Whole-profile soil carbon change after 25 years along an agricultural management gradient

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Introduction

The accumulation of soil organic carbon (SOC) is critical to ecosystem function, and in agricultural systems changes in field management can exert great influence and strongly affect soil carbon and its effects on a system's net global warming impact. Quantifying the impact of different cropping systems on SOC by measuring changes in the soil carbon pool can only be done in long-term experimental settings with decadal measurements.

We examined SOC change over 25 years in different management systems at the W. K. Kellogg Biological Station Long-term Ecological Research site (KBS-LTER) in southwest Michigan, USA. Managed systems included four annual cropping systems (corn-soybean-wheat manage differently), three perennial crops (alfalfa, hybrid poplar, and coniferous trees), and four unmanaged systems in different stages of ecological succession.

Highlights

- Soil organic carbon increased significantly in the 2001-2013 period only in the top soil layers of the Mid-successional and Deciduous forest systems. Gains in the Deciduous forest were offset by losses in deeper layers (**Fig. 1a**).
- Significant SOC gains in managed agricultural systems, relative to the Conventional agriculture system occurred in the upper layers of the No-till (0-10cm), Reduced input with cover crop (0-10cm), Biologically based with cover crop (0-10, 10-25cm), Hybrid poplar (0-10cm), Alfalfa (0-10, 10-25 cm) systems (**Fig. 2a**).
- Only the Early successional system showed significant SOC gain for the whole 1m profile (**Figs. 1a, 2a**), reflecting the strongest rates of gain in upper soil layers (**Fig. 2b**).
- Higher rates of SOC accumulation were found consistently in the Early successional and Mid-successional systems, followed by the Hybrid poplar and Alfalfa systems (**Fig. 2b**). Annual cropping systems that gained SOC (cover-cropped and no-till) at 0-25cm depth accumulated less SOC than the perennial systems.

Acknowledgements

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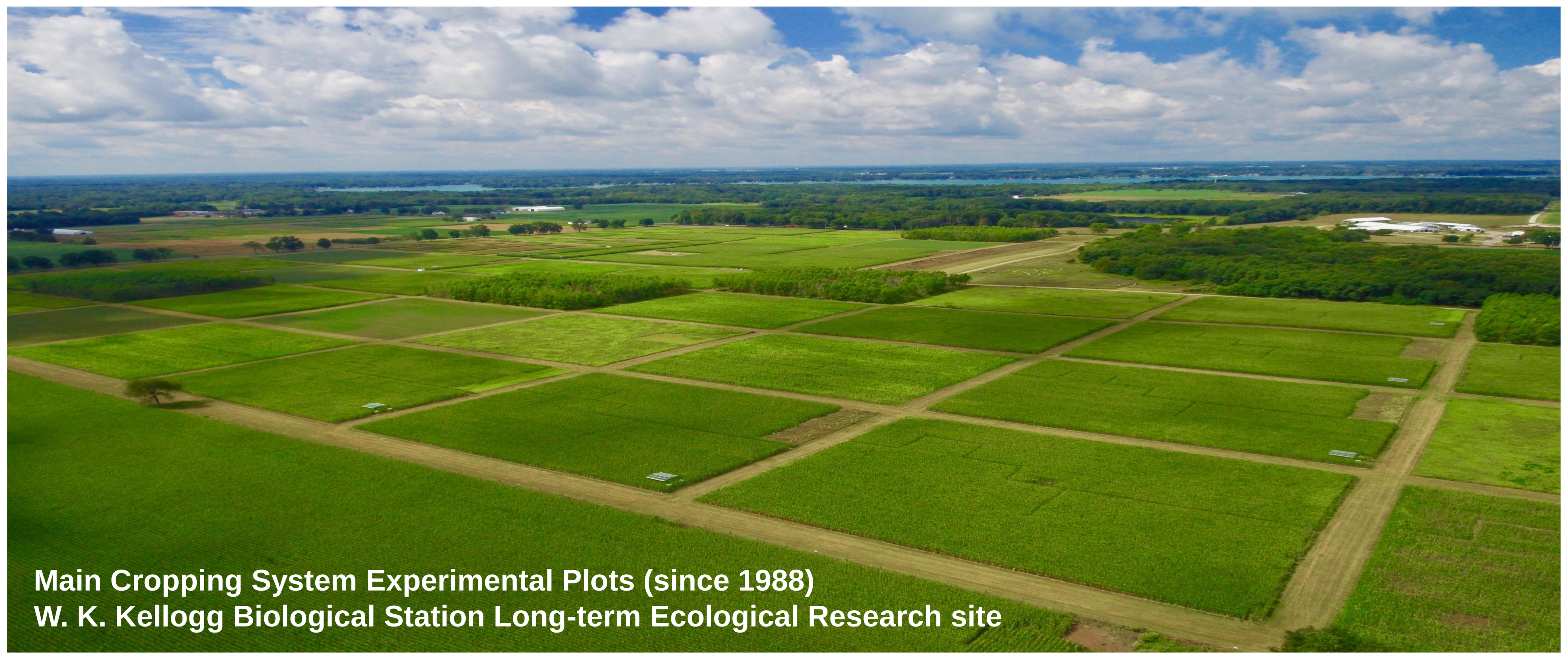

Absolute gain in SOC

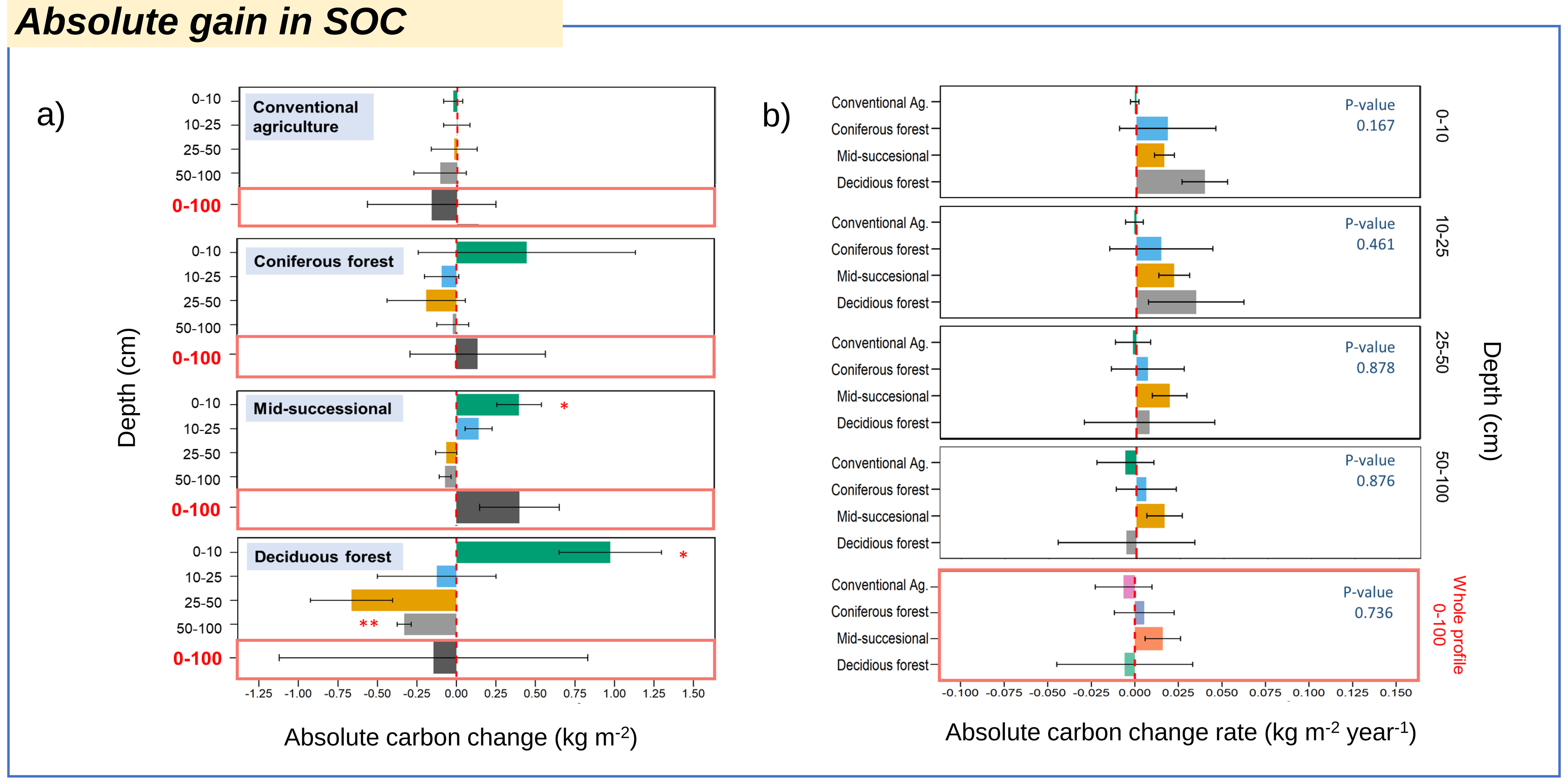

Figure 1. Absolute SOC gain and rates of SOC change measured in four systems up to 1 meter depth. Data are averages (n= 3-6 plots± sd) of 1 ha plot size, and each had 5 sampling stations measured in 2001 and 2013. Statistical analysis compared differences from zero (panel a; asterisks indicate significant differences, p-value <0.1 "*", and p<0.05 "**"); and among treatments within each soil layer (panel b; p-value <0.1).

Gain in SOC relative to conventional system

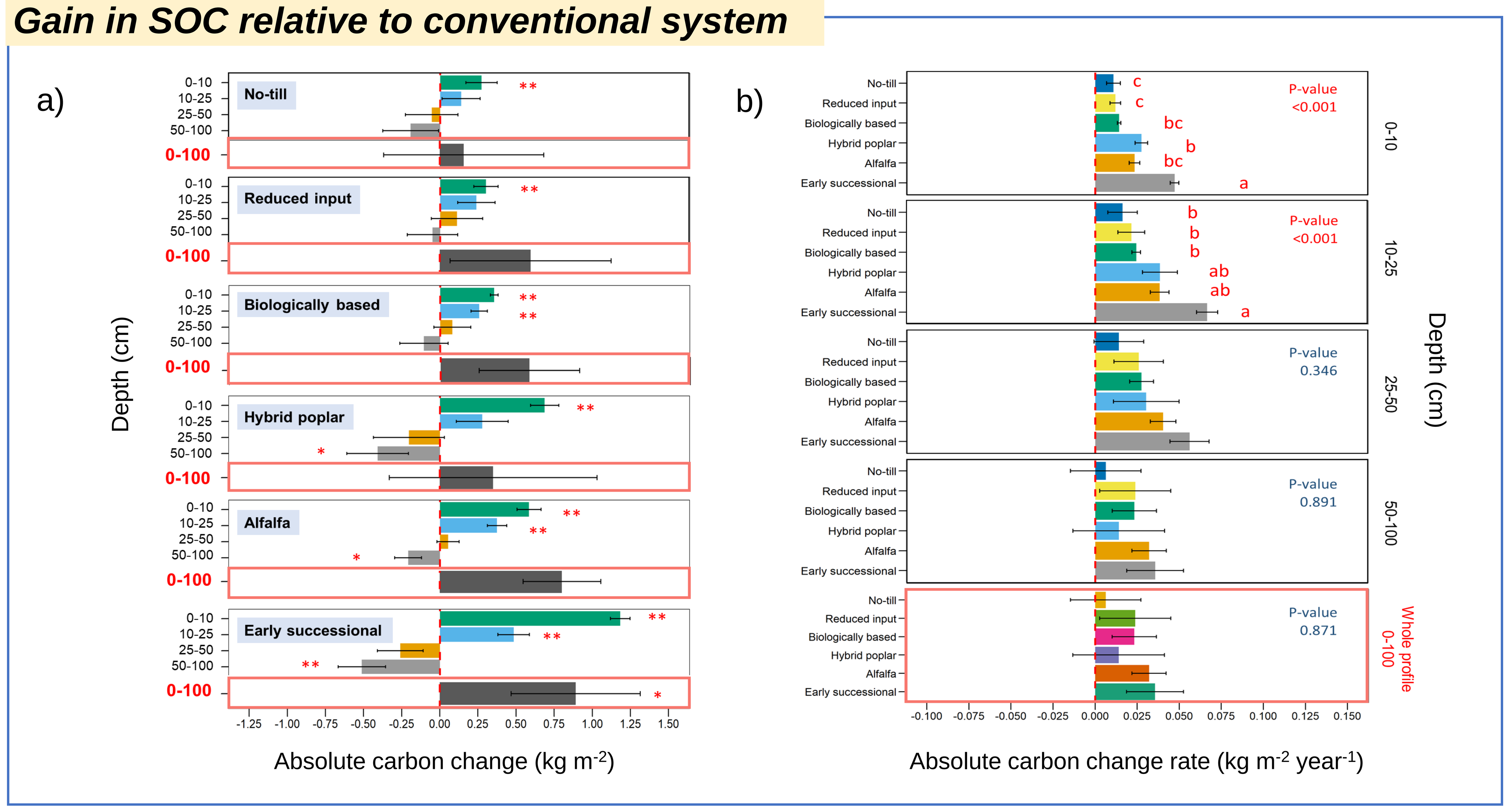

Figure 2. Soil organic carbon gain and rates of SOC change measured in seven systems up to 1 meter depth. Data are averages (n= 6 plots± sd) of 1 ha plot size, and each had 5 sampling stations measured in 2013. Statistical analysis compared differences from zero (panel a; asterisks indicate significant differences, p-value <0.1 "*", and p<0.05 "**"); and among treatments within each soil layer (panel b; p-value <0.1).

Methods

The Main Cropping System Experiment (MCSE) stablished in KBS as a randomized complete block design (RCBD) with 11 management systems replicated in 3 to 6 blocks of 1 ha plots.

Annuals cropping systems:
- Conventional agriculture
- No-till
- Reduced input with cover crop
- Biologically managed with cover crop

Perennials systems:
- Alfalfa
- Hybrid poplar
- Coniferous

Successional systems:
- Early successional
- Mid-successional
- Deciduous forest

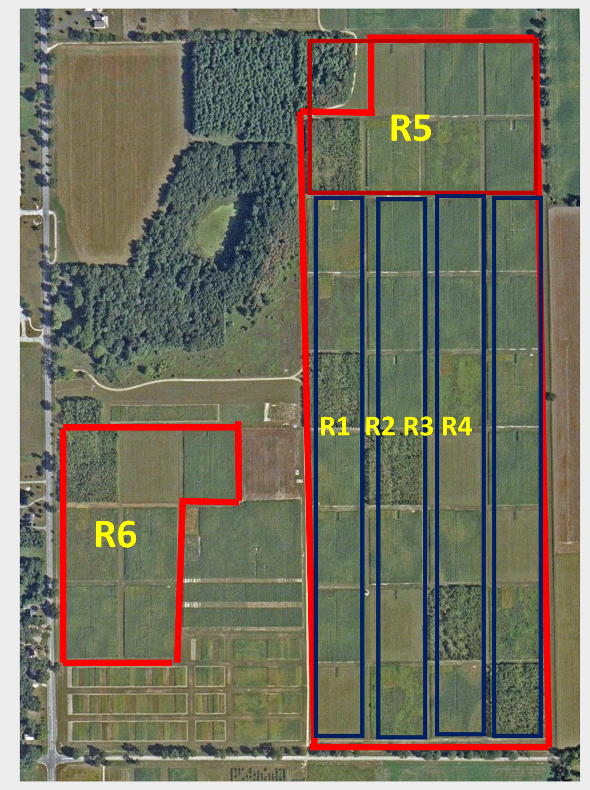

Figure 3. Field plot layout and aerial picture of the LTER MCSE at KBS. Each plot measures 90 x 110 m arranged in 6 blocks (R1-R6); unmanaged systems are replicated nearby on the same soil series.

Deep soil cores were taken in 2001 and 2013 (6 cm diam., 1 m deep). In 2001 deep cores were split by horizons, whereas in 2013 deep cores were split by four depth increments (Fig. 4).

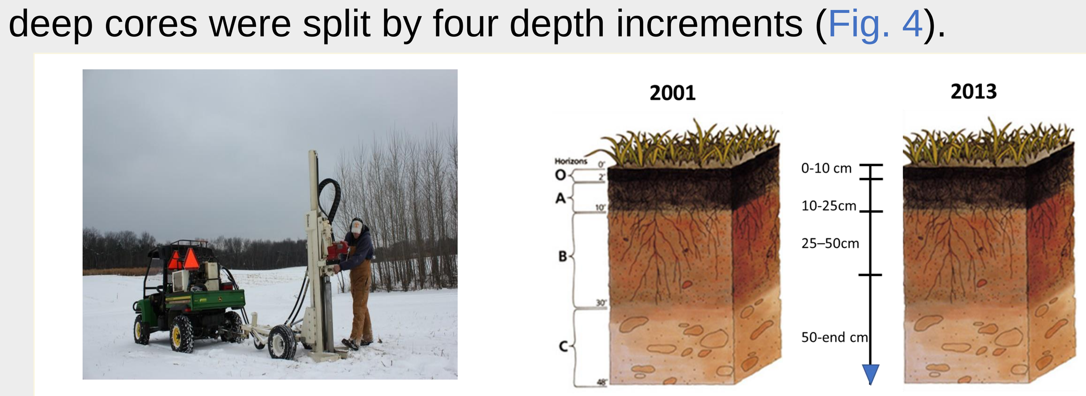

Figure 4. Deep core sampling and processing differences between sampling years (horizons vs. fixed depths).

Data smoothing:
Datasets from both years were first smoothed with the use of non-linear models for each replicate. Then, SOC mass was calculated for each soil layer and replicate by treatment for each year using the SOC mass coordinate method:

Eq. 1) SOC mass [kg SOC m^{-2}] = (SOC % /100) * (Soil d.w. per unit area)

Soil Organic Carbon gain:
Two approaches were used to calculate the change in SOC among treatments and soil sections:

1) Absolute gain in SOC was calculated only in Conventional agriculture, Coniferous forest, Mid-successional and Deciduous forest systems as the difference in SOC mass per unit area measured in 2013 and 2001:

Eq.2) Absolute change SOC = (SOC $T_{x\ 2013}$ – SOC $T_{x\ 2001}$)

2) Space for time substitution (i.e., gain in SOC mass per unit area) was calculated as the difference in SOC mass per unit area measured in all managed systems in 2013 minus the SOC mass measured in Conventional Agricultural system (referred as "T1"):

Eq.3) Gain in SOC = (SOC $T_{x\ 2013}$ – SOC $T_{1\ 2013}$)

The SOC gain rate was calculated for both methodologies by dividing the cumulative SOC gain at each depth by 25 years of management.