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Impact of drip fertigation on arecanut–cocoa system in humid tropics of India

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Abstract A 5-year field trial was conducted on a laterite soil to evaluate the effects of organic and inorganic fertigations in arecanut sole and arecanut–cocoa land use systems at Vittal, India. Arecanut registered similar yield levels in sole and arecanut–cocoa cropping situations (3,022–3,117 kg ha^{-1}). Fertigation of 75 % NPK, vermicompost extract (VCE) 20 % N and VCE (10 and 20 % N)+25 % NPK registered the same yield levels (3,029–3,375 kg ha^{-1}). Dry bean yield of cocoa was at par with fertigation of 75 % NPK and 20 % N VCE + 25 % NPK (291–335 kg ha^{-1}). Fertigation @ 75 % NPK increased the yield of cocoa by 52 % over VCE alone. The productivity per unit area (kg ha^{-1}) was significant and higher by 12 % in arecanut–cocoa system (3,450) than arecanut sole (3,090). Productivity was similar to fertigation of 75 % NPK, 20 % N VCE and VCE (10 or 20 % N) + 25 % NPK (3,316–3,665 kg ha^{-1}). Leaf nutrient status of arecanut and cocoa indicated lower levels of N and K and above normal levels of Ca, Mg and micronutrients. The results indicate that drip fertigation increases the productivity, but precision application of N and K is required for sustaining the yields.

Keywords Arecanut · Cocoa · Drip fertigation · Vermicompost extract · Productivity · Leaf nutrient status

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Introduction

Arecanut (*Areca catechu* L.) and cocoa (*Theobroma cacao* L.) are the two major cash crops sustaining millions of people globally. About 16 million people are dependent on arecanut industry for their livelihood in India (Ravi et al. 2007). The International Cocoa Organization estimated that approximately 14 million people are directly involved in cocoa production (ICCO 2003). The cultivation of arecanut is mainly confined to Southeast Asia with India accounting for maximum area. In India, it is cultivated in 0.38 million hectares with a production of 0.47 million tonnes (GOI 2011). It is essentially a crop of small and marginal holders with low productivity (1,202 kg ha^{-1}). Globally, cocoa is cultivated in 8.92 m ha with a production of 4.23 m tonnes and productivity of 474 kg ha^{-1}(FAO 2010). In India, it is cultivated in 46,318 ha as component crop in arecanut, coconut and oil palm plantations with a production of 12,954 tonnes and productivity of 380 kg ha^{-1} (GOI 2011). The productivity of both the crops is very low because of several crop/soil constraints and improper management practices (Ravi et al. 2007, 2012).

It is imperative to adopt multispecies cropping system approach to increase the yield potential per unit area, as there is little scope for horizontal expansion of the area under huge population pressure in developing countries for agriculture and developmental activities (urbanization and industrialization). It is necessary to grow value-added and export-oriented intercrops in this era of trade liberalization (Sujatha and Ravi 2010, Sujatha et al. 2011a). Cocoa is found to be compatible intercrop in coconut/arecanut plantations. The microclimate existing in arecanut is congenial for cocoa. Land Equivalent Ratio of arecanut–cocoa system can be increased to 1.74 giving 74 % yield advantage over sole arecanut (Balasimha 2009). It is advantageous to grow cocoa at a spacing of 2.7 m × 5.4 m in arecanut with optimum nutrition and irrigation at 100 % ET (Sujatha et al. 2011b). The review of cropping system research in arecanut clearly established the importance of inclusion of cocoa as a component crop for improved productivity, profitability and soil fertility (Ravi and Sujatha 2011a; Sujatha et al. 2011b). Provision of optimal shade is necessary for enhanced cocoa biomass production (Beer et al. 1998; Isaac et al. 2007a, b), and 50 % is very ideal for optimum yields (Ravi 2002).

Irrigation and nutrition are the two most important factors for increasing the productivity in arecanut and cocoa (Ravi 2002; Ravi and Sujatha 2004) due to huge biomass production of 23–87 t ha^{-1} in arecanut–cocoa system at different ages. Annual increments in biomass or net primary productivity ranges from 1,380–2,660 kg ha^{-1} in cocoa and 3,340–7,110 kg ha^{-1} in arecanut (Balasimha 2010). The contribution of fertilizers for 40–60 % yield increase in several crops has been emphasized (Stewart et al. 2005). High cost and scarcity, nutrient imbalance and soil acidity are the problems associated with the use of mineral fertilizers in tropical countries. This led to recent interest in the use of agricultural wastes as nutrient source in crop production. Bulkiness, low nutrient quality and late mineralization were the bottlenecks to the sole use of organic manures for crop production. Clearly,new approaches for irrigation and nutrient management are required that will reduce both water consumption and detrimental environmental effects. Micro-irrigation approach increases the yield of arecanut and cocoa with 45 % water saving (Abdul Haris et al. 1999; Ravi and Sujatha 2004). Drip fertigation is very ideal for arecanut as it resulted in substantial yield increase (Ravi et al. 2007), soil fertility improvement (Ravi and Sujatha 2009) and reduced cost of production (Sujatha et al. 2000; Ravi and Sujatha 2006).

The organic wastes from arecanut and cocoa, which otherwise has no use, can be efficiently converted to vermicompost (Chowdappa et al. 1999). Organic matter recycling in arecanut based cropping system reduces fertilizer requirement of each component crop to 2/3rd of the recommended dose (Ravi and Sujatha 2007). Long term application of vermicompost sustained yield levels of arecanut at 2,700 kg ha^{-1} compared to 3,100 kg ha^{-1} with mineral fertilizers (CPCRI 2011) and 3,500 kg ha^{-1} with drip fertigation (Ravi et al. 2007). Leachates derived from vermicomposting are regarded as beneficial, and can be used as liquid fertilizers due to high concentration of plant nutrients (Gutierrez-Miceli et al. 2008; Tejada et al. 2008). Thus, it was contemplated to apply fresh vermicompost extract (VCE) through drip irrigation in this study to increase nutrient use efficiency and to counteract soil/crop constraints. With this background, the present study was planned to assess the impact of drip fertigation of inorganic fertilizers and VCE alone and in combination on arecanut–cocoa intercropping system and sole arecanut. Further, the leaf nutrient status of arecanut and cocoa was assessed to know whether VCE can meet the nutrient demands of both the crops.

Materials and methods

Details about experimental site

The investigation 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 last 30 years was 3,670 mm, which was distributed over 120 days a year. The mean temperature ranged from 21 °C (minimum) to 36 °C (maximum), and the average relative humidity varied between 61 and 94 %. The total rainfall of the experimental location varied from 3,188 to

3,952 mm during 2007–2011. The pan evaporation varied from 3.6 to 4.9 mm during December to May. The soil of the experimental site is sandy clay loam (laterite) with a 5.6–6.0 pH, 2.0 % organic carbon, 5–10 mg kg^{-1} P and 50–150 mg kg^{-1} K at 0–30 cm soil depth. The soil is well-drained deep laterite comprising 50 % sand, 14 % silt and 36 % clay at 0–60 cm soil depth. The bulk density of soil is 1.61 g cm^{-3} and the field capacity is 18–22 %.

Experimental details

The plantation was established in December 1995 by planting 1-year-old arecanut seedlings (cv. Mohitnagar) in 2,930 m^2 area at a spacing of 2.7 m × 2.7 m. Drip fertigation experiment was conducted from December 1996 to May, 2006 in this plantation. Nutrients were not applied during June, 2006 to November, 2007 to nullify the effects of previous treatment. Covariance analyses of yield data of 2006 and 2007 were done with both average and individual yield data of 2008–2011. The same was not significant indicating clearly the absence of impact 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 3–5 fan branches at 1.0–1.5-m height. From the third year onwards, maintenance pruning was done every year to give tree an umbrella shape. Required recommended practices were followed for both the crops. Bordeaux mixture (1 %) was sprayed on bunches of arecanut twice every year at 45-day interval during monsoon season (June–September) to prevent fruit-rot incidence caused by *Phytopthora palmivora*. Recyclable biomass from cocoa was recorded every year.

Treatment details

The present experiment was laid out in split plot design with three replications in December 2007. Each treatment consisted of 12 arecanut palms and six cocoa trees as net plot. Cocoa cannot be grown as sole crop. The main plots comprised two systems, viz., sole arecanut and arecanut–cocoa cropping system. The sub-plots included six nutritional treatments, viz., control + Organic matter recycling (OMR) through vermicompost, 75 % recommended NPK, vermicompost extract (VCE) 10 % of N equivalency, VCE 20 % of N, VCE 10 % of N + 25 % NPK and VCE 20 % of N + 25 % NPK. In arecanut and cocoa, the fertilizer dose is applied per palm/tree basis and not on unit area basis. The recommended fertilizer dose is 100:18:117 g N: P: K $palm^{-1}$ $year^{-1}$ for both arecanut and cocoa grown on laterite soils (Ravi 2002; Ravi and Sujatha 2004). The nutrients were applied in the active root zone area of palm/tree basin, and competition for nutrients between arecanut and cocoa is unlikely at top soil layers. The fertilizer dose for cocoa is the same as for arecanut. In the first year of cocoa planting, 1/3rd of fertilizer level was applied. Earlier studies indicated that the nutrient requirement of arecanut is the same in sole or arecanut–cocoa cropping situation, and the present treatments were fixed on the basis of results of several long-term studies at this institute (Ravi and Sujatha 2004; Ravi et al. 2007).

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 % E_{pan} during post monsoon season. Two emitters of 8 L hr^{-1} discharge rate were placed 60 cm away from the base of the palm on two sides. Urea (46 % N), Diammonium phosphate (DAP, 18 % N and 21 % P) and Muriate of potash (MOP, 50 % K) were used as sources of N, P and K fertilizers. The DAP was soaked in water and after softening, it was 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 frequency from December to May to both arecanut and cocoa. The quantities of fertilizers and VCE applied to arecanut were the same in both cropping situations.

Reference crop evapo-transpiration (ET_0) was calculated on daily basis using modified Penman method (Doorenbos and Pruitt 1977). The actual evapo-transpiration was estimated by multiplying reference evapo-transpiration with crop coefficient values for different years. The evaporation data were collected from USWB Class An open pan evaporimeter of meteorological observatory situated 20 m away from the experimental site. The estimated crop coefficient values considered for calculating water requirement were 0.95–0.99 for young arecanut palms and 1.00–1.05 for bearing palms during December to May. The same crop coefficient values were adopted for cocoa also.

Preparation of vermicompost extract (VCE)

For preparation of VCE, aqueous extracts were prepared by mixing fresh vermicompost containing worms with irrigation water at a ratio of 1:10 and stored overnight in a cement tank constructed near the fertilizer tank. The VCE was collected from the tank directly into fertilizer tank and allowed to pass through the screen filter and the drip system. Vermicompost was produced by collecting fallen arecanut leaves from the study site as per the procedure standardized by Chowdappa et al. (1999). The VCE and irrigation water were analysed at regular intervals. The nutrient composition of vermicompost, VCE and irrigation water are presented in Table 1.

Quantification of yield

The kernel yields (KYs) of 2007 and 2008 were not considered in this study to nullify the impact of previous treatment and in turn used as pre-experimental yields. Harvesting of arecanut was spread over a period of 6 months from October to March. Ripe nuts were harvested as and when ready and dried to 8 % moisture after recording fresh weight. Dried nuts were de-husked, and kernel weight was recorded for computing the yield. The flowering in cocoa initiated in 2007 and the yield of 2008 were not considered for drawing any inference. Harvesting of cocoa was done throughout the year. Cocoa yield was recorded as fresh pod yield, wet bean yield and dry bean yield (DBY). The yield of cocoa was converted to arecanut kernel equivalent yield for statistical analysis. The kernel equivalent yield of cocoa was estimated using the following formula:

$$\text{Kernel equivalent yield of cocoa} = \frac{\text{Yield of cocoa}\left(\text{kg ha}^{-1}\right) \times \text{Price of cocoa}\left(\text{Rs. kg}^{-1}\right)}{\text{Price of arecanut kernel}\left(\text{Rs. kg}^{-1}\right)}$$

During 2011–12, the prices of arecanut kernel and cocoa dry beans were the same (Rs. 150 kg^{-1} equivalent to USD 3). System productivity of arecanut–cocoa system was obtained by adding the KY of arecanut to the kernel equivalent yield of cocoa.

Leaf and soil sampling in arecanut and cocoa

Leaf samples were collected from the middle portion of the 4th and 6th leaves separately for analysis. As the nutrient concentrations in the 4th and 6th leaves were found to be similar, the mean of two leaves was considered. Leaf samples were cleaned with tap water followed by distilled water, air dried, packed in brown paper bags, oven dried at 60 °C to a constant weight and ground. The ground samples were kept in labelled butter paper bags for further analysis. Mature leaves in cocoa (usually the second or third leaf of the last maturing flush) were collected for nutrient analysis. Soil samples were collected from arecanut and cocoa basins on all four sides and mixed to get a representative sample. Soil samples were collected from 0–30 and 30–60-cm soil depth at 40–50 cm away from the base of the arecanut/cocoa tree during the month of May. Soil samples of 2-mm fraction were used for analysis.

Soil and plant analysis

Soil and leaf nutrient analyses were done using standard procedures (Jackson 1973 and Piper 1966, respectively). The leaf samples were analysed for total

Table 1 Nutrient composition of vermicompost, VCE and irrigation water

Nutrient	Nutrient content (mg kg^{-1})		
	Vermicompost	Vermicompost extract (VCE)	Irrigation water
N	2.0 %	250[a]	10–25[a]
P	0.6 %	132	0.2
K	0.9 %	88–133	3–9
Ca	1.9 %	90–110	30-40
Mg	0.65 %	58–72	4.0–7.5
Fe	4,412	30	0.16
Mn	502	9	ND
Zn	351	15	1.7
Cu	70	4	0.005

[a] NO_3–N

N using micro-Kjeldahl digestion method (Jackson 1973). The powdered plant samples were digested in a 3:1 nitric–perchloric acid mixture for total P, K and micronutrient estimations. Total P was determined by vanadomolybdate method (Piper, 1966). Estimations of K, Ca, Mg and micronutrients like Cu, Zn, Fe and Mn were performed using Atomic Absorption Spectrophotometer (AAS).

Data analysis

Statistical analysis was done using standard analysis of variance (ANOVA) technique. The yield and nutrient data of arecanut were subjected to split plot analysis of variance with three replications using MSTATC. For comparing the yield levels of different fertigation levels in the two land use systems, the yield of arecanut sole and system productivity of arecanut–cocoa were statistically analysed in split plot design. For analysis of cocoa data, simple randomized block design (RBD) was used considering data for each tree as one replication.

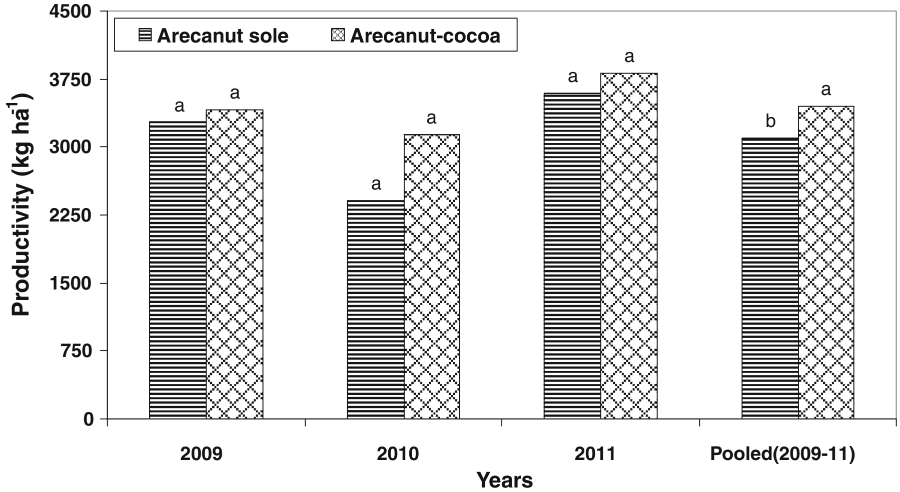
Results

Yield of arecanut and cocoa

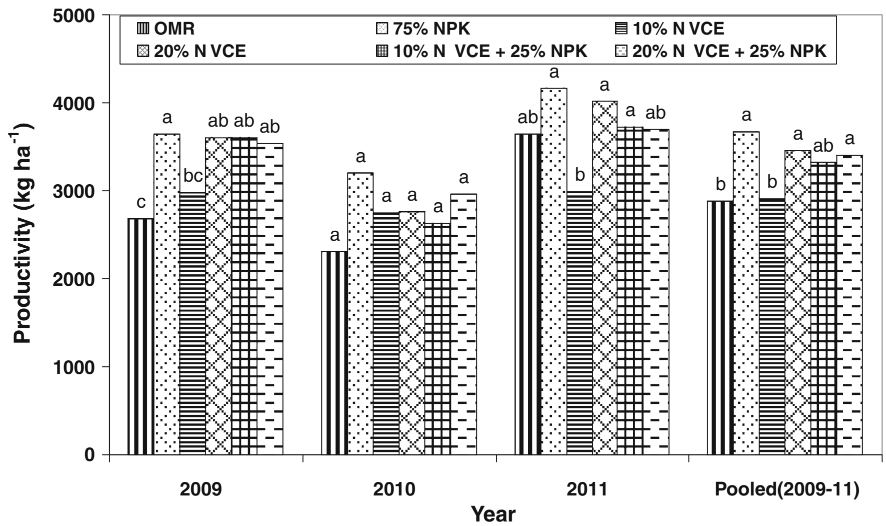
The pre-experimental yield of arecanut was not significantly influenced because of land use system and fertigation in 2007–08. The covariance analysis also showed that there was no impact of previous treatments on the present study. Pooled data of 4 years revealed that years and fertigation treatments significantly influenced the KY of arecanut (Table 2). Among the years of the study, significantly higher yield levels of arecanut were registered in 2011 (3,544 kg ha^{-1}) and 2009 (3,226 kg ha^{-1}) than in 2010 (2,652 kg ha^{-1}). Arecanut registered similar yield levels in sole and arecanut–cocoa cropping situations (3,022–3,117 kg ha^{-1}). Yield levels among 75 % NPK, VCE 20 % N, VCE 10 % of N + 25 % NPK and VCE 20 % of N + 25 % NPK were at par (3,029–3,375 kg ha^{-1}). Similarly, yield levels among OMR, 10 % N VCE and 10 % of N VCE+25 % NPK were not significantly different among themselves.

Table 2 Influence of drip fertigation with inorganic fertilizers and VCE on kernel yield of arecanut (KY) and dry bean yield of cocoa (DBY) in kg ha^{-1}

Years	System (S)	Fertigation (F)						Mean	LSD (5 %)
		OMR	75 % NPK	10 % N VCE	20 % N VCE	10 % N VCE + 25 % NPK	20 % N VCE + 25 % NPK		
2008	KY (Sole)	2539	2805	2999	2992	2581	3003	2820	S : NS
	KY (System)	1950	3294	3418	3240	2497	2965	2894	F : 579.9
	Mean	2244	3050	3209	3116	2539	2983	2857	S × F : NS
2009	KY (Sole)	2704	3646	2431	3835	3778	3263	3276	S : NS
	KY (System)	2473	3266	3370	3173	3224	3552	3177	F : 613.6
	Mean	2588	3456	2900	3504	3501	3407	3226	S x F : NS
	DBY -Cocoa	195	325	159	184	198	263	220	F : NS
2010	KY (Sole)	2294	2655	2585	2052	2138	2705	2405	S : NS
	KY (System)	2168	3467	2689	3274	2877	2922	2900	F : 479
	Mean	2231	3061	2636	2663	2508	2814	2652	S × F: NS
	DBY -Cocoa	155	256	218	194	238	302	227	F : NS
2011	KY (Sole)	3541	4177	2686	3701	3993	3434	3589	S : NS
	KY (System)	3469	3691	3012	4029	3144	3644	3498	F : 671
	Mean	3505	3934	2849	3865	3569	3539	3544	S × F : NS
	DBY -Cocoa	258	423	287	298	305	310	314	F: 101
Pooled	KY (Sole)	2770	3321	2675	3145	3123	3101	3022	S : NS
	KY (System)	2515	3430	3122	3429	2936	3271	3117	F : 389
	Mean (2008–2011)	2642	3375	2899	3287	3029	3186	3070	S × F : NS Y: 392
	DBY -Cocoa (2009–2011)	203	335	221	225	247	291	254	F : 64.7 Y : 63.6



(a)



(b)

Fig. 1 Productivity of arecanut sole and arecanut–cocoa system computed per unit area per unit time (LSD (5 %) for years: 379). *Bars with same letters do not differ significantly* **a**. Influence of land use system on productivity. **b** Influence of fertigation treatments on productivity

Pooled analysis of 3-year data indicated that dry bean yield (DBY) of cocoa was significantly influenced due to fertigations with NPK and VCE (Table 2). Year-wise variation in DBY of cocoa was significant and showed increasing trend during 2009–2011. The DBY (kg ha^{-1}) level was significantly higher in 2011 (314) than those in 2009 and 2010 (220 and 227, respectively). DBY of cocoa was at par with fertigations of both 75 % NPK and 20 % N VCE+ 25 % NPK (291 and 335 kg ha^{-1}, respectively) and significantly more during OMR, with 10 % N VCE and 10 % N VCE+ 25 % NPK. Fertigation of 75 % NPK increased the DBY of cocoa by 65 % over control (OMR).

Productivity per unit area

The influence of land use system and fertigation on the productivity per unit area per unit time is depicted in Fig. 1. The year-wise variation in productivity per unit area was significant. Productivity (kg ha^{-1}) was higher in 2011 (3703) than in 2009 (3339) and 2010

(2768). Pooled data of 3 years revealed that the productivity per unit area was significantly higher in arecanut–cocoa system (3450 kg ha^{-1}) than in arecanut sole (3,090 kg ha^{-1}). This implies that there was 12 % increase in yield per unit area per unit time despite initial bearing stage of cocoa. The productivity increased by 4 % in 2009, 30 % in 2010 and 6.5 % in 2011. Fertigation with 75 % NPK, 20 % N VCE, 20 % N VCE+ 25 % NPK and 10 % N VCE+ 25 % NPK registered statistically similar productivity levels (3,316–3,665 kg ha^{-1}). Average productivity with OMR was less (2,876 kg ha^{-1}) than the fertigation treatments.

Leaf nutrient status of arecanut

The influence factors of different treatments on leaf nutrient status of arecanut in different years are depicted in Figs. 2 and 3. The leaf N content was significantly influenced due to fertigation treatments, but not due to years and land use system (Fig. 2). OMR maintained significantly higher leaf N content (2.62 %) than with VCE application alone (2.37–2.41 %). Leaf P content (%) varied significantly among years, land use systems and fertigation treatments. Leaf P increased from 0.20 % in 2009 to 0.25 % in 2011. Arecanut registered higher P (0.24 %) in sole cropping situation than in system (0.22 %). Leaf P was the lowest with fertigation of VCE alone (0.21 %) compared with other treatments (0.23–0.25 %). Land use system showed significant effect on leaf K with sole crop registering higher K (0.99) than arecanut–cocoa system (0.86). The concentrations of leaf Ca and Mg were not affected by both land use system and fertigation, while their effects over the years were significant (Figs. 2, 3). Leaf Ca increased ranging from 0.59 to 0.88 % and leaf Mg from 0.19 to 0.25 % during 2009–2011.

Leaf Fe concentration significantly increased from 154 to 318 mg kg^{-1} during 2009–2011 (Fig. 3). Arecanut–cocoa system had significant impact of leaf Fe content (279 mg kg^{-1}) compared with sole arecanut (194 mg kg^{-1}). Manganese concentration in arecanut leaf was significantly influenced due to years, land use system and fertigation (Fig. 3). Leaf Mn was nearly doubled during 2009–2011. Manganese concentration in leaf tissue of arecanut was higher in arecanut–cocoa system (176 mg kg^{-1}) than in sole arecanut (116 mg kg^{-1}). Application of VCE alone increased leaf Mn concentration (173–187) significantly over other fertigation treatments (121–128). The leaf Cu in arecanut also varied significantly due to fertigation treatments. The year-wise variation in leaf Cu was significant with increase in leaf Cu from 2.5 in 2009 to 14.2 in 2011. Though years and land use system showed significant effect on the leaf Zn concentration in arecanut, no definite trend was noticed except that leaf Zn increased substantially during 2009–2011. Leaf Zn concentration was significantly lower with 75 % NPK fertigation than with fertigation of VCE.

Leaf nutrient status of cocoa

Leaf nutrient statuses of cocoa in different years are depicted in Fig. 4. The significant reduction in N concentration from 1.77 % in 2010 to 1.56 % in 2011 indicated the higher N demand of cocoa. Leaf N concentration was at par among fertigation treatments except in 10 % N VCE+ 25 % NPK. Leaf P content was high (0.20–0.29 %) in both years. Leaf K (%) increased significantly from 1.08 in 2010 to 1.52 in 2011. Years influenced significantly leaf Ca, which was 1.84 % in 2010 and 1.52 % in 2011. Years significantly influenced leaf Mg, which varied between 0.50 % in 2011 and 0.67 % in 2010. Among micronutrients, leaf Mn was very high in both years (Fig. 4). The leaf Cu in cocoa was influenced due to fertigation in both years. However, pooled data showed significant variation among years. Like in arecanut, years showed huge and significant variation in leaf Zn of cocoa. Leaf Zn showed significant variation due to fertigation with VCE registering higher Zn than NPK application.

Recyclable biomass in cocoa

The recyclable biomass in cocoa, which includes pruned biomass and litter fall, is shown in Fig. 5. Year-wise variation in production of recyclable biomass (3.5–3.6 kg $tree^{-1}$) was not significant. Fertigation of 75 % NPK and VCE 20 % N + 25 % NPK produced significantly higher biomass than OMR and VCE applications alone.

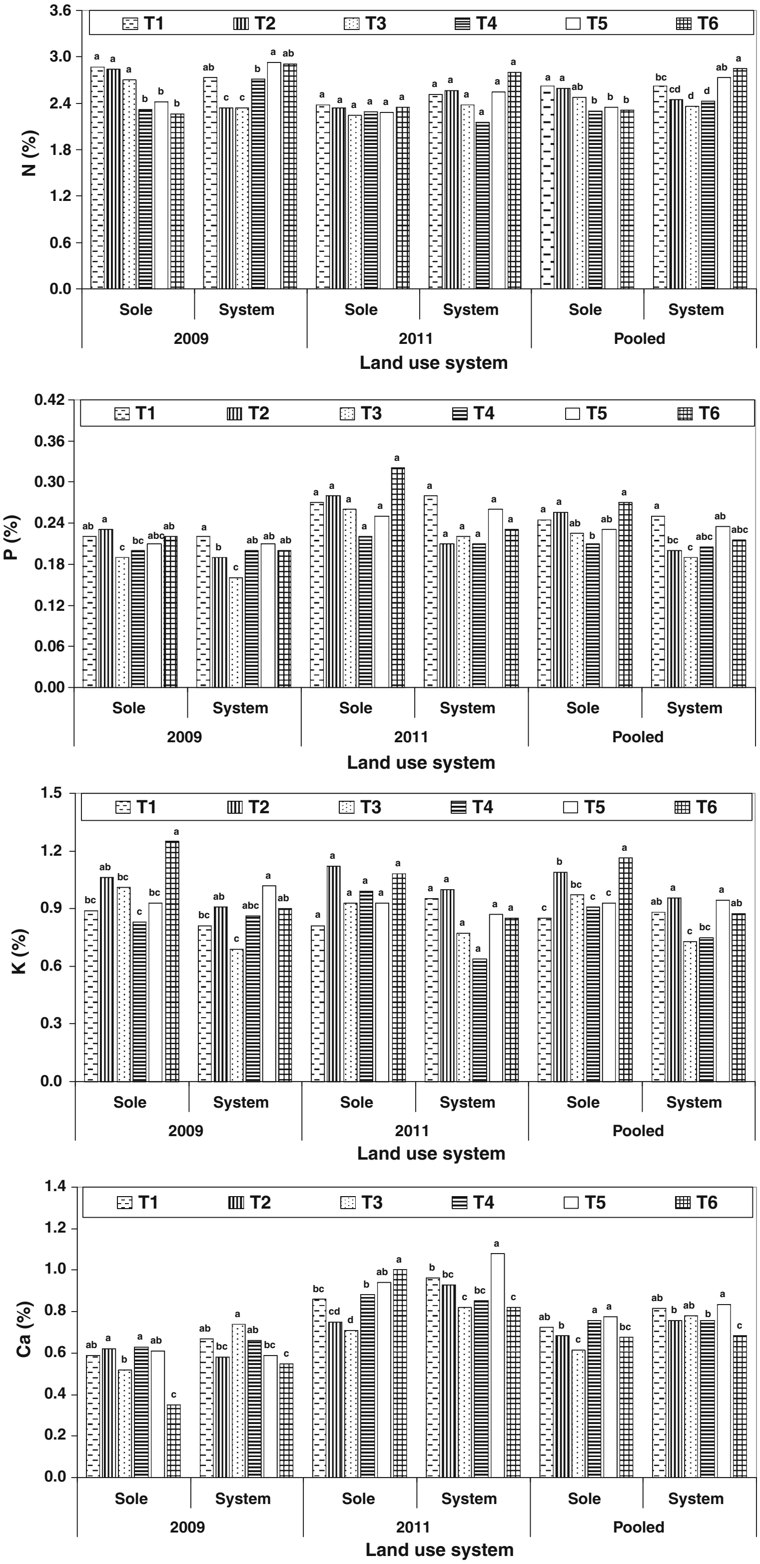


Fig. 2 Nutrient concentration in arecanut leaf as influenced by system and fertigation. (LSD (5 %) for years–N: NS, P: 0.018, K: NS, Ca: 0.136). *Bars* with same letters do not differ significantly. *T1*-OMR through vermicompost, *T2*-75 % recommended NPK, *T3*-Vermicompost extract (VCE) 10 % of N equivalency, *T4*-VCE 20 % of N, *T5*-VCE 10 % of N + 25 % NPK, *T6*-VCE 20 % of N + 25 % NPK

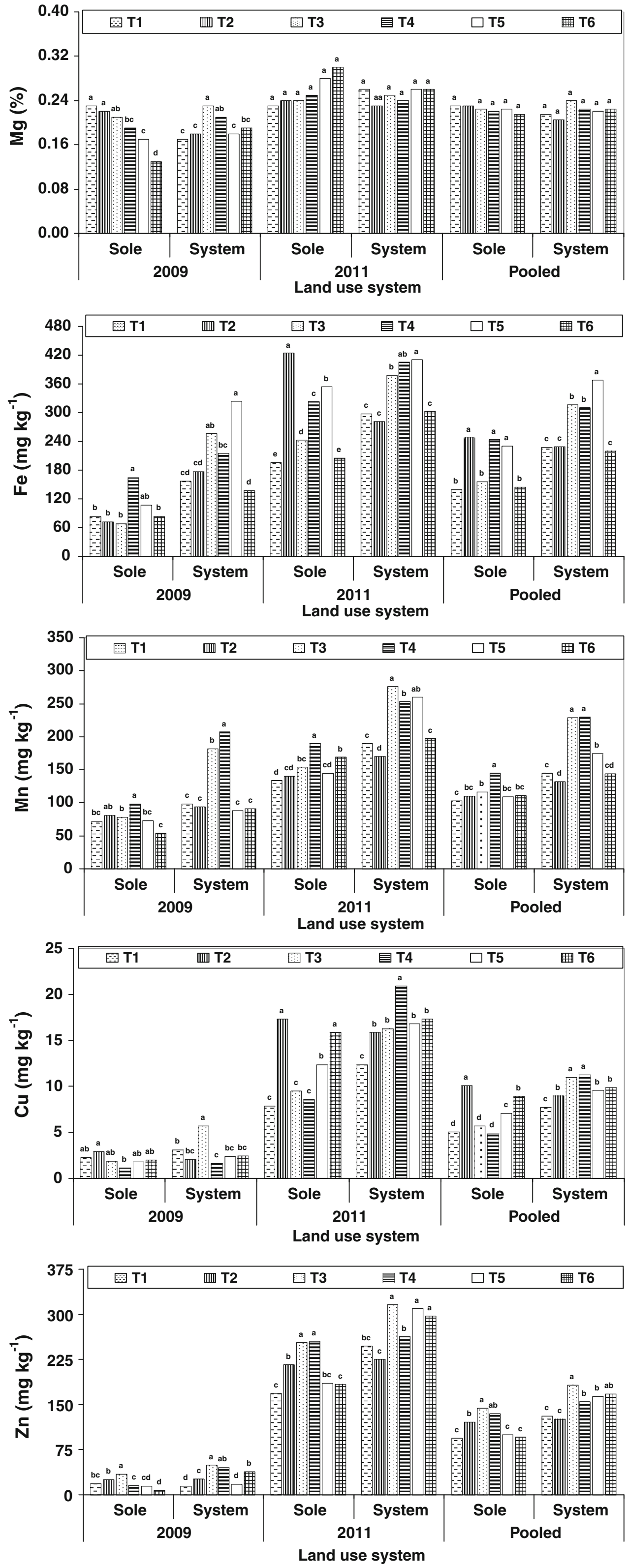
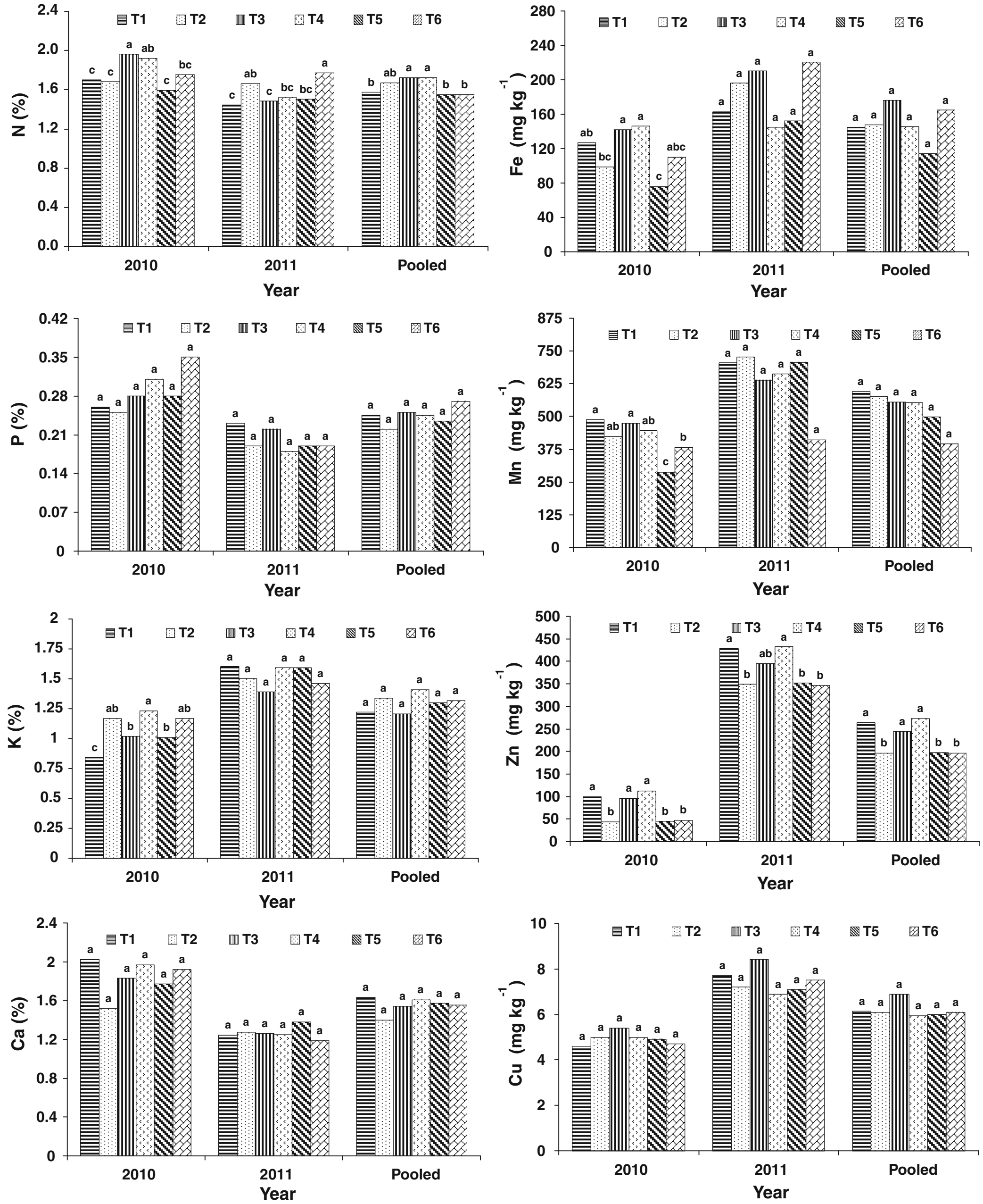
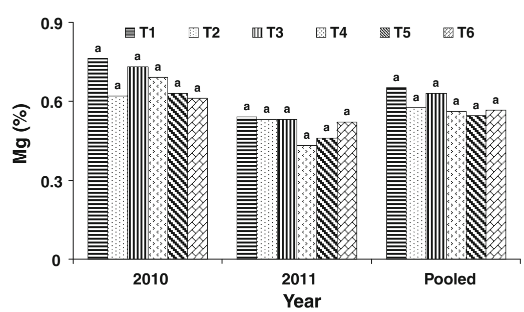


Fig. 3 Nutrient concentration in arecanut leaf as influenced by system and fertigation (LSD (5 %) for years–Mg :0.009, Fe: 41.7 Mn: 22.8, Zn: 10.8, Cu: 0.96). *Bars* with same letters do not differ significantly. *T1*-OMR through vermicompost, *T2*-75 % recommended NPK, *T3*-Vermicompost extract (VCE) 10 % of N equivalency, *T4*-VCE 20 % of N, *T5*-VCE 10 % of N + 25 % NPK, *T6*-VCE 20 % of N + 25 % NPK





Nutrient	Mean value			LSD (5%) for years
	2010	2011	Pooled	
N	1.77	1.56	1.63	0.16
P	0.29	0.20	0.24	0.06
K	1.08	1.52	1.30	0.21
Ca	1.84	1.26	1.55	0.22
Mg	0.67	0.50	0.59	0.065
Fe	117	181	149	50.1
Mn	417	641	530	127.2
Zn	74	383	229	25.3
Cu	4.9	7.5	6.2	1.12

◀ **Fig. 4** Leaf nutrient concentration in cocoa as influenced by fertigation. *Bars* with same letters do not differ significantly. *T1*-OMR through vermicompost, *T2*-75 % recommended NPK, *T3*-Vermicompost extract (VCE) 10 % of N equivalency, *T4*-VCE 20 % of N, *T5*-VCE 10 % of N + 25 % NPK, *T6*-VCE 20 % of N + 25 % NPK

Discussion

The laterite soil region in humid tropics of India is well known for large-scale cultivation of plantation crops especially arecanut. Cropping systems and drip fertigation are ideal technologies to counteract soil and crop constraints in arecanut tract (Ravi et al. 2007; Sujatha et al. 2011b). In India, the cultivation of cocoa is fast increasing as an intercrop in plantations. The biological efficiency and economic feasibility of arecanut–cocoa system have been highlighted recently by Sujatha et al. (2011b). Assessment of nutrient requirement becomes most important for perennial crops as higher fraction of nutrients are immobilized in standing biomass (Hartemink 2005). In the present study, arecanut yields were similar in sole and mixed cropping situations indicating the absence of competition between arecanut and cocoa. This suggests that provision of optimum irrigation and nutrition to both arecanut and cocoa reduces the competition between component crops in a cropping system. In arecanut, fertigation of VCE @ 20 % N registered higher yield level of 3,100 kg ha^{-1} in this study compared to 2,700 kg ha^{-1} with soil application of vermicompost @ 100 % N (CPCRI 2011). It is clear that organic fertigation can enhance nutrient use efficiency over soil application. Another advantage is the reuse of leftover vermicompost after obtaining extract. However, the overall yield levels of arecanut decreased in this study (3,070 kg ha^{-1}) compared to 3,500 kg ha^{-1} with drip fertigation of NPK (Ravi et al. 2007). In general, yield pattern of arecanut stabilizes by the 8th year with uniform yield levels up to 20 years under optimum management. Being a perennial crop, alternate bearing habit is noticed in arecanut once in 4 or 5 years. Though fertigation of 75 % NPK registered yield levels of 3,375 kg ha^{-1}, still the need for increasing the fertilizer dose is noticed. Despite good yield levels in arecanut, combined application of VCE and 25 % NPK might not be able to meet the nutrient demands of N and K in the long run as large quantities of N and K are immobilized in standing biomass of perennial crops (Hartemink, 2005) and in arecanut as well (Ravi and Sujatha 2012).

It is clear from the yield trends of cocoa that VCE alone cannot meet the nutrient demands as yield reduction was 33 % over fertigation of 75 % NPK. Nutrients, especially N, are supplied through different sources like irrigation water, leaf fall of cocoa, and rainfall interception (Ravi and Sujatha 2008a). Fertigation of VCE could meet the N demand of both crops but not K as both these crops are heavy feeders of K (Manikandan et al. 1987; Ravi and Sujatha 2011b; Ravi and Sujatha 2012). Further, reports of lower yields and depletion of soil test K with vermicompost application in arecanut (CPCRI 2011; Sujatha and Ravi 2012), higher optimum level of K for laterite

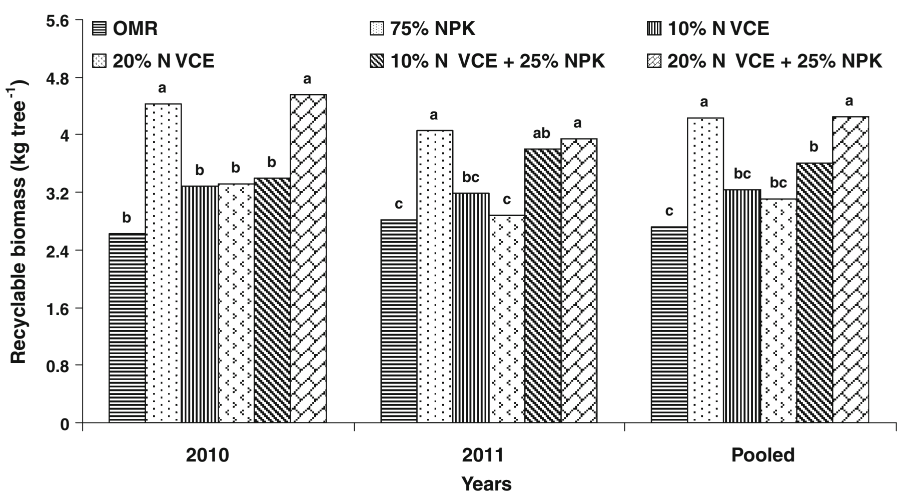


Fig. 5 Influence of fertigation on recyclable biomass production in cocoa. *Bars* with same letters do not differ significantly

soils (Ravi et al. 2012) and optimum leaf nutrient norms of arecanut and cocoa substantiate the above results and the need for supplementing K for sustainable yields of arecanut and cocoa. Though N is supplied based on demand, nitrogen use efficiency might have reduced because of less K. It is well known that K in soil improves nitrogen use efficiency and sustains productivity (Blevins 1985; Brennan and Bollard 2007; Li et al. 2009). In this study, soil organic carbon was above optimum (2.44–2.76 % in arecanut and 1.86–2.27 % in cocoa) and soil test K (30–180 mg kg^{-1}) was below optimum (Personal communication), which is 192 mg kg^{-1} according to Ravi et al. (2012). The results imply that yields might have reduced due to introduction of organic fertigation and insufficient nutrient supply of N and K, which was evident from leaf nutrient status.

As organic products are in great demand, the need for only organics was realized. It was anticipated that direct application of water-soluble nutrients in the root zone through drip fertigation during nut/pod-formation stage would improve the nutrient use efficiency and in turn would reduce the input requirement. However, the present results clearly showed a different trend. Walworth et al. (1986) stated that the realistic strategy would be to maintain nutrient levels at or very close to the optimal levels, although the optimum nutritional ranges may be used as guidelines. Irrespective of land use system, the nutrient concentrations of P, Ca, Mg and micronutrients in arecanut leaves were well above the optimum levels as per the earlier report (CPCRI 2011) and the concentration of N and K was below optimum (Fig. 2). Similar trend was observed in leaf tissue of cocoa also. The optimum level of micronutrients was high for laterite soils in arecanut belt (Ravi et al. 2012). The availability of DTPA extractable Cu, Zn, Fe and Mn (mg kg^{-1}) ranges varied between 1–45, 0–7, 4–67 and 8–119 at 0–60-cm soil depths, respectively, in the present experiment (Personal communication). Soil, being slightly acidic, is the main source of micronutrients like Cu, Fe and Mn. Vermicompost extract, irrigation water and Bordeaux mixture spray to control *Phytophthora* diseases might also have increased the nutrient concentrations of Ca, Mg and micronutrients in arecanut and cocoa (Table 1). Higher fine root production with drip fertigation (Ravi and Sujatha 2008b) might have improved the uptake of water-soluble and readily available nutrients.

In arecanut, the leaf N content reduced from 2.61 to 2.40 % during 2009–2011. Arecanut was not visibly affected, but leaf nutrient data clearly showed insufficient N and K nutrition. Combined application of NPK and VCE did not raise leaf N and K. It should be mentioned that K and Zn are commonly deficient in laterite soil (Badrinath et al. 1998). Leaching of K and higher yield levels might have resulted in higher K removal (Ravi and Sujatha 2012). Lower leaf K of arecanut in arecanut–cocoa system than in sole crop situation might be due to competition. Interspecific root competition is high for resources during the early growth phase (Isaac et al. 2007a, b). However, the concentration of micronutrients in arecanut was higher in arecanut–cocoa system than sole crop. This might be due to cocoa litter fall. Cocoa provides substantial inputs of litter fall to the system (Beer 1988).

For sufficient early growth, nutrition is critical, as deficiencies of N, P, and K may lower biomass allocation to foliar tissue thus reducing active photosynthetic area, particularly for the perennial cocoa crops(Willson 1999; Balingar et al. 2005). This is evident from lower recyclable biomass production of cocoa in VCE applied treatments and reduced yield levels. The leaf nutrient levels in cocoa were compared with critical nutrient limits suggested by Snoeck and Jadin (1992). Like arecanut, the average concentrations of leaf nutrients except N and K were above normal in cocoa. Potassium content (1.52 %) was grossly below the critical level of 2 % in cocoa foliage. During monsoon season of 2011, the symptoms of K deficiency were suddenly visible in cocoa in OMR and 10 % N VCE treatments. The nutrient removal of K from cocoa is very high (Ravi and Sujatha 2011b). This study clearly highlights the heavy feeding nature of cocoa for N and K. Leaf Zn concentration increased substantially during experimental period both in arecanut and cocoa. This aspect needs to be studied in detail to know whether Zn accumulation in leaves might be seasonal or due to continuous application of VCE during post monsoon season. If Zn accumulation is seasonal, then it is likely to be partitioned to reproductive parts as reproductive stage is long and active during June–December in arecanut and cocoa.

In general, the nutrient application is decided on the basis of analysis of soil or plant or both. It was stated that future fertilization requirements can be determined based on leaf nutrient status as it gives an indication of tree nutritional status and current soil fertility (Benton 1985; Walworth and Sumner 1988). Based on yield levels and leaf nutrient status, it can be concluded that the present application rate of NPK and VCE is not sufficient to sustain the yield of both arecanut and cocoa and to meet the nutrient demand in the long run especially K. The present study highlights the need to change the fertilizer program based on yield levels in arecanut and cocoa. Further long-term studies are required to assess nutrient requirements of arecanut and cocoa in mixed cropping situation.

Conclusions

The overall results indicated that arecanut production could be sustained with fertigation of NPK alone or in combination with VCE. However, leaf nutrient status suggests higher nutrient requirement for both arecanut and cocoa to further improve the productivity. The results reveal that recommended dosage needs to be reconsidered and linked with soil and plant analysis. Drip fertigation technology focuses on reducing fertilizer inputs and developing precise plant nutrition technology for arecanut–cocoa system in the tropics. Precision fertilizer application is required based on yield level.

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