GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON, Rome, Italy, 21-23 March2017

Long-term fertilization impacts on temperature sensitivity of soil organic carbon decomposition under wheat based cropping systems

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Abstract

Understanding temperature sensitivity of soil organic carbon (soc) decomposition (q10) from bulk soils and aggregates of long-term fertilized plots is imperative to forecast soil c dynamics. We evaluated the impacts of 43 and 44 years of fertilization under wheat (triticum aestivum) based cropping system on q10 in an alfisol and inceptisol, respectively. Bulk soils as well as macro- and micro-aggregates of 0-15 (topsoil) and 15-30 cm soil layers were incubated for 24 days at 25oc and 35oc. Results revealed that cumulative soc mineralization (ct) of bulk soils with npk + fym and npk treated plots were similar but significantly higher than unfertilized control plots in both soil types. In topsoil, npk + fym plots had ~10 and 26% greater q10 values of macro- and microaggregates than npk in alfislol and similar results were observed in inceptisol. Activation energies required for bulk soil c mineralization was ~2 and 3 times higher in npk + fym and npk + l plots, respectively, compared with unfertilized control plots in alfisol. Thus, long-term npk + fym (in both soils) and npk + l applications (in alfisol) have great potential for less proportional soc decomposition than npk or unfertilized control plots under a temperature rise.

Keywords: Soil organic carbon mineralization, Macroaggregates, Microaggregates, Q_{10}, activation energy, C decay rates, temperature rise, Inceptisol and Alfisol

Introduction, scope and main objectives

Understanding the impact of elevated temperatures on rates of soil organic matter (SOM) decomposition in diverse soil systems is critical to our knowledge of soil C dynamics and this will assist estimation of future global SOC stocks. Different kinetic properties of SOM components provide obstacles to the understanding of thermal stability of SOC decomposition (Davidson and Janssens, 2006). As predicted by Arrhenius, if differences in decomposition rates are entirely due to activation energy (as a measure of the energy required for decomposers to access the material), temperature sensitivity should increase with the organic matter 'recalcitrance' (Davidson and Janssens, 2006). Thus, stable compounds in soils are associated with higher activation energies, as they are less reactive to a temperature rise. But SOC decomposition is also regulated by long-term management practices, as well as by soil aggregate sizes (Manna et al., 2013). Substrate quantity and quality and microbial activities within different soil fractions influence temperature sensitivity. Hence, there is a need to study the effects of aggregate size and long-term fertilization on Q_{10} and activation energy (Ea) in different soils and production systems.

Thus, studying temperature impacts on soil C decomposition as affected by fertilization could provide interesting data for assessing the impacts of integrated nutrient management (INM) on climate change mitigation potential. The hypothesis was that fertilization significantly affects C mineralization and Q_{10} from bulk soils and their aggregates, and INM requires more Ea to mineralize C than NPK or unfertilized control plots (due to probable presence of more recalcitrant C and thus agreeing to the carbon quality-temperature (CQT) hypothesis), even after a heat wave. The CQT hypothesis has not been tested for short heat waves, which are predicted to regularly recur under climate change scenarios (Nianpeng et al., 2013). The objectives were: (i) to evaluate the rates of SOC decomposition in bulk soils and their aggregates as affected by 43 and 44 years of continuous fertilization in wheat-based cropping systems in an Alfisol and Inceptisol and (ii) to assess the temperature sensitivity of SOC decomposition from bulk soils and their aggregates.

Methodology

Study sites and experiment details

The study was conducted in tow long-term fertility experiments of Ranchi (Alfisol) and New Delhi (Inceptisol), India. The latest cropping systems were soybean (*Glycine max*)-wheat and maize (*Zea mays*)-wheat in Alfisol and Inceptisol, respectively. The treatments in Alfisol (since 1972) were: no mineral fertilizer or manure (control), 100% recommended dose of nitrogen (N), N and phosphorus (NP), N, P and potassium (NPK), NPK + lime at 0.4 Mg ha^{-1} (NPK + L), 150% recommended NPK (150% NPK), and NPK + FYM at 10 Mg ha^{-1} (NPK + FYM). In Inceptisol, all but NPK + L treatments were there (since 1971). These were arranged in a complete randomized block design with three replications. Other details of experimentation and crop management practices of Alfisol can be found in Ghosh et al. (2016) and that of Inceptisol in Purakayastha et al. (2008).

Soil sampling, processing and bulk density determination

In April 2015, triplicate soil samples were collected after wheat harvest from the individual plots from two depth layers (0-15 and 15-30 cm). Samples were bulked and then divided into three subsamples. One portion was air-dried, ground in a wooden mortar and with a pestle, and sieved to pass through a 4.75-mm sieve (bulk soils). The second subsample was passed through a 4.75 mm sieve and used for aggregate separation. Processed soil samples were used to determine soil chemical and physical properties.

Soil aggregate separation

A sub-set of samples of the 0-15 and 15-30 cm layers from the second soil sample-set were taken for soil aggregation related studies. Aggregate-size separation was performed by a wet sieving method to obtain three aggregate fractions: (i) 250 to 4750-µm (macroaggregates; MA), (ii) 53 to 250-µm (microaggregates; MI), and (iii) <53-µm (silt- plus clay-size particles).

Analyses of soil C pools

The labile SOC concentrations of bulk soils and aggregates were determined by the modified Walkley–Black method using 18.0 M H_2SO_4 (Chan et al., 2001). Total C concentrations of bulk soils and aggregates were analysed using an isotopic ratio mass spectrometer (IRMS) (Delta V plus; Thermo) coupled with an Elemental Analyser (Owens and Rees, 1989) in a continuous flow mode. Inorganic C concentrations were subtracted from total C concentrations to obtain total SOC.

Carbon mineralization study

Carbon mineralization studies of bulk soils (BS), MA and MI were conducted at two temperatures (25 and 35ºC), set in laboratory incubators, for 24 days. Three replicates of 25 g soil samples from each treatment were placed in 250 ml jars (along with two blanks) with alkali traps. Evolved CO_2 was trapped by 10 ml 0.5 N NaOH (in the alkali trap) and measured at each sampling date (Day 2, 4, 7, 10, 17 and 24). The amounts of CO_2 trapped were determined by back titration of the 0.5 N NaOH with 0.5 M HCl at pH

8.3 in the presence of $BaCl_2$. The CO_2 fluxes were measured and details can be seen in Ghosh et al. (2016). An exponential model (Stanford and Smith, 1972) was used to determine C loss with time:

$$C_t = C_o\ (1-e^{-Kct}) \qquad (1)$$

where C_o represents the labile pool, and C_t is the pool of C mineralized at time t, with decay rate Kc.

Vant Hoff factor (Q_{10}) was calculated using the following formula (Janssens and Pilegaard, 2003):

$$Q_{10} = \{(\text{Rate of C mineralization at 35°C/Rate of C mineralization at 25°C})\}^{(10/T_2\text{-}T_1)} \qquad (2)$$

Activation energy was calculated using the Arrhenius equation (Hamdi et al., 2013):

$$Ea = R^* \ln (Q_{10}) / \{(1/T_1)\text{-}(1/T_2)\} \qquad (3)$$

where R = 8.314 j/mol; T_1 and T_2 are temperatures indicating the 10°C temperature range (T_1 = 25°C, T_2 = 35°C).

Statistical analyses

All data were analysed using ANOVA for a randomized block design. Tukey`s test of honest significant difference was used as a post hoc mean separation test ($P < 0.05$) using SAS 9.3 (SAS Institute, USA).

Results

In Inceptisol, plots under NPK + FYM had ~18 and 136% higher total SOC concentration than NPK plots in topsoil (Table 1). In Alfisol, plots with NPK + L, 150% NPK and NPK treatments had similar total SOC concentrations. In soil surface of Alfisol, cumulative SOC mineralization (C_t) at 25 and 35°C and Q_{10} values of bulk soils with NPK + FYM and NPK plots were similar, but were significantly higher than control plots (Table 1). However, in Inceptisol, NPK + FYM treated plots had significantly higher C_t of bulk soils than NPK. In Alfisol, NPK + FYM treated plots had ~10 and 26% greater Q_{10} values of macro- and microaggregates than NPK (Table 2). But, in Inceptisol, NPK + FYM treated plots had similar Q_{10} values of macro- and microaggregates to NPK. Bulk soils of NPK + L plots had higher Q_{10} values than NPK + FYM plots in both surface and sub-surface soil layers, indicating long-term NPK + FYM application acted as energy barriers to SOC decomposition and had considerable potential in having less proportional (to its total SOC) SOC decomposition under increased temperatures. Overall, long-term NPK + FYM and NPK + L applications have great potentials in having less proportional SOC decompositions than NPK, 150% NPK or unfertilized control plots under a temperature rise in Alfisol and the same is true for NPK + FYM versus NPK or 150% NPK in Inceptisol.

Table 1. Total soil organic carbon, cumulative soil organic carbon mineralized (C_t), and Q_{10} in bulk soil and in soil aggregates as affected by 43 years of fertilization under a wheat based cropping system in an Alfisol of 0–15 cm soil depth (Source: Ghosh et al., 2016)

Treatments	Total SOC (g kg^{-1})			C_t (mg 100 g^{-1})						Q_{10}		
				25°C			35°C					
	BS	MA	MI	BS	MA	MI	BS	MA	MI	BS	MA	MI
Control	3.1b (5.0d)	4.8cd (4.4c)	3.0e (16.8c)	33.9c	20.1d	22.9d	35.9d	21.2d	28.1e	1.07d	1.06c	1.25d
N	3.1b (8.8c)	4.6d (6.8c)	3.3e (16.3c)	40.4bc	27.2c	23.9d	44.7c	29.6d	29.3e	1.12c	1.09c	1.24d
NP	3.6b (8.4c)	4.9cd (12.3b)	4.0d (17.5c)	49.0b	38.5b	38.3c	56.3b	44.6c	47.2d	1.18c	1.18b	1.26d
NPK	3.8b (16.2ab)	5.3c (14.3b)	4.6bc (22.0b)	70.3a	64.6a	51.6b	84.4a	76.1b	66.7c	1.24b	1.21b	1.33c

150% NPK	4.3b (17.9ab)	5.6bc (13.9b)	4.8b (24.2b)	70.0a	65.4a	65.6a	85.8a	76.6b	85.8a	1.26a	1.20b	1.37b
NPK + FYM	6.0a (15.0b)	6.9a (21.9a)	5.7a (39.3a)	68.0a	64.7a	53.1ab	81.0a	83.3a	83.3a	1.22b	1.33a	1.67a
NPK + L	4.0b (19.6a)	6.0b (21.6a)	4.4c (23.5b)	64.6a	61.5a	57.7ab	80.6a	78.7b	75.2b	1.29a	1.33a	1.36b
Mean	4.0 (13.0)	5.4 (13.6B)	4.3 (22.8A)	56.6	48.8A	44.7B	66.6	58.6A	59.4A	1.19	1.20B	1.35A

() Data in parentheses indicate activation energy values (kJ mol^{-1}). Means with same lower-case letters within a column are not significantly different at $P < 0.05$ according to Tukey's HSD test. Significant ($P < 0.05$) effects of macroaggregates versus microaggregates for each parameter (mean of all treatments) are denoted by different upper-case letters in the last row. BS = Bulk soil; MA = Macroaggregates; MI = Microaggregates.

Table 2. Total soil organic carbon, cumulative soil organic carbon mineralized (C_t), and Q_{10} in bulk soil and in soil aggregates as affected by 43 years of fertilization under a wheat based cropping system in an Inceptisol of 0–15 cm soil depth.
BS = Bulk soil; MA = Macroaggregates; MI = Microaggregates.

Treatments	Total SOC (g kg^{-1})			C_t (mg 100 g^{-1})						Q_{10}		
				25°C			35°C					
	BS	MA	MI	BS	MA	MI	BS	MA	MI	BS	MA	MI
Control	3.29d (5.1e)	4.12f (13.3d)	2.98e (5.3d)	41.87d	21.98c	20.22	44.29d	25.85e	21.55d	1.07e	1.19c	1.07d
N	4.05c (9.1d)	4.98e (15.8c)	3.78d (10.3bc)	49.86d	29.73c	34.06b	55.15c	35.99d	38.36c	1.13d	1.23bc	1.14c
NP	3.93c (13.3c)	6.25d (20.8a)	4.66c (14.9ab)	60.54c	42.04b	38.53b	69.50b	53.84c	45.83b	1.19c	1.31a	1.22ab
NPK	6.57b (16.5b)	7.64c (16.3b)	5.38b (14.2ab)	78.31b	64.35ab	42.19ab	93.93ab	77.70b	49.83b	1.24b	1.24b	1.20b
150% NPK	7.02b (18.3a)	8.61b (15.2bc)	6.35a (14.5ab)	77.90b	65.44ab	46.94a	95.56a	78.23b	55.73ab	1.27a	1.22bc	1.21b
NPK + FYM	7.82a (15.6b)	9.10a (16.3b)	6.69a (17.0a)	83.88a	70.18a	49.85a	99.97a	85.03a	60.94a	1.23bb	1.24b	1.25a
Mean	5.45 (13.0)	6.78A (16.3A)	4.97B (12.7B)	65.39	48.95A	38.63B	76.40	59.44 A	45.37B	1.19	1.24A	1.18B

Means with same lower-case letters within a column are not significantly different at $P < 0.05$ according to Tukey's HSD test.
() Data in parentheses indicate activation energy values (kJ mol^{-1}).

Discussion

Less proportional carbon mineralization from NPK + FYM treatment may be due to the formation of compounds which are resistant to microbial action (Cotrufo et al., 2013). Thus, this study highlights consideration of the role of microbial diversity and matrix stabilization within bulk soils and aggregates to understand temperature sensitivity of SOC decomposition (Jagadamma et al., 2014). Thus, the results indicate complex role of P and microbial diversity in Inceptisol and sesqui-oxides and matrix stabilization in Alfisol. Abnormally high Ea in macroaggregates of NP treated plots of Inceptisol could be explained by the highest enrichment factor of SOC within macroaggregates indicating protection of C, whereas high Ea in macroaggregates of sub-surface depth of NPK + FYM could be due to high recalcitrant C (>52%). In Alfisol, at surface depth low Ea in NPK + FYM treated plots than NPK + L and NPK may be due to very low SOC enrichment factor in aggregates.

Conclusion:

Among all practices, NPK + FYM application not only had highest SOC accumulation, but also could have less SOC losses under elevated temperatures and hence could be recommended.

References:

Chan K.Y. et al. 2001. *Soil Sci.* 166:61-67.
Cotrufo M.F. et al. 2013. *Glob. Chang. Biol.* 19:988-995.
Davidson E.A., Janssens I.A. 2006. *Nature* 440:165-173.
Hamdi S. et al. 2013. *Soil Biol. Biochem.* 58:115-126.
Ghosh A. et al. 2016. *Ag. Ecosyst. Environ.* **233**:202–213.
Jagadamma S. et al. 2014. Biogeosciences 11:4665-4678.
Janssens I.A., Pilegaard K.I.M. 2003. Glob. Chang. Biol. 9:911-918.
Manna M.C. et al. 2013. Field Crops Res. 145:10-20.
Nianpeng H. et al. 2013. Ecol. Evol. 3:5045-5054.
Owens N.J., Rees A.P. 1989. Analyst 114:1655-1657.
Purakayastha T.J. et al. 2008. Geoder. 144:370–378.
Stanford G., Smith S.J. 1972. Soil Sci. Soc. Am. J. 36:465-472.