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Soil organic carbon, dehydrogenase activity, nutrient availability and leaf nutrient content as affected by organic and inorganic source of nutrient in mango orchard soil

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Abstract

Changes in soil organic carbon, dehydrogenase activity, nutrient availability and leaf nutrient concentrations in a mango orchard soil was evaluated from four years (2007-2011) field experiment on a *Typic Ustocrepts* soil of subtropical region in Lucknow, India. Organic (FYM, vermicompost, mulching, *Azotobacter*, PSM and *Trichoderma harzianum*) and inorganic (N, P, K) substrates were applied each year within the tree basin. It was observed that soil and leaf nutrients concentrations significantly increased in organic and inorganic amended soils as compared to control. Vermicompost, organic mulching and microbial inoculation significantly enhanced soil organic carbon content, available nutrients, dehydrogenase activity and leaf nutrient concentrations. Dehydrogenase activity was highest (1.85 μg TPF g^{-1} h^{-1}) in organically treated soils. Surface soil (0-10 cm depth) showed higher dehydrogenase activity (1.29 to 1.85 μg TPF g^{-1} h^{-1}) as compared to lower soil depths in all the treatments.

Keywords: Vermicompost, microbial inoculants, dehydrogenase activity, soil chemical properties, leaf nutrient dynamics

1. Introduction

India ranks first in the production of mangoes, accounting for nearly 50% of the total world production, widely cultivated in almost all the states, soil and climatic conditions. Malihabad region of Uttar Pradesh is one of the major contiguous mango producing belts. However, inappropriate production technologies have resulted in deterioration in soil quality, leading to soil organic matter losses and structural degradation affecting water, air and nutrient flows, and consequently poor plant growth and yield (Albiach *et al*., 2001; Ravishankar *et al*., 2010).

Mango orchards under alluvial soils of Indo-Gangetic belt are very poor in organic matter owing to high temperature and rainfall and intense microbial activities (Bhriguvanshi *et al*., 2012). Organic manure is generally applied to maintain soil health and sustainability in intense cropping systems (Singh *et al*., 2010). In this context, attention is given to increase the utilization of different kinds of organic wastes as organic sources of nutrition through composting, vermicomposting, organic mulching, bioinoculants, etc. Transformation of nutrients in soil is an enzyme mediated biochemical process facilitated by a group of microorganisms. Application of vermicompost increases nutrient content, enhances soil respiration and different enzymatic activities (Dehydrogenase, urease, β-glucosidase, phosphatase, arylsulfatase) and activates microorganisms in soil (Arancon *et al.*, 2006; Tejada *et al.*, 2010). Pramanik *et al.*, (2007) demonstrated that the presence of several enzymes in vermicompost ultimately lead to improvement in health of the soil.

Microbial communities are important for the functioning of the ecosystem both in relation to direct interactions with plants and with regard to nutrient and organic matter cycling (Adak and Sachan, 2009). Application of microbial inoculants contributes significantly to the soil surface ecosystem by their organic acid secretions in decomposing soil organic matter, nutrient chelation, fixation and hormonal action (Zahir *et al*., 2004).

Orchard soil management differs from that of intensively cultivated agricultural land use systems (Rahman and Sugiyama, 2008; Rahman *et al.*, 2011). Addition of organic and inorganic sources of nutrients influences soil properties and nutrient dynamics more often, micronutrients. Any shift in their content, interactions or relationship with other soil properties is therefore important to look into. Wide variability in soil organic carbon, micronutrients across different land use system and their variability due to soil management strategy have been reported by many workers (Kumar *et al*., 2009). Since, quantitative and/or qualitative information on the application of organic and inorganic substrates in mango orchard soils of subtropical India is meagre, the present study was intended to assess the changes in soil characteristics and leaf nutrient concentrations in an old alluvial mango orchard soil through integrated nutrient management.

2. Materials and Methods

2.1. Site characteristics and experimental design

This experiment was conducted in experimental farm of Central Institute for Sub-tropical Horticulture, Rehmankhera, Lucknow (26.54^0 N Latitude, 80.45^0 E Longitude and 127 m above mean sea level), Uttar Pradesh, India. The soil of the experimental site belongs to the major group of Indo-Gangetic alluvium with well drained sandy loam texture. Taxonomically, the soil is mixed hyperthermic *Typic Ustocrepts*, alkaline in nature with pH and electrical conductivity ranging from 6.64 to 8.18 (Mean 7.48) and 0.04 to 0.13 dS/m (mean 0.077 dS/m) respectively. Organic carbon (0.32%), available phosphorus (4.5 mg kg^{-1}) and potassium (30.5 mg kg^{-1}) were low. DTPA extractable Fe, Mn, Zn and Cu content were also low in the soil (2.232, 1.961, 0.176 and 0.163 ppm respectively). The field experiment was continuing from 2007 to 2011 with treatments consisting of different organic (FYM, Vermicompost, mulching) and inorganic (N, P_2O_5, K_2O) sources of nutrition including bioinoculants (*Azotobacter*, phosphate solubilizing microbes - PSM and *Trichoderma harzianum*). Paddy straw was used as mulch at the rate of 5 kg per plant. Biofertilizers (*Azotobacter*, PSM and *Trichoderma harzianum*) were applied at rate of 100 g per plant. The nutrient contents in vermicompost were 1.57, 1.15 and 1.75 % N, P and K and 3320, 397, 112 and 48 mg kg^{-1} of Fe, Mn, Zn and Cu, respectively while in FYM were 0.8, 0.3 and 0.92 % N, P and K and 3135, 222, 75 and 34 mg kg^{-1} of Fe, Mn, Zn and Cu, respectively on dry weight basis. The experiment was laid out in a randomized block design with four replications. Mango cv Dashehari was planted in 2007 at a spacing of 10 × 10 m with five treatments comprising T_1- 10 kg FYM + 100, 50,100 g N, P and K / tree /year of age (control), T_2-10 kg FYM + 100, 50, 100 g N, P and K / tree / year of age + *Azotobacter* + PSM + *Trichoderma harzianum* + Organic mulching, T_3-100, 50, 100 g N, P and K / tree / year of age +*Azotobacter* + PSM + *Trichoderma harzianum* + Organic mulching, T_4- 5 kg FYM + 5 kg Vermicompost + 100, 50, 100 g N, P and K/ tree / year of age + *Azotobacter* +

PSM + *Trichoderma harzianum* + Organic mulching and T_5- 10 kg Vermicompost + 100, 50, 100 g N, P and K / tree /year of age + *Azotobacter* + PSM + *Trichoderma harzianum* + Organic mulching. The treatments were applied in the tree basin in 1st week of October. Plants were watered weekly in winter at 2-3 days interval and in summer during first year of establishment. The irrigation was given at the interval of 8-10 days during winter and at weekly interval during summer months in second year onwards. The plants were covered with thatch for protection from frost injury during winter season. The plots were maintained weed free during the course of study and need based plant protection measures were adopted.

2.2. Soil and leaf analysis

Soil samples were collected from Ap horizons at 0-30 cm soil depth from the tree basin in all the treatments replication wise before fertilization each year. Samples were air dried at room temperatures and passed through a 2 mm sieve and homogenated. Soil pH and electrical conductivity (EC) was determined using standard protocol of Piper (1967). Soil organic carbon content was estimated by the standard dichromate oxidation method. Mineralizable nitrogen was estimated by distillation with alkaline 0.32% potassium permanganate (Subbiah and Asija 1956). Available phosphorus was estimated calorimetrically by blue color method after extraction with sodium bicarbonate solution (Olsen *et al*., 1954) and available potassium was extracted with neutral 1 N NH_4OAc (Hanway and Heidel, 1952) and measured by Atomic Absorption Spectrophotometer (AAS). Available Zn, Cu, Mn and Fe contents (DTPA extractable) in the soil were estimated by 'Chemito' AA203D model of atomic absorption spectrophotometer as per the procedure of Lindsay and Norvell (1978). For estimation of biological activity, a separate set of soil samples was collected from 0-10, 10-20 and 20-30 cm soil depths from the tree basin in all the treatments. Soil moisture was determined through gravimetric method and pooled data was presented. Dehydrogenase activity was estimated using 2, 3, 5 triphenyal tetrazolium chloride using 1 g of field moist soil (<2 mm) and expressed as µg of triphenylformazan (TPF) formed per gram of oven dry soil per 24 hours (Casida *et al*., 1964). Recently matured leaf samples (5-7 months old) were collected from the trees of each treatment, decontaminated by washing first with tap water and in N/10 HCl solution to remove residues of chemical spray materials on the leaf surface, followed by washing in single and double distilled water. Excess water on the surface of the leaves was removed by pressing between the folds of blotting paper and the leaves were dried in an oven at 48 ^{0}C for 72 hours. After complete drying, the samples were ground in a grinder and used for analysis. Oven dried leaf samples were analyzed for different nutrients after digesting 1 g leaf sample in di-acid mixture of nitric acid and perchloric acid (9:4), by standard analytical methods (Lindsay and Norvell, 1978). Nitrogen was estimated by micro-Kjeldahl method whereas P by vanado-molybdate yellow colour method (Piper, 1967). K and the micronutrients Fe, Mn, Cu and Zn were analyzed by using AAS.

2.3. Statistical analysis

The data of all soil factors was analyzed statistically by standard analysis of variance (ANOVA) and differences were separated by least significant difference (LSD) using SAS version 9.3 (SAS Institute, Inc., Cary, NC, USA 1990). For statistical analysis of data, Microsoft-Excel software (Microsoft Corporation, USA) was used and significant differences were determined at LSD (p = 0.05).

3. Results and Discussion

3.1. Soil organic carbon, available N, P and K dynamics

The soil organic carbon (SOC) content improved significantly over the years of experimentation. Initially it was in the range of 0.18-0.31 per cent across all the treatments in 2008-09 and later on improved to a level of 0.33-0.60 per cent in 2010-11. Pooled mean data showed improvement in SOC content between 0.27 and 0.45% among various treatments (Figure 1). The organic carbon build up over the years was a function of microbial activity and organic matter decomposition. Highest SOC (0.45%) was observed in the treatment, 10 kg Vermicompost + 100, 50, 100 g N, P and K / tree /year of age + *Azotobacter* + PSM + *Trichoderma harzianum* + organic mulching. The control plot (T_1), where only FYM and inorganic fertilizers were applied, had 0.27% SOC content. Thus, application of microorganisms and organic mulching played significant role in organic matter build up in the soil. In a sandy silty loam soil, Albiach *et al*. (2001) found significant increase in soil organic matter after four years of organic amendment application to a horticultural soil. The volumetric soil moisture content (θv) in mango orchard soils varied from 10 to 22 per cent. Pooled data (Figure 2) showed the variability across different treatments. Organic mulch treated soils had marginally higher θv as compared to the control (T_1) with no mulching. Positive effect of different nutrient sources on availability of N, P and K was inferred from this study (Table 1). Available nitrogen (N) was more in the treatment receiving vermicompost as compared to FYM. The maximum available N was observed as 71.7 mg kg^{-1} in T_5 treatment as compared to 48.4 mg kg^{-1} in T_1. The build up of available nitrogen was significant across the treatments and was more dependent on addition of vermicompost than FYM in soil.

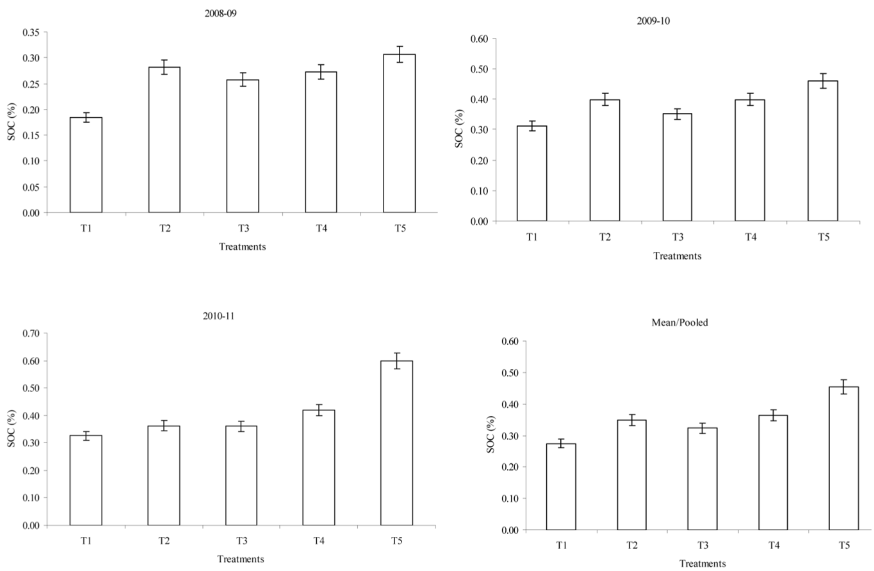

Figure 1. Effects of various substrates on SOC content (%) in different treatments during 2008-09, 2009-10, 2010-11 and pooled mean over years. SOC content was significantly improved over the years of organic amendment application. All plots receiving vermicompost had significantly more SOC content (p<0.05) than plots that received inorganic fertilizers only. Means were statistically significant and differences were concluded at (p <0.05) as per the SAS 9.0 statistical software.

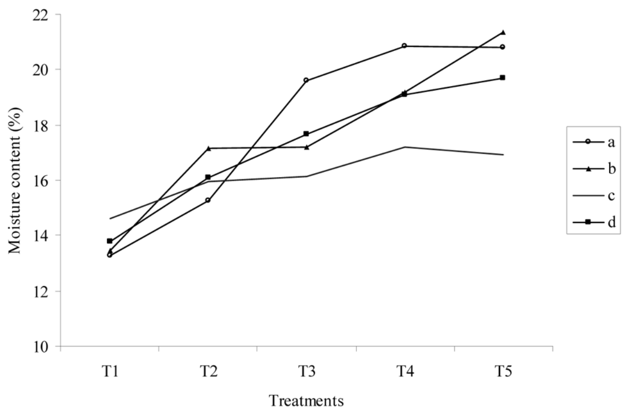

Figure 2. Mean volumetric moisture content (θv) in mango orchard soils. a, b, c and d stands for soil samples at 0-10, 10-20, 20-30 and pooled 0-30 cm soil depth. All plots receiving organic sources had significantly more θv (p<0.05) than plots that received inorganic fertilizers only. The statistical significance was drawn using SAS at p <0.05.

The available phosphate although improved significantly in different treatments over the years in the orchard soil, the build up was more significant in treatments receiving vermicompost as an organic source. The available P increased from 8.1-12.8 mg kg^{-1} in 2008-09 to 21.1 to 31.1 mg kg^{-1} in 2010-11 in the soil due to integrated nutrient management scheduling. The pooled data indicated improvement in P availability in vermicompost and microbial inoculants added soils (18.0 to 24.0 mg kg^{-1}) as compared to T_1. Application of vermicompost in some treatments resulted in higher P availability (24.0 mg kg^{-1}) as compared to its absence and FYM application in T_2 treatment (18.0 mg kg^{-1}). Inclusion of mulching and microbial inoculants resulted in the release of more P from soil nutrient pool and organic substrates. The K availability was significantly improved in the mango orchard soil as a function of nutrient management strategy. Application of microbial inoculants and mulching had showed significant improvement in K availability (83.9 to 111.5 mg kg^{-1}) as compared to 62.9 mg kg^{-1} in T_1 treatment. The mulching might have created congenial environment for microbial activity and nutrient release in the rhizosphere.

The use of organic and inorganic sources of nutrients has been viewed as an important soil management strategy to increase soil organic matter, provide nutrients and improve microbial activity (Tiwari *et al*., 1989). The results are conditioned by the composition of amendment, the rate of application and the soil type (Albiach *et al*., 2001; Basak *et al*., 2012). Even when vermicompost was added as an amendment to a horticultural soil, improvement in soil physical, chemical and biological properties was revealed (Atiyeh *et al*., 2000; Arancon *et al*., 2006). Improvement in organic carbon and available NPK in soils may be due to secretion of organic acids released from application of vermicompost, microbial inoculants and organic mulching in presence or absences of inorganic fertilizers. Actually, vermicompost is an earthworm processed product, rich in humic substances which act as a buffering agent for soil pH. Results of the present experiment suggested the positive side of nutrient recycling through vermicomposting produce nutrient-rich soil amendments. Application of vermicompost not only increased the nutrient content but also improved enzymatic activity of soil. Due to narrower range of C/N ratios of vermicompost, application of vermicompost hastens the mineralization rate, which in turn increases the mineralizable N content in soil. Solubilization of phosphorus to make it available to plants is the most important aspects of fertilizer management in fruit trees. Due to low initial fertility status of orchard soils of semiarid regions, application of vermicompost may be fruitful as it releases phosphate ions from soil ion exchange sites and increases their concentration in soil solution. Vermicompost is also rich in several microorganisms that produce a number of organic acids specially oxalic acid, which facilitates the solubilization of bound phosphorus and potassium in soil (Zhang *et al*., 2000). Higher protease and acid phosphate activity in vermicompost treated soils might be responsible for higher nitrogen and phosphorus content in soil. Tejada *et al*., (2010) also found the improvement in biochemical properties of soil due to vermicompost application. Binet and Trehem, (1992) propose that soil mineralizable nitrogen content increases up to 10% after only 85 days of earthworm cast application. Amylase, protease, and phosphatase enzyme govern the transformation of carbon, nitrogen and phosphorus from organically bound forms to plant available forms in soil. Urease enzyme converts urea, the most commonly used nitrogenous fertilizer, to the plant available nitrate form.

3.2. Dehydrogenase activity

Dehydrogenase activity (DHA) closely followed the pattern of the organic matter and available NPK build up in the soil in various treatments. Its magnitude was higher in surface soil (0-10 cm) as compared to the deeper layers (Figure 3). It varied from 0.71 to 1.85 µg TPF g^{-1} h^{-1} in 0-10 cm soil and lowed down to 0.68 - 0.96 µg TPF g^{-1} h^{-1} in 20-30 cm soil depth.

Table 1. Effect of organic and inorganic sources of nutrients on available N, P and K in soil

	Treatments	2008-09	2009-10	2010-11	Mean
	T_1	33.5 ± 1.5	52.5 ± 1.1	58.0 ± 4.4	48.4 ± 2.1
Available	T_2	44.5 ± 4.1	64.8 ± 5.3	65.3 ± 1.5	57.8 ± 2.5
N (mg kg^{-1})	T_3	43.0 ± 1.4	55.3 ± 6.8	65.3 ± 4.5	54.5 ± 1.1
	T_4	50.8 ± 2.2	68.0 ± 4.9	74.5 ± 1.0	64.4 ± 2.2
	T_5	55.5 ± 1.7	73.3 ± 2.0	86.3 ± 5.9	71.7 ± 1.4
	LSD (p = 0.05)	2.23	3.55	4.17	5.17
Available	T_1	8.1 ± 0.5	14.5 ± 2.1	21.1 ± 2.4	14.6 ± 6.5
P (mg kg^{-1})	T_2	10.1 ± 0.7	19.8 ± 6.0	24.0 ± 2.8	18.0 ± 7.1
	T_3	10.8 ± 0.9	22.3 ± 2.0	24.7 ± 4.4	19.2 ± 7.4
	T_4	11.0 ± 0.2	22.1 ± 4.2	26.5 ± 3.0	19.9 ± 7.9
	T_5	12.8 ± 1.0	28.0 ± 3.7	31.1 ± 1.7	24.0 ± 9.7
	LSD (p = 0.05)	0.32	0.86	0.81	0.64
Available	T_1	33.3 ± 4.2	45.7 ± 8.5	109.6 ± 4.5	62.9 ± 4.9
K (mg kg^{-1})	T_2	44.5 ± 6.4	63.6 ± 4.7	143.4 ± 3.9	83.9 ± 2.4
	T_3	42.4 ± 5.7	65.3 ± 4.3	135.4 ± 3.5	81.0 ± 4.4
	T_4	47.7 ± 1.1	76.2 ± 5.6	158.4 ± 1.2	94.1 ± 5.4
	T_5	52.1 ± 0.8	94.5 ± 3.4	188.0 ± 1.9	111.5 ± 6.5
	LSD (p = 0.05)	1.99	2.26	6.06	3.76

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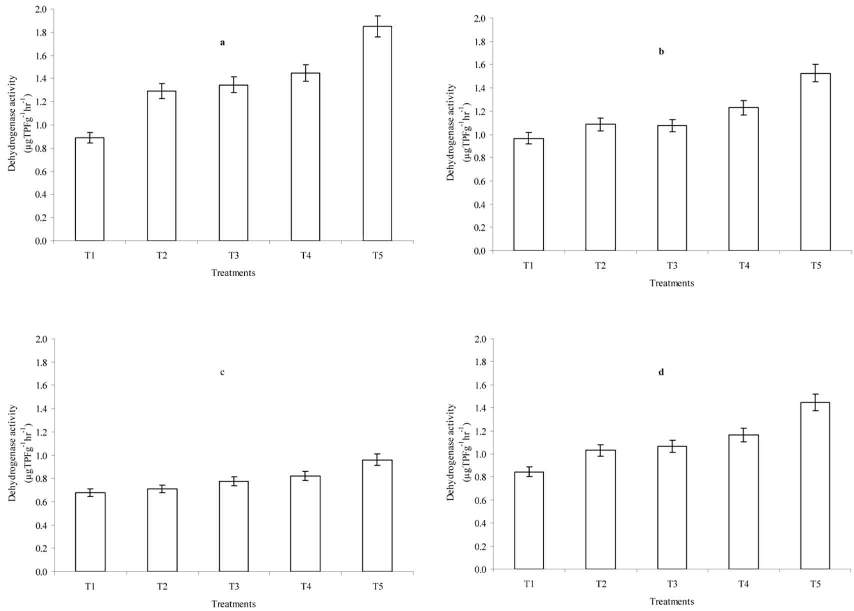

Figure 3. Mean dehydrogenase activity (µg TPF g^{-1} h^{-1}) in mango orchard soils. a, b, c and d stands for soil samples at 0-10, 10-20, 20-30 and pooled mean 0-30 cm soil depth. All plots receiving vermicompost had significantly more dehydrogenase activity (p<0.05) than plots that received inorganic fertilizers only. The statistical significance and differences were concluded using SAS at p <0.05.

The mean dehydrogenase activity (1.37 µg TPF g^{-1} h^{-1}) was significantly higher in 0-10 cm soil depth and decreased with soil depth (0.79 µg TPF g^{-1} h^{-1}). It was interesting to note that the dehydrogenase activity was higher in vermicompost treated soils (1.07 to 1.35 µg TPF g^{-1} h^{-1}) as compared to FYM (0.94 µg TPF g^{-1} h^{-1}). The positive effect of microbial inoculants and mulching on dehydrogenase activity was also revealed from this study as the dehydrogenase activity was higher across the depths as compared to the control. The effect of vermicompost on DHA was also higher as compared to FYM across different depth.

Soil dehydrogenase activity is a function of soil management system as it is directly or indirectly influenced by the orchard ground-floor management systems (Chu *et al.*, 2007). Generally the enzyme activities in the soil were closely related to the organic matter content. Application of balanced amounts of nutrients and manures improved the organic matter and microbial biomass carbon status of soils, which corresponded with higher enzyme activity (Mandal *et al,* 2007). Dehydrogenase activity with application of organic sources might be linked to more substrate availability in the soil. This reflects the greater biological activity in the soil and the stabilization of extracellular enzymes through complexation with humic substances (Basak *et al.*, 2013). It has been reported that the increase in dehydrogenase activity and microbial biomass were proportional to the addition of number and amount of nutrients (Manjaiah and Singh, 2001). In the present study, a similar trend was observed. According to Pramanik *et al.* (2010) dehydrogenase activity is influenced more by the quality than by the quantity of organic matter incorporated into soil. Thus, the stronger effects of vermicompost or microbial inoculants on dehydrogenase activity might be due to the more easily decomposable components of crop residues on the metabolism of soil microorganisms.

3.3. Micronutrients availability

The micronutrient availability in the soil treated with different organic and inorganic sources showed significant difference (Table 2). The DTPA-Fe content of the soils varied from 3.83 to 8.63 mg kg^{-1}, 4.17 to 8.27 mg kg^{-1} and 7.07 to 9.32 mg kg^{-1} in 2008-09, 2009-10 and 2010-11 respectively. Considering critical limits of 2 mg kg^{-1}, the soils are sufficient in Fe. However, the pooled data indicated that mango soils had around 6.8 to 8.74 mg kg^{-1} Fe in Vermicompost, microbial consortia, mulching and inorganic substrate added soils, lowest Fe content being in T_1 (5.02 mg kg^{-1}). There was continuous build up of available Fe in the soil due to various treatments which may be attributed to release from the organic sources because of increased microbial activities in the soil.

Table 2. Effect of organic and inorganic sources of nutrients on available micronutrients (mg kg^{-1}) in orchard soil

	Treatments	2008-09	2009-10	2010-11	Mean
DTPA-extractable Fe	T_1	3.83 ± 0.93	4.17 ± 0.68	7.07 ± 1.23	5.02 ± 1.78
	T_2	6.33 ± 0.67	5.68 ± 1.08	8.39 ± 1.16	6.80 ± 1.41
	T_3	6.35 ± 1.25	6.00 ± 1.94	8.54 ± 1.01	6.96 ± 1.38
	T_4	7.51 ± 0.90	7.08 ± 1.29	8.75 ± 0.49	7.78 ± 0.87
	T_5	8.63 ± 1.01	8.27 ± 1.04	9.32 ± 0.41	8.74 ± 0.53
	LSD (p = 0.05)	0.49	0.85	0.45	0.85
DTPA-extractable Mn	T_1	3.53 ± 1.27	4.70 ± 1.07	6.03 ± 0.31	4.75 ± 1.25
	T_2	6.34 ± 1.72	6.47 ± 2.13	7.45 ± 1.23	6.75 ± 0.61
	T_3	7.08 ± 2.47	6.23 ± 1.53	6.69 ± 0.72	6.66 ± 0.43
	T_4	7.39 ± 1.54	7.57 ± 1.19	7.56 ± 0.48	7.50 ± 0.10
	T_5	8.95 ± 0.97	8.74 ± 1.49	9.13 ± 1.27	8.94 ± 0.20
	LSD (p = 0.05)	0.46	1.22	0.41	0.23
DTPA-extractable Zn	T_1	0.65 ± 0.23	0.63 ± 0.63	1.09 ± 0.47	0.79 ± 0.26
	T_2	1.22 ± 0.42	1.59 ± 0.76	2.32 ± 1.26	1.71 ± 0.56
	T_3	1.31 ± 0.23	1.43 ± 0.25	1.10 ± 0.51	1.28 ± 0.16
	T_4	1.34 ± 0.55	1.57 ± 1.28	3.17 ± 1.59	2.02 ± 1.00
	T_5	1.88 ± 0.13	2.14 ± 0.89	4.13 ± 1.08	2.72 ± 1.23
	LSD (p = 0.05)	0.06	0.36	0.60	0.35
DTPA-extractable Cu	T_1	0.32 ± 0.11	0.95 ± 0.13	1.72 ± 0.36	0.99 ± 0.70
	T_2	0.45 ± 0.09	1.67 ± 0.60	2.55 ± 0.43	1.55 ± 1.05
	T_3	0.49 ± 0.19	1.89 ± 1.01	3.11 ± 0.56	1.83 ± 1.31
	T_4	0.60 ± 0.16	2.36 ± 0.79	3.54 ± 0.68	2.17 ± 1.48
	T_5	0.84 ± 0.15	5.01 ± 0.83	5.49 ± 2.77	3.78 ± 2.56
	LSD (p = 0.05)	0.01	1.01	0.19	1.25

Table 3. Foliar major nutrient concentrations, % (mean ± standard deviations) in mango as influenced by organic and inorganic sources of nutrition

	Treatments	2008-09	2009-10	2010-11	Mean
	T_1	1.10 ± 0.1	1.06 ± 0.2	1.41 ± 0.3	1.19 ± 0.2
Nitrogen	T_2	1.33 ± 0.2	1.35 ± 0.1	1.49 ± 0.3	1.39 ± 0.1
	T_3	1.27 ± 0.1	1.20 ± 0.2	1.45 ± 0.4	1.31 ± 0.1
	T_4	1.35 ± 0.2	1.37 ± 0.2	1.61 ± 0.2	1.44 ± 0.1
	T_5	1.37 ± 0.1	1.49 ± 0.1	1.61 ± 0.3	1.49 ± 0.1
	LSD (p = 0.05)	0.02	0.02	0.06	0.01
	T_1	0.10 ± 0.01	0.17 ± 0.03	0.14 ± 0.03	0.14 ± 0.03
Phosphorus	T_2	0.12 ± 0.03	0.17 ± 0.01	0.16 ± 0.06	0.15 ± 0.02
	T_3	0.11 ± 0.01	0.16 ± 0.03	0.16 ± 0.06	0.14 ± 0.02
	T_4	0.13 ± 0.02	0.17 ± 0.04	0.17 ± 0.03	0.16 ± 0.02
	T_5	0.13 ± 0.01	0.18 ± 0.04	0.18 ± 0.02	0.16 ± 0.03
	LSD (p = 0.05)	0.001	0.001	0.002	0.0005
	T_1	0.23 ± 0.1	0.47 ± 0.1	0.55 ± 0.1	0.51 ± 0.04
Potassium	T_2	0.44 ± 0.2	0.54 ± 0.04	0.61 ± 0.1	0.57 ± 0.04
	T_3	0.39 ± 0.1	0.53 ± 0.03	0.60 ± 0.1	0.56 ± 0.03
	T_4	0.59 ± 0.3	0.54 ± 0.05	0.62 ± 0.2	0.58 ± 0.03
	T_5	0.61 ± 0.1	0.56 ± 0.1	0.66 ± 0.2	0.61 ± 0.05
	LSD (p = 0.05)	0.02	0.002	0.01	0.001

Different treatments have shown significant effect on DTPA-Mn in the soil over the initial level of 1.96 mg kg^{-1}. Similarly, in case of DTPA-Zn and DTPA-Cu, it was observed that soils treated with vermicompost and microbial inoculants had higher availability (2.72 and 3.78 mg kg^{-1} respectively). In general, micronutrients contents were significantly enhanced over initial level primarily may be due to the application of different organic and inorganic nutrient sources. Considering the effects of different organic (FYM, vermicompost, mulching) and inorganic (N, P, K) sources of nutrition including bioinoculants (*Azotobacter*, PSM and *Trichoderma harzianum*), it was revealed that in mango ecosystem, highest content of Fe, Cu, Mn and Zn were recorded in the treatments comprising 10 kg vermicompost + 100, 50, 100 g N, P and K / tree /year of age + *Azotobacter* + PSM + *Trichoderma harzianum* + organic mulching and the lowest in the treatment wherein organic mulching and bioinoculants were not included. Therefore the microbes and organic sources played significant role in nutrient acquisition and availability in the soil which is clearly evident for the dehydrogenase activity in the soil (Kumar *et al*., 2011).

3.4. Leaf nutrient dynamics

The present study indicated that foliar nutrient dynamics was significantly influenced by the application of organic and inorganic substrates to a low fertility mango orchard soil of subtropical region (Table 3). It was observed from the four year study that the nitrogen content of the leaves was in the sufficient level. The total nitrogen concentration in leaf was in the range of 1.06 to 1.61 per cent across the treatments and years. The highest N (1.49 per cent) was found in treatment T_5 closely followed by T_4 (1.44 per cent). The mean nitrogen content in leaf significantly increased over the years. The means value of total leaf nitrogen in T_5 and T_4 were significantly higher than T_1. The pattern of soil available N and leaf N showed similar trend in different treatments.

Table 4. Foliar micronutrient concentrations, mg kg^{-1} (mean ± standard deviations) in mango as influenced by organic and inorganic sources of nutrition

	Treatments	2008-09	2009-10	2010-11	Mean
	T_1	105.5 ± 9.8	139.0 ± 5.0	137.8 ± 4.5	127.4 ± 5.5
Fe	T_2	126.8 ± 8.2	151.8 ± 8.3	174.8 ± 4.3	151.1 ± 9.6
	T_3	120.3 ± 7.6	151.0 ± 8.0	171.5 ± 8.7	147.6 ± 8.0
	T_4	128.3 ± 3.0	157.5 ± 8.4	173.0 ± 6.7	152.9 ± 8.5
	T_5	153.5 ± 3.9	173.0 ± 3.0	175.0 ± 9.7	167.2 ± 9.7
	LSD (p = 0.05)	3.14	5.67	5.75	4.32
	T_1	84.0 ± 4.7	63.8 ± 2.2	158.3 ± 8.1	102.0 ± 4.6
Mn	T_2	100.0 ± 9.3	118.3 ± 11.6	167.0 ± 6.1	128.4 ± 2.2
	T_3	90.3 ± 4.9	103.0 ± 14.7	163.0 ± 6.7	118.8 ± 3.7
	T_4	106.3 ± 8.2	120.0 ± 7.9	184.0 ± 8.9	136.8 ± 3.8
	T_5	110.5 ± 5.2	122.3 ± 4.9	204.0 ± 7.6	145.6 ± 4.5
	LSD (p = 0.05)	1.82	2.46	4.96	8.5
	T_1	16.0 ± 3.1	18.0 ± 3.1	22.5 ± 2.3	18.8 ± 2.7
Zn	T_2	21.3 ± 2.6	18.0 ± 0.8	24.8 ± 6.1	21.3 ± 2.7
	T_3	20.8 ± 1.5	18.0 ± 1.8	24.8 ± 2.0	21.2 ± 2.7
	T_4	21.3 ± 2.7	21.5 ± 3.7	29.3 ± 8.1	24.0 ± 3.7
	T_5	21.5 ± 2.0	23.5 ± 7.5	29.3 ± 8.4	24.8 ± 3.2
	LSD (p = 0.05)	0.65	0.85	0.90	0.41
	T_1	3.8 ± 0.9	4.8 ± 0.9	10.0 ± 2.1	6.2 ± 0.27
Cu	T_2	5.8 ± 1.5	5.8 ± 0.5	13.8 ± 1.5	8.4 ± 0.37
	T_3	5.3 ± 0.5	5.0 ± 0.8	13.5 ± 4.2	7.9 ± 0.39
	T_4	6.0 ± 1.4	6.0 ± 0.8	14.8 ± 2.2	8.9 ± 0.41
	T_5	6.0 ± 1.8	6.5 ± 0.5	17.0 ± 3.4	9.8 ± 0.5
	LSD (p = 0.05)	0.18	0.34	0.32	0.55

In contrast, phosphorus content in leaf did not vary significantly among the treatments during different years. Potassium content was significantly higher in treatment T_5 as compared to T_1, the mean values were recorded as 0.61, 0.56 and 0.66 per cent in 2008-09, 2009-10 and 2010-11, respectively. The range of micronutrients viz. Fe, Mn, Zn and Cu content in leaves were 105.5 to 175.0, 63.8 to 204.0, 16.0 to 29.3 and 3.8 to 17.0 ppm, respectively. The pooled mean value of Fe, Mn, Zn and Cu in T_5 viz. 167.2, 145.6, 24.8 and 9.8 ppm were significantly higher than T_1 (127.4, 102.0, 18.8 and 6.2 ppm, respectively). All the micronutrients content in leaves increased marginally over the years (Table 4). This indicated a positive effect of soil nutrient management system comprising integration modules of organic and inorganic sources of nutrition with microbes. The leaf nutrient concentration followed almost similar trend of soil nutrient status. The effect of vermicompost was superior to FYM and organic mulching and microbes showed positive effect on nutrient build up in the soil and leaves. Studies inferred that tree foliar nutrient dynamics and its management is an essential management tool for rectifying any deficiency and thereby tree growth, yield and sustainability under diverse agroecological region (Rodrigues *et al*., 2011).

4. Conclusions

This study revealed that the soil fertility, foliar nutrient concentrations and soil enzyme activities were significantly influenced by the application of organic and inorganic fertilizer amendments in mango orchard soil of low fertility status. Soil nutrient status was highest in the treatments where vermicompost and microbial inoculants were used as a component. Lowest fertility status was observed where only FYM and inorganic fertilizer were applied without consideration of other organics sources. In general, the soil and leaf nutrients were improved over the years. Dehydrogenase activity was significantly higher in microbial inoculants treated soil as compared to FYM + inorganic substrates. Surface soil (0-10 cm) showed higher dehydrogenase activity (1.29 to 1.85 TPF g^{-1} h^{-1}) in all the treatments as compared to lower soil depths. Vermicompost emerged as more important organic input than FYM in soil nutrient management strategy as a function of crop residues management. Thus, to sustain the long-term fertility of orchard soil and soil and leaf nutrient dynamics, application of vermicompost along with N_2 fixers and P solubilizing microorganisms and organic mulching should be integrated with NPK fertilizers.

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