Measuring Soil Carbon Stocks

A System for Quantifying and Verifying Change in Soil Carbon Stocks due to Changes in Management Practices on Agricultural Land

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Summary

Carbon Soil Sinks:

- **Remove CO_2 from the atmosphere**
- **Encourage sustainable development**
- **Offer environmental benefits**
- **Can be measured accurately at reasonable cost**

Repaying the Soil Carbon Debt

When land was broken from natural forest or grassland for agriculture, a large amount of the native soil organic matter was lost as CO_2 to the atmosphere. However, if land management practices are changed in ways that increase the soil organic carbon, the reverse occurs and CO_2 is effectively removed from the atmosphere and put into the soil. This process is called *carbon sequestration*. Figure 1 illustrates soil carbon changes over time on agricultural lands.

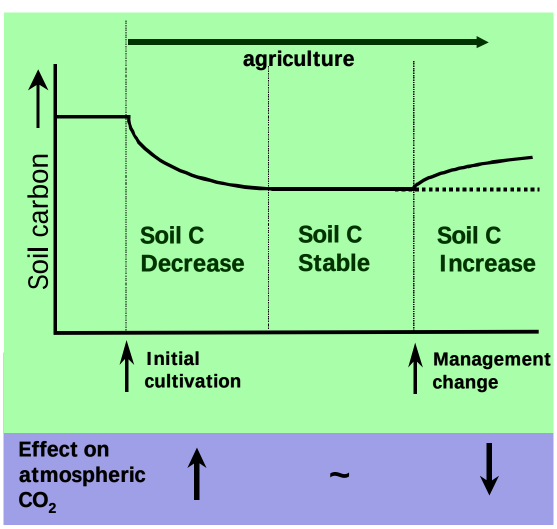

Figure 1. Soil carbon changes due to initial land conversion to agriculture, attainment of a new equilibrium, followed by adoption of management practices that sequester carbon.

Land management practices on agricultural land that increase carbon sequestration include reduction in tillage, restoring degraded land, improving pasture management, and reducing fallow periods. In addition to sequestering carbon in the soil, these soil-improving practices also increase soil productivity, enhance the quality of water draining from agricultural land, and provide a more hospitable environment for wildlife inhabiting that agricultural land. Hence, these practices are fundamental to a more sustainable future.

Figure 2 shows an example from western Canada of how improved land management practices restore soil C. In this case, land that had been conventionally

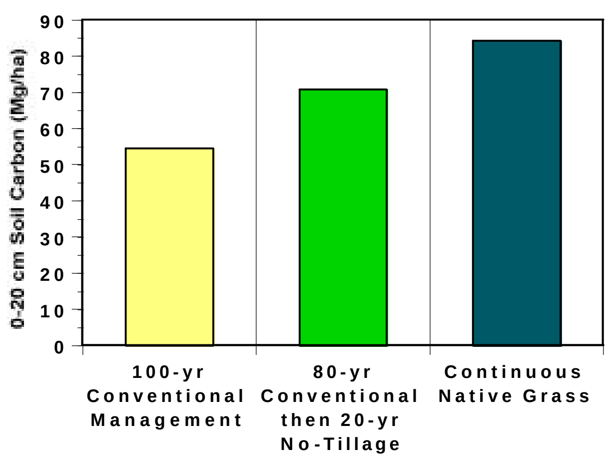

Figure 2 Canadian example of restoration of soil carbon over 20 years from adoption of no-tillage practices.

managed with frequent tillage and fallow has a debt or deficit of 30 Mg/ha or 35% less carbon than adjacent land under native grass. However, the land that had been conventionally managed and then converted 20 years ago to no-tillage without fallow has regained 16 Mg C/ha or about one-half of the soil carbon debt.

Reducing Measurement Variability

When measured through strictly random sampling, the amount of soil carbon appears very variable. Owing to this variability, some have argued that it will be difficult to quantify and verify changes in soil carbon stocks due to changes in land management practices. However, a team of Canadian scientists has developed a reliable method to minimize the variability. This method is the basis for accurately verifying estimates of soil carbon (C) changes due to land management changes. This method involves:

■ Measuring soil C changes on the same small benchmark over time. The benchmarks are located carefully to minimize soil variations within the benchmark itself. Multiple soil samples for C analysis are taken within the benchmark. Collectively, these actions greatly reduce the effects of spatial variability for comparisons across time.

■ Benchmarks are located in known landscape positions and include upper, mid and lower slopes so that the variation of soil C with topography is fully accounted.

■ The density of all soil samples is carefully determined. Further, soil is sampled in 10 cm increments to well below the depth where important soil C changes occur due to agricultural management. Careful adjustment is made so that soil density differences over time or place do not affect soil C stock comparisons.

■ Soils are carefully processed (including exacting treatment of surface plant litter and subsurface large plant roots).

■ Stored air-dried soil samples from the past are analysed for soil C in a random order along with samples from the current time. This, in combination with rigorous laboratory quality control procedures, eliminates the potential for even minute variation in soil C assessments across time resulting from the slight shifts in the dry-combustion C analysis procedure itself.

Figure 3. Careful sampling is an essential step to reducing variability of soil carbon measurements.

System for Quantifying and Verifying Changes in Soil C Stocks

Pilot Project in Canada

To improve the soil quality, including rebuilding soil organic matter, many western Canadian farmers have adopted no-tillage crop production practices. A group of these no-tillage farmers, in cooperation with a team of Canadian scientists from government and universities, has initiated a pilot project using a system to quantify and verify the soil C changes due to this adoption of a no-tillage system. The pilot project involves the province of Saskatchewan, which contains 20 million hectares of the crop land, one-half of Canada's total. Figure 4 is a simplified schematic representation of this soil C quantification and verification system.

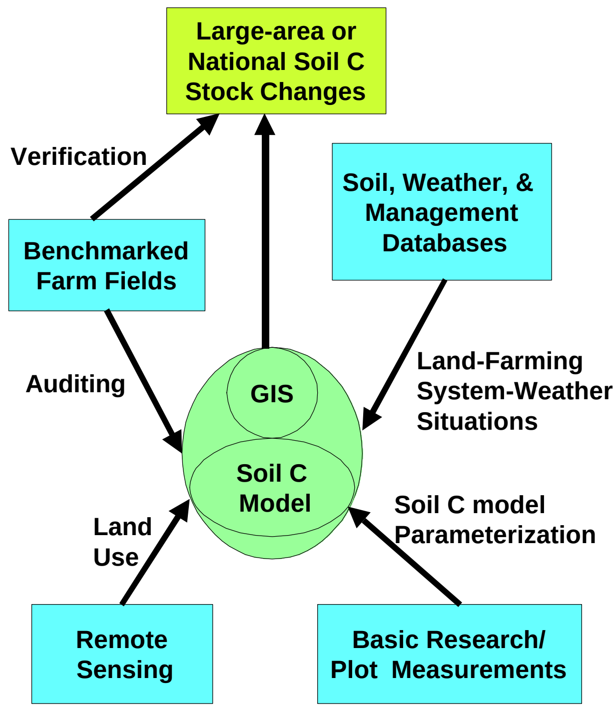

Figure 4 System for quantifying and verifying changes in soil carbon stocks.

System Description

The core of the system is the model of soil C dynamics. This science of soil C dynamics is relatively well developed and several soil C models (e.g. CENTURY) have been used successfully to predict changes in soil C in a wide range of environments. The basic system involves:

1. Model Refinement: appropriate C model parameters are derived and the soil C model is thoroughly tested using a large set of soil C research experiments and data.
2. Define Situations: From databases of soils, landform, weather, and farm management, important situations that result from a combination of the farming system, land, and regional weather are identified. Remote sensing supplements database information on no-tillage extent. (Remote sensing will be more important when the system is expanded to include soil C changes due to changes in management of pastures, farm wood lots, and other land use changes involving perennial vegetation).
3. Scaling Up: Soil C changes for these situations are predicted with the soil C model. These are integrated to make large-area or national estimates using a Geographical Information System (GIS).
4. Verification: The accuracy of the soil C model predictions are audited by comparing the predictions with the rich set of carefully measured C changes in the benchmark situations. Further, if sufficient benchmarks are available so that all important land-farming system situations are represented, an independent estimate of soil C changes is available by scaling up the benchmark soil C changes directly.

A Closer Look at Verification Benchmarks

In the Canadian pilot project, a network of 150 benchmarked fields were established, covering the agriculturally developed portion of the province of Saskatchewan (see Figure 5). The benchmarked fields include every important combination of soil type, texture, and regional climate. The benchmarks were established just before cooperating farmers converted these fields to no-tillage in 1997. On these fields, 2x5m benchmarks were located with Global Positioning System (GPS) and with a buried electromagnetic markers. These benchmarks were carefully sampled according to exacting protocol to minimize variability. The farmers were instructed to manage their fields normally without regard to the benchmark (there is no visible marking of the benchmarks). Soil carbon on the benchmarks will be measured again three years after the initial soil sampling.

Uncertainty of Soil C Changes Low

A well-designed network of passive benchmarks on farm fields is a cost-effective and powerful method of confirming that estimates of soil C stock changes are accurate. Based on our Canadian pilot project, a benchmark verification system can be implemented for a total cost less than 5 cents (i.e. US $0.05) per hectare. With an appropriate quantification and verification system, the uncertainty of changes in soil C stocks due to changes in land management practices will be smaller than those for greenhouse gas emissions from agriculture included under the Kyoto protocol.

A Win-Win Option for the Environment

Sustainable development requires that we leave future generations a productive soil resource. In this light, the wisdom of applying soil-improving practices is unarguable. These practices improve the health and fertility of the soil and decrease the use of fossil fuel, fertilizer, and other inputs per unit of food grown. Opportunities to apply soil improving land management practices exist on farm land throughout the world. Practices that improve the soil clearly contribute to both environmental and economic objectives.

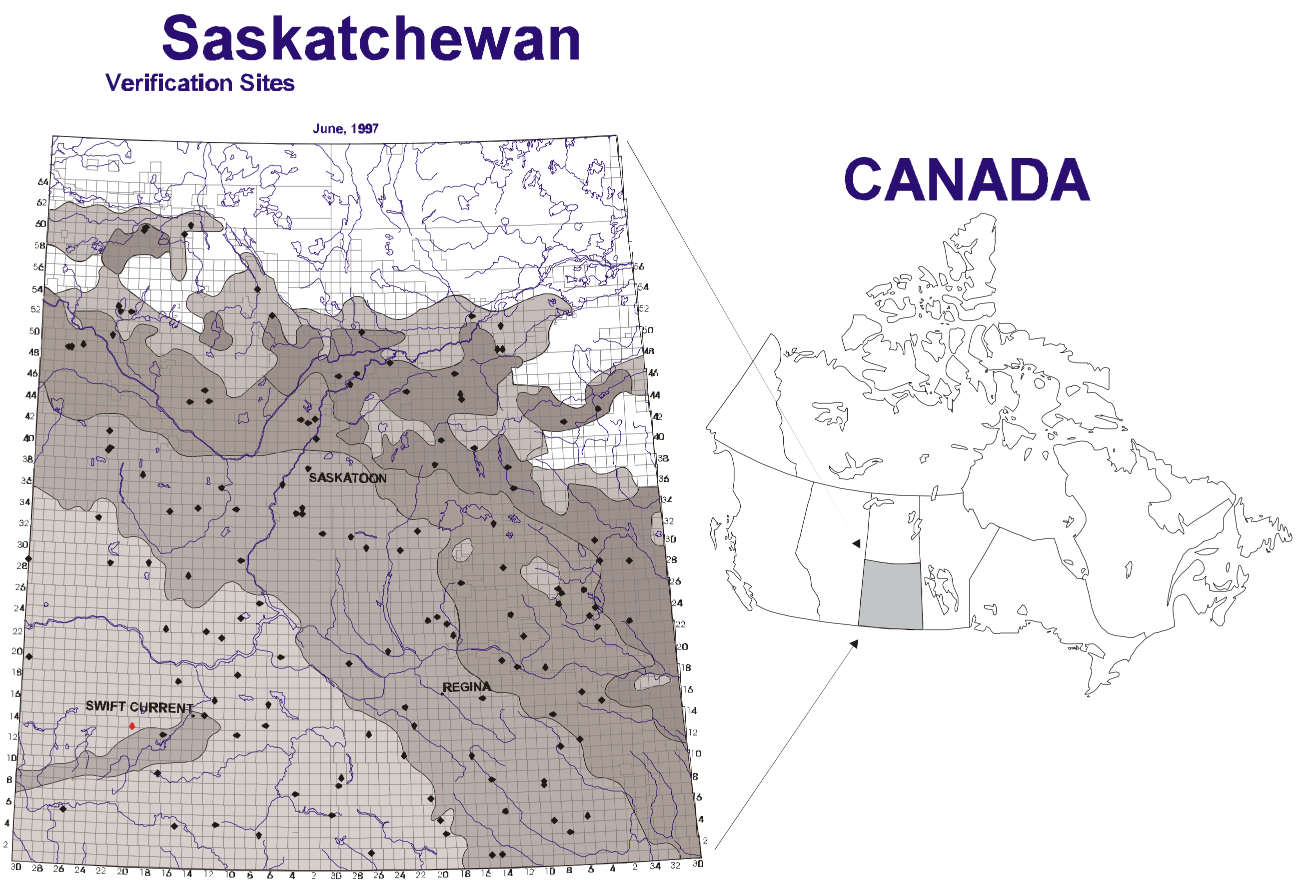

Figure 5 Map of benchmarked fields used in the Canadian pilot project involving the system to quantify and verify soil C stock changes from the adoption of no-tillage farming practices.