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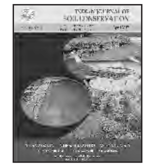

Soil indicators as a tool to assess changes in soil properties in guava orchard ecosystem

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ABSTRACT

The aim of this experiment was to assess the changes in soil properties using physical (bulk density, porosity, water holding capacity, soil organic carbon), biological (soil respiration, dehydrogenase activity and microbial population) and chemical (available nutrients) indicators under guava orchard soil management system. A decrease in bulk density and increase in porosity and water holding capacity was confirmed from this study. Linear regression analysis revealed that Bulk Density (BD) had inverse correlation with Water Holding Capacity (WHC) (r=-0.82**) and porosity (r=-0.88**). Porosity and WHC were strongly associated with Soil Organic Carbon (SOC) content (r=0.68** to 0.76**). Soil respiration ranged between 51.8 ± 7.4 to 71.9 ± 5.0 mg CO_2 kg^{-1} soil day^{-1} across different treatments. Dehydrogenase activity was highest (0.62 to 7.13 μg TPF g^{-1} h^{-1}) in surface soil (0-10 cm) and decreased down the depth to 30 cm soil depth (0.08 to 2.42 μg TPF g^{-1} h^{-1}). An increase in microbial activity was observed in soil treated with organic mulching, biofertilizers and vermicompost. Linear regression analysis indicated that porosity or WHC could explain around 60-70% variation in microbial respiration and enzymatic activity as independent variables. The study, thus confirmed that biological indicator along with physical and chemical could be considered as a potential tool to assess the changes in some soil properties under short-term fruit orchard soil management in order to predict the best treatment combinations for sustaining soil health in low fertile soils of subtropical region.

1. INTRODUCTION

Soil is a natural complex system wherein physical, chemical and biological factors tried to maintain dynamic equilibrium among themselves. Maintaining soil health at a desired level is a very complex issue and is one of the main environmental and agronomic challenges in rainfed orchards of tropical and subtropical semiarid agro-ecosystems (Ramos *et al.*, 2011; Dinesh *et al.*, 2012). Inappropriate production technologies in these orchards have resulted in poor soil quality, leading to soil organic matter losses and structural degradation, affecting water, air and nutrient flows, and consequently orchard productivity and sustainability. Soils of semiarid regions are often coarse-textured, inherently low in fertility, organic matter, and WHC and thus susceptible to erosion and associated nutrient losses (Aseri *et al.*, 2008). Therefore, there is an urgent need to adopt appropriate soil and plant management practices that reduce soil degradation or maintain soil quality at a desired level in orchards of semiarid regions (Adak *et al.*, 2014).

Soil quality assessment is an efficient tool for evaluating sustainability of soil and crop management practices (Karlen *et al.*, 1992) and the quality indicators are the measurable soil properties that reflects dynamism of soil-plant-environmental functions (Herrick, 2000; Shahab *et al.*, 2013; Adak *et al.*, 2015). Improved soil quality is often indicated by short-term improvement in soil physical and chemical indicators *viz.,* increased infiltration, aeration, macropores, aggregate size and stability, enhanced soil organic content, nutrient fluxes and by decreased bulk density, soil resistance, erosion and nutrient runoff (Leroy *et al.*, 2008; Moeskops *et al.*, 2012). Periodic assessment of soil microbiological and biochemical indicators has also been suggested as effective criteria for evaluating long or short-term nutrient management effects (Bending *et al.*, 2004; Stark *et al.*, 2007).

Soil application of organic sources such as vermicompost, organic mulching, crop residues and biofertilizers represents a soil rejuvenation technology that could counteract depletion of organic matter in soils. Under conventional orchard management, intensive tillage, exhaustive nutrient removal and intensive use of pesticides and fertilizers, deteriorates soil physical, chemical and biological properties. Improvement of water stable soil aggregation, moisture retention, thermal regulation and microbial functioning are such beneficial yield of organic fertilization incorporation into a productive orchard ground floor management system (Tejada *et al.*, 2006; Bamberg *et al.*, 2011). Mature compost when added to soil directly affects almost all of soil factors. In many areas of the world, the major benefits derived from compost result from improved soil physical properties. Composted municipal solid waste, composted sewage-sludge or a combination of these materials, earthworm processed products etc. reduce soil BD and increase total porosity in soils over a wide range of textural classes (Tester, 1990). The increase in total porosity has been attributed to increased numbers of 30-50 and 50-500 μm pores and a decrease in number of pores >500 μm. Long-term organic management of agricultural soils showed positive influences on soil properties since the addition of organic amendments can improve total organic carbon accumulation in soil by increasing C pools with a slow turnover rate (Schjonning *et al.*, 2002). Since such information was meager in guava orchards of semi-arid tropical and subtropical India region, the present investigation was laid out with the objective of assessing the short-term response of some soil physical, chemical and biological properties after applications of different organic and inorganic amendments to a course textured horticultural soil under field conditions.

2. MATERIALS AND METHODS

Location, Site and Experimental Design

A field experiment was carried out during 2008-2012 in the Rehmankhera farm of ICAR Central Institute for Sub-tropical Horticulture, Rehmankhera, Lucknow (26.54^{0}N latitude, 80.45^{0}E longitude and 127 m above msl), Uttar Pradesh, India. The experimental soil had 0.21 cm h^{-1} hydraulic conductivity, water retention at different tensions (bars) varied from 9.5 to 30.9% in the basin while it was recorded as 8.8 to 35.1% in the interspaced, 7.2 pH and 0.12 dS m^{-1} electrical conductivity. Available N, P and K content ranged between 39.5-58.3, 26.8-45.7 and 81.4-111.7 mg kg^{-1}, respectively (Table 1a and 1b). The soil, in general, showed low fertility status. Initial microbial count was 1.8 ×10^6 and 8 ×10^3 cfu.g^{-1} soil for bacteria and fungi, respectively. The experiment was conducted in a randomized block design with four replications on newly planted 'Shweta' guava trees, grown at a spacing of 5 × 5 m. The treatments consisted of different organic (FYM, vermicompost, mulching) and in organic sources of nutrients (Nitrogen-N, phosphorus - P, potassium - K) including microbial inoculants (*Azotobacter,* phosphate solubilizing microbes - PSM and *Trichoderma harzianum*). Paddy straw and guava leaf litter (1:1) was used as mulching at a rate of 5 kg plant^{-1}. Biofertilizers (*Azotobacter,* PSM and *T. harzianum*) were applied at rate of 100 g plant^{-1}. The five different treatments were T_1-120 g N, 60 g P and 50 g K tree^{-1} year^{-1} + 10 kg FYM (control), T_2- 120 g N 60 g P and 50 g K tree^{-1} year^{-1} + *Azotobacter* + PSM + *T. harzianum* + organic mulching + 10 kg FYM, T_3- 120 g N 60 g P and 50 g K tree^{-1} year^{-1} + *Azotobacter* + PSM + *T. harzianum* + organic mulching, T_4- 120 g N 60 g P and 50 g K tree^{-1} year^{-1} + *Azotobacter* + PSM + *T. harzianum* + organic mulching + 5 kg FYM + 5 kg Vermicompost and T_5- 120 g N 60 g P and 50 g K tree^{-1} year^{-1} + *Azotobacter* + PSM + *T.harzianum* + organic mulching + 10 kg Vermicompost. The trees were fertilized with N as urea and Diammonium Phosphate (DAP), P as DAP and K as Muriate of Potash (MoP) in the basin before flowering. Half dose of N and K and full dose of P was applied in the month of July and remaining N and K was applied during 3rd week of September. Irrigation was applied through drip during 2nd week of April, May, June and last week of December in the tree basin based on 60% open pan evaporation of this region.

Soil Sampling

Undisturbed core soil samples were collected from the tree basin from 0-10, 10-20 and 20-30 cm depth from all treatments before fertilization on each year. Samples were air

Table: 1b
Soil water retention (% by weight) of the experimental site

	Tension (Bars)					
	0.3	1.0	3.0	5.0	10.0	15.0
Guava basin	30.9	20.9	15.9	13.6	10.4	9.5
Guava Interspace	35.1	25.7	17.0	14.9	9.8	8.8

Table: 1a
Physico-chemical properties of the soil at experimental site

Particle density (g cc^{-1})	Water holding capacity (%)	Bulk Density (g cc^{-1})	Sand	Silt	Clay
2.56	28.40	1.555	7.3	36.2	6.5
Organic Carbon (%)	Available N (mg kg^{-1})	Available P (mg kg^{-1})		Exchangeable K (mg kg^{-1})	
0.28	48.9	26.8		96.5	
pH	EC (dS m^{-1})	Saturated hydraulic conductivity (cm hr^{-1})		Slope (%)	
7.2	0.12	0.21		0-1	

dried at room temperatures and passed through a 2 mm sieve and homogenated. For microbial analysis, separate soil samples were collected, air dried and processed for analysis. Pooled data were used for the study. The soil indicators were estimated following the standard procedures (Table 2). BD, WHC, porosity and particle density were determined as per the standard procedures. Soil pH and Electrical Conductivity (EC) were determined in a 1:2.5 soils: water extract. Particle size distribution was determined as per the standard methodology using Hydrometer. The production of CO_2 was measured as indicator of soil microbial activity to estimate Soil Respiration (SR). Soil samples (100 g) at 75% of WHC were incubated in hermetic flasks (600 cm^3) in layers of approximately 25 mm during 7 days at 25°C. The CO_2 was trapped in 0.5 N NaOH which was titrated with HCl and phenolphthalein indicator in the presence of $BaCl_2$. The CO_2 evolved was calculated by difference between samples and blanks without soil.

Statistical Analysis

Mean values of all the soil parameters were analyzed by analysis of variance (ANOVA) procedure for a randomized block design with four replications. SAS software (version 9.3) was used for Duncan Multiple Range Test (DMRT) for different treatments means and donated by different letters (a, b, c and d) at 5% level of significance (*i.e.* at 95% level of probability). Same letter indicated statistically non-significance among the mean values of different parameters while different letters indicated statistical significance. Histographic presentation, developing Pearson's correlation matrix with statistical significance, analyzing functional relationship, deriving descriptive statistical analysis and drawing significant graphs *etc.* among the indicators were also derived.

3. RESULTS AND DISCUSSION

Physical Indicators

Soil texture is a basic physical indicator to identify the particle size distribution of soil under a cropping system and thereby is necessarily required in order to assess soils of agro-horticultural ecology. Mechanical analysis of undisturbed core soil samples at 0-10, 10-20 and 20-30 cm depth showed that the soil had sand, silt and clay percentage in the range of 49.6 to 68.8, 29.1 to 47.6 and 1.0 to 3.8%, respectively across different treatments (Table 3). The soil is sandy in nature and thereby inherently low in nutrient and water retention capacity. This confirmed the fact that in coarse textured soil, erosion and nutrient depletion loss is higher mainly because of lack of soil organic matter content and any other binding compounds to retain soil moisture and nutrients. Maintaining optimum soil health in semiarid rainfed soils of tropical and subtropical parts of India is indeed a difficult task (Singh *et al.,* 2013). The issue is even more challenging because of a very fragile natural resource base typifies many of the semiarid orchards. These soils encounter several problems including water erosion, shallow depth, hard pan formation, low water and nutrient retention, and restricted rooting depth (Prasad and Biswas, 1999). Poor orchard ground floor management and climatic extremes have significantly contributed towards the deterioration of soil health in these orchards (Singh *et al.*, 1998).

Apart from the intrinsic property of textural indicator, we have evaluated, in the experiment, other effective physical indicators *viz.,* BD, ranged between 1.29 to 1.48 g cm^{-3} (Table 4). A general decrease in BD was observed in the soil treated with 10 kg vermicompost ha^{-1} (T_5). The BD was *at par* in other organic treatments where dose of vermicompost was adjusted (T_2-T_4). The decrease in BD may be due to improvement in pore space particularly micropores in the soil. Porosity of the soil increased significantly with application of both organic and inorganic fertilizer. Highest porosity was recorded as 52.9% (T_5) as compared to 40.08% in NPK+ FYM (T_1). Marinari *et al.* (2000) reported that total porosities in

Table: 2
Methods of soil analysis

S.No.	Analysis	References
1	Soil organic carbon	Walkley and Black, 1934
2	Available N	Subbiah and Asija 1956
3	Available P	Olsen *et al.,* 1954
4	Available K	Jackson, 1958
5	DTPA extractable Zn, Cu, Mn and Fe	Lindsay and Norvell, 1978
6	Dehydrogenase activity	Casida *et al.,* 1964

Table: 3
Descriptive statistical analysis of mechanical properties of soil

	0-10 cm	10-20 cm	20-30 cm	Pooled*	SEm ±	CV	Range
				Sand			
T_1	56.5	58.3	53.6	56.1±2.37[a]	1.9	4.2	52.6-66.8
T_2	56.4	55.0	52.2	54.5±2.14[a]	1.5	3.9	52.2-65.0
T_3	53.3	53.5	54.1	53.6±0.44[a]	0.1	0.8	53.3-67.5
T_4	55.6	56.1	49.6	53.8±3.62[a]	4.4	6.7	49.6-67.1
T_5	53.3	55.4	50.6	53.1±2.40[a]	1.9	4.5	50.6-68.8
				Silt			
T_1	40.5	38.3	42.3	40.4±2.00[a]	1.3	5.0	32.3-44.6
T_2	40.2	42.2	44.0	42.1±1.90[a]	1.2	4.5	32.2-45.0
T_3	43.1	41.3	41.6	42.0±0.96[a]	0.3	2.3	31.3-45.8
T_4	40.6	40.4	44.9	42.0±2.54[a]	2.2	6.1	29.1-47.6
T_5	42.1	40.4	44.6	42.4±2.11[a]	1.5	5.0	30.3-46.6
				Clay			
T_1	3.0	3.5	4.1	3.5±0.55[a]	0.1	15.6	2.0-4.8
T_2	3.4	2.8	3.8	3.3±0.50[a]	0.1	15.1	2.3-4.1
T_3	3.7	5.0	4.3	4.3±0.65[a]	0.1	15.0	3.0-5.8
T_4	3.8	4.8	5.3	4.6±0.76[a]	0.2	16.5	2.7-5.3

SD: Standard deviations, SEm: Standard error of mean, CV: Coefficient of variation, * Mean ± standard deviations, Different letters indicate significantly different treatment means at P<0.05 with Duncan's multiple range test comparison

Table: 4
Some soil physical indicators under different soil management systems

	0-10 cm	10-20 cm	20-30 cm	Mean±sd* BD	SEm ±	CV	Range
T_1	1.47	1.37	1.48	1.44 ± 0.06^{a}	0.001	4.2	1.37-1.48
T_2	1.41	1.38	1.40	1.40 ± 0.02^{a}	0.0001	1.1	1.38-1.41
T_3	1.37	1.38	1.43	1.39 ± 0.03^{a}	0.0003	2.3	1.37-1.43
T_4	1.34	1.44	1.42	1.40 ± 0.05^{a}	0.001	3.8	1.34-1.44
T_5	1.27	1.32	1.29	1.29 ± 0.03^{b}	0.0002	1.9	1.27-1.32
				Porosity			
T_1	39.3	42.9	38.1	40.08 ± 2.5^{c}	2.124	6.3	38.1-42.9
T_2	46.4	45.9	43.8	45.35 ± 1.4^{b}	0.640	3.1	43.8-46.4
T_3	47.7	47.3	45.2	46.75 ± 1.3^{b}	0.604	2.9	45.2-47.7
T_4	50.4	46.9	47.4	48.21 ± 1.9^{b}	1.187	3.9	46.9-50.4
T_5	54.3	51.8	52.6	52.90 ± 1.3^{a}	0.545	2.4	51.8-54.3
				WHC			
T_1	20.1	20.1	19.2	19.80 ± 0.52^{c}	0.090	2.6	19.2-20.1
T_2	20.1	20.2	20.2	20.17 ± 0.06^{c}	0.001	0.3	20.1-20.2
T_3	21.4	20.7	20.4	20.83 ± 0.51^{bc}	0.088	2.5	20.4-21.4
T_4	22.2	21.9	21.2	21.77 ± 0.51^{b}	0.088	2.4	21.2-22.2
T_5	24.6	22.3	23.7	23.53 ± 1.16^{a}	0.448	4.9	22.3-24.6
				PD			
T_1	2.42	2.4	2.39	2.40 ± 0.02^{d}	0.0001	0.6	2.39-2.42
T_2	2.63	2.55	2.49	2.56 ± 0.07^{c}	0.002	2.7	2.49-2.63
T_3	2.62	2.62	2.61	2.62 ± 0.01^{b}	0.0001	0.2	2.61-2.62
T_4	2.7	2.71	2.7	2.70 ± 0.01^{a}	0.0002	0.2	2.70-2.71
T_5	2.78	2.74	2.72	2.75 ± 0.03^{a}	0.0003	1.1	2.72-2.78

BD: Bulk density, WHC: Water holding capacity, PD: Particle density, SD: Standard deviations, SEm: Standard error of mean, CV: Coefficient of variation, * Mean ± standard deviations, Different letters indicate significantly different treatment means at $P<0.05$ with Duncan's multiple range test comparison

soil treated with stabilized manure, vermicompost and fertilizer nitrogen were respectively 46, 24 and 18% higher than in the unfertilized soil. Improvement of 32% porosity in the vermicompost treated soil was recorded as compared to control (NPK+ FYM). The pore size distribution and size fractions of pores are important indicators in the total porosity and it was inferred that the greater porosity in the soil treated with mineral fertilizer could be due to an increase in the amount of rounded pores. Conversely, elongated pores, belonging to the 100-200 µm size class, decreased (-32%) with respect to the control soil. Generally, pores ranging from 50 to 500 µm in equivalent pore diameter as elongated and continuous pores are considered the most important in soil-water- plant relationships. Information on hydrophysical properties of soil is important for crop planning (Singh *et al.*, 2008). The feeding roots need pores ranging from 100 to 200 µm to grow through (Tipktter, 1983). Furthermore, organically treated with vermicompost, soils showed an increase of 32% rounded biopores with respect to the control soil. The present study further confirmed 18.8% enhancement in water holding capacity (WHC) of soil treated with vermicompost (T_5) rather than FYM application (T_1). Particle density in the range of 2.4 to 2.7 g cm^{-3} in this orchard was found. Functional relationship among the soil physical indicators revealed that porosity and water holding capacity were inversely related with the BD (Fig. 1). Linear regression

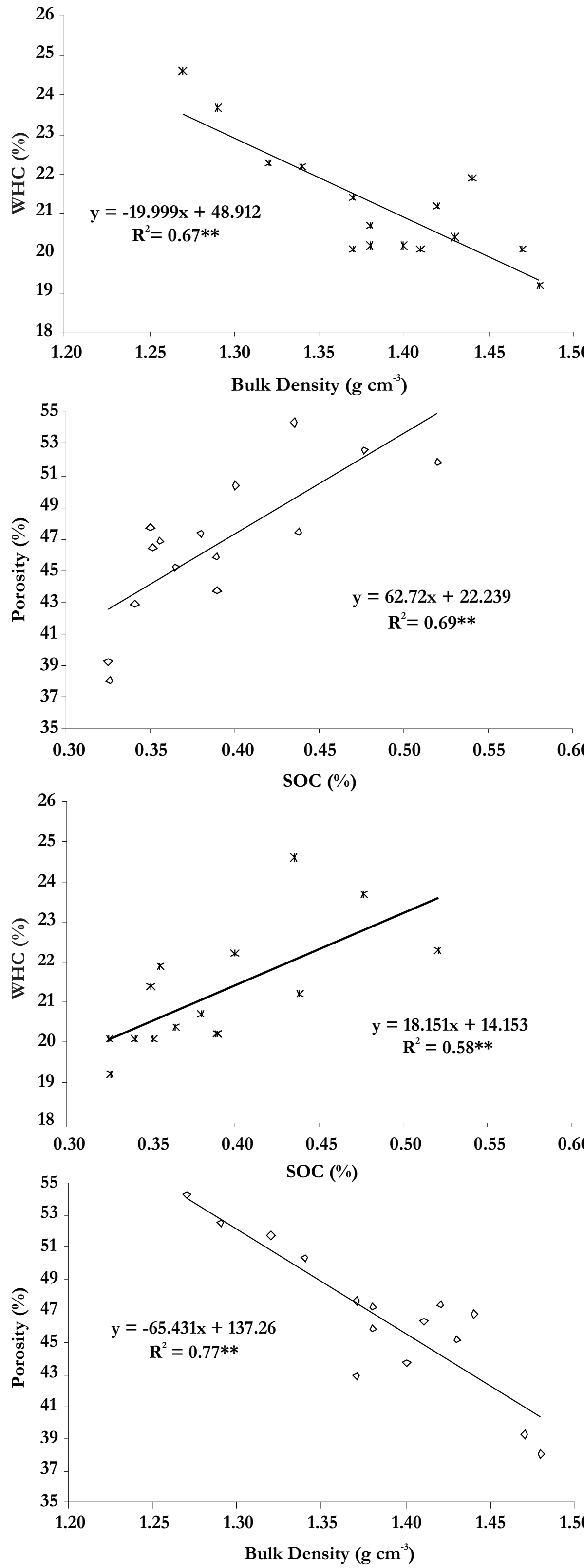

Fig. 1. Functional relationship among the soil physical indicators under different guava soil orchard management systems

analysis indicated significantly strong and negative correlation existed between BD with porosity and WHC and could be predicted using following equations:

$$\text{Porosity (\%)} = -65.43 \times BD + 137.26 \ (R^2 = 0.77^{**})$$

$$\text{WHC (\%)} = -19.99 \times BD + 48.91 \ (R^2 = 0.67^{**})$$

Chemical and Biological Indicators

Soil chemical, microbiological and biochemical indicators are widely accepted as a good quality assessment index for soils across the world. The role of microbial fractions in mediating soil ecological processes and the biogeochemical reaction within the sheets of soil layers could be a sensitive indicator and early predictor of changing soil organic matter and nutrient dynamics in soil. The SOC content acts both as a sink and source of nutrients and also responsible for biogeochemical transformation of C, P, N, K, S and contributes to soil structural development and stabilization by microbes. Actually the study of the short-term soil responses to different management approaches should provide valuable information concerning practices which improve soil quality. Of course, the management systems behave differently in various hydrothermal regimes, but the short-term impact of organic amendments on a sandy soil could be an indicator of an adopted soil management system. Field experimentation across different soil and crop ecosystems indicated that organic amendment leads to improvement in soil health with higher microbiological activity than conventional farming (Arancon *et al*., 2006). Since, the content and the activity of soil microbes are closely related to the C input, the organic management affects soil microbial properties with a large input of organic matter derived from green manure and organic fertilizers. In this study, also improvement in soil organic carbon and nutrients in organic and inorganic treated soil have been observed as compared to their initial levels. However, the influence of these organic sources on soil properties depends on quality, amount, type, and size of the added organic materials. It was observed that the response of soil quality indicators were higher through the addition of vermicompost as compared to FYM. The organic carbon (0.48 ± 0.08%), available N (63.92 ± 6.54 ppm), P (31.43 ± 1.11 ppm), K (260.41 ± 22.05 ppm) content and the DTPA-extractable micronutrients (Fe: 4.24 ± 0.99, Mn: 8.01 ± 0.26, Zn: 0.88 ± 0.03 and Cu; 0.98 ± 0.07 ppm) were recorded highest in T_5 than T_1 (Table 5). Descriptive statistical analysis also revealed wide range of variability of nutrients across different treatments. Considering critical limits for major and micronutrients for guava orchard soils, it was observed that all these nutrients were above their critical limits. Soil physical indicators like porosity and WHC are function of SOC content in soil as it

Table: 5
Descriptive statistical analysis of Chemical indicators under different soil management systems

	Mean ± standard deviations	CV%	Range	Skewness	Kurtosis	Mean	CV%	Range	Skewness	Kurtosis
	Soil organic carbon (%)					Available N (ppm)				
T_1	0.33 ± 0.05^c	15.5	0.25 - 0.45	1.06	1.30	56.08 ± 10.87^a	19.38	37.0-69.0	-0.48	-0.81
T_2	0.38 ± 0.05^b	13.0	0.31 -0.49	0.71	-0.15	61.67 ± 12.46^a	20.21	46.0-84.0	0.35	-1.01
T_3	0.37 ± 0.04^{bc}	11.3	0.29 -0.45	-0.05	-0.50	60.25 ± 14.39^a	23.89	36.0-77.0	-0.49	-1.38
T_4	0.41 ± 0.06^b	13.8	0.33-0.51	0.22	-0.96	62.33 ± 8.46^a	13.57	49.0-76.0	-0.05	-0.59
T_5	0.48 ± 0.08^a	16.5	0.32-0.59	-0.58	-0.39	63.92 ± 6.54^b	25.88	43.0-95.0	0.33	-0.75
	Available P in soil (ppm)					Available K in soil (ppm)				
T_1	23.40 ± 7.16^b	30.6	14.8-41.2	1.40	1.88	187.37 ± 19.99^a	48.03	51.8-350.8	0.39	-0.59
T_2	27.15 ± 9.04^{ab}	33.3	14.4-49.2	1.10	1.16	209.86 ± 20.52^a	57.43	74.8-530.0	1.78	4.28
T_3	25.42 ± 9.58^{ab}	37.7	12.0-44.4	0.76	-0.19	188.89 ± 12.52^a	48.98	77.7-420.3	1.46	2.93
T_4	29.46 ± 1.61^{ab}	39.4	17.1-66.0	2.30	6.50	230.87 ± 19.08^a	82.33	93.1-651.3	1.87	2.26
T_5	31.43 ± 1.11^a	35.3	15.7-56.4	0.67	-0.09	260.41 ± 22.05^b	86.81	61.8-784.0	1.64	1.89
	DTPA extractable Fe (ppm)					DTPA extractable Mn (ppm)				
T_1	3.99 ± 0.92^a	48.1	1.90-7.28	0.66	-1.05	6.33 ± 0.41^a	69.70	1.92-15.96	1.23	0.69
T_2	4.13 ± 0.32^a	31.9	2.30-6.62	0.44	-0.28	6.56 ± 5.61^a	85.43	1.60-20.12	1.63	2.21
T_3	3.84 ± 0.64^a	42.8	1.52-6.88	0.34	-0.53	6.73 ± 0.75^a	70.50	1.80-14.66	0.59	-1.12
T_4	4.04 ± 0.72^a	42.7	1.60-7.80	0.70	0.92	7.03 ± 0.19^a	73.93	1.84-18.56	1.21	1.07
T_5	4.24 ± 0.99^a	23.4	3.20-6.28	0.77	-0.35	8.01 ± 0.26^a	90.68	1.74-22.14	1.27	0.35
	DTPA extractable Zn (ppm)					DTPA extractable Cu (ppm)				
T_1	0.51 ± 0.19^b	37.6	0.24-0.86	0.18	-0.86	0.29 ± 0.01^c	74.03	0.04-0.82	1.57	2.85
T_2	0.68 ± 0.08^{ab}	55.9	0.30-1.74	2.12	5.80	0.32 ± 0.01^{bc}	96.76	0.04-1.00	1.29	0.89
T_3	0.52 ± 0.02^b	41.9	0.34-1.12	2.12	5.14	0.35 ± 0.02^{bc}	67.48	0.08-0.82	0.84	0.10
T_4	0.78 ± 0.05^{ab}	44.3	0.36-1.34	0.75	-0.79	0.55 ± 0.03^{bc}	67.51	0.08-1.18	0.22	-1.01
T_5	0.88 ± 0.03^a	59.5	0.28-1.84	0.87	-0.23	0.98 ± 0.07^a	80.73	0.06-2.08	0.36	-1.71

* Mean ± standard deviations, Different letters indicate significantly different treatment means at P<0.05 with Duncan's multiple range test comparison

directly influenced on them. Linear statistical analysis indicated significant positive relationship of SOC with WHC and porosity (Fig. 1). Henceforth, cutting across the treatments, the linear regression model developed to predict dependent variables (WHC and porosity) as a function of independent variable (SOC) was as follows:

$$\text{WHC (\%)} = 18.15 \times \text{SOC} + 14.15\ (R^2 = 0.58^{**})$$

$$\text{Porosity (\%)} = 62.72 \times \text{SOC} + 22.24\ (R^2 = 0.69^{**})$$

The regression equations developed in this soil may also be applied to other related tropical or subtropical fruits crops or different cultivars of Guava crop grown in different substrates for the prediction of physical parameters across diverse agroecological regions. Such information may be used as important parameter in dynamic crop simulation models wherein soil physical indicators should be considered for enhancing the efficacy of the model towards accurate estimation of fruit crop response to nutrient management systems.

Improvement in organic carbon and available nutrients status in soils may be due to organic acids released from vermicompost, biofertilizers and organic mulch applied in presences of inorganic fertilizers. 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 and microbes produce a number of organic acids specially oxalic acid, which may facilitates the solubilization of bound phosphorus and potassium in soil and thereby productivity (Pramanik *et al.*, 2009; Pawan *et al.,* 2013). Higher protease and acid phosphate activity in vermicompost treated soils might be responsible for higher nitrogen and phosphorus content in soil. Tu *et al.* (2003) showed that enhanced soil microbial biomass and activity were associated with high net N mineralization rates, which resulted in higher N availability. In separate studies, Melero *et al.* (2006) found the activities of enzymes involved in the cycles of N and P enhanced through the organic management, with beneficial effects for soil nutrients supply. Edwards *et al.* (2006) demonstrated that application of humic acids, extracted from vermicompost, improve soil properties and the quality of field crops. Enzymes in vermicompost remain bound with humic substrates that protect the active sites of these enzymes. Therefore, the enzymes of vermicompost do not solely determine the enzyme activity of soil, but humic acids possibly have the maximum influence on the biochemical properties of nutrient deprived orchard soil which in turn helps the solution of nutrients in soil. The release of immobilized nutrient may be attributed to the stimulation of microbial activity and the activation of dormant microbes. Since young microbial cells show a higher rate of soil respiration as compared to mature cells, higher microbial quotient values were also observed in vermicompsot treated soils suggest that in the presence of readily available nutrients from vermicomposts, microorganisms become highly active and proliferate rapidly in that environment. Melero *et al.* (2007) inferred from a 4-year filed study under a dryland system that improvement of soil fertility was achieved in organically fertilized clay soil (*Chromic Haploxeret*).

There were significant differences in soil respiration in plots amended with vermicompost, microbial inoculants and organic mulching (T_2-T_5) as compared to control (T_1). A pooled range of 56.4 ± 3.3 to 71.9 ± 5.0 mg CO_2 kg^{-1} soil day $^{-1}$ was recorded in T_2 to T_5 while the lowest one being 51.8 ± 7.4 mg CO_2 kg^{-1} soil day $^{-1}$ (Fig. 2a). The highest soil respiration was observed in the treatment T_5 and was found to be significantly higher than T_4 and T_3. Histographic presentation showed that majority values lied between 50 and 65 mg CO_2 kg^{-1} soil day $^{-1}$ with >3 frequency level (Fig. 2b).

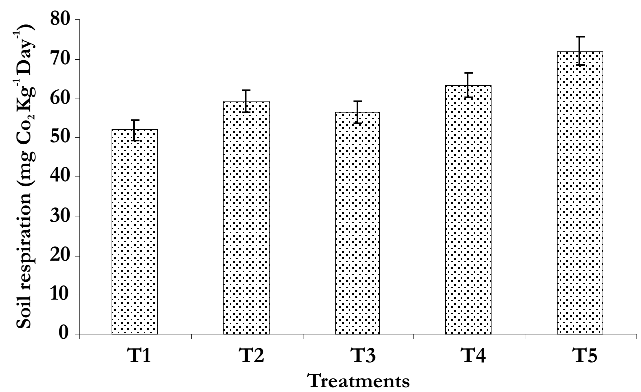

Fig. 2a. Soil respiration (mg Co_2 kg^{-1} day^{-1}) as an efficient biological indicator in guava orchard soil

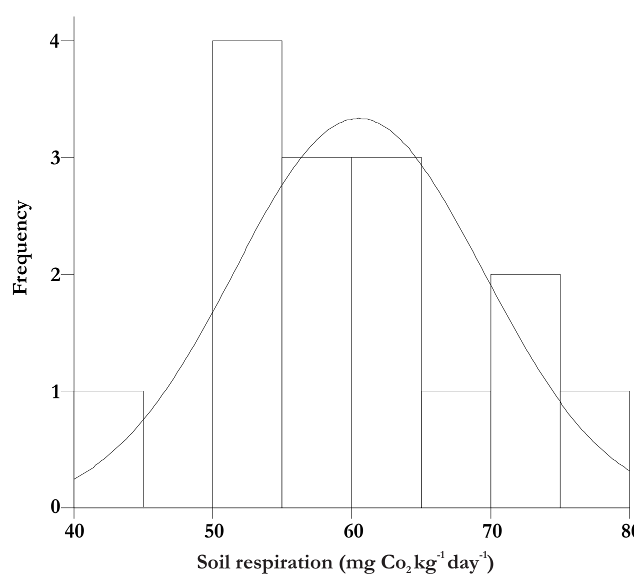

Fig. 2b. Histogram of soil respiration (mg Co_2 kg^{-1} day^{-1}) under different substrate treated guava orchard soil

Higher soil respiration of Vermicompost materials than FYM treated soils may be the consequence of both microbial growth and stimulation of microbial activity by enhanced resource availability, as well as of changes in microbial community composition. Soil physical properties varied as a function of plantation systems and thereby biomass production as well as soil organic carbon (Raizada *et al.,* 2014). Iovieno *et al.* (2009) observed significant enhancement in average soil respiration by organic amendments in two Mediterranean agricultural soils with different organic carbon content and the increase was consistent with the compost rates. Soil respiration, measured through CO_2 production is a direct indicator of microbial activity and indirectly reflects the availability of organic material (Manna *et al.,* 2015). In general soil respiration was stimulated by amendment applications as reported by Marinari *et al.* (2000), who explained their results as probably due to a synergic effect of soil and amendment microorganisms or to a stimulation of microbial growth by organic substrates added with the amendments. Ferreras *et al.* (2006) observed a similar trend of increment in microbial respiration and the higher values was found in plots amended with Vermicompost from household solid wastes. Actually, most of the carbon supplied by this amendment comprises partially decomposed material, easily degradable to be used as energy and nutrient source for soil microorganisms, resulting in an increased soil respiration. The ecological significance of microbial activity in soils may not be evaluated simply by assessing populations of microorganisms. Dehygrogenase enzyme activity is considered to be excellent indices of overall microbial activity (Nannipieri *et al.*, 1990). In this study, dehydrogenase activity as an indicator of microbial activity was significantly higher in plots receiving vermicompost, microbial inoculants and mulching over control (Fig. 3). The dehydrogenase activity was highest (range of 0.62 to 7.13 μg TPF g^{-1} h^{-1}) in surface soil (0-10 cm soil depth) and decreased down the depth to 30 cm (0.08 to 2.42 μg TPF g^{-1} h^{-1}). Higher variability was recorded in the surface layers (0-10 and 10-20 cm depth) which indicated higher microbial activity at the top layer of soil. Even the histographic analysis indicated that the activity was higher in the frequency level of 20% in the range below 1 μg TPF g^{-1} h^{-1}. Comparing among the treatments, the lowest lowest dehydrogenase activity was observed in T_1 (0.10 to 1.50 μg TPF g^{-1} h^{-1}). Cutting across the treatments, our study also confirmed significant differences in population of actinomycetes, fungi and bacteria (Fig. 4). A range of 2.27 ± 0.11 to 4.2 ± 0.02 $\times10^5$ cfu g^{-1}counts in actinomycetes, 7.47 ± 0.12 to 9.73 ± 0.75 $\times10^4$ cfu g^{-1}fungal count and 6.47 ± 0.17 to 9.37 $\times10^7$ cfu g^{-1} bacterial count was observed in the treatment comprising vermicompost, mulching and bioferilizers while the lowest count was recorded in T_1. Furthermore, in order to evaluate the correlation between biological indicators with WHC and porosity in this soil,

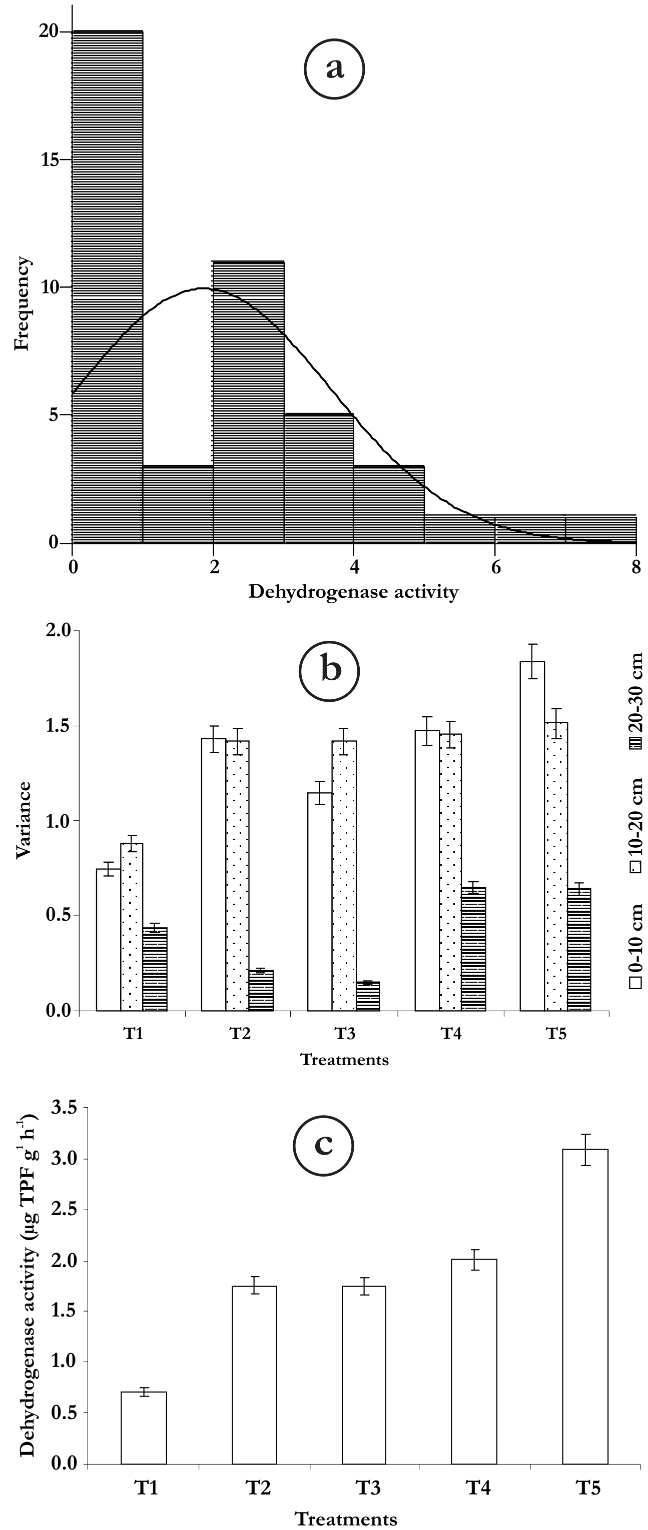

Fig. 3. Statistical representation of dehydrogenase activity as an excellent index of microbial activity a: frequency distribution, b: variability c: treatment difference

linear regression analysis was employed and it was confirmed that porosity was significantly and positively correlated with the dehydrogenase activity and soil respiration (r = 0.63 to

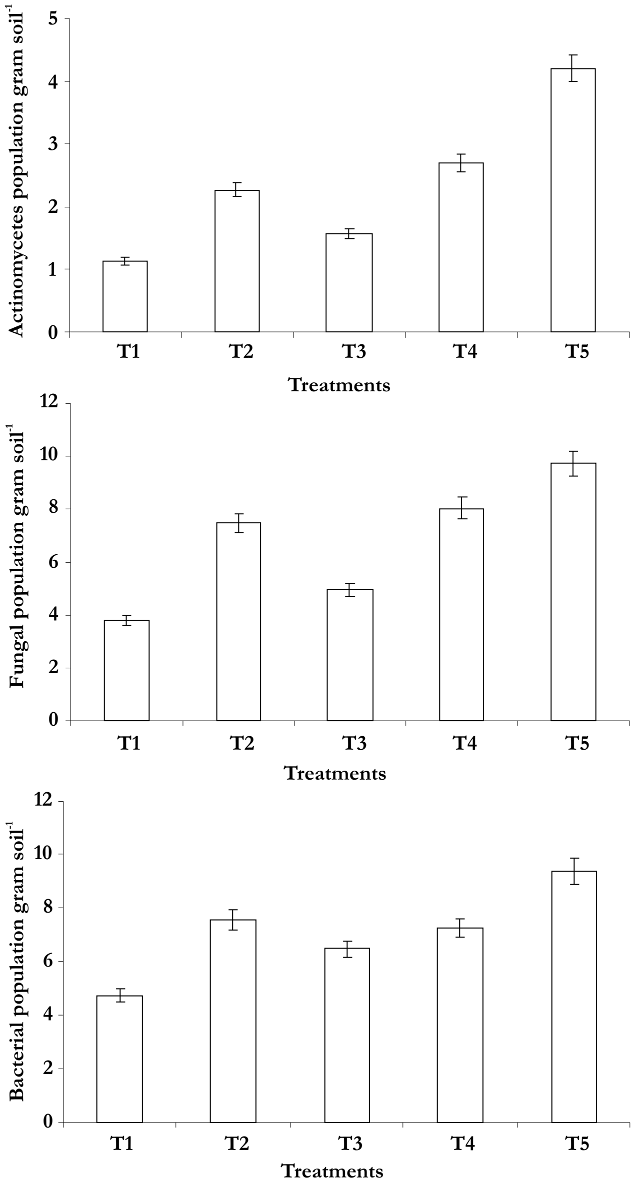

Fig. 4. Significant difference in microbial populations *viz.*, actinomycetes (×10^5 cfu g^{-1}), fungal (×10^4 cfu g^{-1}) and bacterial (×10^7 cfu g^{-1}) as an well recognized biological indicator in guava orchard soil

0.69**) while WHC showed a narrow range of correlation (r = 0.60 to 0.62**) (Fig. 5). Such analysis indicated that porosity or WHC could explain around 60-70% variation in microbial respiration and enzymatic activity as independent variables. The progressive changes in microbial population as a function of porosity and WHC could determine to the tune of 63-71% in Fungal, 60% in actinomycetes and 48-56% in bacterial populations (Fig. 6). We thus, inferred from the results that soil quality indicators may well be employed to assess the dynamic changes in ecological processes occurring beneath the soil layers. Moreover, organic sources (vermicompost, biofertilizer and mulching) which are locally available may be opted as an essential input in the integrated

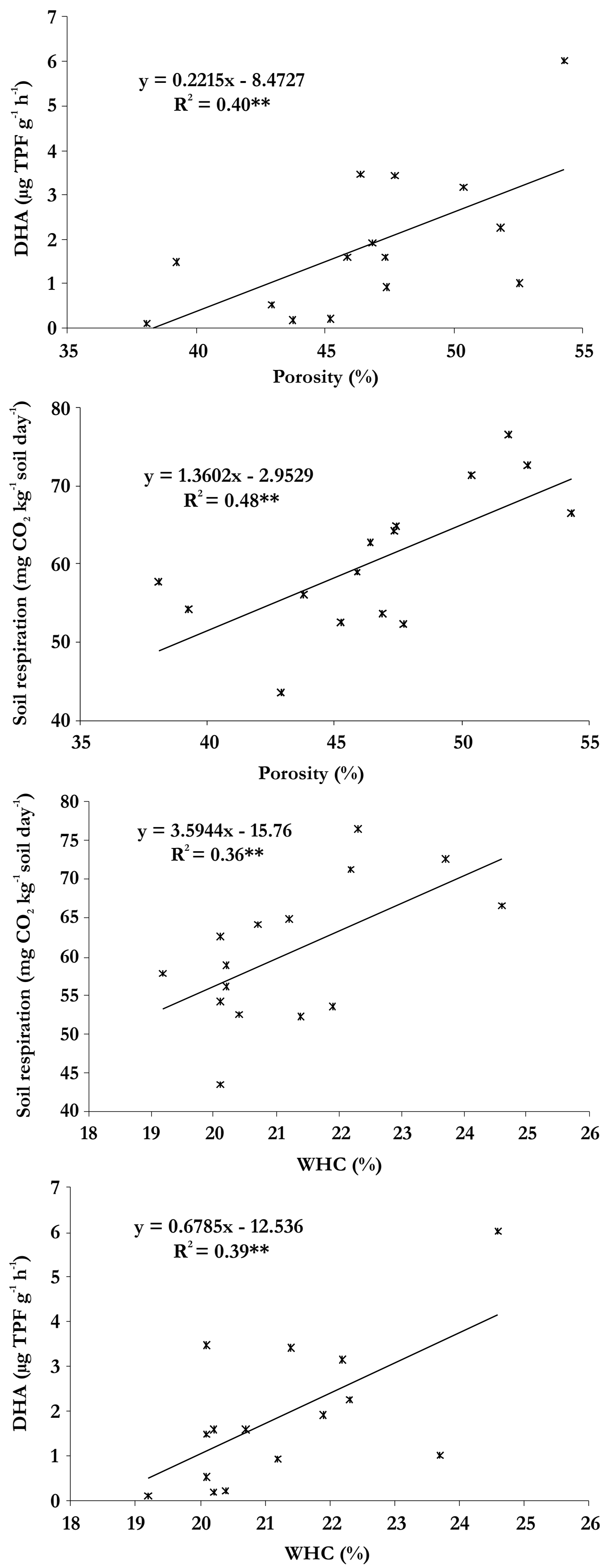

Fig. 5. Functional relationship between soil physical and biological indicators under different guava soil orchard management systems

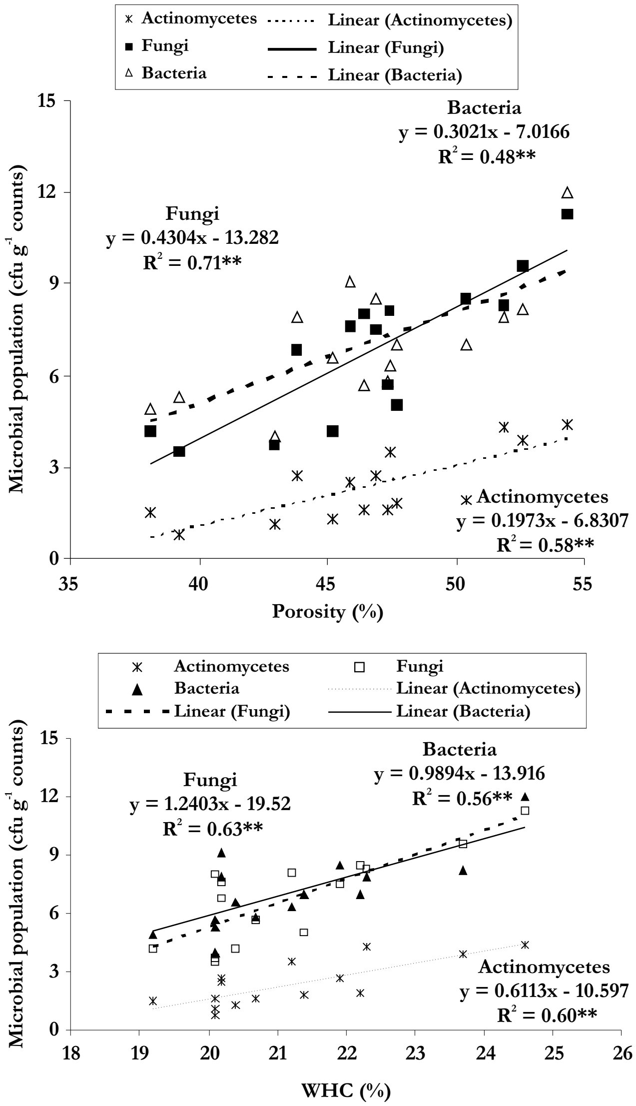

Fig. 6. Functional relationship between soil physical and microbial indicators in guava orchard soil under different management systems

nutrient management modules to enhance different soil microbial processes and interdependent physio-chemical properties for restoration of low fertile orchard soil of subtropical region. There have been reports that organic fertilizers can increase soil microbial activity; many enzyme activities have been reported to be correlated with total organic C in soils. Pascual *et al.* (1999) reported significant increases in dehydrogenase activity after amending soil with composts for 8 years compared with activity in unamended soils. Results over the period of 7-years study suggested that organic management method strongly affects soil quality indicators (Lagomarsino *et al.*, 2009). It has been reported that the increase in dehydrogenase activity were proportional to the organic carbon content and microbial biomass, addition of number and quantity, quality of organic and inorganic nutrients. Marinari *et al.* (2000) revealed that dehydrogenase activity was positively influenced by the high total porosity of soil and the highest level was obtained with organic fertilization. Thus all these reports confirmed that biological indicators along with physical and chemical ones could be considered as a potential tool to assess the changes in some soil properties under short-term orchard soil management system.

Appraisal of Correlation Matrix and Statistical Significance Among the Indicators

Pearson's correlation coefficients among the soil factors showed significant variations among them as some indicators were significant at 1% level of significance and others were at 5% level (Table 6). It was inferred from the analysis that the correlation coefficient r varied from 0.51* to 0.87** in terms of SOC content association with microbial populations (Bacteria r = 0.51*, Fungi 0.71** and actinomycetes 0.87**). Soil respiration was positively and significantly correlated with SOC content (r = 0.81**). Respiration as a function of microbial population were also highly correlated (r = 0.67** to 0.74**). Porosity and WHC was positively correlated with

Table: 6
Pearson's correlation and statistical significance among the ecological indicators in orchard soil

	PD	BD	Porosity	WHC	Sand	Silt	Clay	DHA	Respiration	Actinomycetes	Fungi	Bacteria	SOC
PD	1	.627(*)	.920(**)	.818(**)	NS	NS	NS	.586(*)	.687(**)	.726(**)	.813(**)	.657(**)	.697(**)
BD		1	-.88(**)	-.82(**)	NS	NS	NS	-556(*)	-.570(*)	-.668(**)	-708(**)	-.608(*)	-697(**)
Porosity			1	.894(**)	NS	NS	NS	.624(*)	.689(**)	.762(**)	.841(**)	.695(**)	.765(**)
WHC				1	NS	NS	NS	.626(*)	.596(*)	.773(**)	.793(**)	.746(**)	.680(**)
Sand					1	-990(**)		NS	NS	NS	NS	NS	NSNS
silt						1	NS	NS	NS	NS	NS	NS	NS
clay							1	NS	NS	NS	NS	NS	NS
DHA								1	.348	.349	.596(*)	.582(*)	.64(**)
Respiration									1	.675(**)	.742(**)	.408	.813(**)
Actinomycetes										1	.845(**)	.757(**)	.875(**)
Fungi											1	.779(**)	.706(**)
Bacteria												1	.515(*)
SOC													1

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed), NS: Non-significant, DHA: Dehydrogenase activity, SOC: Soil organic carbon content, WHC: Water holding capacity, PD: Particle density, BD: Bulk density dehydrogenase activity at 1% level of significance (r = 0.62*). Porosity was significant at 5% level (r = 0.69**) while WHC at 1% level (r = 0.59*) with soil respiration. Sand, silt and clays were non-significantly correlated; indicating soil factors had no bearing/residual effect on them in a short-term basis. This confirmed that soil texture is a basic and intrinsic soil property and can't undergo dynamic changes under short-term soil management systems. BD was negatively correlated with WHC (r=-0.82**) and Porosity (r=-0.88**) being significant at 5% level of significance. Particle density was also statistically significant with soil indicators. Porosity and WHC were strongly associated with SOC content (r =0.68** to 0.76**) and with actinomycetes (r=0.77**), Fungi (r=0.79** to 0.84**) and bacterial (r=0.69** to 0.75**) populations. It was observed that the dehydrogenase activity positively correlated with SOC content (r=0.64**) confirming that improvement in dehydrogenase activity were proportional to the substrate availability.

4. CONCLUSIONS

Significant changes in soil properties were observed in different treatment combinations of this short-term field trial under subtropical environment. An improvement of 32% in porosity in the Vermicompost treated soil as compared to control (NPK+FYM) was recorded. The study further confirmed enhancement (18.8%) in WHC and decrease in BD in the soil treated with 10 kg vermicompost ha^{-1} as compared to its adjustment with FYM or sole application of FYM. Functional relationship among the soil physical indicators revealed that porosity and WHC were inversely related with the BD. Improvement in soil organic carbon and available nutrients may be recognized as an early sensitive indicator of soil quality. Higher variability in dehydrogenase enzyme activity was recorded in the surface layers (0-10 and 10-20 cm depth) as compared to deeper depths. The progressive changes in microbial population as a function of porosity and WHC could determine to the tune of 63-71% in fungal, 60% in actinomycetes and 48-56% in bacterial populations. Higher soil respiration and its histographic presentation revealed majority values lied between 50 to 65 mg CO_2 kg^{-1} soil day^{-1} with >3 frequency level. Statistically strong and positive correlation recorded among the soil indicatorsindicated that ecological indicators were directly related to the soil management systems. The study thus, concluded that physical, chemical and biological indicators may be chosen as excellent indicators of short-term alteration in soil parameters under course textured soils of inherently low organic carbon, fertility and physical architecture.

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