Executive Summary

In 2007, the Minnesota State Legislature (ML 2007, ch. 57) requested that the University of Minnesota produce an assessment of the potential capacity for carbon (C) sequestration in Minnesota's terrestrial ecosystems. Terrestrial C sequestration is defined by the legislation as "the long-term storage of C in soil and vegetation to prevent its accumulation in the atmosphere". This report presents research findings and scenarios of land use changes that could offset a modest proportion of Minnesota's current annual CO_2 emissions, in the range of 3 to 6 million metric tons CO_2-equivalents by 2025. Much of this reduction can be achieved on state lands or in partnership with existing state and federal programs targeting a wide array of ecological services and co-benefits. To improve understanding, predictability, and eventually investments into carbon sequestration, the state should invest in monitoring and demonstrations of land use changes and management practices shown to positively benefit carbon stocks. Terrestrial C sequestration alone cannot offset entirely the state's current CO_2 emissions. Other policies and practices targeting emission reductions and renewable energy will have to be implemented to reach the state's net emission reduction goals.

Terrestrial C sequestration can occur as plants and soils exchange carbon dioxide (CO_2) with the atmosphere as part of their natural function, as illustrated in the following diagram and as described below.

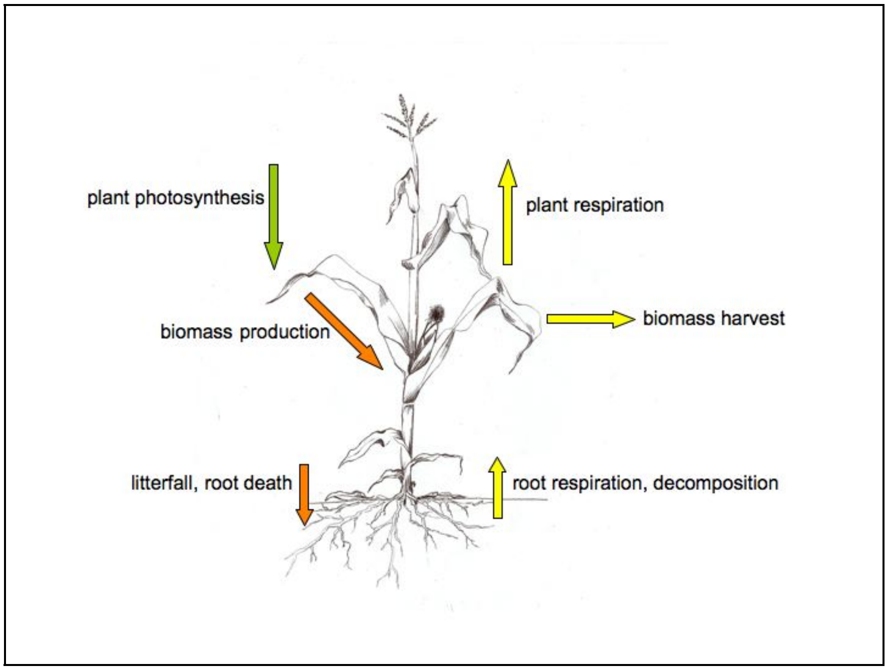

Fig. 1. A simplified diagram of C cycling in a terrestrial plant-soil system. Green arrows indicate CO_2 uptake by plants through photosynthesis. Orange arrows indicate incorporation of C into biomass and C inputs to soil from the death of plant parts (litterfall and root death). Yellow arrows indicate C return to the atmosphere through plant respiration or through the decomposition of litter and soil C by soil organisms. Carbon in harvested tissues also eventually returns to the atmosphere during digestion (by humans and animals), combustion, or eventual decomposition.

Plants take up CO_2 from the atmosphere during photosynthesis and incorporate a portion of it into their biomass. During respiration they also emit CO_2 back to the atmosphere from roots, stems, and leaves. When whole plants or plant parts die, C is transferred to soil where it is incorporated as organic matter. Microbes in soils slowly decompose organic matter, releasing CO_2 back to the atmosphere in a process called "soil respiration". If soils are saturated or water-logged, anaerobic conditions may develop and microbes will emit methane (CH_4) instead. Removal of plant biomass by harvest or grazing is also considered a loss of C from the system, although the rate of C return to the atmosphere depends on the fate of the products. The net C exchange (inputs minus outputs) between terrestrial ecosystems (plants and soils) and the atmosphere can be positive, negative, or neutral, depending on the balance between the rates of these exchange processes.

Carbon sequestration occurs when the rate of plant uptake of CO_2 from the atmosphere is greater than the combined rates of soil respiration, plant respiration, and biomass removal. By contrast, when the rate of uptake is lower than the combined rates of emission and removal, the terrestrial surface becomes a net emitter, or source, of C to the atmosphere. This balance, which is typically calculated on an annual basis, can be affected by a large number of factors, including: type, age, and condition of vegetation; climate; soil type and soil wetness; previous history of the site; harvest; fire; plant pests and disease; and many others. Obviously, some of these factors can be controlled or modified by land management decisions, thereby providing opportunities for informed decision makers to contribute to efforts to reduce the rate of increase in atmospheric CO_2.

In this report we evaluate the potential for a number of land use/land cover changes applicable to Minnesota to sequester C. These include afforestation and reforestation of unforested lands, restoration of peatlands and prairie potholes, the use of reduced tillage or no-till in annual row crop agriculture, inclusion of cover crops or continuous living cover in the corn-soybean rotation, planting of short-rotation woody crops (e.g. hybrid poplar) for biofuels, optimal stocking of under-stocked forest lands, conversion of low-diversity grasslands to diverse grasslands or prairies, conversion of turfgrass to urban forest, and conversion of row crop agricultural lands to grasslands for pasture, biofuel production, or conservation set asides. Many of these practices clearly have or produce other desirable environmental services and co-benefits, such as reduction of erosion and enhanced water quality, expansion of wildlife habitat and increased biodiversity, reduction of fossil fuel usage, and others. Policies and programs already exist that provide incentives for their adaptation for purposes other than C sequestration.

Objectives

The overall objective of this legislative request is to assess the potential of Minnesota lands to sequester C. Multiple steps were required to meet this objective:

- development of an inventory of Minnesota lands having high C stocks that should be protected to prevent C losses and of those having the potential for conversion to land use/land covers with potential to sequester greater amounts of C;
- assessment of the potential of proposed land use/land cover changes to sequester C;

- development of criteria for a network of monitoring sites to measure the rate of C sequestration of selected practices in Minnesota;
- development of criteria for the establishment of demonstration sites for educational and outreach purposes; and
- analysis of existing and proposed state policies for their potential impact on C sequestration activities.

Methods

To attain these goals, this report conducted a comprehensive and critical review of the scientific literature to assess the capacity of the land use/land cover types mentioned above for direct sequestration of C in Minnesota. The policy assessment and the development of criteria for design, establishment, and operation of monitoring networks and demonstration sites flow from the results of that assessment. For each land use/land cover type assessed, the rates of C sequestration obtained from the available scientific literature presented some variability. This variability can be attributed to a number of factors, including: regional and temporal variations in climate; differences in soil characteristics at different sites; differences in experimental, sampling, and analytical procedures used in the studies; and other undetermined factors. Consequently, the statistical mean (average) is presented as the best estimate of potential C sequestration rates. In addition to the mean, measures of two types of statistical certainty were assessed. The first measure concerns the dispersion (or variability) of the data around the mean and indicates how confident we are that the mean accurately estimates the potential C sequestration rate. The second measure assesses the probability that a C sequestration rate is actually positive (greater than zero). This measure is a rough indicator of the probability that a practice actually *does* sequester C from the atmosphere rather than emit C to the atmosphere. Both types of certainty should be carefully considered when interpreting these data.

This report also seeks to evaluate current state policies and programs that affect the levels of terrestrial C sequestration on public and private lands and identify gaps and recommend policy changes to increase sequestration rates. A comprehensive literature review of information from state agencies, including BWSR, MDA, DNR, PCA, and from scholarly publications was done to assess current and proposed state policies related to land use and management. This information was augmented through meetings with agency personnel and others. Policy analysis focused on four potential options for effecting C sequestration: 1) public land management; 2) government incentives and regulations on private lands; 3) private sector initiatives; and 4) research, education and technical assistance. The report does not assess budget impacts of implementing sequestration practices.

Results

Minnesota has more than 16 million acres of forest land and nearly 6 million acres of peatlands (defined as including bogs, marshes, fens and other wetlands). These lands contain very large C stocks in standing plant biomass (1.6 billion metric tons) and peat (4.25 billion metric tons), respectively, that should be protected to prevent additional large emissions of CO_2 to the atmosphere. A single acre of peatland contains, on average, 750 metric tons of C. Total emission of the carbon contained in just 1,000 acres of peatland would increase Minnesota's 2005 CO_2 emissions by almost 2%. On a per acre basis, the total C stock in forests is about one-eighth that of peatlands but is more susceptible to loss by fire, invasive pests or disease, or land use conversion.

Based on the two types of measures of certainty described above, the proposed land use/land cover changes studied fall into three categories. In the first group, the mean rate of C sequestration on a per acre basis is relatively large and clearly positive. This group includes conversion of annual row crops to forests, conversion of annual row crops to short rotation woody crops and prairie pothole restoration. In the second group, the mean rate of C sequestration is more modest, but still clearly positive. This group includes peatland restoration, incorporation of cover crops into the corn/soybean rotation, conversion of annual row crops to perennial grasslands for biofuel production or conservation set asides, and conversion of annual row crops to pasture or hayland and increased stocking of understocked forests. These practices have lower mean C sequestration rates than the first group of practices mentioned, but there is still a high degree of certainty that they do sequester C. In the third group, the mean rate of C sequestration is relatively small and highly variable, with individual values that are both positive and negative. In light of this variability, there is little certainty that conversion of lands to these practices actually results in C sequestration as opposed to C emission. This group includes conversion of lands from low-diversity to high-diversity perennial grassland, and conversion from conventional to conservation tillage. Both of these land use/land management practices have other clearly recognized environmental benefits and should be promoted on that basis.

Scenarios based on reasonable land use/land cover conversions or changes in land management and best estimates of C sequestration rates show that terrestrial C sequestration has the potential to offset a modest proportion of Minnesota's 2005 annual CO_2 emissions, perhaps in the range of 2 - 4 %, or approximately 3-6 million metric tons of CO_2 per year. Much of this reduction can be achieved on state lands or in partnership with existing state and federal programs targeting a wide array of ecological services and co-benefits.

It is clear that terrestrial C sequestration can offset a modest portion of Minnesota's CO_2 emissions and also provide additional environmental benefits and therefore should be part of the state's net CO_2 emission reduction goals, but must be used in conjunction with other emission reduction strategies. Terrestrial C sequestration alone cannot offset entirely the state's current CO_2 emissions. Other policies and practices targeting emission reductions and renewable energy will have to be implemented to reach the state's net emission reduction goals.

Recommendations

1. Preserve the existing large carbon stocks in peatlands and forests by identifying and protecting peatlands and forests vulnerable to conversion, fire, and other preventable threats. Conversion or degradation of these lands may lead to large emissions, thereby increasing atmospheric CO_2 levels and requiring greater reductions elsewhere.

2. Promote those land use and land cover changes that are most certain to cause C sequestration by including them in local, regional, and statewide conservation, renewable energy, and sustainable development priorities. A useful approach to increasing terrestrial C sequestration in the near term is to incorporate C objectives into broader environmental, economic, and renewable energy programs, with an emphasis on those land use or land cover changes that have

high sequestration rates and medium to high certainty regarding whether sequestration rates are greater than zero.

3. Invest in monitoring and demonstration programs in order to build public, practitioner, and investor confidence in terrestrial C sequestration as a viable emission reduction strategy. A major conclusion of this report is that protecting and enhancing the state’s C stocks is an important resource management strategy needing research and education to be implemented successfully. However, given the uncertainty surrounding rates of C sequestration following land use/land cover change, the state should undertake a program to establish 1) monitoring sites for quantifying C sequestration rates of different land use/land cover conversions and 2) demonstrations of land use/land cover changes that are most promising in terms of C sequestration. Such a program will increase public confidence in the viability of terrestrial C sequestration to contribute to Minnesota’s emission reduction targets.