International Journal of Recycling of Organic Waste in Agriculture (2023) Special Issue: 109-118
Doi: 10.30486/IJROWA.2023.1977064.1579

ORIGINAL RESEARCH

Role of organic manures on soil carbon stocks and soil enzyme activities in intensively managed ginger production systems

Nichitha CV[1], Raghavendra S[2], Champa BV[3], Ganapathi G[1], Sudarshan V[1], Nandita S[1], Ravikumar D[4], Nagaraja MS[1*]

Received: 07 January 2023 / Accepted: 11 July 2023 / Published online: 19 July 2023

Abstract

Purpose: Application of organic manures, along with fertilizers, is important to maintain soil fertility to achieve higher productivity. In reality, the farmers apply organic manures and fertilizers in different proportions and quantities depending on their availability and purchasing power of farmers. Organic manures also help to enhance soil carbon stocks and soil biological activities. Hence, this study aimed to assess the role of organic manures on soil carbon stocks and soil enzymes in intensively managed ginger production systems.

Method: Farmers' fields based study was conducted in Shivamogga district coming under Hilly Zone of Karnataka, India. The information on use of organic manures and fertilizers for ginger production were collected from 60 growers and they were grouped into three categories using the K-factorization statistical tool. Soil samples were collected after crop harvest and analysed for soil carbon stocks and soil enzyme activities. The mean values of 3 categories of farmers were compared using suitable statistical tools.

Results: Added organic manure and the soil organic carbon (SOC) varied significantly among high and low organic manure applications. Incremental variations were observed in the order of Category 3 > Category 2 > Category 1 ginger fields. Enzyme activities were found higher in fields applied with high organic manures. Both soil carbon stocks and soil enzyme activities exhibited strong and positive correlations with organic manures.

Conclusion: The study revealed that application of organic manures in intensively managed ginger production systems helps to enhance soil carbon stocks and maintain soil biological activities.

Keywords: Organic manures, Ginger production, Soil-C stocks, Urease, Phosphatase, Dehydrogenase

Introduction

Ginger (*Zingiber officinale*) is an important commercial crop and India is the largest producer, consumer and exporter of the crop (Srinivasan et al. 2019). India accounts for almost 30 percent of the total world's ginger production (Singh et al. 2015). Ginger is consumed directly as rhizome or its extract through beverage and confectionery for its medicinal values (Jabborova and Egamberdiera 2019). Since ages, it has been consumed as folk medicine to cure cold, cough, sore throat, etc. The nutraceutical com-

---

✉ Mavinakoppa S. Nagaraja nagarajams@uahs.edu.in

1Department of Soil Science, College of Agriculture, Shivamogga, Karnataka, India

2Department of Biochemistry, College of Agriculture, Shivamogga, Karnataka, India

3Department of Horticulture, College of Agriculture, Shivamogga, Karnataka, India

4Department of Natural Resource Management, College of Forestry, Ponnampete, India

pounds of ginger are known to boost immunity and help to be in good health. Most importantly, it possesses anti-inflammatory, antioxidant and anti-carcinogenic properties (Shukla and Singh 2007). In terms of nutrients, the rhizome is rich in calcium, phosphorus and potassium. Ginger cultivation is expanding throughout the world as its demand for medicinal and beverage industries are increasing. Nutrient management is critical to achieve optimum growth and productivity in any crop (Srinivasan et al. 2019). Nutrient management not only sustains crop production but also helps to improve soil health and enhance nutrient use efficiency (Dinesh et al. 2012). Ginger, as a nutrient exhaustive crop, demands adequate supply of nutrients at critical stages of its growth (Fageria 2001). Inappropriate agricultural intensification coupled with reckless use of fertilizers can deteriorate soil quality in terms of soil physico-chemical and biological properties (Lal 2015). Injudicious use of fertilizers can damage the natural ecosystem and cause soil and water pollution (Pathak and Ram 2013). Higher yields with better quality can only be sustained through application of nitrogen, phosphorus and potassium through organic or inorganic fertilizers (Okeke and Akinmutimi 2021). Supplementation of secondary and micronutrients through manures and fertilizers also play a significant role (Pathak and Ram 2013). Organic manure is a good source of fertilizer, which enhances soil productivity, increases the soil organic carbon content, enhances the activities of soil microorganisms and supplies major plant nutrients (Sanchez and Miller 1986). Organic management increases the soil carbon content and the overall biological activities (Bai et al. 2019). Even organic wastes from different sources can be used to improve soil fertility and productivity (Palm et al. 2001). Several research results have demonstrated higher nutrient use efficiency with the combined use of organics and inorganics in intensively managed cropping systems (Rushemuka and Bock 2015; Anita et al. 2018). One approach to maintain soil health and quality is through the incorporation of both organic and inorganic fertilizers into the soil in a balanced manner (Dinesh et al. 2012; Rushemuka and Bock 2015). The organic manures feeds both plants and the soil simultaneously and thus, enhances soil health and its quality leading to overall improvement of agro-ecosystem. Exclusive use of only fertilizers can significantly reduce microbial activity (as measured by dehydrogenase), acid phosphatase and other enzymes (Parham et al. 2002; Ning et al. 2017). The biochemical properties are more sensitive to environmental stress and provide rapid and accurate estimates on soil quality. These soil biochemical parameters have been considered as potential indicators of soil quality (Nannipieri et al. 2002). Application of organic manures helps to improve soil structure, soil moisture retention, and available water content and reduce bulk density. Enhancing SOC through organics is crucial for both sustaining intensive production as well as mitigating greenhouse gases (GHGs). However, there are no or little efforts on evaluation of combined use of organics and inorganics and their influence on soil-C stocks and soil enzymes at farmers' field. Thus, the overall objective was to study the effects of farmers' organic manure and fertilizer management practices on soil-C stocks and soil enzyme activities in ginger production. Considering these issues, a survey-based study was carried out to assess the nutrient management practices in ginger cultivation and their effect on soil organic carbon stocks and soil enzyme activities.

Materials and methods

General description of the study area

Ginger is widely grown in the Hilly zone of Karnataka where the soils mostly belong to alfisols and oxisols, having slightly acidic, medium textured and well-drained soil conditions. Thus, the region provides optimum conditions for ginger cultivation. In Karnataka, ginger is widely grown in Shivamogga, Chikkamagaluru, North Canara and Udupi districts. For this study, the Shivamogga district encompassed Sagara, Shikaripura and Shivamogga blocks (taluks). Three villages from each block were selected for this study. The three major ginger growing clusters chosen for the study are depicted in Fig. 1. The average rainfall during the study period was 1037.3 mm in 2021-22. Minimum and maximum temperatures recorded were 27.9 ˚C and 30.1 ˚C.

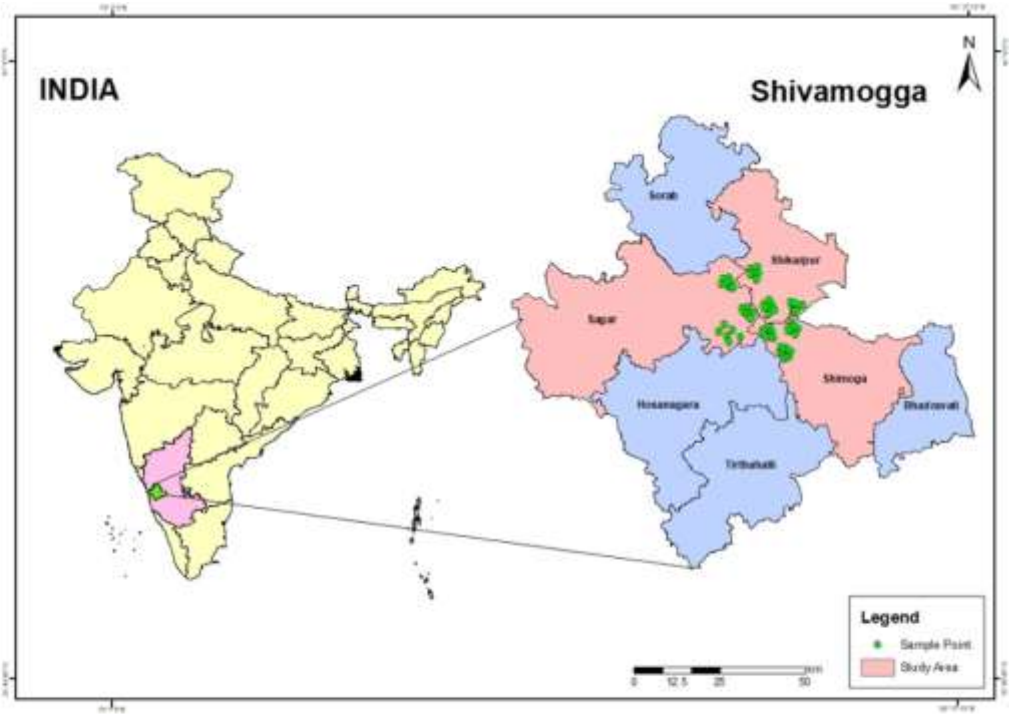


Fig. 1 Map depicting the study area

Selection and categorization of ginger farmers

An initial survey was carried out in Shivamogga district to identify major ginger growing areas. Twenty ginger growing farmers were chosen randomly from three blocks. Information on organic manure and fertilizer additions and ginger rhizome yields were obtained through questionnaires and personal interviews. Based on the above information, the ginger farmers were grouped into three different categories using K-means clustering technique (IBM-SPSS 2011). The ginger farmers were grouped as Category-1 (Low organic manures with high fertilizers), Category-2 (Low organic manures with very high fertilizers) and Category-3 (High organic manures with moderately high fertilizers) and the details are given in Table 1 and presented in Fig. 2.

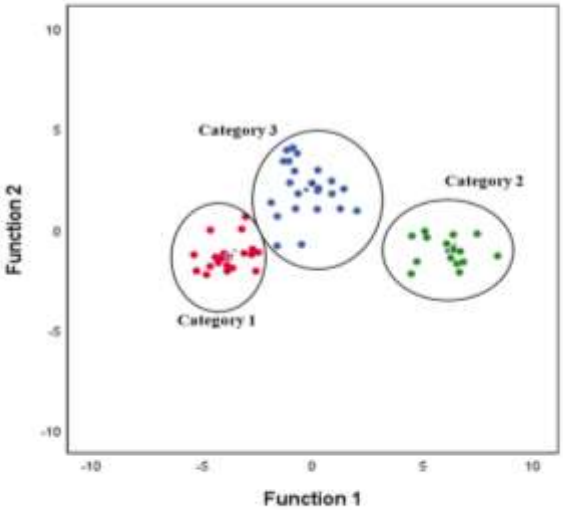


Fig. 2 Categorization of ginger farmers using K-means factorization technique

Table 1 Quantity of organic manure and fertilizer nutrients added among three categories of ginger farmers

Category of ginger farmers	**Organic manures (MT ha^{-1})**	**Fertilizer Nutrients (kg ha^{-1})**
Cat -1: Low Organic Manures with High Fertilizer nutrients *(n=22)*	13.05 ± 2.72^c	293.2 ± 47.3^c
Cat – 2: Low Organic Manures with very High Fertilizer nutrients *(n=15)*	16.62 ± 2.39^b	810.3 ± 57.9^a
Cat -3: High Organic Manures with Moderately high Fertilizer nutrients *(n=23)*	26.33 ± 5.34^a	523.8 ± 56.4^b

(Significant differences in mean values at $p = 0.05$ are indicated by different alphabets)

Soil C stocks assessment

The soil samples were collected from all the 60 ginger fields individually after 3-4 weeks of crop harvest (February - March 2022). Core sampling was done separately for 0-15 cm and 15-30 cm soil depths. The soil samples were dried in shade, powdered and then sieved through 2 mm sieve.

The sieved dry soil samples were stored in air tight containers for soil-C and enzyme analysis. The soil bulk density (BD) was determined by taking the ratio of oven dried soil weight to the volume of the core used for soil sampling (Al-Shammary et al. 2018).

The soil organic-C (SOC) was determined by modified Walkley-Black's wet oxidation method (Allison 1965). The soil-$K_2Cr_2O_7$-H_2SO_4 mixture was taken in a digestion tubes and kept in digestion block at 180 °C for 20 mins. Then, the solutions were cooled and quantitatively transferred to conical flasks for back titration.

The soil carbon stock (SCS) was estimated by multiplying the soil mass and its carbon content separately for two depths and then, added to get the total soil-C stocks in one ha area to a depth of 30 cm soil layer (ha-30 cm soil volume). There was no accumulation of carbonates (inorganic-C) as the soils of the study area were acidic.

Soil enzyme analyses

The stored soil samples were pre-incubated at 25 °C for 2 days, after adjusting the soil moisture content to field capacity, to rejuvenate soil biological activity. These pre-incubated soils were analyzed for dehydrogenase, acid phosphatase and urease enzyme activities. The dehydrogenase activity was determined by incubating soil samples at 37 °C with 3 percent of 2, 3, 5-triphenyl tetrazolium chloride (TTC) aqueous solution. The amounts of triphenyl formazon (TPF) formed were extracted with methanol and measured at 485 nm (Casida et al. 1964). The acid phosphatase activity was determined by the *p*-Nitrophenol Phosphate (*p*-NPP) method (Eivazi and Tabatabai 1977). A known weight of the soil sample (< 2 mm) was incubated with four ml of modified universal buffer (pH 6.5 for any assay of acid phosphatase). One ml of *p*-NPP solution (as substrate) and 0.2 ml of toluene (to suppress further microbial activity). After one hour, the p-nitrophenol (*p*-NP) formed in the supernatant was extracted by centrifugation and the intensity of yellow colour was measured at 420 nm. For urease enzyme, the soil samples were incubated with urea and citrate buffer solution for three hours at 37 °C. The soils were extracted and the amount of ammonia produced was measured colorimetrically by phenate-NaOCl method (Hofmann 1963).

Data analysis

The data obtained were subjected to statistical analysis using Analysis of Variance (ANOVA) and compared ‘F’ values for significance at p = 0.95 (Gomez and Gomez 1984). The correlation coefficient (r) was worked out to understand the effect of organic manures on carbon contents and enzyme activities in soil.

Results and discussion

Soil carbon stocks

The SCS of ginger farmers were estimated by multiplying the SOC content with corresponding BD based soil mass in the top 30 cm layer of 1 ha area. The amounts of organic matter significantly influenced the SOC content and it ranged from 0.32 to 1.37 percent. The SOC was significantly higher in the Category-3 group of ginger farmers with 1.14 ± 0.17 and 1.06 ± 0.14 percent of carbon in surface and subsurface soils respectively. The soils of Category-1 and Category-2 ginger fields recorded lower SOC and the mean values were found to be on par with each other (Table 2). The variations in SOC among different ginger growers may be attributed to additions of different levels of organic manures (Niranjana et al. 2018). The quality of organic matter is also an important factor in any ecosystem (Dattaraja et al. 2018). The organic manures used for ginger differed only in terms of quantity but remained same among all the 3 categories. The relationship between SOC and organic manure added in respective ginger fields also showed a strong positive correlation (Fig. 3; r = 0.914**). The positive effects of organic matter additions in the form of residues, manures, composts etc on SOC are well-documented (Acharya et al. 1998; Dattaraja et al. 2018; Nagaraja et al. 2018). Higher amounts of SOC in surface soils may be attributed to direct addition of old fallen ginger leaves onto the surface and incorporation of organic manures in the surface layer for ginger production (Sharma et al. 2000; Shivakumar et al. 2010).

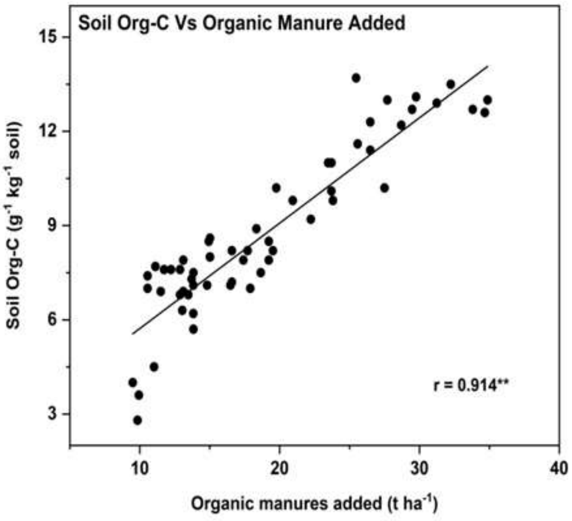


Fig. 3 Relationship between soil organic-C and organic manures added

The soil BD ranged from 1.24 to 1.29Mg m^{-3}. The BD of surface soil was 1.26 ± 0.01 tonnes m^{-3} in ginger fields applied with high organic manures (26.33 ± 5.34 t ha^{-1}) while, it was slightly higher in fields receiving less organic manures (13.05 ± 2.72 t ha^{-1} in Category-1 and 16.62 ± 2.39 t ha^{-1} in Category-2). However, the values were found on par with each other. The amounts of organic manure did not influence soil BD significantly across treatments or with soil depth. Application of high soil organic matter might have reduced BD values in both surface and subsurface soil layers by improved soil structure. The SOC contents in subsurface soils were slightly lower than surface soils. However, the BD values did not differ much among surface and subsurface soils. Soil loosening by growing ginger rhizomes in subsurface layers may be the reason for not observing higher BD values in subsurface layers (Agbede 2019). Moreover, the soil BDs were measured after the ginger harvest. The BD is known to get severely altered when root crops *viz.* potato, cassava, onion, turmeric, groundnut etc. are harvested (Udounang et al. 2022). A minimum threshold level of SOC (Meurer et al. 2020) and quality of soil organic matter are also important to bring significant changes in soil structure (Six et al. 2000).

Table 2 Bulk density and organic-C status of soils of three categories of ginger farmers

Category of ginger farmers	**Bulk density (Mg m^{-3})**		**Soil Organic-C (%)**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**
Cat -1: Low Organic Manures with High Fertilizer nutrients *(n=22)*	1.28 ± 0.01^{a}	1.28 ± 0.01^{a}	0.68 ± 0.18^{c}	0.64 ± 0.18^{c}
Cat – 2: Low Organic Manures with very High Fertilizer nutrients *(n=15)*	1.27 ± 0.01^{a}	1.28 ± 0.01^{a}	0.76 ± 0.06^{b}	0.72 ± 0.07^{b}
Cat -3: High Organic Manures with Moderately high Fertilizer nutrients *(n=23)*	1.26 ± 0.01^{a}	1.27 ± 0.01^{a}	1.14 ± 0.17^{a}	1.06 ± 0.14^{a}

(Significant differences in mean values at p = 0.05 are indicated by different alphabets)

In terms of the SCS, the top 30 cm soil layer recorded 62.2 ± 8.65 t ha^{-1} in the Category 3 group of ginger fields receiving high amounts of organic manures (26.33 ± 5.34 t ha^{-1}). However, the SCS in Category-1 (37.75 ± 7.22 t ha^{-1}) and Category-2 (39.09 ± 9.51 t ha^{-1}) groups of ginger fields were significantly lower (Fig. 3). The results indicated that the SOC and SCS in both surface and subsurface soils were found in the order of Category-3 > Category-2 = Category-1 ginger farmers (Fig. 4a).

Thus, the SOC appears to be the key determinant of SCS (Saiz et al. 2012). The use of BD values of each soil layer in a particular treatment helped to estimate the soil carbon stocks more accurately (Nagaraja et al. 2016). Incremental increase in SCS was very evident among three categories of ginger farmers indicating the importance of organic manures (Six et al. 2000). The relationship between SCS and the organic manure also showed significantly positive correlation (Fig. 4b; 0.918**).

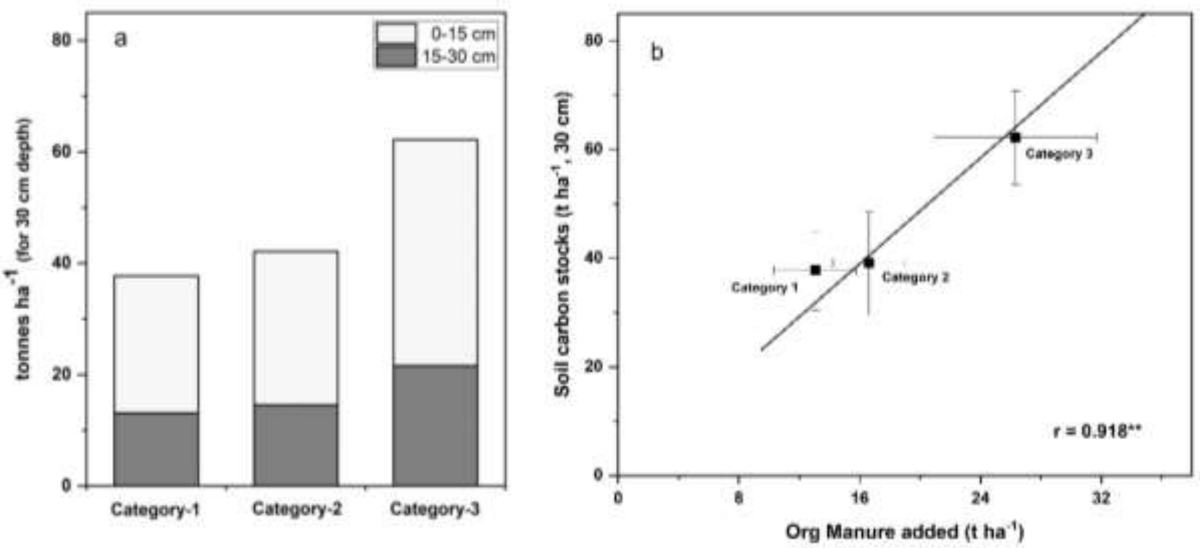


Fig. 4 Soil carbon stocks (a) among three different ginger categories of farmers and (b) its relationship with organic manures added

Soil enzyme activities

The soil enzyme activities are the broad indicators of soil health. The dehydrogenase varied significantly among all the three categories of ginger growers. It was significantly higher (54.49 ± 14.37 µg TPF g^{-1} day^{-1}) in ginger plots applied with high organic manures and moderately high doses of fertilizers (Table 3). Least dehydrogenase activity (31.89 ± 10.00 µg TPF g^{-1} day^{-1}) was recorded in the Category-1 group of ginger fields applied with low organic manures and high fertilizers. Thus, the dehydrogenase varied significantly in the order of Category-3 > Category2 > Category-1 group of ginger fields.

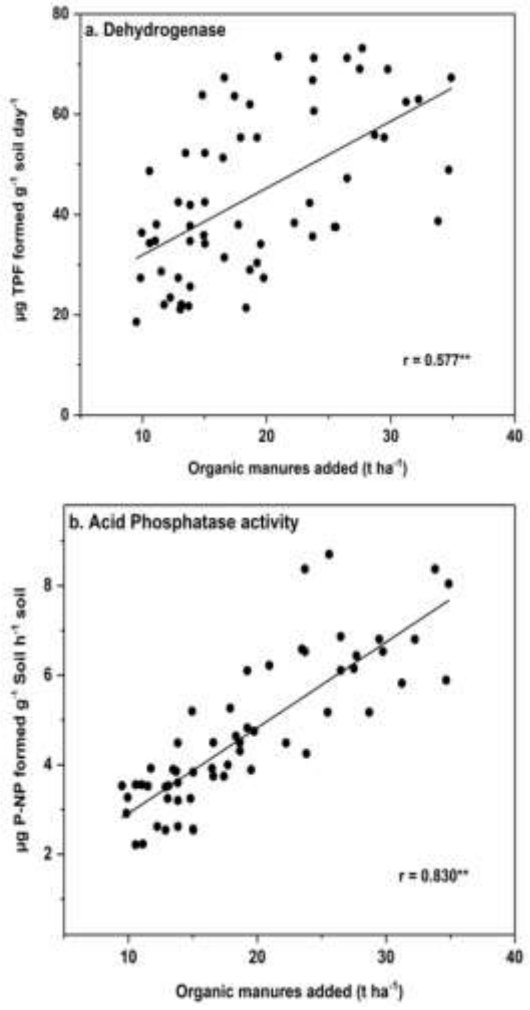
Table 3 Enzyme activities in soils of three categories of ginger farmers

Category of ginger farmer	Dehydrogenase (µg TPF g^{-1} day^{-1})	Acid phosphatase (µg *p*-NP g^{-1} hr^{-1})	Urease (µg NH_4^+–N g^{-1} hr^{-1})
Cat -1: Low Organic Manures with High Fertilizers *(n=22)*	31.89 ± 10.00 ^{c}	3.43 ± 0.71 ^{b}	8.72 ± 1.81 ^{b}
Cat – 2: Low Organic Manures with very High Fertilizers *(n=15)*	45.68 ± 15.37 ^{b}	4.02 ± 0.94 ^{b}	8.52 ± 0.95 ^{b}
Cat -3: High Organic Manures with Moderately high Fertilizers *(n=23)*	54.49 ± 14.37 ^{a}	6.20 ± 1.35 ^{a}	11.62 ± 1.53 ^{a}

Significant differences in mean values at p = 0.05 are indicated by different alphabets)

The biological activity as depicted by the dehydrogenase activity was substantially higher in the Category-3 group of ginger farmers applying high doses of organic manures. Addition of organic matter serves as food for the soil microbes (Lazcano et al. 2013) and hence, higher dehydrogenase activity indicates higher biological activity in soils (Samuel 2010). Moreover, the dehydrogenase enzyme is an endo-enzyme and reflects purely the microbial activity (Parham et al. 2002; Dotaniya et al. 2019). Significant differences in dehydrogenase enzyme activity with corresponding organic manure applications among 3 categories of ginger farmers further strengthens the role of organic manures in maintaining soil biological activity (Prakash et al. 2002).The biological activity as indicated by dehydrogenase activity increased with increase in organic manure applications (Fig. 5a; r = 0.577**). Similar reports of positive relationships between organic manure and dehydrogenase are reported by Kanchikerimath and Singh (2001) and Nagaraja (1997).

In terms of acid phosphatase, the enzyme activity was significantly higher (6.20 ± 1.35 µg *p*-NP g^{-1} hr^{-1}) in ginger fields receiving high doses of organic manures. However, the ginger fields belonging to Category-1 and Category-2 receiving lower organic manures recorded lesser acid phosphatase activities with corresponding values of 3.43 ± 0.71-µg *p*-NP g^{-1} hr^{-1} and 4.02 ± 0.94-µg *p*-NP g^{-1} hr^{-1}. Similar to phosphatase activity, the urease enzyme activities were also found least in ginger soils added with lower amounts of organic manures (8.72 ± 1.81µg NH_4^+-N g^{-1} hr^{-1} in Category-1 and 8.52 ± 0.95µg NH_4^+-N g^{-1} hr^{-1} in Category-2). However, it was significantly higher (11.62 ± 1.53µg NH_4^+-N g^{-1} hr^{-1}) in the Category-3 group of ginger fields which received high organic manures. Both acid phosphatase and urease enzymes showed significantly positive correlations with organic manure additions with respective 'r' values of 0.830** and 0.784** (Fig. 5b and 5c). Addition of high organic manures in the Category 3 group of ginger farmers might have maintained high phosphatase and urease enzyme activities (Parham et al. 2002). No significant differences in Category – 1 and Category -2 group of farmers may be due to low additions of organic manures. Moreover, both acid phosphatase and urease enzymes are ecto-enzymes (Dyhrman 2005). Plant roots and crop residues (Adetunji et al. 2017) might have been secreted them. Enzyme activities showed positive correlation with organic manure addition (Fig. 5) and SOC (Fig. 3). The dehydrogenase, phosphatase and urease activities were significantly correlated (Shi et al. 2008) with applied organic manures (0.577**, 0.830** and 0.784**). Higher enzyme activities were linked to higher SOC (Klose and Tabatabai 2000) and organic manure additions (Morrissey et al. 2014). Incremental increase in the enzyme activities with corresponding increase in SOC clearly demonstrates their positive effects (Liu et al. 2010; Sharan et al. 2020).



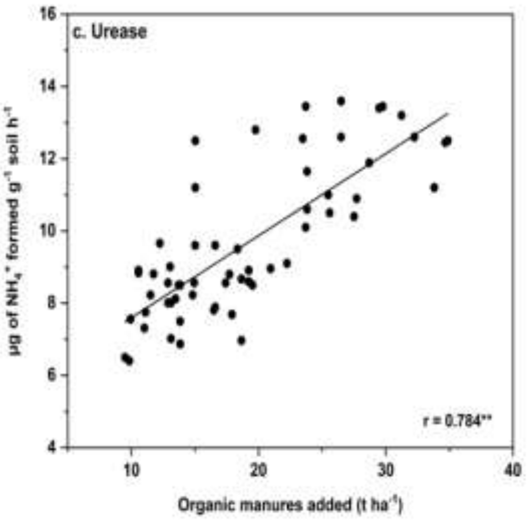


Fig. 5 Enzyme activities in ginger cultivated soils with organic manure applications

Conclusion

Categorization of ginger farmers using K-means clustering technique helped to understand the influence of different levels of organic manures on soil-C stocks and soil enzyme activities. The soils with moderate amounts of fertilizer nutrients and high amounts of organic manures recorded significantly higher enzyme activities. The soils of the category-3 group of ginger farmers with high organic manure additions recorded higher SOC. The SCS was significantly higher in Category-3 ginger fields compared to low organic manure added ginger fields belonging to Category-1 and Category-2 farmers. In terms of biological activity, all the three enzymes studied namely, dehydrogenase, acid phosphatase and urease enzymes increased with increase in organic manure applications. Thus, the addition of organic manure plays a crucial role in maintaining soil health and may even overcome the ill effects of excess fertilizer applications in intensively managed cropping systems.

Acknowledgment: The authors acknowledge the KSNUAHS, Shivamogga for providing the financial grants under the Staff Research Project. The Organic Farming Research Centre, Shivamogga and the Dept. of Soil Science, College of Agriculture are duly acknowledged for providing the facilities to conduct this research.

Compliance with ethical standards

Conflict of interest: The authors declare that there are no conflicts of interest associated with this study.

References

Acharya CL, Bishnoi SK, Yaduvanshi H (1998) Effect of long-term application of fertilizers, and organic and inorganic amendments under continuous cropping on soil physical and chemical properties in an Alfisol. Indian J Agric Sci 58(7):509-516

Adetunji AT, Lewu FB, Mulidzi R, Ncube B (2017) The biological activities of β-glucosidase, phosphatase and urease as soil quality indicators: a review. J Soil Sci Plant Nutr 17(3):794-807. http://dx.doi.org/10.4067/S0718-95162017000300018

Agbede TM (2019) Influence of five years of tillage and poultry manure application on soil properties and ginger (*Ziginber officinale* Roscoe) productivity. J Crop Sci Biotech 22(2): 91-99. https://doi.org/10.1007/s12892-018-0155-0

Allison L (1965) Organic carbon. Methods of soil analysis: Part 2 Chemical and microbiological properties, 9, pp.1367-1378

Al-Shammary AAG, Kouzani AZ, Kaynak A, Khoo SY, Norton M, Gates W (2018) Soil bulk density estimation methods: A review. Pedosphere, 28(4):581-596. https://doi.org/10.1016/S1002-0160(18)60034-7

Anita EK, Prashant CT, Champa BV, Shivanna M, Nagraja MS (2018) Secondary and micronutrient status in soils of wine and table type grape orchards of northern Karnataka. Int J Chem Stu 6(3):2335-2358

Bai X, Huang Y, Ren W, Coyne M, Jacinthe PA, Tao B, Hui D, Yang J, Matocha C (2019) Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis. Global Change Biol *25*(8):2591-2606. https://doi.org/10.1111/gcb.14658

Casida LE, Klein DA, Santoro T (1964) Soil dehydrogenase activity. Soil Sci 98:371-376

Dattaraja HS, Pulla S, Suresh HS, Nagaraja MS, Srinivasamurthy CA, Sukumar R (2018) Woody plant diversity in relation to environmental factors in a seasonally dry tropical forest land scape. J Vegtn Sci 18: 1-11. https://doi.org/10.1111/jvs.12652

Dinesh R, Srinivasan V, Hamza S, Manjusha A (2012) Short-term incorporation of organic manures and biofertilizers influences biochemical and microbial characteristics of soils under an annual crop [Turmeric (*CurcumalongaL.*)]. Bioresour Technol 101: 4697-4702. https://doi.org/10.1016/j.biortech.2010.01.108

Dotaniya ML, Aparna K, Dotaniya CK, Singh M, Regar KL (2019) Role of soil enzymes in sustainable crop production. In Enzymes in Food Biotechnology (pp. 569-589). Academic Press. https://doi.org/10.1016/B978-0-12-813280-7.00033-5

Dyhrman S (2005) Ectoenzymes in *Prorocentrum minimum*. Harmful algae 4(3): 619-627. https://doi.org/10.1016/j.hal.2004.08.011

Eivazi F, Tabatabai MA (1977) Phosphatases in soils. Soil Biol Biochem 9:167-172. https://doi.org/10.1016/0038-0717(77)90070-0

Fageria, VD (2001) Nutrient interactions in crop plants, J Pl Nutritn 24: 1269-1290. https://doi.org/10.1081/PLN-100106981

Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research. John Wiley & sons

IBM-SPSS (2011) IBM SPSS statistics for windows, Version 20.0. Armonk, NY: IBM Corp

Hofmann E (1963) Methods of enzymatic analysis. New York, Academic, USA: 913-946

Jabborova D, Egamberdieva D (2019) Antibacterial, antifungal, and antiviral properties of medical plants. Medically Important Plant Biomes: Source of Secondary Metabolites pp.51-65. https://doi.org/10.1007/978-981-13-9566-6_3

Kanchikerimath M, Singh D (2001) Soil organic matter and biological properties after 26 years of maize-wheat cowpea cropping as affected by manure and fertilization in semi and region of India. Agric Ecosyst Environ 86(2):155-162. https://doi.org/10.1016/S0167-8809(00)00280-2

Klose S, Tabatabai MA (2000) Urease activity of microbial biomass in soils as affected by cropping systems. Biol Fert Soil 31(3):191-199. https://doi.org/10.1007/s003740050645

Lal R (2015) Restoring soil quality to mitigate soil degradation. Sustainability *7*: 5875-5895. https://doi.org/10.3390/su7055875

Lazcano C, Gómez-Brandón M, Revilla P, Domínguez J (2013) Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function: A field study with sweet corn. Bio Fertil Soils 49:723-733. https://doi.org/10.1007/s00374-012-0761-7

Liu E, Yan C, Mei X, He W, Bing SH, Ding L, Liu Q, Liu S, Fan T (2010) Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. Geoderma 158(3-4):173-180. https://doi.org/10.1016/j.geoderma.2010.04.029

Meurer KHE, Chenu C, Coucheney E, Herrmann AM, Keller T, Kätterer T, Nimblad Svensson D, Jarvis N (2020) Modelling dynamic interactions between soil structure and the storage and turnover of soil organic matter, Bio geosciences 17:5025-5042. https://doi.org/10.5194/bg-17-5025-2020

Morrissey EM, Berrier DJ, Neubauer SC, Franklin RB (2014) Using microbial communities and extracellular enzymes to link soil organic matter characteristics to greenhouse gas production in a tidal freshwater wetland. Bio geochem 117(2):473-490. https://doi.org/10.1007/s10533-013-9894-5

Nagaraja MS (1997) Biomass turnover, nutrient status and biological processes in different land use systems, PhD Thesis, University of Agricultural Sciences, GKVK, Bangalore, India

Nagaraja MS, Bharadwaj AK, Prabhakara Reddy GV, Srinivasamurthy CA, Sandeep Kumar (2016) Estimations of soil fertility in physically degraded agricultural soils through selective accounting of fine earth and gravel fractions. Solid Earth 7:897-903. https://doi.org/10.5194/se-7-897-2016

Nagaraja MS, Bhardwaj AK, Champa BV (2018) Biomass turnover interactions with soil-C sequestration among the land uses in the Western Ghats. Current Science 115: 213-216

Nannipieri P, Kandeler E, Ruggiero P (2002) Enzyme activities and microbiological and biochemical processes in soil, In enzymes in the environment: Activity, ecology, and applications, Edn Burns RG, Richard Dick, pp 1-33

Ning CC, Gao PD, Wang BQ, Lin WP, Jiang NH, Cai KZ (2017) Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. J Integrative Agri 16(8):1819-1831. https://doi.org/10.1016/S2095-3119(16)61476-4

Niranjana KS, Yogendra K, Mahadevan KM (2018) Physico-chemical characterization and fertility rating of maize growing soils from hilly zone of Shivamogga district, Karnataka. Indian J Agric Res 52(1):56-60. http://dx.doi.org/10.18805/IJARe.A-4887

Okeke VN, Akinmutimi AL (2021) Enhanced soil chemical properties, nutrient uptake and dry matter yield in a mineral and organic fertilization of Ginger (*Zingiber Officinale* Roscoe) in Umudike, South-Eastern Nigeria. Nigeria Agric J 52(3):142-150. https://www.ajol.info/index.php/naj/article/view/223423

Palm CA, Giller KE, Mafongoya PL (2001) Management of organic matter in the tropics: Translating theory into practice. Nutr Cycl Agroecosyst 61:63-75. https://doi.org/10.1007/978-94-017-2172-1_7

Parham JA, Deng SP, Raun WR, Johnson GV (2002) Long-term cattle manure application in soil. I. Effect on soil phosphorus levels, microbial biomass C and dehydrogenase and phosphatase activities. Biol Fertil Soils 35:328-337. https://doi.org/10.1007/s00374-002-0476-2

Pathak RK, Ram RA (2013) Bio-enhancers: A potential tool to improve soil fertility, plant health in organic production of horticultural crops. Progressive Horticulture 45(2):237-254

Prakash YS, Bhadoria PBS, Rakshit A (2002) Comparative efficacy of organic manures on the changes in soil properties and nutrient availability in an alfisol. J Indian Soc Soil Sci 50(2):219-221

Rushemuka PN, Bock L (2015) Tailoring soil fertility management inputs to specific soil types: Case study of a pot experiment in Rwanda. Nature Faune: 7-12

Saiz G, Bird MI, Domingues T, Schrodt F, Schwarz M, Feldpausch TR, Veenendaal E, Djagbletey G, Hien F, Compaore H, Diallo A (2012) Variation in soil carbon stocks and their determinants across a precipitation gradient in West Africa. Global Change Bio 18(5):1670-1683. https://doi.org/10.1111/j.1365-2486.2012.02657.x

Samuel AD (2010) Dehydrogenase: An indicator of biological acitivities in a preluvo soil. Res J Agril Sci 42(3):306-310

Sanchez PA, Miller RH (1986) Organic matter and soil fertility management in acid soils of the tropics. Trans. 13th Int. Congr Soil Sci (Hamburg) 6: 609-625

Sharan BR, Nagaraja MS, Mallesha BC, Kadalli GG (2020) Enzyme activities at varied soil organic carbon gradients under different land use systems of Hassan district in Karnataka, India. Int J Curr Microbiol App Sci 9(3):1739-1745. https://doi.org/10.20546/ijcmas.2020.903.201

Sharma BR, Chadha APS, Bajpai HK (2000) Response of chili (*Capsicum annuum* Linn.) to nitrogen and phosphorus levels under irrigated condition. Adv Plant Sci 9(2):213-214

Shi ZJ, Lu Y, Xu ZG, Fu SL (2008) Enzyme activities of urban soils under different land use in the Shenzhen city, China. Plant Soil Environ 54(8): 341-346

Shivakumar KM, Nagaraja MS, Champa BV, Kuligod VB (2010) Comparative analysis of different levels of nutrient management in dry Chilli production-A case study. Indian J Fert 6(8):12-16

Shukla Y, Singh M (2007) Cancer preventive properties of ginger: A brief review. Food Chem Toxic 45(5): 683-690. https://doi.org/10.1016/j.fct.2006.11.002

Singh AK, Gautam US, Singh J (2015) Impact of integrated nutrient management on ginger production. Bangladesh J Bot 44(2):341-344. https://doi.org/10.3329/bjb.v44i2.38528

Six J, Elliott ET, Paustian K (2000) Soil structure and soil organic matter II. A normalized stability index and the effect of mineralogy. Soil Sci Soc Amer J 64(3): 1042-1049. https://doi.org/10.2136/sssaj2000.6431042x

Srinivasan V, Thankamani CK, Dinesh R, Kandiannan K, Hamza S, Leela NK, John Zachariah T (2019) Variations in soil properties, rhizome yield and quality as influenced by different nutrient management schedules in rainfed ginger. Agric Res 8(2):218-230. https://doi.org/10.1007/s40003-018-0382-y

Udounang PI, Ekwere OJ, Akata OR (2022) Effect of different tillage practices on the growth and yield of ginger (*Zingiber officinale* Rosc.) in Obio Akpa-Akwa Ibom State, South Eastern Nigeria. AKSU J Agri Food Sci 6(1): 36-45