Depletion of Soil Organic Carbon upon Intensive Tillage and Its Restoration by Conservation Agriculture Production Systems in Cambodian Agroecosystem: Preliminary Results

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Introduction

Expansion of agricultural land due to rural population growth has exacerbated the growing concern in Cambodia over soil degradation. Intensive tillage practices on agricultural land caused degradation of the land area of about 43% of its territory and carbon loss of approx. 2.5 million tons within 23 years (1982-2008) (Bai *et al.*, 2008). Conservation agriculture (CA), a system of agronomic practices, constitutes the best tools to create sustainable agriculture with its three key principles comprising minimum soil disturbance (no-tillage), permanent organic mulch cover, and crop species diversification (FAO, 2008).

Soil organic carbon (SOC) plays an important role in enhancing crop yield (Lal, 2003) and soil properties (Six *et al.*, 2004; Lal, 2008). Continuous soil tillage maximizes soil disturbance and increases SOC decomposition due to greater exposure to microbial oxidation (Reicosky *et al.*, 1995) resulting in significant losses of SOC. Maximizing plant biomass C inputs in the soil under CA offers a potential approach to restore SOC and continuous inputs of high biomass C through crop residues to the soil surface under CA create a positive C budget, enhance the stable C fraction, and accentuate C and N transformation and flow (Boddey *et al.*, 2010).

This research was carried out to examine the medium-term (5 years) impacts of continuous CT on SOC depletion, and the potential of CA with diverse biomass C inputs to restore SOC in whole soils and physical and chemical fractions of SOC.

Materials and Methods

The experiments were initiated in 2009 in Chamkar Leu District (Latitude 12°18′51″N, longitude 105°16′39″E and altitude 104 meters), Kampong Cham, Cambodia. This study was conducted over a three-year period (2011–2013) and there were three distinct experiments: (i) rice-, (ii) soybean-, and (iii) cassava-based cropping systems with four treatments each. The experimental plots were laid out in RCBD with 3 replications with the plot size of 8 m x 37.5 m. The treatments of each cropping system is shown in Table 1. Soil samples were collected in November 2011 and 2013. Composite samples were collected from 7 depths: 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, and 80-100 cm.

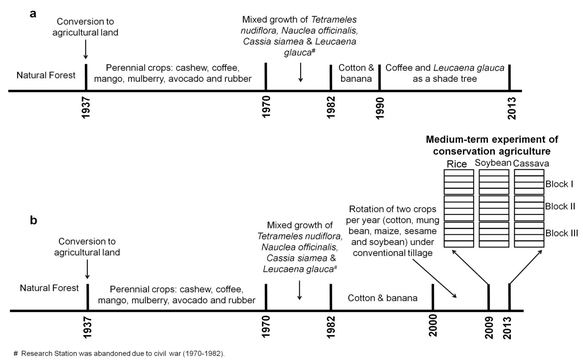

Fig. 1 Chronology of land use in the research site: (a) reference vegetation and (b) experimental plots

Soil Analysis

Total C and N concentrations was determined by the dry combustion method using an elemental CN analyzer (TruSpec CN, LECO, St. Joseph, USA). Particle-size fractionation of SOC was performed into two fractions: particulate organic C-POC (53-2000 µm) and (< 53 µm) mineral-associated organic C-MAOC. Hot-water extractable organic C (HWEOC), permanganate oxidizable C (POXC), and pyrophosphate extractable organic C (PEOC) were measured. The SOC stocks of whole soils and fractions were computed on an equivalent soil mass-depth basis.

Statistical Analysis

The statistical analysis was performed using SAS 9.2. To compare the effects of treatments at each depth in each cropping system, data were subjected to ANOVA and comparisons among treatment means were calculated based on LSD at the 0.05 probability level.

Table 1 Land use and crop sequence in the five-year experiment period (2009-2013)

Production Systems	Land use	Crop sequence
Rice	CT-R	Mb/R – Mb/R – Mb/R – Mb/R – Mb/R
	CA1-R	Mt/R+St – Mt/R+St – Mt/R+St – Mt+St(2011)¥/R+St – Mt+St(2012)/R+St
	CA2-R	Mt+St/R+St – Mt+Cr+St (2009)/M+St – Mt+Cr+St (2010)/R+St – Mt+Cr+St(2011)/M+St – St
	CA3-R	(2012)/R+St Mt+St/M+St – Mt+Cr+St (2009)/R+St – Mt+Cr+St (2010)/M+St – St (2011)/R+St – St (2012)/M+St
Soybean	CT-S	Se/S – Se/S – Se/S – Se/S – Se/S
	CA1-S	Mt/S+Brz – Mt/S+Brz – Mt/S+Brz – Mt/S+St+Sg – Sr+St (2012)/S+St+Sg
	CA2-S	Mt+Brz/S+St – Mt+Cr+St (2009)/M+Brz – Brz/S+St – Mt+Cr+St/M+St – Sr+St (2012)/S+St+Sg
	CA3-S	Mt+St/M+Brz – Mt/S+St – St/M+Brz – St (2011)/S+St+Sg – Sr+Cr+St (2012)/M+St
Cassava	CT-C	C – C – C – C – C
	CA1-C	C+St – C+St – C+St – C+St – C+St
	CA2-C	St/C+St – Mt+St (2009)/M+St – St (2010)/C+St – Mt+Cr+St (2011)/M+St – St (2012)/C+St
	CA3-C	Mt+St/M+St – C+St – Mt+Cr+St (2010)/M+St – C+St – Mt+Cr+St (2012)/M+St

Mb: mung bean; R: rice; Mt: millet; St: Stylo; Cr: *Crotalaria juncea*; M: maize; Se: sesame; S: soybean; Brz: *Brachiaria ruziziensis* cv. ruzi; C: cassava; Sg: sorghum; ¥ St (Stylo) left from the year in brackets. "/" indicates relay cropping with varying planting dates; "+" indicates crops planted in association (same or staggered sowing dates).

Results

Table 2 C and N stocks (Mg C ha^{-1}) in 0- to 100-cm soil depths under three production systems in 2011

Soil depth	Rice-based cropping systems					Soybean-based cropping systems					Cassava-based cropping systems				
(cm)	RV[a]	CT-R[b]	CA1-R	CA2-R	CA3-R	RV	CT-S	CA1-S	CA2-S	CA3-S	RV	CA1-C	CA2-C	CA3-C	CA3-C
C stock (Mg C ha^{-1})															
0–5	15.5 A	9.8 B ns	9.3 B	9.7 B	9.5 B	15.5 A	9.6 Bc	9.9 Bbc	10.4 Ba	10.0 Bab	15.5 A	7.8 Cb	7.8 Cb	9.0 BCa	9.3 Ba
5–10	11.2 A	9.2 B ns	8.5 B	8.6 B	8.4 B	11.2 A	9.8 B ns	9.2 B	9.0 B	9.0 B	11.2 A	8.6 B ns	8.0 B	8.8 B	8.4 B
10–20	16.0 ns	16.0	15.3	14.4	14.4	16.0 ns	17.4	17.3	15.7	17.1	16.0 ns	16.7	14.3	15.9	14.4
20–40	20.7 ns	20.8	18.3	16.9	19.7	20.7 ns	22.2	23.1	19.2	18.9	20.7 ns	22.1	17.9	19.1	17.7
40–60	13.8 ns	14.5	12.2	13.6	13.0	13.8 ns	14.4	14.8	12.9	12.5	13.8 ns	14.9	13.0	13.9	12.9
60–80	10.4 ns	10.2	8.7	9.8	9.4	10.4 ns	10.9	11.7	9.3	9.1	10.4 ns	11.2	10.3	11.5	10.4
80–100	10.3 A	9.5 A ns	7.3 B	9.1 A	8.6 AB	10.3 ns	10.3	11.4	9.0	8.4	10.3 ns	10.9	9.5	10.6	9.8
N stock (Mg N ha^{-1})															
0–5	1.63 A	0.91 B ns	0.94 B	0.94 B	0.98 B	1.63 A	0.93 B ns	0.96 B	1.01 B	0.97 B	1.63 A	0.78 C ns	0.87 BC	0.85 BC	0.95 B
5–10	1.16 A	0.86 B ns	0.87 B	0.90 B	0.94 B	1.16 A	0.87 B ns	0.88 B	0.90 B	0.90 B	1.16 A	0.89 B ns	0.90 B	0.80 B	0.87 B
10–20	1.63 ns	1.48	1.61	1.62	1.61	1.63 ns	1.54	1.69	1.62	1.78	1.63 ns	1.68	1.70	1.52	1.59
20–40	2.42 ns	2.59	2.47	2.42	2.63	2.42 ns	2.44	2.79	2.74	2.71	2.42 ns	2.76	2.73	2.33	2.56
40–60	1.72 C	1.96 BC ns	2.06 AB	2.21 A	2.22 A	1.72 B	2.12 A ns	2.26 A	2.20 A	2.10 A	1.72 C	2.26 AB ns	2.39 A	1.98 BC	2.17 AB
60–80	1.41 B	1.62 AB ns	1.68 AB	1.82 A	1.85 A	1.41 B	1.78 A ns	1.97 A	1.85 A	1.80 A	1.41 C	1.90 AB ns	2.09 A	1.67 BC	1.89 AB
80–100	1.36 ns	1.51	1.60	1.80	1.67	1.36 C	1.63 B ns	1.90 A	1.81 AB	1.74 AB	1.36 ns	1.76	1.95	1.71	1.72

Table 3 SOC stock of POC and MAOC in 0- to 100-cm soil depths under three production systems in 2011

Soil depth	Rice-based cropping systems					Soybean-based cropping systems					Cassava-based cropping systems				
(cm)	RV[a]	CT-R[b]	CA1-R	CA2-R	CA3-R	RV[a]	CT-S[b]	CA1-S	CA2-S	CA3-S	RV[a]	CT-C[b]	CA1-C	CA2-C	CA3-C
POC stock (Mg C ha^{-1})															
0–5	1.70 A	0.69 B ns	0.73 B	0.83 B	0.84 B	1.70 A	0.69 B ns	0.67 B	0.80 B	0.82 B	1.70 A	0.42 B ns	0.43 B	0.51 B	0.99 B
5–10	0.67 ns	0.48	0.43	0.50	0.45	0.67 A	0.43 B ns	0.37 B	0.38 B	0.43 B	0.67 ns	0.47	0.43	0.58	0.43
10–20	0.70 ns	0.61	0.62	0.50	0.52	0.70 ns	0.64	0.60	0.60	0.62	0.70 ns	0.70	0.60	0.69	0.57
20–40	0.71 A	0.39 B ns	0.41 B	0.35 B	0.45 B	0.71 ns	0.49	0.63	0.38	0.46	0.71 A	0.47 B ns	0.33 B	0.51 AB	0.29 B
40–60	0.38 A	0.20 B ns	0.18 B	0.24 B	0.19 B	0.38 A	0.17 Bb	0.35 Aa	0.15 Bb	0.20 Bb	0.38 A	0.22 B ns	0.18 B	0.17 B	0.20 B
60–80	0.24 ns	0.14	0.17	0.19	0.12	0.24 ns	0.12	0.13	0.10	0.48	0.24 ns	0.14	0.12	0.23	0.14
80–100	0.25 ns	0.15	0.14	0.14	0.12	0.25 A	0.14 B ns	0.14 B	0.12 B	0.14 B	0.25 ns	0.19	0.16	0.28	0.32
MAOC stock (Mg C ha^{-1})															
0–5	12.03 A	7.57 B ns	7.78 B	7.95 B	7.63 B	12.03 A	7.79 Bb	8.34 Ba	8.62 Ba	8.41 Ba	12.03 A	6.86 B ns	6.82 B	7.61 B	7.24 B
5–10	9.50 A	7.40 B ns	7.52 B	7.40 B	7.04 B	9.50 A	7.99 B ns	8.01 B	7.73 B	7.64 B	9.50 A	7.27 B ns	6.91 B	7.65 B	7.12 B
10–20	13.75 ns	12.98	13.66	12.53	12.35	13.75 ns	14.77	15.17	13.69	14.16	13.75 ns	14.47	12.43	14.12	12.47
20–40	18.27 ns	17.15	16.48	14.92	16.65	18.27 ns	19.06	20.41	17.00	16.62	18.27 ns	19.53	15.66	17.09	14.83
40–60	12.00 ns	12.24	11.27	12.27	11.42	12.00 B	11.92 Bb	13.70 Aa	11.62 Bb	11.25 Bb	12.00 ns	13.19	11.55	12.47	11.03
60–80	9.36 ns	9.03	8.31	8.86	8.39	9.36 ns	10.53	10.71	8.58	8.05	9.36 ns	9.98	9.19	10.16	8.93
80–100	9.16 A	8.00 ABa	6.92 BCb	8.28 Aa	6.80 Cb	9.16 ns	9.16	10.29	8.13	7.55	9.16 ns	9.79	8.54	9.58	8.45

Table 4 SOC concentrations of HWEOC, POXC and PEOC in 0- to 100-cm depth under three production systems

Depth	HWEOC (g C kg^{-1})					POXC (g C kg^{-1})					PEOC (g C kg^{-1})				
(cm)	RV[a]	CT[b]	CA1	CA2	CA3	RV[a]	CT[b]	CA1	CA2	CA3	RV[a]	CT[b]	CA1	CA2	CA3
Rice-based cropping systems															
0-5	0.87 A	0.59 B ns	0.60 B	0.68 B	0.71 B	3.31 A	2.06 Cb	2.36 Ba	2.32 Ba	2.37 Ba	3.79 A	2.19 B ns	2.12 B	2.35 B	2.28 B
5–10	0.65 ns	0.55	0.57	0.62	0.59	2.48 A	1.89 C ns	2.11 BC	2.03 BC	2.16 B	2.82 A	1.97 B ns	1.84 B	2.16 B	2.04 B
10–20	0.45 ns	0.49	0.44	0.42	0.45	1.93 ns	1.79	1.89	1.82	1.89	2.43 A	1.73 B ns	1.63 B	1.74 B	1.57 B
20–40	0.37 ns	0.35	0.37	0.32	0.34	1.54 ns	1.49	1.49	1.52	1.50	1.76 A	1.38 B ns	1.42 B	1.15 B	1.33 B
40–60	0.33 ns	0.25	0.33	0.35	0.31	1.41 AB	1.32 Bb	1.39 ABb	1.51 Aa	1.36 Bb	1.26 ns	0.99	0.97	0.96	0.92
60–80	0.25 ns	0.21	0.27	0.28	0.28	1.42 AB	1.26 Cb	1.33 BCab	1.43 Aa	1.32 BCb	0.97 A	0.78 B ns	0.78 B	0.64 BC	0.58 C
80–100	0.26 ns	0.26	0.26	0.31	0.30	1.41 ns	1.24 b	1.27 b	1.48 a	1.24 b	0.96 A	0.59 B ns	0.62 B	0.57 B	0.51 B
Soybean-based cropping systems															
0–5	0.87 A	0.61 B ns	0.63 B	0.68 B	0.73 B	3.31 A	2.14 C ns	2.37 BC	2.44 BC	2.54 B	3.79 A	2.65 B ns	2.70 B	2.79 B	2.76 B
5–10	0.65 ns	0.56	0.51	0.50	0.61	2.48 A	2.08 B ns	2.07 B	2.05 B	2.09 B	2.82 ns	2.57	2.57	2.60	2.62
10–20	0.45 ns	0.44	0.43	0.44	0.42	1.93 ns	1.89	1.92	1.93	1.95	2.43 ns	2.26	2.37	2.38	2.33
20–40	0.37 ns	0.38	0.35	0.36	0.38	1.54 ns	1.57	1.55	1.57	1.69	1.76 ns	1.66	1.64	1.73	1.74
40–60	0.33 ns	0.26	0.32	0.32	0.33	1.41 BC	1.47 ABC ns	1.41 C	1.51 AB	1.57 A	1.26 ns	1.13	1.12	1.19	1.25
60–80	0.25 ns	0.23	0.24	0.31	0.34	1.42 ns	1.42	1.40	1.55	1.46	0.97 ns	0.64	0.56	0.69	0.69
80–100	0.26 ns	0.26	0.20	0.26	0.26	1.41 ns	1.39	1.37	1.51	1.42	0.96 A	0.58 B ns	0.50 B	0.59 B	0.61 B
Cassava-based cropping systems															
0–5	0.87 A	0.59 Cb	0.60 Cb	0.68 Ba	0.70 Ba	3.31 A	1.94 Cb	2.00 Cb	2.31 Ba	2.27 Ba	3.79 A	2.34 Bb	2.44 Bb	2.62 Ba	2.62 Ba
5–10	0.65 ns	0.55	0.56	0.56	0.58	2.48 A	1.88 Cc	1.93 Cbc	2.27 ABa	2.13 BCab	2.82 A	2.24 C ns	2.31 BC	2.48 BC	2.54 AB
10–20	0.45 ns	0.42	0.43	0.43	0.40	1.93 ns	1.84	1.71	2.12	1.91	2.43 ns	2.03	2.08	2.16	2.25
20–40	0.37 ns	0.35	0.39	0.33	0.35	1.54 ns	1.54	1.47	1.67	1.58	1.76 ns	1.68	1.77	1.77	1.81
40–60	0.33 ns	0.24	0.31	0.34	0.28	1.41 B	1.32 Cc	1.42 Bb	1.56 Aa	1.50 Aa	1.26 ns	1.43	1.45	1.36	1.35
60–80	0.25 ns	0.23	0.32	0.30	0.29	1.42 BC	1.32 Cb	1.41 BCab	1.54 Aa	1.47 ABa	0.97 ns	1.07	1.07	1.17	1.06
80–100	0.26 ns	0.24	0.25	0.28	0.30	1.41 ns	1.31 c	1.40 bc	1.55 a	1.46 ab	0.96 ns	0.84	0.72	0.87	0.79

RV: reference vegetation; CT: conventional plow-based tillage; CA: conservation agriculture; [a] Comparison between tillage systems CT, CA1, CA2, CA3 and RV; Uppercase letters within the same line in each cropping system indicate the difference among RV and tillage treatments at $P \leq 0.05$ by LSD. [b] Comparison among tillage systems CT, CA1, CA2 and CA3; Lowercase letters indicate difference between tillage treatments at $P \leq 0.05$ by LSD. ns: not significant

Conclusion

SOC stock and fractions decreased upon conversion from reference vegetation to cultivated fields. After three years of CA, SOC stock in whole soil increased in the surface layer of soybean- and cassava cropping systems. CA does not significantly enhance POC and MAOC stocks within this period but there is a trend in increasing POC in the surface layer. A significant increase in HWEOC, POXC and PEOC concentrations in the 0-5 cm depth was observed in cassava-, and only POXC in rice-based cropping systems. The preliminary results presented emphasize the potential of CA to recover a part of original SOC stock and fractions previously depleted by CT, particularly in the surface layer. Soil samples collected after five-year study are still being analyzed and it is expected that there is a significant accumulation of SOC stock and fractions in the surface layer of all cropping systems as a result of high biomass input by CA (e.g. diversity of cover/relay crops and high annual biomass input).

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