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Impact of drip fertigation on productivity of arecanut (*Areca catechu* L.)

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ABSTRACT

The present investigation was conducted at Vittal, Karnataka, India during December 1996 to May 2006 to evaluate the effect of four fertigation levels (25, 50, 75 and 100% of recommended fertilizer dose, 100:18:117 g N:P:K palm^{-1} year^{-1}), three frequencies of fertigation (10, 20 and 30 days) and two controls (control 1, i.e., drip irrigation without fertilizer application and control 2, i.e., drip with 100% NPK soil application) on productivity and resource use efficiency of arecanut. The experiment was laid out in RBD incorporating factorial component (4 × 3 + 2) in 2-year-old arecanut plantation. Pooled analysis of 4-year data indicated the significant influence of both fertilizer dose and frequency of fertigation on kernel yield of arecanut. Among fertigation levels, the kernel yield was significantly higher in 75% NPK fertigation, i.e., 75:13.5:87.7 g N, P, K application per year (3721 kg ha^{-1}) than in other levels (3083–3121 kg ha^{-1}). The yields observed in 10 (3431 kg ha^{-1}) and 20 days frequencies (3382 kg ha^{-1}) were at par and significantly superior to monthly fertigation frequency (2952 kg ha^{-1}). Fertigation of 75% NPK at 10 days frequency registered maximum yield (4017 kg ha^{-1}), which was closely followed by fertigation of 75% NPK at 20 days frequency (3924 kg ha^{-1}) and fertigation of 100% NPK at 20 days frequency (3579 kg ha^{-1}). The yield increase with 75% NPK fertigated at 10 days interval was 100% over control 1 (2008 kg ha^{-1}). Different fertigation levels registered higher dry matter partitioning to kernel, i.e., 6.7–7.4% of the total biomass than no fertilizer application (5.6%). A significant correlation between biomass accumulation in different parts and fertigation levels indicates the importance of efficient application of nutrients at correct time and quantity. Leaf water potential increased significantly with increase in frequency of fertigation from 10 to 30 days interval. A strong linear correlation ($R^2 = 0.914$) was observed between fertigation level and total root biomass. The root biomass increased considerably from 3.23 (no fertilizer) to 7.99 kg per palm (75% NPK). Significant relation between root biomass and organic carbon content in soil based on polynomial regression ($R^2 = 0.769$) was also noticed. Water use efficiency (WUE) was significantly superior at 75% NPK applied at 10 days interval over 100% NPK applied at same interval. However, it was at par with 75 and 100% NPK applied at 20 days interval Agronomic nutrient use efficiency (ANUE) was significantly higher at 25% NPK (14.9 kg kernel produced per kg nutrient applied). Fertigation up to 75% NPK provided a higher ANUE than the combination of drip irrigation and soil application of 100% NPK indicating greater production at lesser application rates. The 11-year study indicated that adoption of fertigation not only increases productivity, but also ensures higher efficiency of the two most critical inputs, i.e., water and nutrients in crop production.

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1. Introduction

Arecanut (*Areca catechu* L.), which belongs to family Palmae, is a tall growing, erect and important commercial plantation crop grown in humid tropics of India. The economic part of the palm is called as 'betel nut' and is mainly used for masticatory purpose in many parts of Asia. It has several alteranate uses and all parts of the palm are useful. The traditional arecanut growing regions in India are coastal Karnataka and Kerala, parts of Maharashtra, Assam and West Bengal. It is cultivated in an area of 0.366 million hectares with a production of 0.439 million tonnes and productivity level of 1202 kg ha^{-1} as per 2003–2004 statistics (GOI, 2005). India ranks first in area and production of arecanut in the world. About 16 million people are dependent on arecanut industry for their livelihood. Moreover, arecanut is essentially a crop of small and marginal holders with insufficient income to sustain dependent families.

In the tropical belt where arecanut is grown (28°N and S of equator), though rainfall is more the distribution is very poor. Precipitation is confined to 6 months from June to November with an average rainfall of 3700 mm. Thus insufficient water has been a major limiting factor in post-monsoon season (December–May) due to high evaporative demand of arecanut (Mahesha et al., 1990) and depleting ground water table. Moreover, the arecanut palm produces maximum number of inflorescences during post-monsoon season, i.e., December to March (Ananda, 2004). Thus, providing irrigation and nutrition during that period would contribute to higher yields and improved resource use efficiency. Faster depletion of ground water, long post-monsoon season, less application efficiency and poor moisture retention capacity of laterite soils limit the use of flood irrigation. The review of agronomic research in arecanut indicated that IW/CPE ratio of 1 with a 30 mm depth of water through basin irrigation and 100:18:117 g N, P, K per palm per year are optimum for arecanut under conventional method of cultivation (Bhat and Sujatha, 2004). Trickle irrigation has gained importance during the last decade due to increased productivity and greater water and nutrient savings (Mmolawa and Or, 2000). Drip irrigation is often preferred over other irrigation methods because of its high water application efficiency on account of reduced losses, surface evaporation and deep percolation. Earlier studies at this station revealed that drip irrigation equivalent to 100% ET increases the yield by 45 with 44% saving in water over basin method of irrigation.

A vast majority of arecanut is predominantly grown in acidic laterite soils in India with a less productivity level of 1202 kg ha^{-1}. The important problems associated with these soils are P fixation, heavy rainfall during monsoon season resulting in nutrient losses through run off, leaching of basic cations and very poor nutrient retention capacity due to low CEC (3–15 cmol kg^{-1}). Deficiency of N and K was reported in laterite soils of this region (Badrinath et al., 1998). The annual nutrient mining by the arecanut palm 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 very low ranging from 10 to 15% for N, 25–30% for phosphorus and 20–25% for potassium. Further, root system is shallow and more than 70% of the roots are concentrated within the first 60 cm depth from the ground level and within a radius of 60 cm from the palm (Bhat and Leela, 1969). Due to these problems, fertilizers should be applied in synchrony with crop demand in the root zone in smaller quantities during post-monsoon season. Drip fertigation has come in handy for this purpose. Fertigation enables the application of fertilizer uniformly and more efficiently (Patel and Rajput, 2000). The advantage of fertigation over conventional method of fertilizer application was emphasized by several workers (Shigure et al., 1999; Mohammad, 2004a,b). Fertigation frequency is one major management variable with drip fertigation. It is often assumed that high frequency fertigation is preferable to less frequent fertigation. Several workers advocated frequent fertigation of crops by low volume irrigation system (Bar-Yosef and Sagiv, 1982; Stark et al., 1983; Burt et al., 1995). Thus, optimum utilization of two most important critical inputs like water and nutrients attains utmost importance in arecanut production. With this background, the present study was conducted to determine suitable fertigation schedule for arecanut in terms of fertilizer dose and frequency of fertigation and its impact on productivity and resource use efficiency.

2. Methods and materials

2.1. Details about experimental site

The investigation 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 at this place over last 30 years is 3670 mm that is distributed over 120 days. Mean temperature ranges from 21 °C (minimum) to 36 °C (maximum). The average relative humidity varies between 61 and 94%. The weather data of the experimental location for 6 years (2000–2001, 2001–2002, 2002–2003, 2003–2004, 2004–2005 and 2005–2006) are shown in Fig. 1.

The soil of the experimental site is sandy clay loam (laterite) with a pH of 5.6, 1.5% organic carbon, 10.1 ppm P and 53 ppm K at 0–30 cm soil depth. The soil is well-drained deep laterite comprising 54.6% sand, 14.4% silt and 36% clay at 0–60 cm soil depth. The bulk density of soil is 1.61 g cm^{-3} and field capacity 18–22%.

2.2. Experimental details

The plantation was established in December 1995 by planting 1-year-old arecanut seedlings (cv. Mohitnagar) in 60 cm^3 pits at a spacing of 2.7 m × 2.7 m. A field plot size of 2930 m^2 was selected. Each treatment consisted of six palms as net plot. The experiment was laid out in RBD with 14 treatments and three replications incorporating factorial component (4 × 3 + 2) in December 1996. The treatments included four fertigation levels *viz*., 25, 50, 75 and 100% of recommended fertilizer dose (100:18:117 g N:P:K palm^{-1} year^{-1}), 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. In the first and second years of planting, 1/3rd and 2/3rd of fertigation levels were applied, respectively.

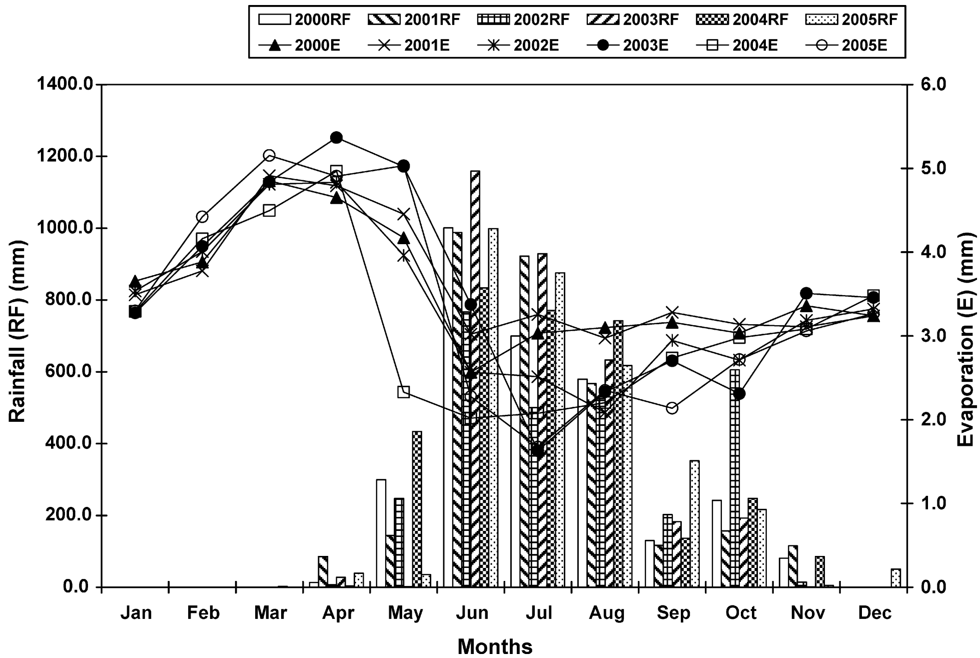

Fig. 1 – Monthwise weather data during 2000–2005.

The drip fertigation system consisted of one 5000 L 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 and the fertilizer was applied from December to May. Three emitters of 8 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 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 was applied in 21, 9 and 6 split doses at 10, 20 and 30 days frequency, respectively, from December to 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 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. Soil samples were collected from arecanut basins on all four sides and mixed to get a representative sample. Soil samples were collected from 0 to 30 and 30 to 60 cm soil depth at 40–50 cm away from the base of the palm during May every year before onset of monsoon. Soil samples of 2 mm fraction were used for analysis. Soil nutrient analysis was done using standard procedures (Jackson, 1973).

Root biomass was estimated using the monolith method (Bohm, 1979). One palm in each treatment was excavated for root biomass estimation in May 2005. Trenches of 1-m deep and 0.5-m wide were dug at 1.5 m from the base of the palm and the edges of root system of the palm were delineated. Monoliths were collected at distances of 0–0.5, 0.5–1.0 and above 1.0 m from base of the palm and complete rhizosphere area was covered to get total root biomass. In the field, the roots of the monoliths were carefully separated from the soil and washed under a jet of water using a 4 mm mesh sieve. Subsequently, fresh roots were washed in the laboratory, oven dried at 65 °C and expressed as kg $palm^{-1}$.

2.3. *Growth parameters, leaf water potential and kernel yield of arecanut*

All the growth parameters were recorded in November and May every year. The trunk dry matter was estimated by the following regression equation and cross-checked with destructive sampling of palms used for root excavation:

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

where Y = trunk dry matter; l = length of trunk; g = girth of the trunk.

Two leaves per treatment were colleted and oven dried to estimate average leaf weight. The average leaf weight was multiplied with number of leaves to arrive at total leaf weight per palm. The weight of leaf, dry kernel and husk was added to trunk dry weight to estimate total biomass. Photosynthetic parameters using LI-6200 Portable Photosynthesis System (Li-Cor Inc., Nebraska, USA) and leaf water potential with Scholander pressure chamber (Soil Moisture Equipment

Corpn. Santa Barbara, USA) were measured in March between 10.00 and 12.00 h. Photosynthetic parameters included net photosynthesis (Pn), transpiration (*E*) and stomatal conductance (gs). Photosynthetic water use efficiency (PWUE) was estimated as ratio of net photosynthesis to transpiration (Peng and Krieg, 1992).

The flowering was initiated in 1999–2000 and the kernel yield was recorded in 2000–2001. The yield of 2000–2001 was not considered for drawing conclusions in this study as first year yield will not be uniform. The 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 dehusked and kernel weight was recorded for computing the yield. Statistical analysis was done using standard analysis of variance (ANOVA) technique. Correlation and regression analysis was done for important parameters.

2.4. Estimation of resource use efficiencies

Use efficiency of water and nutrient was estimated by using following formulae:

$$\text{water use efficiency} = \frac{\text{yield}\,(\text{kg}\,\text{ha}^{-1})}{\text{mm of water applied}} \quad (1)$$

$$\text{agronomic nutrient use efficiency} = \frac{\text{yield}\,(\text{kg}\,\text{ha}^{-1})}{\text{kg nutrient applied}\,(N+P+K)} \quad (2)$$

For computing water use efficiency (kg dry kernel ha^{-1} mm of water applied^{-1}), the total water applied including drip irrigation and effective rainfall with allowances made for runoff and changes in soil water storage was considered. For computing agronomic nutrient use efficiency, total quantity of N, P and K applied through fertilizers was considered to know the overall efficiency.

3. Results and discussion

3.1. Dry matter partitioning in arecanut palm

Estimation of total biomass and partitioning was attempted in 1999 (end of pre-bearing period) and at the end of experimentation in 2006 to the study the response of palms to drip fertigation. The dry matter partitioning to different parts and increment in trunk and total biomass in response to different fertigation levels during 1999–2006 are illustrated in Fig. 2. In the present study, arecanut palms supplied with 25–100% NPK through fertigation produced more or less same amount of biomass (36.6–37.8 kg palm^{-1}), while no fertilizer application reduced the total biomass of the palm to 32.3 kg palm^{-1}. Dry matter partitioning to trunk accounted for 74–76% of the total biomass in fertigated treatments, while it was 77% without nutrient application (Fig. 2a).

Application of 75% NPK increased the marketable kernel yield to 2.8 kg palm^{-1} compared to other fertigation levels (2.5 kg) and control1 (1.8 kg). Different fertigation levels registered higher dry matter partitioning to kernel, i.e., 6.7–7.4% of the total biomass than no fertilizer application (5.6%). Based on regression analysis, 92% of variation in the dry matter partition to nut can be explained by difference in fertigation levels. This trend of dry matter partitioning has obviously resulted in higher yields with 75% NPK fertigation. Arecanut palms supplied with less than recommended fertilizer level, i.e., 25–75% NPK from seedling stage onwards produced sufficient biomass in vegetative parts like trunk and leaves in pre-bearing stage itself and thus contributed to higher partitioning to nuts during bearing stage and resulted in early yield stabilization. Sujatha et al. (2000) recommended 50% NPK fertigation for pre-bearing palms based on growth rate and photosynthetic parameters in the same experiment. However, the present study on dry matter partitioning pattern suggests that 75% NPK is optimum and substantiates higher yields registered with this fertigation level as partitioning to economic part was more (7.8%). From the present findings along with the report by Sujatha et al. (2000), it can be concluded that the fertigation requirement of bearing palms is higher than pre-bearing palms.

Total biomass produced among different fertigation levels were more or less similar (10.0–10.5 kg palm^{-1}) between 1999 and 2006, i.e., initiation of bearing period to 6th year of bearing (Fig. 2b). However, control 1 (no fertilizer application) resulted in significantly lower biomass of 7.8 kg palm^{-1} during the same period. Thus 88% of the variation in biomass increment during 1999–2006 can be related to nutrient stress in control 1 compared to fertigation levels. A significant correlation between biomass accumulation in different parts and fertiga-

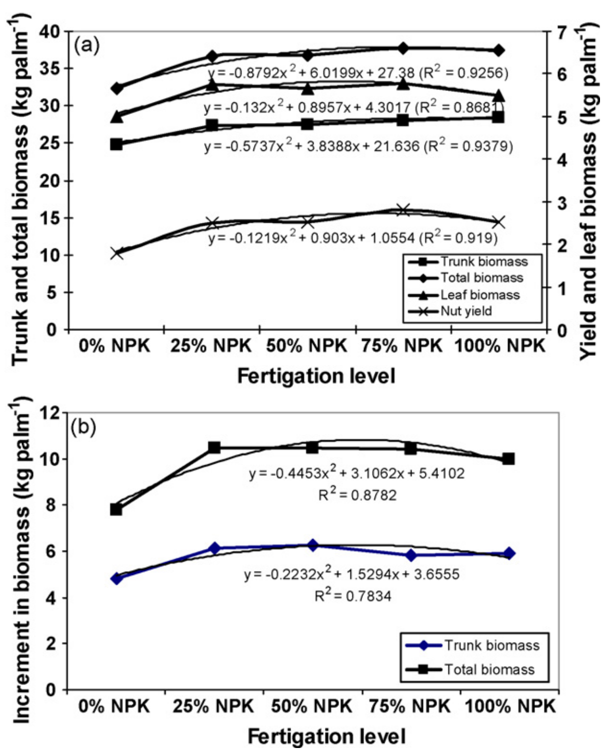

Fig. 2 – Dry matter partitioning and increment in arecanut palm: (a) biomass partitioning to different parts in arecanut palm at the end of experimentation (2006); (b) increment in biomass from pre-bearing stage to end of experimentation (1999–2006).

tion levels indicates the importance of efficient application of nutrients at correct time and quantity. It is also evident that the dry matter partitioning pattern is an important component for yield and has direct impact on kernel yield of arecanut in response to fertigation.

3.2. *Physiological parameters*

The physiological parameters were monitored every year in response to drip fertigation in arecanut. Different levels and frequencies of fertigation did not influence significantly physiological parameters like net photosynthesis (Pn), transpiration (*E*), stomatal conductance (gs) and photosynthetic water use efficiency (PWUE, Pn/*E*) in different years. This might be due to favourable soil moisture availability in the arecanut rhizosphere. However, pooled analysis indicated that year wise variation was significant for Pn and PWUE. The significant correlation between fertigation levels and photosynthetic water use efficiency ($R^2 = 0.728$) and fertigation levels and stomatal conductance ($R^2 = 0.742$) explains the necessity of nutrient application for sustaining the physiology of arecanut (Fig. 3a).

Leaf water potential (LWP) varied significantly in different years. High LWP values in 1999 (−1.07) and 2003 (−1.15) might be due to variation in rainfall in those years. The LWP values of arecanut palms remained more or less constant throughout the experimental period and not influenced by fertigation level. However, different frequencies of fertigation showed significant impact on leaf water potential (Fig. 3b). With increase in frequency of fertigation from 10 to 30 days interval, the leaf water potential increased. The lowest LWP was recorded with application frequency of 10 days interval. Polynomial quadratic regression also showed positive relation between frequencies of fertigation and LWP ($y = 7E{-}05x^2 + 0.0003x - 1.2433$, $R^2 = 0.472$).

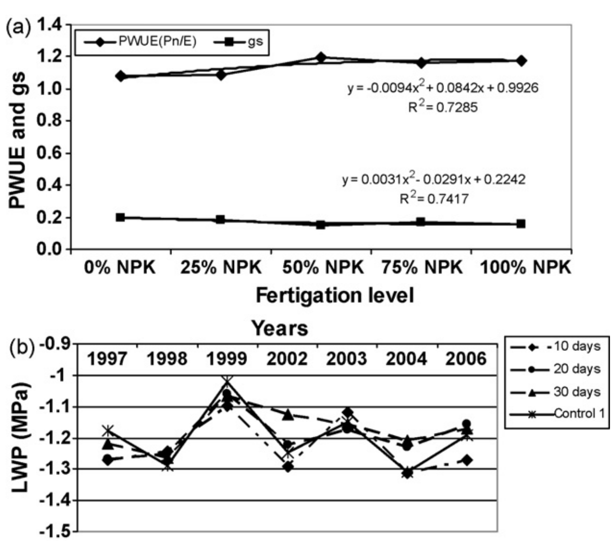

Fig. 3 – Influence of levels and frequency of fertigation on physiological parameters: (a) physiological water use efficiency, PWUE (Pn/E) and stomatal conductance, gs ($mol\ m^{-2}\ s^{-1}$) in arecanut averaged over years; (b) frequency of fertigation on leaf water potential in arecanut in different years (CD (5%) for years, −0.067 and for frequencies, −0.044).

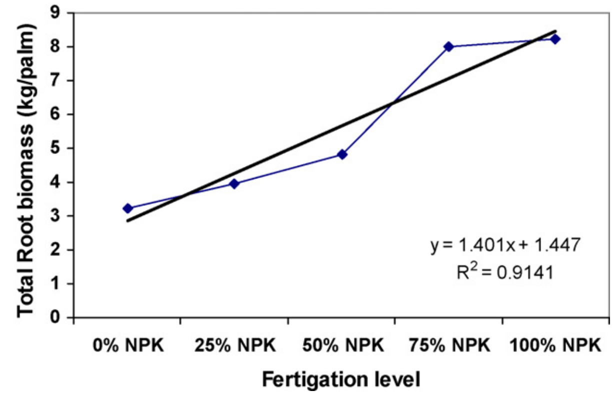

Fig. 4 – Total dry root biomass ($kg\ palm^{-1}$) of arecanut as influenced by different fertigation levels in 2005 (averaged over 10 and 20 days frequency of fertigation).

This indicates that frequent fertilizer applications would reduce leaf water potential. This might be due to increased stomatal conductance and net photosynthesis in absence of water and nutrient stress. The role of major nutrients on regulation of stomatal functioning has been reported earlier (Peaslee and Moss, 1968; Houman et al., 1990; Bednarz and Oosterhuis, 1999). A positive regression relationship indicated that PWUE and total dry matter production were related to fertigation levels by polynomial quadratic relationship. This could be due to increased Pn and lowering of transpiration rate due to efficient regulation of stomata. Balasimha et al. (1996) also reported significant variation in physiological parameters in arecanut due to drip irrigation with soil application of fertilizers. Combined effect of better physiological parameters and dry matter production had direct impact on kernel yield.

3.3. *Root biomass and soil organic carbon*

The root biomass production and its impact on organic carbon status was studied at the completion of treatment imposition in 2005 as initial root studies in 2- and 3-year-old seedlings indicated strong influence of drip fertigation on root growth and distribution pattern (Sujatha and Abdul Haris, 2000). The root biomass per palm increased considerably from 3.23 kg (no fertilizer) to 7.99 kg (75% NPK) (Fig. 4), while the increase was marginal (3%) at 100% NPK over 75% NPK. Of the total root biomass, fine root biomass accounted for 40% in 50% NPK, 37% in 75% NPK and 34% in 100% NPK fertigation compared to 29% in control 1 (no fertilizer). A strong linear correlation ($R^2 = 0.914$) between fertigation level and total root biomass (Fig. 4) indicates that application of N and P fertilizers and soil moisture availability at field capacity in post-monsoon season might have contributed to higher production of total root biomass and fine roots. This agrees with the previous report on root distribution of young arecanut palm in the same experiment, according which drip fertigation resulted in higher root biomass, fine roots and more horizontal root spread along dripping plane (Sujatha and Abdul Haris, 2000). Further, it was noticed that drip fertigation places nutrients in active root zone besides maintaining favourable soil moisture level resulting in much greater movement of phosphorus and

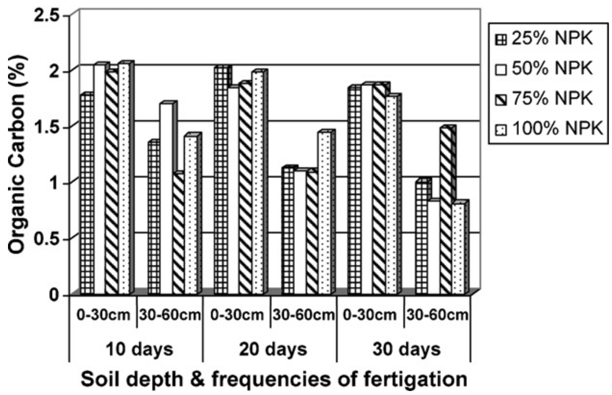

Fig. 5 – Organic carbon content in arecanut basins at different fertilizer doses and their application frequencies in 2005 (CD (5%); control 1: 1.59% (0–30 cm), 1.02% (30–60 cm)).

CD, cm (P = 0.01)	F	f	$F \times f$	Factorial set vs. control 1
0–30	NS	0.079	0.159	0.088
30–60	NS	0.095	0.190	NS

potassium in arecanut rhizosphere (Bhat et al., 2007). Higher root production with drip fertigation would have contributed to improved nutrient and water uptake which was discernable in higher yields, water use efficiency and agronomic nutrient efficiency. Reduced leaching losses were reported due to higher root production as it functions as safety net (Young, 1997).

Low moisture and nutrient retention capacity, less CEC, presence of kaolinite clay and faster organic matter decomposition are inherent constraints of laterite soils (Perur, 1996). Thus, maintenance of organic carbon status and soil fertility becomes essential for sustainability of soil and crop productivity in tropics. Continuous supply of nutrients through inorganic fertilizers in this experiment has been a matter of concern. Interestingly, though organic manures were not applied during the experimental period, the significant enrichment in organic carbon status (Fig. 5) due to fertigation at different frequencies of application was noticed over no fertilizer application. The organic carbon content was significantly higher with frequent application of fertilizers, i.e., at 10 days (1.96%) and 20 days (1.93%) compared to 30 days interval (1.83%). This can be attributed mainly to higher root biomass production especially fine root biomass and *in situ* root decay in the soil. Significant relation between root biomass and organic carbon content in soil based on polynomial regression ($y = 245.48x^2 - 849.38x + 733.15$, $R^2 = 0.769$) confirms the above findings. Several workers also 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. The present findings are supported by above reports.

Table 1 – Interaction effect between fertigation levels and frequency of fertigation on kernel yield and water use efficiency of arecanut (pooled for 4 years, 2002–2003 to 2005–2006)

Treatments	Kernel yield (kg ha^{-1})[a]				WUE (kg kernel produced/mm of water applied)[a]			
	10	20	30	Mean	10	20	30	Mean
Fertigation level (% of recommended NPK)								
25	3125	2954	3172	3084	2.75	2.60	2.61	2.65
50	3308	3071	2983	3121	2.85	2.51	2.45	2.60
75	4017	3924	3222	3721	3.41	3.16	2.59	3.05
100	3273	3579	2428	3093	2.69	3.30	2.01	2.67
Mean	3431	3382	2952		2.93	2.89	2.41	
Control 1 (no fertilizers + drip irrigation)	2008				1.68			
Control 2 (100% NPK soil application + drip irrigation)	3574				3.01			

Treatments	S.Em.±	CD (5%)	S.Em.±	CD (5%)
Fertigation level (F)	106.75	302.00	0.121	0.339
Frequency of fertigation (f)	92.45	184.90	0.105	0.294
Interaction between $F \times f$	184.89	522.96	0.209	0.585
Control 1 vs. factorial set	283.67	829.09	0.238	0.695
Control 2 vs. factorial set	296.14	NS	0.248	NS

Years	Kernel yield (kg ha^{-1})	WUE (kg kernel produced per mm of water applied)
2002–2003	2241	1.81
2003–2004	3511	2.72
2004–2005	3749	3.50
2005–2006	3518	2.95
S.Em.±	106.7	0.121
CD (5%)	302.0	0.339

[a] Frequency of fertigation (days).

3.4. *Kernel yield*

Significant variation in kernel yield was observed in different years. The kernel yield registered in 2001–2002 was 1049 kg ha^{-1} and was increased to 2241 kg ha^{-1} in 2002–2003. The yields registered during 2003–2006 were at par (3511–3749 kg ha^{-1}) indicating the yield stabilization and consistent yielding pattern. In general, arecanut attains yield stabilization after 8th year and delayed yield stabilization is noticed in Mohitnagar cultivar. However, application of fertilizers through drip irrigation at optimum levels would have resulted in early yield stabilization by 8th year in this study. The non-significant difference in yield levels from 2003 to 2005 demonstrated that the natural tendency of alternate bearing in arecanut could be broken by drip fertigation.

The pooled analysis of 4-year data indicated significant influence of both fertigation level and frequency of fertigation on kernel yield of arecanut (Table 1). Factorial set of treatments was significantly superior to control 1 (no fertilizers + drip irrigation), but found non-significant with control 2 (100% NPK soil application + drip irrigation). Interaction effect between fertilizer dose and frequency of fertigation was also found significant. Among fertigation levels, the kernel yield was significantly higher in 75% NPK fertigation, i.e., 75:13.5:87.7 g N, P, K application per year (3721 kg ha^{-1}) than in other levels (3083–3121 kg ha^{-1}). The yields observed in 10 (3431 kg ha^{-1}) and 20 days frequencies (3382 kg ha^{-1}) were at par and significantly superior to monthly fertigation frequency (2952 kg ha^{-1}). It can be presumed that high fertigation frequency might have enhanced the nutrient uptake at low nutrient concentration level. Silber et al. (2003) opined that frequent fertigation improves the uptake of nutrients through continuous replenishment of nutrients in the depletion zone at the vicinity of root interface and enhanced transport of dissolved nutrients by mass flow in lettuce. This explains the importance of nutrient application in small amounts at frequent intervals in laterite soil.

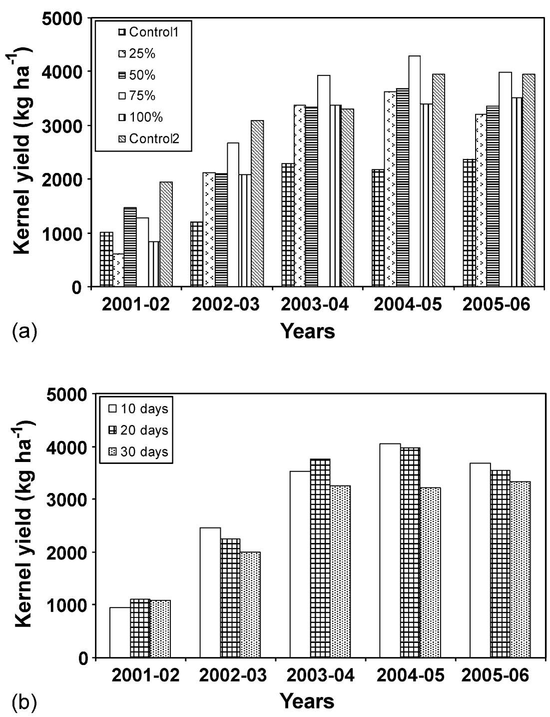

Fig. 6 – Effect of levels and frequency of fertigation on kernel yield of arecanut in different years: (a) fertigation levels (*F*); (b) frequency of fertigation (*f*).

Year		F	f	$F \times f$	Control 1 vs. factorial set	Control 2 vs. factorial set
2001–2002	S.Em.±	219.66	190.23	380.47	283.40	271.09
	CD (5%)	644.28	NS	NS	NS	792.48
2002–2003	S.Em.±	178.12	154.26	308.52	222.65	276.12
	CD (5%)	NS	NS	904.90	650.86	807.17
2003–2004	S.Em.±	161.09	139.51	279.02	220.83	233.90
	CD (5%)	472.49	NS	NS	645.52	NS
2004–2005	S.Em.±	190.71	165.16	330.32	265.14	275.61
	CD (5%)	559.37	484.43	NS	775.04	NS
2005–2006	S.Em.±	297.12	257.31	514.63	394.49	439.21
	CD (5%)	NS	NS	NS	1079.44	NS

Fertigation of 75% NPK at 10 days interval registered maximum yield (4017 kg ha^{-1}) followed by fertigation of 75% NPK at 20 days frequency (3924 kg ha^{-1}) and fertigation of 100% NPK at 20 days frequency (3579 kg ha^{-1}). The kernel yield increased significantly up to 75% NPK fertigation and reduced with 100% NPK. Fertigation of 75:13.5:87.7 g N, P, K (75% NPK) registered yield advantage of 21% and 19% over 25:4.5:29.2 g N, P, K (25%) and 50:9:58.5 g N, P, K (50%), respectively. While, 17% yield reduction was noticed with 100% NPK over 75% NPK. This might be due to delayed flowering in 100% NPK treatment resulting in late yield stabilization or this dose might be above optimum. Highest yield was reported with fertigation at 75% recommended dose followed by 100% fertigation in mango (Thakur and Singh, 2004) and pomegranate (Idate et al., 2001). Fertigation at 10 and 20 days frequency was found significantly superior to 30 days interval. Overall, the study suggests that 75% NPK fertigation at 10 days frequency was superior in terms of productivity as it resulted in consistent yields above 4000 kg ha^{-1} in all the years (4059–4902 kg ha^{-1}). Fertigation with 75% NPK at 20 days frequency was also equally superior in terms of productivity (3928–4669 kg ha^{-1}). Thus, the study reveals that 25% of recommended NPK can be saved. Fertilizer savings through fertigation to the tune of 25–50% were reported (Haynes, 1985; Bussi et al., 1991). Fertilizer savings and increased yields due to fertigation were observed in coconut and oil palm also (Solaimalai et al., 2005). The above reports strengthen the present findings. Higher production of above ground biomass and root biomass and dry matter partitioning to economic part with fertigation up to 75% NPK would have contributed to higher yields and resource use efficiency as evident from Table 1 and Figs. 2, 4 and 8.

The year wise kernel yield of arecanut was depicted in Fig. 6. Fertigation levels significantly influenced the yield of arecanut in 2001–2002, 2003–2004 and 2004–2005, while no significant variation was found among different frequencies in all years. Interaction between fertigation level and frequency of fertigation was not significant in all the years except in 2002–2003. Factorial set of treatments was found significantly superior to control 1 in all years except in first year of bearing, but found non-significant with control 2 (100% NPK soil application). Drip irrigation without fertilizer application also resulted in progressive yield increase over the years, i.e., 1005 in 2001–2002 to 2365 kg ha^{-1} in 2005–2006. This indicates that arecanut is more sensitive to moisture stress than to nutrient stress. The review of agronomic research in arecanut by Bhat and Sujatha (2004) supports the above finding.

No definite trend was observed in 2001–2002 mainly due to initial bearing stage. In 2002–2003, 8th year of planting, i.e., after yield stabilization, yields were significantly higher at 75% NPK than other doses. In 2002–2003, despite receipt of less rainfall (2869 mm) with erratic distribution, the adoption of drip fertigation has maintained same yield levels as in other years, though arecanut is very sensitive to water stress. Large yield reduction was reported in arecanut tract in 2002–2003 (Jose et al., 2004). In 2003–2004, 75% NPK fertigation registered significantly higher yield (3938 kg ha^{-1}) than other doses. Frequency of fertigation had no significant effect on kernel yield. In 2004–2005, 75% NPK recorded significantly higher yield of 4286 kg ha^{-1} than other doses. However, yields obtained with 25, 50 and 100% NPK were at par. Among frequencies, 10 and 20 days were at par and proved significantly superior to 30 days interval. Regression analysis showed a significant quadratic relationship between yield and fertigation level (Fig. 7) with strong correlation at 10 and 20 days interval compared to 30 days interval. From the response

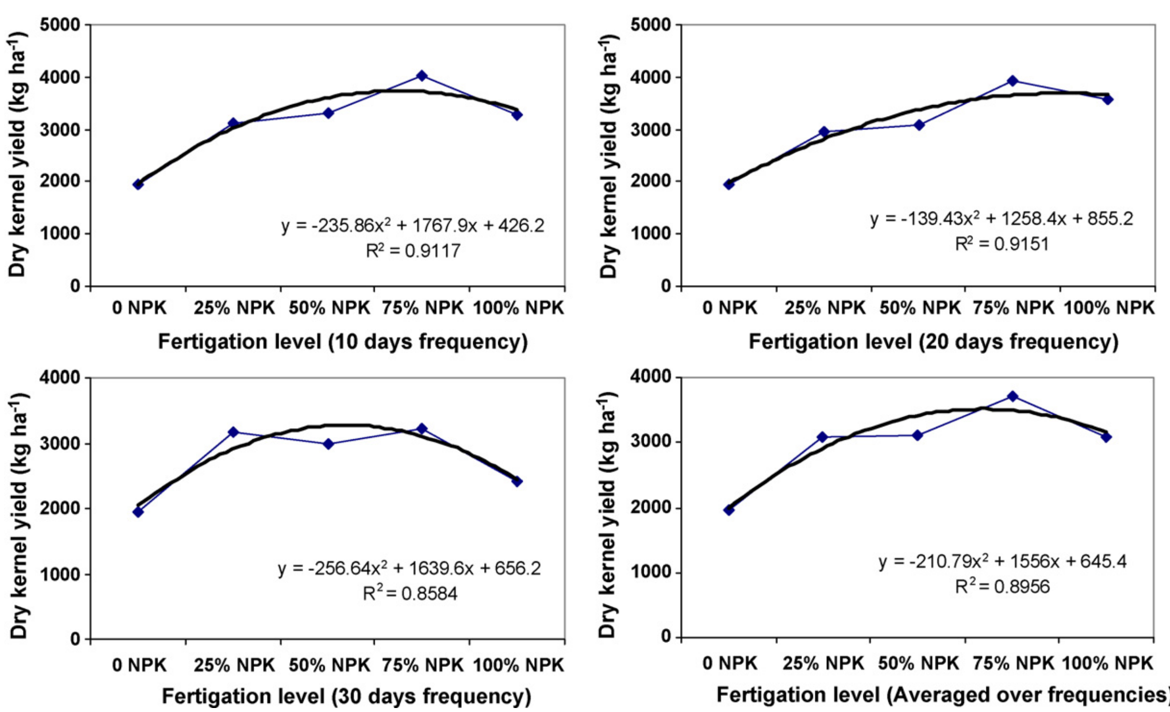

Fig. 7 – Response curve showing the relationship between fertigation level and dry kernel yield (pooled yield of 2002–2003 to 2005–2006) at different application frequencies.

curve of pooled data, optimum fertigation dose was estimated as 92% NPK (92:17:108 g N:P:K palm^{-1} year^{-1}, respectively).

The stabilized average productivity recorded in this study was 3593 kg ha^{-1}, while the national and state productivity are 1202 and 1335 kg ha^{-1}, respectively. Thus, the yield gap was very huge both at national level (199%) and state level (169%). This reveals the importance of fertigation technology in increasing the productivity and arresting the horizontal expansion of area under arecanut which has increased rapidly by 57% (0.1 million ha) during last 10 years. The clear difference in kernel yield of arecanut between fertigation levels and control 1 can be attributed to accurate adjustment of water and nutrient supplies to meet the crop requirement, uniform distribution of nutrients in the root zone and higher nutrient use efficiency. Drip irrigation along with soil application of 100% NPK (control 2) registered yield of 3574 kg ha^{-1} which was at par with drip fertigation treatments. However, estimation of economic feasibility based on annuity value approach revealed that drip fertigation is highly profitable due to considerable saving in input, labour and energy costs to the tune of 54% over conventional method of cultivation (Bhat and Sujatha, 2006). Thus, fertigation is more effective as lower fertilizer dose would be adequate to produce higher yield lowering fertilization cost and minimizing environmental pollution. Similarly Mohammad (2004b) concluded that fertigation is more effective than soil application in terms of yield and fertilizer savings in squash. The above reports along with the present findings highlights the perceived benefits of drip fertigation in arecanut.

3.5. *Agronomic nutrient use efficiency (ANUE) and water use efficiency (WUE)*

The ANUE was estimated in all the years and depicted in Fig. 8. Pooled analysis showed significant variation in ANUE due to years (CD (5%), 3.13) and fertigation levels. The kilograms of kernel produced per kilogram nutrient applied (ANUE) increased from 6.17 in 2002–2003 to 12.49 in 2004–2005 and decreased to 7.10 in 2005–2006. The significant variations in ANUE are due to differences in yields. Agronomic nutrient use efficiency noticed with 25% NPK fertigation was significantly higher over other doses while 50 and 75% NPK fertigation were at par and were significantly superior over 100% NPK fertigation. When the quantity of nutrient application increased from 76.3 kg NPK ha^{-1} (25:4.5:29.2 g NPK palm^{-1} year^{-1}) to 305.5 kg NPK ha^{-1} (100:18:117 g NPK palm^{-1} year^{-1}), the ANUE decreased from 14.9 to 3.79 kg kernel produced per kilogram of nutrient applied. Fertigation up to 75% NPK provided a higher ANUE than the combination of drip irrigation and soil application of 100% NPK indicating greater production at lesser application rates. The finding by Brian (1995) also indicated higher fertilizer use efficiency with fertigation over conventional fertilization in grapefruit. The review on fertigation in high value crops by Solaimalai et al. (2005) indicated increased nutrient use efficiency in fertigation over soil application of nutrients. Reduced yield at 100% NPK fertigation level can be explained by the combined effect of reduced nutrient use efficiency and less dry matter partitioning to kernel.

The data on water use efficiency as estimated from kernel yield of arecanut per mm of water applied are presented in

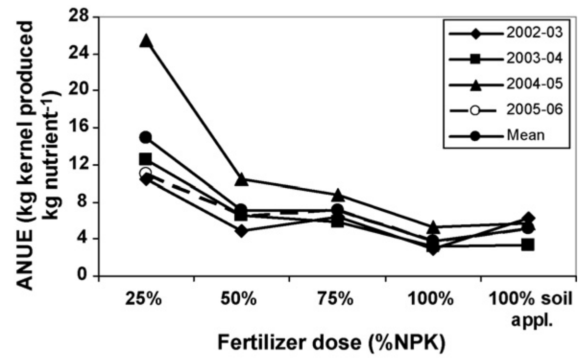

Fig. 8 – Agronomic nutrient use efficiency as influenced by fertigation levels in different years in arecanut.

Year		F	*f*	F × *f*	Control 2 vs. factorial set
2002–2003	S.Em.±	1.85	1.60	3.21	2.33
	CD (5%)	5.43	NS	NS	NS
2003–2004	S.Em.±	1.98	1.71	3.43	2.47
	CD (5%)	5.80	NS	NS	NS
2004–2005	S.Em.±	2.94	2.55	5.09	3.71
	CD (5%)	8.62	NS	NS	NS
2005–2006	S.Em.±	1.91	1.65	3.31	2.34
	CD (5%)	NS	NS	NS	NS
Pooled	S.Em.±	1.11	0.96	1.92	2.01
	CD (5%)	3.13	NS	NS	NS

Table 1. Water use efficiency was significantly influenced by fertigation levels and frequency of fertigation. Among fertigation levels, 75% NPK registered significantly higher value of WUE (3.05 kg kernel per mm of water applied) over other levels. Among frequencies of fertigation, 10 and 20 days intervals were found significantly superior to 30 days interval. Significant interaction between fertigation level and frequency of application indicated that WUE was superior at 75% NPK applied at 10 days interval (3.41 kg kernel per mm of water applied) over 100% NPK applied at same interval (2.69). However, it was at par with 75 and 100% NPK applied at 20 days interval. Year wise variation was also significant. Highest WUE of 3.50 was recorded in 2004–2005. Factorial set of treatments was significantly superior to control 1 (no fertilizers + drip irrigation), but found non-significant with control 2 (100% NPK soil application). Increased water use efficiency in terms of kg kernel per mm of water applied with fertigation levels (2.6–3.05) clearly indicates the synergistic impact of water and nutrients as nutrient stress resulted in decreased water use efficiency (1.68). Higher fertilizer use efficiency and water use efficiency with fertigation was reported by Mohammad and Said (2003) and Mohammad (2004a,b).

4. Conclusions

The 11-year study indicated that adoption of fertigation not only increases productivity, but also ensures higher efficiency of the two most critical inputs, i.e., water and nutrients in crop production as it results in higher WUE and ANUE. The substantial yield response of arecanut to drip fertigation indicates the need for adequate supply of nutrient and water to counteract soil and climatic constraints in laterite soils. The study clearly shows that the arecanut farmers can accrue benefits like higher yields, resource use efficiency and profitability due to adoption of drip fertigation with 75% NPK at 10 days frequency. Thus, fertigation technology has many advantages due to increasing scarcity of water and cultivated land, and escalating fertilizer prices. Further this technology gives scope for reducing environmental pollution by lesser use of fertilizers and fuel.

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