Effect of Long Term Manuring and Fertilization on Carbon Sequestration in Terrace Soil

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ABSTRACT

Background: A laboratory incubation study was carried out to study the influence of long term manuring and fertilization on soil organic matter (SOM) quality by means of C mineralization in terrace soil of Bangladesh.

Methods: Soil samples were collected in 2016 from a highly weathered terrace soil with rice-wheat cropping pattern at Bangabandhu Sheikh Mujibur Rahman Agricultural University experimental farm having five OM (control, cow dung, green manure, rice straw and compost) treatments combined with three mineral N fertilizer (control, 155 kg ha^{-1}, 220 kg ha^{-1}) levels. A model was used to explain detected C mineralization in soil known as parallel-first and zero order kinetic model.

Result: Long term (28 years) application of mineral fertilizers and manure resulted that all the estimated parameters were not significantly influenced by either manure application or N fertilization except C mineralization rate was constant for resistant carbon pool (k_s). The k_s value was significantly influenced by manure application. Cumulative annual C mineralization evolved from SOM under field conditions were estimated between 6.21 to 9.31% of total soil organic carbon. The annual carbon mineralization was found to be significantly influenced by different exogenous organic matter application but not with N fertilization. There was a significant difference in annual C mineralization between green manure, cow dung and compost. However, the annual C mineralization was statistically similar between control and green manure treated soil. This result indicates that more stable organic matter was formed in compost treated soil which is less prone to decomposition if present crop management has been changed.

Key words: Carbon sequestration, Long-term fertilization, Terrace soil.

INTRODUCTION

Soil Organic Matter (SOM) plays vital rule in plant nutrients as a source and a sink, it acts as an ion exchange material which influences soil physical properties and soil water, it also acts as energy source for soil microbes and macrofauna (Allison, 1973). Soil productivity is decreased by loss of SOM if soils are well-fertilized (Aref and Wander, 1997). Organic matter status, biological and physical properties of soil influenced by OM which are enhanced due to crop response to mineral inputs is increased in soils (Cassman, 1999; Avnimelech, 1986). Nowadays study of SOM is not limited to agricultural crop production but also concerns environmental stress such as global warming and climate change by the potential of sequestration of atmospheric CO_2 as SOM. Soil organic matter (SOM) influences all soil functions and represents one of the largest reservoirs of carbon on the global scale (Kögel-Knabner *et al.*, 2005). Organic carbon has potentiality to change CO_2 concentration and global climate. C stabilization mechanisms in soils are poorly understood. SOM management is difficult due to the lack of understanding of the processes that maintain SOM pools. The experimental identification of SOM pools linked to the mechanisms of stabilization is a key of element for reliably assessing SOM dynamics. In terrace soil use of organic and chemical fertilizer could logically enhance soil productivity and have had positive effects on rice yields (Yadav *et al.*, 2000; Rasool *et al.*, 2007; Shen *et al.*, 2004). However, recent studies with the application of either manure

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or straw did not improve grain yields statistically after analyzing 25 long term field experiments with rice-rice and rice-wheat systems in Asia instead of soil organic carbon and total soil N (Dawe *et al.*, 2003). They further observed that long term experiments under rice-cropping system with low fertility indicated prominent positive effects of organic

amendments on rice yields. After 17 years cultivation and fertilization management of a barren land, rice yield reached a high level equivalent to the average yield of local high productivity paddy soils and still responding positively, whereas SOC and total N content were still less than half of those in high productivity paddy soils (Li *et al*., 2010). Therefore, Kader (2012) hypothesized that SOM quality, rather than content can play a vital role in fertility of subtropical paddy soils. Terrace soil of Bangladesh is an unfertile, highly weathered soil dominated with keolinitic clay having very low organic matter content. It covers 8% of the total surface of Bangladesh. Growing demand for food in the country due to rapid growing human population on one hand and environmental vulnerability in another hand bring this unfertile land under intensive cultivation. In view of above facts, the present research work has been carried out to assess the quality of accumulated soil organic matter in terrace soil by means of their decomposability.
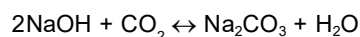
MATERIALS AND METHODS

The site of the experiment was the Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) farm located in salna, Gazipur district, 40 km north of Dhaka and situated in the center of the Madhupur Tract. Five treatments of organic residues and three levels of nitrogen were arranged randomly in each replication. All treatments followed a yearly wheat- fallow-rice cropping pattern and involved 5 OM application treatments (1° no-application (M_0), 2° cow dung at 25 Mg ha^{-1} as fresh manure (CD), 3° compost at 25 Mg ha^{-1} made from cow dung and rice straw (CP), 4° green manure at 7.5 Mg ha^{-1} fresh biomass of *Sesbania rostrata* (GM) and 5° rice straw at 2 Mg ha^{-1}(ML). These were combined with 3 levels of inorganic N fertilizer dressing (0, 75 and 100 kg N ha^{-1} for rice and 0 (N_0), 80 (N_1) and 120 (N_2) kg N ha^{-1} for wheat). Organic residues were applied to the soil once (June) a year 20-25 days before rice transplanting. Every year a high-yielding variety of T. Aman 'BR 14' was transplanted in July and harvested in October. A high-yielding variety of wheat 'Akbar' was sown between mid-November and December and harvested in March. Surface soil samples (0-15 cm) were collected in 2016 from each replicated plot. The field moist soil was gently broken apart by hand and was air-dried and ground to pass a 2-mm sieve prior to soil incubations and determination of soil properties.

Carbon mineralization

Carbon mineralization was studied in an aerobic incubation experiment carried out in a closed system as shown in Fig 1. For the CO_2 determination, small vials containing 10 ml 1 M NaOH solution were placed in the jars to trap the evolved CO_2. The jars were closed with air-tight seals and incubated at 25°C temperature for 98 days. The samples were incubated in two replications including two blank treatment (no soil added) in order to account for the CO_2 present in the air. Decomposition was monitored during incubation period, as CO_2 evolution. The excess alkali was back-titrated with standard 1M HCl after precipitating the carbonate with the presence of $BaCl_2$ (Anderson, 1982). The following reaction takes place when the NaOH-solution is titrated:

$$2NaOH + CO_2 \leftrightarrow Na_2CO_3 + H_2O$$

Modeling of OC mineralization

For these purpose the amount of stable organic C should be ideally determined from long-term laboratory incubations lasting one year, at a temperature comparable to the average temperature under field conditions. Such long incubations are often impracticable, however and therefore estimates are often based on short-term incubations through mathematical description of the dynamics of carbon mineralization. The measurements from the latter might then be extrapolated with theoretical models of C mineralization that can be fitted to the data. A parallel first- and zero-order kinetic model (*e.g.* Van Kessel *et al*., 2000) was used to describe observed C mineralization in soil. According to first-order kinetics the SOM consists of an easily mineralizable pool of C that is mineralized exponentially and according to zero-order kinetics a more resistant fraction that is mineralized (Van Kessel *et al*., 2000), *i.e.* during the incubation period it is assumed that the resistant fraction is not depleted significantly considered:

$$C(t) = C_{A,f} \{1- \exp (-k_f t)\} + k_s t$$

Where,
C(t) is the cumulative amount of C mineralized at time t, k_f is the mineralization rate constant of the easily degradable carbon pool $C_{A,f}$ and k_s is the mineralization rate constant of the resistant pool.

Statistical analysis

Non-linear least-square regression analysis was used to calculate parameters from cumulative C mineralization data in SPSS. Two-way ANOVA (with mineral N levels and OM application treatments as fixed factors) with Duncan's multiple range post-hoc test was used for statistical analysis of the BSMRAU experiment. All statistical analyses were carried out with SPSS 15.
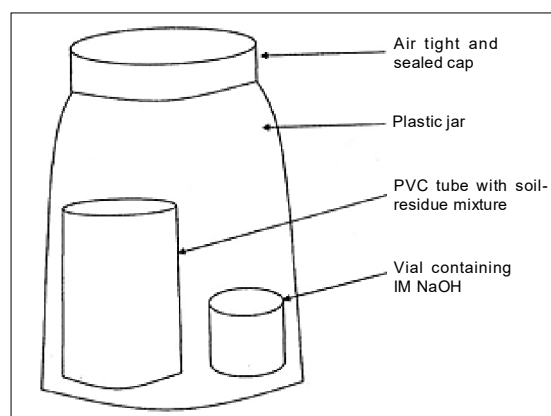

Air tight and sealed cap

Plastic jar

PVC tube with soil-residue mixture

Vial containing IM NaOH

Fig 1: Scheme of an incubation jar.

RESULTS AND DISCUSSION

Carbon mineralization

Modeling OC mineralization

Fig 2 shows measured C mineralization as a function of incubation time and the fitted parallel first and zero order kinetic model for the different doses of N-fertilizer and manure application. In general the R_2 values were all close to 1 and standard errors were very low, which shows that the selected model could describe the mineralization process satisfactorily.

The cumulative C mineralization expressed as percentage of the total SOC varies from 4.29 to 5.18 (g/100 g soil C) between the exogenous organic matter treatments where no N fertilizer was applied. The highest C mineralization value was observed for control (5.18 g/100 g soil C) followed by compost (4.86 g/100 g soil C), green manure (4.54 g/100 g soil C), rice straw (4.34 g/100 g soil C) an) the lowest in cow dung (4.29 g/100 g soil C) (Fig 2). Similarly, the C mineralization rate varies from 4.98 to 4.01 (g/100 g soil C) when manures were applied with 155 kg ha^{-1} N fertilizer. The highest C mineralization rate was observed for rice straw (4.98 g/100 g soil C) followed by control (4.664.98 g/100 g soil C), green manure (4.364.98 g/100 g soil C), compost (4.114.98 g/100 g soil C) and the lowest in cow dung (4.01 g/100 g soil C) when those manures were applied with 155 kg ha^{-1} N fertilizer (Fig 3). On an average the C mineralization rate was observed slightly lower (4.42 g/100 g soil C) when 155 kg ha^{-1} N fertilizer were applied compared with no N fertilizer application (4.64 g/100 g soil C).

Likewise manure and 155 kg ha^{-1} N fertilizer application, there was a narrow range in C mineralization rate varied from 4.96 to 4.36 (g/100 g soil C) when manures were applied with 220 kg ha^{-1} N fertilizer. The highest C mineralization rate was observed for green manure (4.96 g/100 g soil C) followed by control (4.82 g/100 g soil C), cow dung (4.78 g/100 g soil C), rice straw (4.65 g/100g soil C) and the lowest in compost (4.36 g/100g soil C) when those manures were applied with 220 kg ha^{-1} N fertilizer (Fig 4). On an average the C mineralization rate was observed slightly higher (4.71 g/100 g soil C) when 220 kg ha^{-1} N fertilizer were applied compared with no (4.64 g/100 g soil C) and 155 kg ha^{-1} N fertilizer (4.42 g/100 g soil C). This could be due to the priming effect of N fertilizer on C mineralization. Parameters of a parallel first and zero order kinetic models fitted to these mineralization data are given in Table 1. C_{Af} (easily mineralizable C pool expressed in percentage), K_f (mineralization rate constant of the easily degradable carbon pool) and K_s (mineralization rate constant of the stable or resistant carbon pool) were estimated as three parameter.
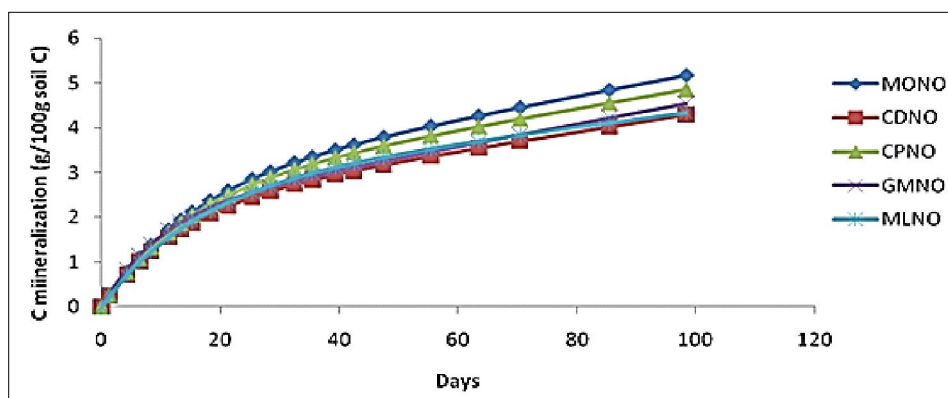

Fig 2: Cumulative C-mineralization expressed as percentage of the total SOC for different manure treated soil with no N fertilizer application.
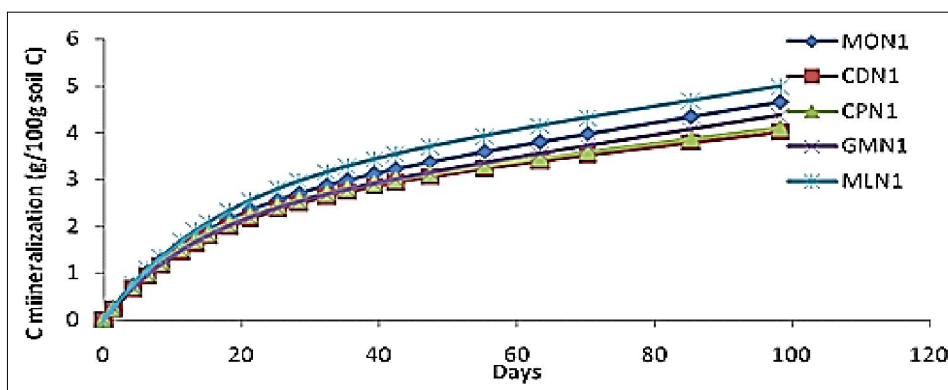

Fig 3: Cumulative C-mineralization expressed as percentage of the total SOC for different manure treated soil with 155 kg N ha^{-1}.

Organic C mineralization

Cumulative annual C mineralization evolved from SOM (expressed as mg C 100 g^{-1} soil) under field conditions varied from 6.21 to 9.31% of total soil organic carbon. Among the different N fertilizer and manure treated soil, green manure application with no N fertilizer had the highest annual C mineralization whereas the application of rice straw as manure with no N fertilizer had the lowest annual C mineralization. The annual carbon mineralization was found to be significantly influenced by different exogenous organic matter application. However, the influence of N fertilization on annual carbon mineralization was insignificant. Irrespective of N fertilization, on an average the highest annual C mineralization was calculated for green manure application (9.06%) followed by control (8.52%), rice straw (7.42%), cow dung (7.42%) and the lowest in compost (7.30%) (Fig 5). There was a significant difference in annual C mineralization between green manure, cow dung and compost. However, the annual C mineralization was statistically similar between control and green manure treated soil. This result indicates that more stable organic matter was formed in compost treated soil which is less prone to decomposition if present crop management has
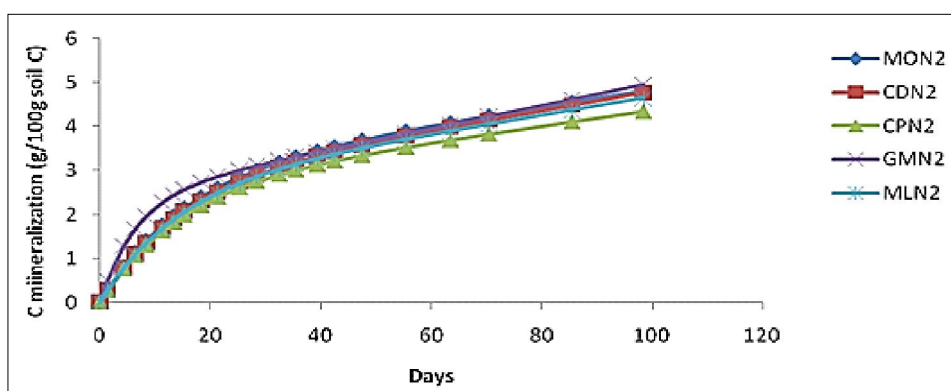

Fig 4: Cumulative C-mineralization expressed as percentage of the total SOC for different manure treated soil with 220kg N ha^{-1}.
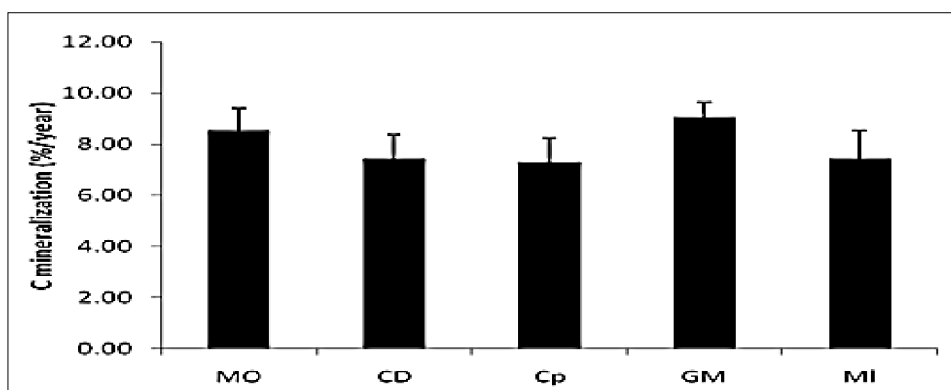

Fig 5: Annual C mineralization rates (%) as influenced by exogenous OM application in a highly weathered terrace soil field experiment (BSMRAU).
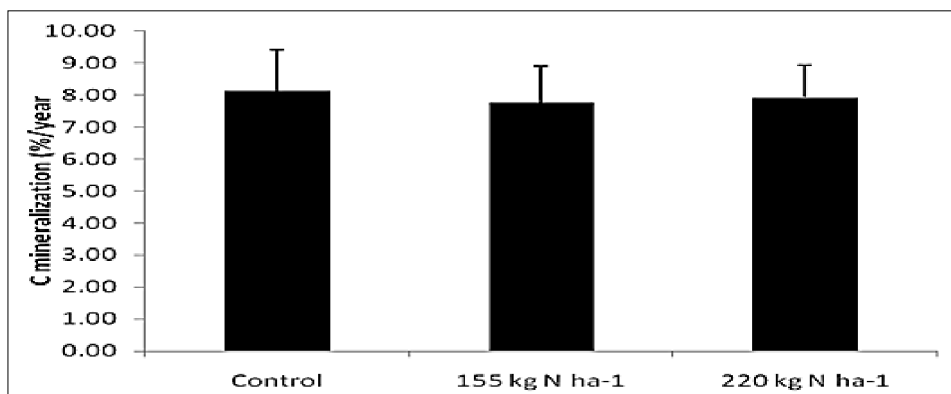

Fig 6: N fertilization influenced annual C mineralization rates (%) in a highly weathered terrace soil field experiment (BSMRAU).

Table 1: Estimated parameters of a fitted parallel first and zero order kinetic model.

Treatments	Parameters			
	C_{Af} (%)	K_f (% day^{-1})	K_s (% day^{-1})	R_2
0 kg N ha^{-1}yr^{-1}				
Control	2.726 (0.079)	0.067 (0.016)	0.025 (0.003)	0.991 (0.000)
Cow dung	2.226 (0.588)	0.078 (0.013)	0.021 (0.003)	0.997 (0.000)
Compost	2.607 (0.276)	0.069 (0.004)	0.023 (0.001)	0.997 (0.000)
Green manure	2.087 (0.177)	0.102 (0.031)	0.025 (0.006)	0.994 (0.003)
Rice straw	2.673 (0.054)	0.063 (0.006)	0.017 (0.001)	0.997 (0.001)
155 kg N ha^{-1}yr^{-1}				
Control	2.299 (0.028)	0.075 (0.009)	0.024 (0.001)	0.994 (0.002)
Cow dung	2.347 (0.124)	0.068 (0.003)	0.017 (0.004)	0.996 (0.001)
Compost	2.338 (0.214)	0.074 (0.002)	0.018 (0.001)	0.994 (0.001)
Green manure	2.105 (0.520)	0.077 (0.022)	0.023 (0.000)	0.993 (0.001)
Rice straw	2.727 (0.051)	0.066 (0.011)	0.023 (0.004)	0.994 (0.002)
220 kg N ha^{-1}yr^{-1}				
Control	2.854 (0.448)	0.068 (0.018)	0.020 (0.002)	0.995 (0.000)
Cow dung	2.625 (0.715)	0.071 (0.018)	0.022 (0.001)	0.995 (0.001)
Compost	2.589 (0.174)	0.071 (0.008)	0.018 (0.002)	0.994 (0.000)
Green manure	2.404 (0.105)	0.154 (0.006)	0.026 (0.000)	0.997 (0.001)
Rice straw	2.593 (0.639)	0.073 (0.022)	0.021 (0.004)	0.992 (0.002)
ANOVA				
OM treatment	NS	NS	NS	*
N level	NS	NS	NS	NS
OMxN level	NS	NS	NS	NS

NS for not significant, **Significant at $P \leq 0.01$ and *Significant $P \leq 0.05$.

Values in parentheses are standard errors on parameter estimates.

been changed. Other ward, compost has the highest potentiality as exogenous organic matter to soil for the purpose of carbon sequestration in highly weathered terrace soil compared to other organic amendments. It could be due to the fact that large amount of labile organic matter fraction were decomposed during the compost preparation. Annual C mineralization was always smaller where N fertilizer was applied compared to no N fertilization (Fig 6) though the differences were insignificant. It indicates that stable organic matter was formed in soil where no N fertilizer was applied. Between the N fertilization treatments, the lower annual C mineralization was calculated for soils treated with 155 kg N ha^{-1} compared with 220 kg N ha^{-1} (Fig 6). Long term (33 years) application of fertilizers and manure resulted in significant differences in the annual carbon mineralization. This result indicates that more stable organic matter was formed in NP treated soil which is less prone to decomposition if present crop management has been changed (Islam *et al.*, 2019).

CONCLUSION

Long term (28 years) application of mineral fertilizers and manure to the BSMRAU terrace soil showed that cumulative annual C mineralization evolved from SOM under field conditions varied from 6.21 to 9.31% of total soil organic carbon. The annual carbon mineralization was significantly influenced by different exogenous organic matter application.

However, the influence of N fertilization on annual carbon mineralization was insignificant. Irrespective of N fertilization, on an average the highest annual C mineralization was calculated for green manure application (9.06%) followed by control (8.52%), rice straw (7.42%), cow dung (7.42%) and the lowest in compost (7.30%). There was a significant difference in annual C mineralization between green manure, cow dung and compost. However, the annual C mineralization was statistically similar between control and green manure treated soil. This result indicates that more stable organic matter was formed in compost treated soil which is less prone to decomposition if present crop management has been changed. Other ward, compost has the highest potentiality as exogenous organic matter to soil for the purpose of carbon sequestration in highly weathered terrace soil compared to other organic amendments.

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