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Effect of long-term nutrient managements on biological and biochemical properties of semi-arid tropical Alfisol during maize crop development stages

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ABSTRACT

Understanding the influence of organic or inorganic nutrient management on soil biology and biochemistry during crop growth may help to develop more sustainable fertilization strategies. Hence, the biological variables including soil organic carbon (SOC), microbial biomass carbon (MBC), six cultivable microbial communities, five hydrolytic enzymes activity and soil respiratory indices from a long-term fertility experiment field (>100 years) were assessed at different growth stages of maize. The samples were taken from four long-term treatments viz., control (no fertilization), balanced inorganic fertilizers (IC), organic amendments (OM) and integrated nutrient management (INM, organic manure plus chemical fertilizers) at five different stages of maize cropping (S1, pre-cropping; S2, five days after sowing; S3, vegetative; S4, flowering; S5, after harvesting). Responses of most of the assessed parameters to organic fertilization (OM and INM) were significantly higher than those from inorganically managed and control soils. There was significant difference in SOC due to long-term nutrient managements (OM > INM > IC > control) but not due to growth stages of maize. MBC was also higher in OM and INM compared to IC and control and found significantly different at growth stages of maize. Values of microbial counts and assessed enzyme activities were highest at vegetative stage of maize following a declined trend at later stages. The respiration studies indicate a difference between the responses of substrate induced respiration rate (SIR) and metabolic quotient (qCO_2). SIR was more significantly influenced by long-term nutrient managements than crop stages, while qCO_2 was by early stage of maize growth (S2) alone. The principal component analysis (PCA) identifies MBC, qCO_2, SIR, dehydrogenase, phosphatase and aryl sulphatase and counts of Actinobacteria and diazotrophs as major drivers for the variability among the samples. PCA discriminated OM and INM samples from IC and control and vegetative stage of maize from other stages. The interaction effects of long-term nutrient managements and maize growth stages were found significant to MBC, counts of Actinobacteria and diazotrophs and activities of dehydrogenase, acid phosphatase and aryl sulphatase. However, the resilience of semi-arid tropical soil, independent of long-term nutrient management adoptions, was not affected due to maize growth. The present study thus provides some reliable biological indicators to monitor the semi-arid tropical soils, those influenced by nutrient managements.

1. Introduction

Soil microorganisms play a key role in nutrients cycling, decomposition of organic residues for plant nutrition and soil structure and fertility. Altering the microbiome may affect the soil ecosystem functioning, nutrient cycling and the crop productivity (Fierer and Jackson, 2006). Equally, the hydrolytic enzymes are important components involved in the dynamics of soil nutrient transformations and their activity in soil is considered to be a major contributor of overall soil microbial activity (Frankenberger and Dick, 1983) and soil quality (Visser and Parkinson, 1992). Hence maintaining the microbial diversity and abundance is very much essential for sustainable agricultural production and long-term soil fertility. Several abiotic and biotic factors (Zak et al., 2003; Sheik et al., 2011) and anthropogenic activities including

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manuring (Gomez et al., 2006), pesticide application (Heilmann et al., 1995) and agronomic practices (Phillips et al., 2000) influence the soil microbial diversity and activity. Nutrient management, the primary agricultural practice, has a significant impact on the soil microbiome. The long-term organic fertility management favored the microbial abundance, diversity and activity of soil (Birkhofer et al., 2008; Chinnadurai et al., 2014) by increasing the soil organic carbon (SOC). The use of inorganic synthetic fertilizers [nitrogen (N), phosphorus (P) and potassium (K)] also brings change in soil properties including enzymes and microbiome (Islam et al., 2009). However, Zhong and Cai (2007) reported that long-term practice of balanced mineral fertilizers (NPK) may cause negligible deleterious effects to the soil biological properties than those from unbalanced fertilization (NP, NK, PK).

The Indian agricultural soils are arable, semi-arid and low in SOC and macro and micronutrients and are under increased pressure to provide food and fiber for ever-increasing population. The agricultural system is a monsoon-driven and low-input farming with limited nutrient management options. The Indian farmers are using organic manures with relatively low quality and quantity to meet the plant nutrients (Roy et al., 2006). With reference to the inorganic chemical fertilization, over-dose of nitrogen and low or nil quantities of P and K application is common to most of the crops (Tandon, 2004). In India, the ratio of chemical fertilizers applied bears no relationship with the ratio of plant nutrients are absorbed by crops or the ratio in which these are removed with the harvest (Roy et al., 2006). This practice further worsened the soil biochemical properties, in turn may cause a threat for the productivity in future. Therefore, continuous monitoring of these soils is essential for developing strategies to sustain the agricultural production (Chand, 2010).

Long-term fertilizer experiments (LTFEs) are valuable assets for assessing soil fertility changes and nutrient dynamics and for predicating soil carrying capacity and yield trends (Dalal and Mayer, 1986; Albiach et al., 2000; Marinari et al., 2000; Kautz et al., 2004; Manna et al., 2005; Hati et al., 2006; Masto et al., 2006; Balachandar et al., 2014; Chinnadurai et al., 2014). Most of the earlier reported are samples obtained at the beginning or at the end of the cropping in order to report the long-term consequences. However, only very few studies have reported the information on the biological processes, such as enzyme activities during active crop growth stages (Barnard et al., 2006; Mandal et al., 2007; Nayak et al., 2007; Masto et al., 2013). Understanding the pattern of fluctuation of soil biological variables during crop growth is of greater importance in relation to nutrient supplying capacity of the ecosystem and crop requirement. Yet, no comprehensive study was conducted so far on biological properties of soil exposed to long-term nutrient management regimes during crop growth stages. Therefore, the present investigation was undertaken to assess the impact of organic, inorganic and integrated nutrient managements on microbial and biochemical properties of semi-arid tropical agro-ecosystem during maize cropping.

2. Materials and methods

2.1. LTFE and sampling

The long-term fertilizer experiment, being conducted in Alfisol (Typic Haplustalf) since 1909 at Tamil Nadu Agricultural University, Coimbatore, India (11°N latitude, 77°E longitude, and 426 m altitude), was selected for this study. The experiment area is characterized as semi-arid sub-tropical climate with a mean annual precipitation of about 670 mm and mean annual maximum and minimum air temperature of 34.2 and 20.0 °C, respectively. The soil is characterized by red sandy loam, arable, enriched with aluminum and iron minerals and low in SOC. It has high contents of available Ca, Mg, K and Na and low in available N and P [Initial soil properties as Table 1, Arulmozhiselvan et al., 2012]. Maize (1st week of June to last week of September) followed by sunflower (2nd week of December to 3rd week of March) is the crop rotation being adopted in the experimental field.

Table 1
Initial physio-chemical properties of long-term fertilizer experimental soil.

Physio-chemical properties	Value[a]
pH	8.30
Electrical conductivity ($dS\,m^{-1}$)	0.25
Soil organic carbon ($mg\,g^{-1}$)	2.90
Available N ($mg\,kg^{-1}$)	145.0
Available P ($mg\,kg^{-1}$)	4.8
Available K ($mg\,kg^{-1}$)	303.0
Available copper ($\mu g\,kg^{-1}$)	1.0
Available manganese ($\mu g\,kg^{-1}$)	12.6
Available iron ($\mu g\,kg^{-1}$)	2.0
Available zinc ($\mu g\,kg^{-1}$)	1.6

[a] Data adopted from Arulmozhiselvan et al. (2012).

Four long-term non-replicated treatment plots ($100\,m^2$) were chosen for this study. Inorganic nutrient management enforced soil (IC) refers to the long-term treatment soil in which 60:20:10 ($kg\,ha^{-1}$) of inorganic N, P_2O_5 and K_2O were applied in the form of urea, super phosphate and muriate of potash, respectively. Organic nutrient management enforced soil (OM) received composted cattle manure on the nutrient equivalent basis corresponding to IC plots. The manure was incorporated into the soil during last ploughing before sowing of every crop. Integrated nutrient management adopted soil (INM) refers the treatment soil in which inorganic fertilizers were applied as similar to IC but with cattle manure ($12.5\,t\,ha^{-1}$). Control refers to the soil in which crop raised without any nutrient input. All the plots were ploughed using country-plough, added with different nutrient amendments and leveled manually. After field preparation, maize was sown on 5th June 2012 with a crop spacing of 75×25 cm. The crop was irrigated as and when required and was kept weed-free by hand weeding.

The soil samples were collected during maize cultivation (0 to 15 cm depth) at five different stages of crop (S1—pre-cropping, before application of nutrient sources; S2—five days after sowing; S3—active vegetative stage, 30 days old crop; S4—flowering stage; 60 days old crop; S5—after harvest) from each of the treatment plots, respectively, and six independent samples were obtained per treatment. The soil samples removed from stones and stubbles were powdered, packed in water and air tight plastic bags and stored at 4 °C for all the analyses.

2.2. Physio-chemical properties

Soil available N was extracted with 2 M KCl for 1 h and determined by Kjeldahl method (Waring and Bremner, 1964). Available P was extracted with Olsen reagent [0.5 M $NaHCO_3$ (pH 8.5)] at soil-extractant ratio of 1:20, shaken for 30 min and quantified by molybdenum–blue colorimetry (Olsen et al., 1954). Available K was extracted with neutral normal ammonium acetate (pH 7.0), shaken for 25 min and measured by flame photometry (Hanway and Heidel, 1952). SOC was determined by dichromate oxidation (Walkley and Black, 1934) and MBC by fumigation extraction method (Jenkinson and Ladd, 1981).

2.3. Culturable microbiological analyses

Soil samples were enumerated for different groups of microorganisms using different growth media and techniques. Microbial habitat groups such as total culturable bacteria (TCB), fungi