

Influence of Biomass Partitioning and Nutrient Uptake on Yield of Arecanut Grown on a Laterite Soil

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The present investigation was conducted on a laterite soil to study biomass partitioning and nutrient-uptake pattern in the aboveground parts of arecanut palm and their relationships to yield. Total biomass production was significantly greater in high-yielding plants (43.6 kg palm⁻¹) than in low-yielding plants (30.8 kg palm⁻¹). Total standing biomass of trunk accounted for 69–74% of the total aboveground biomass in arecanut palm. Dry-matter partitioning to kernel was only 4–10% of the total biomass. The uptake of major nutrients varied significantly between low- and high-yielding plants. Calcium (Ca) uptake was greater by trunk than by other parts, while magnesium (Mg) accumulation was similar in trunk and leaf. The uptake of micronutrients by aboveground parts except leaf was significantly different between low- and high-yielding plants. The present study indicated that combined effect of greater biomass production and nutrient uptake had direct impact on marketable yield of arecanut.

Keywords Arecanut, biomass partitioning, laterite soil, nutrient uptake

Introduction

Arecanut (*Areca catechu* L.), which belongs to family Palmae, is an important commercial plantation crop grown in the humid tropics of India. It is cultivated in an area of 0.397 million ha with a production of 0.559 million tons and productivity of 1200 kg ha⁻¹ (GOI 2008). The economic part of the palm is called a “betel nut” and is mainly used for masticatory purposes in many parts of Asia. It has several alternate uses, and all parts of the palm are useful. It is essentially a crop of small and marginal holders with insufficient income to sustain dependent families. Arecanut has a compact crown and grows to a height of about 10–15 m with an average production of eight to nine leaves per year. The palm attains trunk formation stage by the third year. The longevity of each leaf is 2 years and on an average one leaf falls every 45 days. The average leaf area of the palm is estimated at 25 m², and net photosynthesis ranges between 2.4 and 8.2 μmol carbon dioxide (CO₂) m⁻² s⁻¹ (Reddy et al. 1996; Balasimha 2004). Flowering starts in the fourth year after planting, and maximum inflorescence is produced during December to March (Ananda 2004). Reproductive stage (i.e., from flowering to maturity of kernel) is a long cycle of 9–10 months. The palm has a shallow root system with more than 70% of roots occurring within the top 60 cm of soil and within a radius of 60 cm from the palm (Bhat and Leela

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1969). The root biomass is estimated at 3.94 kg per palm in 8-year-old palm (Bhat and Sujatha 2008).

Arecanut is predominantly cultivated in laterite soils of humid tropics of India. These soils have inherent constraints such as phosphorus (P) fixation and leaching of basic cations as a result of poor nutrient-retention capacity and low cation exchange capacity (CEC; 3–15 $\text{cmol}_c \text{ kg}^{-1}$). Deficiency of nitrogen (N) and potassium (K) was reported in laterite soils (Badrinath, Gajendragad, and Balakrishna Rao 1998). The problems are exacerbated by leaching of K^+ and calcium (Ca^{2+}) as a result of kaolinite clay and heavy rainfall (>3500 mm per annum). This perennial palm requires a large quantity of nutrients to support its growth and yield. The annual nutrient mining by arecanut is 79 kg N, 28 kg P_2O_5 , and 79 kg K_2O per hectare (Rethinam 1990). The nutrient-use efficiency of the crop is reported to be very low (i.e., 10–15% for N, 25–30% for P, and 20–25% for K). Considering the crop and soil constraints, it is essential to know the total nutrient demand of the crop to sustain and improve the yield.

A clear understanding of biomass production, nutrient uptake, translocation, and distribution within a plant are important factors for the development of management strategies to optimize nutrient-use efficiency. Management practices can influence the accumulation and partitioning of dry matter and nutrients. The nutrients drawn from the storage have to be replenished by the annual fertilizer program. Several workers reported that biomass and nutrient partitioning is a tool to provide suitable fertilization program (Alva, Fares, and Dou 2003; Uri et al. 2007; Hanafi et al. 2009). Such knowledge will also provide information on the potential of arecanut plantations with regard to soil fertility status, nutrient cycling, nutrient mining, and carbon sequestration.

Soil properties, crop characteristics, and growing conditions affect the nutrient uptake (Mmolawa and Or 2000). It was reported that nutrients removed in the yield of perennial crops are a fraction of the nutrients immobilized in the above- and belowground biomass (Hartemink 2005). This implies that nutrients immobilized in perennial crops are greater than nutrient removal, and this point needs to be taken into consideration for standardizing fertilizer dose. Tarmizi and Mohd Tayeb (2006) also opined that annual nutrient requirement of oil palm depends on nutrients removed by the crop, nutrients immobilized in trunk/roots, and other potential nutrient losses. Thus, it is essential to know the dry-matter partitioning and nutrient uptake by arecanut to optimize fertilizer use. Very little information is available on biomass partitioning and nutrient uptake in arecanut. It was attempted only in drip-fertigated palms (Bhat, Sujatha, and Balasimha 2007; Bhat and Sujatha 2009). Fertilizer schedule for arecanut was reviewed (Bhat and Sujatha 2004). In recent years, the shift in production practices in the arecanut belt has resulted in yield fluctuations and problems such as crown choking and crown bending. With this background, the present study was contemplated with the main objective to estimate the biomass partitioning and nutrient allocation in the aboveground parts of arecanut palm and its relation to yield.

Materials and Methods

Description 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 masl). The climate of the experimental site is humid tropical with mean annual rainfall of 3670 mm and 120 rainy days. The annual rainfall during 1997–2009 varied from 2869 mm in 2002 to 4325 mm in 1998. Mean temperature ranges from 21 °C (minimum) to 36 °C (maximum).

The average relative humidity varies between 61% to 94%. The soil of the experimental site is sandy clay loam (laterite) consisting of 50% sand, 14% silt, and 36% clay at 0–60 cm deep. The bulk density of soil is 1.61 g cm^{-3} and field capacity 18–22%. The cation exchange capacity (CEC) is $11.4 \text{ cmol}_c \text{ kg}^{-1}$.

The arecanut plantation (variety Sreemangala) was established in September 1997 in 0.456 ha. Arecanut was planted at a spacing of $2.7 \text{ m} \times 2.7 \text{ m}$ in 60-cm^3 pits. For this study, 100 palms were selected randomly from a block of 625 palms covering all rows. Standard recommended cultivation practices were followed for arecanut. Recommended fertilizer dose for arecanut ($100:18:117 \text{ g N/P/K palm}^{-1} \text{ year}^{-1}$) was given in two splits, one third in June with the onset of monsoon and two thirds in October at the cessation of monsoon. The sources of fertilizers used were urea, rock phosphate, and muriate of potash. Farm yard manure (FYM) was applied at 12 kg per palm every year. The nutrient content in FYM was estimated at 0.5% N, 0.12% P, and 0.45% K. The crop was drip irrigated with three emitters of 8 L hr^{-1} discharge at 100% pan evaporation (E_{pan}) during the postmonsoon season. Bordeaux mixture (1%) was sprayed on bunches twice at 45-day interval during the monsoon season (June–September) to prevent fruit rot incidence caused by *Phytophthora palmivora*.

Estimation of Aboveground Biomass

The estimation of aboveground biomass (trunk, leaf, kernel, and husk) was done in 2009. All growth parameters such as trunk height, girth, and number of leaves were recorded in May 2009. The trunk dry matter was estimated using the following regression equation and cross checked with destructive sampling of few palms:

$$Y = 0.01435l + 0.3442g - 1.0017$$

where Y is trunk dry matter, l is length of trunk, and g is girth of the trunk.

Two leaves from 20 palms were collected and oven dried to estimate average leaf biomass. The average leaf biomass was multiplied with number of leaves to arrive at total leaf biomass per palm. The biomass of leaf, dry kernel, and husk was added to trunk biomass to arrive at total biomass. Based on average kernel yield of 5 years (2004 to 2009), the palms were divided into low-yielding plants ($<2.0 \text{ kg dry kernel palm}^{-1} \text{ year}^{-1}$) and high-yielding plants ($>2.0 \text{ kg dry kernel palm}^{-1} \text{ year}^{-1}$) for drawing conclusions in this study. The harvesting of arecanut was spread over a period of 6 months from October to March. Nuts were harvested as and when ripened and dried to 8% moisture. Dried nuts were dehusked, and kernel weight was recorded for computing the yield.

Preparation of Plant and Soil Samples

The samples of different parts of arecanut palm (*viz.*, leaf, kernel, husk, and trunk) were collected in May 2009 and analyzed for nutrients to find out nutrient-uptake pattern. Trunk samples were collected through drilling device at different points and mixed. Leaf samples were collected from the middle portion of the fourth and sixth leaves separately for analysis. Leaf samples were cleaned with tap water followed by distilled water, air dried, packed in brown paper bags, oven dried at $60 \text{ }^\circ\text{C}$ to a constant weight, and ground. The ground samples were kept in labeled paper bags for further analysis. Soil samples were collected at depths of 0–30 and 30–60 cm in the arecanut root zone at 60 cm away from the tree

trunk. 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 and Plant Analysis

Soil samples were analyzed for pH, organic carbon, and available P and K using standard procedures (Jackson 1973). Soil pH was measured in 1:2 soil/water suspensions. Soil organic carbon was measured by the Walkley and Black (1934) method. Available P was estimated by ascorbic acid reductant method (Watanabe and Olsen 1965) for color development after extraction with Bray's reagent. Available K, Ca, and Mg were estimated in an atomic absorption spectrometer (AAS) using ammonium acetate extract. The concentration of micronutrients was estimated in AAS using diethylene triamine pentaacetic acid (DTPA) extract (Lindsay and Novell 1978). Boron (B) in soil was estimated by the hot-water method using azomethine-H in an ultraviolet spectrophotometer (Berger and Truog 1939; Gupta 1979).

The trunk, leaf, kernel, and husk samples were analyzed for total N using the micro-Kjeldahl digestion method (Jackson 1973). The powdered plant samples were digested in a 1:3 perchloric–nitric acid mixture for total P, K, and micronutrient estimation. Total P (vanadomolybdate) was determined following Piper (1966). Estimation of K, Ca, Mg, and micronutrients such as copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) was done in AAS. Boron in plant samples was estimated in the ultraviolet spectrophotometer using azomethine-H (Gupta 1979). Nutrient uptake was calculated by multiplying nutrient content and oven-dry biomass produced.

Statistical Analysis

All data were analyzed using the T-test by MSTATC and Microsoft Excel (Microsoft Corp., Pullman, Wash.). The significant differences between the two means are indicated by least significant differences (LSD) values at the 5% level in the tables. Correlations between yield and other parameters were worked out for better understanding of results.

Results and Discussion

Soil Properties

Soil fertility is one of the most important factors for successful cultivation of arecanut on laterite soils. Recent studies revealed that imbalanced and insufficient nutrition leads to nutritional disorders in arecanut such as crown bending, cross nodes, crown twisting, shortening of leaves, and death of palm (CPCRI 2007, 2008, 2009). Besides, imbalanced nutrition is contributing to pest and disease spread. Soil properties of the study site are presented in Table 1. The soil fertility status was similar between low- and high-yielding plants at both soil depths. This suggests that biomass partitioning and nutrient uptake pattern are more influenced by other factors such as environment, genetic potential, and soil moisture under the same soil fertility conditions. The soil of the study site is slightly acidic with pH values of 6.02–6.10 at a depth of 0–30 cm and 5.73–5.92 at a depth of 30–60 cm. The soil organic carbon content was high (2.45–2.47%), and the availability of Bray's P and K was optimum. The availability of micronutrients such as Cu, Zn, Fe, Mn, and B in the soil was above optimum levels.

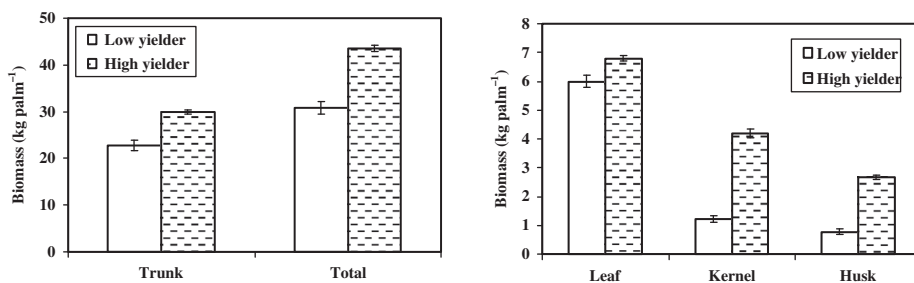
Table 1
Physicochemical properties of soil at study site

Parameters	0–30 cm deep		30–60 cm deep	
	Low yield ^a	High yield	Low yield	High yield
pH	6.10	6.02	5.92	5.73
OC (%)	2.47	2.45	1.66	1.86
Nutrient (mg kg ⁻¹)				
P	12.2	12.6	5.6	5.3
K	263	251	172	186
Ca	899	894	594	676
Mg	168	175	137	156
Cu	25	29	7.5	8.9
Zn	5.9	5.0	1.8	1.7
Fe	30	32	20	20
Mn	71	80	38	44
B	1.9	2.1	2.4	2.6

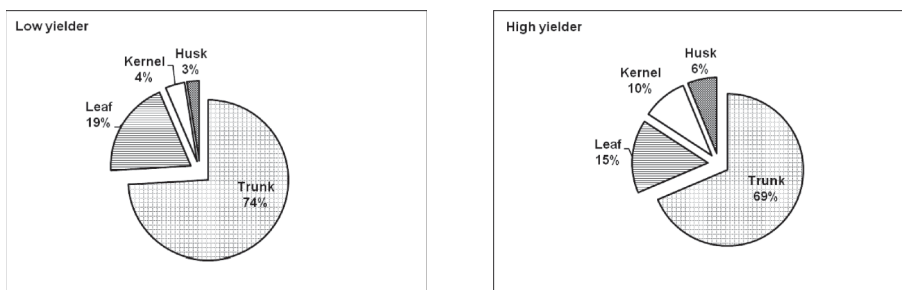
^aLow: <2 kg kernel yield per palm ($n = 20$); high: >2 kg kernel yield per palm ($n = 80$).

Biomass Partitioning in Arecanut Palm

Biomass partitioning is an important component and has a direct impact on kernel yield of arecanut. Reduction in total biomass production and partitioning to kernel due to nutrient stress was reported (Bhat, Sujatha, and Balasimha 2007). Estimation of biomass partitioning to different aboveground parts was attempted in 12-year-old arecanut palms in 2009 (Figure 1). High-yielding plants registered significantly superior growth parameters such as trunk height (969 cm), leaf number (9.1 leaves), and girth (49.4 cm) than low-yielding plants (687 cm, 7.9 leaves, and 40.5 cm, respectively). Total biomass production was significantly greater in high-yielding plants (43.6 kg palm⁻¹) than in low-yielding plants (30.8 kg palm⁻¹). There was a clear and significant difference between low- and high-yielding plants in terms of biomass partitioning to different parts such as trunk, leaves, kernel, and husk. Total standing biomass of trunk varied significantly between low-yielding plants (22.8 kg palm⁻¹) and high-yielding plants (29.9 kg palm⁻¹). A substantial amount of biomass accumulation was noticed in the trunk. Trunk biomass accounted for 69% of the total biomass in high-yielding plants and 74% in low-yielding plants. Leaf biomass of arecanut was significant between low-yielding plants (6.0 kg palm⁻¹) and high-yielding plants (6.8 kg palm⁻¹). A similar trend was noticed with kernel and husk weight. Compared to biomass partition to trunk, a smaller percentage of biomass was partitioned to leaves (15–19%), kernel (4–10%), and husk (3–6%). The increment in trunk biomass per palm per year was estimated at 1.9–2.4 kg per year per palm. The results revealed that greater biomass accumulation in trunk ensures greater partitioning to kernel development. This trend of dry-matter partitioning has obviously resulted in increased yields in high-yielding plants. Besides, substantial biomass production to the tune of 53 t ha⁻¹ in 12-year-old arecanut plantation has a high potential for carbon sequestration because of the large area under arecanut, and this ecosystem can be considered environmentally friendly.



(a) Biomass of trunk, total, leaf, kernel and husk in arecanut palm



(b) Percentage of different components of arecanut palm to total biomass

Figure 1. Difference in biomass partitioning between low- and high-yielding plants in 12-year-old arecanut palm. Low is <math><2\text{ kg}</math> kernel yield per palm ($n = 20$); high is >2 kg kernel yield per palm ($n = 80$). Error bars represent standard errors.

Nutrient Composition in Different Parts

The nutrient concentration varied greatly among different parts of arecanut palm (Table 2). It was observed that the variation in nutrient composition was negligible among low- and high-yielding plants, and thus the average concentration for 100 palms was given. Leaves (2.75%) registered the greatest proportion of N compared to trunk (0.40%), kernel (1.04%), and husk (0.90%). Phosphorus concentrations in trunk, leaf, kernel, and husk were estimated at 0.05%, 0.23%, 0.10%, and 0.09%, respectively. The total K in trunk, leaf, kernel, and husk were estimated at 0.66%, 1.05%, 0.41%, and 1.19%, respectively. The leaf N/P/K ratio (12:1:4.6) and the kernel N/P/K ratio (10.4:1:4.1) were at par. This indicates that major nutrients are limiting factors for growth and yield of arecanut and that better retranslocation of NPK is most important. The Ca allocation was greater in leaves (0.56%), followed by trunk (0.28%), husk (0.22%), and kernel (0.09%). The Mg concentration was greater in leaf (0.19%) compared to trunk (0.05%), kernel (0.04%), and husk (0.08%). The proportion of Fe (167–867 mg kg⁻¹) was more in different parts of arecanut palm than other micronutrients such as Mn (17.1–92.0 mg kg⁻¹), Cu (10.3–63.6 mg kg⁻¹), Zn (4.3–50.8 mg kg⁻¹), and B (11.1–34.1 mg kg⁻¹).

Uptake of Major and Secondary Nutrients by Different Parts in Arecanut

The uptake amounts of major and secondary nutrients (N, P, K, Ca, and Mg) by trunk, leaf, kernel, and husk of arecanut palm are given in Table 3. Significant variation in N and P uptake by all aboveground parts except leaf was noticed between high- and low-yielding plants. Total N uptake (g palm⁻¹) was significantly greater in high-yielding

Table 2
Nutrient concentration in different parts of arecanut palm (\pm standard error)

Nutrient	Trunk	Leaf	Kernel	Husk
Major and secondary (%)				
N	0.40 \pm 0.11	2.75 \pm 0.026	1.04 \pm 0.06	0.90 \pm 0.008
P	0.05 \pm 0.009	0.23 \pm 0.0031	0.10 \pm 0.01	0.09 \pm 0.006
K	0.66 \pm 0.11	1.05 \pm 0.018	0.41 \pm 0.01	1.19 \pm 0.05
Ca	0.28 \pm 0.04	0.56 \pm 0.012	0.09 \pm 0.02	0.22 \pm 0.02
Mg	0.05 \pm 0.01	0.19 \pm 0.004	0.04 \pm 0.003	0.08 \pm 0.005
Micronutrients (mg kg ⁻¹)				
Cu	21.3 \pm 8.2	15.1 \pm 2.6	10.3 \pm 0.27	63.6 \pm 0.88
Zn	4.3 \pm 3.45	50.8 \pm 2.0	ND	9.4 \pm 5.38
Fe	375 \pm 69.7	167 \pm 9.9	406 \pm 9.9	867 \pm 7.07
Mn	29 \pm 12.3	94 \pm 3.09	17.1 \pm 0.65	34.7 \pm 1.83
B	11.1 \pm 3.56	34.1 \pm 2.28	24.4 \pm 3.03	33.9 \pm 0.78

Table 3
Uptake of major and secondary nutrients (g palm⁻¹) by different parts in arecanut (\pm standard error)

Nutrient	Yield level ^a	Nutrient removal					Total
		Trunk	Leaf (L)	Kernel (K)	Husk (H)	(L + K + H)	
N	Low	89 \pm 4.3	172 \pm 7.9	12.8 \pm 1.3	7.2 \pm 0.7	192 \pm 8.4	281 \pm 11.6
	High	117 \pm 1.9	185 \pm 3.0	43.9 \pm 1.5	24.6 \pm 0.9	254 \pm 4.4	370 \pm 5.3
	LSD	8.77	NS	4.00	2.25	19.2	23.8
P	Low	11.4 \pm 0.5	14.7 \pm 0.6	1.2 \pm 0.1	0.9 \pm 0.1	16.8 \pm 0.6	28.2 \pm 1.0
	High	15.0 \pm 0.2	15.7 \pm 0.3	4.2 \pm 0.1	2.9 \pm 0.1	22.8 \pm 0.4	37.7 \pm 0.5
	LSD	1.12	NS	0.38	0.27	1.8	2.4
K	Low	153 \pm 7.3	62.5 \pm 3.3	5.2 \pm 0.5	9.2 \pm 0.9	77 \pm 3.9	230 \pm 9.7
	High	201 \pm 3.3	71.6 \pm 1.6	18.0 \pm 0.6	31.6 \pm 1.1	121 \pm 2.8	322 \pm 5.2
	LSD	15.08	7.06	1.65	2.88	11.5	22.7
Ca	Low	61 \pm 2.9	34.7 \pm 2.1	1.1 \pm 0.1	1.6 \pm 0.2	37 \pm 2.2	98 \pm 4.5
	High	80 \pm 1.3	38.4 \pm 1.1	3.8 \pm 0.1	5.6 \pm 0.2	48 \pm 1.2	128 \pm 2.1
	LSD	6.03	NS	0.34	0.52	5.2	9.39
Mg	Low	11.4 \pm 0.5	11.4 \pm 0.5	0.5 \pm 0.05	0.6 \pm 0.06	12.6 \pm 0.5	24 \pm 1.0
	High	15.0 \pm 0.2	13.2 \pm 0.4	1.7 \pm 0.05	2.1 \pm 0.07	17.0 \pm 0.4	32 \pm 0.5
	LSD	1.12	1.56	0.15	0.19	1.4	2.38

^aLow: <2 kg kernel yield per palm ($n = 20$); high: >2 kg kernel yield per palm ($n = 80$).

Note. LSD indicates significant differences between two means at 5%.

plants (370) than in low-yielding plants (281). The N removal (g palm⁻¹) by leaf, kernel, and husk together was 192 in low-yielding plants and 254 in high-yielding plants. Greater N uptake by leaf (172 and 185 g palm⁻¹ in low- and high-yielding plants) than by other parts could have contributed to greater net photosynthesis and yield. The annual P removal varied significantly between low-yielding plants (17 g palm⁻¹) and high-yielding plants (23 g palm⁻¹).

Potassium uptake by aboveground parts of the palm greatly varied between low- and high-yielding plants. In contrast to N and P, the K uptake was greater by the trunk than by other parts. The total K uptake (g palm^{-1}) varied significantly between 230 in low-yielding plants and 322 in high-yielding plants. This indicates that arecanut is a heavy feeder of K. The trunk K uptake accounted for 66% in low-yielding plants and 62% in high-yielding plants. As a greater quantity of K is immobilized in the trunk, the net retranslocation of this nutrient to economic parts is negligible. This point should be considered while planning for annual nutrient application to the palm. Similarly Ca uptake was greater by trunk (61 and 80 g palm^{-1} in low- and high-yielding plants) than by other parts, whereas Mg accumulation was similar in trunk and leaf. The annual nutrient mining of N, P, and K to produce 1 t of marketable yield (kernel + husk) was 20, 2, and 16 kg, respectively. Arecanut removes substantial quantities of N (236 kg ha^{-1}), P (20 kg ha^{-1}), and K (90 kg ha^{-1}) through leaf, husk, and bunch wastes, which can be recycled through vermicomposting (Bhat and Sujatha 2007) to avoid nutrient loss from the plantation. Total uptake of macronutrients was in the order of $\text{N} > \text{K} > \text{Ca} > \text{P} > \text{Mg}$. The results also suggest that arecanut is a heavy feeder of N and K and not as heavy for P, Ca, and Mg.

The nutrient-uptake pattern indicates that considerable quantities of nutrients are immobilized in trunk. The total uptake of nutrients by leaf, kernel, and husk indicates the nutrients removed every year by the palm from soil. It is clear from the data that the present fertilizer recommendation of 100:18:117 N/P/K seems insufficient though other sources such as irrigation water, atmospheric N, rainfall interception, and native soil fertility can meet N, P, and K requirements to some extent. The irrigation water contained 10–25 mg kg^{-1} $\text{NO}_3\text{-N}$, 0.2 mg kg^{-1} P, 3–9 mg kg^{-1} K, 30–40 mg kg^{-1} Ca, 4.0–7.5 mg kg^{-1} Mg, 1.7 mg kg^{-1} of Zn, and 0.16 mg kg^{-1} of Fe with a pH of 6.9. Rainfall interception by arecanut contributed considerable quantities of N and K (Bhat and Sujatha 2008). Annual nutrient removal by 11-year-old fertigated arecanut palms cv. Mohitnagar was estimated as 198 g N, 25 g P, and 62 g K per palm per year (Bhat and Sujatha 2009). The nutrient uptake by cv. Mohitnagar of arecanut was slightly less (Bhat and Sujatha 2009) than by cv. Sreemangala as indicated in this study. This suggests that nutrient demand varies with cultivar. The relations between yield and trunk (0.63), yield and leaf (0.52), and yield and total biomass (0.83) were positive and significant. The correlations between yield and uptake of N, P, K, Ca, and Mg by leaf were significant (0.26–0.42). Comparatively greater positive relation between yield and leaf nutrient uptake of major nutrients indicate that yield is closely related to nutrient uptake. Nitrogen and K are quantitatively important nutrients in arecanut ecosystems on laterite soils.

The present results clearly indicated the greater K requirement of arecanut grown on laterite soils. In recent years, arecanut production practices have changed considerably with more focus on organic cultivation. The application of only organics continuously might lead to depletion of K and accumulation of micronutrients in soils. Depletion of soil available K was noticed in arecanut basins applied with vermicompost recycled from arecanut wastes in a long-term study (CPCRI 2009). Thus, good knowledge of nutrient requirement of aboveground parts is needed for the nutrient-management plan and greater fertilizer-use efficiency.

Uptake of Micronutrients by Different Parts in Arecanut

The uptake of micronutrients by different aboveground parts except leaf significantly varied among low- and high-yielding plants (Table 4). The uptake of Fe by arecanut was greater than all other micronutrients. The uptake of Cu, Fe, Mn, and B was greater by

Table 4
Uptake of micronutrients (mg palm⁻¹) by different parts in arecanut (\pm standard error)

Nutrient	Yield level ^a	Trunk	Leaf (L)	Kernel (K)	Husk (H)	Nutrient removal	
						(L + K + H)	Total
Cu	Low	486 \pm 23.3	163 \pm 40.7	12.5 \pm 1.3	50 \pm 5.0	225 \pm 41.2	710 \pm 36.9
	High	637 \pm 10.7	75 \pm 16.1	43.0 \pm 1.5	170 \pm 6.0	288 \pm 16.3	926 \pm 19.3
	LSD	47.9	75.0	3.93	15.5	NS	84.4
Zn	Low	99 \pm 4.7	332 \pm 25.1	ND	64 \pm 6.4	396 \pm 26.1	494 \pm 26.9
	High	129 \pm 2.2	336 \pm 15.8	ND	218 \pm 7.6	554 \pm 17.5	683 \pm 18.1
	LSD	9.7	NS	19.9	73.6	76.1	76.1
Fe	Low	8457 \pm 406.1	953 \pm 89.6	496 \pm 50.1	677 \pm 68.4	2127 \pm 176.9	10584 \pm 434.5
	High	11101 \pm 186	1143 \pm 80.4	1701 \pm 59.7	2324 \pm 81.6	5169 \pm 155.2	16270 \pm 291.4
	LSD	834.8	NS	155.3	212.2	472.4	1224.6
Mn	Low	659 \pm 31.6	620 \pm 45.4	21 \pm 2.1	27 \pm 2.7	668 \pm 47.1	1327 \pm 57.1
	High	865 \pm 14.5	622 \pm 23.2	72 \pm 2.5	93 \pm 3.2	786 \pm 23.8	1651 \pm 28.4
	LSD	65.0	NS	6.5	8.4	104.7	125.4
B	Low	255 \pm 12.3	260 \pm 38.6	26.6 \pm 2.7	26.4 \pm 2.7	313 \pm 38.9	568 \pm 38.7
	High	335 \pm 5.6	213 \pm 13.6	91.1 \pm 3.2	90.7 \pm 3.2	394 \pm 15.7	730 \pm 17.4
	LSD	25.2	NS	8.3	8.3	72.7	78.5

^aLow: <2 kg kernel yield per palm ($n = 20$); high: >2 kg kernel yield per palm ($n = 80$).

Note. LSD indicates significant differences between two means at 5%.

trunk than by leaf, kernel, and husk. The Cu removal (leaf + kernel + husk) was 225 and 288 mg palm⁻¹ in low- and high-yielding plants whereas the total uptake was 710 and 926 mg palm⁻¹, respectively. Leaves of arecanut registered greater Zn uptake (332 and 336 mg palm⁻¹ in low- and high-yielding plants) than trunk (99 and 129 mg palm⁻¹ in low- and high-yielding plants) and husk (63 and 218 mg palm⁻¹ in low- and high-yielding plants). The uptake of Fe (mg palm⁻¹) by trunk, leaf kernel, and husk was 8457, 953, 496, and 677 in low-yielding plants and 11101, 1143, 1701, and 2324 in high-yielding plants, respectively. Accumulation of Mn in trunk was 659 and 865 mg palm⁻¹ in low- and high-yielding plants, whereas removal of Mn was 668 and 786 mg palm⁻¹. Boron accumulation (mg palm⁻¹) was greater in the trunk of arecanut (255 and 335 in low- and high-yielding plants) than in leaves (213 and 260 in low- and high-yielding plants), kernel (27 and 91 in low- and high-yielding plants), and husk (26 and 91 in low- and high-yielding plants). Among micronutrients, the Cu uptake by leaf showed significant negative correlation with yield (-0.28). Negative correlation between kernel yield and micronutrient content in leaf except Fe (-0.21 to -0.33) was also noticed. The order of total uptake of micronutrients was Fe > Mn > Cu > B > Zn. The nutrient-uptake pattern indicates the need to revise the nutrient-management strategy in arecanut.

Conclusions

Results of the present study indicated that combined effect of greater biomass production and nutrient uptake had direct impact on marketable yield of arecanut. The high biomass production leads to greater nutrient partitioning to kernel and high productivity in high-yielding arecanut palms. As arecanut is a perennial palm, the amount of nutrients immobilized in trunk and roots along with the nutrients removed by leaf, kernel, and husk should be considered while formulating the fertilizer schedule. The nutrient-uptake pattern of arecanut highlights the importance of continuous application of nutrients to sustain greater growth and yield.

References

- Alva, A. K., A. Fares, and H. Dou. 2003. Managing citrus trees to optimize dry mass and nutrient partitioning. *Journal of Plant Nutrition* 26 (8): 1541–1559.
- Ananda, K. S. 2004. Botany. In *Arecanut*, ed. D. Balasimha, and V. Rajagopal, 7–50. Kasaragod, India: CPCRI.
- Badrinath, M., R. Gajendragad, and K. Balakrishna Rao. 1998. Distribution of micronutrients in laterite soils of Puttur in relation to some soil properties. In *Red and Lateritic soils*, vol. 1, ed. J. Sehgal, W. E. Blum, and K. S. Gajbhiye, 271–274. New Delhi, India: Ibh Publishing.
- Balasimha, D. 2004. Cropping systems. In *Arecanut*, ed. D. Balasimha, and V. Rajagopal, 103–130. Kasaragod, India: CPCRI.
- Berger, K. C., and E. Truog. 1939. Boron determination in soils and plants. *Industrial Engineering Chemistry Analytical Edition* 11:540–545.
- Bhat, R., and S. Sujatha. 2004. Crop management. In *Arecanut*, ed. D. Balasimha, and V. Rajagopal, 76–102. Kasaragod, India: CPCRI.
- Bhat, R., and S. Sujatha. 2007. Soil fertility status as influenced by arecanut-based cropping system and nutrient management. *Journal of Plantation Crops* 35 (3): 158–165.
- Bhat, R., and S. Sujatha. 2008. Root distribution of arecanut (*Areca catechu* L.) as influenced by drip fertigation in a laterite soil. *Indian Journal of Agricultural Sciences* 78 (9): 804–807.
- Bhat, R., and S. Sujatha. 2009. Soil fertility and nutrient uptake by arecanut (*Areca catechu* L.) as affected by level and frequency of fertigation in a laterite soil. *Agricultural Water Management* 96 (3): 445–456.

- Bhat, R., S. Sujatha, and D. Balasimha. 2007. Impact of drip fertigation on productivity of arecanut (*Areca catechu* L.). *Agricultural Water Management* 90 (1–2): 101–111.
- Bhat, K. S., and M. Leela. 1969. The effect of density of planting on the distribution of arecanut roots. *Tropical Agriculture* 46:55–61.
- CPCRI. 2007. *Annual report for 2006–2007*. Kasaragod, India: Central Plantation Crops Research Institute.
- CPCRI. 2008. *Annual report for 2007–2008*. Kasaragod, India: Central Plantation Crops Research Institute.
- CPCRI. 2009. *Annual report for 2008–2009*. Kasaragod, India: Central Plantation Crops Research Institute.
- GOI. 2008. *Area and production statistics of arecanut and spices*. Calicut, India: Directorate of Arecanut and Spices Development, Ministry of Agriculture, Government of India.
- Gupta, U. C. 1979. Some factors affecting the determination of hot-water-soluble boron from podzol soils using azomethine-H. *Canadian Journal of Soil Science* 59:241–247.
- Hanafi, M. M., M. M. Selamat, M. H. A. Husni, and M. A. Adzemi. 2009. Dry matter and nutrient portioning of selected pineapple cultivars grown on mineral and tropical peat soils. *Communications in Soil Science and Plant Analysis* 40:3263–3280.
- Hartemink, A. E. 2005. Nutrient stocks, nutrient cycling, and soil changes in cocoa ecosystems: A review. *Advances in Agronomy* 86:227–253.
- Jackson, M. L. 1973. *Soil chemical analysis*. New Delhi, India: Prentice Hall of India.
- Lindsay, W. L., and W. A. Norvell. 1978. Development of DTPA test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* 42:421–428.
- Mmolawa, K., and D. Or. 2000. Water and solute dynamics under a drip-irrigated crop: Experiments and analytical model. *Transactions of American Society of Agricultural Engineers* 43 (6): 1597–1608.
- Piper, C. S. 1966. *Soil and plant analysis*. Bombay: Hans Publishers.
- Reddy, V. M., R. Bhat, D. Balasimha, and K. B. A. Khader. 1996. Photosynthetic and growth characteristics of high-yielding varieties of arecanut (*Areca catechu* L.). *Journal of Plantation Crops* 24:628–632.
- Rethinam, P. 1990. Potassium in plantation crops. In *Potassium for plantation crops*, ed. M. Singh and M. K. Mishra, 7–15. Bangalore, India: Potash Research Institute of India.
- Tarmizi, A. M., and D. M. Tayeb. 2006. Nutrient demands of *Tenera* oil palm planted on inland soils of Malaysia. *Journal of Oil Palm Research* 18:204–209.
- Uri, V., L. Krista, I. Ostonen, H. Tullus, R. Lastik, and M. Vildo. 2007. Biomass production, foliar and root characteristics, and nutrient accumulation in young silver birch (*Betula pendula* Roth.) stand growing on abandoned agricultural land. *European Journal of Forest Research* 126:495–506.
- Walkley, A., and I. A. Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37:29–37.
- Watanabe, F. S., and S. R. Olsen. 1965. Test of ascorbic acid method for determining phosphorus in water and sodium bicarbonate extracts of soil. *Soil Science Society of America Proceedings* 29:677–678.