizers	$57,150	$64,980	$57,150
Crop Insurance	$7,864	$7,864	$7,864
Other Misc Costs	$1,800	$3,105	$1,800
Machinery Operating Cost	$86,827	$78,238	$67,345
Interest on Operating	$14,846	$15,087	$15,370
Total Operating Cost/Ac	$218,769	$223,677	$224,851
Machinery Ownership Cost/Ac	$74,781	$71,761	$66,500
Total Ownership Cost/Ac	$194,199	$191,179	$185,917
Total Operating and Ownership Cost	$412,968	$414,856	$410,769
Returns over operating cost	$87,810	$82,901	$81,728
Returns over total cost	-$106,389	-$108,277	-$104,190
Total Gallons of Fuel used for this crop mix	$21,799	$20,014	$18,186
Total Fuel and Lubricant costs for this crop mix	$51,487	$47,268	$42,854
Hours of Machinery Time Required	935	824	741
Machinery Investment costs by tillage system	$668,500	$668,500	$668,500
Total Labor Hours for all Enterprises	935	824	741

Table 9. Summary results as in Table 8 with 25% higher energy prices.

	Total Costs for All Enterprises by Tillage System		
	Mechanical Tillage	Minimum Till	No Till
Acres in this operation	4,500	4,500	4,500
Total Income	$306,579	$306,579	$306,579
Seed and Treatments	$11,754	$11,754	$11,754
Total Chemicals	$48,160	$53,312	$79,460
Total Fertilizers	$71,438	$81,225	$71,438
Crop Insurance	$7,864	$7,864	$7,864
Other Misc Costs	$1,800	$3,105	$1,800
Machinery Operating Cost	$97,776	$88,097	$75,755
Interest on Operating	$15,676	$15,819	$15,975
Total Operating Cost/Ac	$254,467	$261,176	$264,045
Machinery Ownership Cost/Ac	$74,781	$71,761	$66,500
Total Ownership Cost/Ac	$194,199	$191,179	$185,917
Total Operating and Ownership Cost	$448,666	$452,355	$449,962
Returns over operating cost	$52,112	$45,402	$42,534
Returns over total cost	-$142,087	-$145,776	-$143,383
Total Gallons of Fuel used for this crop mix	$21,799	$20,014	$18,186
Total Fuel and Lubricant costs for this crop mix	$64,359	$59,085	$53,567
Hours of Machinery Time Required	935	824	741
Machinery Investment costs by tillage system	$668,500	$668,500	$668,500
Total Labor Hours for all Enterprises	935	824	741

- These results indicate that under current conditions, returns over operating costs have a range of about $8,000. With a 25% increase in the cost of fuel, fertilizer and chemicals, returns of operating cost are cut in half and, while small, the range of returns increases from $8,000 to $10,000 favoring the conventional tillage system. This may or may not be enough to prevent producers from adopting tillage practices that store carbon. As indicated earlier, costs may not be the sole decision criteria. Tables 8 and 9 indicate that there is about a 200-hr savings in hours of field work. This may be an important factor in the decision making process.

Subtasks

Montana State University used the broadly defined subtasks noted below to produce a variety of educational material and media-based information.

Subtask 1. Multi-Media Education Materials and Training

- Montana State University, in cooperation with researchers and Extension faculty at other universities, produced outreach publications and educational material for producers, agency personnel and the general population of Montana. This material was largely produced related to activities of subtask 2 and 3.
- In addition to printed or electronic material, much of the education was conducted in field days and other one-to-one meetings with producers.

Subtask 2. Decision Support Systems

- The process of developing a decision support system was started over 4 years ago and included a web-based tool for decision support as well as a desktop tool for producers.
- The desktop tool was in large part aimed at focusing on the economics of alternative farming practices (tillage systems) that enhanced carbon sequestration and mitigation of GHG.
- With the recent advent of new technology, the current focus is on delivery of a desktop decision aid for producers, which is also capable of running on the web.
- *Steps in the development process*
    - A system of ten spreadsheets was developed that compares the economics of conventional, minimum and no-till tillage systems for small, medium and large dryland farm sizes in the Northern Great Plains.
    - This same system of spreadsheets also estimates the impact of costs of energy use by type of tillage system. This system includes the ability to show the financial implications for producers from changes in the price of energy, affecting fuel, fertilizer and other operating input costs.
- While not finalized, a working version of this type of system can be run from web site http://www.montana.edu/extensionecon/software/CASMGSTillageEconomics.swf. This system currently includes the ability to change the percentage of crop mix and adjust other factors to get an estimate of the economics of a particular enterprise mix, while comparing three types of tillage systems, conventional, minimum and no till.
- The economic model is finished and runs on a desktop and the web. This model allows producers to explore crop mixes and tillage systems and compare the economic implications of adopting best management practices for carbon sequestration.
- Of special note is that this example allows the user to change the acreages of the crop mix, fuel prices and indicate a percent change in fertilizer and chemical prices. All of this is done with easy-to-use controls for input values.
- The final version of this software will include the ability to change crop mixes rather than simply select from a given set of crop enterprises and evaluate more completely the use of and economic implications of high cost energy inputs.

Subtask 3. Website and Newsletter Development and Maintenance

Montana State University has developed a website as a means of distributing information relevant to the CASMGS project.

Web Based Information Delivery

- Developed Montana State University homepage for CASMGS, www.casmgs.montana.edu. In a typical month, the website receives about 1,500 hits from off-campus sources.
- Cooperated with the development of the main CASMGS website by providing requested materials.

Newsletters

- Montana State University compiled a database for recipients of CASMGS outreach materials, including the external newsletter and information bulletins. The database includes Montana, Wyoming, Nebraska, South Dakota, North Dakota, Kansas, and Colorado. The mailing list includes 1,988 addresses of policymakers, a wide variety of agricultural groups, energy companies, and other concerned parties. In addition, 56 university departments received the newsletter by email.
- Montana State University sent out 1,988 hardcopies the first edition of the newsletter, and circulated it to 56 university departments by email. Recipients signed up to receive future newsletters and information bulletins via electronic mail.
- *Ag Solutions to Greenhouse Gases*, a series of three newsletters addressing basic awareness of carbon sequestration and brief discussions of current research, other resources and meetings dealing with GHG mitigation.

Item #2 – Impact Statement:

Storing green houses gases in the soil has the potential to impact many areas of concern about climate and the observed changes in climate currently taking place. Carbon sequestration on a large scale could help reduce green house gases, a cause of the negative impacts of these changes. While this is a very positive step, carbon sequestration on a large scale will only take place if it is economically feasible for individual producers to adopt the farming practices necessary to store carbon. While some producers are already using these farming practices, others do not have the right kind of machinery compliment and therefore would have to reinvest in machinery before they could adopt farming practices that would store added carbon in the soil. Clear economic incentives are necessary to get individual producers to reinvest and adopt these types of farming practices.

Item #3 – Publications Resulting from CASMGS Project:

Publications

Book Chapters

Antle, J., S. Capalbo, and K. Paustian. 2006. Ecological and economic impacts of climate change in agricultural systems: An integrated assessment approach. *In* M. Ruth, K. Donaghy and P. Kirshen (eds.) Regional climate change and variability: Impacts and responses. Edward Elgar Publishing, Cheltenham, UK and Northampton, MA, pp. 128–160.

Antle, J.M. and L.M. Young. 2005. Policies and incentive mechanisms for the permanent adoption of agricultural carbon sequestration practices in industrialized and developing countries. *In* R. Lal, N. Uphoff, B.A. Stewart, and D.O. Hansen (eds.) Climate change and global food security. CRC Press, Boca Raton, FL, pp. 679–701.

Journal Articles

Antle, J.M, and S.M Capalbo. 2002. Agriculture as a managed ecosystem: Policy implications. J. Agric. Res. Econ. 27:1–15.

Antle, J.M., S.M. Capalbo, and S. Mooney. 2002. Farming the environment: Spatial variation and economic efficiency in soil: Developing policies for carbon sequestration and agriculture. Choices 17:24–25.

Antle, J.M., S.M. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian. 2002. A comparative examination of the efficiency of sequestering carbon in U.S. agricultural soils. Amer. J. Altern. Agric. 17:109–115.

Antle, J.M., S.M. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian. 2002. Sensitivity of carbon sequestration costs to soil carbon rates. Environ. Pollut. 116:413–422**.**

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Antle, J.M., S.M. Capalbo, K.H. Paustian, and M.K. Ali. In press. Estimating the economic potential for agricultural soil carbon sequestration in the central United States using an aggregate econometric-process simulation model. Clim. Change.

Antle, J.M., S.M. Capalbo, K.H. Paustian, and E.T. Elliott. 2004. Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change: An integrated assessment approach. Clim. Change 64:289–315.

Antle, J.M. and R.Valdivia. 2006. Modeling the supply of environmental services from agriculture: A minimum data approach. Aust. J. Agric. Res. Econ. 50:1–15.

Bricklemyer, R.S., R.L. Lawrence, and P.R. Miller. 2002. Documenting no-till and conventional till practices using Landsat ETM+ imagery and logistic regression. J. Soil Water Conserv. 57:267–271.

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Campbell, S., S. Mooney, J. Hewlett, D. Menkhaus, and G. Vance. 2004. Can ranchers slow climate change? Rangelands 26:16–22.

Capalbo, S., J.M. Antle, S. Mooney, and K.H. Paustian. 2004. Sensitivity of carbon sequestration costs to economic and biological uncertainties. Environ. Manage. 33: S238–S251.

Mooney, S., J.M. Antle, S.M. Capalbo, and K. Paustian. 2004. Design and costs of a measurement protocol for trades in soil carbon credits. Can. J. Agric. Econ. 52:257–287.

Mooney, S., J.M. Antle, S.M. Capalbo, and K. Paustian. 2004. Influence of project scale on the costs of measuring soil C sequestration. Environ. Manage. 33:S252–S263.

Mooney, S., K. Gerow, J. Antle, S. Capalbo, and K. Paustian. In press. Reducing standard errors by incorporating spatial autocorrelation into a measurement scheme for soil carbon credits. Clim. Change.

Young, Linda. 2003. Carbon sequestration in agriculture: The U.S. policy context. Amer. J. Agric. Econ. 85:1164–1170.

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Antle, J.M., S. Capalbo, and S. Mooney. 2003. Soil carbon sequestration and agriculture: Opportunities vary throughout Montana. MontGuide MT200313, Montana State Univ. Extension Serv., Bozeman, MT.

Antle, J.M., S. Capalbo, S. Mooney, E. Elliott, and K. Paustian. 2003. Soil carbon sequestration in agriculture: Can agriculture compete in a market for carbon? MontGuide MT200314 AG, Montana State Univ. Extension Serv., Bozeman, MT.

Griffith, D., T. Angvick, L. Brence, J. Broesder, R. Carlstrom, and M. Manukian. 2005. *Fifteen* electronic publications in restricted distribution to Extension Agents – Enterprise budgets using: a *no-till cropping system* on 1) dryland winter wheat on fallow; 2) dryland recrop spring wheat, 3) dryland spring wheat on fallow, 4) summer fallow, 5) dryland peas on recrop, 6) dryland flax on recrop, 7) dryland recrop durum, and 8) dryland recrop barley; *minimum tillage cropping system* on 9) dryland winter wheat on fallow, 10) dryland recrop spring wheat, 11) dryland spring wheat on fallow, and 12) summer fallow; and *conventional tillage cropping system* on 13) dryland winter wheat on fallow, 14) dryland spring wheat on fallow, and 15) summer fallow. September. (Please note: These are restricted distribution because they contain confidential information on financial aspects of the ranching and farming operations.)

Miller, P. R. Engel, and R. Brinklemyer. 2004. Soil carbon sequestration: Farm management practices can affect greenhouse gases, MontGuide MT200404 AG, Montana State Univ. Extension Serv., Bozeman, MT.

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Young, L.M. 2003. Soil carbon sequestration in agriculture: The U.S. policy context. MontGuide MT200312 AG, Montana State Univ. Extension Serv., Bozeman, MT.

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Mooney, S., J.M. Antle, S.M. Capalbo, and K.H. Paustian. 2003. Incorporating uncertainty in integrated assessment modeling. Working Paper 2003-101, Dept. of Agric. and Appl. Econ., Univ. of Wyoming, Laramie, WY.

Mooney, S., K. Gerow, J. Antle, S. Capalbo, and K. Paustian. 2005. The value of incorporating spatial autocorrelation into a measurement scheme to implement contracts for carbon credits. Working Paper 2005 – 101. Dept. of Agric. and Appl. Econ., Univ. of Wyoming, Laramie, WY.

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Antle, J.M., R. Bricklemyer, S.M. Capalbo, R. Engel, and P. Miller. 2002. Montana State University research on soil carbon sequestration. Power Generation/Industry Workshop, Governor’s Carbon Sequestration Working Group, Helena, MT, 12 December.

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Antle, J.M., S.M. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian. 2002. Montana State Univ. program on climate change and greenhouse gas mitigation. Governor’s Carbon Sequestration Working Group, NCRS Office, Missoula, MT, 21 October.

Antle, J.M., S.M. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian. 2002. Spatial heterogeneity, contract design, and the efficiency of carbon sequestration policies for agriculture. Paper presented at the 2rd World Congress of Environ. and Resource Econ., Monterey, CA, 25 June.

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Mooney, S. 2002. A measurement and monitoring protocol for soil C: Influence on efficient policy design. AAEA Annu. Meet., Long Beach, CA, 30 July.

Mooney, S. 2003. Carbon as a commodity: Options for rangelands. Soc. for Range Manage., 56th Annu. Meet., Casper, WY, 3 February.

Mooney, S. 2003. Data needed for economic analysis of the costs/benefits of adopting different production activities. CASMGS Carbon Sequestration – Farmer Consultation, Great Falls, MT, 24 February.

Mooney, S. 2003. Spatial heterogeneity and efficient contract design for soil carbon sequestration. Dept. of Agric. and Resource Econ. and Dept. of Econ., Colorado State Univ., Fort Collins, CO, 24 March.

Mooney, S. 2003. Adaptation to climate change. Invited testimony to Canadian Senate: Senate Standing Comm. on Agric. and Forestry, Ottawa, Canada, 29 April.

Mooney, S. 2003. Selling carbon credits? Potential new opportunity for agriculture? Dept. of Animal Sci., Univ. of Wyoming, Laramie, WY, 5 September.

Mooney, S. 2003. Opportunities for trading soil carbon credits from managed ecosystems. School of Nat. Resources, Univ. of Nebraska, Lincoln, NE, 23 September.

Mooney, S. 2003. Sequestering carbon to sell carbon credits – Forestry. School of Natl. Resources, Univ. of Nebraska, Lincoln, NE, 23 September.

Mooney, S. 2003. Economics – Factors affecting costs of measuring soil carbon. Carbon Measurement and Monitoring Forum, Kansas State Univ., Manhattan, KS, 17 October.

Mooney, S. 2003. Economics of carbon sequestration in agricultural soils: Existing research and further questions, Dept. of Plant Sciences, Univ. of Wyoming, Laramie, WY, 14 November.

Mooney, S. 2004. What are the economic costs of measuring and monitoring Soil Carbon? Third Annu. Conf. on Carbon Capture and Sequestration, Alexandria, VA, 3 May.

Mooney, S. 2004. Economics and contracting for soil carbon. Carbon Sequestration: Sci., Policy and Marketing in Wyoming meeting, Casper, WY, 22 June.

Mooney, S. 2004. Scaling model results from field to region: Review of models addressing payment approaches for cropland carbon sequestration, and measurement costs. Workshop #3: Modeling to support policy. Forestry and Agric. Greenhouse Gas Modeling Forum. Shepherdstown, WV, October.

Mooney, S. 2004. Climate, carbon and cowboys: Agriculture's role in reducing greenhouse gases. School of Environ. and Nat. Resources, Univ. of Wyoming, 3 November.

Mooney, S. 2005. Environmental and ecological benefits of soil carbon management: Economic benefits of soil carbon sequestration. Lead Author, Meeting, Kansas State Univ., 10 February.

Mooney, S. 2005. Economics of carbon management. Kansas State Univ. Alumni Cent., Public Forum, 11 February.

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Mooney, S. 2006. Contract efficiency and transactions costs from measuring soil carbon credits. Dept. of Econ., Boise State Univ., 9 March.

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Mooney, S., J.M. Antle, S.M. Capalbo, and K.H. Paustian. 2002. A measurement and monitoring protocol for soil C: Influence on efficient policy design. Am. Agic. Econ. Assoc. Annu. Meet., Long Beach, CA, 30 July.

Mooney, S., J.M. Antle, S.M. Capalbo, and K.H. Paustian. 2002. Soil carbon measurement costs, protocols, and sequestration rates using a linked economic and biophysical simulation model. USEPA, USDA/ERS, the Farm Foundation and Agriculture Canada – Forestry and Agric. Greenhouse Gas Modeling Forum, Shepherdstown, WV, 8 October.

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Mooney, S., J.M. Antle, S.M. Capalbo, and K.H. Paustian. 2004. Economics and contracting for soil carbon. Carbon Sequestration: Sci., Policy & Marketing in Wyoming meeting, Casper, WY, 22 June.

Mooney, S., P. Miller, R. Engel, and R. Bricklemyer. 2003. Data needed for economic analysis of the costs/benefits of adopting different production activities. CASMGS Carbon Sequestration – Farmer Consultation. Great Falls, MT, 24 February.

Young, L.M. 2003. Carbon sequestration in agriculture: The U.S. policy context. Am. Agric. Econ. Assoc. Annu. Meet., Montreal, Quebec, 28 July.

Young, L.M. 2003. Issues and options for carbon sequestration in agriculture." Principal paper session for Am. Agric. Econ. Assoc. Annu. Meet., Montreal, Quebec, 27–30.

Young, L.M., A. Weersink, M. Fulton, and B.J. Deaton. 2005. Carbon sequestration in agriculture: Institutional responses to the Kyoto protocol in Australia, Canada, the European Union and the United States. Paper presented at the Workshop on Greenhouse Gas Management and the Biosphere, Victoria, BC, April.

Item #4 – Personnel Count:

(1) M.S. Students: 9
    Ph.D. Students: 0
(2) Post-docs: 2
(3) Other: 35

Item #5 – Grant Awards Related to CASMGS Projects:

National Science Foundation, Methods and Models for Integrated Assessment Program, $275,000, June 2000–November 2003. Economically optimal spatial scale for integrated analysis of agricultural production systems. PIs: J.M. Antle, S.M. Capalbo, S. Mooney, and K.H. Paustian.

U.S. Agency for International Development, Soil Management Collaborative Research Support Program, $2,760,000, 2002–2007. The tradeoff analysis project phase 2: Scaling up and technology transfer to address poverty, food security and sustainability of the agro-environment. PI: J. Antle.

U.S. Department of Agriculture, National Research Initiative, $58,000, 2002–2003. A measurement and monitoring protocol for policies designed to sequester soil carbon. PIs: S. Mooney, J.M. Antle, and S.M. Capalbo.

U.S. Department of Agriculture, National Research Initiative, Air Quality Program, $421,184, February 2004–February 2008. Effect of cropping systems and water on N_2O emission from soil as influenced by fertilization and crop residues in the Northern Great Plains. PIs: R. Engel and P. Miller.

U.S. Department of Agriculture, National Research Initiative Competitive Grants Program, Soil and Soil Biology Program, $42,883, December 2004–December 2005. Improved analytical facilities for quantifying gas fluxes and dissolved gas species in soils and natural waters. PIs: R. Engel, P. Miller, B. McGlynn, and W. Inskeep.

U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Innovation Grant, $71,673, October 2005–September 2006. No-till and cropping intensity to improve soil quality and productivity, promote carbon sequestration, and mitigate drought risk. PIs: R.S. Bricklemyer and P.R. Miller.

U.S. Department of Energy Fossil Energy Research and Development Program, $1,997,889, October 2003–September 2005. Big Sky Carbon Sequestration Partnership. PI: S. Capalbo, J. Antle, and others.

U.S. Department of Energy Fossil Energy Research and Development Program, $17,900,000, October 2005–September 2009. Big Sky Carbon Sequestration Partnership, Phase II. PI: S. Capalbo.

U.S. Environmental Protection Agency, $1,420,860, October 2000–September 2003. Close coupling of ecosystem and economic models: Adaptation of central U.S. agriculture to climate change. PIs: J.M. Antle, S.M. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian.

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Denton H.P. and D.D. Tyler. 2002. Making no-till conventional in Tennessee. *In* E. Swanten (ed) Making conservation tillage conventional: Building a future on 25 years of research. Proc. of the 25th Annu. Southern Conserv. Tillage Conf. for Sustainable Agric., Auburn, AL, 24–26 June.

Devlin, D.L., D.L. Regehr, and J.P. Shroyer. 1999. Effects of no-till on soil and water quality. *In:* S. Watson (ed.) Kansas no-till handbook, Kansas State Univ. Agric. Experiment Stn. and Cooperative Extension Serv., Manhattan, KS, pp.10-13.

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Appendix

Appendix Table 1. Summary Statistics from Selected Questions – Montana Producer Survey 2003.

Section I – General Questions	
Number of respondents	6
Total and farmed (acres)	Mean 3,479 Min 1,820 Max 7,000
Current value per acre (dollars)	Mean 483 Min 400 Max 750
Do you employ hired labor?	Yes = 4 No = 2
Participation in government programs	Counter cyclical = 5 Direct = 1 Disaster = 1 CRP = 3
Mortgage	Yes = 4 (Average % land value = 31%) No = 2
Section II – Test Plot Information	
Test Plot 1 – Legume, till	
Crop planted	Peas = 5 Hay = 1 Lentils = 1 Barley = 1 (Total adds to more than 6 because some crop types were planted simultaneously)
Seed cost/acre ($)	Peas = $17.60 Lentils = $114.00 Barley = $14.00
Sell or Feed Crop	Sell = 5 Neither sell or feed = 1
Yield	Average = 3 Below average = 3
Test Plot 2 – Legume, no-till	
Crop planted	Peas = 5 Hay = 1 Lentils = 1 Barley = 1 (Total adds to more than 6 because some crop types were planted simultaneously)

Seed cost/acre ($)	Peas = $17.60 Lentils = $114.00 Barley = $14.00
Sell or Feed Crop	Sell = 5 Neither sell or feed = 1
Yield	Average = 2 Below average = 4

General Information Section

Test Plot 1 – Legume, till

Tillage Equipment	None used
Seeding Equipment-Row spacing	12" = 4 7.2" = 1 7" = 1
Opener type	Single shoot = 5 Double shoot = 1
Brand/model of opener	Flexicoil Stealth = 3 Adam Jet = 2 Dutch = 1
Row width of opener	Less than 2" = 5 2" to 4" = 1
Type of packer	On row gang packer = 3 On row individual packer = 3
Fertlilzer application	At time of seeding = 4 N/A = 2
Fertilizer placement	In seed row = 4 N/A = 2
How was crop harvested	Swath = 1 Direct cut = 3 Terminate crop with herbicide = 1 Swathed early baled = 1
Height of stubble (inches)	2" = 1 3.5" = 1 4" = 1 5" = 1 5.5" = 1

Test Plot 2 – Legume, no-till

Tractor size (tillage)	200hp – 50hp = 2 350hp – 450hp = 1 Greater than 500hp = 1
Tillage implement	Chisle plow = 2 Cultivator = 2

Width of tillage implement	30 feet – 40 feet = 3
	Greater than 40 feet = 1
Seeding Equipment-Row spacing	12" = 3
	7.2" = 1
Opener type	Single shoot = 3
	Double shoot = 1
Brand/model of opener	Flexicoil Sealth = 2
	Adam Jet = 1
	Dutch = 1
Row width of opener	Less than 2" = 3
	2" to 4" = 1
Type of packer	On row gang packer = 1
	On row individual packer = 3
Fertlilzer application	At time of seeding = 3
	N/A = 3
Fertilizer placement	In seed row = 3
	N/A = 3
How was crop harvested	Swath = 1
	Direct cut = 1
	Terminate crop with herbicide = 1
	Swathed early baled = 1
Height of stubble (inches)	2" = 1
	5.5" = 1

Appendix Table 2. Soil texture (percent clay in parenthesis) by depth for each plot at Chester, Collins, Conrad, Great Falls, Kremlin, and Power, Sept. – Oct. 2002.

	Chester	**Collins**	**Conrad**	**Great Falls**	**Kremlin**	**Power**
			0-10 cm			
Tilled F-W	cl (30)	c (45)	cl (38)	c (56)	cl (27)	c (42)
No-till F-W	cl (32)	c (45)	cl (31)	c (60)	cl (27)	c (43)
Tilled W-L	cl (29)	c (48)	cl (35)	c (58)	cl (26)	c (40)
No-till W-L	cl (30)	c (48)	cl (35)	c (58)	cl (28)	c (47)
% clay SE	0.6	1.2	1.2	0.5	0.5	1.1
			10-20 cm			
Tilled F-W	cl (33)	c (55)	c (41)	c (61)	cl (32)	c (45)
No-till F-W	cl (39)	c (50)	cl (35)	c (64)	cl (32)	c (49)
Tilled W-L	cl (34)	c (51)	cl (40)	c (61)	cl (28)	c (44)
No-till W-L	cl (35)	c (51)	c (41)	c (63)	cl (31)	c (51)
% clay SE	1.0	1.2	1.2	0.5	0.6	1.2
			20-50 cm			
Tilled F-W	cl (35)	c (56)	cl (47)	c (62)	cl (35)	c (48)
No-till F-W	cl (39)	c (52)	c (36)	c (65)	cl (37)	c (45)
Tilled W-L	cl (36)	c (53)	cl (40)	c (66)	cl (39)	c (50)
No-till W-L	cl (37)	c (54)	c (43)	c (66)	cl (36)	c (57)
% clay SE	0.8	1.1	1.4	0.6	0.7	1.9
			50-100 cm			
Tilled F-W	cl (30)	c (58)	c (42)	c (63)	cl (26)	c (46)
No-till F-W	cl (35)	c (56)	cl (40)	c (65)	cl (20)	c (35)
Tilled W-L	cl (33)	c (55)	cl (38)	c (66)	ND	c (44)
No-till W-L	cl (33)	c (54)	c (42)	c (65)	cl (36)	c (42)
% clay SE	1.2	1.4	1.1	1.2	4.3	2.2

W-L = wheat – legume rotation F-W = fallow – wheat rotation

ND = no data, samples were not able to be collected at that depth due to soil conditions.

Appendix Table 3. Soil pH (1:1 soil:H_2O) by depth for each plot at Chester, Collins, Conrad, Great Falls, Kremlin, and Power, Sept. – Oct. 2002.

	Chester	**Collins**	**Conrad**	**Great Falls**	**Kremlin**	**Power**
				0-10 cm		
Tilled F-W	8.0	7.3	7.4	7.5	7.0	8.3
No-till F-W	7.8	7.9	6.9	7.6	7.7	8.2
Tilled W-L	7.7	7.7	7.8	7.5	8.1	8.1
No-till W-L	7.7	8.1	7.5	7.6	8.4	8.1
SE	0.12	0.12	0.15	0.10	0.15	.04
				10-20 cm		
Tilled F-W	8.2	7.9	7.6	8.2	7.4	8.4
No-till F-W	8.2	8.3	7.7	8.2	8.1	8.2
Tilled W-L	8.2	8.1	7.8	8.2	8.4	8.1
No-till W-L	8.2	8.3	7.8	8.2	8.4	8.1
SE	0.03	0.09	0.11	0.05	0.16	.05
				20-50 cm		
Tilled F-W	8.4	8.6	8.1	8.6	8.7	8.6
No-till F-W	8.5	8.6	8.1	8.6	8.7	8.5
Tilled W-L	8.7	8.5	8.4	8.6	8.9	8.6
No-till W-L	8.6	8.5	8.2	8.6	8.8	8.4
SE	0.05	0.04	0.07	0.02	0.05	.04
				50-100 cm		
Tilled F-W	9.0	8.6	8.5	8.7	9.1	8.7
No-till F-W	9.1	8.7	8.6	8.1	9.3	8.5
Tilled W-L	8.9	8.7	8.7	8.4	ND	8.4
No-till W-L	8.5	8.2	8.5	8.3	9.1	8.4
SE	0.13	0.09	0.04	0.08	0.17	.09

W-L = wheat – legume rotation F-W = fallow – wheat rotation

ND = no data, samples were not able to be collected at that depth due to soil conditions

Appendix Table 4. Soil organic carbon (t ha-1) by depth for each plot at Chester, Collins, Conrad, Great Falls, Kremlin, and Power, Sept. – Oct. 2002.

	Chester	**Collins**	**Conrad**	**Great Falls**	**Kremlin**	**Power**
			0-10 cm			
Tilled F-W	10.8	12.5	15.5	17.9	10.1	15.5
No-till F-W	10.3	10.8	12.0	15.1	9.3	17.1
Tilled W-L	10.2	11.8	13.3	14.7	8.3	14.1
No-till W-L	9.9	10.7	13.3	18.5	10.8	11.8
SE	0.3	0.6	0.7	1.1	0.4	0.9
			10-20 cm			
Tilled F-W	10.7	8.6	12.2	11.2	7.7	12.6
No-till F-W	10.7	11.0	11.3	11.6	7.2	12.3
Tilled W-L	10.1	8.8	11.4	11.8	7.8	11.7
No-till W-L	10.2	10.3	11.6	11.8	6.9	13.6
SE	1.0	0.6	0.6	0.4	0.2	0.5
			20-50 cm			
Tilled F-W	7.9	7.4	9.6	9.0	7.8	7.2
No-till F-W	6.3	6.9	10.1	9.0	7.1	7.6
Tilled W-L	7.6	8.2	9.3	8.4	7.5	10.7*
No-till W-L	8.1	8.2	9.5	8.6	6.7	8.7
SE	0.6	0.4	0.5	0.5	0.3	1.3
			50-100 cm			
Tilled F-W	6.9	6.5	8.4	7.4	4.8	5.5
No-till F-W	6.6	6.3	7.8	7.3	3.5*	5.6
Tilled W-L	6.8	5.8	8.2	7.1	ND	5.6
No-till W-L	8.3	6.1	8.7	6.5	5.9	4.1
SE	0.5	0.2	0.7	1.2	0.5	1.2

W-L = wheat – legume rotation F-W = fallow – wheat rotation

ND = no data, samples were not able to be collected at that depth due to soil conditions.

*Values that are under review.

Appendix Table 5. Soil bulk density (g cm-3) by depth for each plot at Chester, Collins, Conrad, Great Falls, Kremlin, and Power, Sept. – Oct. 2002.

	Chester	**Collins**	**Conrad**	**Great Falls**	**Kremlin**	**Power**
			0-10 cm			
Tilled F-W	1.5	1.6	1.4	1.4	1.6	1.3
No-till F-W	1.5	1.6	1.5	1.3	1.6	1.3
Tilled W-L	1.5	1.6	1.4	1.4	1.5	1.3
No-till W-L	1.5	1.6	1.5	1.4	1.6	1.3
SE	0.02	0.04	0.02	0.01	0.02	0.01
			10-20 cm			
Tilled F-W	1.5	1.6	1.5	1.5	1.6	1.3
No-till F-W	1.5	1.5	1.5	1.4	1.5	1.4
Tilled W-L	1.5	1.6	1.5	1.5	1.6	1.4
No-till W-L	1.5	1.6	1.5	1.5	1.5	1.4
SE	0.01	0.02	0.02	0.01	0.01	0.01
			20-50 cm			
Tilled F-W	1.4	1.6	1.3	1.5	1.5	1.3
No-till F-W	1.5	1.6	1.4	1.4	1.5	1.3
Tilled W-L	1.4	1.6	1.4	1.4	1.5	1.3
No-till W-L	1.5	1.6	1.4	1.5	1.5	1.3
SE	0.02	0.01	0.02	0.02	0.02	0.01
			50-100 cm			
Tilled F-W	1.5	1.6	1.5	1.4	1.4	1.5
No-till F-W	1.6	1.7	1.4	1.4	1.5	1.6
Tilled W-L	1.5	1.3	1.5	1.5	ND	1.5
No-till W-L	1.3	1.5	1.3	1.4	1.4	1.6
SE	0.04	0.06	0.04	0.03	0.04	0.02

W-L = wheat – legume rotation F-W = fallow – wheat rotation
ND = no data, samples were not able to be collected at that depth due to soil conditions.

Appendix Table 6. Crop biomass (t ha-1) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2003.

Cropping System	Location and crop					
	Chester peas	Collins peas	Conrad lentils	Great Falls pea/barley	Kremlin peas	Power pea/barley
Tilled W-L	1.5	1.7	0.8	4.1	2.3	2.2
No-till W-L	1.8	1.8	0.7	4.1	2.5	1.6
Tilled F-W	----	----	----	----	----	----
No-till F-W	----	----	----	----	----	----

Appendix Table 7. Wheat crop biomass (t ha-1) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2004.

Cropping System	Chester	Collins	Conrad	Great Falls	Kremlin	Power
No-till	6.3	6.5	8.2	11.3	6.9	5.9
Tilled	6.7	5.5	8.2	10.2	7.0	4.0
Alternate Yr	7.8	7.7	9.3	12.6	8.2	5.2
Continuous	5.2	4.3	7.1	8.9	6.1	4.8

Appendix Table 8. ANOVA results for total wheat biomass (t ha-1), 2004.

Source	df	Prob>F	Effect
Site	5	<0.0001	
Tillage	1	0.0019	NT (7.5) >T (6.9)
Intensity	1	<0.0001	AY (8.5) > Cont (6.1)
SxT	5	0.0001	NT > T @ farms 2), 4), and 6)
SxI	5	<0.0001	AY > Cont @ all farms except 6)
TxI	1	0.6484	
SxTxI	5	0.2479	

Appendix Table 9. Wheat yield (bu ac-1) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2004.

Cropping System	Chester	Collins	Conrad	Great Falls	Kremlin	Power
No-till	36	29	46	48	38	33
Tilled	34	23	45	40	40	22
Alternate Yr	40	32	52	55	44	28
Continuous	30	21	38	32	34	27

Appendix Table 10. ANOVA results for wheat yield (bu ac-1), 2004.

Source	df	Prob>F	Effect
Site	5	<0.0001	
Tillage	1	<0.0001	NT (38) >T (34)
Intensity	1	<0.0001	AY (42) > Cont (30)
SxT	5	0.0003	NT > T @ farms 1, 2, 4, and 5
SxI	5	<0.0001	AY > Cont @ all farms
TxI	1	0.3257	
SxTxI	5	0.7775	

Appendix Table 11. Wheat protein (%) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2004.

Cropping System	Chester	Collins	Conrad	Great Falls	Kremlin	Power
No-till	11.5	14.5	15.1	15.3	13.8	12.3
Tilled	11.1	15.5	15.2	17.1	13.4	14.6
Alternate Yr	11.2	16.5	15.3	16.0	13.4	13.2
Continuous	11.3	13.5	15.1	16.4	13.9	13.8

Appendix Table 12. ANOVA results for wheat protein (%), 2004.

Source	df	Prob>F	Effect
Site	5	<0.0001	
Tillage	1	<0.0001	NT (13.8) <T (14.5)
Intensity	1	0.0733	
SxT	5	0.0003	NT > T @ farm 6
SxI	5	<0.0001	AY > Cont @ farms 1 and 4
TxI	1	0.1246	
SxTxI	5	0.0307	

Appendix Table 13. Residue carbon (t ha-1) for each plot at Chester, Collins, Conrad, Great Falls, Kremlin and Power, 2003-4.

Cropping System	Chester	Collins	Conrad	Great Falls	Kremlin	Power
No-till	2.6	2.7	2.5	4.0	2.9	1.9
Tilled	2.7	2.4	2.6	3.7	3.0	1.4
Alternate Yr	2.4	2.5	2.7	4.0	2.4	1.6
Continuous	2.9	2.6	2.4	3.7	3.4	1.7

Appendix Table 14. ANOVA results for residue carbon (t ha-1), 2003-4.

Source	Df	Prob>F	Effect
Site	5	<0.0001	
Tillage	1	0.0033	NT (2.8) <T (2.6)
Intensity	1	0.0033	Cont (2.8) > AY (2.6)
SxT	5	0.0038	NT > T @ farms 1, 2, 3, 5
SxI	5	<0.0001	Cont > AY @ farms 1, 2, 3, 6
TxI	1	0.9382	
SxTxI	5	0.0260	

Appendix Table 15. Summary of possible production cost changes from adopting practices to sequester additional soil C.

Studies	**Range of Findings**
Labor costs – field operations	
Aller et al. (2001); Harper (1996); Massey (1997); Olson and Senjem (2002); Yin and Al-Kaisi (2004)	*Labor savings* for field operations due to tillage reduction range between $2.47/ha and $19.13/ha
Fuel costs	
Williams, Llewelyn, and Barnaby (1990); Parsh et al. (2001); Massey (1997); Aller et al. (2001); Williams et al. (2004)	*Fuel cost reductions* from reducing tillage range between $1.39/ha and $16.93/ha
Fuel use	
Williams, Llewelyn, and Barnaby (1990); Williams et al. (2004)	*Fuel use reductions* as a result of reducing tillage range between 26.2 l/ha and 35.71 l/ha
Bashford and Shelton (1981); Schrock, Kramer, and Clark (1985); West and Marland (2002)	These studies provide a range of estimates showing that *fuel use is lower for operations that do not involve tillage*.
Machinery repair costs	
Johnson et al. (1986); Mikesell, Williams, and Long (1988); Williams, Llewelyn, and Barnaby (1990); Weersink et al. (1992); Parsch et al. (2001); Williams et al. (2002)	Machinery repair costs are lower for no-till in comparison to conventional till. Estimates of *cost savings* range between $2.77/ha and $27.92/ha.
Lazarus and Selley (2005)	*Repair costs are lower* for equipment not used in tillage.
Equipment ownership costs	
Llewelyn, Williams, and Thompson (1988); Williams et al. (1989); Weersink et al. (1992); Ribera, Hons, and Richardson (2004); Aller et al. (2001)	*Equipment ownership costs can be reduced* by between $10.13/ha and $117.96/ha as a result of switching from conventional to no till.
Lazarus and Selley (2005); Schnitkey, Latlz and Siemens (2003)	*Higher ownership costs* for no-till planting equipment than conventional till.
Overall cost effects	
Dhuyvetter et al. (1996); Williams, Roth, and Claassen (2000); Parsch et al. (2001); Epplin et al. (2005)	No till systems have higher overall costs than conventional till. Labor and machinery cost reductions can be offset by increases in chemical costs.
Williams, Llewelyn, and Barnaby (1990); Weersink et al. (1992); Mitchell (1997); Yin and Al-Kaisi (2004)	No-till per hectare costs found to be less than those for conventional till.
Langemeier (2005)	Farms that use less tillage have lower per-unit production costs.

Source: Mooney, S. and J. Williams. In Press. Private and societal benefits of carbon sequestration. *In* J. Kimble, C. Rice, D. Reed, S. Mooney, R. Follett, and R. Lal. (eds) Soil carbon management: Economic, environmental and societal benefits. Taylor and Francis Group, LLC, Boca Raton, FL.

Appendix Table 16. Summary of yield and net revenue changes from adopting practices to sequester additional soil C.

Studies	**Range of Findings**
Yields	
Dhuyvetter and Kastens (1996); Llewelyn, Williams, and Thompson (1988); Williams, Llewelyn, and Barnaby (1990); Williams (1988); Ribera, Hons and Richardson (2004); Bushong and Peeper (2004); Harper (1996); Parsch et al. (2001); Denton and Tyler (2002); Yin and Al-Kaisi (2003); Hellwinckel, Larson, and DeLaTorre Ugarte (2003); Wilhelm and Wortman (2004); Devlin et al. (1999).	Yields are highly dependent on climate and soil conditions. The *impact of no-till and reduced till on yields varies by crop and location.* Some studies have found an increase in crop yield resulting from the adoption in no-till, some have found that yields decrease and others find no statistical difference between yields. In general, *additional soil carbon sequestration is expected to increase yields in areas where soil moisture is limiting or soil has been previously degraded by erosion*.
Net returns	
Dhuyvetter et al. (1996); Williams, Llewelyn, and Barnaby (1990); Harper (1996); Katsvairo and Cox (2000); Parsch et al. (2001); Williams et al. (2004); Ribera, Hons and Richardson (2004); Yin and Al-Kaisi (2003); Pendell et al. (2005).	Several studies found no-till to be more profitable than conventional till, while others found the opposite result. *Results vary by crop and by region*.

Source: Mooney, S. and J. Williams. In Press. Private and societal benefits of carbon sequestration. *In* J. Kimble, C. Rice, D. Reed, S. Mooney, R. Follett, and R. Lal. (eds) Soil carbon management: Economic, environmental and societal benefits. Taylor and Francis Group, LLC, Boca Raton, FL.

Appendix Table 17. Examples of societal costs that could be partially offset by increasing soil C sequestration.

Studies	**Range of Findings**
Water erosion	
Hansen et al. (2002); Clark, Havercamp, and Chapman (1985); Ribaudo (1986).	Dredging of inland waterways estimated to cost $257 million annually. *Total damages estimated between $7 billion to $30 billion annually.*
Wind erosion	
Uri (2001); Pimental et al. (1995)	*Total damages estimated between $12 billion to $36 billion annually.*
Wind and water erosion in total	
Uri (2001); Pimental et al. (1995)	*Total combined annual cost estimated between $37 billion and $44 billion annually.*
Nutrient run off and water quality	
NYC watershed	Value of water improvements in Catskills and Delaware watersheds estimated to be between *$6 billion to $8 billion*.
Wildlife and recreation	
Feather, Hellerstein, and Hansen (1999)	Benefits wildlife viewing from CRP lands estimated at $348 million.

Source: Mooney, S. and J. Williams. In Press. Private and societal benefits of carbon sequestration. *In* J. Kimble, C. Rice, D. Reed, S. Mooney, R. Follett, and R. Lal. (eds) Soil carbon management: Economic, environmental and societal benefits. Taylor and Francis Group, LLC, Boca Raton, FL.