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.

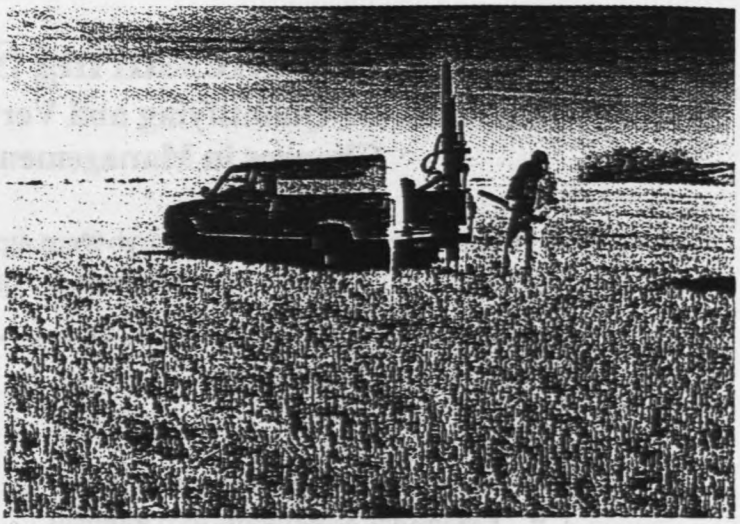

Figure 3. Careful sampling is an essential step to reducing variability of soil carbon measurements.

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.