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Soil carbon efflux and sequestration as a function of relative availability of inorganic N pools in dry tropical agroecosystem

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ABSTRACT

The complex interaction between nitrogen (N) availability and soil organic carbon (SOC) dynamics in the nutrient-limited dry tropical agroecosystem requires investigation in the changing climatic conditions. Organic amendment shows a direct linkage between nutrient availability and SOC dynamics, and improves SOC by mediating soil physicochemical and biological properties. Therefore, plots under various ages of organic cultivation (viz., organic plots under one (O_1), three (O_3), five (O_5) and ten (O_{10}) years) along with nearby native forest ecosystem (REF) were taken in this study to explore the linkage between the nutrient availability and SOC dynamics. Soil moisture content (SMC), soil temperature, SOC, soil carbon efflux (SCE), microbial biomass carbon (MBC), soil ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N) were investigated. SMC showed positive (power and linear) while the soil temperature showed polynomial (quadratic) relationship with SCE. Interestingly, the soil temperature and SMC also showed contrasting relationships with the soil ammonium-N:nitrate-N ratio (ANR) in the summer season. Further, the ANR was also observed to indirectly govern SOC by affecting MBC and SCE, particularly in summer. It suggests that the long term organic amendment indirectly sequesters SOC by moderating SCE, through increase in the ANR, possibly by affecting the microbial community associated with nitrification. Therefore, consideration of the ANR in SOC management assessment in the dry tropical agroecosystem, owing to its significant coverage and C-sink potential, may help to mitigate the rapidly increasing, CO_2-induced global climate change. It also indicates that the organic amendments may potentially nullify the predicted positive climate change-carbon cycle feedback. Thus, inclusion of the ANR in climate models may better predict the future course of climate.

1. Introduction

Identification of the factors controlling soil carbon dynamics is necessary for understanding the changing global carbon cycle (Neff and Hooper, 2002). It is proposed that soil ecosystem may acclimatize with the warming temperature through changes in microbial physiology rather showing predicted positive climate change-carbon cycle feedback (Luo et al., 2001). Soil moisture content (SMC) and temperature are identified as major regulators of the soil organic carbon (SOC) dynamics in the tropical ecosystems (Singh and Gupta, 1977; Davidson et al., 2000). Further, they also affect the N-mineralization (Cassman and Munns, 1980), and thus N availability, which is crucial in the functioning of dry tropical ecosystem (Jha et al., 1996). However, the key driver working at the intersection of these regulators (i.e., SMC and soil temperature), having an immediate relationship with SOC dynamics is yet unidentified due to the complexity of interactions (Davidson et al., 2000).

Forest to agriculture conversion in the dry tropics affects soil physicochemical properties and nutrient dynamics (Srivastava and Singh, 1991) resulting in the SOC loss as soil carbon efflux (SCE) (Lal, 2004). In the face of burgeoning atmospheric concentration of CO_2, agroecosystem has also been identified as a potential carbon sink (Lal, 2004), if managed properly. For example, in the past decades, the beneficial impact of organic over the conventional agro-management on SOC dynamics (Gattinger et al., 2012), has been reported to be primarily mediated by microbial community

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change (Peacock et al., 2001). The interactions between soil biological processes and physical factors within soil have been found crucial in the production and consumption of greenhouse gases (Smith et al., 2003). For example, the interactions between microbial processes and abiotic factors play central role in SCE (Singh et al., 2010). It has been reported that the SMC and soil temperature, which affect SCE (Singh and Gupta, 1977) by modifying the SOC dynamics in management-specific manner (Alvaro-Fuentes and Paustian, 2011), also regulate N-mineralization (Cassman and Munns, 1980). So far, the complex relationship between the N availability and SOC storage has not been considered in the SOC mechanistic models (Neff and Hooper, 2002), leading to the conflicting future predictions.

Profound seasonal effect on the soil N availability viz., ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N), governs the functioning of nutrient-limited dry tropical ecosystems (Jha et al., 1996). Their behavior under high soil temperature may be of environmental significance in these ecosystems, due to wide coverage and their potential ability to acclimatize to the increasing soil temperature. The organic amendment in agroecosystem shows a direct linkage between the nutrient availability and SOC dynamics (Buchanan and King, 1992), and improves SOC by mediating soil physicochemical and biological properties. The present study aims to identify that how SMC and soil temperature interactively affect the availability of inorganic-N and SOC dynamics. Therefore, to understand their close interrelationship under organic cultivation, following objectives were undertaken (1) to observe the variation in the SOC and SCE with the age of organic cultivation, (2) to observe the concomitant variation in the soil physical (SMC and soil temperature), chemical (inorganic-N availability) and biological (microbial biomass) properties, and (3) to identify the mechanism by which soil physicochemical properties affect SOC dynamics.

2. Materials and methods

2.1. Study area

The study sites are located in Vindhyan highlands, having a typical monsoonal, seasonally dry tropical climate characterized by a cold winter (10–25 °C), a hot and dry summer (30–45 °C), and a warm rainy season (24–36 °C). The annual rainfall averages 820 mm, of which 86% occurs during the rainy season. The soils of these sites are residual, well-drained, sandy to sandy-loam textured Ultisols (Singh et al., 1989). It bears shallow, intensively leached, nutrients- and organic matter-deficient soil having the moderate water holding capacity (Roy and Singh, 1994). The organic sites, located in Dagmagpur area, were earlier under conventional management, which were brought under organic management since 2000 with a moderate rate of manure application (about 5–7 ton ha^{-1} year^{-1}). One site, referred as O_1 in this study, has been brought in organic management just with the onset of the first sampling. Therefore, we have also considered this system as a representative of soil degradation under conventional management system for comparative examinations.

2.2. Experimental design and analysis

The experimental design includes soil sampling on the season's peak during winter (December/January), summer (April/May) and rainy (August) season (Roy and Singh, 1994) in the year 2010 and 2011 from four organic sites (O) under varied cultivation ages (1, 3, 5 and 10 years; respectively referred as O_1, O_3, O_5 and O_{10}) having rice-wheat-fallow cropping system and one native forest as reference (REF). Each site was comprised of three plots (25 m × 25 m). Soil samples were collected from 0–15 cm depth using a soil corer following a simple random sampling approach. From each plot, one sample was prepared by the mixing of five random subsamples. Standard methods for soil percent fine particle (texture), SMC, SOC, soil organic nitrogen (SON), soil nitrate-N (NO_3^--N), soil ammonium-N (NH_4^+-N) were followed, as applied by a previous researcher working in the same area (Raghubanshi, 1992). Microbial biomass C (MBC) was estimated using the chloroform fumigation extraction method (Vance et al., 1987). Soil temperature was taken using a temperature probe attached with LI-COR 6400 photosynthetic meter.

2.3. Measurement of soil CO_2 efflux

Soil CO_2 efflux was measured by a closed chamber method using an IRGA (Infra-Red Gas Analyzer) based LI-COR photosynthetic meter (LI-6400-09, LI-COR Inc., Lincoln NE, USA). Three polyvinyl chloride collars (having 6 cm height and 11 cm internal diameter) were randomly inserted at each site to a depth of 2 cm, a day before measurement. The measurements were taken between 10:00 and 11:00 h of the day (Kaye et al., 2005).

2.4. Statistical analysis

All the statistical analyses were performed using SPSS software (version 16) package. Data on the soil physicochemical properties, MBC and SCE were subjected to ANOVA and Post hoc (Tukey) for testing the differences across the systems. Also, stepwise regression analysis was performed to identify the major determinant of SOC and SCE.

3. Results and discussion

We used compost based organic systems as it better shows the direct linkage between the SOC dynamics and nutrient availability (Buchanan and King, 1992). To examine the relative sensitivity of SOC and SON in the dry tropical agroecosystem to the conventional and organic management, their loss and recovery under respective management systems were observed. Forest conversion to conventional agro-management (as represented by O_1) showed higher loss of SON than SOC (66.75 vs 35.2%, respectively), whereas the organic system after ten years (i.e., O_{10}) showed higher recovery of the SON than SOC (162.1 vs 46.8%) (Fig. 1a). It is consistent with the results reported by Hu et al. (1997). It suggests the high sensitivity of SON to agro-management than SOC, and comparatively better N use efficiency in the organic systems (Dhar and Pant, 1944). It may possibly be due to shift in microbial community (Peacock et al., 2001). It also suggests that SON may have primary importance in the SOC loss and sequestration, which may possibly be attributed to its role in the nitrification (Quastel and Scholefield, 1949).

To examine the relationship between SOC and SCE, regression analysis was performed (n = 15). Positive and linear relationship (R^2 = 0.725, p < 0.001, n = 15) observed between them confirms the general supposition that more SOC emit more SCE (Singh and Gupta, 1977). To examine the effect of the organic amendment on SOC and SCE, Post hoc (Tukey) analysis was performed. We found significantly (p < 0.05) similar SOC (Fig. 1a) and SCE (seasonal) pattern (i.e., highest in rainy and lowest in winter) between O_{10} and REF (Fig. 1b). It indicates that organic system may achieve functional similarity to the REF after ten years of cultivation. Further, to examine the SCE response across season in the nutrient-limited dry tropical agroecosystem, seasonal means were compared by post hoc analysis. Compared to rainy season, significant decrease by 65.8 and 83.3% in SCE was observed in the winter and summer season, respectively. It suggests that processes which are affected at high soil temperature and low SMC, typical to summer season, might