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# Soil Fertility Changes due to Drip Fertigation in Arecanut-Cocoa System

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*The effects of drip fertigation of NPK and vermicompost extract (VCE) on soil fertility status of arecanut-only and arecanut-cocoa systems were assessed in a 4-year field study. In arecanut, soil pH was reduced over initial levels. At 0–30 cm deep, fertigation of 75 percent NPK to arecanut only and organic-matter recycling in arecanut + cocoa maintained significantly greater soil organic carbon (SOC) and soil-test phosphorus (P). At the first depth, soil potassium (K) was significantly greater with 75 percent NPK (246 mg kg$^{-1}$) than other treatments. In cocoa, soil pH varied significantly due to fertigation at both depths. The SOC was reduced due to 75 percent NPK at the first depth. In cocoa, the P availability increased significantly with application of VCE at 20 percent N. Fertigation of 75 percent NPK maintained significantly greater soil K and soil Mg than other treatments. The results suggest that drip fertigation of NPK sustains the soil fertility status in arecanut and cocoa.*

**Keywords** Arecanut, cocoa, drip fertigation, laterite soil, soil fertility

## INTRODUCTION

Soil fertility decline is perceived to be widespread in tropics (Hartemink 2006). Soil fertility is a reflection of both inherent soil properties and management practices. The plantation crops like arecanut (*Areca catechu* L.) and cocoa (*Theobroma cacao* L.) are predominantly grown on laterite soils in humid tropics of India. It is imperative for farmers to adopt a cropping system approach for greater profitability and to avoid risks due to heavy rainfall, water stress in summer, pests, diseases, and price fluctuations. In India, the productivity of both arecanut (1180–1260 kg ha$^{-1}$) and cocoa (380–550 kg ha$^{-1}$) remained stagnant during the past two decades. It is often ascribed to the absence of adequate information on soil fertility and plant nutrition and adoption of conventional irrigation methods. The inherent constraints of laterite soils are widely reported (Lal 1995; Perur 1996; West et al. 1997; Shiva Prasad et al. 1998) and the sustenance of soil fertility through suitable strategies is indispensable to tackle these constraints. The poor nutrient-retention capacity of laterite soils due to low CEC (3–14 cmol$_c$ kg$^{-1}$), the undulating topography, and high rainfall of more than 3000 mm accentuate the process of leaching of nutrients. Shallow root system, large nutrient removal, and poor nutrient-use efficiency are major constraints in arecanut cultivation (Bhat and Sujatha 2008, 2012). The microclimate existing in arecanut plantations is very congenial for cocoa. Earlier studies in arecanut

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demonstrated a yield increase of 45 percent with drip irrigation over the basin method (Bhat and Sujatha 2004). An arecanut-cocoa system requires optimum nutrition and irrigation for good productivity (Abdul Haris et al. 1999; Bhat and Sujatha 2011a; Sujatha et al. 2011b; Sujatha and Bhat 2013a).

Crop yields increase substantially with fertigation (Papadopoulos 1987; Castellanos et al. 2001a; Bhat, Sujatha, and Balasimha 2007). Increased use efficiency of fertilizers and water with reduced N loss are reported with fertigation (Mmolawa and Or 2000; Mailhol et al. 2011; Lekakis et al. 2011; Kennedy, Suddick, and Six 2013). Fertigation reduces cost of production (Sujatha et al. 2000; Bhat and Sujatha 2006). The other positive aspects of drip fertigation with inorganic fertilizers are better nutrient mobility of soil P in root zone (Bhat et al. 2007) and soil fertility improvement (Bhat and Sujatha 2009). The organic wastes from arecanut and cocoa, which otherwise find no use, can be efficiently converted to vermicompost (Chowdappa, Biddappa, and Sujatha 1999). Recycling of organic wastes as vermicompost in arecanut-based cropping system (Bhat and Sujatha 2007) and arecanut alone (Sujatha and Bhat 2012; Sujatha and Bhat 2013b) results in sustainable yields but exhausts soil K. Most farmers prefer an organic farming approach and there is a need to find organic nutrient sources for fertigation. Leachates derived from vermicomposting can be used as liquid fertilizer because of the high concentration of plant nutrients (Gutierrez-Miceli et al. 2008; Tejada et al. 2008). It is assumed that fertigation of organic sources such as vermicompost extract increases the nutrient-use efficiency of major nutrients, especially K. Drip fertigation in an arecanut-cocoa system increases the productivity per unit area by 12 to 30 percent over only arecanut (Sujatha and Bhat 2013a).

Drip fertigation is an ideal option for both arecanut alone and an arecanut-cocoa system because of improved resource-use efficiency. The ultimate aims of a cropping system are not only to obtain additional income but also to improve the soil fertility status in the long run. High rates of outputs from the cropping system can deplete the soil of its nutrient store and make the system ecologically unsustainable (Nair 1999). Quantification of nutrient flows and stocks becomes important for development of sustainable land-use systems, especially on low-fertility soils of the humid tropics (Schroth et al. 2001; Hartemink 2005). Arecanut and cocoa are heavy feeders of nitrogen (N) and potassium (K) (Bhat 2002; Bhat and Sujatha 2009, 2012) and place great demands on nutrients on soil. Manikandan et al. (1987) noticed a negative balance in available K in an arecanut-cacao system. Litter decomposition is a very important process for soil fertility in perennial systems (Wardle et al. 2003). The litter fall from cocoa is considerable (Abdul Haris et al. 1999; Sujatha and Bhat 2013a), which might influence the soil fertility status of both cocoa and arecanut. Optimum nutrient limits established for laterite soils (Bhat, Sujatha, and Jose 2012) help in assessing the soil fertility status accurately and formulating suitable nutrient-management practices in tune with crop need. With this background, the present study examined the impact of drip fertigation of inorganic fertilizers and organic source such as VCE alone and in combination on soil fertility statuses of both an arecanut-cocoa system and arecanut alone.

## MATERIALS AND METHODS

### *Details of Study Site*

The study was conducted at the Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India (12° 15′ N latitude and 75° 25′ E longitude, 91 m above sea level) during December 2007 to December 2011. The average annual rainfall at this place over past 43 years was 3686 mm, which was distributed over 120 days a year. Mean temperature ranged from 21 ºC (minimum) to 36 ºC (maximum) and the average relative humidity varied between 61 to 94 percent. The total rainfall of the experimental location varied from 3188 to 3952 mm during 2007–2011. The pan evaporation varied from 3.6 to 4.9 mm during December to May. The soil of the study site is sandy clay loam classified as kaolinitic Kanhaplic Haplustults under Ultisols. The soil is slightly acidic with 5.6–6.0 pH, 2.0 percent organic carbon, 5–10 mg $kg^{-1}$ Bray's P, and 50–150 mg $kg^{-1}$ available K at 0–30 cm deep. The textural composition of the soil is 50 percent sand, 14 percent silt, and 36 percent clay at 0–60 cm soil deep. The cation exchange capacity (CEC) is 11.2 $cmol_c\ kg^{-1}$. The bulk density of soil is 1.61 g $cm^{-3}$ and the field capacity varies between 18 and 22 percent at 0–30 and 30–60 cm deep.

### *Experimental Material*

The arecanut plantation was established in December 1995 by planting 1-year-old seedlings (cv. Mohitnagar) in 2930 $m^2$ area at a spacing of 2.7 m × 2.7 m. The experiment on drip fertigation with inorganic NPK was conducted during 1996–2006 in the same plantation and the results on yield levels and soil fertility are reported (Bhat, Sujatha, and Balasimha 2007; Bhat and Sujatha 2009). Nutrients were not applied from June 2006 to November 2007 to nullify the effect of previous treatment. Grafted cocoa (variety VTLCC-1) was planted in the existing 12-year-old arecanut plantation in October 2006. Cocoa was planted as mixed crop at a spacing of 2.7 m × 5.4 m in arecanut plantation. During the first and second years of planting, grafted seedlings were maintained by giving structural pruning, allowing jorquette with three to five fan branches at 1.0 to 1.5 m high. From the third year onward, maintenance pruning was done every year to give trees an umbrella shape. Recommended control measures for pests and diseases were followed for both crops as and when necessary. Bordeaux mixture (1 percent) was sprayed on bunches of arecanut twice at 45-day intervals during the monsoon season (June–September) every year to prevent fruit rot caused by *Phytopthora palmivora*.

### *Treatment Details*

The present experiment was laid out in a split-plot design with three replications in December 2007. Each treatment consisted of twelve arecanut palms and six cocoa trees as net plot in an arecanut-cocoa system. The main plots had two land-use systems, only arecanut (AS) and arecanut-cocoa (AC). The subplots included six nutritional treatments: control + organic-matter recycling (OMR) through vermicompost, 75 percent recommended NPK, vermicompost extract (VCE) 10 percent of N equivalency, VCE 20 percent of N, VCE 10 percent of N + 25 percent NPK, and VCE 20 percent of N + 25 percent NPK. In arecanut and cocoa, the fertilizer dose is applied per palm or tree basis and not on a unit area basis. In laterite soils, the recommended fertilizer dose for both arecanut and cocoa is 100:18:117 g NPK $palm^{-1}$ $year^{-1}$ as soil application. For drip fertigation, 75 percent of recommended NPK is the standard dose for arecanut. In the first year of cocoa planting, one third of the recommended fertilizer level was applied. The drip fertigation system consisted of one 5000-L tank, fertilizer tank, sand filter, ventury, screen filter, and two pressure gauges. One lateral line was provided for each treatment with a valve to control the treatment application.

The crop was drip irrigated at 100 percent $E_{pan}$ during postmonsoon season. Two emitters of 8 L $h^{-1}$ discharge rate were placed 60 cm away from the base of the palm or tree on two sides. Urea (46 percent N), diammonium phosphate (DAP, 18 percent N and 21 percent P), and muriate of potash (MOP, 50 percent K) were used as sources of N, P, and K. The DAP was soaked in water and, after softening, mixed with urea and MOP just before application. A ventury was used to inject the fertilizer solution into the main line of drip system after allowing the solution to pass through screen filter. Every year the fertilizer and VCE were applied in 21 split doses at 10-day frequencies from December to May. Reference crop evapotranspiration ($ET_0$) was calculated on a daily basis using a modified Penman method (Doorenbos and Pruitt 1977). The actual evapotranspiration was estimated by multiplying $ET_0$ with crop coefficient values. The estimated crop coefficient values were 0.95 to 0.99 for young arecanut palms and 1.00 to 1.05 for bearing palms during December to May. The same crop coefficient values were adopted for cocoa also.

### *Preparation of Vermicompost Extract (VCE)*

Vermicompost extract was obtained by mixing fresh vermicompost containing worms with irrigation water at a 1:10 ratio and storing overnight in a cement tank constructed near the fertilizer tank. The VCE was collected from the tank directly into the fertilizer tank and allowed to pass through screen filter and the drip system. Vermicompost was produced by collecting fallen arecanut leaves from the study site as per standard procedure (Chowdappa, Biddappa, and Sujatha 1999). The nutrient compositions of vermicompost, VCE, and irrigation water are reported (Sujatha and Bhat 2013a). The N, P, and K contents of VCE were estimated as 250, 132, and 88–133 mg $kg^{-1}$, respectively.

### *Soil Sampling and Analysis*

Soil samples were collected from arecanut and cocoa basins on all four sides and mixed to get a representative sample. Six arecanut palms and three cocoa trees in each treatment were selected for soil sampling. Soil samples were collected from 0–30 and 30–60 cm deep at 40–50 cm away from the base of the arecanut palms and cocoa trees in May 2007 and 2011. The air-dried soil samples were ground to pass through a 2.0-mm sieve and kept in labeled plastic bags for further analysis. Soil samples were analyzed for pH, CEC, organic carbon, available phosphorus (P), and available potassium (K) using standard procedures (Jackson 1973). Soil pH was measured in a 1:2 soil/water suspensions. Soil organic carbon was measured by the Walkley and Black method after digesting the soil samples with 1 N potassium dichromate and titrating with ferrous ammonium sulfate. Available P was estimated by the ascorbic acid reductant method (Watanabe and Olsen 1965) for color development after extraction with Bray's reagent. Available K, calcium (Ca), and magnesium (Mg) were estimated using an atomic absorption spectrometer (AAS) after extraction with neutral normal ammonium acetate. Micronutrients were estimated in AAS using diethylene triamine pentaacetic acid (DTPA) extract (Lindsay and Norvell 1978).

### *Data Analysis*

The soil fertility parameters in arecanut were subjected to split-plot analysis of variance (ANOVA) with three replications using MSTATC. For analysis of soil fertility parameters in cocoa, a simple randomized block design (RBD) was used, considering each tree data as one replication. Correlations were worked out in Microsoft Excel.

## RESULTS

### *Soil pH and Soil Organic Carbon (SOC) in Arecanut*

The pre-experimental soil pH in 2007 was not significant and varied from 5.93 to 6.10 at 0–30 cm deep and from 6.10 to 6.18 at 30–60 cm deep. Year-wise variation in soil pH was significant at both depths but the land-use system and fertigation did not influence the soil pH significantly (Figure 1 and Table 1). The soil pH values were reduced by 0.4 and 0.6 units in a 4-yr period at 0–30 and 30–60 cm deep, respectively, over pH levels in 2007.

Soil organic carbon varied significantly due to years at both depths (Figure 1). At 0–30 cm deep in 2007, SOC was significantly greater in AS (2.78 percent) than in AC (2.61 percent) systems. In 2011, the interaction effect of land-use system and fertigation was significant on SOC at both soil depths. Soil organic carbon in arecanut was significantly greater in intercropped situation with cocoa (2.63 percent) than in arecanut alone (2.43 percent) at 0–30 cm deep. At first depth, fertigation of 75 percent NPK (2.79 percent) to only arecanut maintained significantly greater SOC than OMR (2.25 percent) and VCE 20 percent N + 25 percent NPK (2.27 percent). In arecanut + cocoa system, OMR (3.04 percent) resulted in significant enrichment of SOC over 75 percent NPK (2.39 percent) and VCE 10 percent N + 25 percent NPK (2.26 percent). At the second depth, SOC status was significantly greater in the AC system (1.41 percent) than in AS system (1.30 percent) in 2011. Interaction effect was similar to that in the first depth.

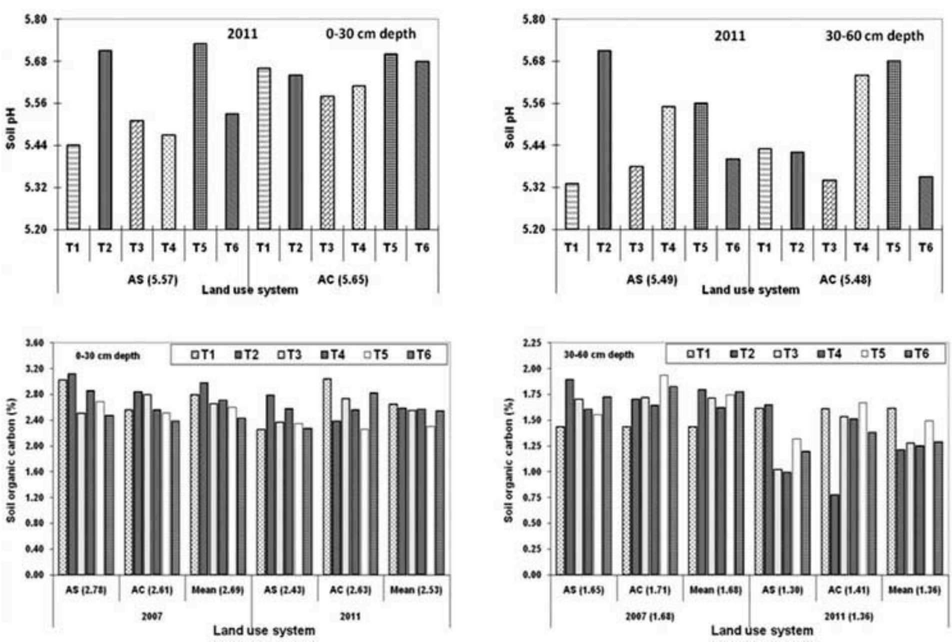



**Figure 1.** Soil pH and organic carbon as influenced by land-use system and fertigation in arecanut at two depths. T1, OMR through vermicompost; T2, 75 percent recommended NPK; T3, vermicompost extract (VCE) 10 percent of N equivalency; T4, VCE 20 percent of N; T5, VCE 10 percent of N + 25 percent NPK; and T6, VCE 20 percent of N + 25 percent NPK.

**Table 1.**
LSD (5 percent) for different soil fertility parameters at two depths in arecanut

| | 0–30 cm deep | | | 30–60 cm deep | | |
|---|---|---|---|---|---|---|
| Parameter | 2007 | 2011 | Year | 2007 | 2011 | Year |
| Soil pH | | | 0.04 | | | 0.05 |
| System (S) | NS | NS | | NS | NS | |
| Fertigation (F) | NS | NS | | NS | NS | |
| S × F | NS | NS | | NS | NS | |
| SOC | | | 0.051 | | | 0.056 |
| S | 0.19 | NS | | NS | 0.05 | |
| F | NS | NS | | NS | NS | |
| S × F | NS | 0.50 | | NS | 0.62 | |
| Soil P | | | 1.44 | | | 0.75 |
| S | NS | 1.89 | | NS | NS | |
| F | NS | NS | | NS | NS | |
| S × F | NS | 3.17 | | NS | 0.91 | |
| Soil K | | | 36 | | | NS |
| S | NS | NS | | NS | NS | |
| F | NS | 85 | | NS | NS | |
| S × F | NS | NS | | NS | NS | |
| Soil Ca | | | 241 | | | 232 |
| S | NS | NS | | NS | NS | |
| F | NS | NS | | NS | NS | |
| S × F | NS | NS | | NS | NS | |
| Soil Mg | | | NS | | | 39 |
| S | 15.3 | 16.5 | | NS | NS | |
| F | NS | NS | | NS | NS | |
| S × F | NS | NS | | NS | NS | |

### *Soil Nutrient Availability in Arecanut*

Year-wise variation in P availability was significant (Figure 2 and Table 1) and the soil-test P (mg $kg^{-1}$) reduced from 7.5 to 5.3 at 0–30 cm deep and from 2.4 to 1.4 at 30–60 cm deep during 2007–2011. During the same period, the availability of soil P reduced from 8.4 to 3.9 mg $kg^{-1}$ in arecanut alone but remained the same in an arecanut + cocoa system (6.6 mg $kg^{-1}$) at 0–30 cm deep. Interaction of land-use system and fertigation showed a significant effect on P availability at both soil depths in 2011. At the first depth in arecanut alone, the soil P was greater with fertigation of 75 percent NPK (6.2 mg $kg^{-1}$) than with other fertigation treatments except OMR and VCE 10 percent N + 25 percent NPK. In arecanut + cocoa system, soil P (mg $kg^{-1}$) was significantly greater with OMR (8.8) than 75 percent NPK (4.2) but at par with VCE 10 percent N + 25 percent NPK (7.6).

In arecanut, temporal variation in soil-test K (Figure 2) and Ca (Figure 3) was significant at first depth (Table 1). The availability of soil K and Ca decreased over a 4-yr period at the first depth, whereas the availability of soil Mg increased (Figure 3). During 2007–2011, the availability of soil K reduced from 200 to 155 mg $kg^{-1}$ at 0–30 cm deep but the remained same at the second depth (93–96 mg $kg^{-1}$). The land-use system showed

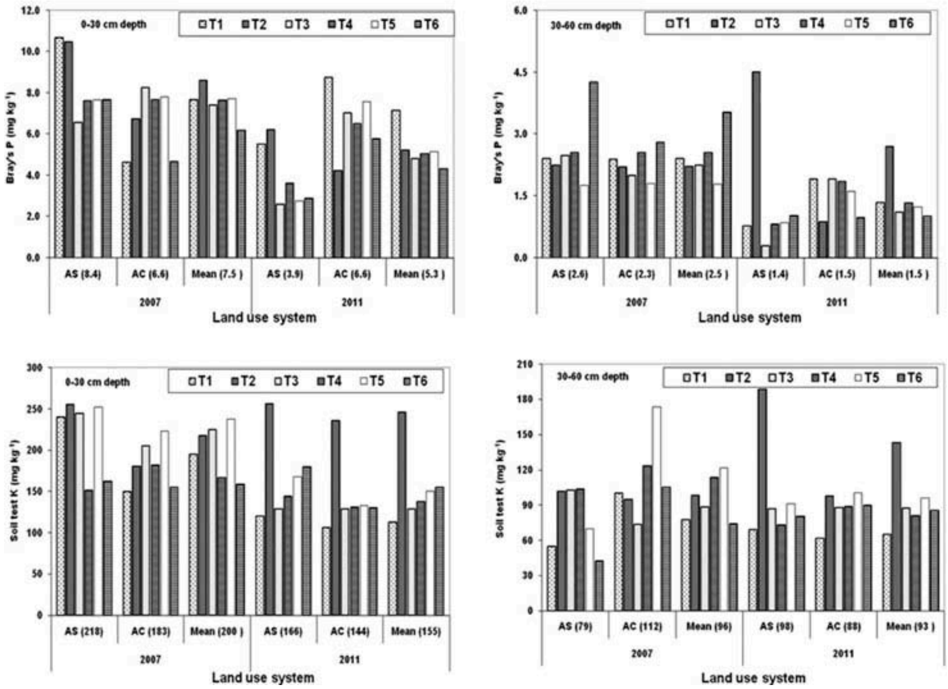



**Figure 2.** Soil-test P and K as influenced by land use system and fertigation in arecanut at two depths. T1, OMR through vermicompost; T2, 75 percent recommended NPK; T3, vermicompost extract (VCE) 10 percent of N equivalency; T4, VCE 20 percent of N; T5, VCE 10 percent of N + 25 percent NPK; and T6, VCE 20 percent of N + 25 percent NPK.

no significant effect on soil-test K at 0–30 cm deep (Table 1). In 2011, the available K in soil was significantly greater with fertigation of 75 percent NPK (246 mg $kg^{-1}$) than other fertigation treatments (113–155 mg $kg^{-1}$) at 0–30 cm deep. The trend was similar at the second depth. During 2007–2011, the soil Ca reduced drastically from 1577 to 473 and from 1202 to 403 mg $kg^{-1}$ at first and second depths, respectively. Soil test Ca values were greater in AS than in AC system. In contrast, the availability of soil-test Mg was greater in 2011 (128–143 mg $kg^{-1}$) than in 2007 (66–107 mg $kg^{-1}$). The arecanut + cocoa system maintained greater soil Mg than arecanut alone. No definite trend was noticed with respect to the availability of soil Ca and Mg among fertigation treatments.

In arecanut, the availability of micronutrients was not significantly influenced due to years except for for Mn and fertigation treatments (Table 2). The availability of Fe and Mn was significantly greater in the AC system than in AS at both soil depths. The availability of Zn was not influenced by land-use system but Cu availability was significant in both years at the first depth.

### *Soil pH and Soil Organic Carbon (SOC) in Cocoa*

In contrast to arecanut, soil pH in cocoa varied significantly in different years due to fertigation treatments at both soil depths (Figure 4 and Table 3). At 0–30 cm deep, soil pH reduced significantly from 5.98 to 5.37 during 2007–2011. The trend was similar at the second depth. Reduction in soil pH was greater in 75 percent NPK and 20 percent N VCE + 25 percent NPK

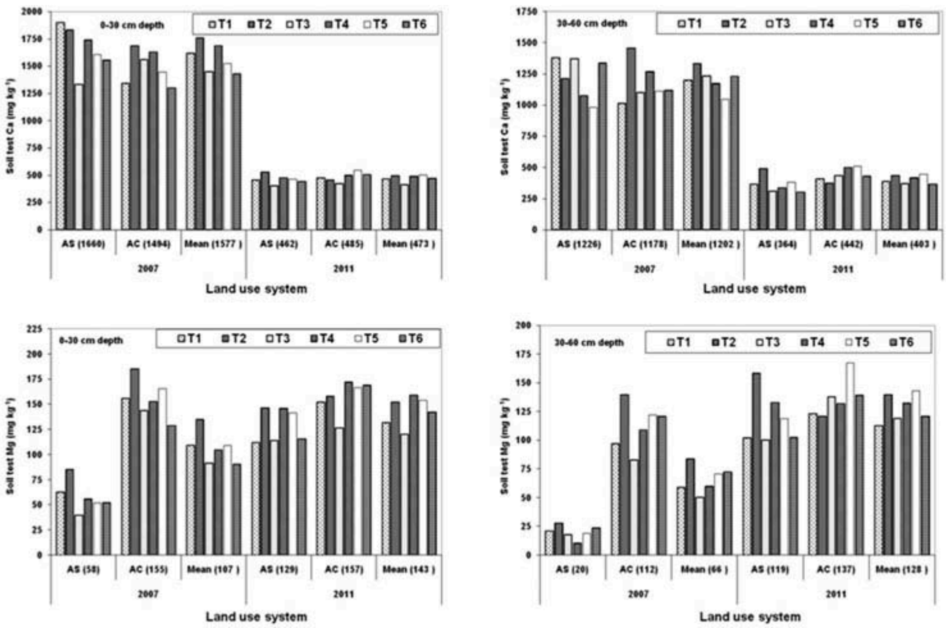



**Figure 3.** Soil-test Ca and Mg as influenced by land-use system and fertigation in arecanut at two depths. T1, OMR through vermicompost; T2, 75 percent recommended NPK; T3, vermicompost extract (VCE) 10 percent of N equivalency; T4, VCE 20 percent of N; T5, VCE 10 percent of N + 25 percent NPK; and T6, VCE 20 percent of N + 25 percent NPK.

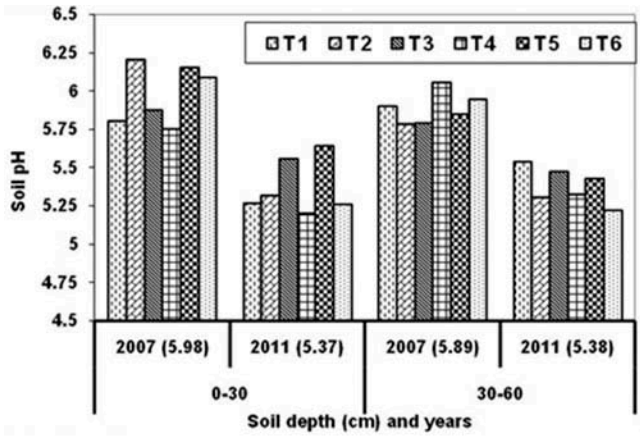
than in other fertigation treatments. Temporal variation in SOC was significant and showed decline during 2007–2011 in cocoa (Figure 4 and Table 3). Drip fertigation of NPK or VCE alone or in combination for 4 years reduced the SOC content in cocoa compared to initial levels in 2007 at both soil depths except in organic-matter recycling treatment. Initial SOC in cocoa ranged from 2.04 to 2.56 percent at 0–30 cm deep and from 1.52 to 2.15 percent at 30–60 cm deep. Fertigation of 75 percent NPK reduced the SOC (percent) status from 2.05 to 1.65 and from 1.52 to 0.84 at 0–30 and 30–60 cm deep, respectively.

### *Soil Nutrient Availability in Cocoa*

Soil-test P significantly increased at the first depth but remained the same at the second depth in cocoa during 2007–2011 (Figure 5 and Table 3). During 2007–2010, the availability of P increased from 7.3 to 11.6 mg $kg^{-1}$. At 0–30 cm deep, the P availability (mg $kg^{-1}$) increased significantly with application of VCE at 20 percent N (31.6) compared to NPK (1.5) and NPK + VCE (5.3–12.2). Year-wise variation was significant for soil-test K and Ca at 0–30 cm deep (Figure 5 and Table 3). The availability of K, Ca, and Mg was greater in 2007 than in 2011 (Figure 5). At first depth, the availability of soil K (mg $kg^{-1}$) was 285 and 168 in 2007 and 2011, respectively. Fertigation of 75 percent NPK (231 mg $kg^{-1}$) maintained significantly greater soil K than other fertigation treatments (132–176 mg $kg^{-1}$). The soil Ca (mg $kg^{-1}$) was 1360 in 2007 and 295 in 2011. Soil-test Ca did not show any trend among fertigation treatments in cocoa. Soil-test Mg (mg $kg^{-1}$) was significantly greater with fertigation of 75 percent NPK (140) than other fertigation treatments (67–92) but at par with 20 percent N VCE (100).

**Table 2.**
Availability of DTPA-extractable micronutrients in arecanut at different soil depths

| | Zn | | | | Cu | | | | Fe | | | | Mn | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0–30 | | 30–60 | | 0–30 | | 30–60 | | 0–30 | | 30–60 | | 0–30 | | 30–60 | |
| System (S) | 2007 | 2011 | 2007 | 2011 | 2007 | 2011 | 2007 | 2011 | 2007 | 2011 | 2007 | 2011 | 2007 | 2011 | 2007 | 2011 |
| Areca alone | 3.1 | 1.0 | 1.2 | 0.5 | 5.2 | 8.9 | 3.8 | 5.3 | 16.3 | 14.1 | 13 | 12 | 57 | 48 | 47 | 42 |
| Areca + cocoa | 4.2 | 3.5 | 3.5 | 1.6 | 20.3 | 21.1 | 5.2 | 7.1 | 32.6 | 24.3 | 28 | 22 | 84 | 70 | 86 | 72 |
| Mean | 3.6 | 2.2 | 2.4 | 1.0 | 12.7 | 15.0 | 4.5 | 6.2 | 24.5 | 19.2 | 21 | 17 | 71 | 59 | 67 | 57 |
| LSD (5%) | | | | | | | | | | | | | | | | |
| Year | NS | | NS | | NS | | NS | | NS | | NS | | 5.6 | | 4.9 | |
| S | NS | NS | 0.9 | NS | 2.1 | 1.9 | NS | NS | 4.9 | 3.7 | 3.6 | 4.1 | 10.1 | 7.9 | 9.2 | 11.1 |
| Fertigation (F) | | | | | | | | | | | | | | | | |
| T1 | 3.2 | 2.1 | 3.2 | 0.8 | 14.3 | 12.1 | 4.0 | 5.6 | 22.5 | 19.3 | 16 | 17 | 80 | 65 | 71 | 66 |
| T2 | 4.3 | 2.8 | 2.2 | 1.2 | 12.2 | 16.6 | 2.6 | 7.2 | 25.9 | 19.2 | 26 | 16 | 72 | 52 | 71 | 52 |
| T3 | 3.6 | 1.6 | 2.6 | 0.7 | 10.9 | 14.6 | 3.3 | 5.3 | 26.6 | 19.3 | 23 | 15 | 58 | 58 | 72 | 62 |
| T4 | 3.5 | 1.8 | 2.2 | 0.7 | 11.4 | 12.5 | 5.9 | 4.9 | 22.5 | 19.2 | 16 | 18 | 70 | 59 | 59 | 50 |
| T5 | 4.2 | 2.1 | 1.6 | 1.2 | 12.9 | 14.9 | 5.9 | 8.4 | 22.8 | 19.2 | 21 | 19 | 66 | 62 | 61 | 55 |
| T6 | 3.1 | 2.9 | 2.4 | 1.7 | 14.9 | 13.6 | 5.5 | 5.8 | 26.6 | 19.2 | 23 | 17.9 | 80 | 61 | 68 | 58 |
| LSD (5%) | | | | | | | | | | | | | | | | |
| F | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |



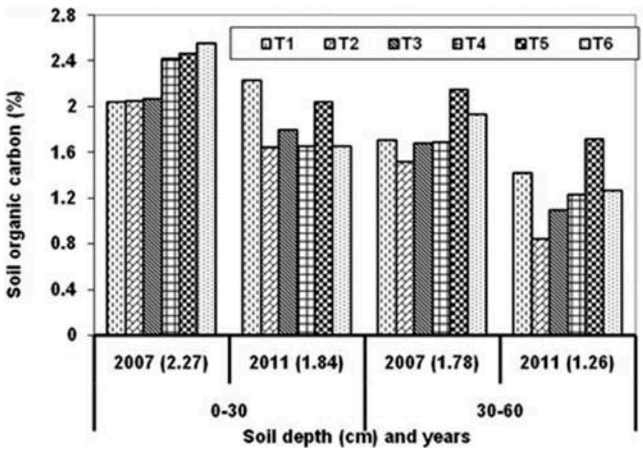




**Figure 4.** Soil pH and organic carbon in cocoa as influenced by fertigation. T1, OMR through vermicompost; T2, 75 percent recommended NPK; T3, vermicompost extract (VCE) 10 percent of N equivalency; T4, VCE 20 percent of N; T5, VCE 10 percent of N + 25 percent NPK; and T6, VCE 20 percent of N + 25 percent NPK.

Year-wise variation in the availability of micronutrients was significant for Mn, Zn, and Cu at first depth and for Fe, Zn, and Cu at second depth (Figure 6 and Table 3). The availability of Fe, Mn, and Zn was greater in 2007 than in 2011 at both soil depths. At first depth, soil Zn reduced drastically from 10.1 to 1.3 mg $kg^{-1}$ but soil Cu showed an increasing trend during 2007–2011. Fertigation treatments significantly influenced the availability of soil Zn at second depth in 2011 and that of soil Cu at first depth in both years. Soil Zn was significantly greater with fertigation of 20 percent N VCE + 25 percent NPK (2.8 mg $kg^{-1}$) than with other treatments. Soil Cu was significantly greater with fertigation of 10 percent N VCE + 25 percent NPK (19.3 mg $kg^{-1}$) than with other treatments in 2007. In 2011, soil Cu was significantly greater with OMR (25.5 mg $kg^{-1}$) than other treatments but at par with 10 percent N VCE + 25 percent NPK.

**Table 3.**
LSD (5%) for different soil fertility parameters at two depths in cocoa

| | 0–30 cm deep | | | 30–60 cm deep | | |
|---|---|---|---|---|---|---|
| Parameter | 2007 | 2011 | Year | 2007 | 2011 | Year |
| pH | NS | NS | 0.29 | NS | NS | 0.18 |
| SOC | NS | NS | 0.34 | NS | NS | 0.33 |
| P | 4.31 | 9.85 | 1.86 | NS | 2.16 | NS |
| K | 85 | 51 | 114 | NS | NS | NS |
| Ca | NS | NS | 481 | NS | NS | 304 |
| Mg | NS | 42 | NS | NS | NS | NS |
| Fe | NS | NS | NS | NS | NS | 2.84 |
| Mn | NS | NS | 15.9 | NS | NS | NS |
| Zn | NS | NS | 3.6 | NS | 1.8 | 0.78 |
| Cu | 6.6 | 7.0 | 3.1 | NS | NS | 2.34 |

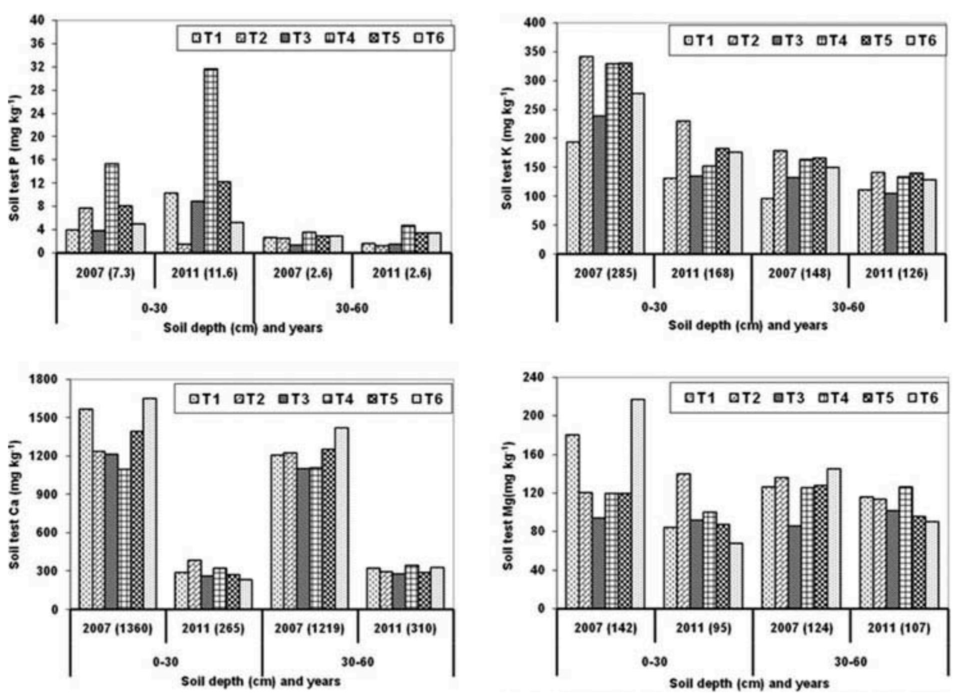



**Figure 5.** Soil test P, K, Ca and Mg at two soil depths in cocoa as influenced by fertigation. T1, OMR through vermicompost; T2, 75 percent recommended NPK; T3, vermicompost extract (VCE) 10 percent of N equivalency; T4, VCE 20 percent of N; T5, VCE 10 percent of N + 25 percent NPK; and T6, VCE 20 percent of N + 25 percent NPK.

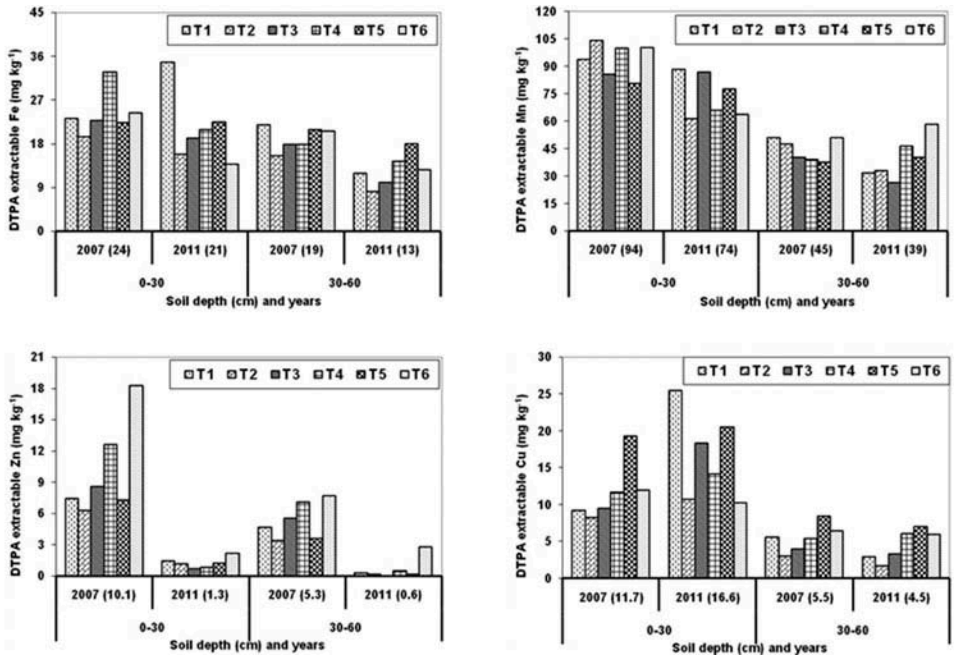



**Figure 6.** Micronutrient availability at two soil depths in cocoa as influenced by fertigation. T1, OMR through vermicompost; T2, 75 percent recommended NPK; T3, vermicompost extract (VCE) 10 percent of N equivalency; T4, VCE 20 percent of N; T5, VCE 10 percent of N + 25 percent NPK; and T6, VCE 20 percent of N + 25 percent NPK.

## DISCUSSION

Balanced nutrition is critical for both plant and soil health. Assessment of soil fertility status in response to any management practice is an essential safeguard for perennial crops such as arecanut and cocoa. Published reports on the same study, nutrient-uptake patterns in arecanut and cocoa, and optimum nutrient norms for laterite soils (Bhat and Sujatha 2011b, 2012; Bhat, Sujatha, and Jose 2012; Sujatha and Bhat 2013a) are considered for assessment of soil fertility in the present study. During 2007–2011, soil fertility parameters such as pH, SOC, and nutrient availability of P, K, Ca, Zn, Fe, and Mn showed significant decline both in arecanut (Figures 1–3, Table 1) and cocoa (Figures 4–6). Despite similar fertigation doses to arecanut and cocoa, the reduction in soil pH, SOC, K, Ca, Mg, and Zn was greater in cocoa than in arecanut. It might be due to early growth stage with greater biomass production and greater nutrient uptake by cocoa. Sufficient nutrition at an early growth stage is critical for cocoa (Wood and Lass 2001; Baligar et al. 2005), and soil resources decrease during the early stages of cocoa establishment (Isaac et al. 2005). The results imply that cocoa is a heavy feeder of nutrients and might compete with the main crop under nutrient-stress conditions. Similar nutrient statuses in soil except that of K and significant yield differences of arecanut and cocoa (Sujatha and Bhat 2013a) among different fertigation treatments indicate greater nutrient-use efficiency of fertigation of inorganic NPK or VCE + NPK.

The soil of study site is slightly acidic and pH fluctuates due to low CEC (11.2 $cmol_c\ kg^{-1}$) and leaching of bases in soils of humid regions (Alloway 1996).

Decline in soil pH status of arecanut and cocoa due to fertigation of NPK or VCE or both (Figures 1 and 4) can be attributed to reduction in soil-test values of Ca and Mg (Figures 3 and 5) and greater crop uptake of Ca and Mg (Sujatha and Bhat 2013a). Previous reports also indicate lower soil pH in cocoa rhizosphere than in arecanut and other component crops (Manikandan et al. 1987; Bhat and Sujatha 2007). The differences in SOC status of arecanut and cocoa can be attributed to quality and decomposition rate of litter and microclimate (Aerts 1997; Kurzatkowski et al. 2004). Greater soil organic carbon in arecanut in intercropped situation with cocoa and drip fertigation of NPK (Figure 1) might be due to slow decomposition rate of OM, litter fall from cocoa, greater root biomass production, and in situ root decay. The root system is a major pathway for the input of carbon to soil (Ruess et al. 1996) and drip fertigation results in greater fine root production (Bhat and Sujatha 2008). In contrast to SOC changes in arecanut, SOC decline was greater with fertigation of NPK than fertigation of VCE in cocoa (Figure 4). This might be due to early growth stage with greater biomass production and tap root system with less fine root production.

In general, soil P availability is lower than optimum levels (Bhat, Sujatha, and Jose 2012) in this study (Figures 2 and 5). The problem of P fixation is reported in laterite soils (Perur 1996; Bhat and Sujatha 2009). Low P availability is common in acidic soils within tropical agroforestry systems (Alpízar et al. 1986) and the affinity of iron oxides and hydroxides for P decreases its availability to plants (Chacon et al. 2006). The effect of land-use system on soil P was clearly evident with arecanut maintaining high P in mixed cropping with cocoa (Figure 2). Similar soil P levels in all fertigation treatments such as NPK or VCE application (2.6–8.8 mg $kg^{-1}$) highlight the P-fixation capacity of laterite soils and uptake by crop. The increased P availability in cocoa can be attributed to the tap root system enabling nutrient cycling, reduction in P adsorption, or solubilization of organic P due to greater root CEC and VCE application. The results imply that drip fertigation is a better strategy to meet P demand as it satisfies adsorption capacity of laterite soil and ensures sufficient crop uptake (Sujatha and Bhat 2013a) besides minimizing negative impact on environment.

Hartemink (2005) stated that the accumulation of K is low in a cocoa ecosystem and the nutrient balance is negative in the absence of inorganic fertilizers, especially for K. Greater K availability in soil with fertigation of 75 percent NPK (Figures 3 and 5) and decline in leaf K concentration to below-optimum range with VCE application (Sujatha and Bhat 2013a) highlight the necessity of K fertilizer application to meet the crop demand. The multistrata systems result in either neutral or positive effects on soil exchangeable K pools because of high K inputs from litter and elevated K transfer via rainwash (Hartemink 2005). Our results illustrate a negative effect for K because of crop and soil constraints. From the availability trend of basic cations in arecanut, it is clear that greater K and Ca in soil might have reduced Mg availability (Figure 3). Significant negative correlations between K/Ca and Mg ($r = -35$ to 0.45) support this explanation. The drastic reduction in soil-test Ca during the experimental period can be attributed to greater uptake as evident from the leaf nutrient status of arecanut and cocoa (Sujatha and Bhat 2013a). Though organic manures were not applied in this study, irrigation water and VCE might have ensured the availability of micronutrients except Fe at optimum range (Bhat, Sujatha, and Jose 2012). Reduced availability of micronutrients in soil except Cu in 4-yr period implies greater uptake by arecanut and cocoa (Sujatha and Bhat 2013a). Increase in soil Cu might be a consequence of the continuous use of Cu-based fungicides to control *Phytophthora* diseases.

The results indicate that soil fertility might influence the yield of arecanut by affecting uptake of major nutrients due to competition from high-valent micronutrients and secondary nutrients. This is clear from relations obtained between yield and soil nutrients: significant positive correlation of yield with K ($r$ = 0.31) and negative correlation with Fe ($r$ = −0.57), Mn ($r$ = −0.35), and Mg ($r$ = −0.23) in arecanut. In cocoa, correlations indicated significant negative correlation of yield with Mn ($r$ = −0.42), Cu ($r$ = −0.42), P ($r$ = −0.20), and Fe ($r$ = −0.20) and significant positive correlation with K ($r$ = 0.273). The canopy of cocoa (12.1–16.9 $m^2$) and significant increase in biomass production of cocoa from 3.5–4.7 to 8.7–12.6 kg per tree during 2009–2012 highlight the rate of production of standing and vegetative biomass. The canopy cover of cocoa in interspaces might have reduced nutrient losses in the AC system due to reduced runoff and improved conservation. The present findings and previous report (Sujatha and Bhat 2013a) suggest that the consideration of nutrient-uptake pattern, yield, and soil fertility status becomes important in perennial crops instead of blanket manurial additions every year. The results imply that drip fertigation of NPK can meet the nutrient demand of both arecanut and cocoa and continuous replenishment of K is required for plant and soil health. These findings also highlight that the drip fertigation sustains SOC status in perennial crops and ensures availability of nutrients in tune with crop demand.

## CONCLUSIONS

Our findings suggest that drip fertigation reduces competition between arecanut and cocoa as both are heavy feeders of major nutrients. Drip fertigation to both land-use systems with perennials sustained the organic carbon status in soil. The arecanut-cocoa system maintained K levels at less than optimum level, implying immobilization of large amount of K. Drip fertigation of NPK alone or in combination with VCE is more effective than VCE fertigation alone in maintaining the soil fertility status. In cocoa, a different nutrient-distribution pattern was exhibited in relation to drip fertigation. There is a need for precision nutrient application instead of blanket recommendations to minimize environmental impact of overfertilization.

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