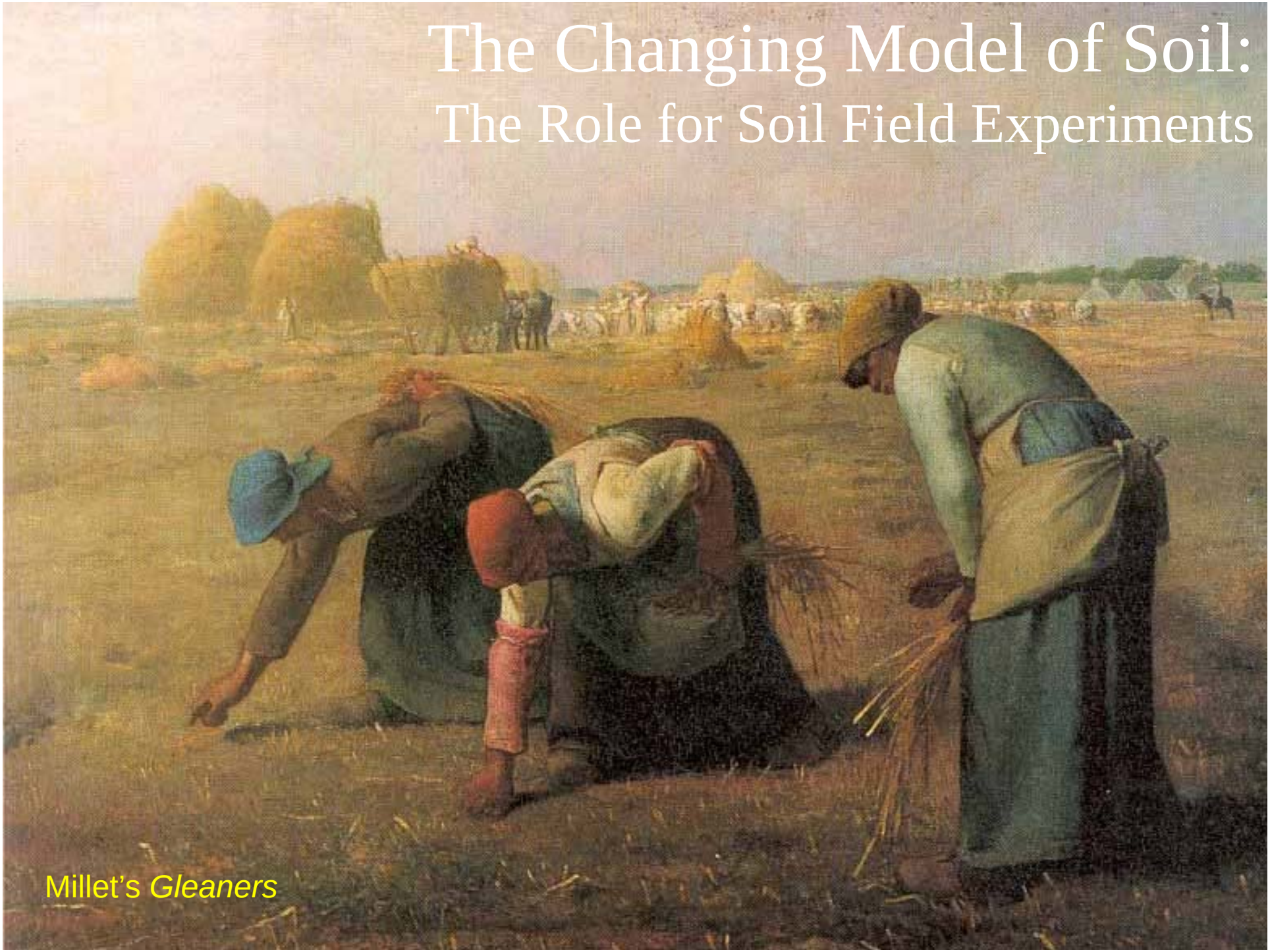
The Changing Model of Soil:
The Role for Soil Field Experiments



Millet's *Gleaners*

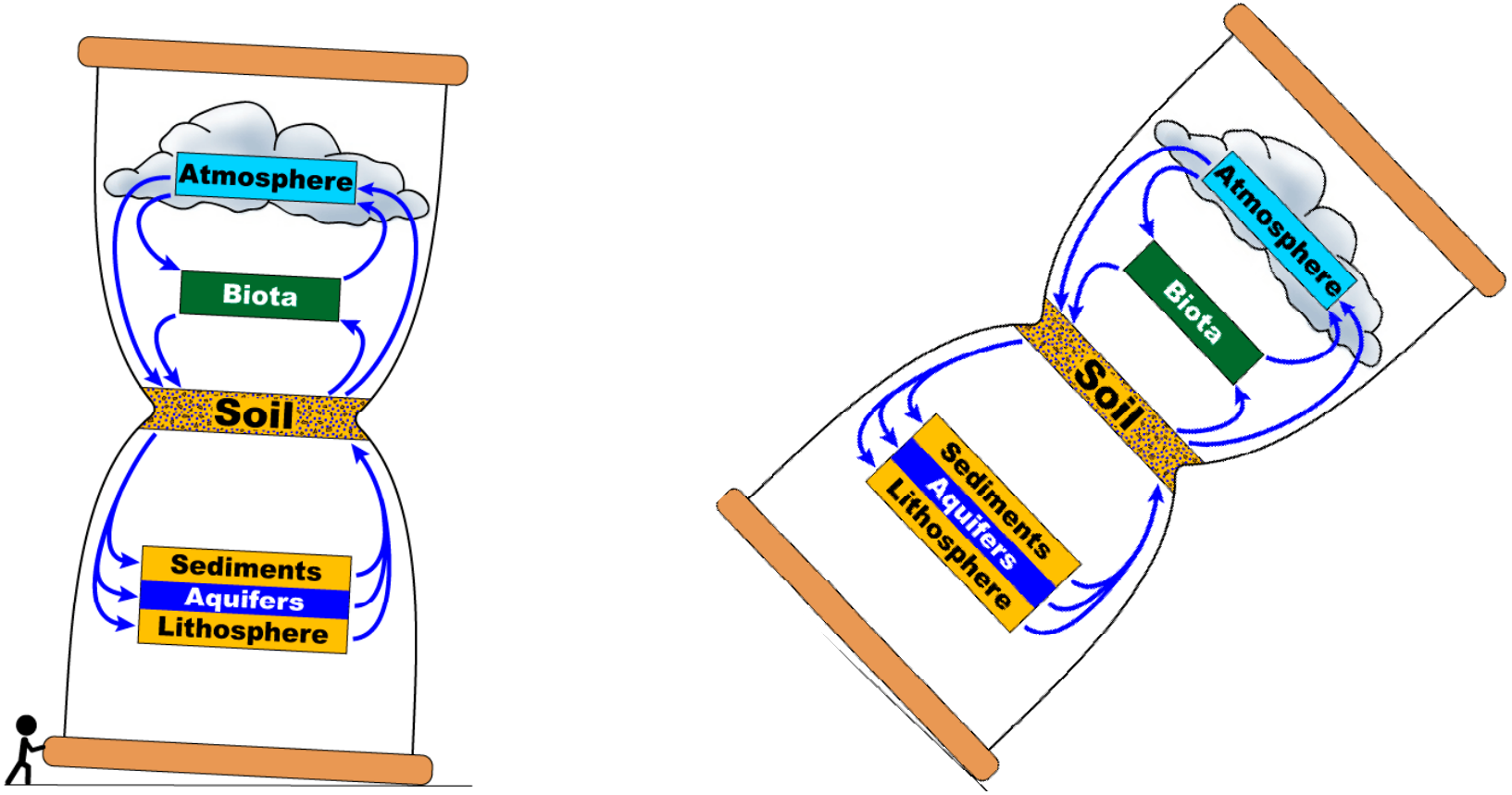
Geologists tell us we have left the Holocene, 10,000 years of human civilization

Geo. Catlin ‘s *Southside of the Missouri River,* 1832, Smithsonian

We have stepped into the **Anthropocene…**

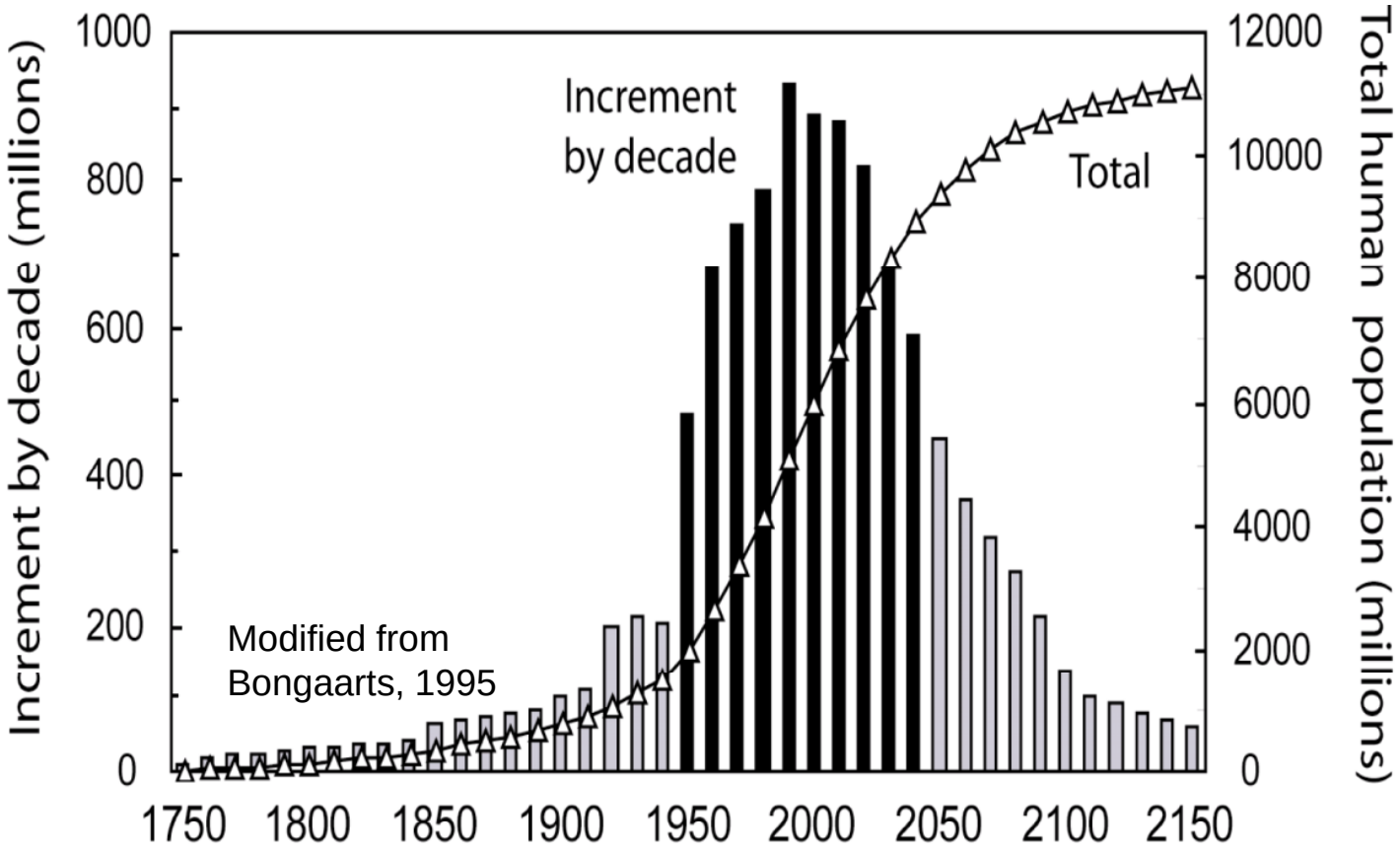
P.J. Crutzen 2002, *Nature*

<u>Hypothesis</u>: The Anthropocene is transforming many academic disciplines & governmental agencies



Courtesy of Penn State Anthropocene Group

We are half way thru
the most exciting century in Earth history



An Anthropocene reading list

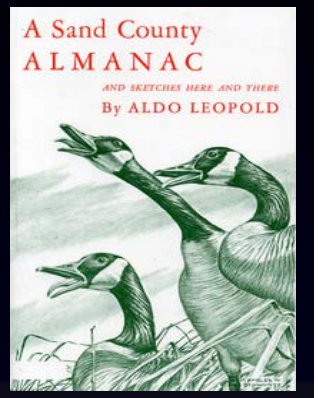
29 BC — Virgil's *Georgics*

1854 — Thoreau's *Walden*

1864 — Marsh's *Man & Nature*

1938 — Sauer's *Plants & Economic Exploitation*

1949 — Leopold's *Sand County Almanac*



1962 — Carson's *Silent Spring*

1995 — Cronon's "Trouble with Wilderness"

1998 — Keeling's "Rewards & Penalties of Monitoring the Earth"

2002 — Cruzen's "Geology of Mankind"

2003 — Richard's *Unending Frontier*

?

Suggestions welcome …

Point of talk

The Anthropocene has forced itself
upon the venerable science of pedology,

creating a new model of soil, the anthro-soil,
which require new approaches for study
i.e., field experiments

Four Holocene models of soil

- Agro-model: Soil as medium for plant growth
- Hydro-model: Soil as water transmitting mantle
- Engineering model: Soil as structural foundation
- *Natural-body model: Soil as product of natural process*

Natural-body soil model,
a new science of Earth's soil in the 19th c

Soil, as independent natural body,
with multiple forming factors.

A system worthy of scientific study

Many 19th c. scientists originated the natural-body model of Earth's soil

E.W. Hilgard, *Geology & Agriculture of Mississippi* (1860)

V.V. Dokuchaev, *Russian Chernozem* (1883)

"The most fundamental change in the concept of soil in history…" (Cline, 1961)

Ironically, Hilgard was employed to study soil as a medium for cotton growth in Mississippi and Dokuchaev to develop a soil-taxation system on the Russian Steppe.

but what endures is that
"soil … is a distinct system and segment of nature, possessing its own internal organization, genesis, and dynamics"

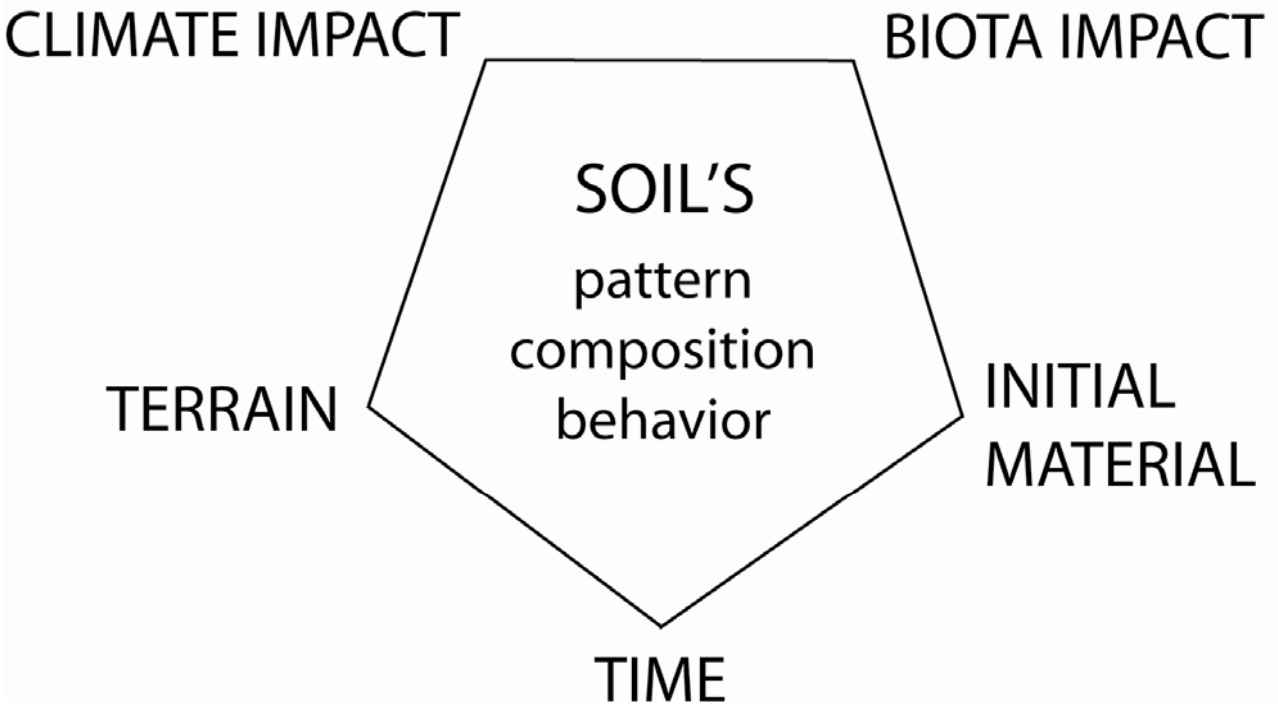
H. Jenny (1961)

How nature forms soil may always be a mystery

- Soil, “the most complex biomaterial on the planet”
- High-order interactions result in near-infinite varieties of soils
- Much about soils impossible to directly observe

Young & Crawford (2004)
Richter (2007)

Dokuchaev featured five natural soil-forming factors or fashioners



Evtuhov (2006)
Buol et al. (2003)

The natural-body model was hardly static

Marbut (1935) emphasized:

natural soil process, formation & continuum

VS

Soil Survey Staff (1960) emphasized:

mapping units over soilscape,
quantifying properties “unlikely to be affected by management”

Cline, M.G. 1961.
The changing model of soil.
SSSAJ 25: 442-446.

Natural-body pedology

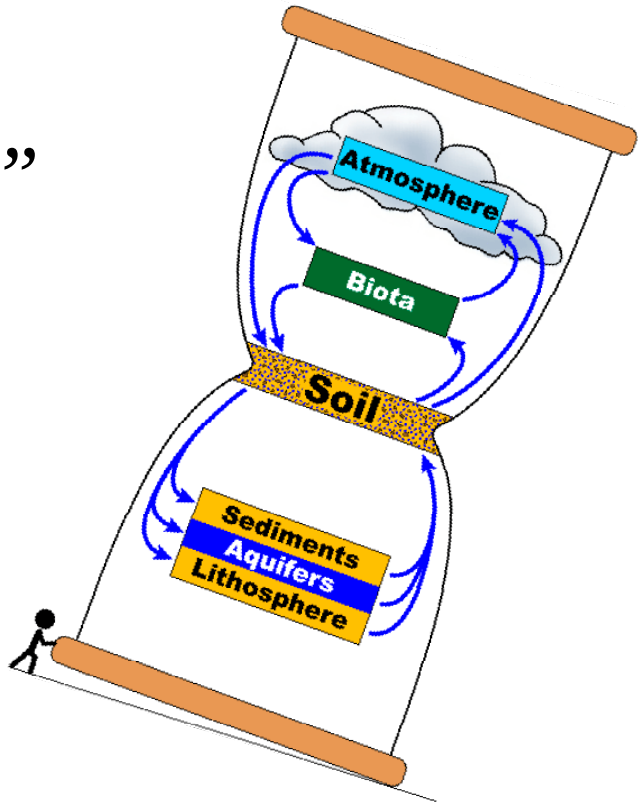
"a science that aims to consider the soil purely as a natural entity, with little regard for practical utilization" (eg, Lyons, Buckman, Brady, Weil, 8 editions, 1937-1990)

E.W. Hilgard (1860) asked "What is soil?" replied with unequivocal interest in "virgin soil" i.e., soil *not* influenced by Mississippi cotton planters

Yet in the 21st century, the Anthropocene makes inadequate the natural-body model

R. Dudal (2002): "Are we a soil-forming factor short?"

Like it or not, humanity needs "to become a fully fledged soil-forming factor," an integral part of soil genesis rather than only one who disrupts, upsets, or disturbs



the majority of contemporary soils are

- cultivated or managed for hay or pasture
- harvested for wood
- managed for residences, industries, transportation, restoration/reclamation
- flooded or drained
- burned or altered in fire regime
- chemically contaminated
- process waste streams
- altered by changing climate

Such anthro-pedogenesis was first described by Dan Yaalon in the 1960s

***Soil Science* (1966)**

FRAMEWORK FOR MAN-MADE SOIL CHANGES—AN OUTLINE OF METAPEDOGENESIS

DAN H. YAALON AND BRUNO YARON

On Facebook,
Dan Yaalon

Others: Bidwell, Hole, Yaron

"The anthro-soil model is as important to the development of pedology as was the natural-body model of Hilgard & Dokuchaev in the 19th c."

Dan Yaalon,
IUSS-Dokuchaev Prize
Winner 2010

Showers (2006)
Galbraith et al (2006)
Richter (2007)

Anthro-soil model

- Soil, a dynamic system affected by natural & human forcings, historical & contemporary
- Given this acceleration of Global Soil Change: *field experiments are needed to test soil behavior, resilience, thresholds, hysteresis, in response to human activities.*

Pedology today

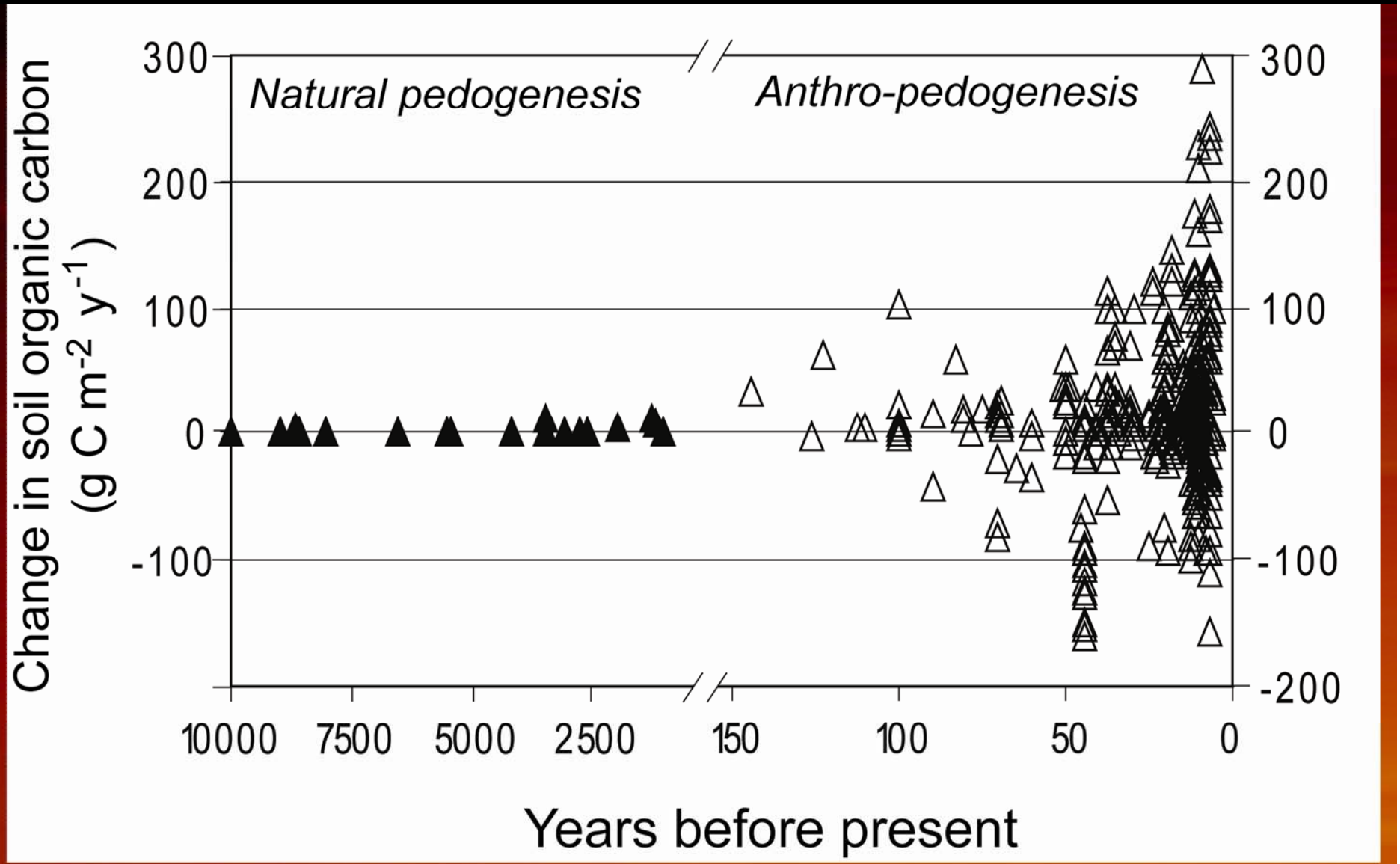
as much about slash & burn, wetland drainage, soil erosion, compaction, brownfield contamination, acid deposition, & sealing by macadam,

as about tree-throw, earthworms & termites, volcanic ash deposition, river flooding, or glacial ice.

Implications

- Soil as system and as concept now rapidly changing
- Given the diversity of human-soil relations, we have few observations of this accelerated soil change
- Much needed are LT field studies to test soil responses to a wide range of human activities.

On-going changes in soil carbon emphasize the importance of soil field studies



How to study soil change?

- Laboratory 10^{-2} to 10^{0} years
- LT field experiments 10^{0} to 10^{2} years
  (repeated soil surveys)
- Space for time 10^{1} to 10^{6} years
  (chronosequence)
- Models 10^{0} to 10^{6} years

Report on Experience of a Real-Time and On-line Inventory & Network of LTSEs

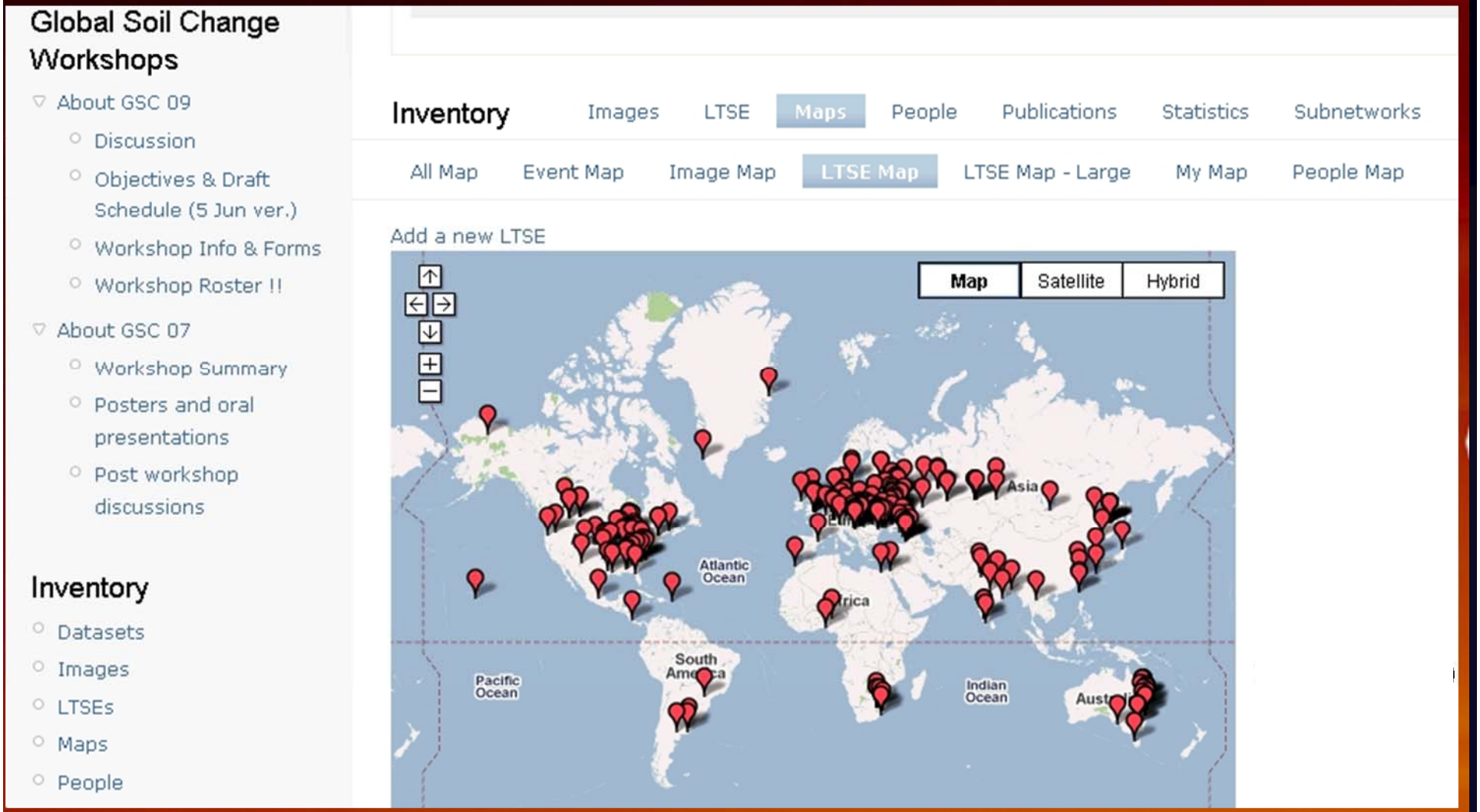
Ready conclusion:

LT field experimentation needs to expand & diversify

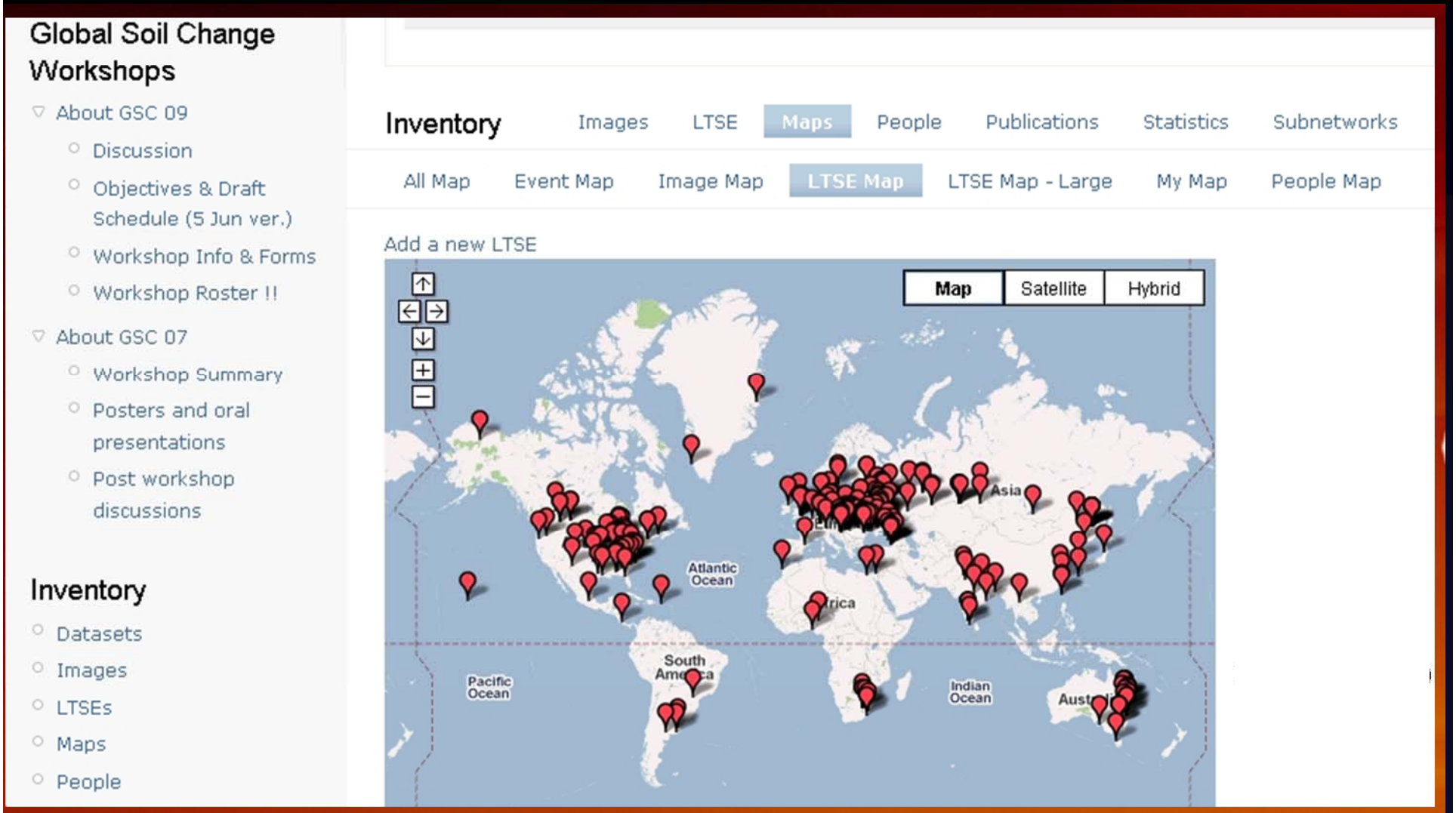
-- Google “LTSE” --

~ 300 soil experiments inventoried w/ metadata; LT

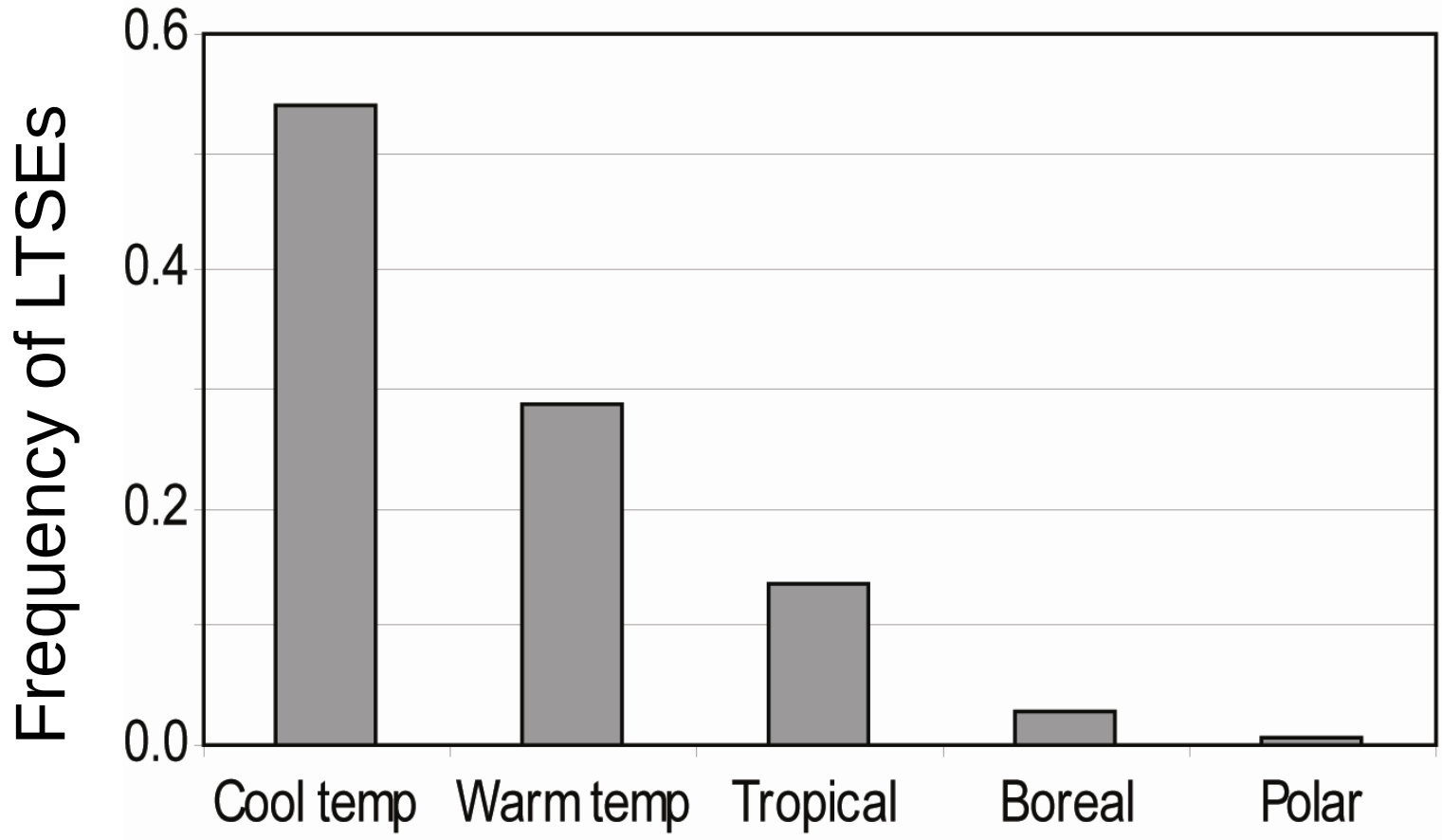
field studies on all continents



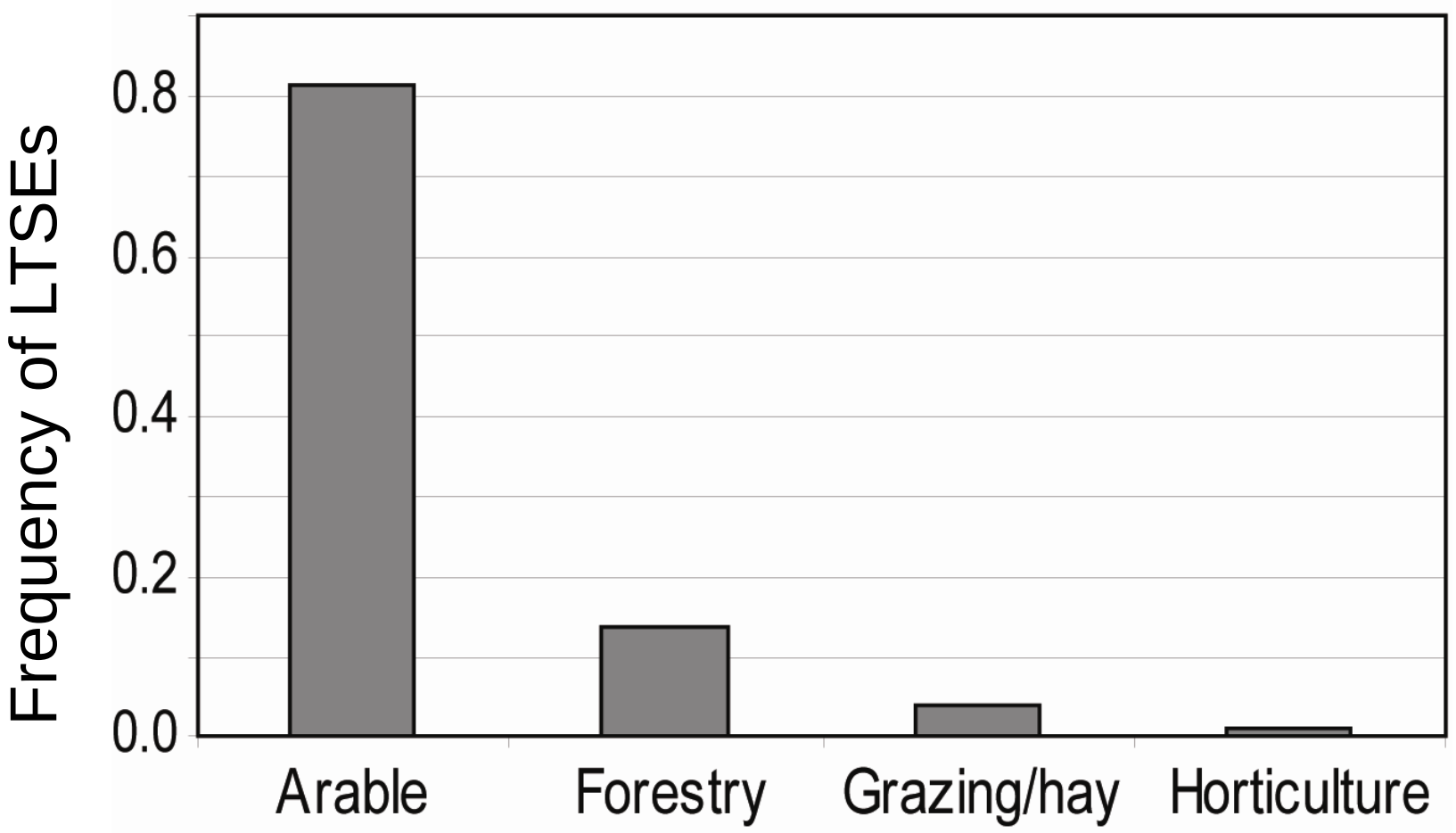
LTSEs, field experiments aimed at decades-long observation of soil change in response to management



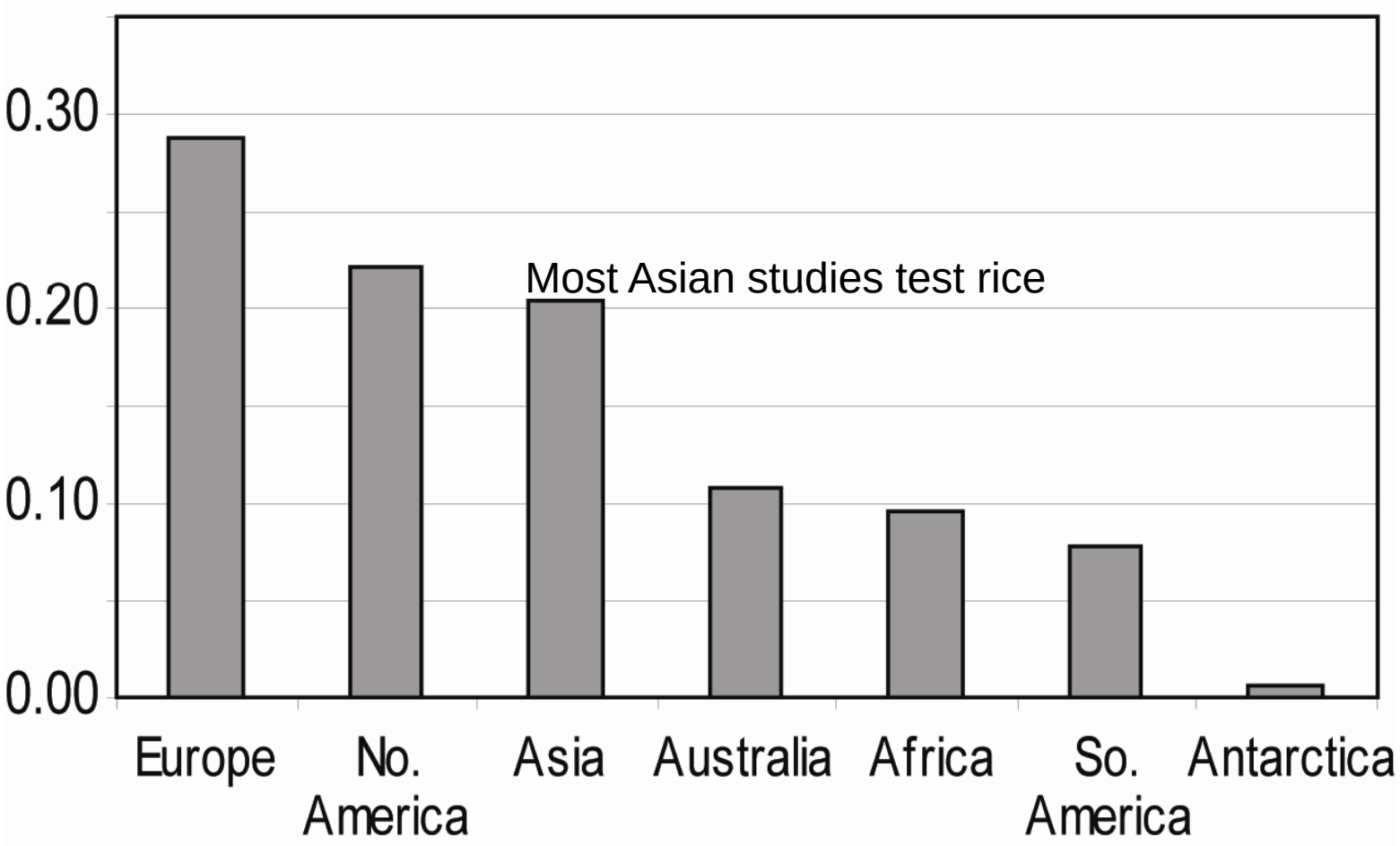
1) Most LTSE data are from the temperate zone



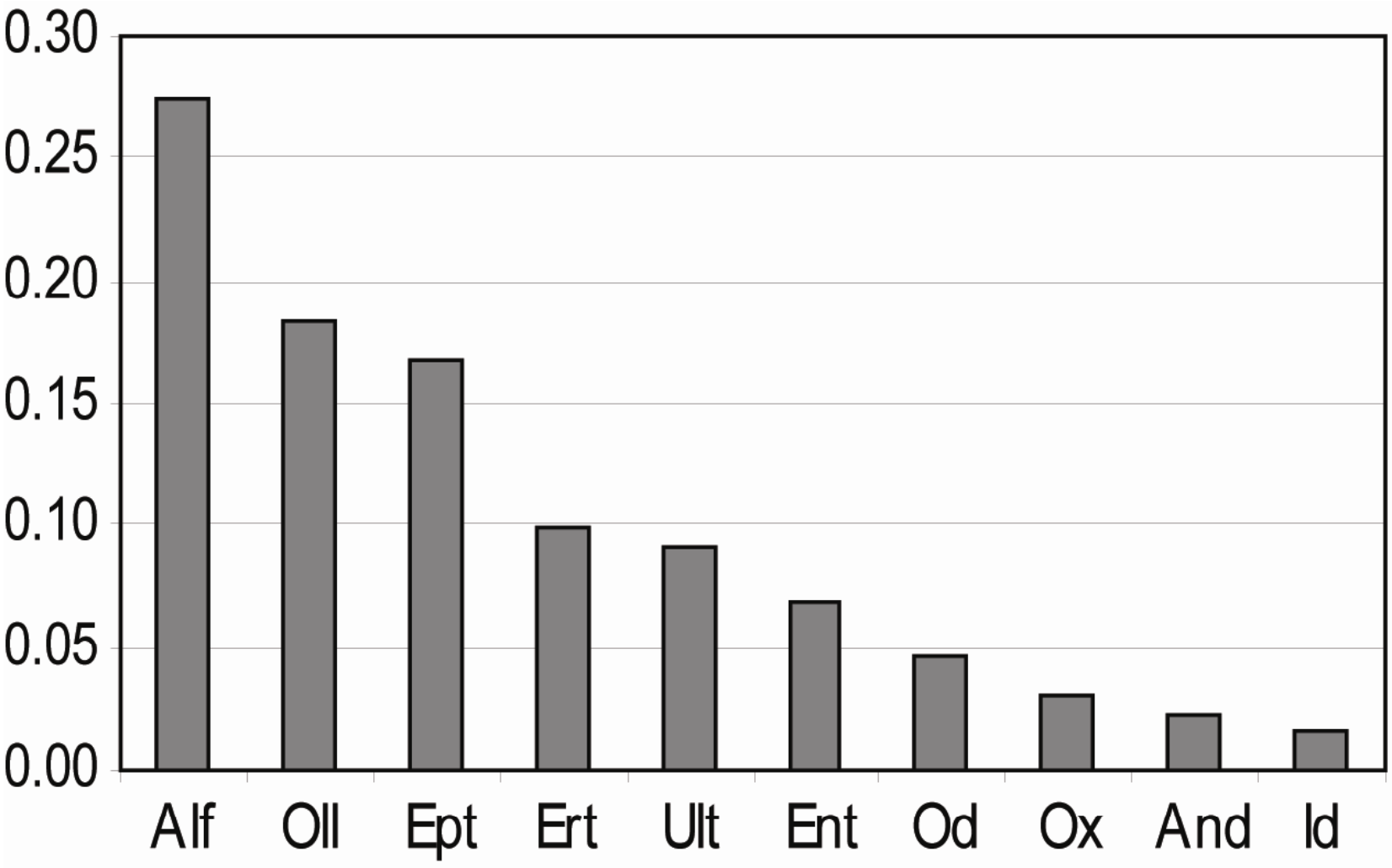
2) Nearly all LTSE data are from arable ecosystems



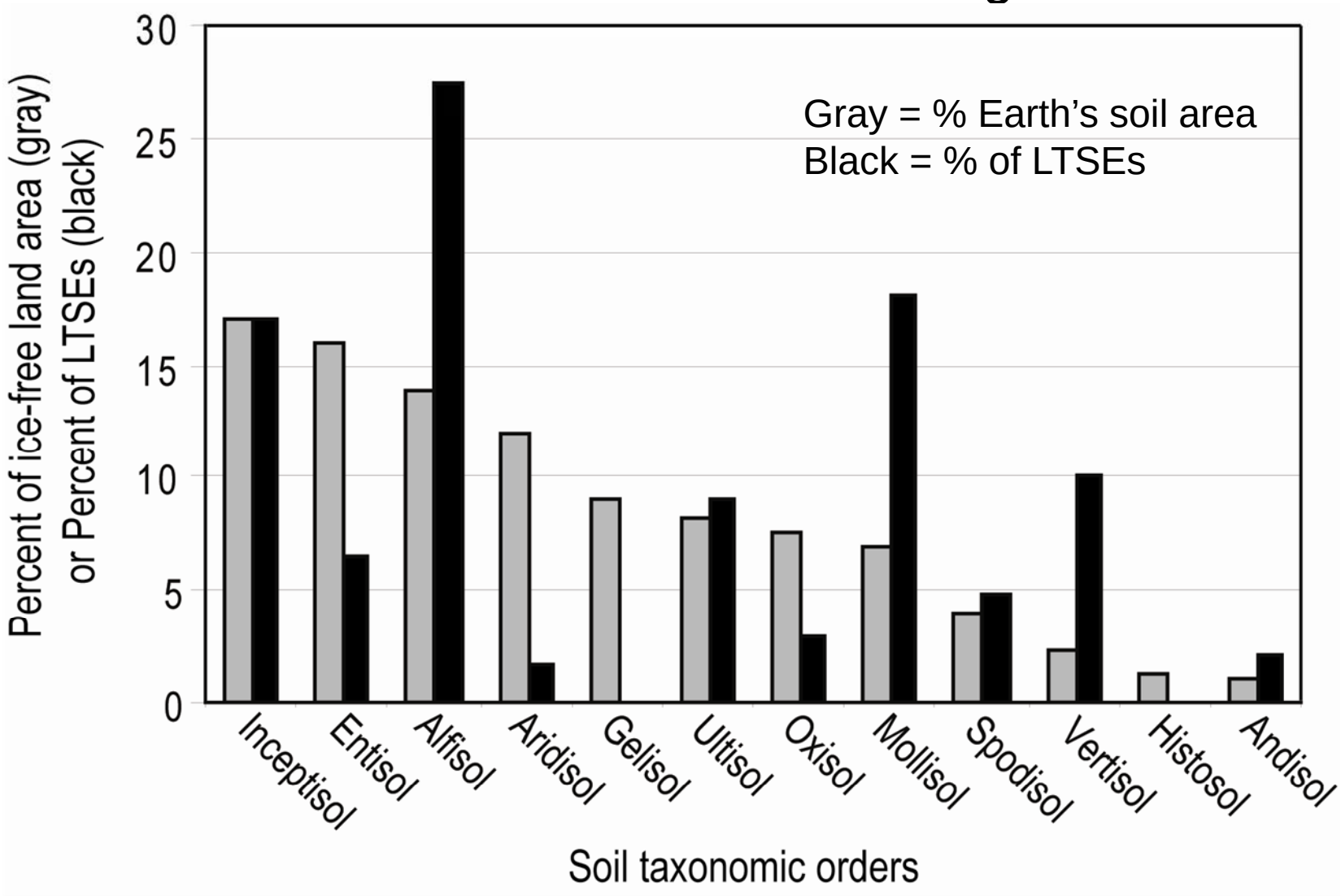
3) Most LTSE data are from developed nations, with the exception of SE Asian rice

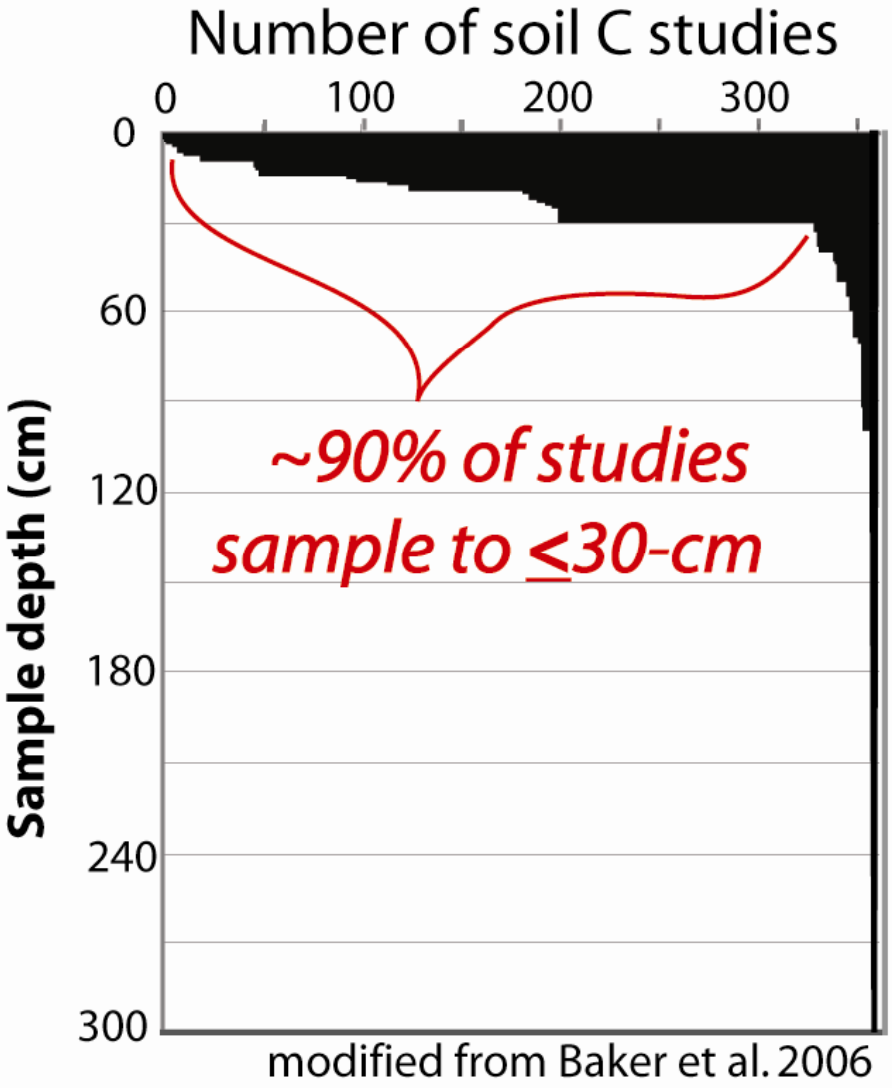


4) Most LTSE data are from Alfisols, Mollisols, Inceptisols;
few Oxisols, Aridisols, Histosols, & Gelisols



4) Distribution reflects priorities for intensive agriculture on Alfisols & Mollisols; raises questions about what we are not observing





Post and Kwon 2000, West and Post 2002

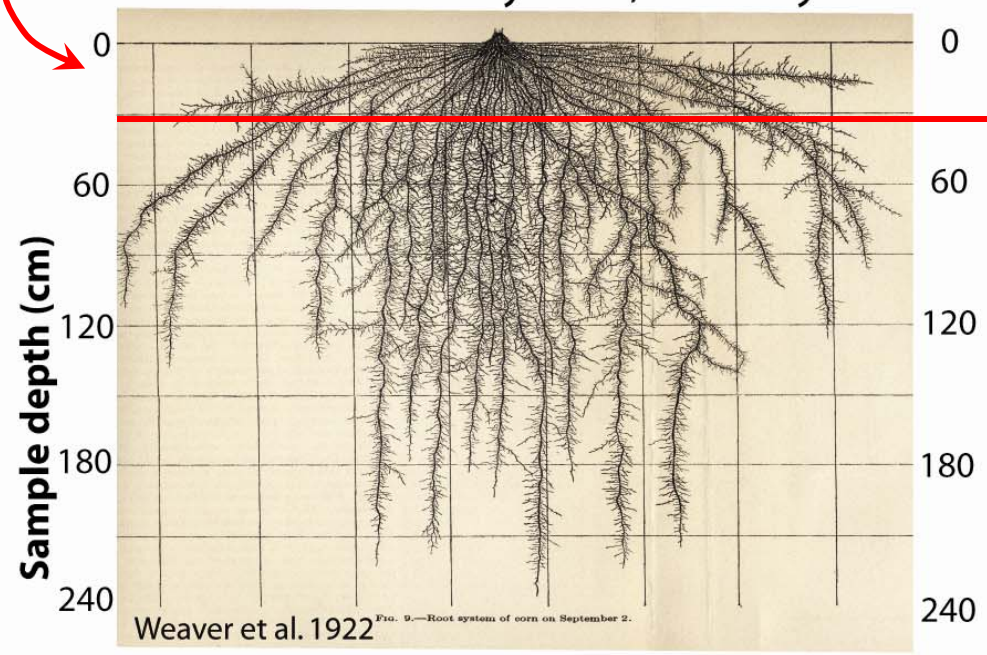
5) Soil-change data continue to be remarkably surficial

Metadata from 365 carbon-change studies in the Post reviews

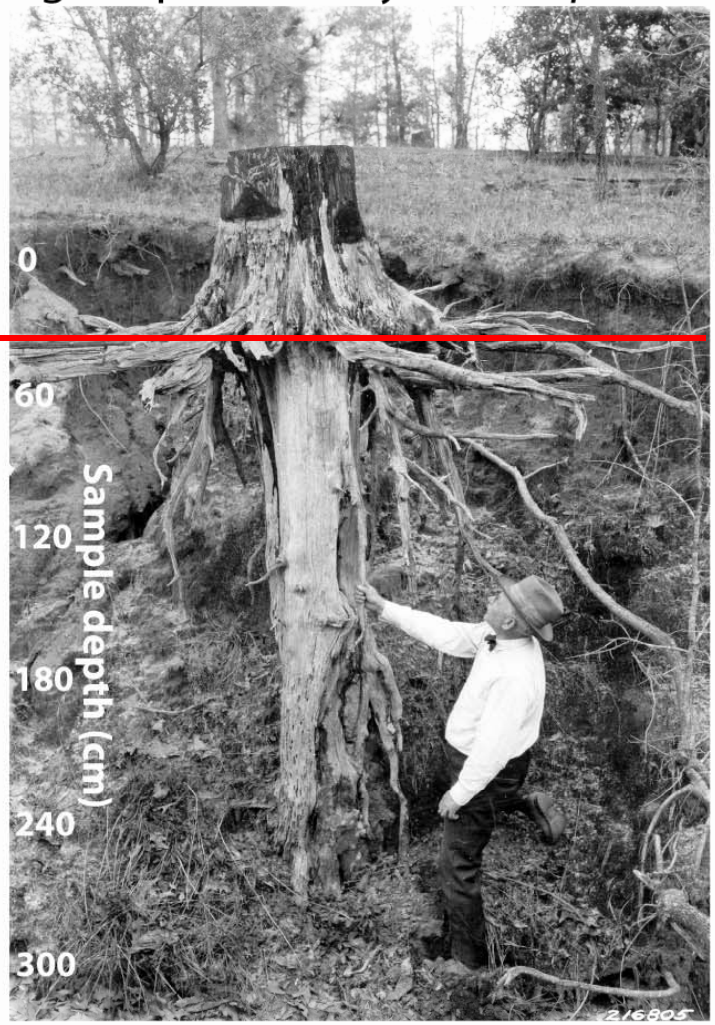
5) Superficial sampling, despite knowing well that plants root deeply

90% of SOC data from upper 30 cm

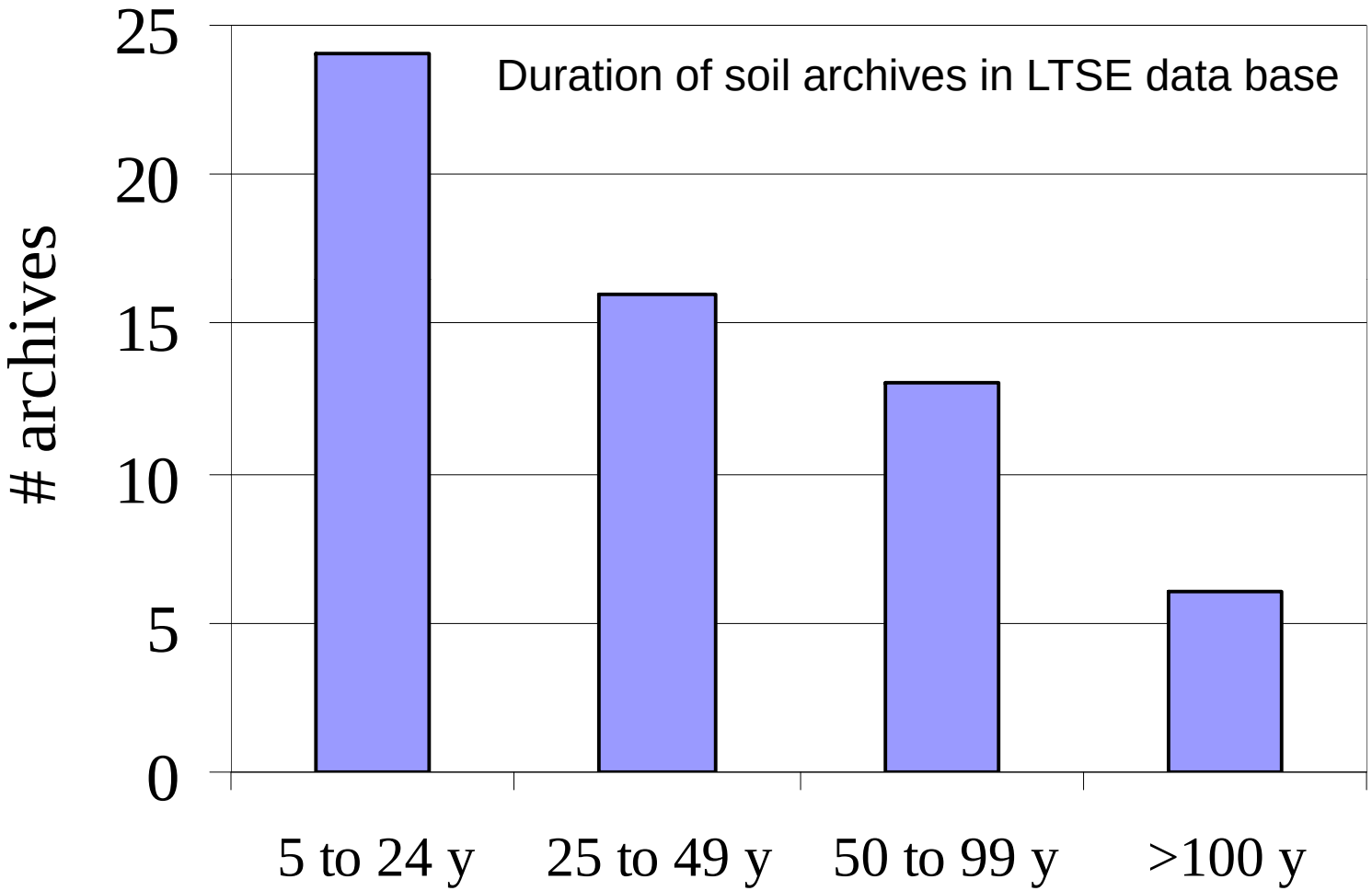
Corn root system, *Zea mays*



Longleaf pine root system, *P. palustris*



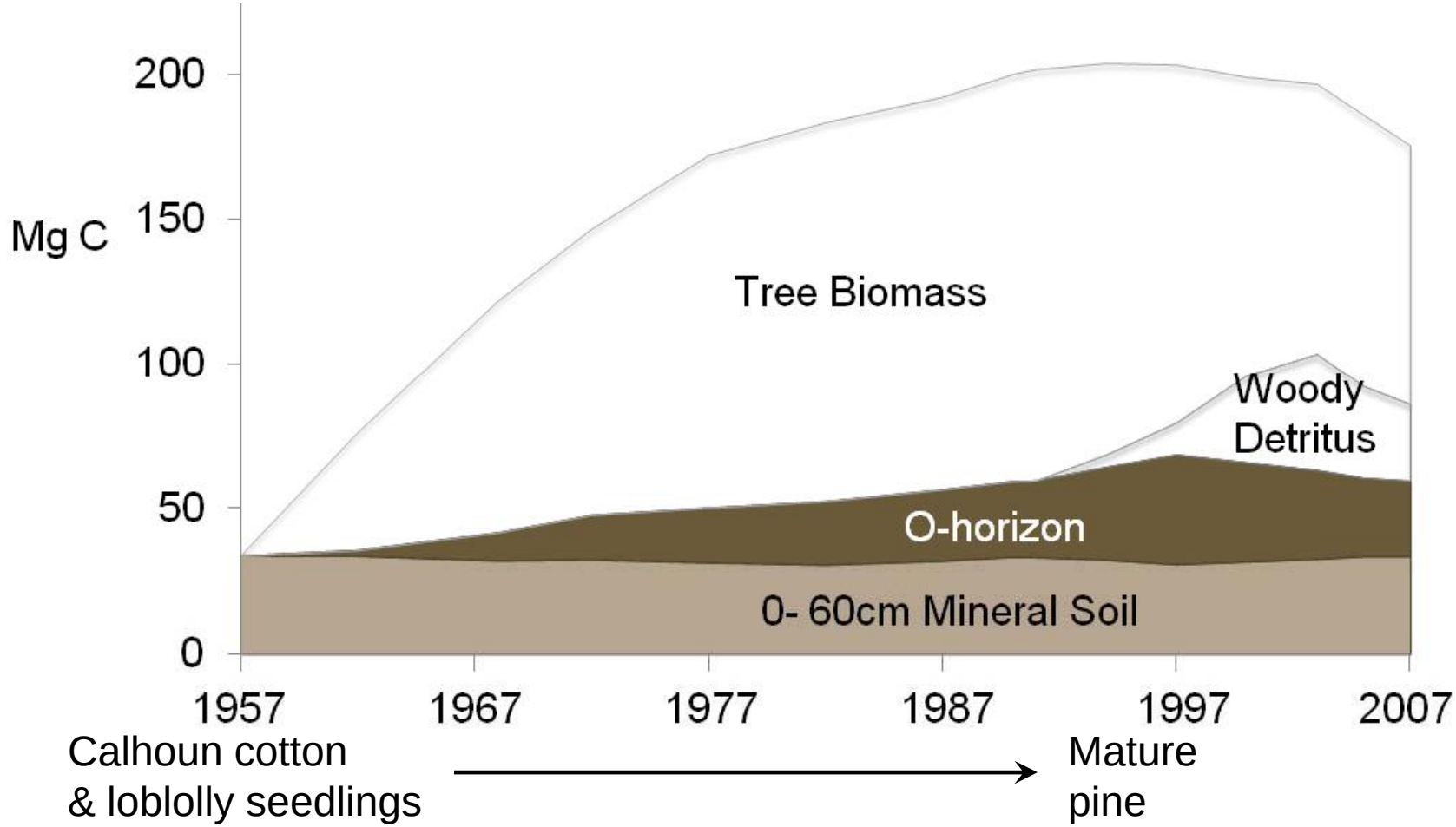
6) Soil archives greatly enrich long-term field experiments



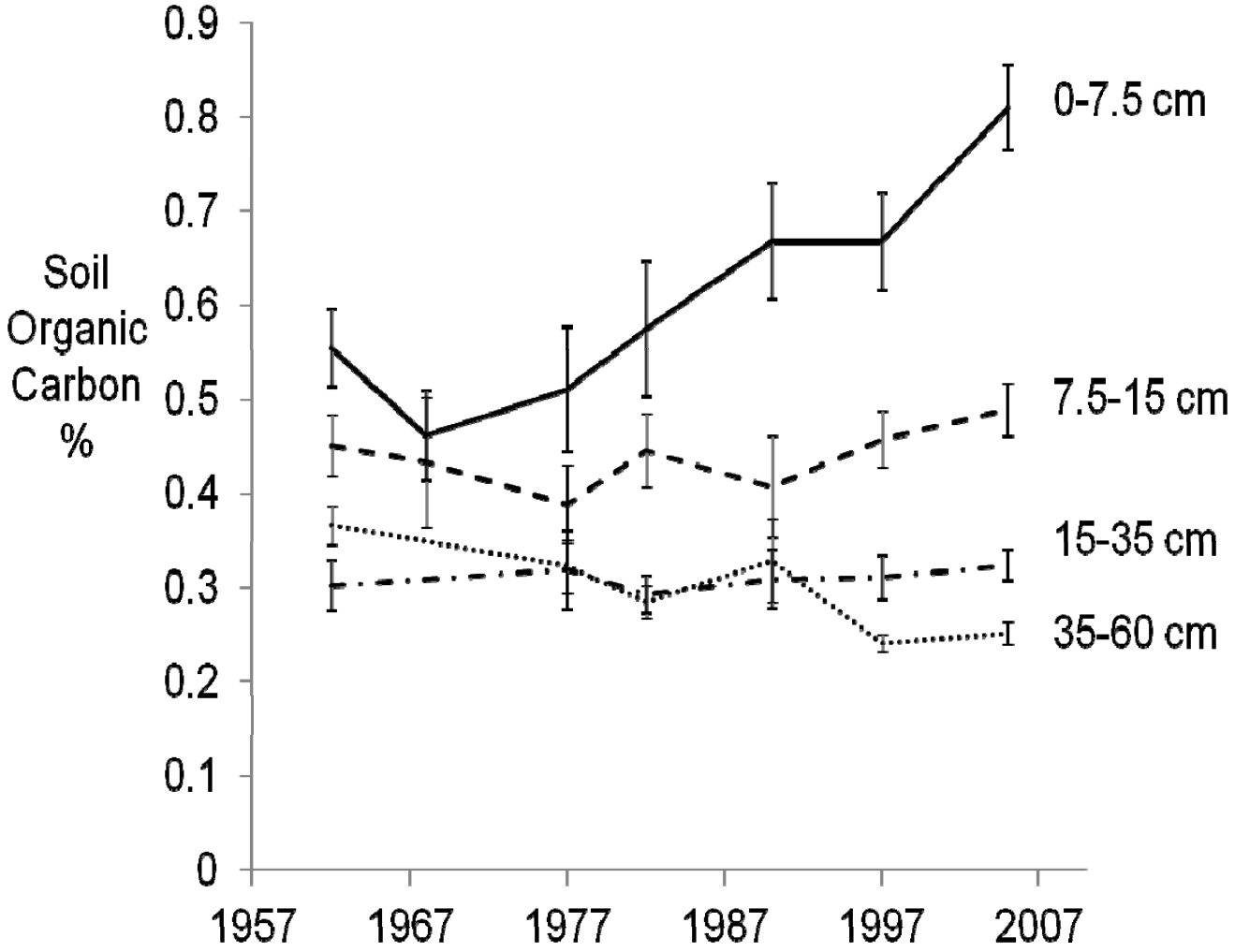
Calhoun Case Study, one LTSE

16 0.1-ha plots in old cotton fields. Mineral soils resampled with 20 punch tubes per plot (four depths to 60-cm)

-- Google “Calhoun LTSE” --



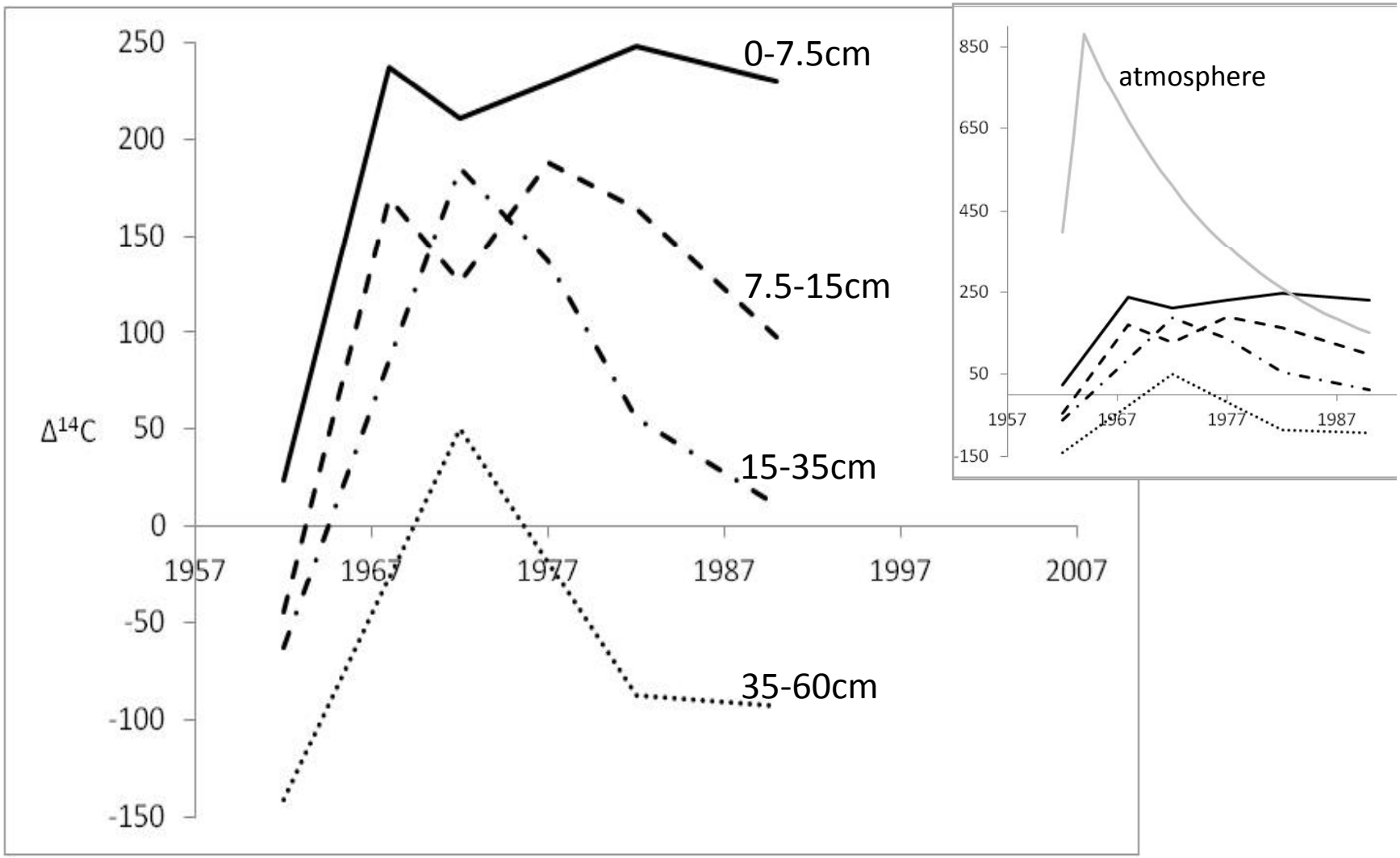
Strong depth-dependent changes in soil carbon during secondary forest growth



Calhoun cotton & loblolly seedlings → Mature pine

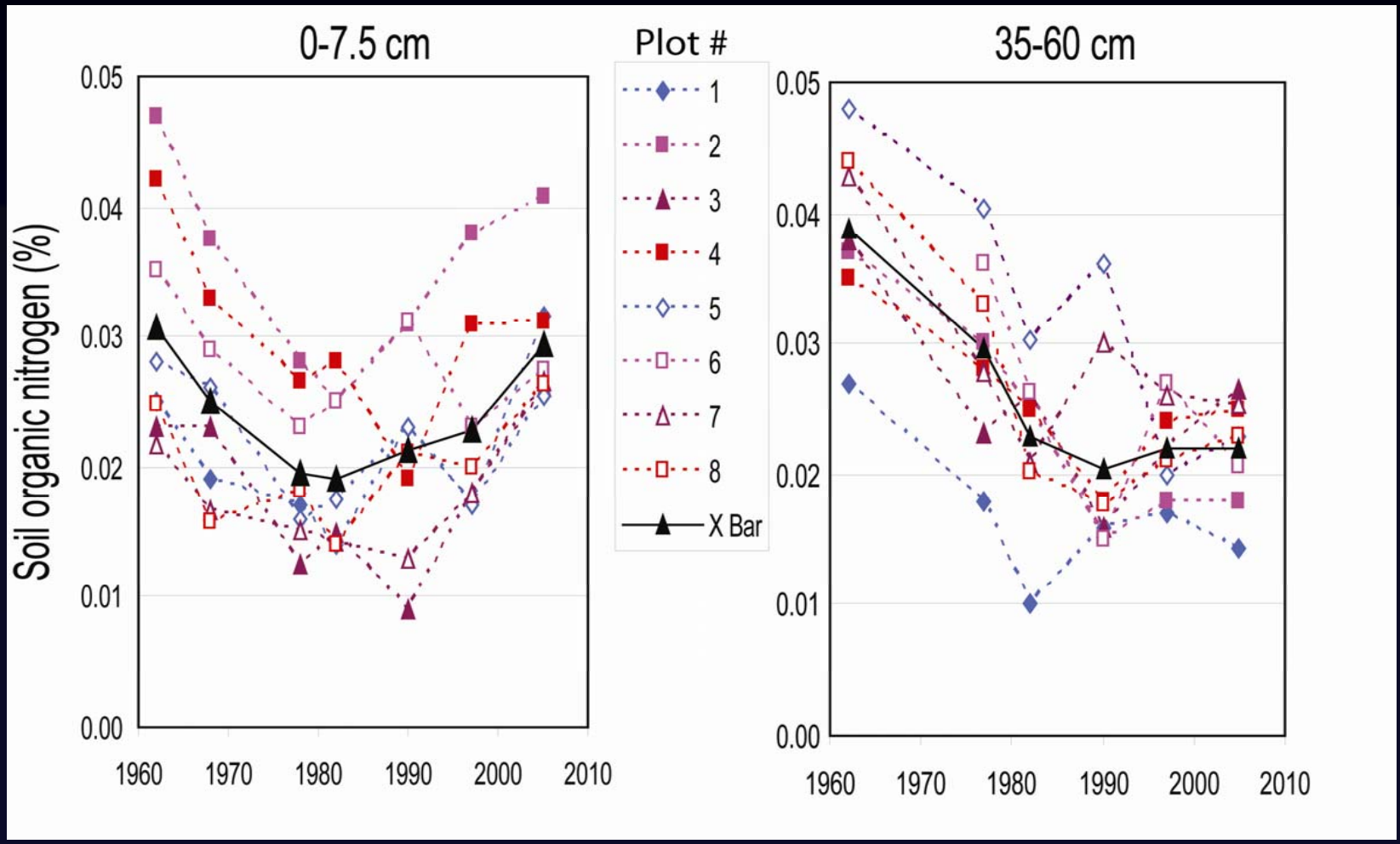
from Mobley and Richter, in process

Large ^{14}C enrichment indicates rapid turnover of fresh organic matter throughout 60-cm profile

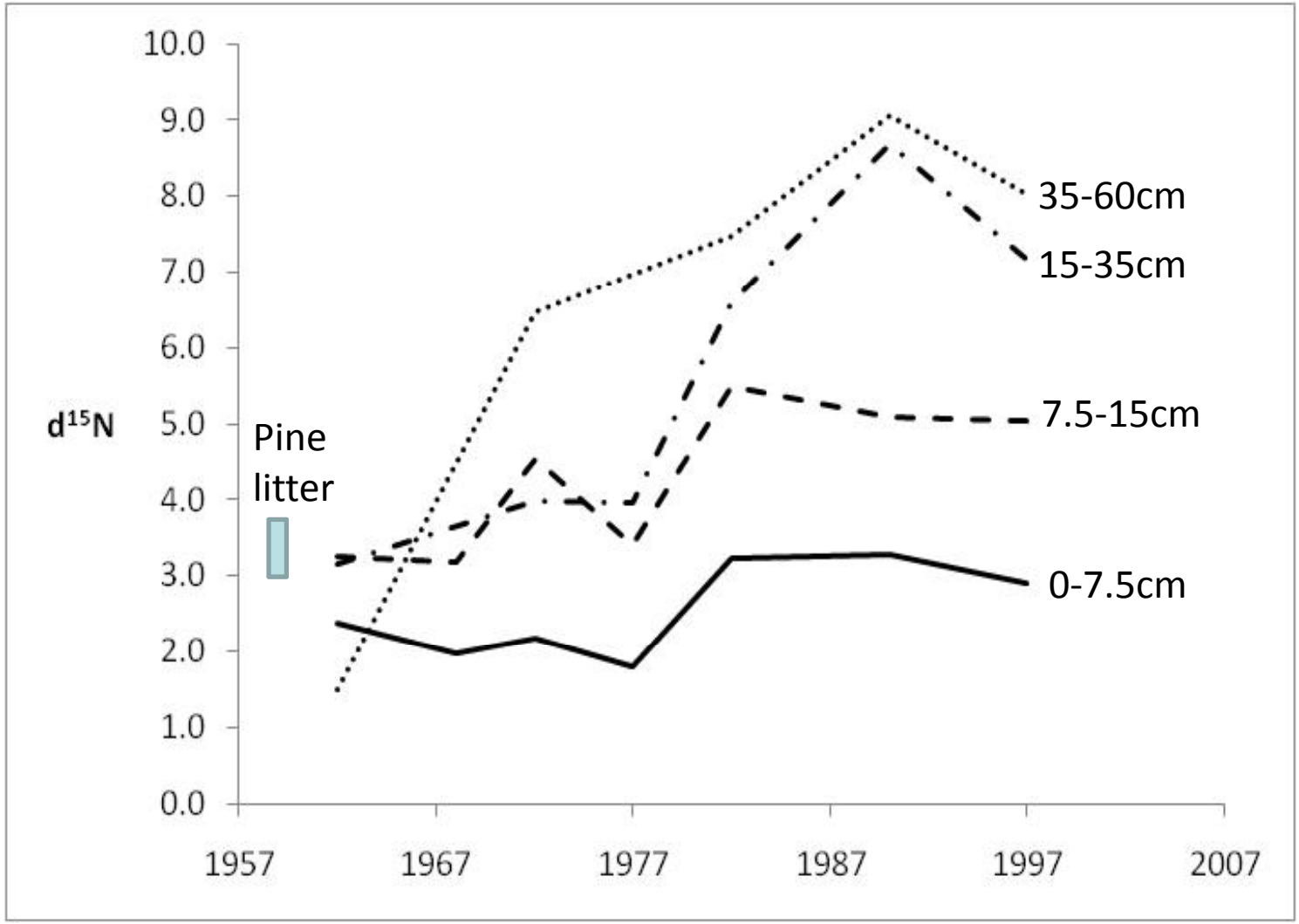


from Richter et al. 1999 *Nature*

Mineral soil N depletion -- Initially a mining operation; Note the story of adequate within-plot sampling

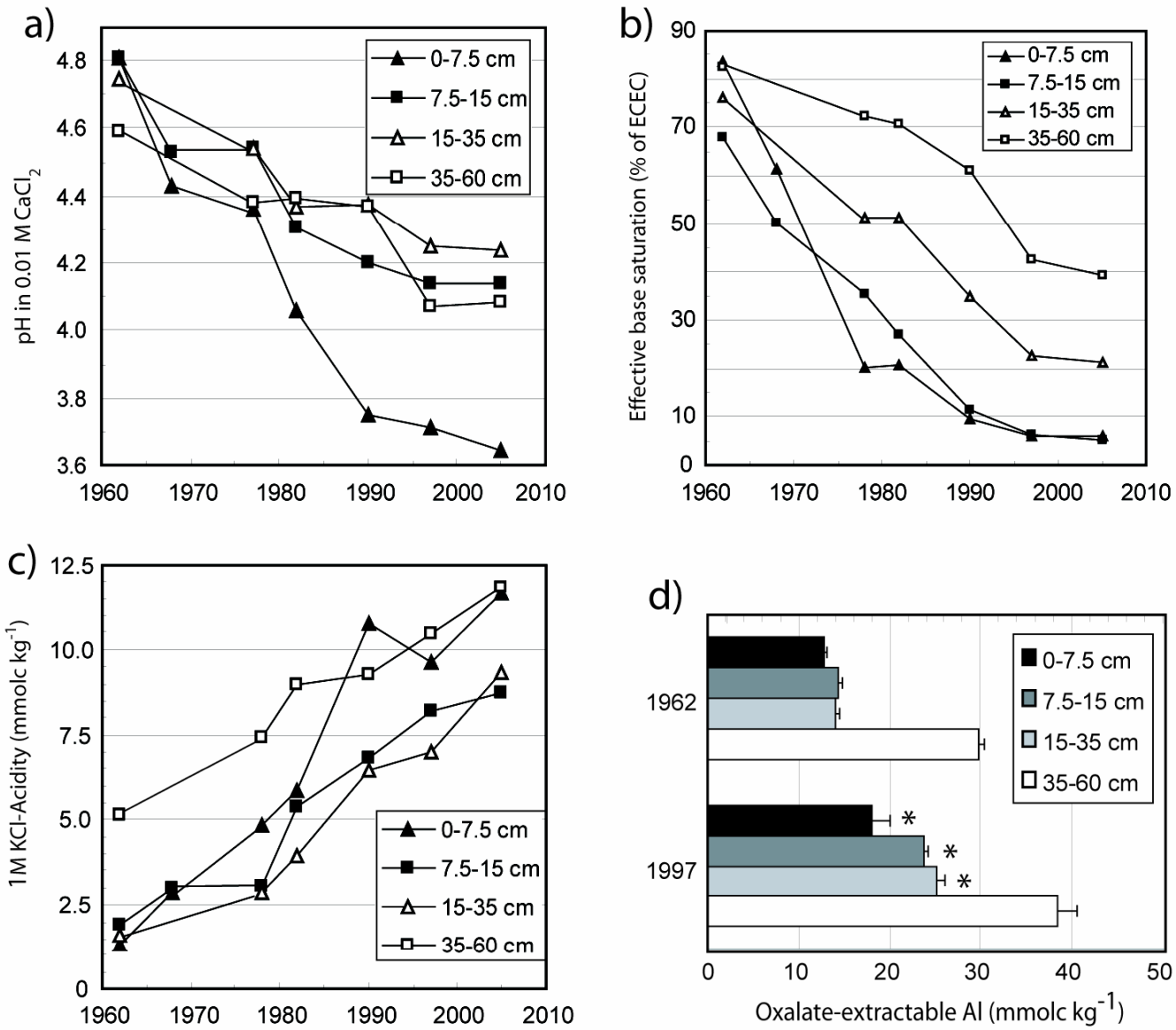


Depth-dependent ^{15}N progressively enrichment with deep N "mining" & surficial recycling



from Billings and Richter 2006 *Glob. Change Biol.*

Calhoun's invaluable record of soil acidification



from Richter 2006 et al. *Oecologia*

Much to learn from LTSEs, from individual soils to global scale

Too little data about soil changes at depth, >30-cm

Soil-change observations mainly from agro-ecosystems

Observations skewed to developed nations

Far too few LT field experiments in:

- the boreal zone & tropics;
- forest, grass, wetland systems;
- the urban-suburban ecosystem there is nothing;
- any land uses in developing nations;
- Oxisols, Histosols, & Gelisols

We have but an elementary understanding of soils

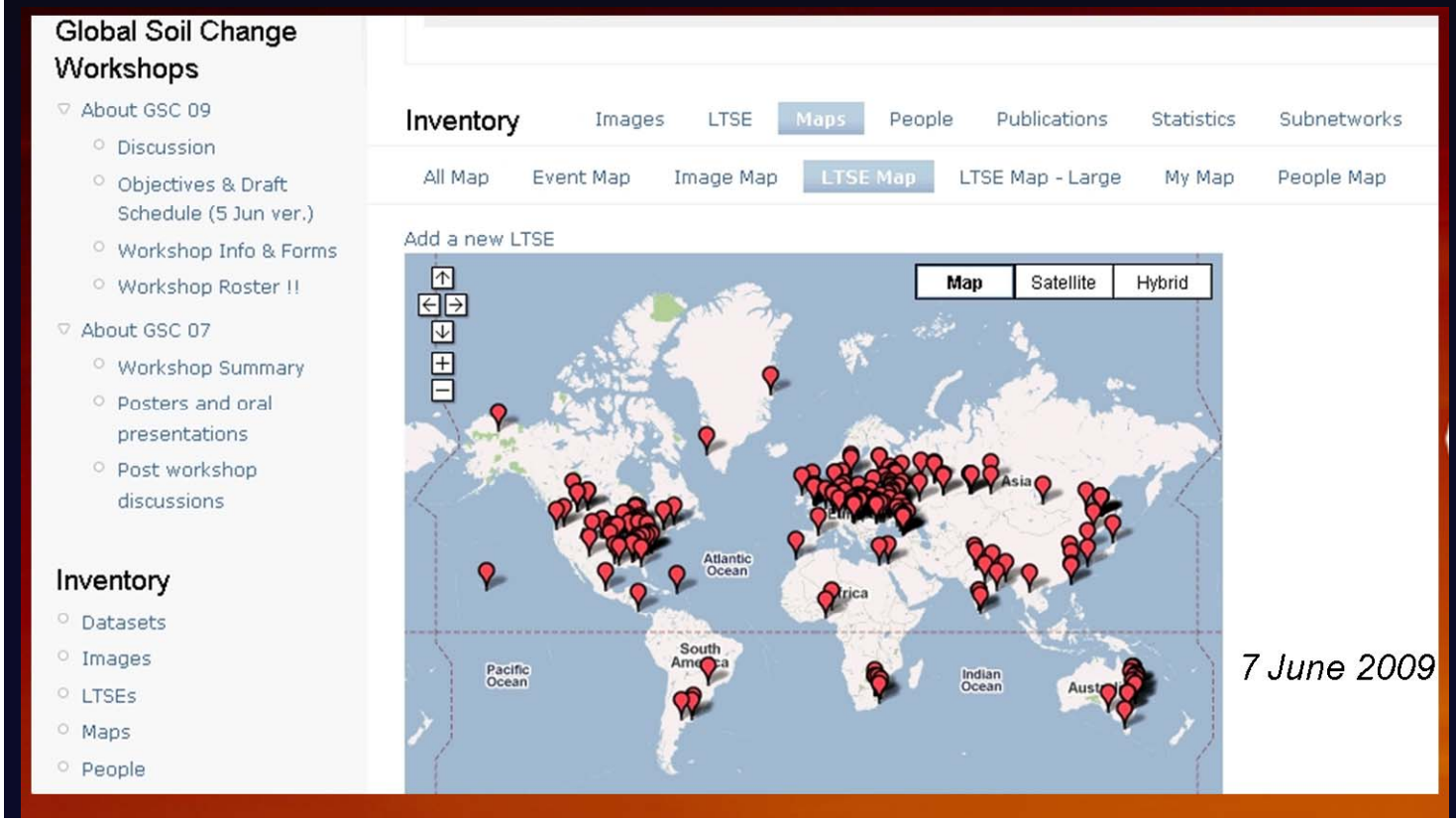
given what is required in the next few decades

End on a note that soil change figures prominently in society's most important scientific questions

- Can humanity double or triple food & fiber production in a few decades, all while minimizing adverse effects on the wider environment?
- Can we estimate & manage land-use effects on the global C cycle?
- Can we improve soil management of nutrients, toxics, wastes, & water?

For more information on the international networking project of LTSEs,

google "LTSEs"



“Years teach much that days never know.”
R.W. Emerson, *Experience*

The rapid & unprecidented global soil change indicates clearly that

- The world's invaluable long-term soil experiments (LTSEs that provide periodic observations of soils over decades time scales) are seriously deficient
- A new global inventory of LTSEs with meta-data needs continued attention but is on-line & with nearly 300 research sites.

Richter et al. (2007)
Richter & Billings (2009)

The Changing Model of Soil

Natural-body soil science → Anthro-soil science sits among the natural & social sciences, the humanities, & the environment

sits among the natural sciences & agriculture

Pedology - *basic* science of how soil forms in nature

- *VS* -

Edaphology - *applied* science of how soil grows crops

Brady's dichotomy repeated in eight editions of Soil Properties 1937 to 1990

Today, pedology needs to embrace human influence in a re-birth of a science that can be called anthro-pedogenesis