**Cooperative Extension**
**Colorado State University**

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# FROM THE GROUND UP
## agronomy news

## INSIDE THIS ISSUE



# The Greenhouse Effect and Carbon Sequestration

**Agriculture emits and stores atmospheric gases that absorb radiation.**

All organic substances contain carbon (C). The C cycle, through which carbon dioxide from the atmosphere is converted to organic forms by plant photosynthesis and then returned to the atmosphere through respiration, is the basis for life on earth. Soil organic matter (SOM) contains three times as much C as is found in vegetation, on a worldwide scale. Therefore, soil organic matter plays a critical role in the global C balance and the greenhouse effect. In fact, when SOM is measured, it's actually soil organic carbon (SOC) that is measured, and then a conversion factor is used to calculate SOM.

What is the greenhouse effect? Radiation from the sun warms the earth, and the earth radiates some of that energy back into outer space. The energy radiated away from Earth has a longer wavelength than the incoming energy. This long-wavelength radiation is absorbed by gases in the air, resulting in increased temperatures. The heat-retaining process of atmospheric gases is referred to as the "greenhouse effect." Without this greenhouse effect, the average temperature of the

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Knowledge to Go Places

## The Greenhouse Effect and Carbon Sequestration (cont.)

Earth would be considerably colder (about 86° F colder) and would be inhospitable to humans. However, many scientists have documented increased global temperatures during the past century and are concerned about continuing global warming and its impacts on the Earth and human life.

The greenhouse effect is quite noticeable in the cooling of the Earth at night. When it's clear, the energy that the Earth absorbed during the day radiates to outer space, and nights are cold. When it's cloudy, the water vapor absorbs radiation, and nights are relatively warm.

The gases that absorb the long-wavelength radiation emitted by the earth are known as "greenhouse gases." They include water vapor, carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and chlorofluorocarbons (CFCs). The concentrations of these gases have been increasing steadily since the Industrial Revolution.

All three of the major gases of general concern for global warming, carbon dioxide ($CO_2$), nitrous oxide ($N_2O$) and methane ($CH_4$), are important for agriculture. The overwhelming source of $CO_2$ is fossil fuel use, with deforestation and biomass burning an important source in the tropics. Agriculture provides a potential sink for $CO_2$, through building up soil organic matter stocks, which incorporate $CO_2$ taken from the atmosphere by plants. This is called "carbon sequestration."

Within agriculture, methane is emitted by ruminant digestive processes and from livestock waste systems. Flooded rice cultivation is a major source of $CH_4$ worldwide, but of less importance in the U.S. Reducing emissions is the most important component of mitigation of methane, but well-aerated soils also act as a sink (that is, take up and oxidize $CH_4$). Soils are a major source of $N_2O$ emissions, which tend to increase with additions of nitrogen, whether from mineral fertilizers, legumes, or manure.

An important point to consider in the overall effect of greenhouse gases is the relative difference in global warming potential (GWP), which is a measure of the 'heat-trapping' ability of the gas and its longevity in the atmosphere. Relative to $CO_2$ (assigned a GWP of 1), $N_2O$ has about 300 times the effect of $CO_2$, and $CH_4$ has about 20 times the effect. Thus, while the concentration and flux rates of $N_2O$ and $CH_4$ are much lower than for $CO_2$, their effects are significant due to the characteristics of those gases with respect to global warming.

Our focus in this newsletter is on carbon, specifically $CO_2$ and $CH_4$. When organic matter decays in the presence of oxygen, $CO_2$ is formed. But when there is a shortage of oxygen, C is released as $CH_4$. We will evaluate the potential for reducing the emission of these greenhouse gases from agriculture and for increasing the sequestration of C in agricultural land. Many agricultural practices that reduce emission or increase sequestration of C have other favorable impacts. For example, many of these practices may also increase farmers' profit, conserve soil and water, or improve ecosystem health.

*Jessica Davis, Professor and Extension Soil Specialist, Soil & Crop Sciences*
*and*
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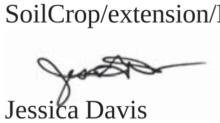

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# Global Carbon Sequestration Potential

## Management-induced C sequestration is a temporary solution to greenhouse gas buildup.

Knowing how much water is needed to fill up a drinking glass or a water trough is easy: the empty volume equals the amount of water needed. Ordering the right amount of food for dinner to fill your stomach is a little more difficult since measuring the empty space is not as straightforward and, further, the amount of available space varies with the tastiness of the meal. This is similar to estimating the potential to sequester atmospheric $CO_2$ in agricultural, range, or forest soils and biomass. Most (but not all) C that can be sequestered is C that was lost from the biosphere due to past management practices – equivalent to the empty space in your stomach. However, the portion of this potential that might become occupied varies with land managers' appetites for C sequestration policies and practices. The absolute amount that can be sequestered is calculated as the difference between what the biosphere can hold and what it holds now. This calculation is by no means simple, and it is further complicated by our incomplete knowledge of how land managers (those who will actually be deciding how that land is

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***Table 1. Area, portion of area likely to adopt a new practice or land use, rate of C gain with change, and total potential for area in which improved management practices can be implemented (A) and in which land use changes are likely to occur (B). Within each activity, the top line (unshaded) contains data for developed countries and the bottom line (shaded) contains data for developing countries.***

| Activity | Area (million acres) | Adoption (% by 2010) | Rate of C gain (lbs C $acre^{-1}$ $yr^{-1}$) | Potential (billion lbs C $yr^{-1}$) |
|---|---|---|---|---|
| *A. Improved management within a land use* | | | | |
| Cropland | 1455 | 40 | 286 | 166 |
| (reduced till, rotations, etc.) | 1729 | 20 | 321 | 111 |
| Agroforestry | 205 | 30 | 446 | 27 |
| (better tree man. on cropland) | 783 | 20 | 196 | 31 |
| Grazing land | 3204 | 10 | 473 | 152 |
| (grass, legume, fire, herd, etc.) | 5197 | 10 | 714 | 371 |
| Forest | 4688 | 10 | 473 | 222 |
| (regeneration, fertilization, etc.) | 5318 | 10 | 277 | 147 |
| *B. Land-use change* | | | | |
| Agroforestry | 0 | 0 | 0 | 0 |
| | 1556 | 20 | 2767 | 861 |
| Restoring severely degraded land | 30 | 5 | 223 | <1 |
| | 655 | 5 | 223 | 7 |
| Grassland | 1487 | 5 | 714 | 53 |
| (conversion from cropland) | 2112 | 2 | 714 | 30 |
| Wetland restoration | 519 | 5 | 357 | 9 |
| | 49 | 1 | 357 | <1 |

## Global Carbon Sequestration Potential (cont.)

managed and, thus how much C is sequestered) will behave. Therefore, any estimates of C sequestration potential are obligated to carry a number of assumptions and caveats that confine them to a limited number of future scenarios.

Since potential C sequestration is such an important issue for greenhouse gas management, a variety of likely C sequestration policies and practices have been evaluated with the aforementioned issues in mind. The Intergovernmental Panel on Climate Change (IPCC) recently published a special report on Land Use, Land-Use Change, and Forestry (Sampson et al., 2000) that reviewed how various management practices might impact C sequestration worldwide. Carbon sequestration rates were based on review data from published studies, and adoption rates were based on expert opinion. Results from this report are listed in Table 1 (p.3). In general, C storage potentials for management changes within a particular land use are substantially larger than changes associated with those arising between different types of land use. Within grazing lands, for example, nearly 525 billion lbs C might be sequestered annually by 2010, but only 83 billion lbs C are likely to be sequestered with conversion from cropland to grassland. Of these estimated total potentials, most (71%) is in the developing world, but of the C sequestration likely with changes in management, almost half (45%) is in the developed world.

Within the U.S., it has been estimated that 165-459 billion lbs C can be sequestered annually in croplands (Lal et al., 1998) and between 65-243 billion lbs C $yr^{-1}$ in grazing lands (Follett et al., 2001a). These calculations, like those presented above, are based on published studies examining changes in soil C with changes in management, and they assume very widespread adoption. Furthermore, these sequestration estimates, again like those done by the IPCC and most others, do not account for management-induced changes in other biogenic greenhouse gases (nitrous oxide and methane) that could increase as a result of some of the practices evaluated.

In the mid 1990s, $CO_2$ emissions in the US were about 11 trillion lbs C $yr^{-1}$. So compared to emissions, C sequestration in terrestrial ecosystems can account for about 6.4% of 1990 emissions. While a considerable amount of C can be stored in terrestrial ecosystems, management-induced C sequestration is only a temporary and partial solution to the greenhouse gas problem. The degree to which sequestration is applied as a solution depends in large part on the appetite of land managers for C sequestering practices.

*Rich Conant*
*Research Associate*
*Natural Resources Ecology Laboratory*

# Meet Keith Paustian

Keith Paustian is Professor of Soil Ecology, Department of Soil and Crop Sciences and Senior Research Scientist, Natural Resources Ecology Laboratory at Colorado State University. His main fields of interest include agroecosystem ecology, soil organic matter dynamics and global change. He is currently leading projects to assess soil C sequestration in several states, and to develop national inventories of C emissions and sequestration. His research also involves development of ecosystem and economic assessments to advise policy makers on climate change mitigation. He is a leader on the Inter Governmental Panel on Climate Change (IPCC) and the Council for Agricultural Science and Technology taskforce on agricultural mitigation of greenhouse gases. He is an editor of a recent book entitled Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America. Keith can be reached at (970)491-1547 or keithp@nrel.colostate.edu.

# State Level Assessments of Carbon Sequestration

## Soils in mid-Western states have large C sequestration potential.

Land managers have long known the importance of soil organic matter in maintaining the productivity and sustainability of agricultural land. More recently, interest has developed in the potential for using agricultural soils to sequester C and mitigate increasing atmospheric $CO_2$ by adopting practices that increase standing stocks of carbon in soil organic matter and vegetation. To help local land owners and land mangers in their decision-making process, we initiated state level assessments in Iowa, Indiana and Nebraska to determine how management decisions involving cropping and tillage systems affect soil organic matter.

Our approach utilized a variety of resource data (on climate, soils, land use and management), long-term field experiment results, and the Century EcoSystem Soil Organic Matter Computer Model developed at Colorado State University. The initial Phase I studies of cropland in the states used existing information on climate, soils and management factors (e.g., drainage, irrigation, crops grown, production levels and tillage systems) to estimate current rates of C sequestration. From these early studies, we found that individual counties had land use information, including management histories of crop rotations and tillage practices, drainage histories, irrigation histories, fertilizer rates, and conservation practices that were not available in published databases. This information is very important in determining the C sequestration rates within a state.

To capture this information and utilize it in the state level C assessments, a Phase II study was done that involved all 284 counties. To communicate with the local land managers and collect the local data, a new survey instrument called the Carbon Sequestration Rural Appraisal (CSRA) survey instrument was developed, tested and modified. Through the use of geographic information systems (GIS) and existing databases of land use and soil types, individual tailored spreadsheets were prepared for each county detailing existing land use and soils interactions. Local land managers used this information to assess land use changes since the start of cultivation in their area and provided information on cropping systems, tillage systems, fertilizer application rates from manure and commercial sources, irrigation, drainage and the application of conservation practices. This local data provided additional inputs into the Century Model that were not available in previously published databases, and refined the output for the individual counties and the soils and crop/tillage systems. Century Model estimates for multiple scenarios are now available in the CarbOn Management Evaluation Tool (COMET) databases for each state.

Final assessments suggest that agricultural soils are currently sequestering 11 billion lbs of C per year in these three states (equivalent to 42 billion lbs of $CO_2$ per year), largely through increased adoption of conservation practices over the past 10 to 20 years. It is also apparent that agricultural soils have the potential to sequester even larger amounts of C, should land managers make C conserving decisions.

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# Management Practices that Sequester Carbon

## Cropland Management for Carbon Sequestration

### Management practices that promote C sequestration improve soil quality and productivity.

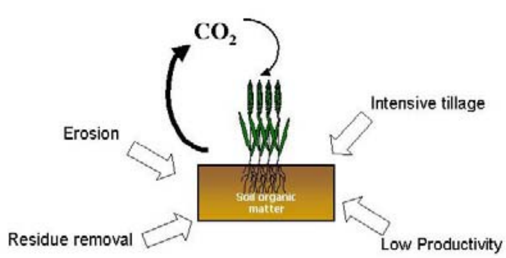
There are about 400 million acres of cropland in the US and about 9 million here in Colorado. On most of this area, annual crops are grown and harvested each year – thus, there is little C (as biomass) stored above ground. However, soils in general, including cropland soils, are huge repositories of organic C. In most ecosystems, the amount of C in the top 3 feet of soil is greater than that stored in all the vegetation, even in forests. Thus, C sequestration in croplands means increasing the storage of C in soil.

Most cropland soils contain much less C than they did in their original condition under prairie or forest vegetation – soils brought under the plow usually lost 30 to 50% or more of their organic matter within a few decades. Frequent and intensive tillage combined with low productivity and minimal residue yields were typical in the past when most of our croplands were established. Such conditions tended to reduce C inputs to soil and accelerate C losses through organic matter decomposition and erosion, reducing soil C stocks (see Fig. 1a). Worldwide, it is estimated that conversion of land to agricultural uses resulted in the loss of 50-100 billion tons of C from soils, over the past 200 years. Even today, conversion of forests to agriculture in the tropics continues to be an important source of $CO_2$ emissions, from biomass and soils, to the atmosphere. However, with improved management practices, the organic matter and C stocks of these soils can be restored, effectively removing $CO_2$ from the atmosphere (Fig. 1b).

The amount and rate of C sequestration varies according to natural factors such as climate (temperature and rainfall) and soil physical characteristics (soil texture, clay mineralogy, soil depth), as well as agricultural management practices. In general, the amount of C stored in soils is determined by the balance between C inputs from plant (and animal) residues and C emissions from decomposition. Thus, increasing soil C stocks requires increasing C inputs and/or decreasing C decomposition. Hence, C sequestration will be favored under

Continued on page 7

***Fig. 1a. Effects of agricultural practices on the soil carbon balance. The thickness of the arrows represents the extent of each process.***




***Degradative practices associated with past agricultural practices promoted soil C losses.***

## Cropland Management for Carbon Sequestration (cont.)

management systems that (1) minimize soil disturbance and erosion, (2) maximize the amount of crop-residue return, and (3) maximize water- and nutrient-use efficiency of crop production (Paustian *et al.*, 2000). Although it may be impossible to optimize all these system attributes simultaneously, management practices that effectively sequester C share one or more of these traits.

Decreasing tillage intensity, especially by using no-till, has been found to promote C sequestration. In long-term field experiments comparing no-till to conventionally tilled annual cropping systems, adoption of no-till typically resulted in increases in soil C of 100 to 1000 lbs C/acre/year over periods of 20-30 years (Paustian *et al.*, 1997). Sequestration rates tend to be higher in moist climates with high levels of crop residue inputs and lower in semi-arid regions supporting lower levels of primary production. In semi-arid regions, no-till also provides increased water storage, enabling more continuous crop rotations and a reduction in summer fallow frequency (Peterson *et al.*, 1998). The effects of no-till systems under these conditions are synergistic, in that, no-till enables higher crop inputs through more intensified rotations, reduced decomposition rates with less summer-fallowing, greater water use efficiency, and less soil disturbance. No-till by itself, without decreasing or eliminating summer fallow, will have much less of a positive impact on soil C sequestration.

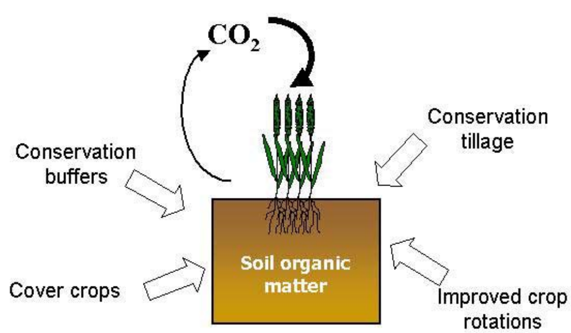
Increasing the amount of residue returned to soil can be accomplished through a variety of practices, including growing high-residue yielding crops, using hay in rotation with annual crops, application of

Planting annual cropland to perennial grasses, such as in the Conservation Reserve Program (CRP) or in field buffer strips, grass waterways, shelterbelts, or other conservation plantings, tends to promote high rates of C sequestration and can also greatly reduce emissions of another soil-borne greenhouse gas, nitrous oxide ($N_2O$). With productive grass or grass-legume cover, the amount of C returned to the soil is often high, and the lack of tillage disturbance promotes stabilization of SOM. Rates of soil C increase as high as 1000-1500 lbs C/acre/year have been reported for CRP land in the Corn Belt region; however, lower rates of soil C increase would be expected in semi-arid regions such as eastern Colorado (see Follett article starting on p. 13).

Regardless of how management or land use changes, C sequestration does not go on indefinitely.

Continued on page 8

***Fig. 1b. Effects of agricultural practices on the soil carbon balance. The thickness of the arrows represents the extent of each process.***




***Improved agricultural and conservation practices can rebuild soil organic matter stocks.***

## Cropland Management for Carbon Sequestration (cont.)

Eventually, under a new management regime, soil C levels tend toward an equilibrium, where the amount of C in soil remains roughly constant. In addition, energy costs associated with manufacture and distribution of agricultural inputs such as fertilizer, energy for machinery and irrigation pumping, as well as emissions of other greenhouse gases (nitrous oxide and methane) must be considered in choosing the best management practices to sequester C. In general, practices that promote efficient use of resources, including water, nutrients and energy, will have the greatest benefits in terms of sequestering C and reducing other greenhouse gases.

Whereas, C sequestration through improved agricultural practices can help to reduce the buildup of greenhouse gases, the benefits to the health and productivity of the soil are of equal or greater importance. Soil organic matter is widely recognized as one of the key attributes affecting soil quality. Soil organic matter performs many important functions controlling water and nutrient availability to crops. Increasing the amount of organic matter in agricultural soils is almost always beneficial and carries along with it increased water infiltration, reduced runoff (and erosion), increased soil buffering capacity, and increased storage of essential plant nutrients. Thus, management practices that promote C sequestration can provide a host of resource and environmental benefits that improve the health and sustainability of the soil and ultimately the farmer's bottom line.

*Keith Paustian, Professor,*
*Dept. of Soil and Crop Science*
*and Natural Resource*
*Ecology Laboratory*

# Dryland Corn Field School

Colorado State University Cooperative Extension is hosting a dryland corn field school that will address dryland corn production issues. The outdoor classroom will be held on August 15, 2002 beginning at 7:00 a.m. at the Akron USDA/ARS Station (4 miles east of Akron on Hwy 34).

Topics include planting decisions, water use in dry land rotations and limited irrigation, soil fertility and management zones, insects and diseases, weed management, and economics of dryland corn production. Continuing education credits will be offered for certified crop advisors (CCA CEUs: 2 CP, 2 PM, 1 SW, and 1NM). Pre-registration is required due to limited space, although there is no registration fee.

***For registration questions, call Karen at (719) 346-5571. REGISTRATION Deadline – July 26***

***Detach and mail this registration form to:***
***Or fax to: 719-346-5660***
***Or e-mail to: kitcarso@coop.ext.colostate.edu***

***Corn Field School***
***Attention: Karen***
***Kit Carson County Extension***
***251-16th Street, Suite 101***
***Burlington, CO 80807***

***Name*** ____________________________________

***Please list additional names from your organization that will be attending.***
***1)*** ____________________________ ***2)*** ____________________________ ***3)*** ________________________

***Organization*** ____________________________________________________________

***Mailing Address*** ____________________________________________________________

***City*** ____________________________ ***State*** ________________________ ***Zip*** ________________________

***Daytime Phone*** (____)____________________ ***E-mail*** ________________________________

# Eliminating Summer Fallow Maximizes Carbon Sequestration in Dryland Cropping Systems

## Increasing cropping intensity increases C sequestration.

Water is the most limiting factor in dryland cropping systems in the central Great Plains. Summer fallow was implemented to stabilize production in this region by storing two years of soil water for one years crop. The traditional dryland cropping system in this region was conventional tillage management of crop-fallow, commonly wheat-fallow, which produced one crop every two years. In order for the fallow period to be successful, weeds and volunteer plants need to be controlled by tillage to provide soil profile water storage. However, summer fallowing every other year is economically and environmentally costly. Tillage accelerates the amount of soil carbon that is used as an energy source by microorganisms. The mixing action of tillage also increases aeration and places surface crop residues into the soil where they are decomposed faster. Conventional tillage in a crop-fallow system has accelerated losses of soil organic carbon (SOC), with estimates of 30 to 50% reduction in the Great Plains.

Implementing no-tillage management practices has allowed a reduction in the frequency of summer fallowing by increasing the cropping intensity. No-tillage management is superior in conservation of precipitation. Increasing water storage efficiency allows for more opportunities to grow crops. It is even possible to successfully intensify the cropping system to continuous cropping without needing summer fallow.

Production sustainability depends on management practices that promote the sequestration of carbon from crop production inputs. Management systems that continue to lose soil organic matter and thereby lose soil carbon will become increasingly less sustainable as soils become more susceptible to erosion. Cropping systems that maximize production and reduce and/or eliminate the practice of summer fallowing will provide the carbon inputs that will maintain or even increase soil organic matter levels.

A no-till dryland rotational experiment was initiated in the fall of 1985 near three eastern Colorado communities [Sterling (low ET), Stratton (medium ET), and Walsh (high ET)] located along a evaporation-transpiration (ET) gradient from 63 inches to 76 inches, each with an average annual precipitation of 16.5 inches. Each site has cropping system treatments imposed across a landscape of summit, side, and toeslope positions. Systems include wheat-fallow (WF), wheat-corn-fallow (WCF), wheat-corn-millet-fallow (WCMF), and continuous cropping (CC). At the high ET site (Walsh), grain sorghum is substituted for corn. Soil organic C changes over 12 years were determined by taking the final SOC and subtracting the initial SOC in 1986. The change in SOC in the top four inches was divided by the number of years to obtain an average annual sequestration rate over the 12 year period.

Continued on page 10

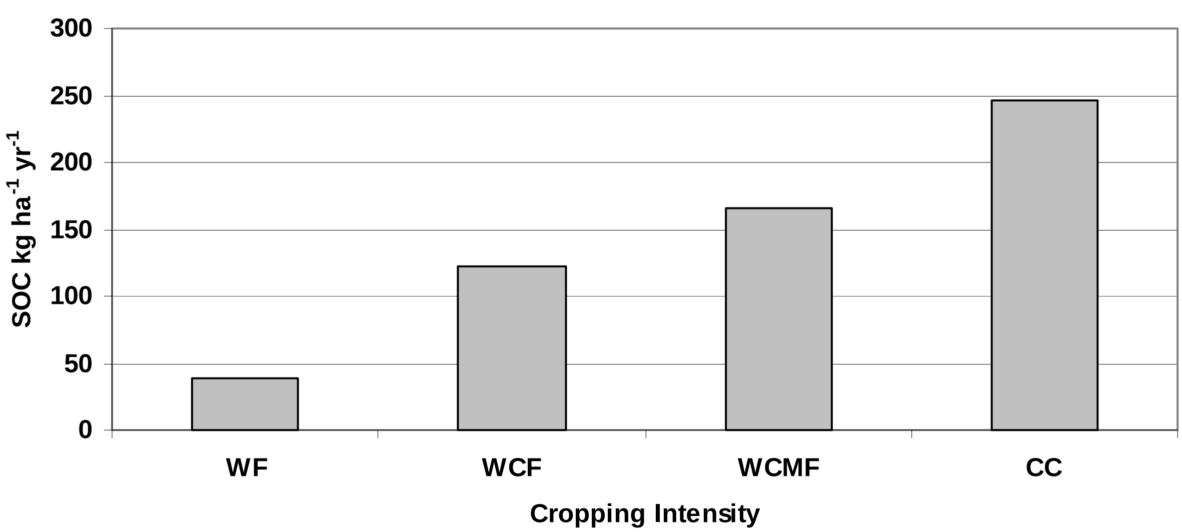
## Eliminating Summer Fallow Maximizes Carbon Sequestration in Dryland Cropping Systems (cont.)

The amount of SOC sequestered was affected by the intensity of cropping systems imposed (Figure 2 on p. 10). Cropping systems that intensify the frequency of cropping and reduce and/or eliminate summer fallowing maximize SOC sequestration rates. The rate of SOC was 223 lbs/acre/yr (245 kg/ha/yr) for CC in comparison to 36 lbs/acre/yr (40 kg/ha/yr) for WF when averaged over sites and slopes. Overall, the SOC levels have increased in surface soils to a depth of 4 inches as a result of intensification of cropping systems with no-till management. Sequestration rates increased with increasing cropping intensity at all ET locations.

The amount of carbon sequestered is dependent on inputs that control the primary production including ET, site location, and landscape slope position. Losses of soil organic matter are accelerated in the hotter and dryer climates. The impact of change is greatest on sites with the lowest initial organic matter levels. Where average annual rainfall, soil depth, and texture allow intensification, significant increases in SOC can be attained. For more information on dryland cropping systems, look up the web site www.colostate.edu/Dept/AES/ and click on publications for the most recent technical bulletins.

*Lucretia Sherrod USDA-ARS,*
*Fort Collins, CO*
*and*
*Gary Peterson, Professor,*
*Soil & Crop Sciences*


*Figure 2. Rate of SOC sequestration after 12 years as affected by cropping intensity.*



# Managing Rangelands to Sequester Carbon

**Grazing management practices influence C sequestration on the most extensive terrestrial ecosystem on the planet.**

Rangelands make up the most extensive terrestrial ecosystem on the planet. Over eight hundred million acres of rangeland are located in 19 western states, more than twice the area of cultivated cropland in the U.S. Unlike annual crops, the vegetation of most rangelands is predominantly perennial and often consists of a mixture of cool-season and warm-season species which lengthens the amount of time during the year that plants are actively growing and taking up atmospheric $CO_2$. Perennial grasses, a major component of most rangeland plant communities, enhance C storage into the soil because grasses have a much higher portion of total plant biomass in belowground tissues than do trees, most shrubs, or annual crops. The magnitude of land area involved, plus attributes of rangeland vegetation that promote high levels of C storage, make rangelands a potentially important sink for atmospheric C.

Until recently, little consideration has been given to the possibility that rangelands can be managed to enhance C storage. Potential improvements in management to promote higher vegetation productivity and higher levels of soil C include fertilization, seeding improved plant varieties, and manipulating the timing, duration and intensity of grazing.

**Potential**

Rangelands are located predominately in arid or semi-arid regions, where both the production of vegetation and its response to fertilizer are limited by water. In these ecosystems, intensive management practices such as fertilization, irrigation, or seeding improved plant varieties usually are economically impractical. Improvements in management to promote higher vegetation productivity and increased soil C will therefore generally be restricted to modifying stocking rates and the timing of livestock grazing. For rangelands in good condition with no serious ecological or management problems, we can assume that there is little potential for further C storage because the C content of these soils is relatively stable and already at or near maximum expected concentrations. In these healthy rangelands, the goal is to preserve existing C stocks by maintaining or establishing optimal grazing strategies to avert C losses. Most rangelands, however, cannot be classified as in good condition. Because of excessive grazing and poor management in the past, approximately two-thirds of western rangelands are classified as in fair to poor condition. These degraded rangelands have lost much of their plant diversity, productivity, and native soil C, and would benefit from improved management. However, the rate at which C can be added to the soil by improved grazing management will be relatively low because of the low natural productivity of arid and semi-arid ecosystems. Improvements in grazing management usually will induce gradual rather than rapid improvements in plant species composition and production, so the impact on soil C may not be measurable for years.

**Strategies**

Research to develop grazing management strategies that optimize C storage in rangelands is in its

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## Managing Rangelands to Sequester Carbon (cont.)

infancy, and the current literature suggests no clear general relationship between grazing and C sequestration. Some studies have reported no effect of grazing on soil C, while others have reported increases or decreases in soil C as a result of grazing. Several generalizations concerning the impact of grazing on ecosystem C can be made, however:

*(1) Grazing management that leads to a shift in plant species composition causes changes in soil C stocks.* This is because plant roots are the major source of C to the soil, and plant species differ in the distribution, mass and turnover of their root systems. Change in plant community composition as the result of grazing management is a major reason for the lack of a clear relationship between grazing and soil C sequestration.

*(2) Prolonged heavy grazing with inadequate recovery periods ultimately decreases C stocks in the soil.* Heavy grazing without adequate rest periods to allow regrowth weakens plants and decreases biomass production, which decreases inputs of C into the soil from the roots. With overgrazing, especially in conjunction with drought, plants begin to die and the removal of plant cover exposes the soil to loss of organic matter C by wind and water erosion.

*(3) Removing livestock grazing entirely can lead to lower C stocks in the soil.* Studies on a mixed-grass prairie near Cheyenne, Wyoming showed that C stocks in the top 12 inches of the soil were lower in 40-year-old livestock exclosures compared to adjacent pastures that had been lightly grazed. Excluding grazing by livestock tied up a large amount of C in excessive aboveground plant litter, and caused an increase in annual forbs and grasses which lack dense fibrous rooting systems conducive to soil organic matter formation and accumulation.

*(4) Grazing at stocking rates that maintain a diverse plant community dominated by perennial grasses optimizes C stocks in the soil and overall rangeland health.* Studies on a mixed-grass prairie near Cheyenne, Wyoming showed that grazing at light-to-moderate stocking rates resulted in a stable plant community dominated by desirable forage grasses and maximum plant biodiversity. Light-to-moderate grazing also stimulated early season photosynthesis and earlier spring green-up, and enhanced C and nutrient cycling among plants, animals and the soil, all of which contribute to building C stocks in the soil.

Most rangeland ecosystems evolved under grazing by large herbivores, and for these ecosystems, grazing appears to be a necessary component to overall health of the ecosystem. Developing livestock grazing strategies that optimize the stability and diversity of the plant community will also optimize soil C sequestration. The challenges in developing a best management grazing strategy for a given rangeland ecosystem are (1) determining the optimal length and timing of rest "heavy" for a given ecosystem, and (3) fine-tuning the stocking rate and the timing and duration of grazing to take into account annual fluctuations in precipitation and temperature.

We can expect the rate of C sequestration to be low as the result of improving grazing management on arid and semi-arid rangelands. However, because of the vast land areas occupied by rangelands, very small changes in the amounts of C lost or gained in rangeland soils become extremely important.

*Jean Reeder, Soil Scientist,*
*USDA-ARS,*
*Fort Collins, CO*

# The Conservation Reserve Program and Carbon Sequestration

## CRP offsets at least 25% of agriculture's $CO_2$ emissions.

Emissions of carbon dioxide ($CO_2$) to the atmosphere are expected to continue to increase in the future and, along with other greenhouse gases, contribute to the potential for global climate change. The capture and incorporation into plant tissues of atmospheric $CO_2$ by photosynthesis incorporates $CO_2$-C into plant tops and roots. The subsequent incorporation (sequestration) of plant tissue C into soil organic matter as soil organic C (SOC) is among the best options for C storage in terrestrial ecosystems.

Adverse impacts of ongoing soil erosion in the U.S. resulted in legislative authority for the conservation reserve program (CRP) under the Food Security Act of 1985 (P.L. 98-198). The CRP is a voluntary program offering annual rental payments and cost-share assistance to establish long-term resource-conserving covers on eligible land. Placing cultivated or highly erodible land into permanent plant cover potentially increases the amount of atmospheric $CO_2$-C captured and sequestered as SOC. The change in the SOC pool size is the net result of C additions minus C losses. Establishment of a permanent grass cover can increase the mass of C added into the soil, relative to what may be returned by traditional cropping systems, while lack of mechanical disturbance and absence of tillage decreases rates of SOC oxidation to $CO_2$ and the rate at which $CO_2$-C is returned to the atmosphere.

Increasing storage of C in vegetation and soil potentially offers significant accompanying benefits including: improved soil quality, sustainable productivity, decreased pollution of surface and ground waters by agricultural chemicals, reduced soil erosion, and less overall off-site environmental degradation. Carbon that is stored below ground is more permanent than plant biomass; however, it, too, can be easily lost by the adoption of unsuitable soil management practices. Historically, there has been little emphasis given to developing or implementing strategies for C sequestration. Rather, C sequestration was not considered at all or had a low priority, and losses of SOC occurred along with the release of large quantities of C to the atmosphere as $CO_2$.

The CRP is a highly important land use in the west and especially within Colorado, as indicated by the following data. The current area in the CRP program is 33.8 million acres (www.fsa.usda.gov), an area equivalent to about 10% of all US cropland. The CRP is not evenly spread across the U.S. For example, within the Great Plains and western Corn Belt (a 13 state region including TX, NM, CO, WY, MT, OK, KS, NE, SD, ND, MO, IA, and MN) there are 25.1 million acres, or 74.3 % of all CRP land in the US. In Colorado, the area under CRP is 2.2 million acres, an area that accounts for 6.5 % of all CRP land in the U.S. and an area that is equivalent to 26.3% of all cropland within Colorado. Of 37 counties in CO with active CRP contracts, just six counties (Baca, Weld, Washington, Kiowa, Kit Carson, and Prowers) account for about 55 % of the CRP area within Colorado. Answers are needed about the accrued beneficial effects of CRP from placing land under permanent cover and benefits that may be lost by removal of land from CRP and returning it to cultivation, especially effects upon SOC sequestration.

Current literature documents rates of SOC sequestration under the CRP by use of models. Such estimates indicate rates of C sequestration for the western and central U.S. are <90 to 360 lbs/ac/yr of soil organic matter and 220 to 1200 lbs/ac/yr of total below ground C, including roots. Some estimates suggest that about 450 and 580 lbs C/ac/yr are sequestered under the CRP as SOC in the 0 to 2 and 0 to 4 inch depths, respectively. Research reported in 1994 at five sites across TX, KS, and NE indicated that about 710 and 980 lbs SOC/ac/yr were sequestered in the 0 to 15 and 0 to 120 inch depths under the CRP. Research that returned cultivated fields in southeastern Wyoming to perennial grasses showed increasing labile soil C pools; however, only a slight increase in SOC was observed after six years in the CRP. Thus, there is a considerable range reported in the

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## The Conservation Reserve Program and Carbon Sequestration (cont.)

literature for the amounts of SOC that can be sequestered under the CRP.

A recent, well-documented, study was conducted by Unger (2001) in which "paired comparisons" were used for determining the rate at which the SOC pool changed over 10 years under CRP vs. cropped soils at eleven sites in TX. Unger's study is especially valuable because of the number of sites studied within a relatively small region of the Great Plains. His results showed SOC was sequestered at an average rate of 830 lbs/ac/yr within the 0 to 8 inch depth. The rate at which SOC pools change under the CRP as compared to cropped soils is likely a function of climate, previous cropping history, current management practices, plant species seeded on the CRP, topographic location, soil texture and mineralogy, and time.

Follett *et al.* (2001b) designed a study to provide broad regional information about the potential of using the CRP as a means to sequester atmospheric $CO_2$-C in soil and to provide an estimate of the importance of the use of the CRP within the U.S. as a management option to address the issue of climate change. The area represented by the Follett *et al.* study statistically represented 13.9 million acres of land in the CRP or about 40 % of the current-total area of CRP in the U.S. Using a paired plot design, fourteen sites that had been in the CRP a minimum of five years were sampled across a matrix of three soil temperature regimes and three soil moisture regimes found in the Great Plains and western Corn Belt. Estimates of annual rates of SOC sequestration by the CRP were fairly wide and, not unexpectedly, included both negative as well as positive values. The range observed was due to differences among climatic regimes studied, difficulties associated with paired-sampling designs, and that CRP grass stands and cropped fields often had different ownership (and likely different management) even though soil and landscape factors were well matched. Irrespective, a high statistical confidence (>95%) was achieved for sequestration rates obtained (500, 660, and 810 lbs SOC/acre/yr in the 0 to 2, 0 to 4, and 0 to 8 inch depths, respectively). These estimates compare well with those from 1994 at five sites in TX, KS, and NE (710 and 980 lbs SOC/acre/yr sequestered in the 0 to 16 and 0 to 120 inch depths) and with the eleven sites in Unger's (2001) study (average of 830 lbs/acre/yr within the 0 to 8 inch depth).

Assuming that 500 to 800 lbs of SOC/ac/yr are sequestered across the 33.8 million acres of CRP land in the U.S., between 8.5 and 13.5 million tons of SOC are sequestered annually within the U.S. All U.S. agriculture has been reported to emit about 47.3 million tons of C/yr and, thus, the CRP can be estimated to offset from 25 to perhaps 40% of agriculture's $CO_2$ emissions, in addition to other environmental benefits attributed to the CRP.

*Ron Follett, Supervisory Soil Scientist,*
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# Meet Ron Follett

Ron Follett is Supervisory Soil Scientist with the U.S. Department of Agriculture, Agricultural Research Service, Soil Plant Nutrient Research Unit in Fort Collins. He is an author of several books, including two on carbon sequestration, The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect and The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. His publications cover many topics including: nutrient management for forage production, soil N and C cycling, groundwater quality protection, global climate change, agroecosystems, soil and crop management systems, soil erosion and crop productivity, plant mineral nutrition, animal nutrition, irrigation, and drainage. He can be reached at (970)490-8220 or email at rfollett@lamar.colostate.edu.

# Potential for Soil Carbon Sequestration with Livestock Systems

## Best management practices reduce greenhouse gas emissions and improve beef cattle productivity and profitability.

Livestock production systems emit 26% of the methane and more than 50% of the nitrous oxide, contributing significantly to greenhouse gas emissions. In fact, these emissions represent about 15% of the U.S. total $CO_2$ emissions equivalent (U.S. EPA, 2002). However, livestock systems also have potential for emission offsets or sequestration.

The potential of U.S. grazing land to sequester C has been estimated at 119 billion lbs C per year (Follett et al., 2001a). This is approximately 5% of U.S. $CO_2$-C emissions. A spreadsheet model developed at Colorado State University evaluates "whole-farm" greenhouse gas emissions from several beef production scenarios. Results indicate that pasture management and feed consumption can significantly impact the amount of C sequestered or emitted.

Land use by simulated U.S. beef production systems, representing needs of the cow-calf through feedlot, vary from 3.0 to 18.5 acres per cow unit. If median sequestration responses from best management practices (BMP's) to pasture, range and hay land of 357, 45 and 178 lbs C/acre/year are applied to these hectares, the estimated C sequestration potential ranges from 46 to 94 tons C/yr for 100 cow production systems (Table 2). Recent measurements by colleagues (Conant et al., 2001, unpublished) support annual C-sequestrations of approximately 357 lbs/acre in response to intensive, rotational grazing management of pastures in the southeastern U.S. However, such increases in soil C are not likely in areas with less than moderate rainfall. Several other factors must also be considered when evaluating the imposition of BMP's such as, changes in yield and quality of forage, fertilizer inputs, or animal response. One simulation projected 357 lbs of C-sequestration/acre/yr in response to intensive rotational grazing. Other changes triggered by intensive grazing included forage yield increases (+ 50%), increased fertilizer inputs/ha (+20%), modest forage digestibility and protein content increases, faster animal growth, and lower land requirements. The increased C-sequestration for the herd in this case was estimated to be 50 tons/yr, representing approximately 30% of the total greenhouse gas ($CO_2$ equivalent) emissions (Johnson et al., 2001).

It is likely that some sequestration of C is being realized under current pasture/forage management practices. Additionally, the application of BMP's to the grain cropping inputs into these production systems, primarily the feedlot, can provide additional C-sequestrations of 6 or more tons/yr. While it is not likely that sequestration will offset all livestock system emissions, the overall potential of more than 1/2 ton of C sequestered annually per mature cow projects significant advantages. These strategies will reduce greenhouse gas emissions, improve soil tilth and improve beef cattle productivity, potentially improving profitability.

*Don Johnson, Professor, Animal Sciences;*
*Hope Phetteplace, Post-doctoral Research Associate, Animal Sciences;*
*and Andy Seidl, Assistant Professor and Extension Policy Specialist, Agric. & Resource Economics*

***Table 2. C sequestration potential of simulated U.S. beef production systems (100-cow herd including progeny through feedlot).***

| **C-sequestration** | | **Location in U.S.** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **AL** | **TX** | **UT** | **VA** | **WI** | **Mean** |
| | **lbs C/acre/yr** | ---------------- **tons C/herd/yr** ---------------- | | | | | |
| BMP on pasture | 357 | 63 | 45 | 57 | 46 | 42 | 51 |
| BMP on range | 45 | 0 | 13 | 32 | 0 | 0 | 9 |
| BMP on hay crop | 178 | 3 | 4 | 4 | 3 | 4 | 4 |
| **Total Forage C-seq**: | | 66 | 63 | 93 | 50 | 46 | 64 |
| BMP on grain crop | 714 | 12 | 37 | 6 | 11 | 7 | 14 |
| Total C-sequestration | | 78 | 100 | 99 | 61 | 53 | 78 |

# Livestock Manure Impacts on Carbon Cycling

## Manage manure to reduce C emissions and build soil organic matter.

The way that manure is managed through the collection, storage, treatment, and utilization processes affects the extent of C emission and sequestration. Emission of $CH_4$ from manure accounts for approximately 20% of the $CH_4$ emitted by livestock (see Agriculture and Agri-Food Canada website). Most of the $CH_4$ from manure is produced during storage. When manure is stockpiled, the interior of the pile is usually anaerobic, which leads to $CH_4$ production. Liquid manures or slurries tend to produce more $CH_4$ than stockpiled manure, because of limited aeration.

Therefore, key management practices to reduce $CH_4$ emission during manure collection and storage include using solid rather than liquid manure collection and handling systems, providing better aeration (encourages the formation of $CO_2$ rather than $CH_4$), and reducing the length of time that the manure is in storage (apply it to land as soon as possible). Using less bedding will reduce the C supply in the manure. For liquid manures, keep storage tanks cool by placing them below ground to slow the rate of C decomposition. Cover lagoons or slurry tanks to reduce $CH_4$ emissions (Sommer et al., 2000).

There are numerous treatment options for manure, but composting may be the best-known approach. Composting will release less $CH_4$ than manure stockpiling, due to the aeration required for composting. Cattle feedlot manure composting has been shown to result in 46-62% of C lost as $CO_2$ (Eghball et al., 1997). Good aeration during composting will encourage complete decomposition of C to $CO_2$ rather than releasing C as $CH_4$. Hao et al. (2001) found that active composting increased emissions of $CO_2$, $CH_4$, and $N_2O$ as compared to passive composting; in addition, active composting requires greater fuel combustion.

Creating fully anaerobic conditions promotes emission of $CH_4$ that can be collected and used as fuel. Burning $CH_4$ as fuel coverts it to $CO_2$, thus reducing it's global warming potential. Methane capture has a double effect, in that this process can also reduce consumption of fossil fuel. Available energy production is about 70 Btu/hr for a hog, 380 for a dairy cow, and 520 for a steer (see the University of Missouri webpage for more information). It takes manure from three feeder cattle to run a refrigerator, 11 to run a range, 15 to run a water heater, and 72 to heat a 1500 sq.ft. home. If energy and fertilizer costs continue to rise, $CH_4$ generation from manure treated in anaerobic digesters is likely to become more widespread.

In addition to composting and anaerobic digestion, other practices that can reduce $CH_4$ emission include: constructed wetlands, lagoon aeration, lagoon covering, and solids removal from liquid waste streams (see Livestock and Poultry Environmental Stewardship webpage for more information).

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***Table 3. Yield and soil organic matter contents from two eroded soils treated with manure and composted manure (Greg Vlaming's thesis project).***

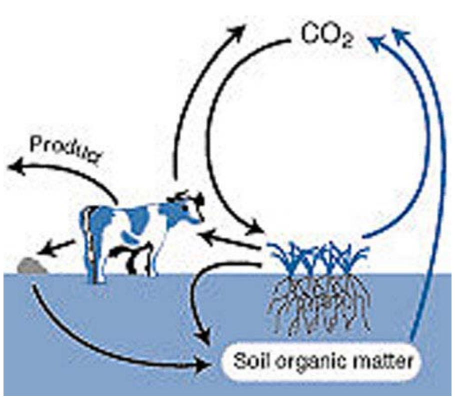
| Treatment | Weld County (dryland) | | Morgan County (irrigated) | |
|---|---|---|---|---|
| | Relative Millet Yield (lbs/ac) | SOM (%) | Relative Corn Yield (lbs/ac) | SOM (%) |
| Control | 100% | 1.4 | 100% | 1.2 |
| 10 T compost/ac | 127% | 1.6 | 100% | 1.1 |
| 10 T manure/ac | 139% | 1.8 | 112% | 1.2 |
| 30 T manure/ac | 166% | 2.0 | 127% | 1.4 |
| 60 T manure/ac | 173% | 2.0 | 126% | 1.5 |

## Livestock Manure Impacts on Carbon Cycling (cont.)

Manure application to land is known to increase soil organic matter and SOC. Adding organic matter to soils will rebuild C stocks. In particular, applying manure to nutrient deficient soils or otherwise degraded soils will have the greatest impact on increased productivity and C sequestration. For example, studies on using manure to restore eroded land in Weld and Morgan counties have shown both increased yield and SOM (Table 3).

Once manure is applied to land, $CH_4$ emission is minimal due to its exposure to air. However, injection of liquid manure or immediate incorporation of solid manure is important in order to reduce losses of $CO_2$ and $N_2O$. Manure should never be put in landfills, not only because this practice wastes a resource, but also due to the high rates of $CH_4$ emission from landfills, due to their anaerobic conditions.

*Jessica Davis*
*Professor and Extension Soil Specialist*
*Soil & Crop Sciences*




# Future Outlook

## Carbon: A Future Ag Commodity?

### Financial benefits may brighten farmers' future.

Will farmers of the future one day call themselves, "a wheat, corn, carbon farmer?" There's speculation among some farmers in eastern Colorado agricultural communities that contracts that purchase C offset credits will be a welcome addition to a bleak future on the farm.

What is C sequestration? What is the market for C offset credits? Who decides what the commodity is worth? How much can I make? How is C measured and who will do the measuring? These are the questions beginning to be asked by agricultural producers who are just becoming aware of the potential of their farms and ranches to provide a different type of commodity. Researchers are finding the answers to these questions through ongoing studies.

As scientists pursue these answers, agricultural producers need to become aware of what agricultural systems, conservation practices, and type of farm management are demonstrating the most C storage in an economically feasible manner. Fortunately, many proven and accepted conservation practices commonly used on farms and ranches in Colorado offer significant C storage benefits in the soil and in tree biomass.

Resource professionals in the field know that conservation practices such as windbreaks, living snowfences, rotational grazing, and no-till farming already provide proven erosion control and water quality benefits and contribute to improved wildlife habitat. These are benefits that society, in general, enjoys, but depressed crop and cattle prices often fall short of paying for them.

While there are currently no requirements for U.S. utility companies to reduce $CO_2$ emissions, some companies are looking at their alternatives. Although Colorado agricultural producers are just learning about the potential of C sequestration to provide financial benefits, people on the farm are interested. At this point, changes to the Kyoto Protocol would need to be incorporated to broaden the potential for participation by Colorado farmers and ranchers, but the prospects for the future appear a little bit brighter with C as a potential agricultural commodity.

It's too early to know how future U.S. policy issues might develop, but judging from the interest of the agricultural community, the time may be right to begin an information exchange between researchers, natural resource practitioners, and agricultural producers.

*Kristi Gay,*
*USDA-NRCS District Conservationist - Flagler, CO*
*East-Slope Director, Colorado Chapter, Soil and Water Conservation Society*

# Colorado Carbon Conference Coming Up

## Conference will be held on December 3-4 in Denver.

A conference has been scheduled for December 3-4, 2002, tentatively titled "Carbon as a Future Ag Commodity" sponsored by the Colorado Chapter of the Soil and Water Conservation Society (SWCS). As planning committee chair, Dr. Ron Follett, and SWCS committee members (Dr. P. Lorenz Sutherland, Kristi Gay, Mary Miller, Gary Finstad, and Willa Holgate) have assembled a cadre of speakers who will present the possibilities of C storage in Colorado from both research and producer perspectives.

Plenary sessions on December 3 will address: C-sequestration potential and non-$CO_2$ greenhouse gas emissions, National Carbon Policy issues and initiatives, the role of biofuels in C-sequestration and C recycling, potential markets for the sale of C by producers, C projects on agricultural lands, and the potential of U.S. soils, forests, agroforestry practices, and urban landscapes to sequester C. Breakout sessions for cropland, rangeland, agroforestry, and urban land will follow with presentations by both researchers and agricultural producers in their respective sessions.

On December 4 the plenary session will include presentations such as: a national and SWCS perspective on farm legislation and C-sequestration, leasing $CO_2$ offsets from agricultural practices, the Wyoming Carbon Project, the Nebraska Carbon Project, how money can be made from urban lands, and The Innovative Cropping Systems Incentive Program.

The conference will conclude with presentations highlighting the technology available for determining C-pools. A poster session has been scheduled for December 3, 2002 from 5:30 p.m. to 8:00 p.m. The location of "Carbon as a Future Ag Commodity" will be the Denver Renaissance Hotel just south of I-70 on Quebec St. in Denver, Colorado. A detailed agenda and registration information will be available soon on the Colorado Chapter SWCS website at www.ccswcs.org or by calling (719) 765-4676.

*Kristi Gay,*
*USDA-NRCS District Conservationist - Flagler, CO*
*East-Slope Director, Colorado Chapter, Soil and Water Conservation Society*

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## Colorado Wheat Field Days 2002

| | | |
|---|---|---|
| Walsh | June 10 | 9 a.m. at Plainsman Research Center, Baca County (1/8 mi west of Walsh, 4 mi north, 1 mi west to station) |
| Lamar | June 10 | 5 p.m. at John Stulp's house, Prowers County (at John Stulp's house, 6 mi south of Lamar on Hwy 385) |
| Cheyenne Wells | June 11 | 1 p.m. at the Cheyenne County Fairgrounds (at the Cheyenne Country Fairgrounds in Cheyenne Wells) |
| Burlington | June 11 | 5 p.m. at Barry Hinkhouse farm, Kit Carson County (1/2 mi South of Burlington on Hwy 385 to Rd U, 1 mi west to Rd 47) |
| Genoa | June 12 | 8 a.m. at Ross Hansen farm, Lincoln County (I-70 exit, ½ mi north of Genoa on Rd 31, 2 1/2 mi east on Rd 3H) |
| Haxtun (Irrigated) | June 12 | 5 p.m. at Steve Smith farm, Phillips County (2 mi north of Haxtun on hwy 59, 1 1/8 mi east on Rd 32) |
| Julesburg | June 13 | 8 a.m. at Joe Kinnie farm, Sedgwick County (12 mi south on Hwy 385 to Rd 8, 1.6 mi west) |
| Orchard | June 13 | 3 p.m. at Cary Wickstrom farm, NW Morgan County (12 ½ mi east of Briggsdale on Hwy 14, 8 mi south on Rd 105) |
| Briggsdale | June 13 | 5 p.m. at Stan Cass farm, N Weld County (4 mi south of Briggsdale on Hwy 392, ½ mi east on Hwy 84) |
| Stratton (2) | June 17 | 10 a.m. at Kenny Pottorff farm, Kit Carson County (1 mi east of town on Hwy 24) |
| Bennett | June 17 | 5 p.m. at John Sauter farm, Adams County (Bromley Lane east of Brighton for 13 mi, 1 mi south on 25 N, 6 ½ mi east on 144th) |
| Akron | June 19 | 8 a.m. at Central Great Plains Res. Station, Washington County (4 mi east of town on Hwy 34) |

# References

Conant, R.T., J. Six and K. Paustian. 2001. Land use effects on soil carbon fractions in the southeastern United States I: Management intensive versus extensive grazing (unpublished). Colorado State Univ., Nat. Res. Ecol. Lab.

Eghball, B., J.F. Power, J.E. Gilley, and J.W. Doran. 1997. Nutrients, carbon, and mass loss during composting of beef cattle feedlot manure. J. Environ. Qual. 26:189-193.

Follett, R.F., J.M. Kimble, and R. Lal. 2001a. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers, Wash., DC. 442 pp.

Follett, R., S.E. Samson-Liebig, J.M. Kimble, E.G. Pruessner, and S.W. Waltman. 2001b. Carbon sequestration under the CRP in the historic grassland soils in the USA. pp. 27-40 In: R. Lal and K.McSweeney (eds) "Soil Management for Enhancing Carbon Sequestration," SSSA Special Publication, Madison, WI.

Hao, X., C. Chang, F.J. Larney, and G.R. Travis. 2001. Greenhouse gas emissions during cattle feedlot manure composting. J. Environ. Qual. 30:376-386.

Johnson, D.E. H.W. Phetteplace and A.F. Seidl. 2001. Methane, nitrous oxide and carbon dioxide emissions from ruminant livestock production systems. Proc. 1st Inter. Conf. Greenhouse Gases and Animal Agric., Obihiro, Japan. Nov. 2001.

Lal, R., J. M. Kimble, R. F. Follett, and C. V. Cole. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Lewis Publishers, Wash., DC. 128 pp.

Paustian, K., O. Andren, H.H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Van Noordwijk, and P.L. Woomer. 1997. Agricultural soils as a sink to mitigate carbon dioxide emissions. Soil Use and Management 13:230-244.

Paustian, K., C.V. Cole, D. Sauerbeck and N. Sampson. 1998. $CO_2$ mitigation by agriculture: An overview. Climatic Change 40:135-162.

Paustian, K., E.T. Elliott, J. Six and H.W. Hunt. 2000. Management options for reducing $CO_2$ emissions from agricultural soils. Biogeochemistry 48:147-163.

Peterson, G.A., A.D. Halvorson, J.L. Havlin, O.R. Jones, D.J. Lyon, and D.L. Tanaka. 1998. Reduced tillage and increasing cropping intensity in the Great Plains conserves soil C. Soil and Tillage Research 47:207-218.

Sampson, R. N., R. J. Scholes, C. Cerri, L. Erda, D. O. Hall, M. Handa, P. Hill, M. Howden, H. Janzen, J. Kimble, R. Lal, G. Marland, K. Minami, K. Paustian, P. Read, P. A. Sanchez, C. Scoppa, B. Solberg, M. A. Trossero, S. Trumbore, O. Van Cleemput, A. Whitmore, D. Xu, B. Burrows, R. Conant, G. Liping, W. Hall, W. Kaegi, P. Reyenga, N. Roulet, K. E. Skog, G. R. Smith, and Y. Wang. 2000. Additional human-induced activities - article 3.4. Pages 180-281 *in* R. T. Watson, I. R. Noble, B. Bolin, N. H. Ravindranath, D. J. Verardo, and D. J. Dokken, editors. Land Use, Land-Use Change, and Forestry. Cambridge University Press, Cambridge.

Continued on page 20

# References (cont.)

Sommer, S.G., S.O. Peteren, and H.T. Sogaard. 2000. Greenhouse gas emission from stored livestock slurry. J. Environ. Qual. 29:744-751.

Unger, P.W. 2001. Total carbon, aggregation, bulk density, and penetration resistance of cropland and nearby grassland soils. pp. 77-92. In: R. Lal and K.McSweeney (eds) "Soil Management for Enhancing Carbon Sequestration," SSSA Special Publication, Madison, WI.

U.S. Environmental Protection Agency. 2002. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000.

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# Webpages

http://res2.agr.ca/research-recherche/science/Healthy_Air/toc.html
The Health of our Air, excellent website on greenhouse gases and agriculture from Agriculture and Agri-Food Canada

http://www.epa.gov/globalwarming/index.html
Environmental Protection Agency's global warming website

http://cdiac2.esd.ornl.gov/
Department of Energy website on C sequestration

http://www.usda.gov/oce/gcpo/sequeste.htm
Department of Agriculture's Frequently Asked Questions about C sequestration

http://www.lpes.org/Lessons/Lesson25/25_Manure_Treatment.html
Manure Treatment Options, Livestock and Poultry Environmental Stewardship curriculum

http://muextension.missouri.edu/xplor/agguides/agengin/g01881.htm
Generating Methane Gas from Manure (University of Missouri extension factsheet)

http://icp.giss.nasa.gov/research/methane/greenhouse.html
Institute on Climate and Planets methane research projects

http://www.ornl.gov/carbon_sequestration/
Oak Ridge National Laboratory website on C sequestration