Measuring SOC in USA and Brazil: Varying methods and implications

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Abstract

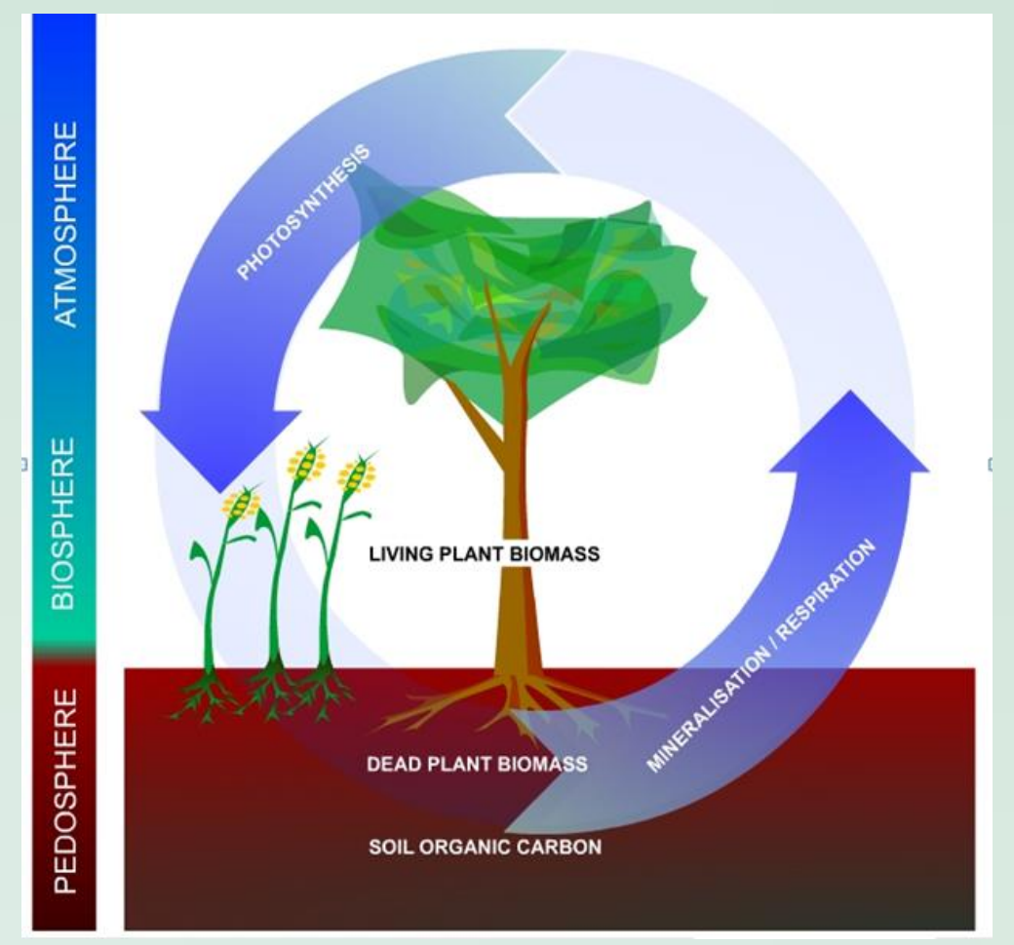
Soil organic carbon (SOC) is often seen as the most important indicator of soil productivity and is therefore a key aspect of sustainability for agricultural production systems. Additionally, the potential influence of soil carbon cycling on greenhouse gas emissions (GHG) is a major concern for climate change. Since the widespread use of bioenergy is seen as a possible strategy to mitigate global climate change, carbon (C) sequestration is also a concern for this industry. If a gain in SOC is found, life-cycle assessments (LCA) of bioenergy production systems can indicate enhanced GHG savings (i.e. "negative emissions") as compared to a reference energy system. However, sampling protocols for measuring SOC are varied and can have significant effects on the calculation of this environmental sustainability indicator. The objective of this literature review was therefore to identify SOC sampling methodologies used in Brazil and the US and to define differences that could result in varying SOC estimates. These results can be used in efforts to define common sampling protocols for the assessment of key aspects of sustainability for bioenergy. We have started with Brazil and the US, the two largest producers and exporters of ethanol in the world, and have focused on corn and sugarcane production. Results indicate the following: (i) sampling the top soil profile to 30 cm may yield inaccurate estimates; (ii) within the conterminous United States, studies that measured for SOC in bioenergy croplands collected the soil samples by using the core method and conversely, much of the studies in Brazil use excavated pits; (iii) pre-treatment samples to establish a baseline are not often taken and can provide a better understanding of soil carbon sequestration under different management practices; (iv) there is a wide variability in the sample sizes and research design (e.g., random, systematic or stratified) for SOC measurements, even within the same crop and region. Therefore, care must be taken when making comparisons between these studies.

Central Question

How can measurement protocols affect the calculation of soil organic carbon and what would the influence on baseline and targets be?

Impact

The USA and Brazil are the two largest producers and exporters of ethanol in the world. One key issue affecting the sustainability of bioenergy production that requires joint-research is the formation of common methodology to measure key indicators of bioenergy sustainability. Consistent and comparable indicators, with standardized measurement protocols, will facilitate international trade, comparisons of energy options and allow compilation of better baselines, targets, and best available practices. Bioenergy and climate change are global challenges that can only be effectively addressed through international cooperation.



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USA studies measuring SOC

Table 1.
Summary of studies measuring for SOC in bioenergy crops in the USA

Reference	Latitude	Crop[a]	Soil Series[b]	Depth (cm)	Samples Collected	Sample Design
Gál et al. (2007), S&TR 96: 42-51	40⁰ 28'N	C-S	Chalmers SiCL	100	Cores	Systematic
Follett et al. (2013), SSAJ 77: 951-963	40⁰ 39'N	C	Fort Collins CL	120	Cores	GPS
Follett et al. (2012), BioR 5: 866-875	41⁰ 46'N	C/SG	Yutan SiCL	150	Cores	Systematic
Karlen et al. (2013), S&TR 130: 24-41	42⁰ 01'N	C-S	Clarion L	15	Cores	Systematic
Bolinder et al. (1999), P&S 215: 85-91	45⁰ N	C	Neubois SiL	30	Cores	Random
Clapp et al. (2000), S&TR 55: 127-142	44⁰ 44'N	C	Waukegan SiL	30	Cores	Random
Wilts et al. (2004), SSAJ 68: 1342-1351	45⁰ 36'N	C/W/O	Hamerly CL	45	Cores	Random
Duiker and Lal (1999), S&TR 52: 73-81	40⁰ 00'N	C/W	Crosby SiL	30	Cores	Systematic
Franzluebbers et al. (2012), JSWC 67: 178-182	33⁰ 62'N	C/S/W	Cecil SaCL	150	Cores	Random
Halvorson et al. (2002), AJ 94: 1429-1436	31⁰ 33'N	C/W	Weld SiL	15.2	Cores	Random
Hooker et al. (2005), SSAK 69: 188-196	41⁰ N	C/W/B	------------	15	Cores	Systematic
Motta et al. (2000), JSWC 65: 6-13	31⁰ 31'N	C/S/Co/So	Lucedale CL	30	Cores	Random
Olson et al. (2005), S&TR 181: 217-225	42⁰ 42'N	C/S	Luvisol Si	75	Cores	Systematic
Al-Kaisa et al. (2005), ASE 30: 174-191	41⁰ 52'N	C-S	Canisteo SiL	15	Cores	Random
Varvel and Wilhelm (2010), SSAJ 74: 915-921	40⁰ 48'N	C/C-S/S-C	Sharpsburg SiCL	30	Cores	Random
Aziz et al. (2013), S&TR 131: 28-35	39⁰ 30'N	C/C-S/W	SaSiC	30	Cores	Random
Evers et al. (2013), AJ 105: 1271-1276	39⁰ 11'N	C/S/SG	Kahola SiL	15	Cores	Random
Lee et al. (2007), AJ 99: 462-468	44⁰ 10'N	SG	Egan SiCL	90	Cores	Random
Yang and Wander (1998), S&TR 49: 179-183	40⁰ 06'N	C/S	Thorp SiL	30	Cores	Random
Rhoton et al. (2002), S&TR 66: 1-11	34⁰ 37'N	C/Co	Grenada SiL	15.2	Cores	Random
Sainju et al. (2008), AEE 127: 234-240	34⁰ 41'N	Co/C/R	Decatur SiL	20	Cores	Systematic
Ramirez et al. (2007), S&TR 43: 131-167	40⁰ 29'N	C/C-S	Drummer SiCL	100	Cores	Random

[a] Crop abbreviations: C, corn (Z. mays L.); S, soybean (G. max L. Merr); SG, switchgrass (Panicum virgatum L.); SO, sorghum (Sorghum bicolor (L.) Moench; W, wheat (Triticum ssp.).

[b] Texture abbreviation: C, clay; L, loam; Sa, sand, Si, silt.

Brazil studies measuring SOC

Table 2.
Summary of studies measuring for SOC in bioenergy crops in the Brazil

Reference	Latitude	Crop[a]	Soil Series[b]	Depth (cm)	Samples Collected	Sample Design
Sousa et al. (2005), PAB 40: 271-278	21⁰ 22'S	Sc	Basaltic C	30	Pits	Random
Razafimbelo et al. (2006), AEE 115: 285-279	21⁰ 22'S	Sc	Basaltic C	10	Pits	Systematic
Cerri et al. (2004), AAF 62: 23-28	21⁰ 22'S	Sc	Basaltic C	20	Pits	Systematic
Resende et al. (2006), P&S 281: 339-351	08⁰ 02'S	Sc	Entisol	60	Pits	Systematic
Szacks et al. (2007), Doctoral dissertation	21⁰ 22'S	Sc	-----------	30	Pits	Systematic
Galdos et al. (2009), Georderma 153: 347-352	21⁰ 22'S	Sc	Ferralsol C	100	Pits	Systematic
Pinheiro et al. (2010) , PS 333: 71-80	19⁰ 18'S	Sc	Acrisol C	100	Pits	-----------
Tivet et al. (2013), Georderma 210: 214-225	25⁰ 09'S	Sc	Oxisol C	100	Pits	Random
Macedo et al. (2008), FE&M 225: 1516-1524	23⁰ 02'S	Sc	Ferralsol C	60	Pits	Random
Rossi et al. (2013), AE&E 170: 36-44	17⁰ 47' S	Sc	Oxisol SaL	60	Pits	Systematic
Carvalho et al. (2009), S&TR 103: 342-349	-----------	Sc	-------------	30	Pits	Random
Calegari et al. (2008), SQ&F 100: 1031-1019	26⁰ 07'S	C/S	Oxisol C	60	Pits	Systematic

[a] Crop abbreviations: C, corn (Z. mays L.); S, soybean (G. max L. Merr); Sc, sugarcane (Saccharum officinarum)

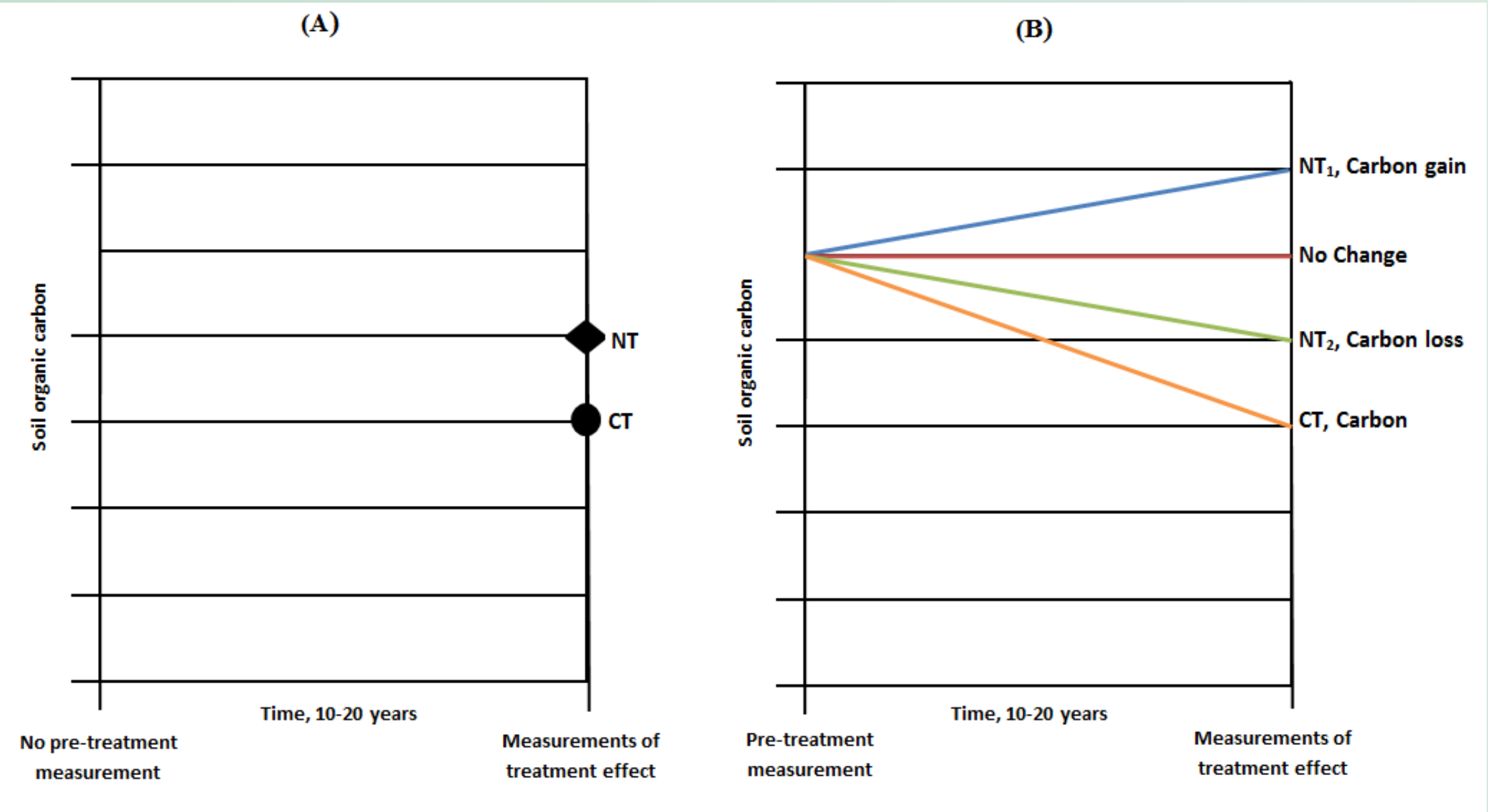
[b] Texture abbreviation: C, clay; L, loam; Sa, sand, Si, silt.

Pits (Brazil) or Cores (USA)

Table 3. Matrix of sampling method and their benefits and drawbacks

Sampling method	*Benefits*	*Drawbacks*
Cores	Precise measurement Able to employ large number of samples Whole field assessment Detect significant change Flexible Less labor intensive Portable/weighs less Little surface disturbance Faster in time	Inability to sample below rocks larger than the corer Includes rocks in sample Grinding of rock Compression/compaction
Pits	Accurate measurement Direct measurement of soil mass Accurate assessment of bulk density and coarse fraction Avoid rocks Recognition of soil horizon Large volume of soil samples Undisturbed and disturbed soils	Labor intensive Time consuming Destructive Precludes use in small plots Fewer observations No repeated sampling

Long-term studies



(A) No pre-treatment sample (i.e. to establish a baseline) are taken. Measurements of SOC to determine effects of differing treatments such as no-till (NT) vs. conventional may yield higher sequestration rates for one treatment without the context of changes over time. This may lead to inaccurate estimates of carbon sequestration.

(B) Olson (2013) argues that if pre-treatment samples are taken and SOC levels are shown to have no significant differences between both field sites (converging lines), measurements after long-term treatments will show a change in both management practices but NT changes at a slower rate. Only when the carbon levels within the NT system shows an increase between the pre-treatment to the final measurement of the treatment effect (NT_1), could it be accurately concluded that carbon was sequestered (McGuire, 2013).

Conclusions

The majority of the studies included in this literature review varied in depth, sample sizes, and design, thereby making it difficult to compare how these could influence SOC results. Therefore, more research is needed before comparisons are made between energy options based on these widely varying studies.

Information on long-term management is crucial in order to explain patters in SOC changes, but long-term studies are costly and are often difficult to keep going with unpredictable research funding. Additionally, long-term experiments are rarely replicated, which hinders validation of SOC models. Studies have shown that when baseline measurements are included, conclusions can be significantly different from studies without these measurements. Additionally, making comparisons between samples taken in one season of one year with samples taken several later years and in a different seasons is unlikely to provide reliable estimates of difference in SOC sequestration rates.

Continual Improvements

SOC is dynamic and it varies spatially and temporally throughout the terrestrial biome. This allows for a continual improvement process, as an ongoing effort to improve the soil quality with management practice, land-use, residue remnants, and a common set of protocols that best assess the capture of carbon into the soil. These efforts can provide incremental improvement over time or a great developmental improvement all at once. However, contributions are needed from soil scientists, land managers, and farmers to build a robust foundation for soil sampling protocols. The following research needs have been identified:

- ➢ Replicated studies in different regions, soil types, and management practices in order to clarify management and environmental interactions on C sequestration and GHG emissions.
- ➢ Field studies comparing short-term and long-term frequency to understand when carbon is changing in that area.
- ➢ Research to determine if measurements taken deeper than 1m will provide a better understanding of the influence that depth has on SOC and resolve which type of management practices are likely to have impacts deeper in the soil profile.
- ➢ All studies should explicitly include clear and transparent methodology (i.e. all steps used for sampling or a reference to a established protocol) in order for future researchers to be able to make comparisons.
  - ❖ Additionally, investments should be made in long-term field experiments to determine real changes in SOC over time.
  - ❖ Using the results of these long-term studies, SOC models should be validated to provide greater confidence in estimates.
  - ❖ To obtain complimentary results (similar to Karlen et al., 2013), additional studies are needed to measure soil organic carbon on corn-soybean rotation compared to other crop rotations including corn.

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