Long-term Perspectives on Anthropogenic Soil Change From Ancient Agriculture

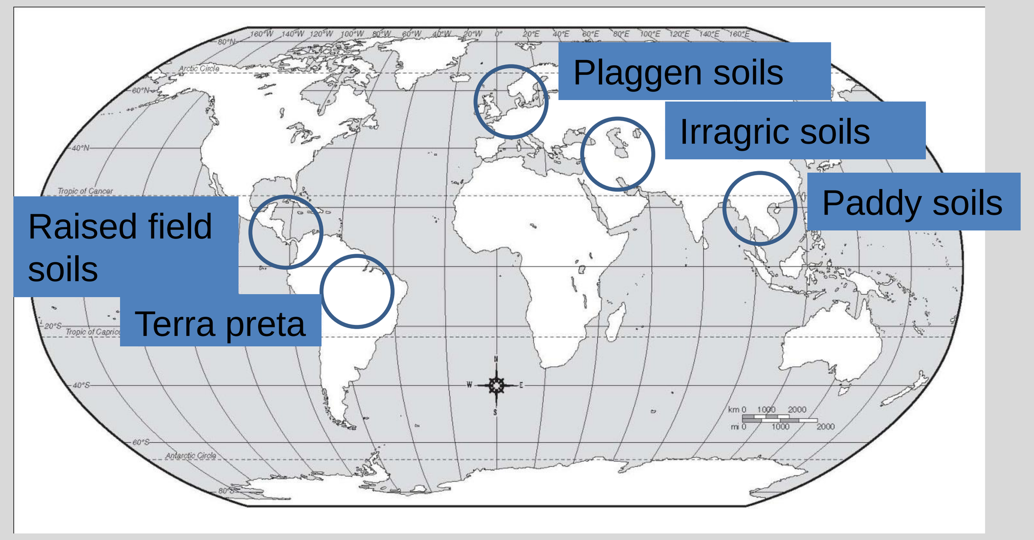
Iowa State University
Department of Agronomy

Jonathan Sandor, Iowa State Univ., and Jeffrey Homburg, Statistical Research, Inc.

Introduction

Among agents of anthropogenic soil change, agriculture's impact on soil is immense in magnitude, spatial extent, and duration. Agriculture has profoundly altered soil properties, processes, and formation pathways world-wide since its inception about 10 millennia ago. Much knowledge about recent agricultural soil change at scales of years to a century has been gained through monitoring long-term experiments and observational studies. However, far less is known about agricultural soil change at scales of centuries to millennia. Deep time perspectives on soil change can help predict long-term effects of agriculture on land resources and to test for sustainability. Information on soil change in longer time frames can be obtained by studying ancient agricultural soils, even though data are more limited than those from modern agricultural soils. Ancient agricultural sites in archaeological and contemporary traditional contexts in the Americas and other regions are presented to illustrate the wide range of soil change in relation to complex, interacting factors such as kind of agricultural system, time scale, and environmental setting and resilience. Soil changes detected in ancient fields are interpreted as a gradient from degradation to enhancement in the context of agricultural productivity and land resource conservation.

Objective: To increase awareness of the potential wealth of information about long-term soil change available from ancient agricultural soils.



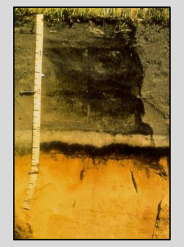
Methods (General approach and comments)

• Inferring soil change is primarily based on a space-for-time substitution method in which ancient cultivated soils are compared with nearby uncultivated reference soils in similar geomorphic and pedogenic settings.

• Soils are palimpsests, bearing imprints of environmental change and multiple land use in the many years between ancient agriculture and present observations. Because soils are dynamic, reference soils do not represent the original soils, but rather what cultivated soils would be like now had they not been farmed.

Major Ancient Anthropogenic Agricultural Soils

Soil	Oldest Age/Main Age (Yr BP)	Geographic Location (major)	Pedogenic Features/ Processes	Relevance to Soil Change & Quality Issues
Plaggen	3000/Middle Ages	Northern Europe	Thick epipedon from long-term manuring and other additions	Soil organic matter (SOM) management Fertility Soil structure
Terra preta (Amazonian Dark earth - ADE)	2500/1000	Amazonia	Dark soil from charcoal and other added organic materials	SOM mngmt. Biol. activity C sequestr. Bioenergy
Terraced soils	6000/ 1000-4000	5 continents & Oceania	Thickened A horizons from construction & sedimentation	Soil thickening Water management
Paddy soils (wet rice production)	6000/2000	SE Asia	Anthraquic, hydraquic features	Wet soil / redox proc. Water mngmt
Raised Field soils	3000-1500/1000	Central & S. America	Soil buildup in ridges on wetlands	Drainage Wet soil proc.
Irragric soils	5000 Mesopotamia / 3000 Central Asia	Middle East Central Asia	Accum. sediment from long-term irrigation	Texture SOM mngmt. Salt, sed. management



Oxisol ADE

Major Forms of Degradation in Ancient Agricultural Soils

Soil Degrad. Process	Oldest Age (Yr BP)	Geographic Location (major)	Pedogenic Features/Processes
Accelerated erosion (water, wind, colluvial) and deposition	9000 New Guinea 5000 Mesopotamia , Mediterranean, Europe 3500 Americas	Widespread in mountainous to hilly landscapes on 5 continents	Degradation/loss of surface horizons with loss of soil cover and other landscape change. Counterpart is excessive sedimentation.
Organic matter and nutrient loss	5000 Europe 1000 Americas	Widespread in semiarid to humid regions	Organic matter oxidation, crop removal of nutrients < inputs, vegetation change
Compaction/ structural degradation	5000 Europe 1000 Americas	Widespread	Structure/pore change, increase bulk density from tillage, SOM loss
Acidification/ podzolization	4000	Northwestern Europe	Forest clearing for agriculture, followed by climate-vegetation change and altered soil formation
Salinity, sodium accum.	4400 4000	Mesopotamia Central Asia	Accumulation of salt, Na (high SAR, ESP) through irrigation, insufficient drainage, rising groundwater
"Laterization"	?	S, SE Asia Equatorial Africa, S. America	Primarily exposure of pre-existing indurated plinthic material by accelerated erosion; also possible hardening of exposed plinthite with agriculture

Soil Change in Ancient Agriculture by Outcome Documented Examples

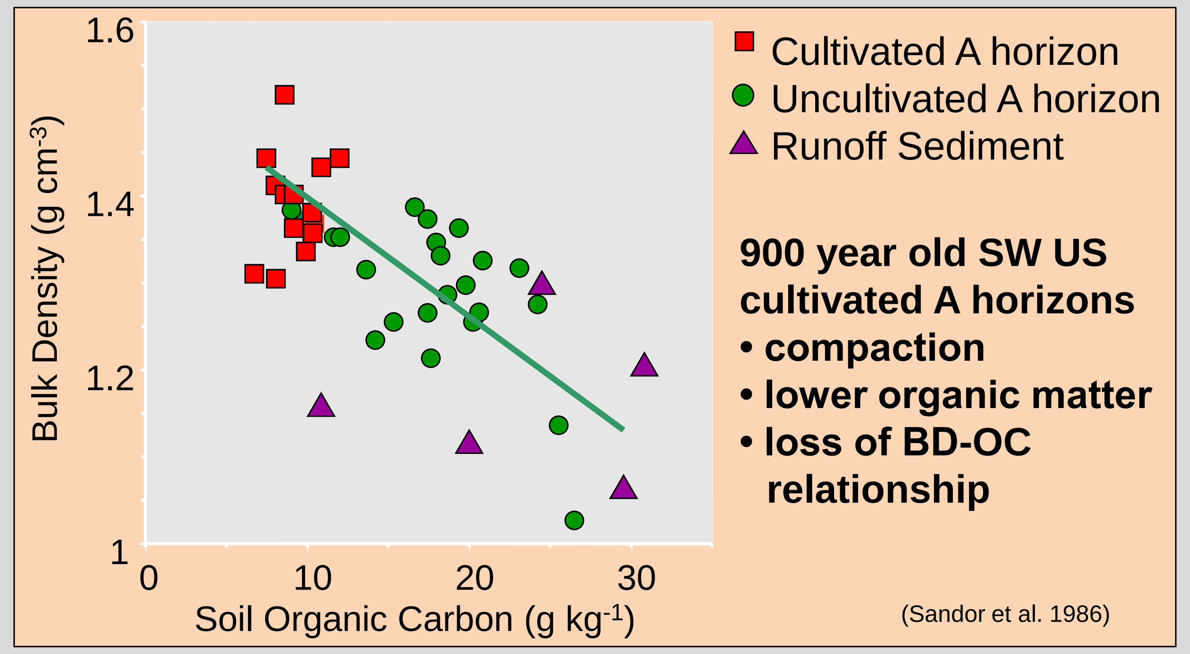
Positive Soil Change (enhanced productivity; soil resource protection and sustainability)
Soil Landscape and Ecosystem: e.g., agricultural terraces can stabilize slopes and protect against accelerated water erosion.
Physical/Morphology: thickened A horizons, increased available water content & capacity, decreased bulk density, structure stability, improved pore properties
Chemistry: organic C, N, P increase or replenishment; pH optima for nutrient availability; examples of increase in other macro and micro nutrients; increased CEC, base saturation; decreased salinity.
Biology: increased microbial activity, biomass, and diversity, C mineralization, soil enzyme activity, vesicular arbuscular mycorrhizae, nitrogen fixation.
Causes and Factors:
Geomorphic/ecosystem processes: decreased slope angle and length. Runoff sedimentation; post-agricultural native vegetation patterns.
Management: terracing, runoff/sediment capture, irrigation, drainage, conservation tillage, additions of organic matter, manure, and other fertilizing and physical amendments.

Negative Soil Change (soil degradation; unsustainable land use)
Soil Landscape and Ecosystem: accelerated erosion-surface removal and incision; wind deflation; excessive sedimentation; loss of grass and other native species; decreased vegetation cover. For agroecosystems: maize nutrient deficiency, decreased growth.
Physical/Morphology: A horizon erosion, soil structure degradation and compaction, soil crusting, hardening/cementation.
Chemistry and Biology: decreased organic carbon, total and available nitrogen, phosphorus, and other nutrients; acidification; high pH, salinity and sodium increase, ferrolysis, iron cementation.
Causes and Factors:
Geomorphic/ecosystem processes: accelerated water erosion, slope instability, wind erosion on soil cleared of vegetation and rock fragments.
Management problems: vegetation clearing; intensive cultivation, tillage; nutrient removal by crops, irrigation problems (inadequate drainage, use of saline, sodium-rich irrigation water).

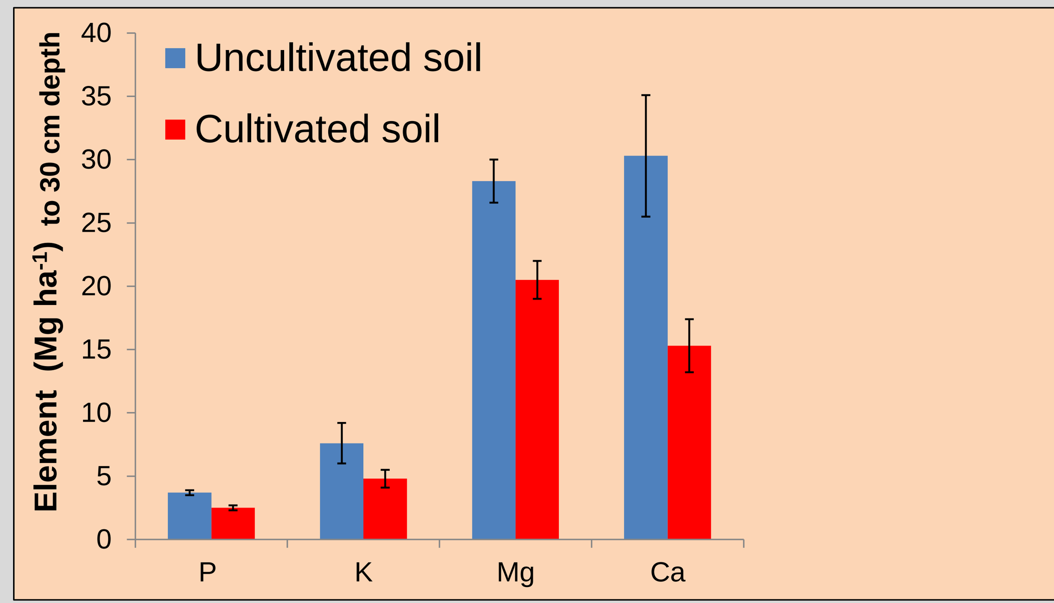
Intermediate (~ no net soil change; insignificant change; offsetting, mixed, inconclusive or contradictory change; recovery from degradation or reversion from enhancement).
Soil Landscape and Ecosystem: fields showing neither enhancement or degradation; subtle field features; ecosystem changes.
Physical/Morphology: no or insignificant change in bulk density (i.e., no compaction or not enough to be detrimental to crops), buried horizons, clay-silt-SOM translocation.
Chemistry and Biology: no or contradictory or insignificant change in organic carbon, soil nutrients, and pH. Little definitive data on salt or sodium accumulation in soils resulting from irrigation agriculture.
Causes and Factors:
Geomorphic/ecosystem processes: not significantly impacted over long-term.
Management: sufficient maintenance of soil quality; soil conservation.

Ancient Agricultural Soil Data by Outcome

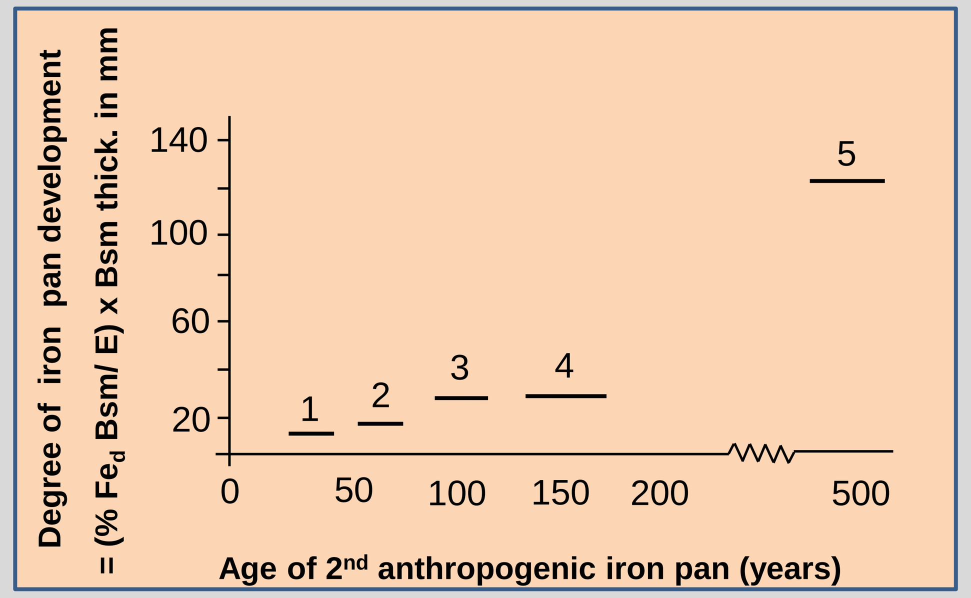
Soil Degradation



Nutrient loss – prehistoric (~ 500 years) Hawaii (Hartshorn et al. 2006).

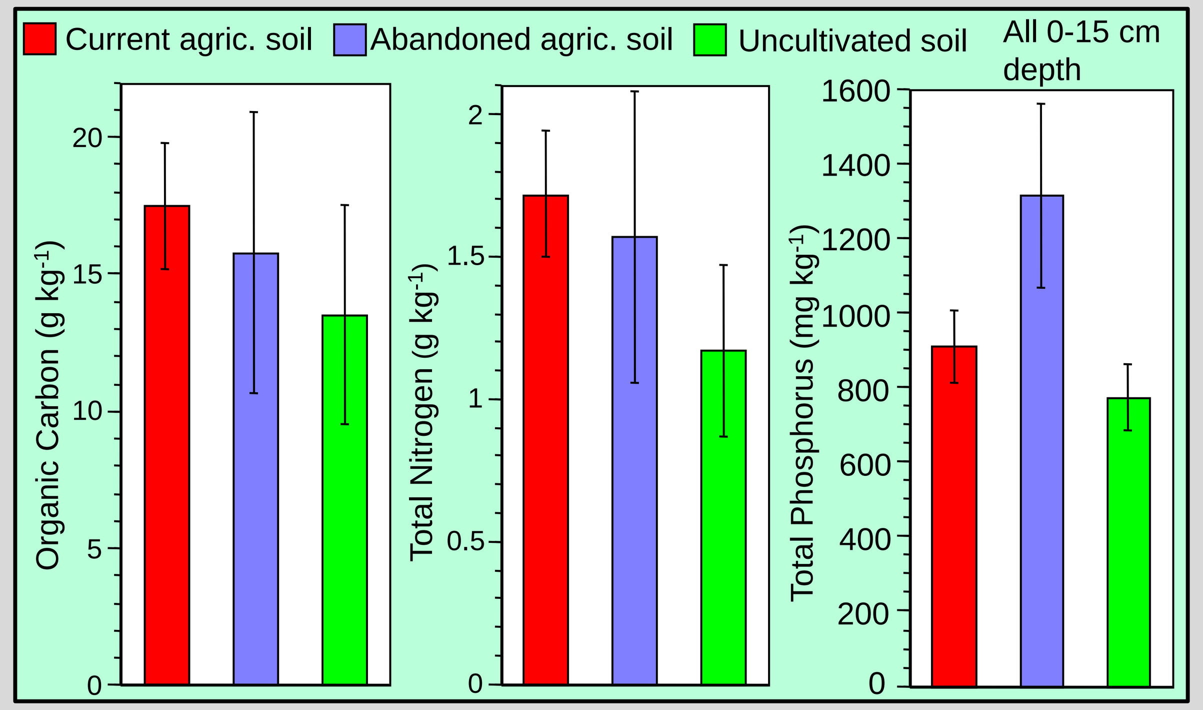


Podzolization-acidification in anthropogenic soil chronosequence (~ 500 years) Ireland (Cunningham et al. 2001).

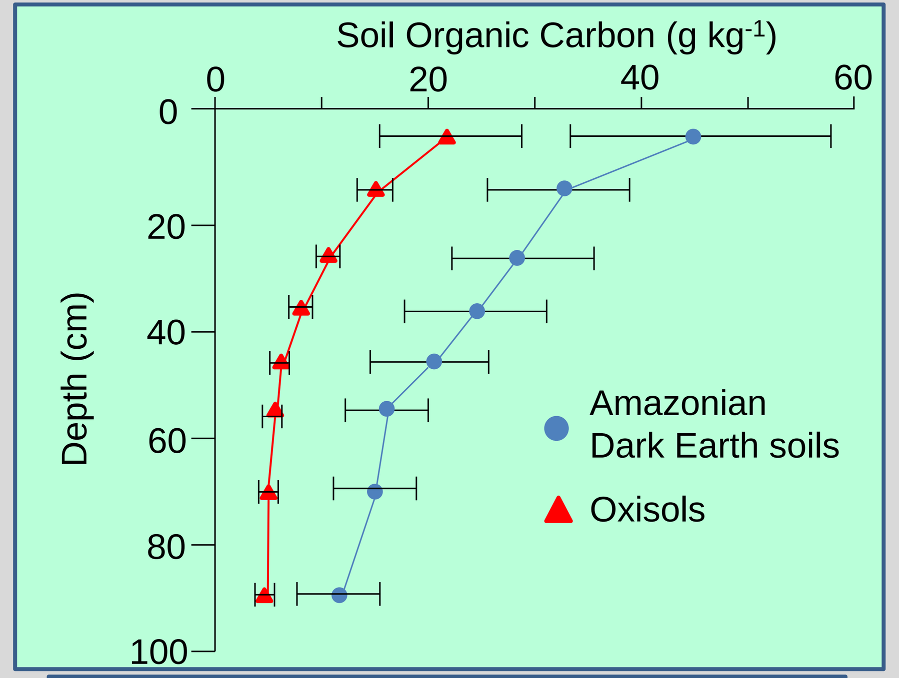


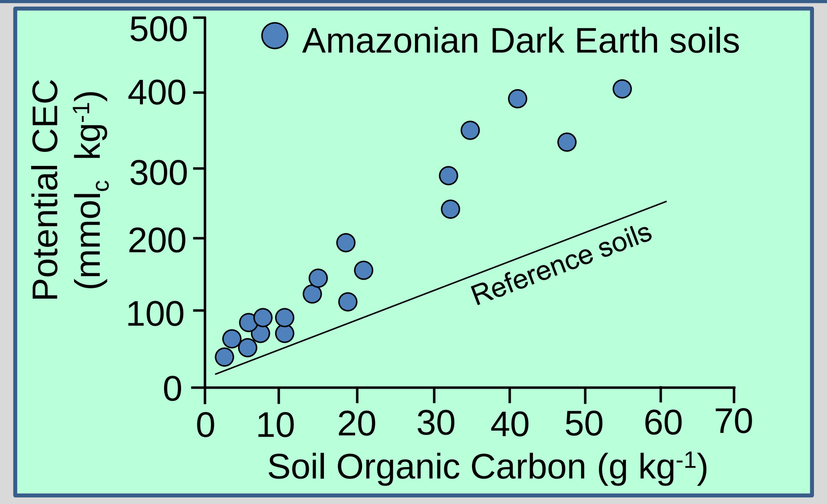
Soil Enhancement

Increased organic matter and fertility in ancient (15+ centuries) terraced soils in Peru (Sandor and Eash, 1995)



Increased organic matter and cation exchange capacity in Amazonian Dark Earth soils (Lehmann et al., 2003)





Conclusions

• Ancient agricultural soils are important sources of long-term information about soil change and related current agricultural challenges involving soil quality and conservation, water resources, climate change, and sustainability.
• More research on ancient agricultural soils is needed because of the relative scarcity of quantitative soil studies, methodological limitations, the complexity of agricultural systems and soils, and imprints of multiple land use and environmental change.

References (a few examples)
Beach, T. et al. 2009. A review of human and natural changes in Maya Lowland wetlands over the Holocene. Quat. Sci. Rev. 28:1710-1724.
Bell, M. and J. Boardman (ed.). 1992. Past and present soil erosion: archaeological and geographical perspectives. Oxbow Monograph 22, UK.
Blume, H. P. and P. Leinweber. 2004. Plaggen soils: landscape history, properties, and classification. J. Plant Nutr. and Soil Sci. 167: 319-327.
Cunningham, D. et al. 2001. Anthropogenically-triggered iron pan formation in some Irish soils over various time spans. Catena 43 167-176.
Gong, Z.-T. 1983. Pedogenesis of paddy soil and its significance in soil classification. Soil Sci. 135:5-10.
Hartshorn, A. et al. 2006. Prehistoric agricultural depletion of soil nutrients in Hawai'i.PNAS103:11092-97.
Kostyuchenko, V. and G. Lisitsyna. 1976. Genetic characteristics of ancient irrig soils. Sov. Soil Sci.8:9-18.
Lehmann, J. et al. 2003. Amazonian Dark Earths: origin, properties, management. Kluwer, Dordrecht.
Richter, D. Jr. and D. Markewitz. 2001. Understanding soil change: soil sustainability over millennia, centuries, and decades. Cambridge Univ. Press, N.Y.
Sandor, J. et al. 2005. Factors of soil formation: human impacts. p. 520-532. In D. Hillel (ed.) Encyc. soils in the environment. Elsevier, Oxford.
Sandor J. 2006. Ancient agricultural terraces and soils. p. 505-534. In B. Warkentin (ed.) Footprints in the soil: people and ideas in soil history. Elsevier, Amsterdam.
Tugel, A. et al. 2005. Soil change, soil survey, and natural resources decision making: a blueprint for action. Soil Sci. Soc. Am. J. 69:738-747.