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Fertigation Effects on Productivity, and Soil and Plant Nutrition of Coconut (*Cocos nucifera* L.) in the Eastern Indo-Gangetic Plains of South Asia

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ABSTRACT

Fertigation has the potential to reduce extra chemical load by improving nutrient and water use efficiency of coconut (*Cocos nucifera* L.), but studies demonstrating the fertilizer reduction through drip irrigation in comparison to conventional ring basin method are rare in the Eastern Indo-Gangetic Plains (IGP) of South Asia. A long-term field experiment was conducted during 2007–2013 in West Bengal, India, to study the effect of fertigation on coconut var. DXT. The experiment was laid out in a randomised complete block design (RCBD) with six treatments (control – no fertilizers and water applied with drip irrigation; 25%, 50%, 75% and 100% of the recommended dose of fertilizer (RDF), each applied with drip irrigation; and 100% of the RDF and water applied with ring basin method of irrigation (i.e., conventional method)). Nuts yield was significantly higher for 75% of RDF (24.44 t ha^{-1} $year^{-1}$) followed by 100% of RDF, each drip irrigation (23.79 t ha^{-1} $year^{-1}$) compared to control (21.89 t ha^{-1} $year^{-1}$). Copra yield was significantly higher for 75% of RDF (3.19 t ha^{-1}) compared to 100% of RDF (3.12 t ha^{-1}) and no fertilizer (1.87 t ha^{-1}). Nitrogen (N), phosphorus (P) and potassium (K) contents of soil increased by 4.9%, 10.4% and 9.4%, respectively, with 75% of RDF applied through drip irrigation. Microbial population showed inverse relationship with amount of fertilizer application. The most water-use efficient fertigation treatment was 75% RDF (13.48 kg copra m^{-3}) followed by 100% RDF (13.18 kg copra m^{-3}) with drip irrigation as compared to conventional way soil application of fertilizers through ring basin method of irrigation (4.23 kg copra m^{-3}). Role of N on yield variability was most prominent by both available soil N status (R^2 = 0.49**) and leaf N concentration (R^2 = 0.51**). The study indicated that there is a great scope for reducing the N, P and K fertilizers by up to 25% of the present RDFs for coconut when applied through drip irrigation compared to ring basin method of irrigation for its higher productivity and profitability through efficient use of nutrients and water in the Eastern IGP of South Asia.

KEYWORDS
Coconut; fertigation; drip irrigation; water use efficiency; soil and leaf nutrients

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Introduction

Coconut (*Cocos nucifera* L.) is grown in different farming systems and soils in almost all countries of South Asia, and most notably in the coastal areas (Coconut Development Board, 2015). It is an important commercial plantation crop in India and plays an important role in the Indian economy by contributing around $105 million per year to the national GDP (Jayakumar et al., 2015). In India, it was grown in approximately 2.08 million ha with production of 2.39 million nuts in 2016–2017. In West Bengal alone, which is in the Eastern Indo-Gangetic Plains (IGP) of South Asia, the area under coconut was 0.30 million ha with the production of 3.75 million nuts in the same year (Coconut Development Board, 2018). Due to high cost of production and low profit, coconut cultivations are carried out with negligence and as a result coconut farming is often considered to be a non-profitable enterprise in India.

To make the coconut cultivation profitable, improved management practices are needed to increase its yield. Water and nutrients are the main inputs contributing to higher productivity of coconut (Jayakumar et al., 2017). Insufficient water is the most limiting factor in post monsoon season (December–May) in coconut palm growing regions of South Asia due to high evaporative demand in those months (Mahesha et al., 1990). Presently, scarcity of water, high cost of labor and energy, and inappropriate fertilizer and irrigation application methods are deterrents in adopting traditional irrigation methods for coconut. Among the various irrigation systems, drip irrigation is gaining importance in South Asia as it can maintain soil moisture near field capacity and appropriate air balance in the root zone of coconut throughout the dry season (Carr, 2011). In other words, drip system can be used to apply water and water-soluble fertilizers or chemicals in precise amount directly to the root zone (e.g., fertigation) as and when required to match the plant needs (Jayakumar et al., 2014,2015).

In fertigation method, nutrient use efficiency could be as high as 90% compared to only 40–60% in conventional methods (Basavaraju et al., 2014). In fertigation method, the amount of nutrients lost through leaching can be as low as 10%, whereas it can be >50% in the traditional system (Solaimalai et al., 2005). The advantage of fertigation method over conventional method of fertilizer application was also emphasized by several other works (Mmolawa and Or, 2000;Mohammad, 2004a,2004b;Shigure et al., 1999). However, there is very meager information on fertigation effects on productivity, and soil and plant nutrition of coconut in the Eastern IGP of South Asia, or largely in India. Keeping this in view, the present investigation was carried out to determine the effect of different fertigation levels on yield, and soil and plant nutrient contents of coconut with a goal of improving the coconut productivity in the IGP of South Asia.

Materials and methods

Experimental site, weather and year

The experiment was conducted in a 27-year-old well-established coconut palm planted during 1980–1981 and spaced at 7.5 × 7.5 m in squared pattern at the Horticultural Research Station (under All India Coordinated Research Project on Palms – AICRPP) of Bidhan Chandra Krishi Vishwavidyalaya (BCKV), Mondouri, India, from 2007–2008 to 2012–2013. The experimental site is characterized by the subtropical humid climate, situated at 23° 30′ 13″ N lat. and 89° 20′ 32″ E long. with an average altitude of 9.75 meters above sea level. Average annual rainfall during the experimental period was 1582 mm ranging from 995 mm in 2010 to 2808 mm in 2011. Mean monthly minimum and maximum temperature over the experimental period was 22° C and 32°C, respectively. Mean monthly minimum and maximum relative humidity over the period was 60% and 93%, respectively (Table 1). The soil of the experimental site is well drained clay loam with pH 6.6. The experiment was laid out in a RCBD with six treatments replicated four times: T_1 – Control (no fertilizers) and water with drip irrigation; T_2 – 25% of the recommended dose of fertilizer (RDF) applied with drip irrigation; T_3 – 50% of the RDF applied with drip irrigation; T_4 – 75% of the RDF applied with drip irrigation; T_5 – 100% of the RDF applied with drip irrigation; and T_6 – 100% of the RDF applied with ring basin method of irrigation (i.e., conventional method).

Irrigation water requirement and application

The drip system consisted of one 2000 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. As per earlier recommendations (Sivanappan, 1994), water application efficiency for all treatments with drip irrigation was assumed 90% while it was assumed 50% for ring basin of 2 m radius (surface) irrigation. In the 100% of the RDF with ring basin method of irrigation, 5 cm water was applied once in 10 days interval. Four emitters at the rate of 6 l h^{-1} discharge rate were placed on four sides of the palm, each 100 cm away from the base of the plant. In all treatments with

Table 1. Weather at the experimental site in West Bengal, India.

	2007	2008	2009	2010	2011	2012	2013
Total rainfall (mm)	2023	1318	1292	995	2808	1215	1426
Evaporation (mm)	930	890	950	993	963	945	861
Av. max. temp. (°C)	32	32	32	32	31	32	32
Av. min. temp. (°C)	21	22	22	22	21	22	21
Av. max. RH (%)	95	93	93	93	93	93	91
Av. mini. RH (%)	63	61	58	60	62	60	62

drip irrigation, average 24 l day^{-1} was applied in 3 days interval. The quantity of water application was calculated using FAO CROPWAT model (FAO, 2009) which uses Penman–Monteith equation for calculation of reference crop evapotranspiration (ET_0) (FAO, 1998). The calculated 'long-term average ET' values were subsequently used to calculate ETc by multiplying ET_0 with crop coefficient (Kc) for coconut. Irrigation water requirement (IRR) for a specific area (A) was then defined as the difference between the actual crop evapotranspiration (Etc) and effective rainfall (PeEa) while considering the irrigation efficiency.

$$IRR = ETc - PeEa \times A$$

Fertilizer schedule and application

The fertilizers were applied through drip irrigation at an interval of 21 days with total of 10 splits with urea (46% N), diammonium phosphate (18% N, 46% P_2O_5) and muriate of potash (60% K_2O) as source of N, P and K, respectively. The conventional fertilizer application through ring basin irrigation was followed as per the recommended practice (N: P_2O_5: K_2O@ 500:250:750 g $palm^{-1}$ $year^{-1}$). DAP was soaked in water, softened and mixed with urea and potash just before application. A ventury was used to inject the fertilizer solution to pass through screen filter. In case of 100% N, P and K as soil application with ring basin method of irrigation, it was applied in two splits, i.e., half in May–June with the onset of monsoon and remaining half just at the end of monsoon, e.g., September–October. Weeding and other plant-protection measures and all cultural practices were carried out as per BCKV's earlier recommendations (Anonymous, 2004).

Soil analysis

Initial (before initiation of experiment) and final (after 7 years of experiment) soil samples were collected from 30–60 cm depth at about 100 cm away from the base of the palm from each treatment. On both occasions, samples were taken before onset of monsoon in May. Soil available N, P and K contents were analyzed using established, standard analytical procedures (Jackson, 1973).

Coconut copra and oil yield

A total of four plants from each treatment were selected for collection of nut samples. Nuts were harvested four times a year at three monthly intervals. Fresh kernels were removed from the de-husked nuts of collected samples. Kernels were dried in oven to get copra and oil was extracted through oil extraction unit.

Water use efficiency

The treatment-wise quantity of water applied per irrigation was added cumulatively. Total water use for each treatment considered the effective rain fall. The water use efficiency (WUE) as ratio of coconut (copra) yield to total water use was calculated for each treatment.
Considering the variability in size of nuts, copra yield was considered as a stable unit for the calculation of WUE.

$$\text{WUE} = \frac{\text{Coconut yield (kg copra ha}^{-1}\text{)}}{\text{Total water use (m}^{3}\text{)}} \quad (\text{kg ha}^{-1}\ \text{m}^{3})$$

Leaf analysis

Leaf samples were collected from the index leaf (14th leaf) before the initiation and after six years of experimentation. Samples were collected in September after receding of monsoon rain. Leaf N content on dry weight basis was estimated in percentage by Micro-Kjeldahl method (Jackson, 1973). Leaf P content was estimated by colorimeter using vanadomolybdate yellow color method (Jackson, 1973) and leaf K content was determined by flame photometer (Ward and Johnston, 1962).

Microbial analysis

Soils were sampled for microbial analysis before initiation and after six years of experimentation. Samples were analyzed immediately after collection to enumerate the colony-forming units (c.f.u.) of bacteria, actinomycetes and fungi following the serial dilution technique and pour plate method in asparagines – mannitol agar, dextrose-casein agar and rose-bengal agar media, respectively. The agar plates were incubated at 30°C ± 1°C for 7 days for viable soil microbial population counts (Salle, 1973).

Statistical analysis

Statistical analysis for each variable was conducted as per the procedure given by Gomez and Gomez (1984). Wherever the results were significant, least significant differences (LSD) were calculated at probability level p 0.05 using the ANOVA and designated as significant. The non-significant treatment differences were denoted as NS. The coefficient of determination (R^2) was determined to indicate the degree of association between the dependent and independent variables.

Results and discussion

Effect of fertigation on leaf production

Six years (2007/2008–2012/2013) of pooled data indicated that the number of functional leaves palm^{-1} year^{-1} varied significantly among the different treatments (Table 2). Significantly higher numbers of functional leaves ($p \le 0.05$) were recorded when 75% or 100% of the RDF was applied through drip irrigation (28.9 and 28.7 leaves palm^{-1}, respectively) as compared to no fertilizer (27.4 leaves palm^{-1}). Similarly, annual number of leaf production palm^{-1} was also significantly higher with 75% of the RDF (11.9) and with 100% of the RDF and ring basin method of irrigation (11.8) as compared to no fertilizer (11.2). Thus, fertigation had a significant positive influence on coconut leaf production, a finding also reported by Palaniswami et al. (2010).

Effect of fertigation on coconut copra and oil yield

The trends for number of inflorescence, and nut and copra yield palm^{-1} year^{-1} across treatments were almost similar during the period of experimentation. A significantly higher number ($p \le 0.05$) of inflorescence palm^{-1} year^{-1} (9.4) was recorded for 75% of RDF and 100% of RDF with ring basin method of irrigation as compared to no fertilizer (8.6) (Table 3a). Nut yield was also significantly higher ($p \le 0.05$) in 75% of RDF (24.44 t ha^{-1} year^{-1}) and 100% of RDF (23.79 t ha^{-1} year^{-1}) as compared to no fertilizer (21.89 t ha^{-1} year^{-1}) (Table 3b).

Copra yield was also significantly higher ($p \le 0.05$; 3.19 t ha^{-1} year^{-1}) in 75% of RDF than no fertilizer The highest copra yield with 75% RDF with drip irrigation may be explained by the higher nutrient use efficiency with deficit nutrient regime due to enhanced root activity. On the contrary, the RDF with conventional ring basin method of irrigation resulted in higher nutrient loss and

Table 2. Functional leaf and annual leaf production in coconut as influenced by fertigation levels.

Treatments	Average functional leaf Palm^{-1}	Average annual leaf palm^{-1}
T1	27.4	11.2
T2	28.4	11.2
T3	28.6	11.5
T4	28.9	11.9
T5	28.7	11.8
T6	28.6	11.8
SEM ±	0.1	0.1
LSD (p = 0.05)	0.2	0.2

T1 – Control (no fertilizers) and irrigated through drip.
T_2 – 25% of the recommended dose of fertilizer (RDF) through drip system.
T_3 – 50% of the RDF through drip system.
T_4 – 75% of the RDF through drip system.
T_5 – 100% of the RDF through drip system.
T_6 – 100% of the RDF in soil with ring basin irrigation as conventional method.

Table 3. Number of inflorescence (a) and nut production (b) in coconut as influenced by fertigation levels.

Treatments	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	Pooled mean
a: Inflorescence number (inflorescences palm^{-1} year^{-1})							
T1	8.9	9.3	8.6	8.2	8.3	8.4	8.6
T2	8.8	8.8	9.4	8.8	8.7	8.5	8.8
T3	8.7	9.1	9.4	9.5	9.2	9.2	9.2
T4	9.1	9.4	9.5	9.4	9.6	9.7	9.4
T5	8.4	9.2	9.5	9.4	9.4	9.5	9.2
T6	9.0	9.5	9.5	9.5	9.6	9.6	9.4
SEM ±	0.1	0.1	0.1	0.1	0.1	0.1	0.0
LSD (p = 0.05)	0.3	0.3	0.4	0.3	0.3	0.2	0.1
b: Nut production (t ha^{-1} year^{-1})							
T1	21.37	21.45	21.45	21.76	22.19	23.23	21.89
T2	21.34	22.17	22.74	22.79	23.20	24.51	22.79
T3	21.32	21.94	22.79	23.82	24.80	26.32	23.46
T4	21.50	22.81	24.26	25.39	25.67	26.99	24.44
T5	21.16	22.63	23.07	24.36	25.00	26.58	23.79
T6	21.29	22.45	23.02	24.41	24.75	25.52	23.56
SEM ±	0.09	0.08	0.13	0.07	0.08	0.07	0.09
LSD (p = 0.05)	0.27	0.25	0.39	0.20	0.24	0.20	0.26

T1 – Control (no fertilizers) and irrigated through drip.
T_2 – 25% of the recommended dose of fertilizer (RDF) through drip system.
T_3 – 50% of the RDF through drip system.
T_4 – 75% of the RDF through drip system.
T_5 – 100% of the RDF through drip system.
T_6 – 100% of the RDF in soil with ring basin irrigation as conventional method.

lower factor productivity. Oil yield also revealed significantly higher response ($p \leq 0.05$; 2.14–2.19 lit ha^{-1} year^{-1}) with 75% or 100% of RDF (Table 4b). The data reveal the fertigation response of up to 75% of RDF, suggesting for the scope of reducing 25% fertilizer load through drip fertigation over surface application of fertilizer through ring basin method of irrigation. Similar to our results, Basavaraju et al. (2014) also reported the application of 75% N, P and K through drip irrigation can result in nut and copra yield palm^{-1} at par with the application of 100% N, P and K through either drip irrigation or ring basin method of irrigation. It must be emphasized that, although application of fertilizers @75% RDF resulted in only about 10% increase in nut yield compared to 50% RDF, obtaining higher copra yield is very important for the farmers as currently fertilizers are heavily subsidized and copra prices are high in India (and many countries in South Asia), and by applying fertilizers @75% RDF, farmers will receive higher income. In addition, in our study, the benefit cost ratio of 75% RDF (2.36) is significantly higher than 50% RDF (2.30) (data not shown).

Effect of fertigation on water use efficiency

Fertigation influenced WUE of coconut. The most water use efficient fertigation treatment was 75% of the RDF (13.48 kg copra m^{-3} water used) followed

Table 4. Copra production (a) and oil production (b) in coconut as influenced by fertigation levels.

Treatment	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	Pooled mean
a: Copra production (t ha^{-1} $year^{-1}$)							
T1	1.82	1.83	1.83	1.85	1.89	1.98	1.87
T2	2.80	2.90	2.98	2.98	3.04	3.21	2.99
T3	2.79	2.88	2.98	3.12	3.25	3.45	3.08
T4	2.81	2.98	3.17	3.32	3.36	3.53	3.19
T5	2.78	2.97	3.03	3.19	3.29	3.48	3.12
T6	2.17	2.30	2.35	2.49	2.53	2.61	2.41
SEM	0.01	0.01	0.02	0.01	0.01	0.01	0.01
LSD (p = 0.05)	0.03	0.04	0.06	0.02	0.03	0.02	0.03
b: Oil production ('000 lit ha^{-1} $year^{-1}$)							
T1	1.29	1.25	1.25	1.24	1.28	1.36	1.28
T2	1.94	1.98	2.02	2.03	2.06	2.15	2.03
T3	1.90	1.98	2.04	2.15	2.24	2.36	2.11
T4	1.94	2.00	2.16	2.26	2.30	2.46	2.19
T5	1.88	2.03	2.04	2.15	2.26	2.48	2.14
T6	1.48	1.55	1.65	1.68	1.77	1.79	1.65
SEM	0.02	0.02	0.03	0.03	0.02	0.03	0.02
LSD (p = 0.05)	0.06	0.07	0.08	0.10	0.07	0.10	0.06

T1 – Control (no fertilizers) and irrigated through drip.
T_2 – 25% of the recommended dose of fertilizer (RDF) through drip system.
T_3 – 50% of the RDF through drip system.
T_4 – 75% of the RDF through drip system.
T_5 – 100% of the RDF through drip system.
T_6 – 100% of the RDF in soil with ring basin irrigation as conventional method.

by 100% of RDF with drip irrigation (13.2 kg copra m^{-3}) (Figure 1). Ring basin method of irrigation had the least WUE, with only 4.2 kg copra production m^{-3} water used. De Azevedo et al. (2006) reported that the application of higher volume of irrigation water does not necessarily result in higher coconut yield. In their study, the WUE of coconut, in fact, decreased with the increasing amount of irrigation water in coconut (De Azevedo et al., 2006). Evapotranspiration, fruit yield and WUE all were strongly affected by irrigation water volume in coconut palms (Tolk and Howell, 2003). Jayakumar et al. (2014) also reported the highest WUE (34 nuts $tree^{-1}$ m^3 of water) in 100% of RDF with drip fertigation and 100 µm polythene mulching, whereas the lowest WUE (14 nuts $tree^{-1}$ m^3 of water) was observed in conventional flood irrigation without mulch.

Our results are also in line with the findings of Seyfi and Rashidi (2007), who showed that drip irrigation with black polythene mulch markedly decreased the amount of water applied, and increased WUE and crop yield due to increase in number of fruits per plant, fruit weight and fruit thickness in Cantaloupe. Earlier studies in coconut with drip irrigation @ 40 l $tree^{-1}$ showed a saving of 40% of water applied compared with surface irrigation (Jayakumar et al., 2017). Drip irrigation equal to 66% of open pan evaporation (E_0) also proved to be economically efficient method with water saving of 34% compared to 100% of E_0 in lateritic soils of Kerala (Dhanapal et al., 2003;2004a,2004b). Similar to our

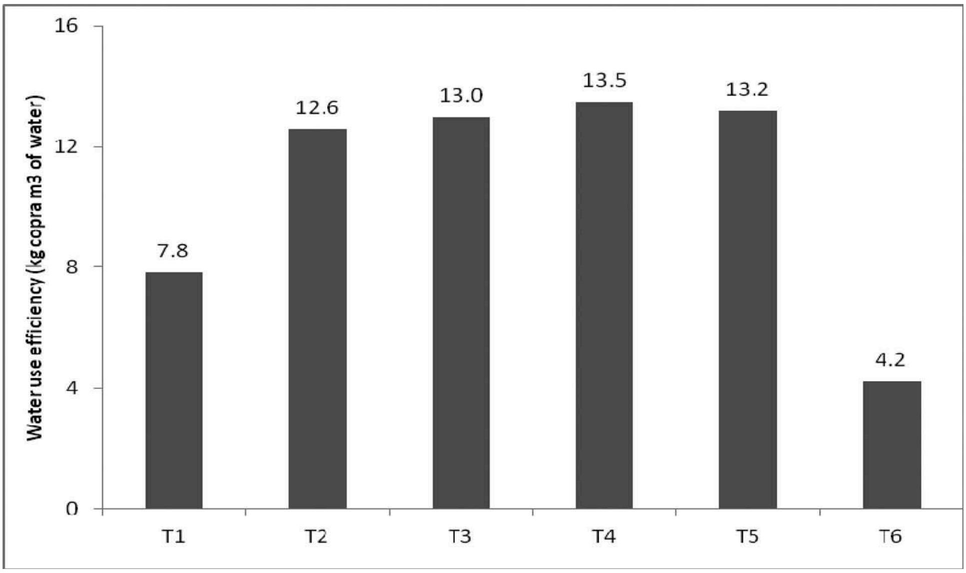

Figure 1. Water use efficiency in coconut as influenced by fertigation levels.

results, Nagwekar et al. (2006) and Nainanayake et al. (2008) also indicated that drip irrigation can save about 45–50% water over surface irrigation without any significant reduction in coconut yield. Overall, our results signify higher WUE with deficit nutrition and irrigation with the scope of reducing fertilizer load by up to 25% of the presently recommended doses. Drip irrigation permits point application of water and fertilizers, and thus can achieve better water and nutrient use efficiency by minimizing application losses.

Effect of fertigation on soil nutrient content

Fertigation affected soil fertility by increasing available N, available P and available K of soil compared to no fertilizers (Table 5a). Soil available N, P and K levels tended to increase in systems with application of 100% of RDF. It can be hypothesized that the significant change in the soil N, P and K content with time under different irrigation levels helps in buildup of nutrients especially under 75% and 100% of RDF. It can be stated that, under higher soil N status, N application through drip fertigation played a dominant role on copra yield over soil application through ring basin method. Thus, nutrient availability in soil can be maintained at a higher level under fertigation compared to soil application of fertilizers with flood or ring basin irrigation. Fertigation enables the application of fertilizers uniformly and more efficiently as has also been reported for onion by Patel and Rajput (2000). Fares and Alva (2000) reported that the fertigation system retains the applied water and nutrients in the root zone of coconut and hence results in increased level of soil nutrient status (Subramanian et al., 2012). Basavaraju et al. (2014) also reported that application of fertilizers in split doses

Table 5. Initial and final (after six years of experimentation) soil nutrient contents (a) and leaf nutrient contents (%); (b) at the experiential site under different fertigation levels.

Treatments	Available N	Available P	Available K
a: Soil nutrient content (kg ha^{-1})			
Initial	264	82.3	288
T1	255	80.8	266
T2	268	81.7	274
T3	270	82.7	291
T4	275	86.8	291
T5	277	90.9	314
T6	273	89.7	315
SEM±	3.0	1.3	4.1
LSD (p = 0.05)	9.1	3.9	12.2
	N	P	K
b: Leaf nutrient content (%)			
Initial	1.53	0.10	1.15
T1	1.50	0.10	1.16
T2	1.57	0.10	1.19
T3	1.67	0.11	1.22
T4	1.81	0.13	1.28
T5	1.82	0.13	1.26
T6	1.67	0.12	1.26
SEM±	0.04	0.00	0.03
LSD (p = 0.05)	0.11	0.01	0.08

T1 – Control (no fertilizers) and irrigated through drip.
T_2 – 25% of the recommended dose of fertilizer (RDF) through drip system.
T_3 – 50% of the RDF through drip system.
T_4 – 75% of the RDF through drip system.
T_5 – 100% of the RDF through drip system.
T_6 – 100% of the RDF in soil with ring basin irrigation as conventional method.

through drip irrigation in coconut minimizes the leaching losses of N and K and fixation of P in the soil, and thus increases soil nutrient levels. Higher soil N, P and K levels with fertigation in coconut was also reported for the coastal sandy soils of Kerala (Anonymous, 2011), supporting the results of the present investigation.

Effect of fertigation on leaf nutrient content

Leaf N, P and K content increased significantly under fertigation after 6 years of the experiment as compared to initial (Table 5b). Leaf N content increased with increased level of fertigation. Leaf N content was significantly higher (1.81–1.82%; $p \leq 0.05$) with 75% and 100% of RDF applied with drip irrigation than with no fertilizers and 25% of RDF with drip irrigation (1.5%). Similarly, P content in leaf also increased with 75% of RDF (0.13%) and 100% of RDF with drip irrigation (0.13%) followed by 100% of RDF applied in soil with ring basin irrigation (0.12%). Change in leaf K content also followed the same trend as that of N and P, with highest concentration (1.28%) for 75% of RDF and 100% of RDF followed by 50% of RDF (1.22%). The leaf N content data revealed that soil N application through conventional ring basin method resulted in lower uptake by plant roots and reduced copra yield, which was even lower than 75% of RDF through drip fertigation. Leaf N content and copra yield did not vary much between 75% and 100% RDF through drip fertigation. From this pattern, it can be stated that, leaf N content played a highly significant role on copra yield. Soil P application through conventional ring basin method resulted in higher fixation and lower availability to root zone as reflected by the lower leaf P content. The lower P uptake and lower P availability thus resulted in reduced copra yield, which was even lower than 75% of RDF through drip fertigation. Leaf P content and copra yield did not vary much between 75% and 100% RDF through drip fertigation. These data reveal that leaf P content also played a dominant role on copra yield. Soil K application through conventional ring basin method favored in rapid K movement in the lower soil profile, resulting in lower leaf K concentration and its lower uptake by plant roots. Such lower uptake resulted in reduced copra yield, which was even lower than 75% of RDF through drip fertigation. Leaf P content, leaf K content and copra yield also did not vary much between 75% and 100% RDF through drip fertigation. Thus, it can be stated that leaf K content also played a dominant role on copra yield. Alva et al. (2008) also reported K leaf concentration below 3–4 mg kg^{-1} affected the quality of citrus fruit especially acidity of juice. As drip fertigation placed nutrients directly in the active root zone area, it not only helped in maintaining favorable soil moisture level but also resulted in much greater movement of P and K in the root rhizosphere. Khandekar et al. (2016) and Subramanian et al. (2012) reported the increased leaf N, P and K contents after receiving various levels of fertilizers through drip. Thus, higher soil nutrient contents with fertigation might have resulted in higher nutrient contents in the leaves, ultimately resulting in increased nutrient uptake by coconut.

Effect of fertigation on soil microbial content

Microbial population in the soil was also affected by fertigation level (Table 6). There was significantly higher population of soil bacteria under control (131×10^5 CFU g^{-1} soil) compared to 100% of RDF with ring basin irrigation ($98–102 \times 10^5$ CFU g^{-1} soil). Similarly, there was significantly highest soil fungi population under control (59.6×10^4 CFU g^{-1} soil) and least under 100% of RDF (34.8×10^4 CFU g^{-1} soil). Soil actinomycetes population was also significantly higher under control (39.6×10^3 CFU g^{-1} soil), and least with 100% of RDF with ring basin method (31.3×10^3 CFU g^{-1} soil). Increased population of soil microorganisms can influence the decomposition of the soil organic matter, resulting in increased availability of the inherent nutrient elements. Higher population of soil bacteria, fungi and actinomycetes with no fertilizer may be due to the quick

Table 6. Initial and final (after six years of experimentation) soil microbial contents (0–25 cm depth) of coconut basin as influenced by fertigation levels.

	Microbial population (CFU g^{-1} soil)		
Treatment	Bacteria (10^5)	Fungi (10^4)	Actinomycetes (10^3)
Initial	96	32.4	28.7
T1	131	59.6	39.6
T2	121	48.2	39.0
T3	119	45.7	38.5
T4	115	43.3	36.2
T5	102	34.8	33.5
T6	98	36.5	31.3
SEM ±	2.9	1.9	1.2
LSD (p = 0.05)	8.7	6.0	3.8

T1 – Control (no fertilizers) and irrigated through drip.
T_2 – 25% of the recommended dose of fertilizer (RDF) through drip system.
T_3 – 50% of the RDF through drip system.
T_4 – 75% of the RDF through drip system.
T_5 – 100% of the RDF through drip system.
T_6 – 100% of the RDF in soil with ring basin irrigation as conventional method.

decomposition of plant wastes along the tree basin as a result of continuous supply of irrigation water through drip irrigation. Presumably, the decomposed plant residue in the tree basin was helpful for the microbial growth (Hebbar et al., 2010;Shobana et al., 2012). Soil fertility not only depends on the chemical composition of soil but also on the qualitative and quantitative nature of microorganisms inhabiting it. Shivanand (2003) and Nguyen (2003) reported that high amount of above-ground biomass is accompanied by an active root system, which releases an array of organic compounds into the rhizosphere. These compounds support the growth of the microbial community and result in dense population with no fertilizer compared to fertilizer treatments. Most of the microorganisms play an important role in the C, N, P and S cycles and the availability of certain trace elements like Mn, Cu and Fe in the soil. Some soil microbes act as antagonists for soil-borne pathogens, thus aiding normal growth of plants. Besides, the soil microbes can influence the permeability, water holding capacity and tilth of the soil, as has been observed in soils grown to tomato and cocoa in India (Balasubramanian, 2007;Govindan and Nair, 2011). From this study, however, it is revealed that in case of coconut, the nutritional support from microbial sources is not enough for achieving higher yield and that microbial population is inversely related to externally applied chemical fertilizers.

Yield – N, P and K relationships

There was a significant linear relationship between copra yield and total soil N. At the lower end of soil N, i.e., when total soil N content was between 245 and 265 kg ha^{-1}, there was a steady increase in copra yield with an increase of total soil N. However, when the total soil N was higher (265–280 kg ha^{-1}), a wide variation (2.37–3.23 t ha^{-1}) in copra yield was recorded . The regression equation as shown in Figure 2 revealed that for each kg ha^{-1} decrease in total soil N there was a reduction in copra yield to the tune of 40 kg ha^{-1}. There were however slightly different (and non-significant) relationships between copra yield and soil P or soil K (Figure 2).

The relationship between copra yield and leaf N content was also similar to that of soil N, with a steady increase in copra yield with the increase of leaf N concentration (Figure 3). The regression equation revealed that per unit decrease in leaf N concentration (%), there was a reduction in copra yield to the tune of 2.93 t ha^{-1}.

There was also a steady increase in copra yield with increase in leaf P concentration with significant coefficient of determination. The regression equation showed that per unit decrease in leaf P concentration (0.1%) copra yield reduced to the tune of 1.97 t ha^{-1} (Figure 3) .

As for soil P, there was also significant linear relationship between copra yield and leaf K content, with a steady increase in copra yield with an increase in leaf K concentration (Figure 3). The regression equation revealed that with per unit decrease in leaf K concentration (0.1%) there was reduction in copra yield to the tune of 0.59 t ha^{-1} (Figure 3). Palaniswami et al. (2010) also observed similar response with significant correlation coefficients between coconut yield and soil N, P and K levels in a study in Kerala, India.

Importance of coconut in the Eastern IGP is being increased due to multifaceted use, especially value addition of inflorescence sap, green coconut water, fresh kernel and copra and oil. Considering the increasing concern on water scarcity and global warming in the Eastern IGP of South Asia, our findings provide an impetus to the governments' special initiative of popularization of drip irrigation technology in different countries. This in turn will help both vertical and horizontal expansion of coconut cultivation in the region, including the new alluvium zone of India where there is great potential of expanding coconut cultivation.

Conclusion

Results from the current study suggest that there is a potential for higher coconut production with efficient use of water and nutrients through drip irrigation and fertigation in comparison to conventional system of irrigation and fertilizer application. Drip fertigation of N, P and K (i.e., fertilizers applied through drip irrigation) results in higher coconut yield than soil application of N, P and K through conventional ring basin irrigation. Drip fertigation reduces fertilizer requirement by up to 25% of recommended N, P and K. Increased fertilizer application reduces soil microbe population.

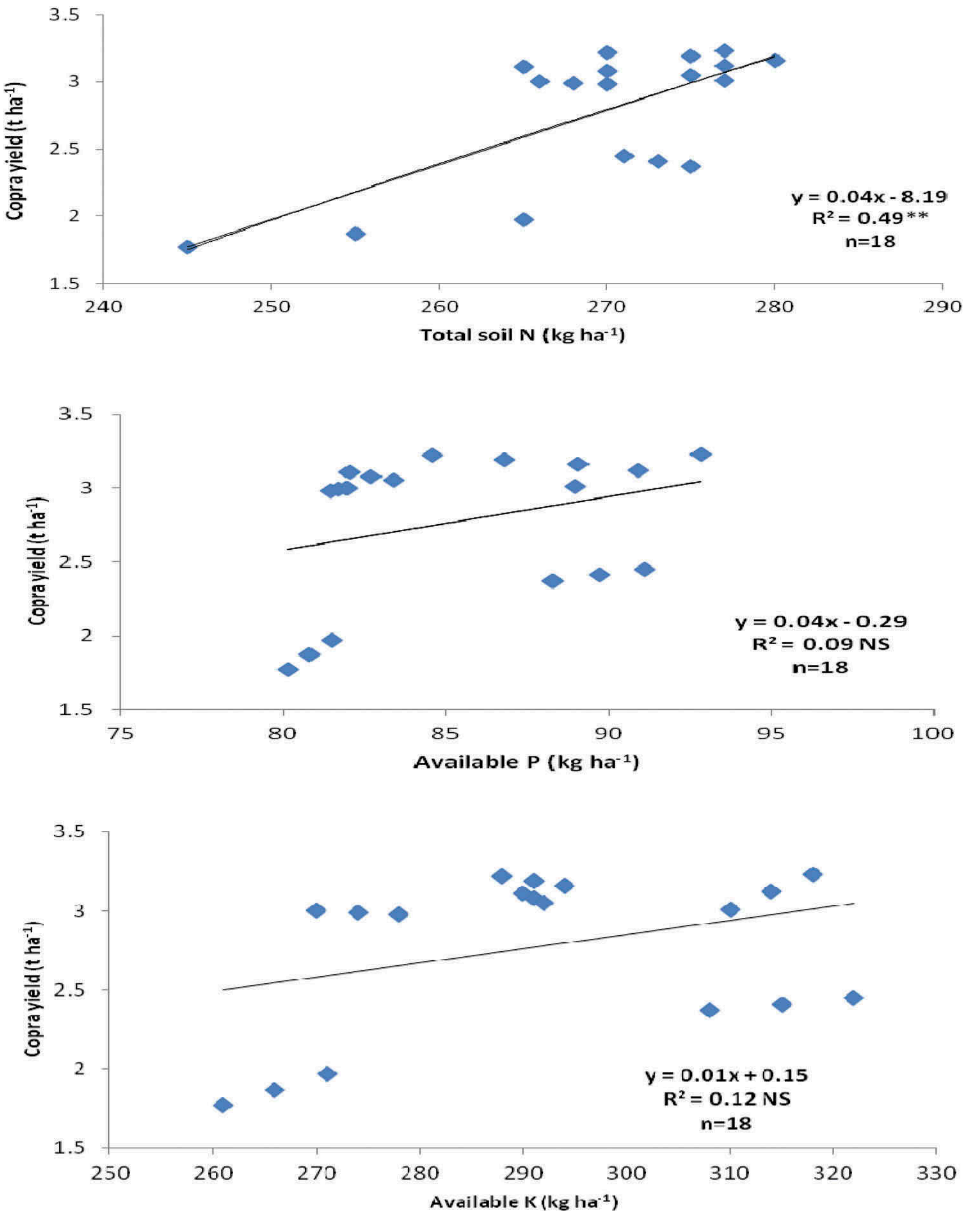

Figure 2. Relationship of copra yield with total soil N content, available soil P content and available soil K content in coconut as influenced by fertigation levels.

Water use efficiency with 75% N, P and K with drip irrigation can be greater by up to 3.2 times compared to 100% N, P and K with ring basin method. Yield relationships with soil N and leaf N contents are much stronger than with soil P and K and P or K contents. Our findings suggest that there is a great scope of reducing the external application of N, P and K by up to 25% of the presently recommended doses for higher productivity and profitability of coconut through efficient use of nutrients and water in the Eastern IGP of South Asia.

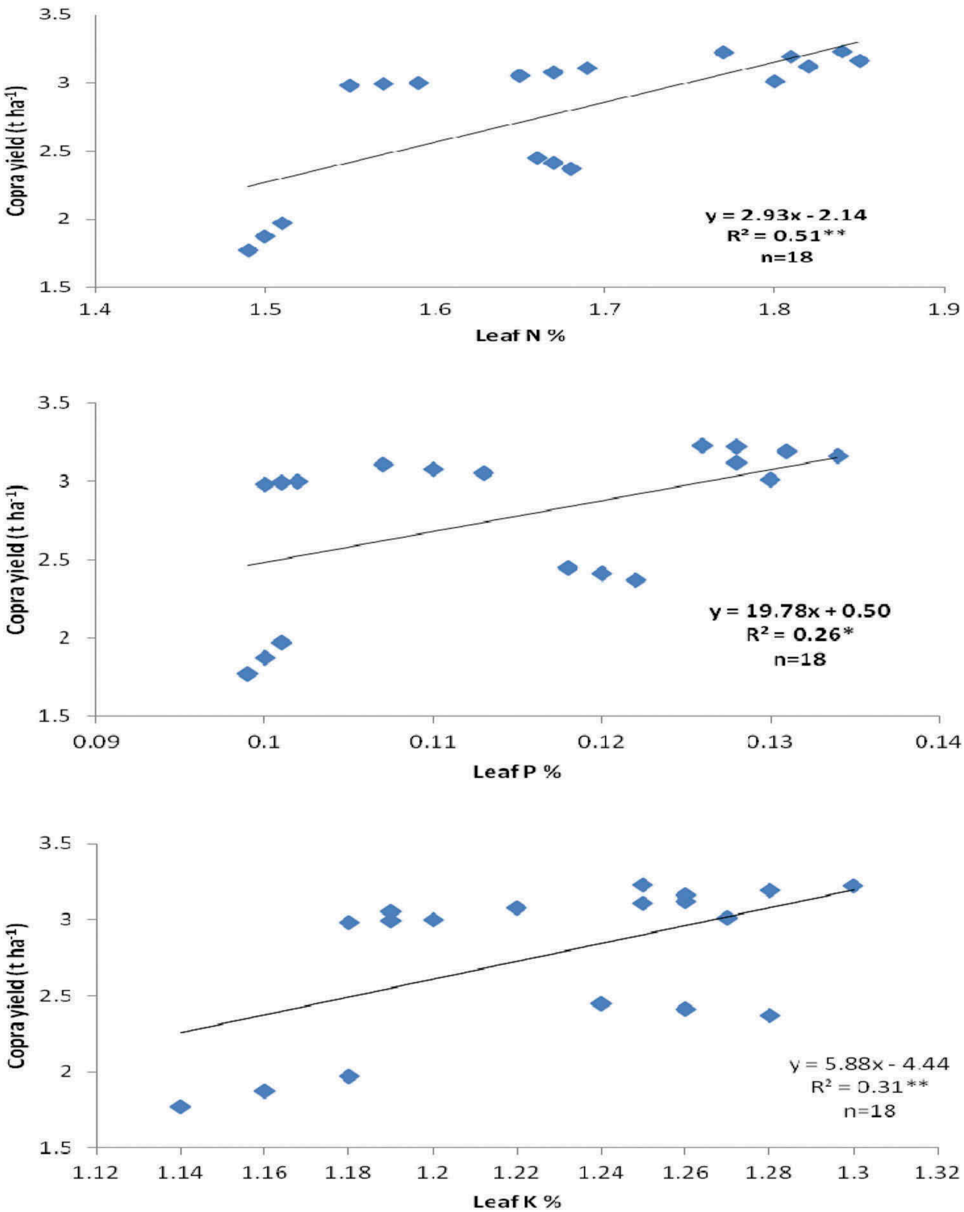

Figure 3. Relationship of copra yield with leaf N, P and K content in coconut as influenced by fertigation levels.

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