Soil Carbon Sequestration and Nitrogen Management for Greenhouse Gas Mitigation

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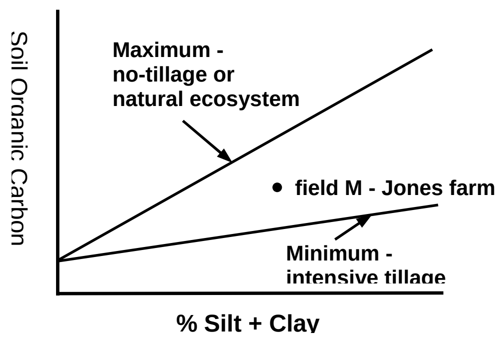
Carbon Sequestration Principles

Soils have a finite capacity to sequester organic carbon (OC) that is determined by soil texture and aggregation. SOC levels increase with silt + clay content and the maximum level is achieved when soils are most highly aggregated, i.e. when they are not tilled. Tillage breaks aggregates and exposes SOC to biological decomposition. Loss of SOC is proportional to the intensity of tillage. Soils therefore have both a potential maximum and potential minimum SOC content.



Most agricultural soils, e.g. field M of the Jones farm, are somewhere between their potential maximum and minimum SOC content and the difference between the current value and the maximum represents the carbon sequestration potential when no-tillage (NT) is adopted. The gain of SOC following adoption of NT is slow and it will take many years (20-30 in NE USA) for most soils to reach their maximum SOC level. Soils in the USA gain an average of about 350 lb C ac^{-1} under NT, depending on texture and residue input levels. Without adopting NT, residue input levels have a small, but measurable effect on SOC content. The gain of SOC is greatest shortly after adoption of NT and declines with time until the maximum level is reached.

Carbon Sequestration and Greenhouse Gas Budget for Maize

The carbon balances for a switch from conventional till (CT) to no-till (NT) agriculture for grain production in the USA has been evaluated by West and Marland (2002). For maize, the net C benefit is 301 lb C ac^{-1} yr^{-1}. However, a change to NT also alters fluxes of N_2O and CH_4, two other important greenhouse gases, which also need to be included in the calculation. Adding these changes to the C budget alters the picture substantially. An additional fertilizer N input of 38 lb N ac^{-1} is used on NT corn, which adds 67 lb of carbon equivalents (Cequiv) ac^{-1} of greenhouse gases to the atmosphere. A switch to NT agriculture is estimated to add an additional 196 lb Cequiv ac^{-1} in emissions of N_2O from soil (Smith et al., 2002). The combined offsets reduce the C benefit of changing to NT corn to 32 lb Cequiv ac^{-1} yr^{-1}. A similar calculation reduces the C benefit for NT soybeans from 330 to 138 lb Cequiv ac^{-1} yr^{-1}. It should be noted that the value assigned to N_2O emissions associated with the change to NT is uncertain and additional research is needed to better define this number. A fuller discussion of this topic is given in Duxbury, 2005.

Greenhouse Gas Source (+) or Sink (-)	**Conv. Till** lb C_e ac^{-1} yr^{-1}	**No-Till**
Soil C sequestration	**0**	**-301**[1]
Carbon dioxide emissions		
- Ag. Inputs	**+139**[1]	**+180**[1]
- Machinery	**+64**[1]	**+21**[1]
Net C Flux	**+203**	**-100**
Relative C Flux	**0**	**-303**
Relative N_2O Emission		
Additional N input (38 lb ac^{-1}) [1]		
- Manufacture	**0**	**+10**[2]
- Use	**0**	**+57**[3]
Switch to No-Till	**0**	**+196**[4]
Relative CH_4 Emission		
- additional N	**0**	**8**
Total Additional GHG Flux	**0**	**+271**
Revised Relative GHG Flux	**0**	**-32**

[1] From West and Marland, 2002; negative values indicate C sink
[2] Based on 22% of fertilizer as NH_4NO_3, and N_2O release from Kramer et al, 1999
[3] Using IPCC formula of 1.25% fertilizer N released as N_2O from 90% of applied N
[4] Average value from Smith et al, 2002

Questions about the net greenhouse gas benefit of NT agriculture together with verification difficulties are likely to prevent soil carbon sequestration from becoming a tradable commodity. Nevertheless, increasing SOC has direct benefits for soil health and agricultural sustainability. Indirect effects of improved soil health on input use and GHG emissions in crop production have not been fully evaluated but are likely to be positive.

Improved Nitrogen Use Efficiency

Improving N use efficiency (defined as % recovery of applied N by a crop) and reducing N fertilizer inputs in crop production is an important goal given the energy and greenhouse gas costs of fertilizer N manufacture and the potency of N_2O as a greenhouse gas (310x that of CO_2). The basic management goal is to reduce N losses from the soil plant system, especially those by denitrification which is a major source of N_2O emissions from soil. Key parts of improving N efficiency are to avoid excessive N applications and to synchronize N supply with crop demand. The latter is more easily achieved when nitrogen is supplied from fertilizer than from organic N sources, where release is controlled by biological mineralization processes. In general, release of N from organic N sources continues beyond the period of crop production and can contribute to leaching losses and off-site pollution problems, including additional generation of N_2O. Research has also shown that emissions of N_2O from cropland are higher when manure is used as the N source (Duxbury et al., 1982)

The principles of sound fertilizer N management are well understood. These are:

- time N applications to the period of maximum crop demand
- incorporate N into soil to avoid volatilization of ammonia from urea fertilizer and animal manures
- use mixtures of nitrate (NO_3^-) and ammonium (NH_4^+) N sources to provide rapidly and more slowly assimilated N forms, including mixtures of inorganic and organic N sources
- consider ways to recycle N (in plant biomass) mineralized from organic sources that is not used by the main crop or if drought (or any other production problem) reduces crop yield and N recovery

A major difficulty in N management is predicting weather; this leads to both over and under fertilization. Recent research has focused on real time N management. The pre-sidedress soil N test is available for maize production and simple models using current season weather to adjust N fertilization rate are being developed.

Summary

- C sequestration in soil requires a change to no-tillage
- Annual C sequestration rates average 350 lb ac^{-1} yr^{-1}
- Soil C sequestration benefits of no-tillage are largely offset by increased emissions of N_2O and CH_4
- Nitrogen management should focus on reducing losses of N from the system as these can lead to additional generation of N_2O
- The basic principles of sound N management are well known and need to be promoted within the context of reducing greenhouse gas emissions as well as increasing profitability
- Organic N sources lead to higher N_2O emissions than inorganic fertilizer N

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