Sequestration Rates, Duration, Capacity, and Saturation:
Determining Factors for Current and Future Soil Carbon Stocks

A Joint CASMGS-CSITE Session on
Soil Carbon Sequestration:
Science, Technology, and Economics

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I. Introduction to terms

- **Soil carbon capacity** is the amount of carbon held by the soil in a steady state under a specific management scenario.

- Δ Soil C capacity =
  Mean sequestration rate x Sequestration duration

- **Duration** is:
  (a) the time period in which rates of soil carbon accumulation or loss occur until a new steady state is reached (i.e., duration of active sequestration); and
  (b) the time period in which soil carbon remains sequestered (i.e., duration of previously sequestered carbon).

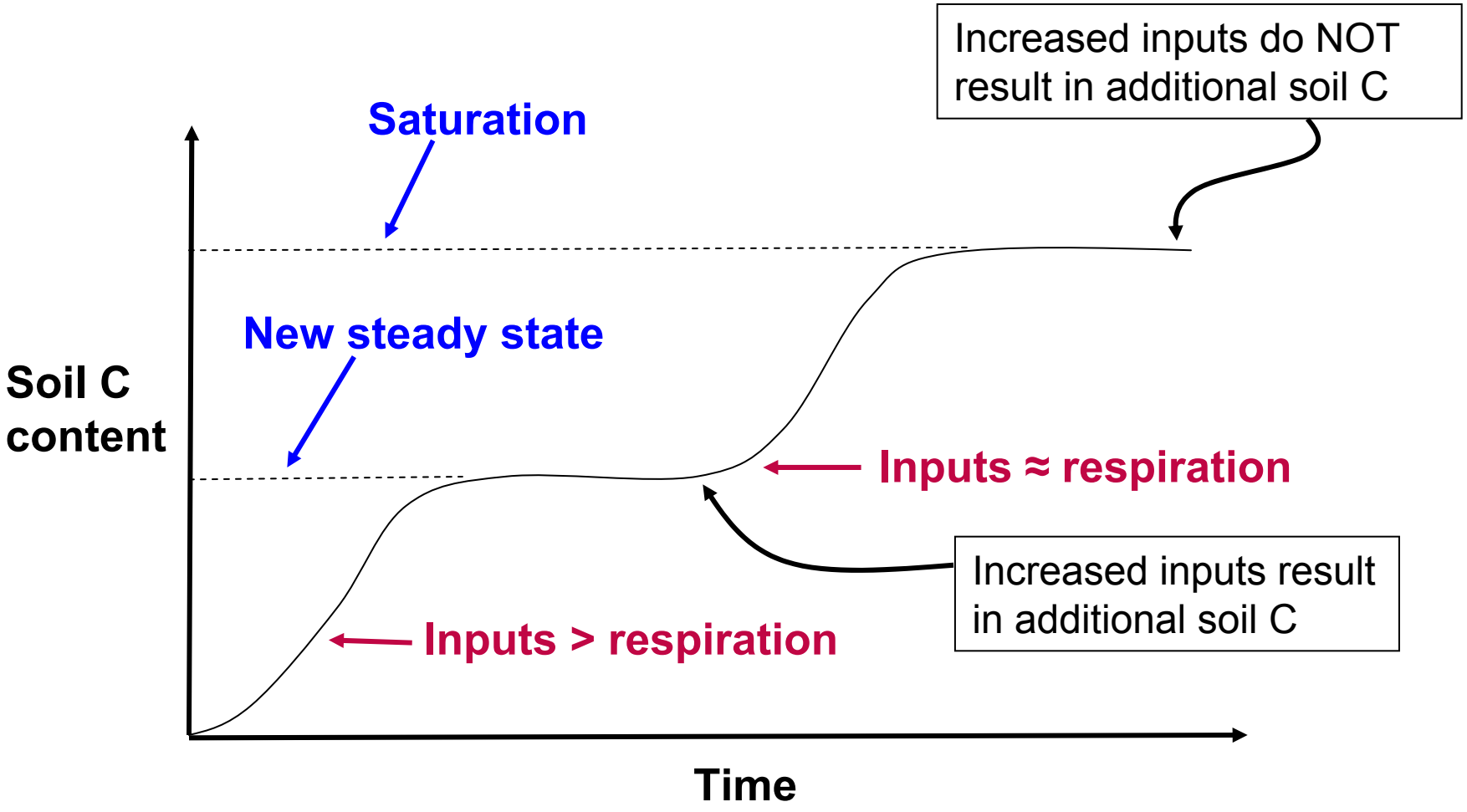
I. Introduction to terms

- Soil carbon capacity may be (i) increasing or decreasing, (ii) remaining at **steady state**, or (iii) may have reached **saturation**.

- Soil carbon reaches a **new steady state** some time following the adoption of a new practice; it does **not** necessarily reach saturation following adoption of a new practice.

- **Soil carbon saturation** occurs when soil can no longer accumulate carbon.

Soil C steady state vs. C inputs vs. time

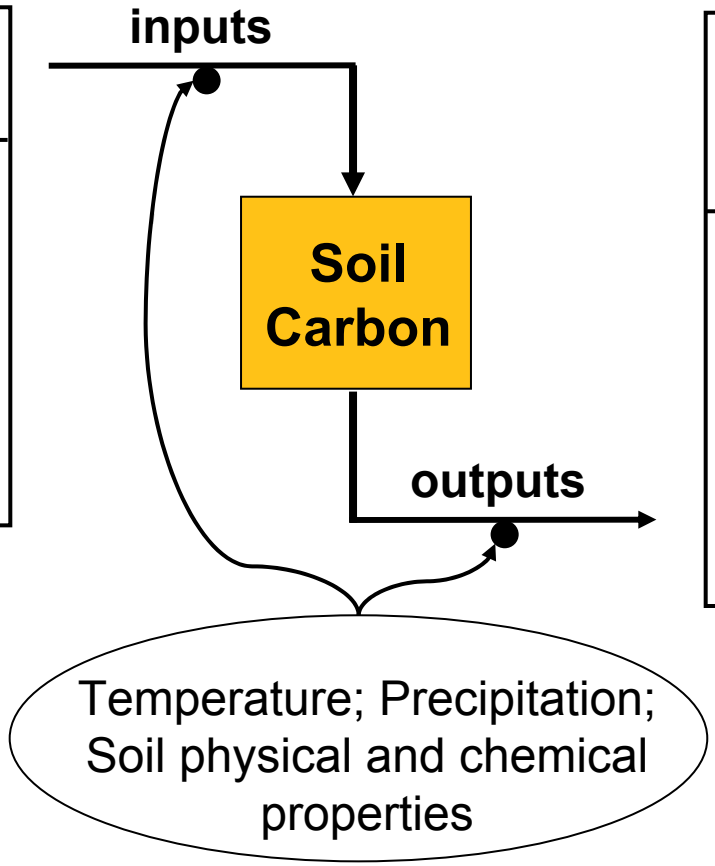


Revised from Johan Six, CASGMS Forum presentation (2004)

Rates, duration, capacity, and saturation of stored carbon depend on carbon cycle dynamics and carbon sequestration strategies.

Increase organic matter inputs

- Fertilize
- Irrigate
- Weed control
- Increase rotation complexity
- Manure application



Decrease decomposition and erosion

- Decrease tillage
- Increase aggregate formation (earthworm introduction)
- Increase surface residue / cover crop

II. Sequestration rates – brief overview

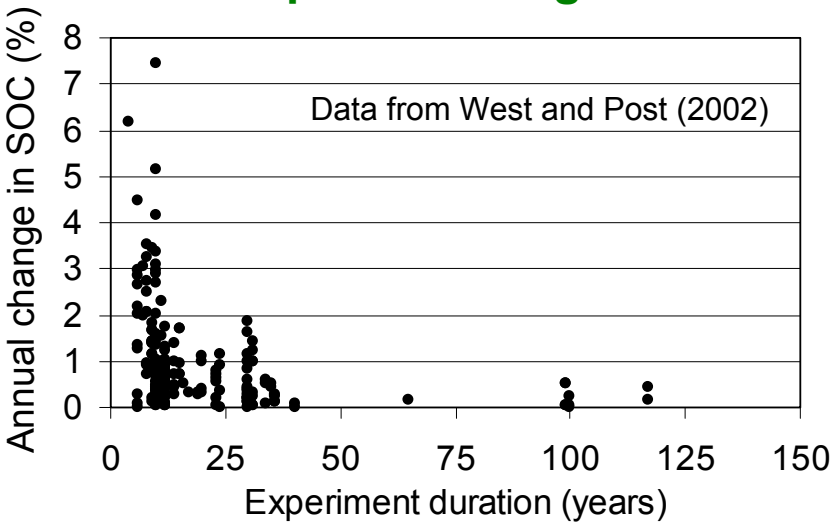
Comparison of soil C sequestration rates between IPCC guidelines and two other analyses

	Coverage	CT → NT	Enhanced residue production
IPCC (1997)	Global (temperate)	10%	10%
West & Post (2002)	Global	15 ± 3%	6 ± 2%
Ogle et al. (2003)	U.S.	13 ± 3%	7 ± 2%

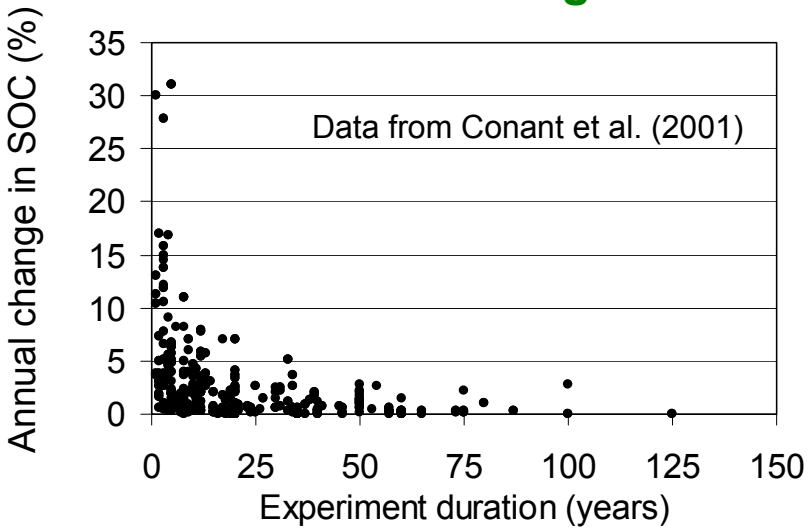
IPCC. 1997. Greenhouse Gas Inventory Reference Manual, v. 3.
West and Post. 2002. Soil Science Society of America Journal 66:1930-1946.
Ogle et al. 2003. Global Change Biology 9:1521-1542.

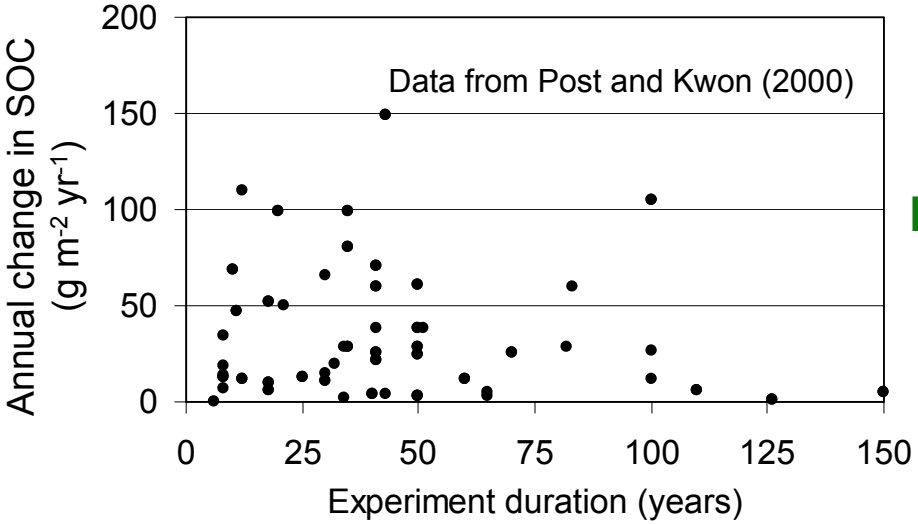
III. Duration of active soil carbon sequestration

Cropland management



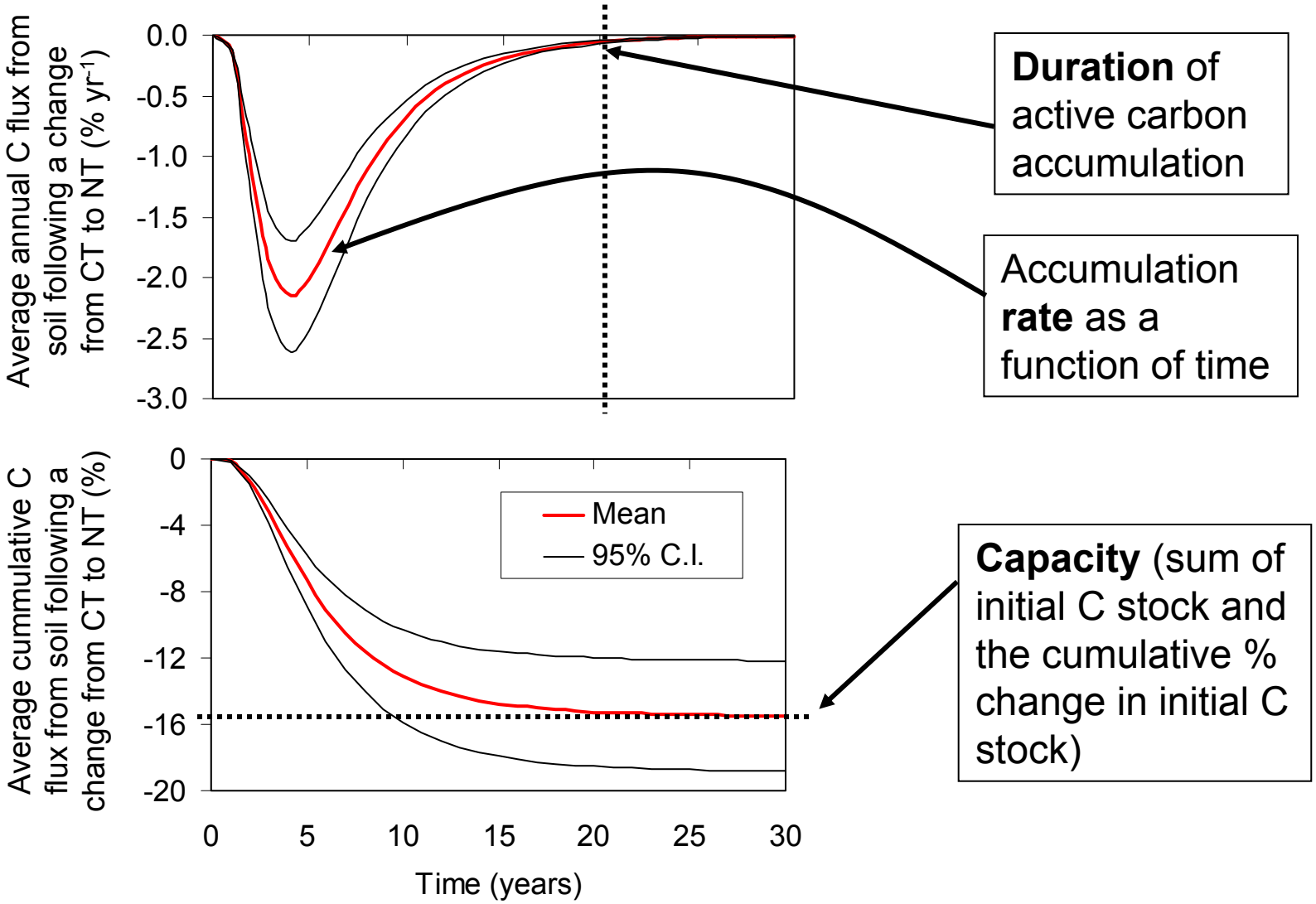
Grassland management





Reforestation

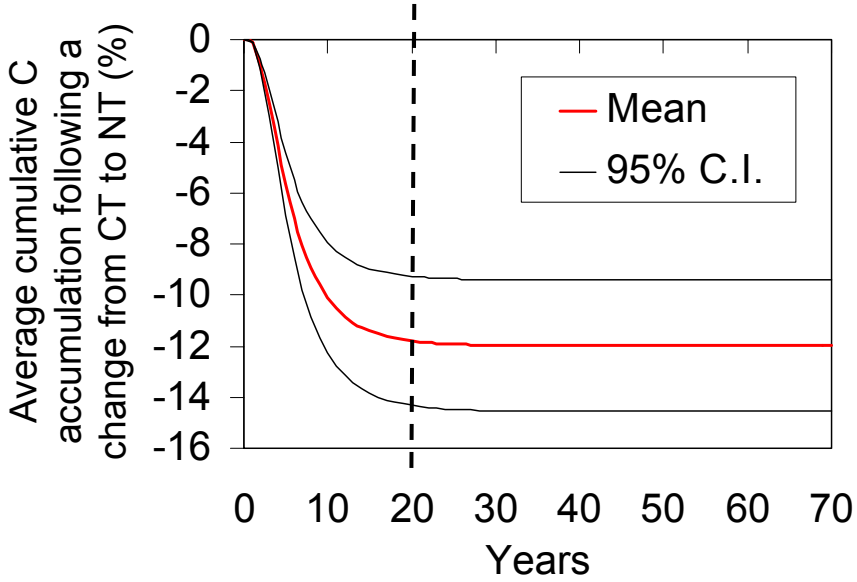
Determining factors represented in Carbon Management Response (CMR) curves

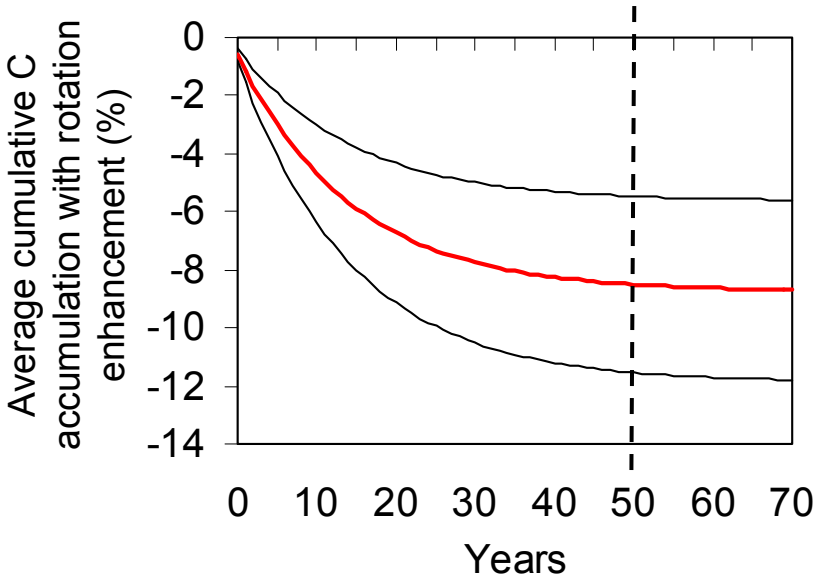


West et al. 2003. Environmental Management (in press).

III. Duration of active soil carbon sequestration

Cropland management



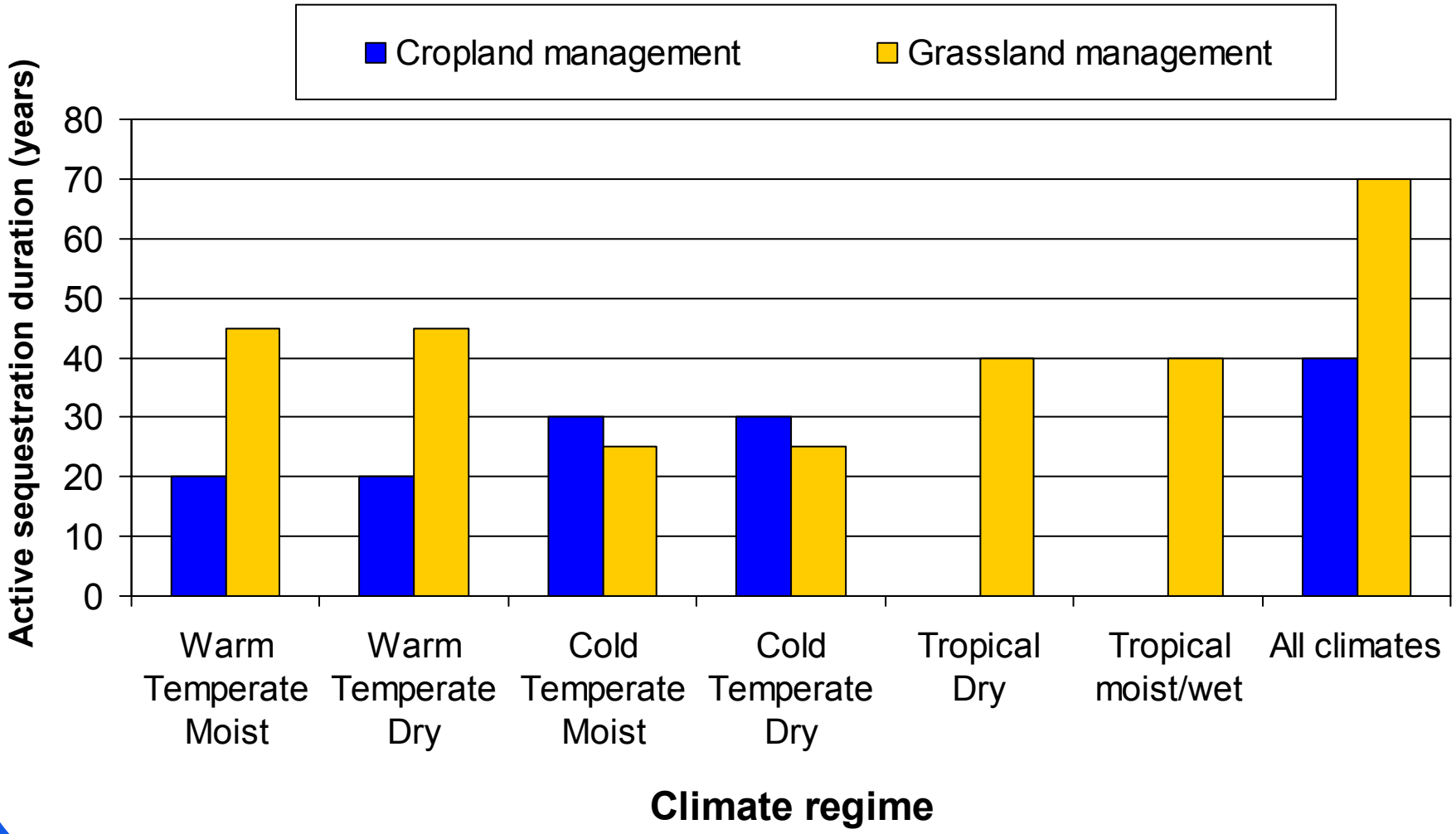


Duration of sequestration rates may be longer for changes in inputs (increased residue production) than for changes in outputs (decreased respiration/decomposition).

Estimates of cropland improvement derived from West and Post (2002).

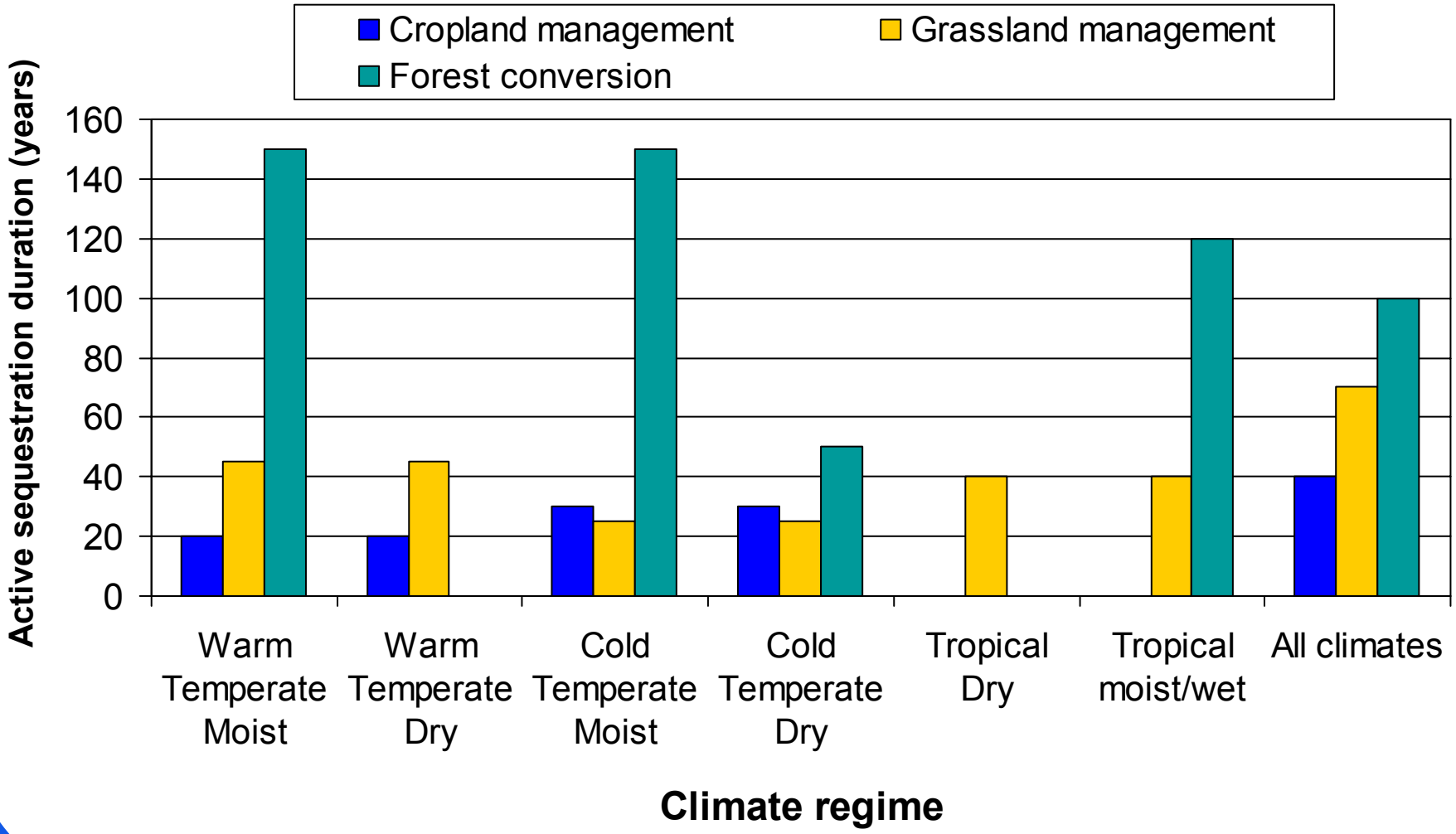
III. Duration of active soil carbon sequestration

Duration and climate regime



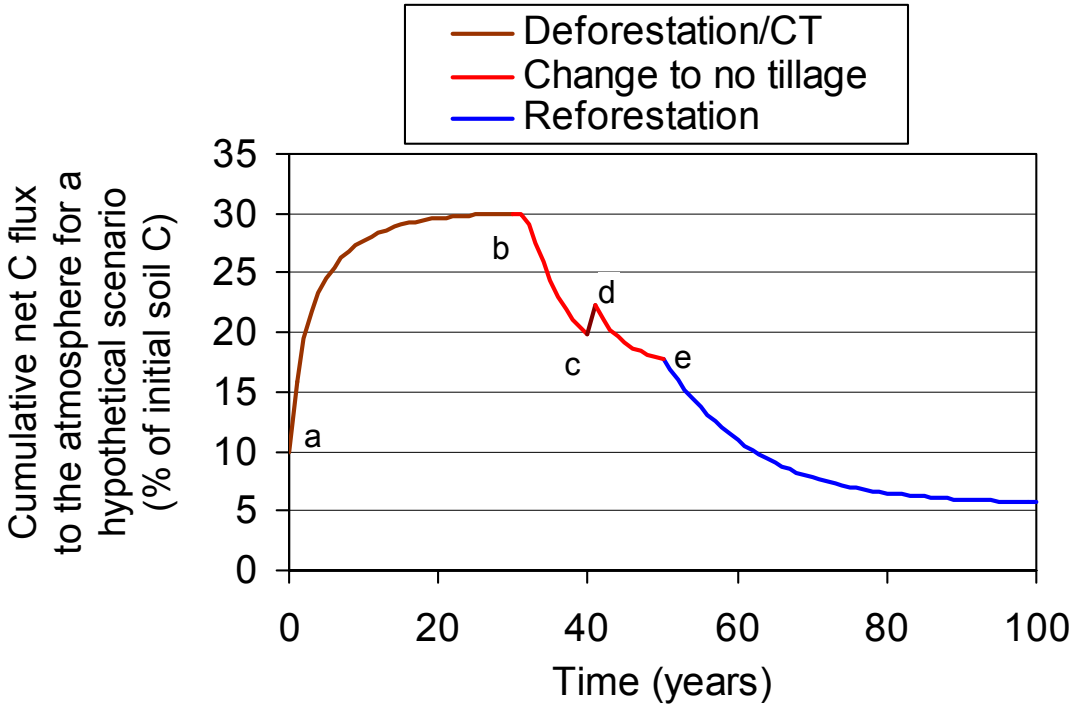
III. Duration of active soil carbon sequestration

Duration and climate regime



IV. Duration of previously sequestered carbon

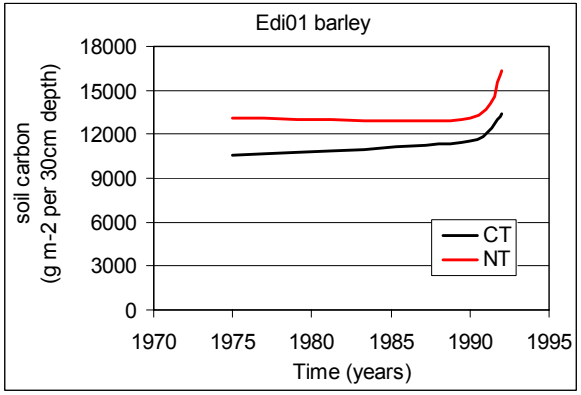
Terrestrial carbon is expected to remain sequestered until there is a subsequent change in management.

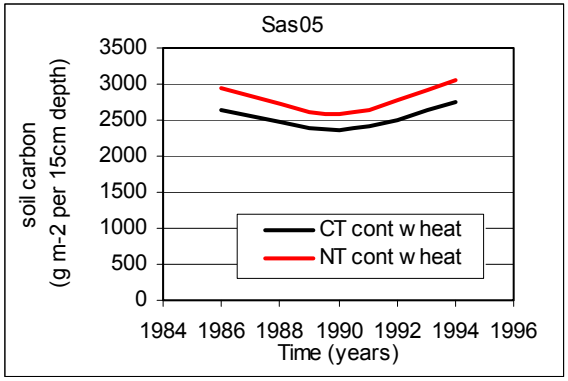


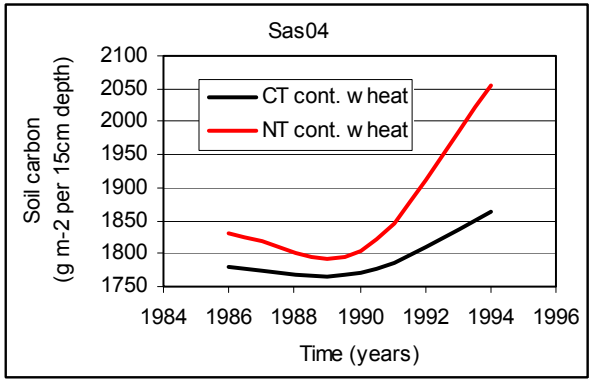
Hypothetical scenario consists of (a) deforestation and cultivation of soil using conventional tillage, (b) changing from conventional tillage to no-till, (c) use of conventional tillage for one year, (d) returning to the use of no-till, and (e) abandoning the land and allowing forest conditions to re-establish. From West et al. (2003).

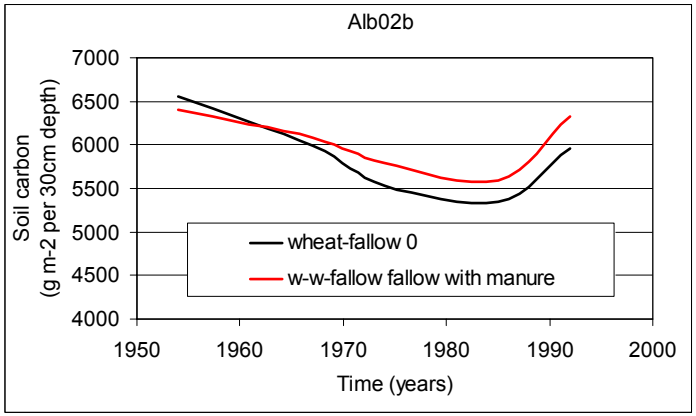
IV. Duration of previously sequestered soil carbon

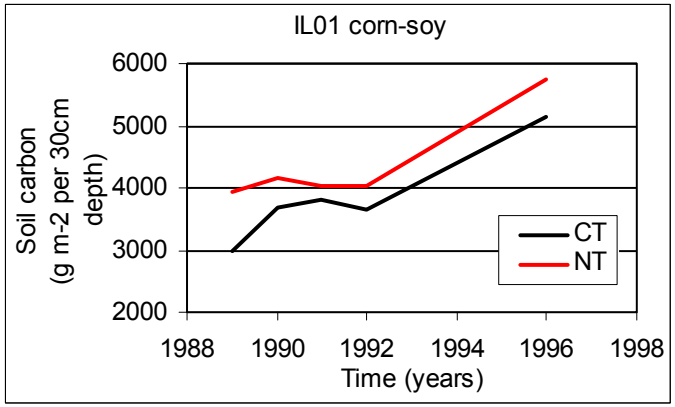
Duration and capacity of soil carbon also depend on changes in climate and annual variation in weather (i.e., mean annual temperature, precipitation, and percent radiation). Shown below are possible effects of a climate anomaly on soil carbon in the early 1990's.





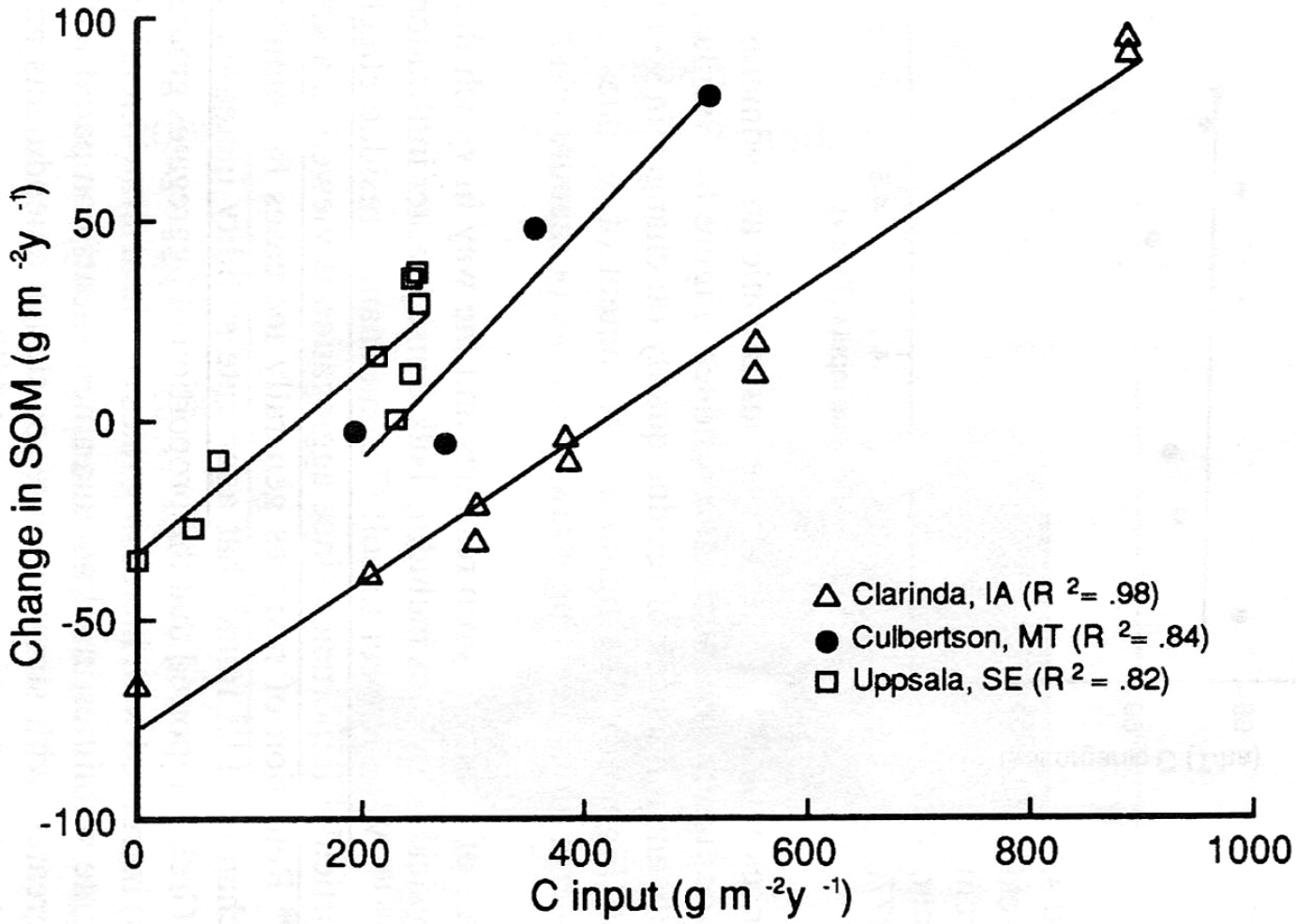






V. Soil carbon saturation

Increase in inputs ~ increase in soil C



Paustian et al.(1997)

V. Soil carbon saturation

Evidence of C saturation in high C soils

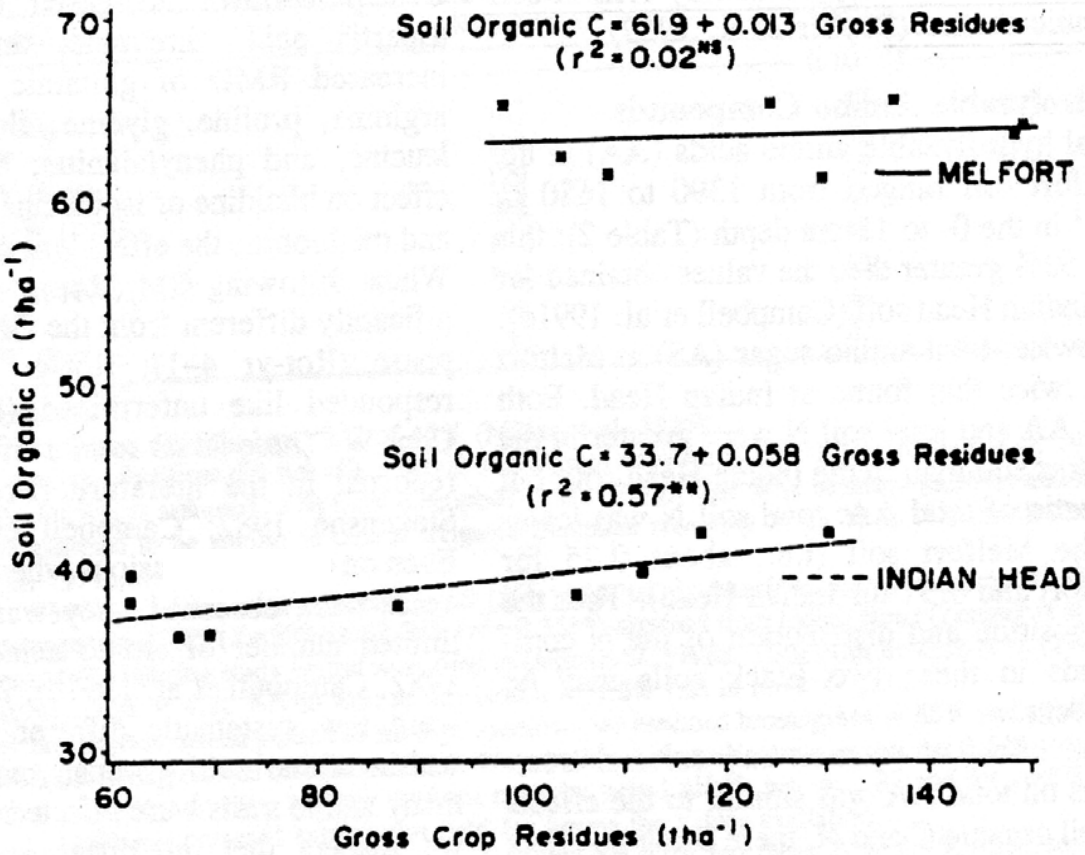


Fig. 1. Relationships between soil organic C and N in the 0- to 15-cm depth and estimated crop residues returned to Melfort soil (31 yr) and Indian Head soil (30 yr). (Indian Head data taken from Campbell et al. 1991a.)

Campbell et al. (1991)

V. Soil carbon saturation

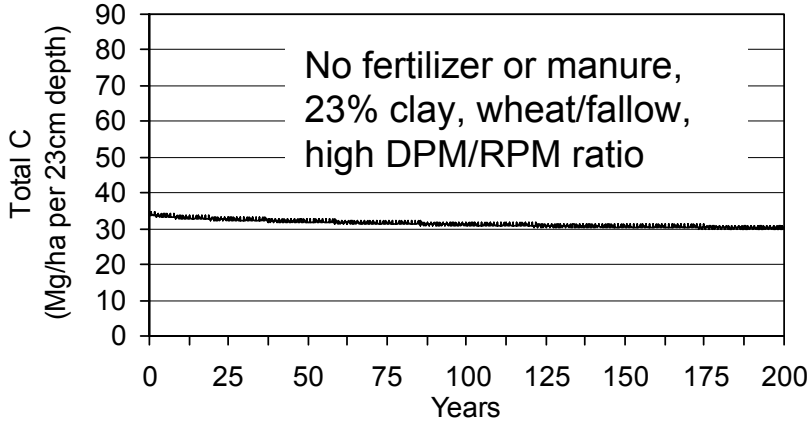
Soil carbon may be increased over that in native soils.

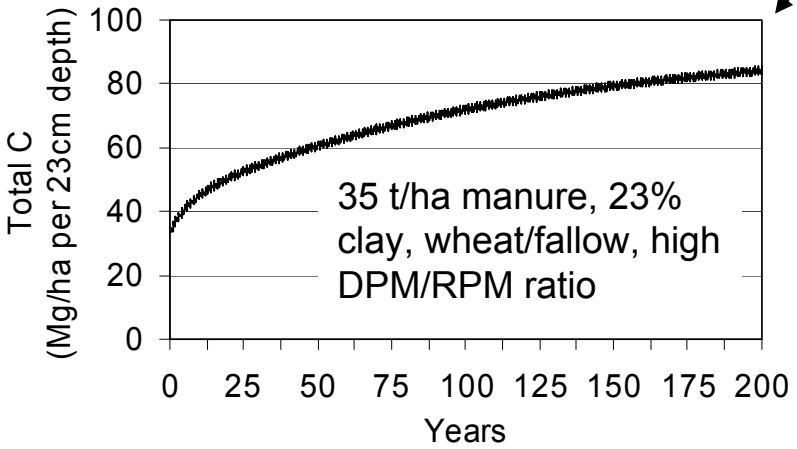
	Bluegrass sod	CT	NT
	-------Mg C ha^{-1} (0-30 cm)-------		
1970	**53.4**	53.4	53.4
1975	53.4	43.3	48.7
1980	53.4	42.9	48.8
1989	54.9	55.7	**59.9**

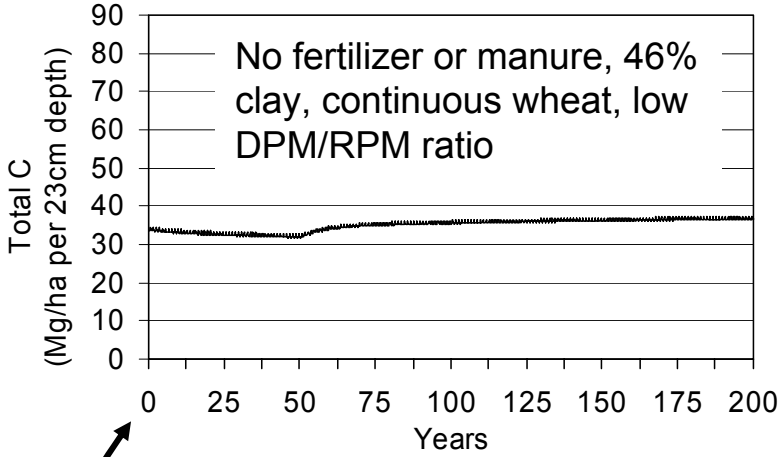
Continuous corn under conventional (CT) and no-tillage (NT) management. Results averaged across fertilization treatment rates of 0, 84, 168, and 336 kg N ha^{-1}. From Ismail et al. (1994).

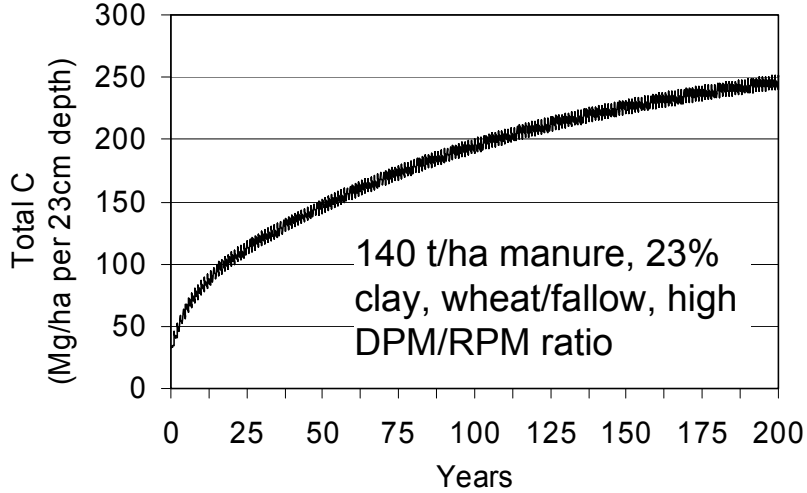
VI. Duration and saturation in soil C models: Rothamsted Carbon Model

Increase in inputs:
~25 g m^{-2} yr^{-1} for 200 yr









Decrease in decomp.
~20 g m^{-2} yr^{-1} for 20yr

VII. Summary

- Sequestration potential depends on both the rate of sequestration and the duration of sequestration rates.
- The new carbon capacity represents a new steady state of soil carbon, and not necessarily soil carbon saturation.
- The “ultimate” carbon capacity, based on estimates of soil carbon saturation, may be significantly larger than traditional estimates of sequestration potential and larger than the “natural” capacity.
- Current soil carbon sequestration potentials may be underestimated without fully considering issues of “duration” and “saturation”.

Acknowledgments

OAK RIDGE NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Consortium for Research on ***Enhancing***
Carbon **S**equestration **i**n **T**errestrial **E**cosystems