

Minnesota Agriculture and the Reduction of Greenhouse Gases

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Minnesota Agriculture and the Reduction of Greenhouse Gases

Executive Summary

The decade of the 1990s was the warmest period of the warmest century of the last 1,000 years (Crowley 2000). Extensive scientific evidence indicates that the greenhouse gases produced by human activities are the major contributors to this global warming. The agricultural sector contributes carbon dioxide, methane, and nitrous oxide to the increase in greenhouse gases.

However, efforts to reduce greenhouse gas emissions can provide Minnesota agriculture with opportunities to profit both economically and agronomically. Carbon can be sequestered in agricultural soils through the adoption of less intense tillage practices, and through other land management practices, such as creating buffer strips and establishing wetlands. Federal policies enacted to address climate change can be designed to benefit Minnesota farmers by creating a higher market value for good agricultural stewardship practices. Thus, farm practices that sequester carbon dioxide can create a new income source for Minnesota farmers. With proper domestic farm policy, farmers can benefit financially from practices that store carbon, by selling carbon storage credits to industries that emit greenhouse gases. Carbon sequestered in agricultural soils could provide a supplemental agricultural income of \$1,000 or more per year to the average Minnesota farm over the next twenty to thirty years. Increasing soil organic carbon through carbon sequestration will bring multiple benefits to rural communities and other citizens of Minnesota, including better soil, water and air quality, and increased wildlife habitat.

1. Soil Organic Carbon and Carbon Dioxide

1.1 Soil Organic Carbon

Land management practices can increase or decrease the level of soil organic carbon (SOC). The relationship depends on the amount of carbon incorporated into the soil from plant residues versus the amount of carbon leaving the soil as gaseous CO₂ due to decomposition. The conversion of land from native vegetation to cropland oxidizes SOC and releases CO₂. The amount of carbon that remains in an agricultural soil, following years of production, depends on a wide variety of factors - climate, crop selection, residue management, and tillage equipment. A change to a less intense tillage practice can increase SOC (Lal et al. 1999). SOC can also be increased through various other land use changes such as wetland restoration, installation of buffer strips, restoration of eroded soils, and the enrolling of land in the Conservation Reserve Program (Lal et al. 1999). Depending on future government treaty obligations, such increases in SOC may provide farmers with an additional source of income. Farmers sequestering carbon in the soil may receive payments for this practice. (See Section 7, page 19, for a further discussion of these possibilities.)

According to the Century Model, soil organic matter such as SOC can be treated as existing in three pools (Colorado State 2000). First, there is SOC in the fast pool. Carbon in this pool turns over rapidly, on the order of months to a few years, and is generally made up of soil microbes and microbial products including water soluble carbon compounds (sugars and proteins), starches or polysaccharides. This material is available for microbial or plant use or chemical reactions with atmospheric oxygen. This pool is readily supplemented and readily depleted. The second pool of SOC is referred to

as the slow pool. The carbon in this pool remains in the soil for years to decades at a time. It exists in more complicated organic molecules such as cellulose, hemicellulose, and lignin. It takes microbes and chemical reactions much longer to break these molecules down into simpler molecules that can be more readily consumed by plants or microbes. The third pool is known as the recalcitrant pool. The carbon in this pool may remain in the soil for centuries. The recalcitrant carbon is physically and chemically stabilized into soil aggregates and so is protected from the action of oxygen and microbes.

Long-term intensive tillage increases the rate at which the three pools are chemically depleted and so reduces SOC. Plowing stirs the soil and disrupts aggregates exposing previously protected carbon compounds. Plowing also buries surface crop residue. Microbes in the soil then have increased supplies of food and newly incorporated atmospheric oxygen on which to exist. The microbes convert available oxygen and much of the residue from the fast pool of SOC to CO₂. The CO₂ then escapes into the atmosphere. It is estimated that 50 to 70 percent of the carbon present in the residue is lost as CO₂ during the first year after cultivation (Collins 1997.)

Soils and the atmosphere develop an equilibrium carbon exchange depending on the management of the land. Over time, the carbon incorporated in plant material comes into equilibrium with CO₂ released from the microbial decomposition of plant matter. Upon conversion from native vegetation to cropland, SOC is rapidly depleted, making the converted land a temporary net source of atmospheric CO₂. The twenty million acres of Minnesota cropland now in cultivation contained roughly 320 million metric tons (MMT) of carbon to a depth of 20 cm before cultivation (estimated from Paustian et al. 1997 and

Donigian et al. 1997). Under the intensive tillage historically practiced in much of Minnesota, SOC has probably been reduced by 30% - 60% in the top 15 – 30 cm compared to the original prairie and forests (Paustian et al. 1997). This amounts to about 160 MMT of carbon lost from the cropland, equivalent to 30 years of Minnesota's agricultural GHG emissions at the present rate.

The equilibrium between carbon in soils and the atmosphere will change as Minnesota warms. Due to faster decomposition of plant matter caused by higher average temperatures, it is expected that soil carbon storage will be reduced.

Intensive tillage practices continue to dominate the agriculture of Minnesota.¹ According to a recent survey (Fisher 1999), Minnesota is the eleventh state in the country in terms of crop acreage (19,111,901 acres), but it ranks second in terms of acreage intensively tilled (9,005,897 acres). In other words, 47 percent of the cropland in Minnesota undergoes intensive tillage. In other states and Canadian provinces, reduced tillage or no-till techniques are practiced more extensively. For example, Iowa is first in the country in terms of cropland acreage (23,192,441), but eighth in terms of intensively tilled land (4,409,597). Only 19 percent of the Iowa cropland is intensively tilled. A larger fraction of highly erodible land in Iowa may contribute to that state's greater implementation of conservation tillage.

¹ Intensive tillage dominates Minnesota cropland because of the relatively short growing season and poor drainage in much of the state's farmland. Farmers need the soil to dry and warm rapidly in the spring so crops can be planted as early as possible. Tillage that thoroughly aerates the soil and leaves the surface bare and black facilitates warming and drying.

1.2 Conservation Tillage Practices

A multi-year, field-level study of net global warming potential (GWP) of various cropping systems in the upper Midwest found that the net GWP of no-till agriculture was substantially lower than that of conventional tillage (Robertson et al. 2000.)

Tillage practices are considered forms of conservation tillage if 30 percent or more of the surface is covered by residue after planting. No-till and strip till are the best-known conservation tillage practices. These practices generally increase SOC, maintain profitability, and depend heavily on herbicides for weed control. Changes to less intensive tillage practices will sequester carbon in the soil until a new, higher equilibrium of SOC is achieved.

In no-till cultivation, the seed is drilled directly into the soil through the surface residues. The crop residues are allowed to decay on the surface, physically protecting the soil from erosion and replenishing soil nutrients. The surface residue tends to insulate the soil surface and retain moisture. However, this practice may shorten the growing season and reduce yields in regions that are cool and wet (Paustian et al. 1997).

Strip till methods create and cultivate “berms” of soil 6 to 8 inches wide while leaving strips of undisturbed residue between the berms. Some research indicates that the berms will warm and cool more rapidly than conventionally tilled fields and will allow water to infiltrate as rapidly as no-till fields.²

These research conclusions suggest that strip till practices may prove a useful cultivation technique for Minnesota agriculture.

² See <http://progressivefarm.com/html/monsanto2.html>

Conservation tillage methods reduce the amount of tillage performed on agricultural lands. This reduction leads to reduced fuel consumption. But the reduction of mechanical tillage and weeding requires an increase in herbicide applications. This increased herbicide usage may create problems if the chemicals are applied incorrectly or excessively.

Minnesota is well situated to increase the SOC of its agricultural lands. The adequate, but fairly low, precipitation provides for good plant growth and biomass production. The low annual average temperature of the region slows the decay of this organic matter. These two factors – extensive biomass production and slow decay – allow SOC to remain or increase relatively rapidly compared to other regions of the US (Paustian et al. 1997). If half of the SOC lost from Minnesota cropland can be restored through changes in tillage practices over the next 25 years, 3.2 MMT per year will be sequestered. This amounts to 0.40 MT per hectare per year or 0.16 MT per acre per year. Lal et al. (1999) have calculated a potential increase of SOC of 0.50 MT /ha/yr over several decades. Gurney (2000) estimates a potential increase of 0.25 MT/ha/yr can be sustained through the improved management of croplands. Some increase in SOC, perhaps 0.10 MT/ha/yr (U.S. Department of State 2000), is expected to occur even without changes in tillage practices. This increase is due to increased yields providing increased plant residue to be incorporated into the soil, but greater increases will be determined by management practices.

A wide variety of factors will affect the actual amount of carbon sequestered. For example, the variability of soils, precipitation, frost depth, animal activity and residue management regime will affect carbon sequestration.

Difficulties in the accurate determination of SOC are reviewed in Appendix II.

1.3 SOC in Pastures

The effects of grazing on SOC are not well determined. Moderate grazing seems to have no significant impact on SOC when compared to ungrazed pastures (Burke et al. 1997). However, in well-managed pastures in the southeastern US, cattle production and SOC accumulation have shown correlation with each other (Franzluebbbers and Stuedemann in press). It appears that the conversion of cropland to pasture may increase SOC but the recovery time is quite slow (decades) to return to the SOC levels of native vegetation (Burke et al. 1997).

1.4 Restoration of Wetlands and Maintaining Histosol Soils

Large quantities of SOC can be stored in wetlands. Organic soils rather than mineral soils dominate wetlands. Organic soils have up to twenty times the carbon storage capacity of mineral soils (Lal et al. 1999). The drainage of such a wetland aerates this organic material and produces a burst of CO₂ from the area (Brady and Weil 1999).

Historically about 28 percent of the surface area of Minnesota was covered by wetlands (U.S. Geological Survey 2000). By the 1980s, Minnesota's wetlands had been reduced to 16 percent of the surface area. Over six million wetland acres have been drained in the state, primarily to improve agricultural productivity. Wetland drainage has released carbon that had been stored for centuries.

The restoration of wetlands through the federal Wetland Reserve Program or through the efforts of the state, local governments, or individuals could sequester carbon.

The high bio-productivity of wetlands exceeds the rate of decomposition, especially in the cool climates of the northern United States.

Wetlands produce methane (CH₄), another major GHG, through the anaerobic decomposition of organic material. The net effect of wetlands on atmospheric levels of GHGs requires further research (Kusler 2000). However, the variety of environmental services provided by wetlands and the carbon sequestration that occurs in them make wetlands extremely valuable parts of the ecosystem.

Protection of Minnesota's histosols can also enhance carbon storage. Histosols, or organic soils, presently cover about three million acres of Minnesota (Anderson et al. 1996). In organic soils, the major constituent is organic matter rather than the mineral materials that dominate most soils. In northern Minnesota, these soils support peatland vegetation, spruce and tamarack forests. These soils are rare in southern Minnesota, but what is present is used for specialty crops such as vegetables and sod production. Disturbing these soils through tillage can release large amounts of CO₂ as the organic matter oxidizes.

1.5 Fossil Fuels

Fossil fuels such as gasoline, diesel fuel, liquid propane, and natural gas are used to power most agricultural equipment in Minnesota. The machinery that is powered by these fuels is used for tillage, cultivation, chemical applications, harvesting, and drying crops. According to the U.S. Department of Agriculture/National Agricultural Statistics Service (2000), Minnesota farmers spent \$306,292,000 on petroleum products for agricultural activities in 1997. The combustion of this fuel released approximately 2.5

MMT of CO₂ to the atmosphere.³ Since the cropland soils have reached a new equilibrium between carbon added and lost from the soil, fossil fuel consumption is the major source of CO₂ associated with Minnesota agriculture.

2. Nitrogen and Nitrous Oxide

2.1 Nitrogen Fertilizer

Improving our understanding of the nitrogen cycle is a challenge for soil and atmospheric scientists. Nitrogen is a necessary macronutrient for crops that must be replenished in croplands through the use of synthetic or organic fertilizers. It is an essential component of the proteins present in plants and animals. However, nitrogen-based compounds can be chemically converted in the soil into various oxides of nitrogen. For example, some fraction of organic or synthetic nitrogen-based fertilizer applied to soil is chemically changed into nitrous oxide (N₂O). N₂O is a GHG with a large global warming potential (GWP) -- the GWP of N₂O is 310 times the GWP of CO₂ (Intergovernmental Panel on Climate Change 1996). About 70 percent of the anthropogenic N₂O emissions result from agricultural practices (U.S. Department of Energy/Energy Information Administration 1998a).

Some activities that sequester carbon may require increases in fertilizer use and thus increases emissions of non-CO₂ GHGs. Scientific studies do not agree on the net effect of no-till agriculture, for example, on N₂O emissions.

Data from the U.S. Department of Agriculture/National Agricultural Service (2000) and U.S. Environmental Protection Agency (1999) indicate that 0.58 million

³ See Appendix I.

metric tons (MMT) of nitrogen-based fertilizers were used on Minnesota croplands in 1997. The efficiency of the application of nitrogen fertilizers will determine if soils will be sources of N₂O. It is estimated that this application of nitrogen-based fertilizer resulted in 0.038 MMT of nitrous oxide being released into the atmosphere with a warming potential of 3.2 MMT of carbon equivalent (MMTCE).⁴

2.2 Precision Agriculture

More widespread use of precision agriculture, also known as site specific agriculture, could produce multiple benefits for agriculture including reduced GHG emissions. Precision agriculture uses global positioning systems to map the yield from agricultural fields. These yield maps can then be used to more accurately place seed, fertilizers, and pesticides for the desired results, thus reducing costs and maximizing yields. The maps can also indicate where remediation of the soil would be useful and where soils might be more appropriately used for purposes other than cropland.

Precision agriculture can reduce GHG emissions from agriculture by reducing fuel and fertilizer usage. The more accurate application of fertilizers will result in more effective uptake of the nutrients by the crops and in less denitrification. The increased efficiency of fertilizer application will reduce the threat of leaching or run-off to ground and surface water quality.

⁴ See Appendix I.

3. Methane

Livestock generate methane (CH₄), another greenhouse gas. Ruminant digestion produces CH₄ through the anaerobic decomposition of manure. For cattle and hog operations, this anaerobic decomposition often occurs in sealed manure lagoons. Generally, the CH₄ is not recovered but escapes into the atmosphere.

Minnesota livestock produce 0.254 MMT of CH₄ per year. This level of agricultural CH₄ is equivalent to 1.4 MMTCE per year.⁵

Table 1. Methane Production Due to Minnesota Livestock (1997)

	Kg CH ₄ /yr
Beef Cattle	3.0x10 ⁷
Milk	8.3x10 ⁷
Heifers and calves	3.5x10 ⁷
Steers and bulls	3.7x10 ⁷
Hogs	6.6x10 ⁷
Poultry	<u>0.3x10⁷</u>
Grand Total	25.4x10⁷

Sources: U.S. Department of Agriculture/National Agricultural Service (2000); Agriculture and Agri-food Canada (1999). Methane production totals include digestion and manure sources.

⁵ See Appendix I.

For some large livestock operations it may be feasible to capture the CH₄ generated by decomposing manure and use the gas as a fuel source. The Minnesota Project, working with the Minnesota Department of Commerce, is evaluating the feasibility of a methane digester on a 500-head dairy herd.⁶ The manure is allowed to react anaerobically in a heated tank. The biogas generated is approximately 60 percent CH₄ and 40 percent CO₂. Hydrogen sulfide is also produced in small quantities. The biogas is collected, burned and then used to power electrical generators. Estimates show that the electrical production savings will pay for the digester in less than ten years.

According to the U.S. Environmental Protection Agency (2000c), manure deposited on fields or pastures in a dry form produces insignificant amounts of CH₄. Therefore, with respect to GHG production, pasture-raised animals may be preferable to confinement-raised animals whose operations tend to use manure lagoons.

Since the majority of the CH₄ generated by livestock is produced during digestion, techniques to reduce this source should be developed. Biotechnology may be able to contribute by developing varieties of cattle, hogs, and poultry that produce meat and milk more efficiently. It may also be possible to alter the feeding and/or digestive process of livestock to reduce CH₄ emissions.

CH₄ can also be generated or decomposed in soils. Methanotrophic bacteria present in some soils will oxidize the CH₄ and produce methanol (Brady and Weil 1999). Organic nitrogen seems to enhance the presence of the methanotrophic bacteria.

⁶ See The Minnesota Project website at <http://www.mnproject.org/id51.htm>

4. Effects of Crop Selection on Greenhouse Gases

Crop selection can affect whether or not the soil acts as a source or sink of GHGs. The biochemistry of different crop species has varying effects on the interaction of the crops with GHGs.

Legumes such as soybeans and alfalfa “fix” nitrogen from the air. These plants are able to convert atmospheric nitrogen gas into nitrogen compounds that can be used by themselves or other plants. Just as with other fertilizers, excess nitrogen fixed by the legumes can be chemically converted to N₂O and enter the atmosphere.

Corn, a heavy nitrogen consumer, is often rotated with soybeans in a field to take advantage of the nitrogen fixed by the legume. Corn grown for the grain produces a large amount of residue. This residue, if properly managed, can be used to increase SOC. Small grains produce less residue than corn and therefore cannot increase SOC as much as a corn crop.

Residue quality also affects the amount of carbon stored in the soil (Paustian et al. 1997). Residues high in lignin tend to increase SOC more than low lignin residues. Lignins are complex organic polymers whose exact chemical structure is unknown. They are only slowly biodegradable. Wheat and barley are somewhat higher in lignin content than corn.

Perennial crops, such as alfalfa, included in rotations increase SOC. This increase can be attributed to reduced tillage and the root systems of perennial plants. The roots of perennials are conducive to the formation of soil aggregates that tend to protect SOC physically and chemically.

While crop selection can increase or decrease the SOC content of the soil, crops are not now selected with this factor in mind. Crops are selected for their overall agronomic/economic effect.

5. Agronomic Research

Various research projects could aid in the development of crops able to sequester carbon. For example:

1. Varieties of corn, soybeans, and other crops could be developed with greater root to shoot ratios while maintaining yield. The greater root material would increase the carbon available for the longer lasting pools of SOC.
2. Deeper roots could store organic material deeper in the soil below the depth of disturbance by tillage.
3. Increased lignin content of plants. Lignin is a complicated organic compound that binds the incorporated carbon for an extensive period of time.
4. The expansion of the use of perennial crops for food, fiber, and fuel. Perennial crops generally have larger root to shoot ratios, thereby increasing carbon availability for the longer-term pools. Perennial crops do not require the extensive tillage of annual crops. This reduction in tillage would also result in less fuel consumption. Wes Jackson at the Land Institute in Salina, Kansas is exploring this possibility (<http://www.landinstitute.org>).
5. Increasing the variety of available herbicide-resistant crops. These crops require less fuel for weed control and are more compatible with no-till management practices.

6. Multiple Benefits of Reducing Greenhouse Gases and Increasing Soil Organic Carbon

6.1 A Win-Win Situation

GHG mitigation strategies in the agricultural sector would produce multiple benefits for farmers and society. Dr. Rattan Lal, a soil scientist who has published widely on the value of carbon sequestration, presents the opportunities for agriculture in the mitigation of GHGs as a win-win situation (Lal et al. 1999). An increase in SOC would sequester carbon out of the atmosphere and would produce agronomic improvements. Changing other agricultural practices would affect the production and release of the other major GHGs, methane and nitrous oxide. If the practices that reduce GHGs and increase SOC were widely implemented, the atmosphere, soil and water quality would be improved, erosion would be reduced, and economic benefits from new agricultural products and markets would become evident.

6.2 Soil Quality

Increased organic matter in the soil increases soil quality. Soil quality is defined as “the fitness of a specific kind of soil to function within its surroundings, support plant and animal productivity, maintain and enhance water and air quality, and support human health and habitation” (U.S. Department of Agriculture/National Resource Conservation Service 1996).

6.3 Water Quality

Several of the practices described above to sequester carbon or to reduce the production of GHGs would have water quality benefits. Soil containing relatively large fractions of SOC can improve water quality. The organic compounds tend to retain nutrients and pesticides at the intended location in the soil and prevent them from being leached into the ground water. Precision agriculture results in the more efficient application of fertilizers. The efficient application decreases the amount of these materials available to reduce water quality and to be chemically changed into gaseous nitrogen compounds. The Wetland Reserve Program and Conservation Reserve Enhancement Program promote the growth of native plant species. (See Section 8.5, page 24.) These plants sequester carbon and reduce nutrient runoff into lakes and rivers.

6.4 Reduced Soil Erosion

Soil erosion is defined as the detachment and movement of soil particles. The force responsible for the erosion can be provided by water and wind. Usually the smallest of soil particles, clays are important in water and nutrient retention and are the most easily detached and carried away. This process removes a very important part of the soil's constitution and can reduce the soil's fertility. Through erosion, carbon that had been physically protected in soil aggregates can be exposed. This exposure can lead to oxidation and the release of CO₂. Lal et al. (1999) estimate that 20 percent of all dislocated SOC is eventually released to the atmosphere.

Increased amounts of SOC improve the aggregate size distribution in the soil. This improvement makes the soil less likely to erode from water or wind. The increased

residue cover associated with conservation tillage practices also reduces the effects of water and wind erosion.

Tillage can also produce a kind of erosion. Over decades, tillage, combined with gravity, can move topsoil from the higher parts of a field, hilltops or upper levels of slopes toward the swales or lower on the slopes. This long-term effect exposes the subsoil on the higher elevations. This tillage erosion thereby reduces the productivity of the higher areas.

Bare soils provide the greatest opportunity for erosion. Since conservation tillage techniques keep more of the soil covered with crop residue, these techniques reduce soil erosion and reduce the loss of SOC.

Some of the very productive agricultural areas of Minnesota have severe erosion potential with respect to wind and extreme erosion potential with respect to water (University of Minnesota Soil and Landscape Analysis Laboratory 2000). Wind buffers, conservation tillage, and shifts to grazing or perennial plantings would contribute to soil conservation in these areas.

7. Farm Income from Increased Soil Organic Carbon

The market mechanisms proposed through the Kyoto Protocol and other carbon trading proposals may provide an income source for Minnesota farmers. The cost of emitted carbon may be as high as \$348 per ton if no trading across national borders is permitted (U.S. Department of Energy/Energy Information Administration 1998b), \$61 per ton if trading is only allowed among Annex I countries of the Kyoto Protocol⁷ or

⁷The text of the Kyoto Protocol can be found at <http://www.unfccc.de/resource/cop3.html>

around \$14 per ton if the US can trade with Russia but European countries cannot. The details of the final negotiated treaty will have a great effect on the value of carbon emissions. Presently, Iowa farmers entering into Greenhouse Emissions Management Company (GEMCo) agreements are being paid an estimated \$3 to \$15/acre/yr (Donnelly 2000a). At a sequestration rate of 0.16 MT/acre/yr, this amounts to payments of approximately \$20/MT/yr to \$100/MT/yr.

Proven increases in sequestered carbon may be worth a large fraction of the amounts quoted above. Overhead, measurement, and verification costs will also be factors in the value of sequestered carbon. If carbon sequestration in agricultural soils proves to be a cost effective, verifiable, and long term technique for reducing the carbon released into the atmosphere, farmers may profit economically from converting to conservation tillage techniques.

The table on the following page provides information on the possible income from a carbon “crop” to Minnesota farmers. The figures are based on the average Minnesota farm’s cropland acreage (318 acres)⁸ and a sequestration rate of 0.16 MT/acre/yr. Based on those assumptions, the average farm is estimated to sequester 51 MT/yr. It is likely that this rate of sequestration can be maintained for several decades into the future until a new equilibrium between carbon addition and decomposition is reached.

⁸ U.S. Department of Agriculture/National Agricultural Statistics Service (2000).

Table 2. Average Minnesota Farm Income from Carbon Sequestration

	<u>\$/metric ton</u>	<u>Annual Income</u>	<u>Income over 25 years</u>
U.S./Russian Trades	\$14	\$714	\$17,850
GEMCo (Low Range)	\$20	\$1,020	\$25,500
Annex I Trading only	\$61	\$3,111	\$77,775
GEMCo (High range)	\$100	\$5,100	\$127,500
U.S. Trading only	\$348	\$17,748	\$443,700

8. Public and Private Policies to Support Greenhouse Gas Mitigation

8.1 The Kyoto Protocol

The Kyoto Protocol is a treaty proposed to reduce the build up of GHGs in the atmosphere. The protocol was developed in December 1997 at the meeting of the Conference of Parties to the United Nations Framework Convention on Climate Change. One hundred fifty-nine nations negotiated an agreement to reduce worldwide GHG emission by 5.2 percent from 1990 levels by 2012. The first commitment period of the treaty is to be from 2008 until 2012. If the treaty is ratified and implemented, the United States will be required to reduce its net GHG emission to 7 percent less than its net 1990 emissions.

An international climate change treaty may stimulate new incentives for soil conservation practices in the U.S. Lal et al. (1999) have estimated that changes in

agricultural management could sequester 75 - 208 MMTC per year nationwide. If Lal is correct, changes in agricultural practices alone could meet 20 percent to 55 percent of the requirements of the Kyoto treaty. Recently, the U.S. government has taken a position in favor of including agricultural soil sinks in the Kyoto arithmetic (U.S. Department of State 2000). Mechanisms for including these sinks were negotiated at the sixth Conference of Parties held in The Hague in November of 2000, but no resolution was reached. Sequestration of SOC is difficult to accurately measure and can be reversed relatively quickly by a change in agricultural management techniques. The Kyoto Protocol Article 3.4 does indicate that uncertainties, transparency in reporting, verifiability and permanence should be taken into account when the guidelines and protocols for agricultural soil sinks are established. The measurement accuracy of SOC is discussed in Appendix II.

8.2 A Private Sector Carbon Trading Program

The Kyoto Protocol and the U.S. government encourage the private sector to be involved in reduction of GHGs. GEMCo, the Greenhouse Emissions Management Company, has developed a system of carbon emission reduction credits (CERCs) in cooperation with some Iowa farmers and IGF, a major farm insurance company. The CERCs are traded without verification of the sequestered carbon. The CERCs are calculated from computer models and payments are based on sustained changes in management practices. The changes must be documented for at least six years. Farmers “do not have to produce soil samples or physical evidence of soil carbon gain” (Donnelly 2000b).

GEMCo appears to have goals beyond sequestering carbon in the Iowa carbon sequestration arrangement. One of GEMCo's expectations appears to be that a sampling protocol will be established soon and that the farmers will take advantage of the sampling to increase their proven carbon sequestration and thereby increase their payments. GEMCo expects this initial deal to spark the interest of farmers and ultimately garner the attention of senators from farm states, various research institutions, land grant universities and federal agencies.

8.3 Selected Public Policy Innovations to Address Climate Change

It is not certain that the United States Senate will ratify the Kyoto Protocol. Other approaches are being explored to determine the emission and possible mitigation strategies for GHGs.

Various pieces of legislation have been introduced in the U.S. Congress to address the interaction among global climate change, GHGs, and agriculture. One such piece of legislation is the Conservation Security Act sponsored by Senator Tom Harkin of Iowa and former Representative David Minge of Minnesota (Kemp 2000). In this bill, farmers would be compensated for conservation practices rather than agricultural production. The bill would promote a variety of environmental goals including GHG reduction and carbon sequestration by treating the farm as a system. The farm system would be developed to increase sustainable practices including soil and residue management and prairie and wetland restoration.

Another example of national legislation designed to improve our knowledge of the carbon cycle, sequester carbon in agricultural soils, and promote best management

practices in agriculture is the Carbon Cycle and Agricultural Best Practices Research Act introduced by Senator Pat Roberts of Kansas. This legislation would develop remote sensing capabilities for monitoring the carbon cycle. The information derived from such monitoring would greatly improve the accuracy of the computer modeling of SOC and its changes. This bill would also promote the best practices to improve soil quality and thus, increase SOC.

A number of other bills have been introduced in the U.S. Congress dealing with carbon sequestration and GHG emission and mitigation. Even without the commitments required by the Kyoto Protocol, the United States government may soon begin to more strongly promote management practices that sequester carbon and reduce the emission of other GHGs.

8.4 Conservation Reserve Program and Wetland Reserve Program

The 1985 Food Security Act established the Conservation Reserve Program (CRP). This program was originally designed to take highly erodible land out of crop production to protect the soil from erosion and waterways from sedimentation. The Wetland Reserve Program (WRP) was included in the same act to maintain and expand wetlands. According to the U.S. Department of Agriculture/National Agricultural Statistics Service (2000), CRP and WRP account for 1.3 million acres or 5.8 percent of Minnesota's total cropland.

The CRP and WRP have demonstrated a number of associated benefits beyond cropland and wetland protection. With respect to GHGs, CRP reserves sequester SOC and enhance soil quality (Mitchell et al. 1997). However, the effects on the production of

N₂O are not well understood. Extensions of these programs for other reasons may offer the benefit of increasing carbon storage. For example, the Conservation Reserve Enhancement Program (CREP) partially funds the planting of buffer strips along major rivers and tributaries. The main purpose of these buffers is to filter sediment and various pollutants out of runoff water. However, the strips also provide wildlife habitat and sequester carbon in the soil. The further benefits associated with wetlands and histosols were discussed in Section 1.4.

8.5 Biofuels

Biofuels and other bio-based materials represent an opportunity for agriculture to benefit from efforts to reduce GHG emissions by replacing petroleum-based materials with materials developed from renewable resources farmers can harvest on their land. Biofuels provide the agricultural community of Minnesota with a chance to profit from efforts to mitigate GHG emission. Burning a biofuel, such as ethanol, releases no new CO₂ into the atmosphere. Existing atmospheric CO₂ is cycled through the plant into the fuel. This fuel is then burned in an engine producing energy, water, and CO₂. The CO₂ is then exhausted back into the atmosphere. To the extent that ethanol replaces petroleum-based products in fuels, the amount of new CO₂ released into the atmosphere is reduced.

Presently, the major biofuel is ethanol. Ethanol can be produced from various agricultural products – corn, sugar cane, potatoes, brewery waste, and milo.

In Minnesota, almost all of the ethanol is produced from corn. The industrial production of ethanol requires the starch present in the grain. After the starch has been extracted, the protein component of the corn can be used as livestock food.

Minnesota has an ethanol industry with a present capacity of approximately 217 million gallons per year (Renewable Fuels Association 1999). This capacity is expanding yearly. By law, all gasoline sold in Minnesota must contain at least 10 percent ethanol.

Currently, there are vehicles on the market that can burn fuel covering a wide range of gasoline and ethanol mixtures. These flexible fuel vehicles (FFVs) may provide a bridge to the future as petroleum reserves are depleted and alternative fuel sources are developed. The FFVs can burn a mixture of up to 85 percent ethanol. Expanding the fleet of FFVs would reduce GHG emissions and increase the use of ethanol as a fuel.

Lugar and Woolsey (1999) have recently written of the importance of researching, and commercially developing, the production of cellulosic ethanol. Cellulosic ethanol is produced from the cellulose in plant material rather than from the plant's starches. The raw material for such cellulosic ethanol - essentially all plant material, such as leaves, stems, twigs, paper, etc. - would be extremely plentiful and inexpensive. Lugar and Woolsey present a case for the development of cellulosic ethanol based on the requirements of national security as well as the value of such a product to agriculture.

The potential exists to use plant material to supplement fossil fuels used in the generation of electricity. Alliant Power is operating a pilot plant in southern Iowa that uses switch grass as a fuel to replace a portion of the coal burned at the plant. The majority of the switch grass for the project is grown on local CRP land. This combination protects the soil from erosion and reduces GHG emissions.⁹

Descriptions of a number of other bio-based materials and their applications are available at the website of the Institute for Local Self-Reliance (<http://www.ilsr.org>).

⁹ The organizers of this project are looking for other biomass applications. Go to <http://www.cvrtd.org/projectdescription.htm> for more information.

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Additional copies of this paper may be downloaded from ME3's web site, www.me3.org/issues/climate.

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Appendix I. Estimated GHG Emissions from Minnesota Agriculture (1997)

<u>Gas</u>	<u>MMT *</u>	<u>GWP**</u>	<u>MMTCE***</u>	<u>% of MN Emissions</u>
CO ₂	2.5	1	0.68	2.5
CH ₄	0.25	21	1.4	5.1
N ₂ O	0.038	310	<u>3.2</u>	<u>11.7</u>
Totals			5.28	19.3

* Million metric tons

** Global warming potential

*** Million metric tons carbon equivalent

Sources: Ciburowski 2000

U.S. Environmental Protection Agency 2000a and 2000b

Appendix II. Determination of SOC

The Kyoto Protocol Article 3.4, as well as organizations interpreting the protocol and publicizing the issues of global climate change (such as the Pew Center on Global Climate Change), have stressed that accurate measurement of various aspects of GHG emissions and mitigation is necessary for the integrity of a market-based system to limit GHGs (Petsonk et al. 1998).

SOC is extremely variable both spatially and temporally. Over a distance of a meter in an agricultural field, the SOC can vary by 10 percent or more. The SOC also varies with the depth of the A horizon (topsoil) and with the presence of crops. SOC varies throughout the growing season as crops develop, respire, and photosynthesize. Tillage and erosion by wind or water affect the amount of SOC present.

This great variability makes accurate measurement difficult. If a field is randomly sampled, numerous determinations are necessary to determine the SOC to the 0.1 percent level (Izaurrealde et al. 1997). Yearly changes in SOC may occur at the 0.1 percent level. This level of sampling appears impractical.

As the carbon content increases, measurements of SOC are further complicated by changes in the soil (Ellert et al. 2000). As SOC increases, the bulk density of the soil decreases. This decreasing density means that soil should not be sampled to a consistent depth, the simplest measurement, but should be sampled to a consistent mass of soil. These quantities are more difficult to measure in the field.

Ellert et al. (2000) have developed a sampling protocol that samples the same location over a period of years to determine the change in the SOC. Two meter by five meter plots have been established in a part of the field thought to be reasonably uniform.

Electromagnetic markers and global positioning systems have been used to establish the plot location and orientation. Soil samples were examined in 1997 and locations nearby (within a few meters) will be sampled in 2003 to determine changes in the SOC content. Several such plots are being used to determine SOC changes in large fields (30 to 65 hectares or 74 to 161 acres). This system assumes that the measured changes can be associated with the entire field subjected to the same management practices. The development of this sampling protocol is part of the Prairie Soil Carbon Balance Project being carried out in the Canadian prairie provinces.

The impracticality of randomly sampling the soil of a field, region, or nation in order to determine changes in SOC indicates the importance of developing accurate computer models of SOC. Various groups around the world are attempting to develop such models. The Century Model (Patwardhan 1997; Colorado State 2000), whose modeling of various pools of SOC was mentioned in the beginning of this report, is one such attempt. These models must be verified by actual sampled data and be able to accurately predict changes in SOC on a variety of scales. Model assumptions and accuracy are checked by correct “retrodictions” of past changes in SOC. Accurate baseline SOC data is a requirement for models.

Presently, SOC is most commonly measured by taking a sample of the soil and combusting it in an enclosed chamber. The CO₂ evolved is then measured and the carbon content of the soil is calculated. This procedure is carried out in laboratory apparatus. The LECO CNS-2000 is an example of such an apparatus (LECO 2000). The method is costly, time consuming, and requires the appropriate laboratory facility.

The development of an accurate field probe for the determination of SOC would represent a great technological advance in this area. Such a probe would undoubtedly increase the acceptance of SOC sequestration as a practice to mitigate GHGs.

The eddy covariance method (Baldocchi et al. 1988) can also be used to determine the uptake and release of carbon by vegetation. In this method, atmospheric CO₂ is measured and changes in the CO₂ concentration are calculated. The observation of such carbon fluxes over a sufficient period of time can be used to calculate changes in SOC (Goulden et al. 1996). This technique may be more applicable to forested areas than to agriculture.

The development of remote sensing techniques sensitive to SOC would greatly expand our knowledge of the factors that impact SOC. Remote sensing would provide the data necessary to establish the validity of SOC computer models.