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Soil quality as influenced by land use history of orchards in humid subtropics

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ABSTRACT

This study assessed how land use change from native deciduous forest to tropical fruit orchards viz. guava (*Psidium guajava* L. cv. Allahabad Safeda) and sapota (*Manilkara achras* Mill. cv. Cricket Ball) under humid subtropics of India impacts the soil physical, chemical and biological properties. This study also validated whether the existing orchard management practices are adequate to maintain sustainable soil quality in different guava and sapota orchards established along a chronosequence by comparing the changes in soil quality attributes between native forest (considering as baseline ecosystem) and orchards. The land-use-induced change caused significant reduction in soil physical properties (12.0 to 31.4%), chemical properties (8.8 to 61.5%), earthworm density (32.0 to 58.7%), earthworm biomass (43.6 to 68.0%) and soil enzyme activities (8.8 to 54.1%) beneath orchards relative to native forest. There was significant increase in bulk density (12 to 14%), available-P (104 to 296%) and DTPA-Fe content (36.3 to 81.4%) in orchard soils. The combined results of the principal component analysis and the analysis of similarity revealed that stronger influencing factor of variability in soil quality attributes was in the order of land-use change > orchard age > orchard type. The soil deterioration index (SDI) values (ranged from −35.3 to −77.8%) for orchard soils relative to FS indicated that orchard soils were in the serious state of deterioration in terms of physico-chemical and biological properties; and the extent of deterioration of soil quality increased with the increase of orchard age ($r = 0.57^*$, $P < 0.01$). Soil organic carbon showed a significant positive correlation with earthworm populations, soil enzyme activities and pH and these soil attributes were the important factors influencing SDI values. In conclusion, the progressive deterioration of orchard soil quality over time was the outcome of poor/inadequate management of soil organic matter (SOM) in guava and sapota orchards. As a result, there is a need for modification of existing SOM management practices. The reason is that they are not as efficient enough to help prevent the deterioration of soil quality in orchards over time, after conversion from baseline ecosystem.

1. Introduction

The consequences of land use change on soil processes and agro-ecosystem functioning are many and are of global importance (Saurette et al., 2008; Vitousek, 1994). Both the land use history and those changes in soil management practices have profound influences on the physical, chemical, and biological environments, thereby affecting fertility and productivity of soils (George et al., 2013; Gonnety et al., 2012; Tondoh et al., 2011 and 2013). The assessment of soil properties due to the land-use-induced changes is critical in understanding the agro-ecosystem functioning and sustainable production (Yao et al., 2010). Arable land for agricultural purposes is getting limited due to both utilization and encroachment by the ever-increasing human population for its non-agricultural uses. The arable land (hectares per person) of India is currently 0.13 and this ‘land to man ratio’ is projected to decline to 0.10 in 2025. Hence, there is a strong need to understand the changes in soil quality due to cultivation in order to manage the sustainability of production systems. In the recent times, horticultural crops have substantial growth acceleration in terms of area coverage worldwide. In India, the area under fruit plantation in 2000 was 3.4 million ha, which has increased by two-folds in 2010 (World Bank Report, 2010). Most fruit plantations were established by clearing native forest land. Hence, the land-use-induced changes, upon the conversion of native forest land to fruit plantations, and the associated management practices determine soil quality and productivity (Ganeshamurthy et al., 2012).

Cultivation of deforested land under tropical humid climate may rapidly diminish soil quality as the ecologically sensitive components are not able to buffer the induced detrimental effects of agricultural practices. Hence, the deterioration in soil quality may be severe, and

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rapid decline in productivity may occur (Islam et al., 1999; Kang and Juo, 1986; Nardi et al., 1996). The physico-chemical and biological changes in soils following deforestation and subsequent cultivation of crops in the humid tropics have been reported extensively (Ghuman and Lal, 1991; Juo et al., 1995; Koutika et al., 1997; San José and Montes, 2001; Schroth et al., 2002; Sisti et al., 2004; Tchienkoua and Zech, 2004; Walker and Desanker, 2004). Such studies on the land-use-induced changes on soil quality in different agro-ecosystems of India have focused only on the problems of the land use change from forest to seasonal agriculture (Panwar et al., 2011; Sharma et al., 2009; Singh et al., 2011). Very few reports are available on the changes in soil quality due to the conversion of native forest into fruit orchards and their long-term management effects in India (Wanshnong et al., 2013). The objective of the present study was to assess the impact of land use change from native deciduous forest to tropical fruit orchards. These orchards of guava (*Psidium guajava* L. cv. Allahabad Safeda) and sapota (*Manilkara achras* Mill. cv. Cricket Ball) were compared, along with the changes in soil quality attributes between native forest (considering as baseline ecosystem) and fruit plantations. Furthermore, this study aimed to validate whether the existing orchard management practices are adequate to maintain sustainable soil quality in different guava and sapota orchards established along a chronosequence.

2. Materials and methods

2.1. Study area

The study site was the Central Horticultural Experiment Station, Kodagu, Karnataka, India (geographic location 12°26′ N, 75°47′ E and 945 m above mean sea level), where four orchards of varying ages namely guava (*P. guajava* L. cv. Allahabad Safeda) and sapota (*M. achras* Mill. cv. Cricket Ball) were studied. Two guava orchards were established in the year 1986 and 1992 (hereafter referred to as GO1986 and GO1992, respectively) and other two sapota orchards were established in the year 1970 and 1987 (SO1970 and SO1987, respectively). The entire area was forest land with gentle slope (1–5%) before establishment of these orchards. There was no record of initial soil properties at the time of orchard establishment and hence, the undisturbed forest soil (FS) adjacent to these orchards is considered as control plot for comparative evaluation of soil quality attributes of different land use systems. Orchard soils are deep, dark-brown, well-drained, sandy loam to sandy clay loam in texture and classified as *Alfisols* (USDA taxonomy). The site lies in humid sub-tropical climate with mean annual rainfall of 1803 mm. The mean annual maximum and minimum temperatures vary from 36 °C in May to 8 °C in January. We distinguished the land-use classes as forest and fruit plantation and the effect of land use change was evaluated by comparing the soil properties between forest soil and soils under the fruit plantations. Long-term orchard management effect on soil quality attributes was evaluated through a chronosequence study of different orchards by considering the secondary forest as the baseline ecosystem.

2.2. Orchard management

The areas under GO1986, GO1992, SO1970 and SO1987 are 3.0, 1.4, 1.3 and 1.5 ha, respectively. The planting densities of guava and sapota trees per hectare area are 277 and 148, respectively. The spacing maintained between guava trees was 6 m × 6 m and sapota trees were 7.5 m × 7.5 m. Nutrient ($N:P_2O_5:K_2O$) was applied within the circle area of 1.5 m radius from tree trunk (basin area) at 600:450:600 g plant^{-1} year^{-1} for guava and 400:160:450 g plant^{-1} year^{-1} for sapota in the form of urea, single superphosphate (SSP) and muriate of potash (MOP). The recommended dose (RD) of fertilizer was applied in two splits i.e. 50% of RD during pre-monsoon (March–April) and remaining 50% of RD during post-monsoon (September–October). The external application of nutrient ($N:P_2O_5:K_2O$) through chemical fertilizers in GO1986, GO1992, SO1987 and SO1970 orchards till October, 2009 (year of sampling soils) was estimated to be 3.82:2.87:3.82, 2.83:2.12:2.83, 1.30:0.52:1.47, and 2.31:0.92:2.60 t ha^{-1}, respectively. Organic manure was applied sporadically to the orchard at 7.0 t ha^{-1} for guava and 3.5 t ha^{-1} for sapota during pre-monsoon (March–April). Weeding was done manually. Within the drip circle bare soil surface was maintained to facilitate irrigation and fertilizer/manure applications. Fertilizers were applied in two split doses i.e. April and September. Weeds in the inter-row space were slashed and incorporated in soils. Bordeaux paste and solution were applied in orchards as and when required. When drought prevails during winter months (November to March) life saving irrigation was provided.

2.3. Soil sampling procedure

Each orchard was divided into five replicated blocks across the slope (1–5%) to ensure proper randomization of soil sampling and minimization of sampling errors (Fig. S1). Surface soil (0–15 cm) sample was collected in the month of October, 2009 after recession of South-West monsoon using 5 cm diameter core. From each block 60 random soil samples (20 spots each from drip circle, inter-row, and interface of drip and inter-row spaces) were collected and were combined to make one composite soil sample per block (Fig. S1). Thus, five composite soil samples were obtained from each orchard/land use system. Similarly, the forest surrounding the orchards was divided into five replicated blocks across the slope. From each block, one composite surface soil (0–15 cm) sample consisting of soils from 60 random spots was collected. Altogether, five composite soil samples were collected from FS. Each field moist composite soil sample was divided into 2 sub-samples. A subsample was air dried under a shade, ground to pass a 2 mm sieve and stored in a plastic container until analyzed for physical and chemical parameters. A portion of sieved (2 mm) soil sample was ground to pass through a 0.5 mm sieve for estimation of organic carbon. The remaining field moist composite sub-sample was stored at 4 °C for analysis of soil enzymes.

2.4. Earthworm populations

In a given orchard, the earthworm populations {earthworm biomass (EB) and density (ED)} were sampled randomly at three sites namely drip circles, inter-row and interface of drip and inter-row spaces. Altogether, fifteen sampling sites were used in each of the orchards and FS. Individuals were sampled following formalin extraction method (Raw, 1959). The rationale behind choosing the formalin extraction method was to ensure rapid collection of surface active earthworm species, species living in deeper soil layer and large earthworm species of forest soil for relative comparison with orchard soil. The aqueous diluted (0.5%) formalin was applied on soil surface within 50 × 50 cm^2 area (Baretta et al., 2007). After 30 min, all the earthworms that came out from 50 × 50 cm^2 soil area were hand-picked, and live earthworms were rinsed in tap water, counted, blotted dry on tissue paper and weighed to measure EB. The density and biomass of extracted worms in forest soil (baseline ecosystem) were also measured following the same procedure. Units of ED and EB were expressed as number of individuals per square meter (no. of indiv. m^2) and fresh weight in g m^2, respectively.

2.5. Soil analysis

Bulk density (BD) of soil was determined from intact soil cores of 102 cm^3 volume collected from the same quadrates that was used for counting EP. Soil porosity was derived from BD using the formula: Porosity = [1 − (BD / PD) × 100], where PD is the particle density determined using a Keen box (Baruah and Barthakur, 1999). Maximum water holding capacity (MWHC) was determined by equilibrating the