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EFFECT OF LONG TERM MANURING AND FERTILIZATION ON CARBON MINERALIZATION IN SOILS OF FINGER MILLET – MAIZE CROPPING SYSTEM IN *ALFISOLS*

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ABSTRACT

Quantitative information on carbon (C) mineralization of soil under different long term nutrient management is essential for better assessment of easily hydrolyzable C and loss of C from soil. With an aim to evaluate the differences in C mineralization due to long term fertilization and manuring treatments, a laboratory incubation study was conducted with soils (0-15 cm depth), collected from 33 years old finger millet – maize cropping system which involved application of 100% N, 100% NP, 50% NPK, 100% NPK, 150% NPK, 100% NPK + FYM (farmyard manure), 100% NPK + lime, control and uncultivated fallow land. Long-term application of fertilizers and manures significantly ($p < 0.05$) influenced C mineralization in soil. Long term integrated application of chemical fertilizers and organic manure in soil resulted in higher cumulative carbon mineralization, basal soil respiration (BSR), microbial and mineralization quotients. A judicious FYM application strategy through integration of both organic and inorganic sources is essential for improving and maintaining soil organic C pool.

Key words : Carbon, Mineralization, Cumulative mineralization, Basal soil respiration, Microbial quotient, Mineralization quotient, Long term fertilization, Farm yard manure.

Introduction

Soil organic matter is a major terrestrial pool for C, N, P, S and the cycling and availability of these elements are constantly being changed by microbial immobilization and mineralization (Liu *et al*., 2006). The rate of organic C mineralization and the equilibrium levels that can be maintained in different soils are crucial measures of potential soil productivity (Raffaldi *et al*., 1996). Mineralization of organic matter and accumulation of carbon in soil is affected by several environmental factors and management practices; further rate of mineralization has a strong relationship with quantity and quality of both applied and in situ organic matter of soil (Balkcom *et al*., 2009).

The turnover rate of different fractions of soil organic carbon determines the potential carbon storage and loss in the soil. The oxidation of easily mineralizable pool of organic C is mainly responsible for flux of CO_2 from soil to environment (Iqbal *et al*., 2009). Crop productivity substantially influences soil C turnover by differential C inputs, thus altering microbial activities responsible for C mineralization. Microbial indices (ratios between microbiological parameters) are often used to evaluate microbial ecophysiology indicating an inter-linkage between cell-physiological functioning and environmental factors (Anderson, 2003). Most of the studies on C mineralization are based on decomposition of added C to a soil of uniform C status, whereas, the present study determined the C mineralization in soil that have been treated with different nutrient management practices for 33 years.

Several studies have reported build-up of SOC as a result of long-term application of fertilizers and organic manure (Benbi, 2015). However, the mineralization potential of accrued C has not been adequately studied; consequently the underlying reasons for the development of SOC in long-term experiments are poorly understood. We hypothesized that the C mineralization in soil will be differently influenced by stabilized forms of SOC and newly added C through organic manure. Therefore, the specific objective of the present study was conducted to examine mineralization of SOC accumulated as a result of long-term application of fertilizers and manures to soil under finger millet – maize cropping system.

Materials and Methods

Location of the study area

The long term fertilizer experimental (LTFE) site in the Zonal Agricultural Research Station, GKVK campus of University of Agricultural Sciences, Bengaluru, India is located in Eastern Dry Zone of Karnataka at 13° 4' 37" N latitude, 77° 34' 13" E longitude with an altitude of 930 meters above mean sea level (MSL). The experiment was started during 1986-87 with two cropping sequence of finger millet - hybrid maize.

Experimental design and treatment details

The experiment consists of eleven treatments which are replicated four times in a Randomized Complete Block Design. However, for the present study only selected three replications of traditional treatments and one more additional treatment of fallow land adjacent to the LTFE site were considered. The details of experiment, treatments, recommended dose of fertilizers for the study crops, sources of fertilizers *etc*., are as follows.

Number of treatments : 9

Number of replications : 3

Design : Randomized Complete Block Design

Plot dimension : 16 m × 9 m

Cropping sequence : Finger millet (*Kharif*) - Hybrid maize (*Rabi-summer*)

Table 1 : Details of the treatments and fertilizer sources.

Treatment	Fertilizer Source
T_1: 50% NPK	Urea, SSP, MOP
T_2: 100% NPK	Urea, SSP, MOP
T_3: 150% NPK	Urea, SSP, MOP
T_6: 100% NP	Urea, SSP
T_7: 100% N	Urea
T_8: 100% NPK + FYM	Urea, SSP, MOP
T_{10}: 100% NPK + FYM + lime	Urea, SSP, MOP, lime
T_{11}: Control	—
T_{12}: Fallow land	—

Lime was applied based on lime requirement following the method given by Shoemaker *et al*. (1961) during *kharif* season. If the pH is more than 6.00 then lime is applied @ 500 kg ha^{-1}. Well decomposed farmyard manure (FYM) at the rate of 15 t ha^{-1} has been incorporated every year into the soil 10-15 days prior to sowing of the *kharif* crop (Details of fertilizer dose is missing).

Carbon mineralization

Soil samples collected in the LTFE plots treatment wise after the harvest of maize crop (2020) were processed and used for the carbon mineralization study. Carbon mineralization was studied in the laboratory by conducting aerobic incubation under controlled conditions. 200 grams of soil was wetted to 50% water-filled pore space and placed in a 1000 mL conical flask along with vials containing 10 mL of 0.1M NaOH to trap evolved CO_2 and incubated for 32 days at 25 ± 1^{0}C. Alkali traps were replaced at 1, 2, 3, 4, 5, 7, 9, 11, 14, 17, 20, 23, 26, 29 and 32 days after incubation. Evolved CO_2 was determined by titrating the alkali in the traps with 0.1 M HCl using phenolphthalein as indicator. The CO_2 evolved in 32 days of incubation was used as cumulative mineralization (CO_2- C_{cum}). Basal soil respiration (BSR), an estimate of potential microbial activity, was calculated as the linear rate of respiration during 29th to 32nd day of incubation because during that period the soil reached a relatively constant hourly CO_2 production rate. Microbial indices (microbial quotient and mineralization quotient) were calculated by using the formulas mentioned as follows:

$$\text{Microbial quotient}(\mu g \text{ of biomass C } \mu g \text{ TOC}^{-1}) = \frac{\text{Microbial biomass carbon (MBC)}}{\text{Total organic carbon}}$$

$$\text{Mineraliation quotient } (\mu g \text{ of biomass C } \mu g \text{ TOC}^{-1}) = \frac{\text{Cumulative } CO_2\text{- evolved in 32 days}}{\text{Total organic carbon}}$$

Results and Discussion

Effect of long term application of organic manure and fertilizers on soil mineralizable carbon

Carbon mineralization rate varied significantly among the different treatments from the initial day of incubation experiment. Cumulative mineralization of carbon in different treatments is represented in the Table 2 and Fig. 1.

Carbon mineralization was significantly higher in the treatments that received farm yard manure along with inorganic fertilizers. The rate of carbon mineralization

Table 2 : Effect of long term manuring and fertilization on cumulative carbon mineralization (μg g^{-1}) in soil under finger millet-maize cropping system.

Treatment	1st day	2nd day	3rd day	4th day	5th day	7th day	9th day	11th day	14th day	17th day	20th day	23rd day	26th day	29th day	32nd day
T_1: 50% NPK	17	43	83.00	113.00	139.00	217.00	269.00	289.00	310.00	324.00	340.00	354.00	375.00	391.00	414.00
T_2: 100% NPK	26	66	104.00	140.00	186.00	263.00	333.00	371.00	399.00	422.00	446.00	467.00	486.00	505.00	534.00
T_3: 150% NPK	39	84	135.00	200.00	264.00	352.00	423.00	466.00	509.00	555.00	599.00	627.00	653.00	679.00	710.00
T_6: 100% NP	10	29	52.00	80.00	113.00	179.00	226.00	243.00	261.00	271.00	285.00	295.00	304.00	317.00	334.00
T_7: 100% N	7	20	35.00	60.00	91.00	151.00	192.00	208.00	218.00	226.00	236.00	244.00	252.00	264.00	282.00
T_8: 100% NPK+FYM	41	87	139.00	217.00	304.00	401.00	480.00	529.00	590.00	641.00	686.00	716.00	742.00	772.00	802.00
T_{10}:100%NPK+FYM+lime	48	97	151.00	237.00	321.00	415.00	495.00	550.00	611.00	666.00	701.00	735.00	758.67	788.00	820.00
T_{11}: Control	9	21	38.00	63.00	96.00	141.00	172.00	182.00	195.00	202.00	214.00	222.00	228.00	237.00	250.00
T_{12}: Uncultivated soil	17	42	71.00	101.00	133.00	200.00	252.00	277.00	304.00	322.00	341.00	358.00	368.00	385.00	415.00
SEm±	**2.51**	**4.31**	**7.49**	**6.84**	**8.69**	**8.72**	**8.37**	**8.47**	**8.43**	**8.26**	**9.32**	**9.90**	**10.27**	**10.89**	**11.29**
CD @ 5%	**7.36**	**12.65**	**21.97**	**20.07**	**25.49**	**25.58**	**24.55**	**24.86**	**24.73**	**24.23**	**27.33**	**29.03**	**30.13**	**31.93**	**33.11**

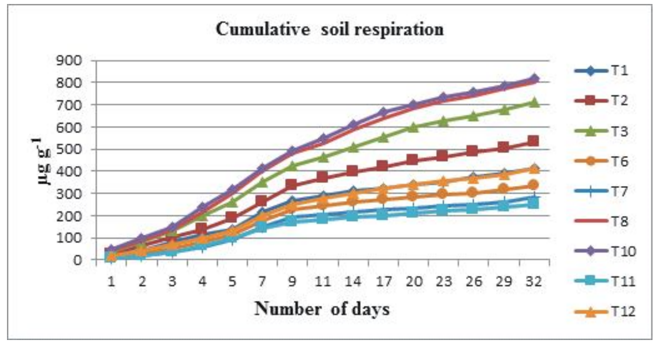

Fig. 1 : Effect of long term manuring and fertilization on cumulative carbon mineralization (μg g^{-1}) in soil under finger millet-maize cropping system.

was recorded significantly higher in T_{10}: 100% NPK + FYM + lime (820 μg g^{-1} of soil), which was on par with the plot treated with FYM + 100% NPK (T_8: 802 μg g^{-1} of soil). Application of super optimal dose of inorganic fertilizer (T_3: 150% NPK) has markedly increased cumulative carbon mineralization over 32 days of incubation period compared with the treatment received sub optimal dose (T_1: 50% NPK) of fertilizer. The carbon mineralized from T_3 and T_1 throughout the incubation period was 710 μg g^{-1} of soil and 414 μg g^{-1} of soil, respectively. Significantly lesser carbon mineralization was noticed in an absolute control treatment (T_{11}: 250 μg g^{-1} of soil) and it was on par with the treatment received only 100% N (T_7: 282 μg g^{-1} of soil). Application of lime along with 100% NPK has recorded increased values of carbon mineralization compared with the plots treated with 100% NPK. Carbon mineralization in the uncultivated soil did not recorded any higher values when compared with the FYM treated plots.

The SOC mineralization was faster at the beginning of the incubation study, which progressively decreased with the increase in time. The decrease in decomposition rate over time is probably due to rising concentrations of structural carbohydrates (such as lignin and hemicelluloses) as a result of the loss of other constituents (sugars and starches) in the detritus (Mfilinge *et al.*, 2002). The treatment, 100% NPK + FYM+ lime showed greatest cumulative carbon mineralization throughout the incubation period, while the lowest mineralization was observed in control. Higher mineralization potential observed under NPK compared to imbalanced fertilizer application (100% NP and 100% N alone) can be attributed to the long term extraneous application of balanced fertilizer (100% NPK) that could prevent the depletion of soil nutrients and at the same time maintained higher level of organic carbon through recycling of biomass which facilitated the growth of microbes. Rudrappa *et al.* (2006) reported that, the differences in the rates of C mineralization are indicative of the variable amounts of labile organic C accumulated in different fertilizer treatment.

Microbial activity, total organic C and several other physical and chemical parameters determine the mineralization potential of soil. Studies on long term fertilizer experiment showed integrated application of chemical fertilizer and organic manures apart from creating favorable environment for growth and activity of microorganisms also provided substrates for the mineralization processes. Similar results were also reported by Chen *et al.* (2008). The lowest value in the unfertilized control plot seems to be related to the unfavorable environment in the control arising out of the depletion of nutrients due to continuous cropping without any fertilization. This results in the depletion of nutrients and negatively affects the physical, chemical and biological parameters of soil thus creates an unfavourable environment for the microbial activity.

Effect of long term application of organic manure and fertilizers on basal soil respiration

The BSR has been considered as a sensitive indicator of soil quality, and has been considered a valid biomarker to reflect changes in soil microbial activity in response to a change in soil management, agronomic practices and climates (Saikia *et al*., 2020).

Basal soil respiration varied significantly among the different treatments during the incubation study. The results obtained are presented in Table 3 and Fig. 2.

The different treatments had a significant impact on basal soil respiration. Basal soil respiration over 32 days of incubation period recorded significantly higher value of 0.444 µg CO_2-C g^{-1} hr^{-1} in the treatment that received FYM and lime along with 100% NPK (T_{10}), which was on par with the treatment received 150% NPK (T_3: 0.431 µg CO_2-C g^{-1} hr^{-1}) and the plot treated with FYM along with 100% NPK (T_8: 0.417 µg CO_2-C g^{-1} hr^{-1}). The BSR was highest under integrated application of fertilizer, FYM and was higher than untreated control. Similar results were reported by Majumder *et al*. (2008). The availability of easily decomposable organic matter and readily available nutrients provided conducive environment for microbial activity, resulting in higher rate of respiration (Sayre *et al*., 2005).

Basal soil respiration was significantly maintained lower values throughout 32 days of incubation period in an absolute control treatment (T_{11}: 0.181 µg CO_2-C g^{-1} hr^{-1}), which was on par with the treatment T_7 (100% N: 0.250 µg CO_2-C g^{-1} hr^{-1}) followed by the treatment received 100% NP (T_6: 0.236 µg CO_2-C g^{-1} hr^{-1}).

Table 3 : Effect of long term manuring and fertilization on basal soil respiration (µg CO_2-C g^{-1} hr^{-1}) in soil under finger millet-maize cropping system.

Treatment	1st day	2nd day	3rd day	4th day	5th day	7th day	9th day	11th day	14th day	17th day	20th day	23rd day	26th day	29th day	32nd day
T_1: 50% NPK	0.708	1.083	1.667	1.250	1.500	1.417	1.083	0.417	0.887	0.194	0.222	0.194	0.292	0.222	0.319
T_2: 100%NPK	1.083	1.667	1.583	1.500	1.917	1.604	1.458	0.792	0.984	0.319	0.333	0.292	0.264	0.264	0.403
T_3: 150%NPK	1.625	1.875	2.125	2.708	2.667	1.833	1.479	0.896	1.589	0.639	0.611	0.389	0.361	0.361	0.431
T_6: 100%NP	0.417	0.792	0.917	1.208	1.375	1.375	0.979	0.354	0.581	0.139	0.194	0.139	0.125	0.181	0.236
T_7: 100%N	0.292	0.542	0.625	1.042	1.292	1.250	0.854	0.333	0.271	0.111	0.139	0.111	0.111	0.167	0.250
T_8: 100%NPK+FYM	1.708	1.917	2.167	3.250	3.625	2.021	1.646	1.021	2.302	0.708	0.625	0.417	0.361	0.417	0.417
T_{10}:100%NPK+FYM+lime	2.000	2.042	2.250	3.583	3.500	1.958	1.667	1.146	2.302	0.764	0.486	0.472	0.333	0.403	0.444
T_{11}: Control	0.375	0.500	0.708	1.042	1.292	0.979	0.646	0.208	0.445	0.097	0.167	0.111	0.083	0.125	0.181
T_{12}: Uncultivated soil	0.708	1.042	1.208	1.250	1.333	1.396	1.083	0.521	1.036	0.250	0.264	0.236	0.139	0.236	0.417
SEm ±	**0.105**	**0.124**	**0.157**	**0.172**	**0.150**	**0.071**	**0.067**	**0.057**	**0.438**	**0.038**	**0.036**	**0.029**	**0.031**	**0.028**	**0.038**
CD @ 5 %	**0.307**	**0.362**	**0.461**	**0.504**	**0.439**	**0.209**	**0.197**	**0.167**	**1.285**	**0.112**	**0.106**	**0.084**	**0.091**	**0.082**	**0.112**

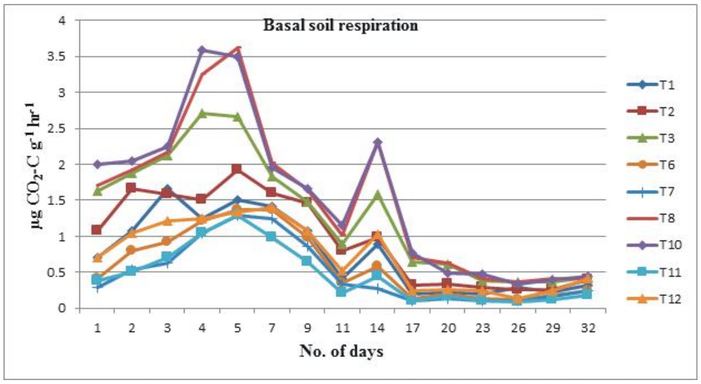

Fig. 2 : Effect of long term manuring and fertilization on basal soil respiration (μg g^{-1}) in soil under finger millet-maize cropping system.

Application of lime along with 100% NPK has not shown any significant effect, but it increased basal soil respiration over the treatments received inorganic fertilizers and T_{10} over T_8. Application of suboptimal dose (50% NPK) of fertilizer has recorded lower basal respiration values (T_1: 0.319 μg CO_2-C g^{-1} hr^{-1}) compared to the treatments received optimal dose (100% NPK) of fertilizer (T_2: 0.403 μg CO_2-C g^{-1} hr^{-1}, T_4: 0.472 μg CO_2-C g^{-1} hr^{-1} and T_9: 0.403 μg CO_2-C g^{-1} hr^{-1}). Basal soil respiration in the uncultivated soil was lower (T_{12}: 0.417 μg CO_2-C g^{-1} hr^{-1}), when compared to the treatments received 100 per cent of inorganic fertilizer and FYM in combination. Similar results were reported by Sharma *et al.* (2020). The lower BSR for the uncultivated and the cultivated soils under cotton–wheat cropping system indicates reduced root respiration rates, which are associated with a lower nutrient, labile C and C stability in the cultivated soils (Fuentes *et al.*, 2009).

The BSR reflects the catabolic degradation of soil microbial communities under aerobic conditions. It decreased according to the order of 100% NPK+FYM >150% NPK > 100% NPK >100% N > untreated control. Treatments had statistically similar values of BSR (Chakraborty *et al.*, 2011). The lower value of qCO_2 and ratio of BSR to Cmic in soils with balanced fertilization and C supplementation have been reported by many (Goyal *et al.*, 1993; Lupwayi *et al.*, 1998). High value of qCO_2 and ratio of BSR to Cmic for fallow are indicative of the presence of readily mineralizable C that has not yet led to growth of the microflora (Franzluebbers *et al.*, 1999). The increase of qCO_2 was also reflected in an increase in the ratio of active: dormant components of the microbial population.

Effect of long term application of organic manure and fertilizers on soil microbial indices

Microbial indices in the soil treated with continuous application of manures and fertilizers after 33 years of cropping sequence under finger millet – maize cropping system varied significantly among the different treatments. The results obtained are presented in Table 4.

The microbial quotients are important indicators to assess the long term impact of nutrient management practices on soil quality (Liu *et al.*, 2010). A high microbial quotient generally implies presence of easily available C pool that sustains a large microbial community (Nilsson *et al.*, 2005).

Microbial quotient was significantly higher in the treatment T_2: 50% NPK (2.98 μg of biomass C 100 μg total organic C^{-1}), which was on par with the treatment T_{11}: absolute control (2.87 μg of biomass C 100 μg total organic C^{-1}). Significantly lower microbial quotient was recorded in the treatments that has received FYM along with 100% NPK [T_8: 100% NPK + FYM (1.92 μg of biomass C 100 μg total organic C^{-1})], which was on par with T_{10}: 100% NPK + FYM + lime (2.36 μg of biomass

Table 4 : Effect of long term manuring and fertilization on soil microbial indices under finger millet-maize cropping system.

Treatment	**Microbial quotient (μg of biomass C μg total organic C^{-1})**	**Mineralization quotient (μg CO_2-C 100 $μg^{-1}$ TOC)**
T_1: 50% NPK	2.85	5.00
T_2: 100% NPK	2.98	6.18
T_3: 150% NPK	2.80	7.63
T_6: 100% NP	2.70	4.13
T_7: 100% N	2.72	3.75
T_8: 100% NPK + FYM	1.92	5.99
T_{10}:100% NPK + FYM + lime	2.36	6.74
T_{11}: Control	2.87	3.67
T_{12}: Uncultivated soil	2.23	2.86
SEm ±	**0.227**	**0.2428**
CD @ 5%	**0.667**	**0.712**

C μg 100 total organic C^{-1}). Application of super optimal dose (T_3: 150% NPK) of fertilizer has lower microbial quotient of 2.80 μg of biomass C 100 μg total organic C^{-1} compared to the treatment that received optimal dose (T_2: 100% NPK) of inorganic fertilizer and suboptimal dose (50% NPK) of fertilizers with the values of 2.98 μg of biomass C 100 µg total organic C^{-1} and 2.85 µg of biomass C 100 µg total organic C^{-1}, respectively. Rudrappa *et al*. (2006) reported that microbial metabolic quotient was significantly lower in 100 per cent NPK + FYM to make it the most efficient manuring practice to preserve organic carbon in soil. A low microbial quotient suggests a higher accumulation of resistant organic carbon pool. This suggests an accumulation of resistant pool of C in the treatment NPK + FYM. Balanced fertilization with NPK provided better nutrition to microbial population thus increased the quotient over sole N or NP particularly in surface soil.

Mineralization quotient was recorded significantly higher value in the treatment received super optimal dose of fertilizer [T_3: 150% NPK (7.63 µg of biomass C 100 µg total organic C^{-1})] followed by the treatment which has received FYM along with 100% NPK (6.74 µg of biomass C 100 µg total organic C^{-1}). Mineralization quotient was significantly lower in uncultivated soil (T_{12}: 2.86 µg of biomass C 100 µg total organic C^{-1}) which was on par with absolute control treatment (T_{11}: 3.67 µg of biomass C 100 µg total organic C^{-1}) followed by the plot treated with imbalanced nutrient supply of 100% N (T_7: 3.75 µg of biomass C 100 µg total organic C^{-1}).

Higher mineralization quotient observed in the treatments with balanced application of chemical fertilizer suggests higher efficiency of utilization and conservation of organic matter under the particular nutrient management (Mocali *et al*., 2008). With the combined application of chemical fertilizer and organic manure, the immediate N requirement of plant was met from the chemical fertilizer; only a fraction of the organic N in manure is mineralized during the season of application, while the remainder decomposes slowly over many years (Endelman *et al*., 2010).

Conclusion

Our observations showed significant variations in carbon mineralization due to long term fertilization and manuring practices; higher potentially mineralizable C was recorded under combined application of chemical fertilizer and FYM. Apart from that higher values of microbial and mineralization quotients were also observed in balanced fertilizer treated plots. Moreover, 3 decades of manure application significantly improved the C mineralization potential for SOC. The turnover rate of mineralization for SOC is ascribed to higher microbial activities which are crucial for the breakdown of organic matter. Therefore, maintaining soil fertility depends on the biomass of microorganisms and the activity of extracellular enzymes, which are crucial in SOC mineralization potential. Future studies need to quantify net ecosystem C budget to understand the effect of long-term nutrient management practices on soil's feedback to atmospheric CO_2.

Conflict of interest : None

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