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Long-term management effects on spatial variability of quality characteristics of soils under guava (*Psidium guajava*) and sapota (*Manilkara achras*) orchards in south-western climate of India

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Long-term orchard management effects on spatial variability of quality characteristics of soils of guava (*Psidium guajava* L.) and sapota (*Manilkara achras* Mill.) orchards at Chettalli, Kodagu, Karnataka was examined by comparing the drip circle soil with the inter-row space soils. Orchard soils are deep, dark-brown, well drained, sandy loam to sandy clay loam in texture and classified as Alfisol. Long-term recommended soil management practices caused significant fall in *p*H (0.6–0.9 unit), concentration of soil organic carbon (10.9–19.1%), carbon stock (9.8–23%), exchangeable Ca (14.4–34.0%), exchangeable Mg (17.1–62.7%) and activities of acid phosphatase (20.1–47.0%) and ß-glucosidase (19.4–46.0%) enzymes in drip circle soil, while exchangeable K (34.9–82.7%) and DTPA extractable Cu (18.4–111.3%), Fe (18.4–75.7%) and Mn (40.9–95.3%) increased significantly. Long-term application of inorganic fertilizers and removal of basic cations caused reduction in *p*H of drip circle soil. Maintenance of bare soil surface in drip circle was responsible for the decline in organic carbon of soils. Activities of enzymes reduced due to fall in soil organic carbon and *p*H of the soils because enzyme activities showed significant ($P<0.001$) positive correlation with these soil parameters. Increase in concentration of DTAP Cu, Fe and Mn resulted from significant fall in soil *p*H and contamination from inorganic fertilizers. Long-term recommended management practices significantly altered the quality characteristics of drip circle soil of the orchards and calls for modification to improve the soil quality.

The intensification of agriculture has led to concerns about the adverse impacts of farm management on soil quality. High input agriculture using monoculture systems commonly observed in horticultural orchards unfavourably affect the soil quality resulting in unsustainability of production systems. Tillage, fertilizer application, crop rotation, water management, liming, and cover crops are soil management practices that can significantly affect soil quality. Fertilizer applications can have either positive or negative effect on soil quality. However, repeated application of ammoniacal fertilizers and leaching of excess nitrate nitrogen can degrade soil quality through acidification (Barak *et al.* 1997). In India, the long-term management effects on quality characteristics of soils under annual crops have been studied by many workers (Manna *et al.* 2005, Masto *et al.* 2007). However, such studies on horticultural crops are limited and deserve attention.

In fruit orchards, soil management practices such as application of fertilizers, manures, irrigation, lime etc. is concentrated mainly in soils within 1.0–1.5 m radius (drip circle/irrigation basin) from the tree trunk and therefore, the soil in the inter-row spaces of trees is less affected by these management practices. The long-term effect of soil management practices on quality characteristics of drip circle soils may be more compared to the soils of inter-row spaces. Therefore, studies on spatial variability of soil quality characteristics are needed for refinement of recommended management practices being adopted in the orchards for long. Understanding soil management impacts on spatial variability of soil quality characteristics is important to achieve soil improvement, better yields, input optimization and consequent savings. Therefore, the present study was conducted to assess the impact of long-term soil managements on quality characteristics of drip circle soils of guava (>15 years old) and sapota orchards (>20 years) compared with the soils of inter-row space of the plants under tropical south-western climate of India.

MATERIALS AND METHODS

The study was conducted in 'Allahabad Safeda' guava (*Psidium guajava* L.) and 'Cricket Ball' sapota (*Manilkara achras* Mill.) orchards at Central Horticultural Experiment

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Station, Indian Institute of Horticultural Research, Chettallii, Kodagu, Karnataka (12º 26‘ latitude, 75º 47‘ longitude) during 2008–09. Orchard soils are deep, dark-brown, well-drained and sandy loam to sandy clay loam in texture. The site is at an elevation of 945 m above mean sea level, lies in the tropical zone and has humid to sub-humid climate with mean annual rainfall of 1 803 mm. The mean annual maximum and minimum temperature vary from 36ºC in May to 8ºC in January.

Two orchards under each crop were used for the study. Bare soil surface in drip circle (area having 1.5 m radius from tree trunk) is being maintained to facilitate placement of inorganic fertilizers and irrigation water. Each orchard was divided into five replicated blocks across the slope (1–5%) containing 30 trees. In each block, composite soil samples were collected from 2 soil depths, viz 0–15 cm and 15–30 cm and from two locations, viz drip circle and mid point of inter-row-space. Each composite soil sample collected from drip circle consisted of soils collected from drip circles of 20 randomly selected plants. Similarly, each composite soil sample of inter-row-space consisted of soils from 20 randomly selected points. Altogether, 20 composite soil samples (5 blocks × 2 depths × 2 sapling sites) were collected from each of the orchards. Field moist soil samples were air-dried under shade. Plant debris was removed and ground to pass 2 mm mesh. A portion of each soil sample was ground to pass through a 0.5 mm sieve for estimation of organic carbon. Sieved samples were stored in plastic container at room temperature until analyzed. A sub-sample of each field moist composite soil sample was stored at 4°C for analysis of soil enzymes.

Bulk density of surface (0–15 cm) and sub-surface (15–30 cm) soils of each orchard was determined from intact soil cores of 102 cm^3 volume. Altogether, 20 core samples from each orchard were taken for bulk density determination. Soil *p*H was measured in a 1:2.5 soil: water suspension using glass electrode. Soil organic carbon was determined by Walkley-Black method and the carbon stock in soils on mass equivalent basis were calculated following procedures described by Ellert and Bettany (1995). DTPA-extractable soil Cu, Zn, Fe and Mn was determined by Lindsay and Norvell 1978 method using Atomic Absorption Spectrophotometer (Analyst 200). The exchangeable K, Ca and Mg in soil were extracted with 1 N ammonium acetate (pH 7.0) solution and determined using flame photometer and AAS, respectively. The activity of soil enzymes, viz acid phosphatase and ß-glucosidase was determined following the procedures described by Tabatabai (1982). Results are expressed based on oven dry soil. Throughout this paper, the 0–15 and 15–30 cm soils depths are referred to as the surface and sub-surface soils, respectively.

The t-test for comparison of the means of two independent samples (Snedecor and Cochran, 22) was used to compare the properties of drip circle soils with the soils of inter-row-space. The relationships among various properties of orchard soils were found out by simple linear regression analysis.

RESULTS AND DISCUSSION

There were marginal differences in the values of soil quality parameters of the two orchards under the same crop and therefore, reported value of soil parameters for each crop is the mean value of two orchards.

The bulk density values of surface and sub-surface soils of drip circle and inter-row space are given in Table 1. There

Table 1 Effect of long-term orchard management on spatial variability of soil quality indicators (mean±SD) of surface (0–15 cm) and sub-surface (15–30 cm) soils of guava and sapota orchards

Soil property	Sampling depth (cm)	Inter-row space	Drip circle	Change in drip circle soil (%)	Statistical significance	Inter-row space	Drip circle	Change in drip circle soil (%)	Statistical significance
		Guava				Sapota			
Bulk density (Mg/m^3)	0–15	1.49±0.01	1.52±0.03	2.0+	NS	1.52±0.01	1.51±0.03	<1.0 +	NS
	15–30	1.54±0.03	1.57±0.02	<2.0 +	NS	1.56±0.02	1.54±0.04	1.3 +	NS
*p*H (1:2.5)	0–15	6.32±0.14	5.73±0.11	9.3–	***	6.15±0.16	5.47±0.21	11.1–	***
	15–30	6.21±0.14	5.29±0.08	14.8–	***	6.20±0.12	5.28±0.21	14.8–	***
Organic carbon (%)	0–15	1.83±0.09	1.65±0.09	10.9–	*	1.74±0.04	1.55±0.12	10.9–	*
	15–30	1.47±0.12	1.19±0.06	19.1–	**	1.40±0.10	1.34±0.14	4.3–	NS
Carbon stock (Mg/ha)	0–15	41.8±2.92	37.7±1.96	9.8–	*	39.7±0.96	35.8±2.88	9.8–	*
	15–30	36.9±5.02	28.4±1.45	23.0–	*	34.6±2.59	31.6±0.82	8.7–	NS
Activity of acid	0–15	335±39.25	247±32.92	26.3–	**	269±29.52	215±36.02	20.1–	*
phosphatase enzyme#	15–30	268±42.91	142±13.86	47.0–	**	174±26.97	150±26.93	13.8–	NS
Activity of *β*- glucosidase	0–15	123±15.37	103±5.9	19.4–	*	74.5±7.69	55±8.92	26.2–	**
enzyme#	15–30	87±27.82	47±7.64	46.0–	*	33±5.38	29±4.41	12.1–	NS

One, two or three asterisks indicated the level of significance at $t_{5\%}$ (*P*=0.05), $t_{1\%}$ (*P*=0.01) and $t_{0.1\%}$ (*P*=0.001), respectively, # µg *p*-nitrophenol/g soil, + increase, – decrease

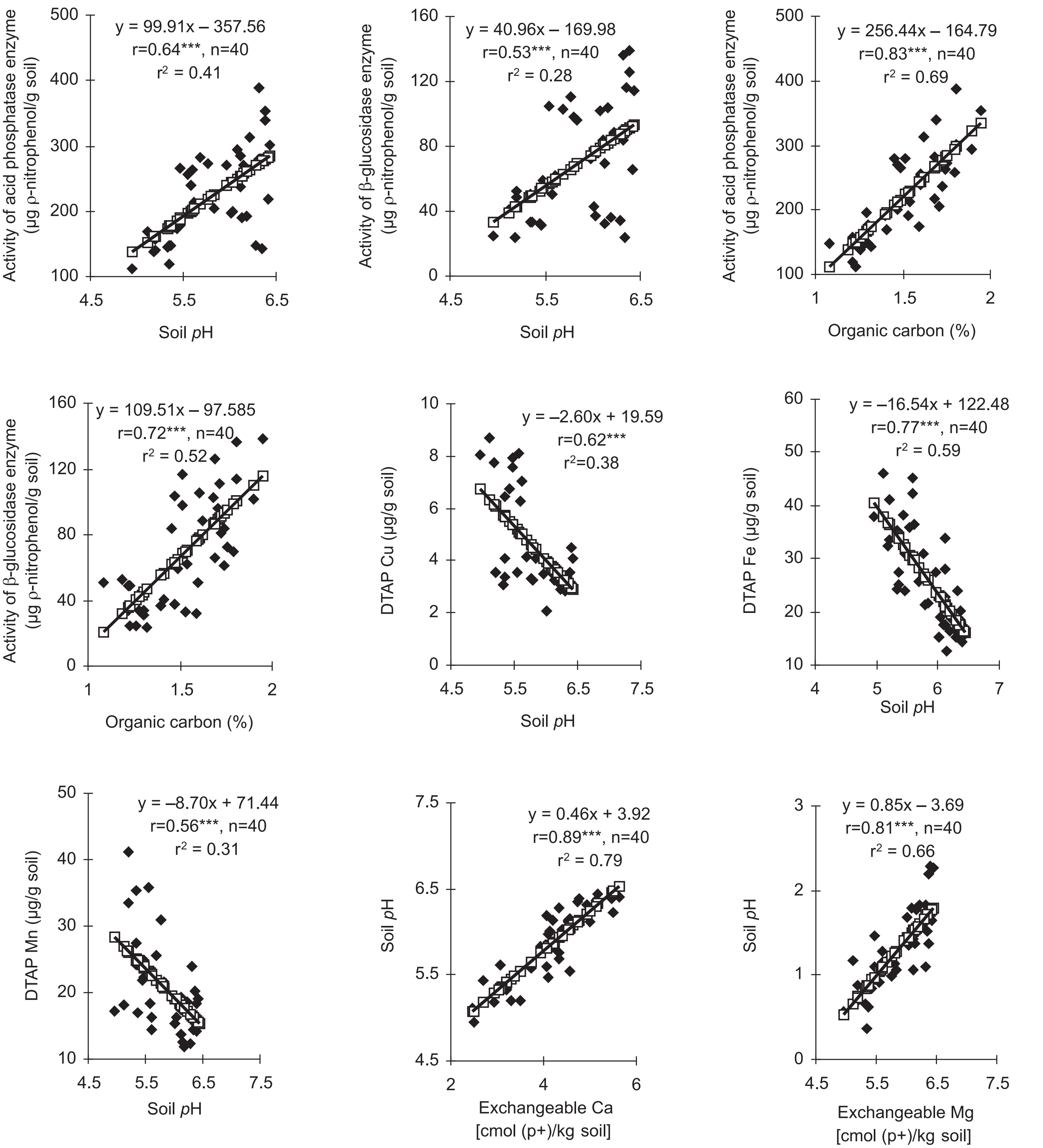

Fig 1 (*A-I*). Correlation of different properties of orchard soils under long-term soil management: between soil *p*H and activity of acid phosphatase enzyme (*A*), *p*H and ß-glucosidase enzyme (*B*), organic carbon and activity of acid phosphatase enzyme (*C*), organic carbon and activity of ß-glucosidase enzyme (*D*), soil *p*H and DTPA extractable Cu (*E*), Fe (*F*), Mn (*G*), *p*H and exchangeable Ca (*H*) and Mg (*I*)

was no significant difference in bulk density values of drip circle soil and soils of inter-row space. However, the bulk density values of the orchards are greater than the ideal value (<1.4 Mg/ $m^{3)}$ reported (Hillel 1982) for sandy loam to sandy-clay-loam soils to facilitate proper growth and development of root. The bulk density of surface soils of these orchards is about 13% higher than the adjacent undisturbed soil (1.34 Mg/m^3). Because of high rainfall in the region and sloppy

(1–3%) nature of the land, water velocity near the soil surface increased with greater bulk density. As a result, erosion rates increased as bulk density became larger (Parker *et al.* 1995). The soil organic carbon pool is concentrated in the vicinity of the soil surface and is lighter than mineral particles (density of soil organic carbon is 1.2 to 1.5 Mg/m^3 compared with 2.5 to 2.7 Mg/m^3 for mineral particles). Therefore, it is preferentially removed by runoff water (Avnimelech and McHenry 1984, Lowrance and Williams 1989). Along with soil organic carbon other soil nutrients are also depleted due to soil erosion.

The long-term orchard management significantly reduced (0.6–0.9 unit) the *p*H of the surface and sub-surface of drip circle soils compared with the soils of inter-row space (Table 1). Low *p*H in drip circle soils resulted from long-term application of inorganic fertilizers as well as removal of basic cations from the soil. Soil acidification resulting from long-term fertilizer application has been reported by many workers (Nambiar and Abrol 1989, Bouman *et al.* 1995). Application of urea and muriate of potash has been a regular practice to take care of N and K nutrition in these soils. Oxidation of ammoniacal form of N resulting from breakdown of urea in soil to nitrate N and the salt effect due to application of muriate of potash reduced the *p*H of the drip circle soils. Low concentration of basic cations in the drip circle soil as evidenced by our findings (Table 2) also contributed towards drop in soil *p*H. The soil *p*H showed significant (P<0.001) positive correlation with the exchangeable Ca and Mg in orchard soil (Fig 1 H, I).

In general, the concentrations of soil organic carbon and carbon stock in drip circle soils are significantly lower (10.9–19.1% for soil organic carbon, 9.8–23.0% for carbon stock) than soils of the inter-row space. Data from long-term experiments in India and abroad (Hati *et al.* 2007, Gong *et al.* 2009) showed that balanced application of NPK fertilizers increases the organic carbon content of soils. But in our study, continuous application of balanced dose of NPK fertilizer in drip circle soils for more than 15 years did not increase the soil organic carbon of drip circle soils. Maintenance of bare soil surface in drip circle for longer period of time might have significantly reduced the soil organic carbon in the soil because of accelerated soil erosion. Soil erosion by water is the most widespread degradation process to replenish the organic carbon pool in soil (Lal 2004). Soil organic carbon influences the physical, chemical and biological aspects of soil health and data from long-term experiment showed a close relationship between decline in soil organic matter content and agronomic productivity (Mitchell *et al.* 1991). Though, the status of soil organic carbon in the orchards is high (>0.75%) but under the existing orchard management and climatic conditions, the concentration of soil organic carbon in drip circle soil may decrease further provided no organic matter management practices are adopted.

Activities of soil enzymes are especially good early indicators of changes in soil quality because of their rapid response to change in soil management practices, their relationship to soil biology, and ease of assay. Management practices that minimize the addition of organic matter to soil may reduce enzyme and microbial activities and thus affect the ability of soils to supply nutrients needed for plant growth.

Table 2 Effect of long-term orchard management on spatial variability of nutrients (mean±SD) of surface (0–15 cm) and sub-surface (15–30 cm) soils of drip circle and inter-row space of guava and sapota orchards

Soil property	Sampling depth (cm)	Inter-row space	Drip circle	Change in drip circle soil (%)	Statistical significance	Inter-row space	Drip circle	Change in drip circle soil (%)	Statistical significance
		Guava				Sapota			
Zn	0–15	2.85±0.55	3.71±0.36	30.2 $^+$	*	2.40±0.40	2.29±0.18	4.6$^-$	NS
	15–30	2.10±0.64	2.21±0.21	5.2 $^+$	NS	1.45±0.49	2.24±0.16	54.5$^+$	**
Cu	0–15	3.67±0.41	4.20±0.21	14.4 $^+$	*	3.70±0.47	7.61±0.95	105.7$^+$	***
	15–30	2.87±0.47	3.53±0.37	23.0 $^+$	*	3.39±0.31	7.30±0.68	115.3$^+$	***
Fe	0–15	26.64±3.34	31.54±3.22	18.4 $^+$	*	24.64±7.42	40.24±6.42	63.3$^+$	**
	15–30	21.94±3.34	26.45±0.84	20.6 $^+$	*	17.92±3.12	31.49±6.75	75.7$^+$	**
Mn	0–15	18.00±3.68	27.13±6.21	50.7 $^+$	*	17.46±2.17	18.41±3.93	5.4$^+$	NS
	15–30	16.55±2.99	32.32±6.65	95.3 $^+$	**	14.86±3.01	20.94±3.91	40.9$^+$	*
K	0–15	467±67.64	853±131.60	82.7 $^+$	***	476±37.75	807±165.33	69.5$^+$	*
	15–30	425±167.66	635±147.61	49.4 $^+$	*	421±59.51	568±142.00	34.9$^+$	*
Ca	0–15	5.00±0.33	4.28±0.22	14.4 $^-$	**	4.69±0.63	3.49±0.71	25.6$^-$	*
	15–30	4.85±0.52	3.26±0.15	32.8 $^-$	**	4.41±0.24	2.91±0.33	34.0$^-$	***
Mg	0–15	1.77±0.53	1.05±0.11	40.7 $^-$	*	1.40±0.21	1.16±0.07	17.1$^-$	*
	15–30	1.85±0.19	0.69±0.20	62.7 $^-$	***	1.47±0.11	0.84±0.36	42.9$^-$	**

One, two or three asterisks indicated the level of significance at $t_{5\%}$ (P=0.05), $t_{1\%}$ (P=0.01) and $t_{0.1\%}$ (P=0.001) respectively. + increase, – decrease, DTPA extractable Zn, Cu, Fe, Mn in mg/kg soil, available K in kg/ha, exchangeable Ca and Mg in cmol (p+)/kg soil

Our study showed that long-term orchard managements significantly reduced the activities of acid phosphatases (20.1–47.0%) and ß-glucosidase (19.4–46%) enzymes in drip circle soils compared to the soils of inter-row space. The reduction in activities of these enzymes can be attributed to the decrease in soil organic carbon and pH of the soils because the activities of these enzymes showed significant (P<0.001) positive correlations with soil organic carbon and pH of the soils (Fig 1 A to D). These observations are in agreement with the findings of other workers (Dick *et al.* 1988, Deng and Tabatabai 1996, 1997). Soil organic matter plays an important protective role in maintaining soil enzymes in their active forms and supports the hypothesis that enzymes are immobilized in a three-dimensional network of clay and humus complexes (McLaren 1975) and/or associated with a larger microbial population resulting from the increase in soil organic matter. The *p*H effect activity of enzymes by altering their ionization and solubility (Tabatabi 1982) and variation in these properties influences the rate of catalyzed reactions.

The DTPA extractable micronutrients, viz Zn, Cu, Fe and Mn in the orchard soils are well above the critical limits. The concentration of DTPA Cu, Fe and Mn are significantly higher in drip circle soils compared with the soils of inter-row space (Table 2). However, there was no specific trend observed in case of Zn. High concentration of Cu, Fe and Mn in drip circle soils is the result of fall in soil *p*H because concentration of these nutrients showed significant (P<0.001) inverse correlation with soil *p*H (Fig 1 E to G). Further drop in soil *p*H might cause toxicity of Cu, Fe and Mn in soil provided liming is not done. Besides low *p*H, long-term application of inorganic fertilizers might have contributed towards build-up of these nutrients in drip circle soils. Commercial fertilizers, particularly phosphatic fertilizers and soil amendments such as lime contain small amounts of trace elements as contaminants (Raven and Loeppert 1997).

There was significant fall in exchangeable Ca and Mg in drip circle soils while reverse trend was observed in case of exchangeable K (Table 2). Relatively low exchangeable Ca and Mg in drip circle soil was the result of loss of these nutrients due to erosion. Low *p*H increased the solubility of these cations and removal by surface run-off was further enhanced. Soils of these orchards are high in available K (NBSS & LUP 1998) and long-term application of recommended dose of muriate of potash further enhanced the K level of drip circle soils.

In general, long-term application of fertilizers, maintenance of bare soil surface, and poor organic matter management deteriorated the quality of drip circle soils compared with the soils of inter-row space. Soil management practices, viz light forking, application of organic matter, mulching and liming based on soil test value are necessary to improve the quality characteristics of drip circle soil for sustainability of these production systems. Theses findings will help in developing soil management strategies for sustainability of these fruit orchards under Kodagu region of Karnataka and its neighboring areas with similar soil and climatic environment.

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