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# Soil fertility and nutrient uptake by arecanut (*Areca catechu* L.) as affected by level and frequency of fertigation in a laterite soil

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## ABSTRACT

Changes in soil fertility status were evaluated for 10 years, from 1996 to 2006 to examine the impact of drip fertigation in a laterite soil and to determine the nutrient uptake pattern of arecanut (*Areca catechu* L.). Four fertigation levels (25%, 50%, 75% and 100% of recommended fertilizer dose, 100:18:117 g N:P:K palm<sup>-1</sup> year<sup>-1</sup>), three frequencies of fertigation (10, 20 and 30 days) and two controls (control 1: drip irrigation without fertilizer application and control 2: drip irrigation with 100% NPK soil application) were studied. The soil pH increased to 6.0 at the end of experiment in 2006 compared to the pre-experimental soil pH of 5.6 in 1996. In 0–25-cm depth interval, the soil organic carbon (SOC) increased significantly from 1.06% in 1999 to 1.84% in 2006, and in 25–50-cm depth interval, it increased from 0.68% to 1.13%. Temporal variation in available P and K content in arecanut root zone was significant due to drip fertigation. Pooled analysis of data, from 2000 to 2005, revealed significant impact of level and frequency of fertigation and their interaction on available P and K content. At 0–25-cm depth interval, increase in fertigation dose from 50% to 100% NPK did not result in significant increase of Bray's P content, which remained at par ranging from 5.24 to 5.32 mg kg<sup>-1</sup>. Fertigation every 30 days resulted in significantly higher available P (5.32 mg kg<sup>-1</sup>) than fertigation every 10 days (4.49 mg kg<sup>-1</sup>), while it was at par with fertigation every 20 days (5.09 mg kg<sup>-1</sup>). The K availability at 0–25-cm depth interval was significantly lower at 25% NPK level (114 mg kg<sup>-1</sup>) than at 75% (139 mg kg<sup>-1</sup>) and 100% (137 mg kg<sup>-1</sup>). With respect to fertigation frequency, the 30-day interval resulted in higher available K of 139 mg kg<sup>-1</sup> than 20-day (128 mg kg<sup>-1</sup>) and 10-day intervals (120 mg kg<sup>-1</sup>). Availability of P and K at 25–50-cm depth interval followed similar trend as that of 0–25-cm depth interval. The total N uptake (g palm<sup>-1</sup> year<sup>-1</sup>) by leaves, nuts and husk varied between 143 in 0% NPK to 198 in 75% NPK fertigation level. Similarly, the total P uptake (g palm<sup>-1</sup> year<sup>-1</sup>) ranged between 15 for the 0% NPK and 25 for the 75% NPK treatment. The total K uptake (g palm<sup>-1</sup> year<sup>-1</sup>) was 62 for the 75% NPK treatment followed by 56 for the 25%, 56 for the 50%, 54 for the 100% and 46 for the 0% NPK treatments. The nutrient uptake pattern and marginal availability of soil P and K highlight the importance of drip fertigation during post-monsoon season to improve and sustain the yield of arecanut in a laterite soil.

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## 1. Introduction

Arecanut (*Areca catechu* L.), which belongs to family Palmae, is one of the most important plantation crops in humid tropics of India. It is cultivated in an area of 0.381 million hectares with an annual production of 0.483 million tonnes as per 2005–2006 statistics (GOI, 2008). The palm grows to a height of about 10–15 m with an average production of 8–9 leaves per year. The average leaf area of the palm is estimated as 25 m<sup>2</sup> and net photosynthesis ranges between 2.4 and 8.2  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  (Reddy et al., 1996; Balasimha, 2004). The maximum numbers of inflorescences are produced during December–March (Ananda, 2004). Hence, the post-monsoon period from December to May is highly critical for nutrient and water supply. The palm has a shallow root system with more than 70% roots occurring in the upper 60 cm of the soil and within a radius of 60 cm from the palm (Bhat and Leela, 1969).

Arecanut is predominantly cultivated in laterite soils, which have inherent constraints like P fixation, rapid hydraulic conductivity, faster infiltration rate, leaching of basic cations and low CEC (3–15 cmol kg<sup>-1</sup>). Deficiency of N and K was reported in laterite soils of Karnataka (Badrinath et al., 1998). Further, the authors noticed that leaching of K<sup>+</sup> and Ca<sup>2+</sup> due to heavy rainfall is a major production constraint in arecanut tract. The annual nutrient mining by arecanut is estimated as 79 kg N, 28 kg P<sub>2</sub>O<sub>5</sub> and 79 kg K<sub>2</sub>O per hectare (Rethinam, 1990). The nutrient use efficiency of the crop is reported as very low: 10–15% for nitrogen, 25–30% for phosphorus and 20–25% for potassium. Thus, this perennial palm requires large quantity of nutrients to support its growth and yield. Considering the soil and crop constraints, fertilizers should be applied in synchrony with crop demand in smaller quantities during post-monsoon season.

In the present-day context, agriculture is challenged to manage water and nutrients such that production benefits are maximized, while adverse environmental effects are minimized. The right combination of water and nutrients is a prerequisite for higher yields and good quality produce. The method of fertilizer application is also important in improving the use efficiency of nutrients. Fertigation enables adequate supplies of water and nutrients with precise timing and uniform distribution to meet the crop nutrient demand (Bar-Yosef and Sagiv, 1982; Haynes, 1985; Bar-Yosef et al., 1989; Mohammad, 2004b). Further, fertigation ensures substantial saving in fertilizer usage and reduces leaching losses (Mmolawa and Or, 2000). Earlier studies in arecanut demonstrated a yield increase of 45% with drip irrigation over basin method (Bhat and Sujatha, 2004) and improved nutrient movement of soil P and K in root zone with drip fertigation (Bhat et al., 2007b).

Drip fertigation schedule for arecanut was optimised based on yields and cost benefit analysis with a fertilizer saving of 25% over conventional fertilization (Bhat et al., 2007a; Bhat and Sujatha, 2006). However, proper fertigation management also requires the knowledge of soil fertility status and nutrient uptake by the crop. Monitoring soil and plant nutrient status is an essential safeguard to ensure maximum crop productivity. Soil properties, crop characteristics and growing conditions affect the nutrient uptake (Mmolawa and Or, 2000). Few studies reported the effect of drip fertigation on soil fertility

status (Hebbar et al., 2005; Treder, 2005) and nutrient uptake (Bacon and Davey, 1989; Shock et al., 1995). Treder et al. (1997) noticed an increase in soil pH with drip fertigation in plum, while some authors reported acidification due to fertigation (Belton and Goh, 1992; Alva and Obreza, 1993; Kamosa et al., 1999). Hartemink (2005) stated that nutrients in the harvested yield of perennial crops are a fraction of the nutrients in the above and below ground biomass. This implies that nutrients immobilized in perennial crops are higher than nutrient removal and this point needs to be taken in to consideration for standardizing fertilizer dose. Hence, it is pertinent to elucidate the impact of drip fertigation on soil fertility status and nutrient uptake by arecanut to optimise fertilizer use. With this background, the present study was contemplated to examine the changes in soil fertility status attained due to adoption of drip fertigation for 10 years (1996–2006) and to determine the nutrient uptake pattern of arecanut palm in a laterite soil.

## 2. Materials and methods

### 2.1. Details about experimental site

The field experiment was conducted at Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India (12°15'N latitude and 75°25'E longitude, 91 m above MSL) during December 1996 to May 2006. The average annual rainfall during the past 30 years is 3670 mm, which occurs primarily during 120-day long monsoon season during June–October (Fig. 1). Mean temperature ranges from 21 °C (minimum) to 36 °C (maximum). The average relative humidity varies between 61% and 94%.

The soil at the experimental site is sandy clay loam (laterite) with a pH of 5.6, 1.5% organic carbon, 10.1 mg kg<sup>-1</sup> P and 53 mg kg<sup>-1</sup> K within 30-cm soil depth. The soil is well-drained lateritic (Bhat and Mohapatra, 1971) comprising 54.6% sand, 14.4% silt and 36% clay within 60-cm soil depth. The bulk density of soil is 1.61 g cm<sup>-3</sup> and the field capacity varies between 18% and 22% at different soil depths.

### 2.2. Experimental details

The experimental site selected for the study was the arecanut plantation of 1-year-old seedlings (cv. Mohitnagar) established in December 1995 at a spacing of 2.7 m × 2.7 m. The gross plot area of the plantation was 2930 m<sup>2</sup>. Each treatment consisted of six palms as net plot and total net plot area was 1873 m<sup>2</sup>. The experiment was laid out in December 1996 using a Randomised Block Design incorporating factorial component with 14 treatments and three replications. The treatments included four fertigation levels viz., 25%, 50%, 75% and 100% of recommended fertilizer dose (100:18:117 g N:P:K palm<sup>-1</sup> year<sup>-1</sup>), and three frequencies of fertigation viz., 10, 20 and 30 days. Two controls viz., control 1 (drip irrigation without fertilizer application) and control 2 (drip irrigation with 100% NPK soil application) were included for better appraisal of the results. About 1/3rd of recommended fertilizer dose (33:6:39 g N:P:K palm<sup>-1</sup> year<sup>-1</sup>) was applied to arecanut seedlings in the first year of planting and 2/3rd (67:12:78 g N:P:K palm<sup>-1</sup> year<sup>-1</sup>) in the second year.

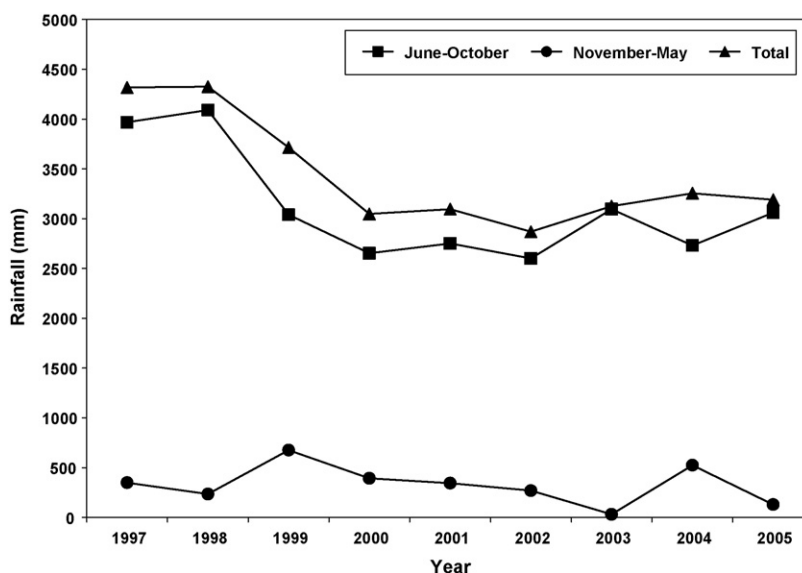


Fig. 1 – Rainfall during monsoon (June–October) and post-monsoon (November–May) seasons from 1997 to 2005.

The drip fertigation system consisted of one 5000 L tank, sand filter, screen filter, venture injector and two pressure gauges. One lateral line was provided for each treatment with a valve to control treatment application. The crop was drip irrigated at 100%  $E_{pan}$  and the fertilizers were applied from December to May. Three emitters of  $8 \text{ L h}^{-1}$  discharge rate were placed 60 cm away from the base of the palm on three sides. The sources of fertilizers used were urea (46% N), diammonium phosphate (DAP, 18% N and 21% P) and muriate of potash (MOP, 50% K). The DAP was soaked in water and after softening mixed with urea and MOP just before application. A venture injector was used to inject the fertilizer solution into the main line of drip system after allowing the solution to pass through the screen filter. Every year the total quantity of fertilizer was applied in 21 splits for the fertigation frequency of 10 days, 9 splits for the fertigation frequency of 20 days and 6 splits for the fertigation frequency of 30 days during December–May. In case of 100% NPK soil application, fertilizers were applied in two splits i.e., 1/3rd in May–June with the onset of monsoon and 2/3rd in September–October at the cessation of monsoon.

Reference crop evapotranspiration ( $ET_0$ ) was calculated on daily basis using modified Penman method (Doorenbos and Pruitt, 1977). The actual evapotranspiration was estimated by multiplying reference evapotranspiration with crop coefficient values for different years. The evaporation data was collected from USWB Class A open pan evaporimeter at a 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–May (Mahesha et al., 1990).

### 2.3. Soil fertility parameters and nutrient uptake

The available P and K in May 1999 remained in low to medium range even after imposition of treatments from December to

May during 1996–1999 (Bhat et al., 2007b). Thus to assess the impact of heavy monsoon rains, the soil samples were collected before imposition of treatments in October every year. In 2006, the soil samples were collected in May to evaluate the changes in pH and soil organic carbon (SOC) at the end of experimentation. In case of control 2, fertilizers were applied to soil in September–October every year and soil samples were collected one month after fertilizer application in this treatment. Soil samples were collected at 0–25 and 25–50-cm depth intervals in arecanut root zone at 60 cm distance from the tree trunk. Samples were air dried, ground and sieved through a 2 mm screen. Soil samples were analysed for pH, organic carbon, available P and K using standard procedures (Jackson, 1973). Soil pH was measured in 1:2 soil–water suspension. Soil organic carbon was measured by Walkley and Black (1934) method. Available P was estimated by ascorbic acid reductant method for colour development after extraction with Bray's reagent. Available K, Ca and Mg were estimated using ammonium acetate extraction method. Irrigation water was analysed for pH,  $\text{NO}_3\text{-N}$ , P, K, Ca and Mg using standard procedures at regular intervals. The irrigation water contained  $10\text{--}25 \text{ mg kg}^{-1}$   $\text{NO}_3\text{-N}$ ,  $0.2 \text{ mg kg}^{-1}$  P,  $9\text{--}11 \text{ mg kg}^{-1}$  K,  $6.5\text{--}20 \text{ mg kg}^{-1}$  Ca and  $1.5\text{--}4.0 \text{ mg kg}^{-1}$  Mg with a pH of 6.9.

The samples of root, leaf, nut, husk and trunk tissues were collected in October 2005 and analysed for major nutrients for determination of nutrient uptake. The samples were oven dried at  $70^\circ\text{C}$ , ground and stored for tissue analysis. The samples were then analysed for total N using micro-Kjeldahl digestion method (Jackson, 1973). The powdered leaf samples were digested in a 1:3 perchloric–nitric acid mixture for total P and K estimation. Phosphorus (vanadomolybdate) and potassium (flame photometry) were determined following Piper (1966). Nutrient uptake was calculated by multiplying nutrient content and oven-dry biomass produced. The dry matter partitioning to different parts of palm from the same trial was attempted earlier (Bhat et al., 2007a).

Statistical analysis was done using standard analysis of variance (ANOVA) technique. Correlation and regression analysis was done for important parameters.

### 3. Results and discussion

#### 3.1. Soil pH

Drip fertigation significantly influenced the soil pH during experimental period of 10 years (Fig. 2). In 0-25-cm depth interval, the soil pH before initiation of the trial in 1996 was 5.6 and it remained same in 1999. Some authors have reported that acidification may occur after fertigation (Belton and Goh, 1992; Alva and Obreza, 1993; Kamosa et al., 1999). However, in this study the soil pH increased to 6.0 at the end of experiment in 2006 despite continuous application of inorganic fertilizers. The soil pH did not vary significantly due to level and frequency of fertigation both in 1999 and 2006, while their interaction was significant in 1999 at 0-25-cm depth interval. Factorial set of treatments and control 1 registered same soil pH (6.0) in 2006. Therefore, it can be inferred that the variation in soil pH in arecanut root zone was not due to addition of

nutrients, but irrigation water could be a major source for change in soil pH.

The use of non-acid forming fertilizers and the quality of irrigation water might have contributed to the increase in soil pH irrespective of treatments. The irrigation water used had a pH of 6.9-7.0 and naturally occurring calcium and magnesium ions, resulting in accumulation of these nutrients in arecanut root zone. Presence of Ca and Mg in arecanut root zone at optimum range (Table 2) substantiates the above results. Since the laterite soils have low CEC and buffering capacity, the pH may fluctuate with application of irrigation water containing high Ca and Mg content. The increase in soil pH within the wetted soil zone in drip-irrigated plum was attributed to irrigation water containing a high amount of calcium and magnesium (Treder et al., 1997).

#### 3.2. Soil organic carbon

Drip fertigation significantly improved the soil organic carbon status in arecanut root zone between 1999 and 2006 (Fig. 3). At 0-25-cm depth interval, SOC increased from 1.06% in 1999 to 1.84% in 2006. Similar increase in SOC, from 0.68% to 1.13%, was recorded during the same period at 25-50-cm depth

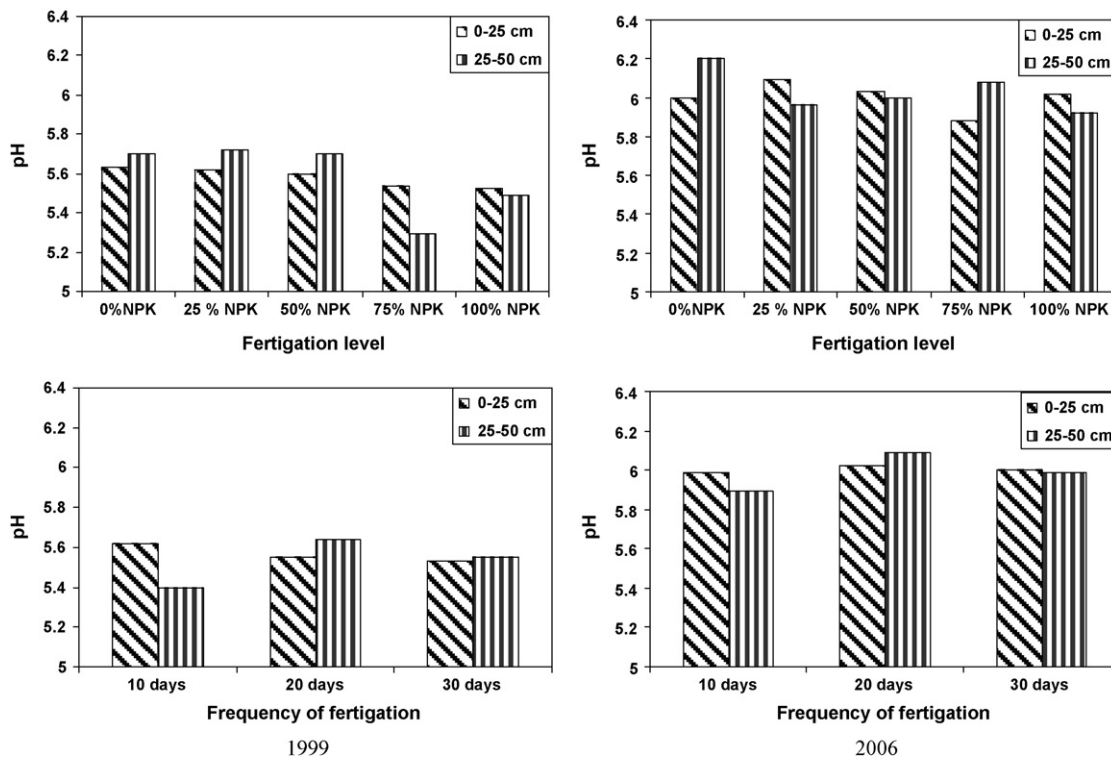


Fig. 2 – Variation in soil pH in arecanut root zone as influenced by levels and frequencies of fertigation at two soil depth intervals. (LSD (0.05) for years = 0.076 for 0-25 cm; 0.081 for 25-50 cm).

Soil depth (cm)	Soil pH				LSD (0.05)					
	Year mean for factorial set		Control 2		Fertigation level (F)		Fertigation frequency (f)		F × f	
	1999	2006	1999	2006	1999	2006	1999	2006	1999	2006
0-25	5.6	6.0	5.5	6.0	NS	NS	NS	NS	0.25	NS
25-50	5.5	6.0	5.3	5.6	0.19	NS	NS	0.12	NS	NS

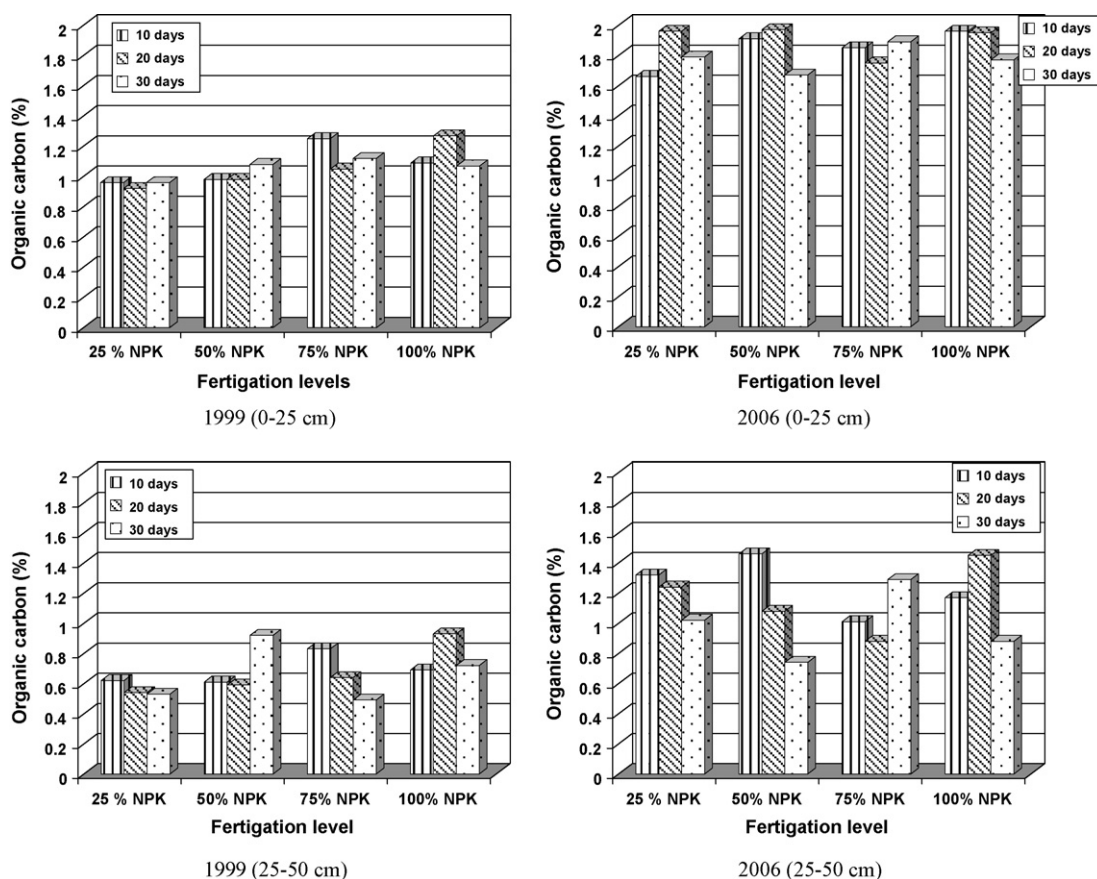


Fig. 3 – Variation in soil organic carbon content (%) in arecanut root zone as influenced by levels and frequencies of fertigation at two soil depth intervals (LSD (0.05) for years = 0.052 (0–25 cm); 0.09 (25–50 cm)).

Soil depth (cm)	Organic carbon content (%)						LSD (0.05)					
	Year mean for factorial set		Control 1		Control 2		Fertigation level (F)		Fertigation frequency (f)		F × f	
	1999	2006	1999	2006	1999	2006	1999	2006	1999	2006	1999	2006
0–25	1.06	1.84	0.96	1.43	1.01	1.72	0.07	NS	NS	0.12	0.12	NS
25–50	0.68	1.13	0.66	0.93	0.74	1.04	0.13	NS	NS	0.19	0.23	0.37

interval. Interaction effect showed higher SOC content in 100% NPK fertigated at 20-day interval (1.27%), which was closely followed by 75% NPK fertigated at 10-day interval (1.25%). The improvement of SOC was significantly greater in 75% and 100% NPK fertigation than in 25% and 50% NPK treatments. At 0–25-cm depth interval, SOC content in control 1 (1.43%) was significantly lower than in factorial set of treatments (1.84%), but it was not significant in 25–50-cm depth interval (0.93–1.13%).

The polynomial quadratic regression also showed significant positive relation between fertigation levels and SOC content both at 0–25-cm ( $y = -0.0464x^2 + 0.3696x + 1.154, R^2 = 0.83$ ) and at 25–50-cm depth intervals ( $y = -0.0164x^2 + 0.1336x + 0.868, R^2 = 0.373$ ) in 2006. This can be attributed to higher root dry matter production and *in situ* root decay in arecanut root zone due to drip fertigation. An earlier report from the same experiment has shown that fine root biomass accounted for 34–40% of total root biomass (3.94–8.23 kg palm<sup>-1</sup>) with different fertigation levels (Bhat et al., 2007a). Several workers reported

that root systems are major pathway for the input of carbon to soil (Vogt, 1991; Ruess et al., 1996). Young (1997) also noticed soil organic matter enrichment due to recurrent shedding of fine roots.

### 3.3. Available soil P

Pooled analysis of 4-year data, from 2000 to 2005, revealed significant variability in Bray’s P content among different years, levels and frequencies of fertigation at 0–25-cm depth interval (Table 1 and Fig. 4). Their interaction also had significant impact on P availability. From Fig. 4 it is clear that the mean Bray’s P content was significantly higher in 2005 (5.90 mg kg<sup>-1</sup>) than in other years (3.70–5.25 mg kg<sup>-1</sup>). Increase in fertigation dose from 50% to 100% NPK did not result in significant increase of Bray’s P content, which remained at par ranging from 5.24 to 5.32 mg kg<sup>-1</sup> (Table 1). Among fertigation frequencies, 30-day interval significantly increased the available P content (5.32 mg kg<sup>-1</sup>) in arecanut root zone than 10-day

**Table 1 – Interaction effect between levels and frequency of fertigation on Bray's P (pooled for 4 years) and available K (Pooled for 5 years) content in soil**

Treatments	Frequency of fertigation (days)																
	Bray's P ( $\text{mg kg}^{-1}$ ) at different depth intervals								Available K ( $\text{mg kg}^{-1}$ ) at different depth intervals								
	0–25 cm				25–50 cm				0–25 cm				25–50 cm				
	10	20	30	Mean	10	20	30	Mean	10	20	30	Mean	10	20	30	Mean	
Fertigation level (% of recommended NPK)																	
25	3.89	3.85	4.27	4.00	3.52	3.07	3.26	3.28	99	126	117	114	83	76	76	78	
50	4.45	6.73	4.70	5.29	2.89	3.91	2.85	3.22	121	135	123	126	82	82	71	78	
75	5.06	5.48	5.41	5.32	2.48	4.52	4.39	3.80	122	127	167	139	66	61	103	77	
100	4.54	4.29	6.89	5.24	3.45	3.21	5.17	3.94	139	122	150	137	77	71	85	78	
Mean	4.48	5.09	5.32	4.96	3.08	3.68	3.92	3.56	120	128	139	129	77	73	84	78	
Control 1 (no fertilizers + drip irrigation)		2.62				2.73				95					62		
Control 2 (100% NPK soil application + drip irrigation)		5.55				4.47				158					95		
LSD (0.05)																	
Fertigation level (F)		0.79				NS				13.7					NS		
Frequency of fertigation (f)		0.68				0.68				11.9					6.2		
Interaction between F × f		1.37				1.36				23.7					12.5		
Control 1 vs factorial set		0.92				NS				19.9					9.6		
Control 2 vs factorial set		NS				NS				19.7					11.9		

interval ( $4.49 \text{ mg kg}^{-1}$ ), while it was at par with 20-day interval ( $5.09 \text{ mg kg}^{-1}$ ). Interaction between level and frequency of fertigation indicated significantly higher available P at 100% NPK fertigated at 30-day interval ( $6.89 \text{ mg kg}^{-1}$ ). This suggests that the P was not utilized efficiently by the palm and could be one of the factors for lesser uptake (Fig. 6) and yield in this treatment.

At 25–50-cm depth interval, available P content showed similar trend as that of the 0–25-cm depth interval. It is clear from Fig. 4 that the available P content remained same in all the years ( $4.13\text{--}4.34 \text{ mg kg}^{-1}$ ) except in 2004 ( $1.62 \text{ mg kg}^{-1}$ ). At both soil depth intervals, the available P was significantly lower in 2004 than in other years. It is likely that this reduction in available P in 2004 was due to higher crop yields obtained in successive years from 2002 onwards (Bhat et al., 2007a).

The results of the present study also showed that the available P content was  $4.96 \text{ mg kg}^{-1}$  at 0–25-cm depth interval and  $3.56 \text{ mg kg}^{-1}$  at 25–50-cm depth interval (Table 1). Greater mobility of P beyond 25 cm depth is an added advantage noticed with drip fertigation. A previous report from the same experiment (Bhat et al., 2007b) revealed that drip fertigation places nutrients in active root zone besides maintaining favorable soil water content resulting in much greater movement of phosphorus and potassium in arecanut root zone. The present results confirm the findings of several workers attributing greater mobility and availability of P to high frequency drip fertigation (Bacon and Davey, 1982; Mikkelsen, 1989; Kargbo et al., 1991). Kargbo et al. (1991) reported that the increasing P application frequency resulted in greater P uptake, greater mass flow and mixing reaction, leading to the breakdown of regions of immobile P.

From Table 1, it can be observed that the factorial set of treatments ( $4.96 \text{ mg kg}^{-1}$ ) was significantly superior to control 1 ( $2.62 \text{ mg kg}^{-1}$ ), but not significant with control 2 ( $5.55 \text{ mg kg}^{-1}$ ). In control 2: 100% NPK soil application, the availability of P remained in medium range even though soil samples were collected one month after fertilizer application. This point highlights the high P fixation capacity of the soil as well as the importance of split application of fertilizers for improving the use efficiency.

The year wise variation in available P content at both soil depth intervals is depicted in Fig. 4. Fertigation levels significantly influenced the soil available P in 2000 and 2005, while frequencies of fertigation showed no significant variation. Interaction between level and frequency of fertigation was significant in 2000 and 2004. The factorial set of treatments was significantly superior to control 1 in all years except in 2005.

In this long-term trial, the availability of Bray's P content at 0–25-cm depth interval remained in medium range both during pre-bearing stage (Bhat et al., 2007b) and during bearing stage of this study ( $3.7\text{--}5.9 \text{ mg kg}^{-1}$ ). In control 1, where no fertilizers were applied, the mean available P content was low ( $2.62\text{--}2.73 \text{ mg kg}^{-1}$ ) compared to fertigation ( $3.56\text{--}4.96 \text{ mg kg}^{-1}$ ). It implies that P is a limiting nutrient in laterite soils due to greater P fixation and higher P uptake by the palm. This is expected in laterite soils as the acid soils of this region are rich in hydrated as well as amorphous oxides of Fe and Al, which are potent phosphorus fixers (Perur, 1996). Silber et al. (2003) reported that fertigation enables higher availability of P to plants thus reducing concentration of P in soil and irrigation water leading to reduction in environmental pollution. The present findings also suggest that continuous application of P fertilizers is

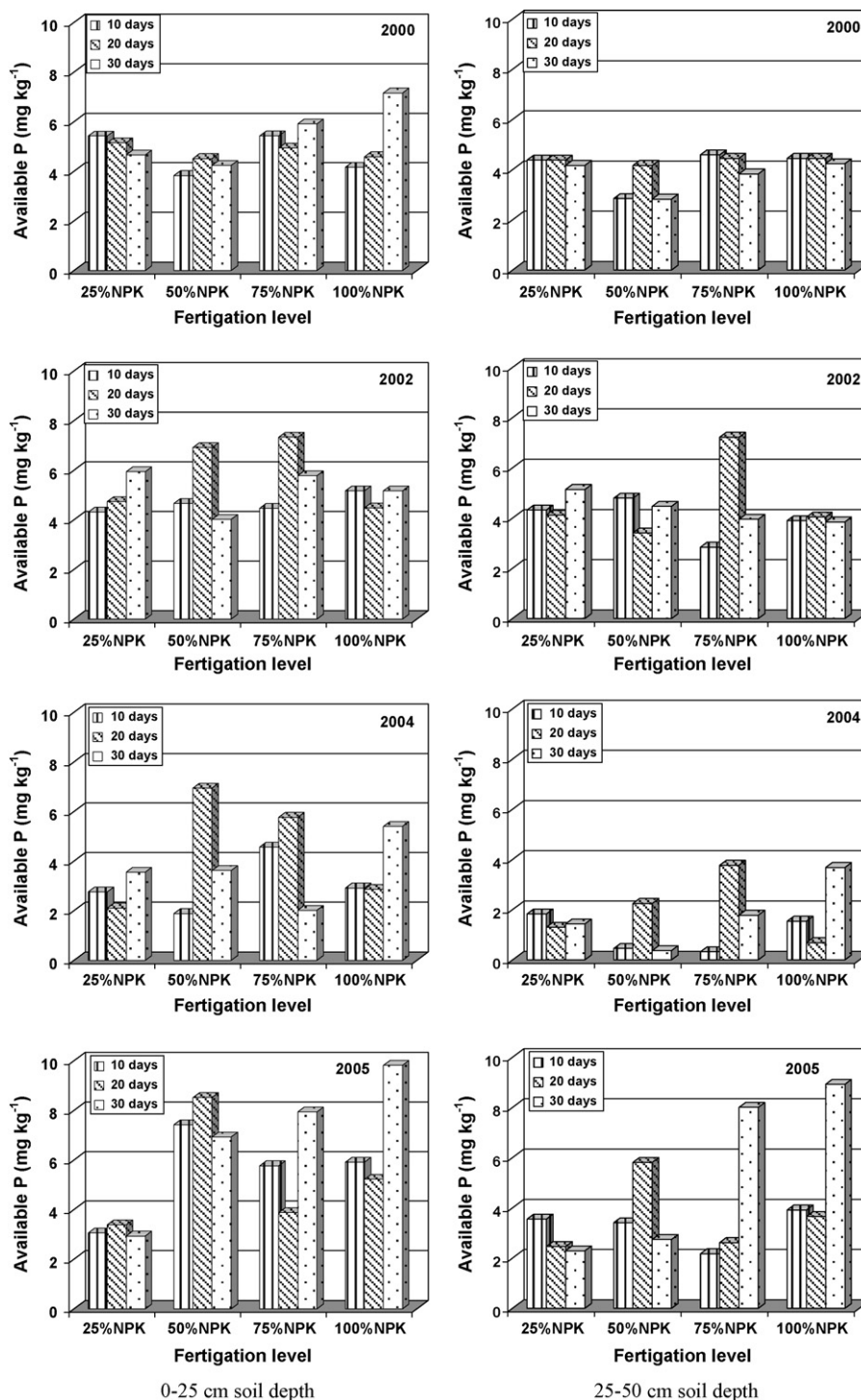


Fig. 4 – Variation in Bray’s P content ( $\text{mg kg}^{-1}$ ) in arecanut root zone as influenced by levels and frequencies of fertigation at two soil depth intervals (LSD (0.05) for years = 0.79 (for both depths)).

Year	Bray’s P ( $\text{mg kg}^{-1}$ )				LSD (0.05)							
	Year mean for factorial set		Control 1		Fertigation level (F)		Fertigation frequency (f)		F × f		Control 1 vs factorial set	
	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50
2000	5.00	4.15	3.03	2.76	0.89	NS	NS	NS	1.55	NS	1.14	0.81
2002	5.25	4.34	3.53	3.46	NS	NS	NS	NS	NS	NS	1.63	NS
2004	3.70	1.62	1.30	1.79	NS	NS	NS	NS	2.86	2.04	2.01	NS
2005	5.90	4.13	2.61	2.93	2.33	NS	NS	NS	NS	4.13	2.47	NS

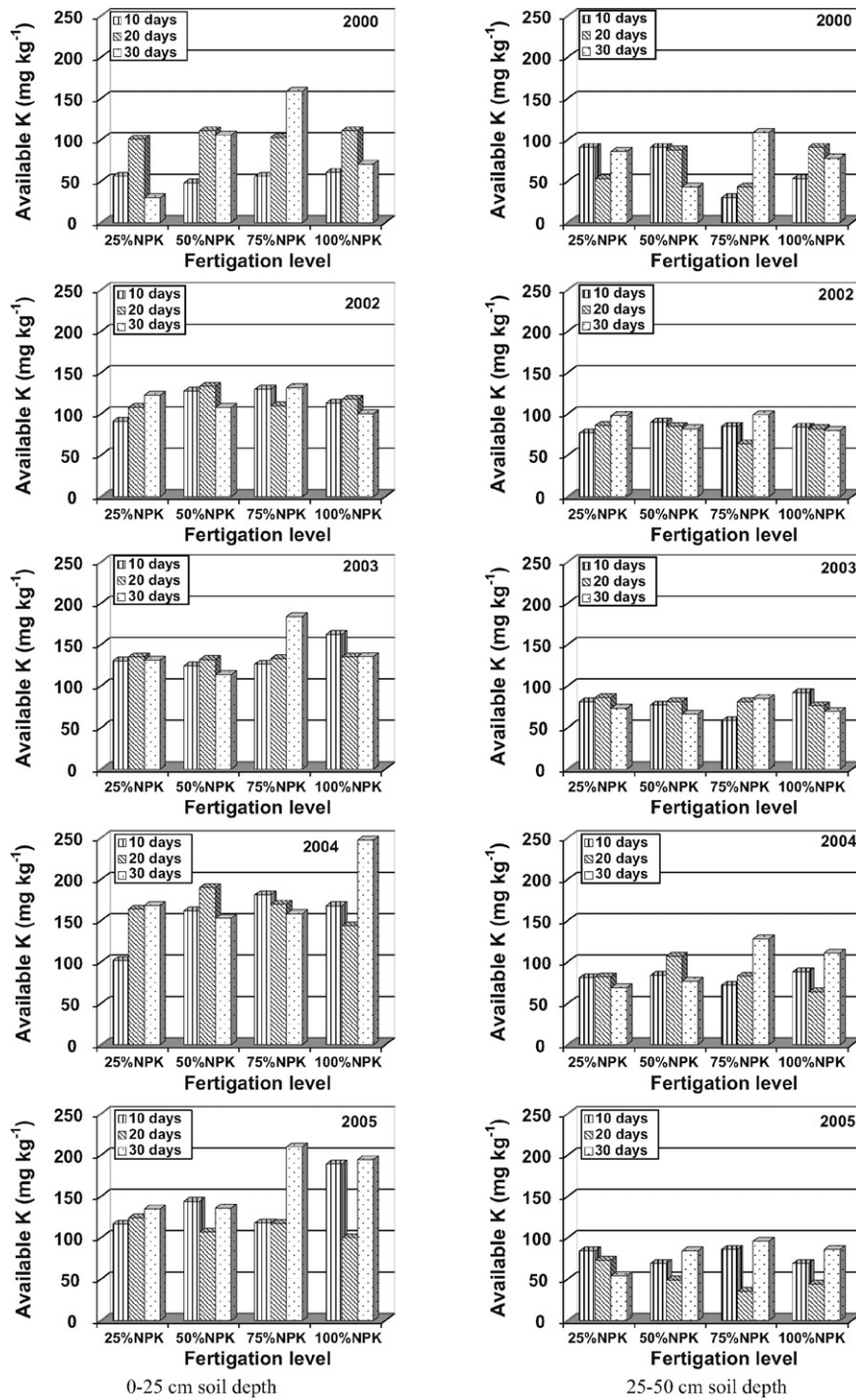


Fig. 5 – Variation in available K content ( $\text{mg kg}^{-1}$ ) in arecanut root zone as influenced by fertigation level and frequency at two soil depth intervals (LSD (0.05) for years = 15.3 (0–25 cm); 8.05 (25–50 cm)).

Year	Bray's P ( $\text{mg kg}^{-1}$ )				LSD (0.05)							
	Year mean for factorial set		Control 1		Fertigation level (F)		Fertigation frequency (f)		F × f		Control 1 vs factorial set	
	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50
2000	84	71	35	20	NS	NS	26.8	NS	53.6	33.3	37.9	23.5
2002	116	84	98	78	NS	NS	NS	NS	NS	NS	NS	NS
2003	137	77	111	73	NS	NS	NS	NS	NS	NS	NS	23.6
2004	167	87	138	69	NS	NS	NS	NS	51.7	31.9	NS	NS
2005	141	67	91	69	NS	NS	35.8	12.0	NS	24.1	NS	NS

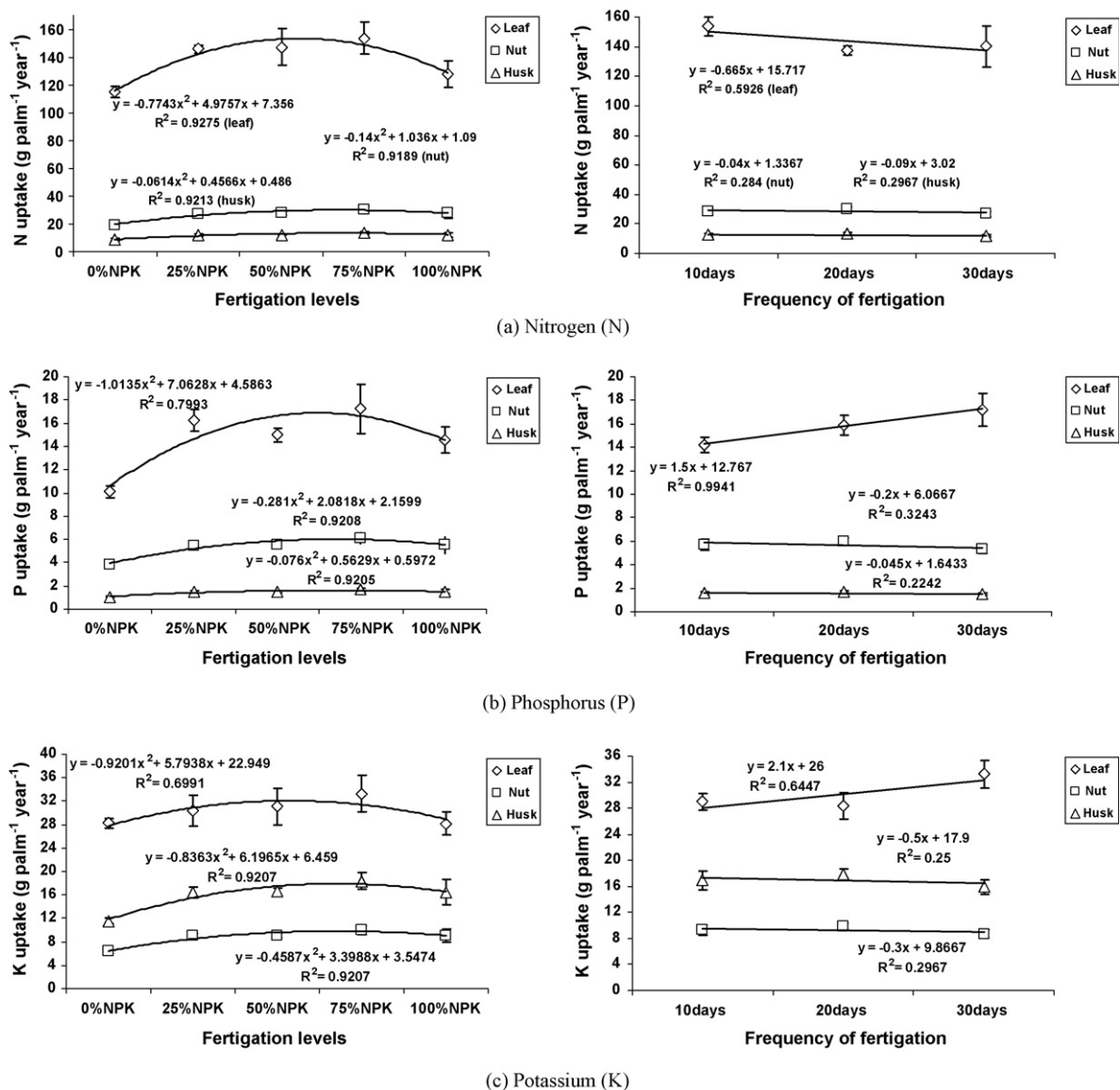


Fig. 6 – Uptake of nitrogen, phosphorus and potassium by leaf, nut and husk of 11-year-old arecanut palm as influenced by levels and frequency of fertigation.

needed to satisfy the P fixing needs of the soil and plant requirement.

3.4. Available soil K

Pooled analysis of 5-year data, from 2000 to 2005, showed significant impact of levels and frequencies of fertigation and their interaction on available K content (Table 1). Temporal variation in available K was significant due to drip fertigation at both soil depth intervals in arecanut root zone (Fig. 5). The potassium content increased gradually during experimental period reaching a peak content of 167 mg kg<sup>-1</sup> in 2004; it then decreased to 141 mg kg<sup>-1</sup> in 2005. Higher K content in 2004 might be due to less rainfall (Fig. 1) during monsoon season.

From Table 1, it is clear that the available K status at 25% NPK (114 mg kg<sup>-1</sup>) was significantly lower than at 75% (139 mg kg<sup>-1</sup>) and 100% NPK (137 mg kg<sup>-1</sup>). With respect to fertigation

frequency, a 30-day interval (139 mg kg<sup>-1</sup>) maintained significantly higher available K than 20-day (128 mg kg<sup>-1</sup>) and 10-day intervals (120 mg kg<sup>-1</sup>). This can be attributed to higher K uptake by the palm to satisfy the nutrient demand (Fig. 6). Interaction between levels and frequencies of fertigation indicated significantly higher available K at 75% NPK fertigated at 30-day interval (167 mg kg<sup>-1</sup>). In these soils with low CEC and K fixation, potassium ions move along with the water when injected through drip irrigation. Thus, it will be prudent to apply K fertilizers through drip irrigation in more splits to achieve maximum nutrient use efficiency.

Pooled data of 5 years (Table 1) revealed that the factorial set of treatments (129 mg kg<sup>-1</sup>) registered significantly higher available K content than control 1 (95 mg kg<sup>-1</sup>). While, control 2 (158 mg kg<sup>-1</sup>) was found significantly superior to factorial set. In contrast to P availability in control 2, the availability of soil K was above optimum level. This implies that the palm



available Mg with no definite trend. This can be attributed to the contribution of irrigation water towards Mg addition to soil.

### 3.6. Nutrient uptake

The nutrient uptake by leaf, nut and husk of arecanut as influenced by different levels and frequencies of fertigation is illustrated in Fig. 6. The nitrogen uptake by leaf was significant due to fertigation levels, frequencies and their interaction. The leaf N uptake ( $\text{g palm}^{-1} \text{ year}^{-1}$ ) was significantly lower at 100% NPK level (127) than at other levels (146–153). The increment in trunk biomass every year was estimated as  $1.1 \text{ kg palm}^{-1}$  in 0% NPK to  $2.2 \text{ kg palm}^{-1}$  in 100% NPK. In arecanut, trunk biomass accounted for 75% of the total biomass of the palm. The average nitrogen content in trunk was 1%. Thus, a large quantity of the nitrogen taken up by the palm would be immobilized in trunk. The higher trunk biomass and lower leaf biomass in 100% NPK fertigation (Bhat et al., 2007a) might have contributed to lower N uptake by the leaf. Tarmizi and Mohd Tayeb (2006) from Malaysia reported similar findings in oil palm. The influence of frequency of fertigation on the leaf N uptake ( $\text{g palm}^{-1} \text{ year}^{-1}$ ) showed that fertigation at 10-day interval (154) was significantly superior to 20-day (137) and 30-day intervals (140).

In the present study, net photosynthesis ( $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) ranged from 4.8 to 5.2 during pre-bearing stage (1997–2000) and 7.4 to 12.0 during bearing stage (2001–2005). Higher N uptake by the leaf would have contributed to higher net photosynthesis and yield levels in drip fertigation (Bhat et al., 2007a). The N uptakes by nut ( $19\text{--}31 \text{ g palm}^{-1} \text{ year}^{-1}$ ) and husk ( $9\text{--}14 \text{ g palm}^{-1} \text{ year}^{-1}$ ) were not significant among different fertigation levels. However, polynomial regression equation showed a positive relation between fertigation levels and N uptake by nut ( $y = -0.14x^2 + 1.036x + 1.09$ ,  $R^2 = 0.919$ ) and husk ( $y = -0.0614x^2 + 0.4566x + 0.486$ ,  $R^2 = 0.921$ ). Comparatively higher positive relation between yield and N uptake by nut ( $R^2 = 0.984$ ) was noticed than between yield and N uptake by leaf ( $R^2 = 0.877$ ). These findings clearly indicated that yield is closely related to fertigation and nutrient uptake.

The P uptake by leaf, nut and husk did not vary significantly among different levels and frequencies of fertigation. However, the polynomial regression equation showed significantly higher P uptake by different parts in fertigation treatments than control 1 i.e., 0% NPK (Fig. 6). A significant relation between P uptake by nut/husk and yield ( $R^2 = 0.984$ ) indicates importance of continuous P application in laterite soil at frequent intervals through drip irrigation. In this study, the total P content in trunk was 0.02% and in roots 0.16%, which are considered immobilized. Mikkelsen (1989) reported increased uptake of P with drip irrigation compared to other P fertilization methods.

The K uptake by leaf varied significantly due to fertigation levels and frequencies and their interaction. Higher K uptake of  $33.2 \text{ g palm}^{-1} \text{ year}^{-1}$  by the leaf was registered in 30-day interval irrespective of fertigation level. Though K uptake by nut and husk did not differ significantly among different treatments, the polynomial regression equation showed positive and significant relation to levels and frequencies of fertigation (Fig. 6). The present results and the findings of Bhat

et al. (2007a) indicated that 75% NPK fertigation results in higher K uptake by economic parts. Results also showed that fewer nutrients would be available for partitioning to the nut at lower doses, as nutrients are required for immobilization in trunk and roots. The roots contained on an average 0.56% K, which varied between 0.14% and 1.14% in fine and thick roots in this study. The K content in trunk was 0.27%, which means that the annual need for the trunk was  $3.8 \text{ g of K palm}^{-1} \text{ year}^{-1}$ .

The total N uptake ( $\text{g palm}^{-1} \text{ year}^{-1}$ ) by the above ground parts varied between 143 in 0% NPK to 198 in 75% NPK fertigation. Similarly, the total P uptake ( $\text{g palm}^{-1} \text{ year}^{-1}$ ) varied between 15 in 0% NPK and 25 in 75% NPK fertigation level. The maximum total K uptake ( $\text{g palm}^{-1} \text{ year}^{-1}$ ) occurred in the 75% NPK level (62) followed by 25% and 50% NPK (56), 100% NPK (54) and 0% NPK (46). Drip irrigation maintained adequate soil water content in arecanut root zone above field capacity level (18–22%) up to a distance of 90 cm from the drip line (Sujatha and Abdul Haris, 2000; Bhat et al., 2007b). Favorable soil water content and nutrient availability strongly influenced the nutrient uptake by arecanut palm. The nutrient uptake pattern of arecanut and the marginal availability soil P and K highlight the importance of split application of nutrients during post-monsoon season to improve and sustain higher yields.

## 4. Conclusions

The results of the present investigation indicated that the adoption of drip fertigation is a good management technique to use for lateritic soils to counteract climatic and soil constraints and to satisfy the nutrient demand of arecanut. Drip fertigation had a positive impact on soil pH, SOC, Bray's P and available K content. Nutrient distribution pattern showed that both 75% and 100% NPK levels maintained similar available phosphorus and potassium status in arecanut root zone over the years. The study indicates that 75% of recommended NPK applied at a 10-day interval will result in higher nutrient partitioning to economic parts in arecanut. As arecanut is a perennial palm, the amount of nutrients immobilized in trunk and roots along with the nutrients removed by leaf, nut and husk should also be considered while formulating the fertigation schedule.

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